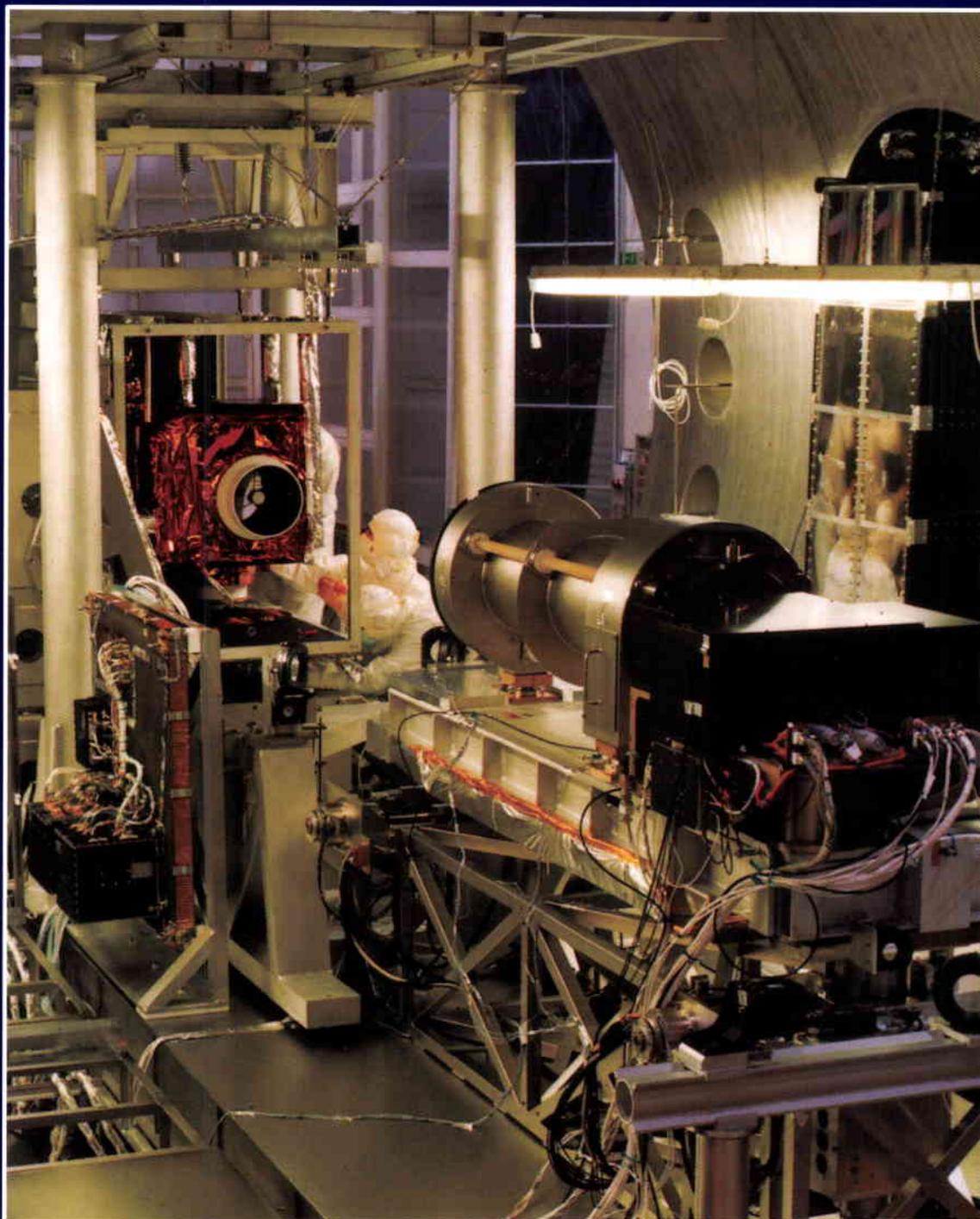


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number 91 - august 1997



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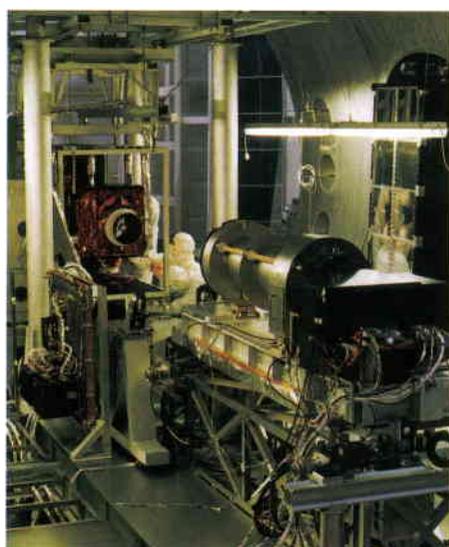
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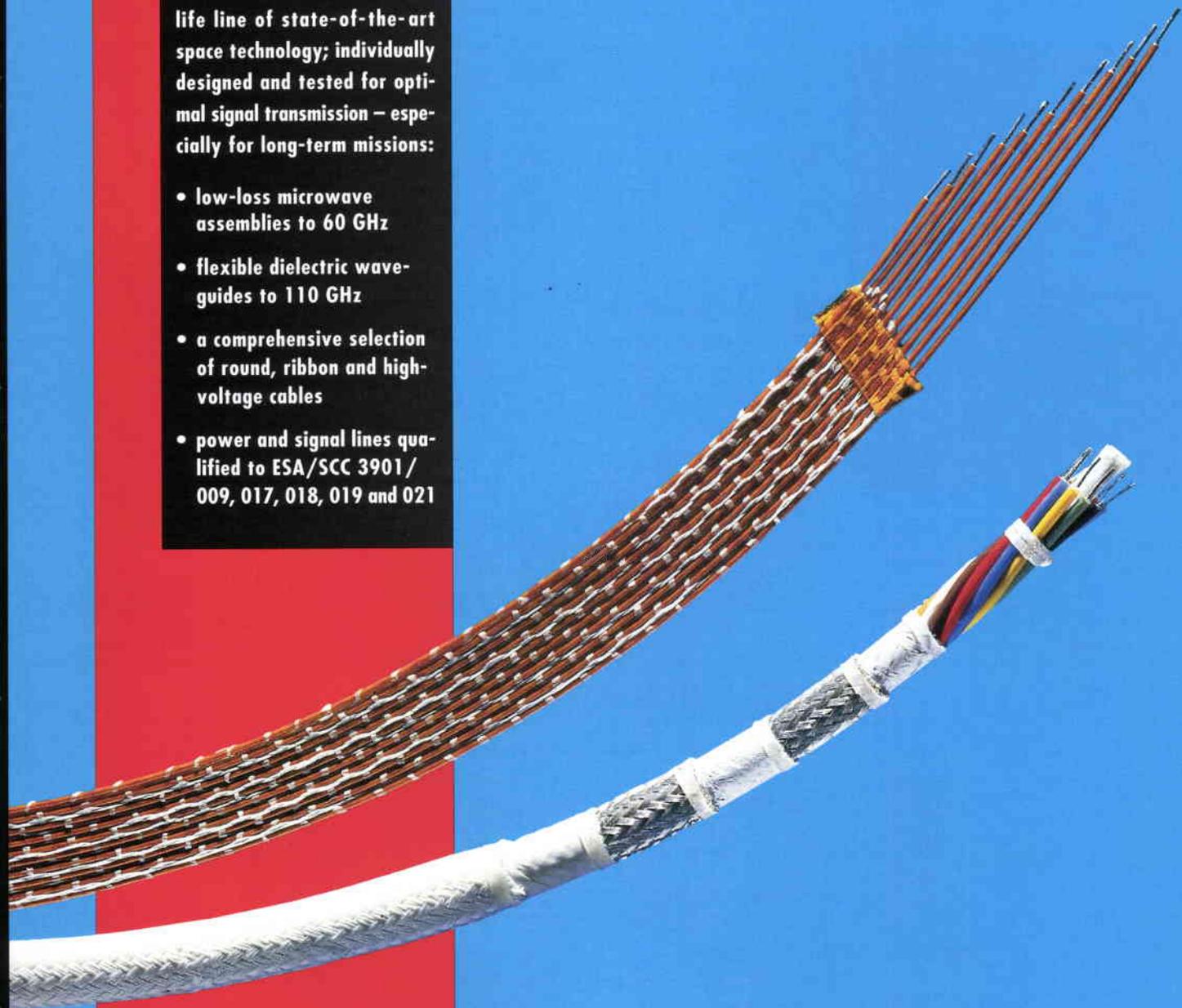
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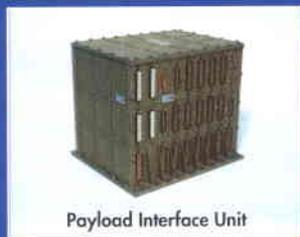
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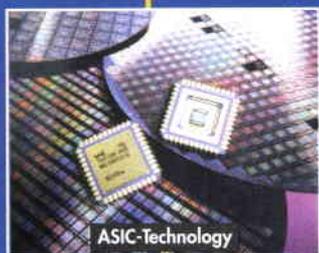
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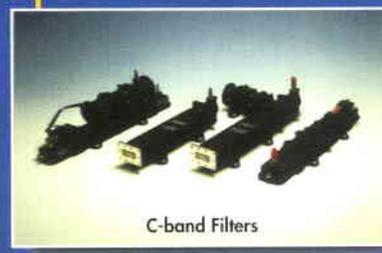
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The Resurrection of the Cluster Scientific Mission

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Introduction

The launch of Cluster, one of the Cornerstone missions of the ESA Scientific Programme, was scheduled for the early morning of 4 June 1996. After a short delay during the countdown due to bad weather over the launch pad, Ariane-5 rose flawlessly to an altitude of 3.5 km, at which point a sudden swivelling of both solid-booster nozzles caused the vehicle to tilt sharply. The resulting intense aerodynamic structural loads caused the launcher to begin to break up, prompting the onboard safety systems to initiate self-destruction of all launcher elements. The original four-spacecraft Cluster mission was lost in the ensuing explosion.

would permit the accurate determination of three-dimensional and time-varying phenomena and make it possible to distinguish clearly between spatial and temporal variations for the first time. The four Cluster spacecraft were to be placed into nearly identical, highly eccentric polar orbits, with a nominal apogee of 19.6 R_e , and a perigee of 4 R_e . Such an orbit is essentially inertially fixed, so that in the course of the two-year mission a detailed examination could be made of all significant regions of the magnetosphere. If launched in summer, the plane of this orbit bisects the geomagnetic tail at apogee during the northern-hemisphere summer, and passes through the northern cusp region of the magnetosphere six months later.

The Cluster mission was first proposed to the Agency in late 1982 and was subsequently selected, together with SOHO, as the Solar Terrestrial Science Programme (STSP), the first Cornerstone of ESA's Horizon 2000 Programme. This article gives an overview of the complex chain of events that have taken place between the loss of the original mission with the Ariane-5 launch failure and the recent approval of the recovery mission known as Cluster-II.

Cluster-II is a new four-spacecraft mission for which the go-ahead was given on 3 April 1997, ten months after the loss of the original spacecraft. Cluster-II will be basically identical to the previous mission except for changes introduced as a result of the non-availability of components. The launch date for the new mission has been set for mid-2000. The four spacecraft will be launched by two Russian Soyuz rockets, from Baikonur in Kazakhstan.

The original Cluster mission was planned to conduct an in-situ investigation of plasma processes in the Earth's magnetosphere using four identical spacecraft simultaneously. It

The Cluster spacecraft also carried their own propulsion stages in order to perform all necessary manoeuvres for the transfer from the Geostationary Transfer Orbit (GTO) to the final polar orbit. In addition, it was required to change the in-orbit constellation of the satellites periodically by modifying the distances between them to match the scale lengths of the plasma phenomena being investigated. The relative separations would therefore vary from a few hundred kilometres to a few Earth radii. In the original programme baseline, all four spacecraft had to be injected into GTO on a single Ariane-5 launch vehicle and then transferred in pairs to their mission orbits via a complex series of orbital manoeuvres.

This article describes the sequence of events that eventually led to the approval of Cluster-II by ESA's Science Programme Committee (SPC). Numerous meetings took place in order to either prepare position papers or, more often, to re-act to new challenges raised by

either ESA committees or national agencies. The following paragraphs highlight the most important milestones in the decision process, without addressing in detail the many technical and management meetings held with industry and the scientific institutions.

The ten-month period from the launch disaster to Cluster mission recovery was rich in excitement, disappointment and emotional discussion. It was also characterised by the excellent support from and collaboration with the scientific teams, the national agencies and industry, without whose help Cluster-II would never have materialised.

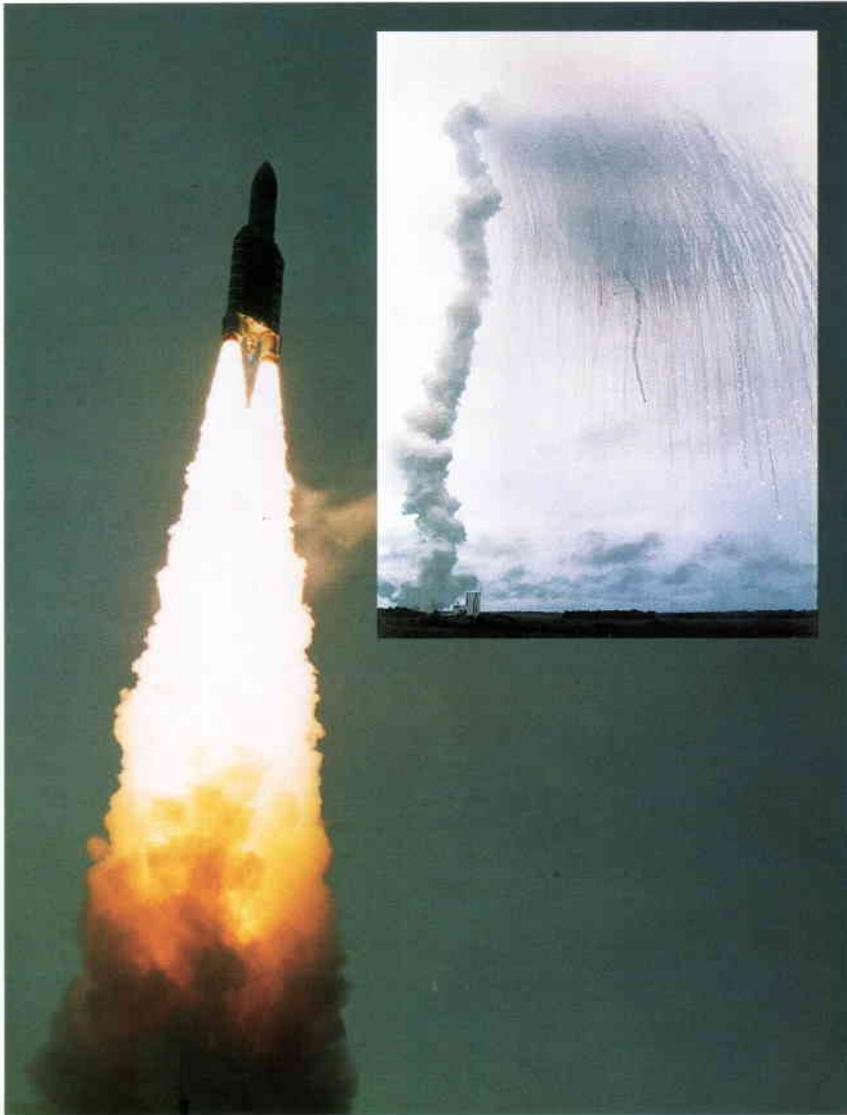


Figure 1. The first Ariane-5 test flight leaving the pad

In fact, Cluster-II will retain all of the critical mission parameters, including the original orbit. The launch scenario will, however, be totally different due to the use of the Soyuz vehicle. Two launchers, each carrying a pair of satellites (so-called payload 'stack'), will deliver them into a low circular orbit, about 250 km high and with a 51.8° inclination. A kick stage attached to each stack will raise the apogee to 18 000 km. Separation from the kick-stage will then take

place and each satellite will be transferred to the final 4 by 19.6 R_e orbit using its own propulsion capability.

The road to recovery

One day after the Ariane-5 launch failure, Roger Bonnet, the Director of ESA's Scientific Programme, met with the Cluster Principal Investigators to assure them of his full support regarding the recovery from the loss of Cluster. It was agreed that a Science Working Team (SWT) meeting would be held immediately after returning to Europe. This meeting took place on 17 and 18 June in Paris. Taking advantage of the fact that most ESA and Dornier engineers were still in Kourou, brainstorming meetings were held there to devise a cost-efficient recovery strategy based on maximum re-use of spare elements, including the payload.

Within a few days, the Cluster Project proposed a replacement mission to the scientific community based on the remaining structural model of the spacecraft, which could be made ready for flight in little more than a year. This spacecraft, initially called Cluster-5 but later renamed 'Phoenix', was considered to be the first of a new fleet of Cluster spacecraft. The rationale for recommending an early Phoenix launch was to keep the scientific and industrial teams together until approval for a full replacement mission could be secured.

This proposal did not find unanimous support among the science community because it was feared that the proposed launch of the single Phoenix would be seen as sufficient compensation for the loss of the four original spacecraft. With hindsight, the immediate start on the assembly of Phoenix turned out to be the correct approach, keeping both the scientific and industrial teams together as the battle for approval for three more spacecraft lasted far longer than was originally expected.

The scientific case for the quick launch of a single Phoenix spacecraft into a 'Cluster-type' orbit rested upon two central arguments: (a) primary investigation using modern high-resolution plasma and field instrumentation of key magnetospheric regions, principally the high-altitude dayside cusp, and (b) co-ordinated observations with a number of other key spacecraft from Japan, NASA and Russia making up the International Solar-Terrestrial Physics Programme (ISTP), and with the new ground-based infrastructure that was timed for Cluster. A further important collaborative aspect was the execution of coordinated measurements with ground-based observatories located in the northern hemisphere.

The Principal Investigators, meeting on 17 June for the first in a long series of emergency SWT meetings, stressed that an early launch of Phoenix could in no way achieve the scientific objectives of the four Cluster spacecraft. They re-confirmed the original Cluster scientific objectives and, after an extensive discussion of the scientific aspects of the recovery scenario, prepared a resolution listing two possible options that could meet those objectives:

- (i) Re-fly the Cluster mission: this option would use four re-built Cluster spacecraft and would totally recover the scientific objectives of Cluster and a substantial portion of the ESA Solar Terrestrial Science Programme (STSP). This was the highest priority option and the one that would best exploit previous investments.
- (ii) Re-build one Cluster spacecraft, namely Phoenix, and launch it together with three potentially smaller spacecraft provided through a special programme with national agencies.

Two important meetings took place on 21 June at ESA Headquarters in Paris. The recommendation by the SWT was presented to the Space Science Advisory Committee (SSAC), which met that morning. Having heard the recommendation of the Cluster Science Working Team, the SSAC advised the Science Programme Committee (SPC), which convened for an emergency meeting immediately afterwards, that, as an initial step, the Phoenix spacecraft should be made ready for flight without delay, with the aim of launching it in the summer of 1997. An early launch of Phoenix was considered essential for Europe to remain a valid partner in the International Solar Terrestrial Physics (ISTP) Programme.

The SPC did not reach a consensus on how to proceed and postponed the decision to its subsequent meeting in early July. It did, however, accept the SSAC's view that there was a strong case for Phoenix as part of ISTP, but several Delegations were reluctant to proceed with it without a simultaneous commitment to the remaining three spacecraft. The Chairman therefore asked the Delegates to consult their science communities and insisted that a decision on Phoenix needed to be made at the next meeting. He proposed that further iterations be undertaken during the summer regarding procurement of the remaining three or four spacecraft.

The Cluster community anxiously awaited the outcome of the 3 July meeting, at which the SPC was briefed on the costs of potential recovery missions for Cluster. The total cost of

Phoenix, assuming a free launch in mid-1997, amounted to 30 MAU. The cost for rebuilding four Cluster satellites according to the original design, without changes to either the spacecraft or the payload, were predicted to be 351 MAU. If a completely new design of mission had to be implemented, then the estimated costs would rise to about 640 MAU. The discussions also focussed on the potential impact of a recovery mission on the overall Scientific Programme, as the Directorate would not be given fresh money for the implementation of a recovery mission. It was clear that most future missions, except those already being implemented, would have to suffer delays and therefore solidarity and support from the other science communities that would be affected was extremely important.

The SPC finally recommended going ahead with the industrial contract for Phoenix and requested that studies be conducted to determine the most cost-efficient way of launching Phoenix and procuring the remaining three satellites to achieve a four-spacecraft mission by the year 2000.



Figure 2. Remains of one of the four Cluster spacecraft in the swamps of Kourou

This request triggered three main activities: immediate negotiations were started with Dornier regarding the procurement of Phoenix; in parallel, ESA also began negotiating cost reductions for a full implementation of Cluster, by procuring either three or four more spacecraft from Dornier, an activity termed Cluster-II Option 1; and studies were begun of realising the recovery mission by using nationally provided small satellites, an activity known as Cluster-II Option 2.

Following the SPC's recommendation, Prof. Gerhard Haerendel of the Max-Planck Institute in Garching (D) called in mid-July for a meeting

of engineers and representatives of the national agencies to initiate a study of Option 2 with the aim of procuring small spacecraft able to fulfil all of the scientific objectives of the original Cluster mission. It appeared feasible to build spacecraft of about 1.4 m diameter which could carry the Cluster payload and be launched in pairs by Ukrainian Cyclone launch vehicles. It was decided to carry out a full study and provide a final report in time for the SPC's scheduled 28/29 November meeting.

The ESA Solar System Working Group (SSWG), which provides detailed scientific advice to the SSAC, met on 22 and 23 July for a special brainstorming session on the recovery of Cluster. The SSWG reiterated that the Cluster scientific objectives remained compelling and timely and it recommended the early launch of Phoenix and expressed its solidarity and willingness to assist in exploring solutions that would meet the most essential scientific needs of the European space-plasma community.

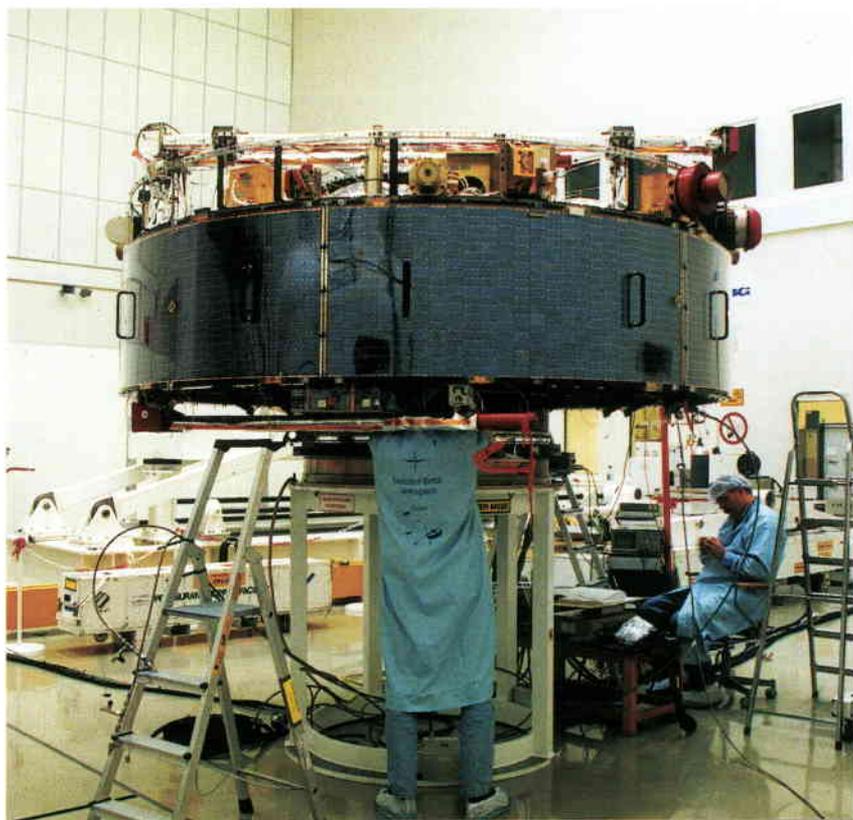


Figure 3. The Phoenix spacecraft during the final stages of its integration

In order to ensure that Cluster-II Option 1 would receive as much scientific attention as Option 2, Prof. André Balogh of Imperial College London (UK) was nominated as its co-ordinator, playing a similar role to that which Prof. Haerendel was undertaking for Option 2.

Prof. Haerendel presented the status of the Option 2 concept to the SWT on 5 September. He expressed his optimism concerning the

accommodation of the entire payload and also informed them that he had asked small industries to provide quotations. The total weight of an Option 2 spacecraft was to be around 300 kg. The Principal Investigators offered their full support to his activity and also refined their strategy regarding the expected decisions to be taken at the November SPC. The conducting of a 'public-relations' campaign in the relevant Member States was agreed.

A few days later, the Working Group responsible for implementing the Cluster Science Data System was called together to discuss the impacts of the various options on the overall system. In view of the relatively good prospects of getting Phoenix as a minimum, and perhaps even Option 1 or Option 2 at a later stage, it was decided to maintain the computer systems in a ready-for-launch condition.

Along the way, a financially attractive option of launching one pair of spacecraft into a low earth polar orbit together with a SPOT spacecraft for a cost of 20 MAU had to be abandoned due to the inherent technical difficulties.

On 8 October, Arianespace submitted its formal quotes for the launch of Phoenix and Cluster-II. It offered a Phoenix-alone launch for 33.5 MAU. Cluster-II, based on two independent launches for a pair of spacecraft together with another passenger, was quoted at 90 MAU (both launches into a standard GTO orbit).

During the SWT of 17 October, after a long debate, the Principal Investigators agreed upon a reduced payload complement for the Cluster-II mission in order to alleviate the payload funding problems within certain national agencies. This complement later became known as the 'minimum payload'. Had the eventual overall funding situation for the payload been unsatisfactory, the minimum payload would have been flown and some Investigators would not have participated in the four-spacecraft recovery mission. They would, however, have had an instrument on at least one spacecraft. The repercussions of this approach were fully realised by the scientists and it was gratifying to observe the relatively unemotional and business-like manner in which these decisions were adopted.

Prof. Haerendel's Option 2 working group meanwhile had received several responses from industry. These proposals were evaluated and ranked during a weekend session on 12 - 14 October. The conclusions were

documented and organised into a form in which they could be presented to the SPC.

The SSAC, meeting on 7 and 8 November, recommended that a cost cap of 210 MAU be imposed on the Cluster recovery programme in order to minimise its impact on the Agency's other already approved missions.

Meeting again on 13 November, the Principal Investigators expressed their satisfaction with the positive recommendations by both the SSWG and the SSAC. The Cluster recovery programme had now become a credible and realistic possibility. Still, there was some discussion about the relative scientific merits of Options 1 and 2, and the choice between them was creating some tension in the community, which had the potential to divide the otherwise united front of the Principal Investigators.

A major step forward occurred on 25 November when NASA's Associate Administrator for Space Science, Wesley Huntress, sent a letter to ESA confirming NASA's commitment to the Cluster recovery programme. He stated that NASA would fund its contributions to the minimum payload and expressed his hopes regarding a positive decision on the recovery programme.

The SPC was convening again on 27 and 28 November, and the hopes of the Cluster community were riding high. It appeared that all of the main problems had been resolved ahead of this meeting but, as so often in life, just hours before the meeting began it became apparent

that one Member State was unable to fund its relatively large share of the payload, making a positive decision on Cluster-II very unlikely.

Nevertheless, the SPC approved the principle of recovering the Cluster mission; it authorised the ESA Executive to submit a procurement proposal to ESA's Industrial Policy Committee in January 1997 for the Option 1 programme. The ESA Executive was also asked to ascertain the availability of funds from the national agencies for the 'minimum payload' as identified by the Cluster SWT. The Cluster recovery programme, be it Option 1 or Option 2, would only be undertaken if the national agencies were able to commit the funds needed for rebuilding and operating the payloads.

The SPC endorsed the cost cap proposed by the SSAC and invited the Executive to continue to study Option 2 and report on the results at the SPC meeting scheduled for February 1997. The SPC also asked for details regarding a stand-alone launch of Phoenix, in order to enable the Committee to take a decision at its February meeting.

The SWT met again in January to review the overall funding situation in the Member States. It became very obvious that this issue would finally become the one that would make or break the recovery mission. The tide was against Cluster at this point and the optimism in the community therefore began to fade once again.

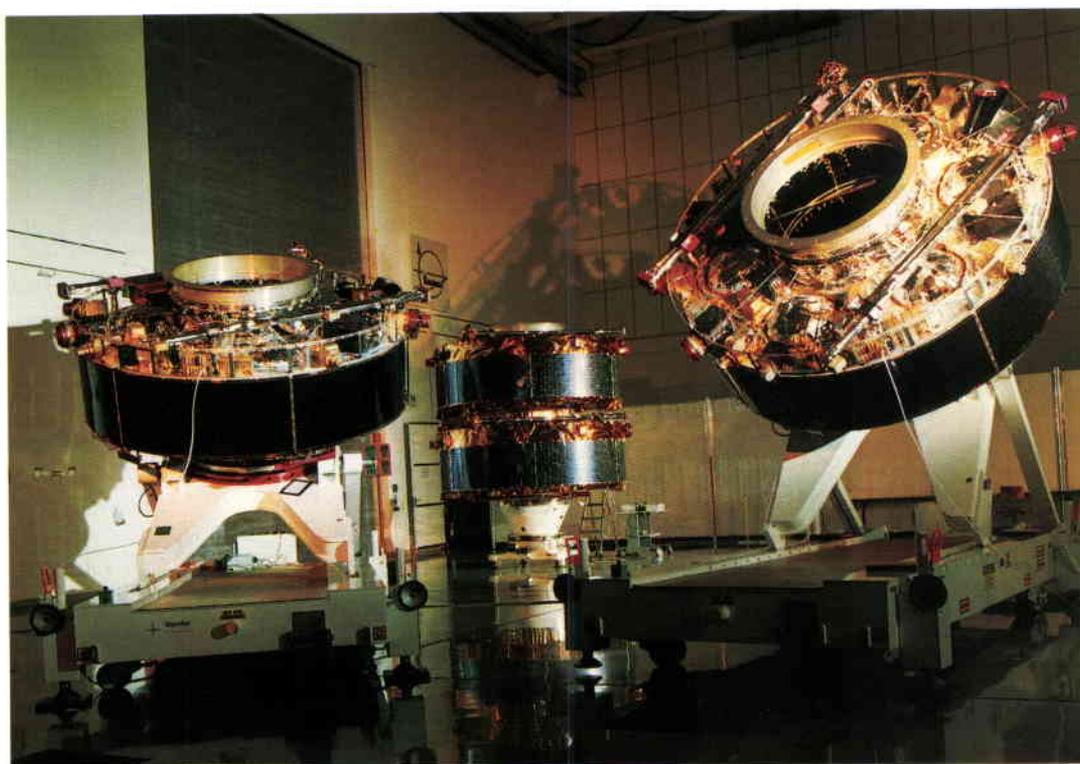


Figure 4. The four original Cluster spacecraft

The SPC, meeting on 18 and 19 February, confirmed worrying rumours as more Member States announced their inability to fund the payloads. In addition, launch opportunities on Ariane had receded for reasons completely outside the influence of ESA and the situation did not look good for Cluster's recovery. Arianespace had, however, suggested that ESA might look into the use of Russian Soyuz launchers, to be marketed in future by the STARSEM Consortium (consisting of Aérospatiale, Arianespace and two Russian companies). ESA's Director of Scientific Programmes, in an attempt to alleviate the payload funding problems, offered limited financial support to those Member States that contributed to the Cluster payload. Concluding a very intense debate, the SPC authorised ESA to continue the launcher-related study and to prepare a payload funding proposal for submission to a special SPC meeting in April. Should neither launcher nor payload funding be acceptable, then Phoenix should be launched as soon as possible and a detailed study of Option 2 initiated.

The SWT meetings of 4 and 26 February focussed on the payload funding issue and how to ensure that all contributing Member States would vote in favour of a recovery mission at the decisive meeting of the SPC in April.

The day of decision

After a long discussion at its 3 April meeting, the SPC approved Cluster-II Option 1 within a financial envelope of 214 MECU, using two Soyuz launch vehicles, and gave the go-ahead to start its implementation immediately. Ten months of struggle and hectic searching for solutions had been brought to a successful conclusion.

One of the key elements in bringing about this positive decision was the offer by the Director of Scientific Programmes to contribute to the funding of the payload elements, whereby ESA will support the Member States by covering about 40% of the total payload costs.

After many hectic SWTs, this body met again the next day in a more relaxed frame of mind for the first time in a year and discussed the implementation work for Cluster-II. The scientific community expressed its deep satisfaction with the positive decision and specifically acknowledged the support provided by Roger Bonnet, ESA's Director of Scientific Programmes.

Current status of the project

Cluster-II is now moving ahead at full speed.

The industrial contract is being placed with Dornier (D). The Phoenix spacecraft has been completed and was scheduled to undergo environmental testing at IABG, Germany, when the positive decision about Cluster-II was taken. Following this decision, the test activities were interrupted and the spacecraft was put into storage. The Phoenix payload has been returned to its providers for refurbishment. As Phoenix has become an integral part of Cluster-II, some of its subsystems will also be modified to make it identical to the new set of spacecraft. The instrument teams have started their procurement and manufacturing activities. As some of the original electronic components are no longer available, a limited redesign will be necessary.

One of the major payload-related activities concerns the establishment of contracts between Dornier and some national agencies or scientific institutes. In view of legal regulations, ESA's financial contributions to the payload must be channelled through contracts between Dornier and the national institutions. The Agency has not supported instruments in this way in the past and therefore new approaches must be explored by Dornier and the Member States, requiring some additional effort.

In parallel with the industrial activities at Dornier, detailed discussions have started with STARSEM, the European-registered provider of the two Soyuz launchers. No major technical difficulties have been identified and the prospects for launching the four new Cluster spacecraft from Baikonur in the summer of 2000 look very promising.

Acknowledgement

The scientific community and all of the other teams involved in the original Cluster project are very excited by the possibility of re-flying this unique mission. It is the Member States, through the positive decision communicated by their representatives in the SPC, that have made this possible. We are confident that the ultimate scientific success of Cluster-II will demonstrate that their confidence and financial support have been well placed.

It must also not be forgotten that the implementation of Cluster-II is having an impact on other future scientific missions. The Cluster community is very grateful for the solidarity and support shown by those communities, who have had to accept delays in some of their own missions.

The Cluster Data-Processing System

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Introduction

The definition, design and implementation of the Cluster ground segment is the responsibility of the European Space Operations Centre (ESOC) in Darmstadt. The Cluster Data Processing System (CDPS) is an important part of that ground segment and one which is crucial to achieving the complex scientific objectives of the mission. Its definition was started at ESOC in late 1990 with a careful analysis of these objectives to map out an operational scenario, and hence define a system that would best fulfil them.

The Cluster mission is designed to study the small-scale structures that are believed to be fundamental in determining the key interaction processes in cosmic plasma. The mission will be controlled from ESOC, which will also be responsible for commanding the scientific payloads of the four spacecraft, in collaboration with the Cluster Principal Investigators (PIs), and for collecting and distributing the mission results to the scientific community. To support the Cluster mission operations, ESOC has developed the Cluster Data Processing System (CDPS), the architecture of which is based on three main components:

- **the Cluster Mission Planning System (CMPS), which produces the schedules for running both the spacecraft and payload operations, as well as controlling the unmanned ground stations**
- **the Cluster Data Disposition System (CDDS), which distributes the Cluster data relevant to the scientific community, and**
- **the Cluster Mission Control System (CMCS), which is responsible for the on-line monitoring and control of the four spacecraft.**

This article reflects the ground-station scenario for the original Cluster mission in as far as the station complement for the re-flight mission is still under discussion.

The CDPS is part of the ESOC Operations Control Centre (OCC), which is the central facility responsible for operating the four Cluster spacecraft, and has been developed by ESOC's Data Processing Division. It is a distributed system, the main components of which (see Fig. 1) are:

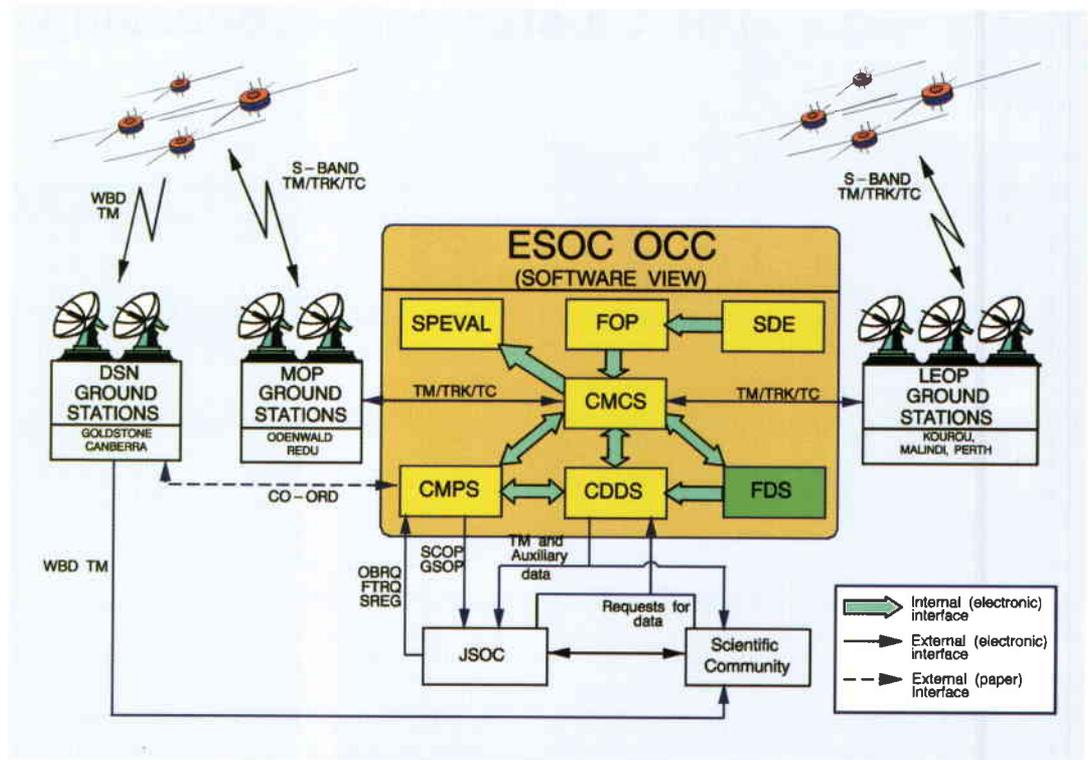
- The **Cluster Mission Planning System (CMPS)**, which is an off-line system that provides tools for the advance planning of the mission operations based on inputs from the scientific Principal Investigators

and the operations staff at ESOC. The final output of this system takes the form of machine-readable schedules for commanding the four spacecraft and the two ground stations.

- The **Cluster Mission Control System (CMCS)**, which supports the exchange of telemetry, telecommand and ranging data between the OCC and the spacecraft via the dedicated communications lines and appropriate interfacing to the ground stations. It allows the real- and near-real-time data processing essential for monitoring and controlling the mission. The CMCS also has facilities for managing the operational database and for maintaining the on-board software (the so-called 'Software Development Environment', or SDE).
- The **Cluster Data Disposition System (CDDS)**, which receives housekeeping and science telemetry data in real time from the CMCS and stores it temporarily (for ten days) to allow remote access by the Cluster scientific community for the quasi-real-time inspection of mission data. In addition, it provides facilities for the regular daily production of compact disks, both for distribution to the scientific community and for the permanent archiving of raw telemetry and auxiliary data.
- The **Cluster Spacecraft Evaluation System (CLUSPEVAL)**, which allows the archiving of all housekeeping, telemetry and auxiliary data and their retrieval based on complex queries for spacecraft performance evaluation. It supports the derivation of basic and complex statistics and the sophisticated plotting of this information.

In addition, there is an offline **Flight Operations Procedure System (FOP)** that is used by the Mission Operations Team to prepare Cluster operations procedures and command sequences, which can then be imported into the operational database.

Figure 1. Overall architecture of the Cluster Data Processing System (CDPS)



These last two systems are not addressed in this article as they form part of the generic ESOC infrastructure, i.e. they can be reused with minor modifications in support of other missions.

In designing this distributed system, great care has been paid to the concepts of back-up and redundancy in order to be able to cope effectively with emergency situations. The CMCS, for example, is a fully redundant system with no single-point failure.

The Cluster Mission Planning System

The Cluster mission planning is a complex task that involves four spacecraft each carrying eleven identical and independent payloads and all of the traditional platform

subsystems. The main role of the CMPS is to schedule the onboard and ground operations so as to maximise the scientific return from the mission within the prevailing constraints, e.g. the onboard storage and power capacities, and ground-station visibility and availability.

The routine mission-control concept is based on the use of a single control centre in conjunction with the two dedicated ESA ground stations, at Redu in Belgium and in the Odenwald in Germany. All payload operations will be conducted according to an agreed plan produced in advance via an iterative mission-planning process. A slightly different approach is necessary for Cluster's WBD payload as it requires coverage from the NASA Deep Space Network (DSN). The

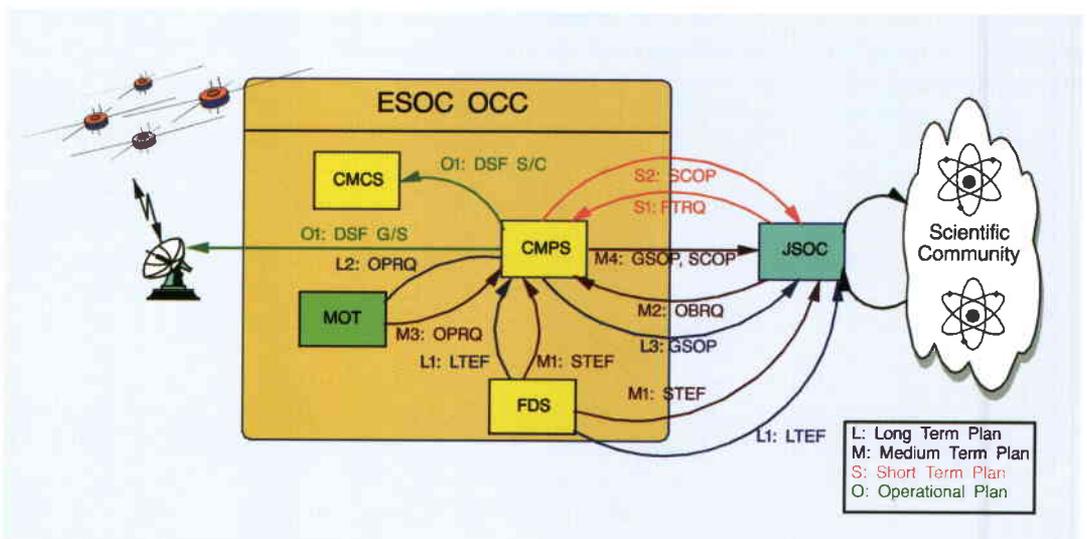


Figure 2. Overview of the Cluster Mission Planning System (CMPS)

CMPS partially supports the coordination with the DSN authority for allocation of Cluster coverage periods and, upon their confirmation, it allows the scheduling of WBD operations. Real-time payload operations are not foreseen during the routine phase, except for special operations like payload software maintenance activities. In addition, most of the platform operations, including dumps from the onboard recorders, are also included in the planning exercise.

To coordinate and consolidate the requests for scientific observations by the Cluster scientific community, a Joint Science Operations Centre (JSOC) has been established in the United Kingdom. The process of planning the Cluster operations (Fig. 2) involves several iterations between ESOC and JSOC. These have been formalised into four planning levels:

- (i) The long-term plan, which initialises the planning process and covers a period of about six months. It has to be finalised three months before the start of the period itself.
- (ii) The medium-term plan, which has a duration of six orbits (the average period of the nominal Cluster orbit is about 57 hours).
- (iii) The short-term plan, which covers the period of three orbits.
- (iv) The operational plan, also for three orbits, which is completely frozen and can only be used to generate the six Detailed Schedule Files (DSFs): one for each of the four spacecraft and the two ground stations.

The Cluster Mission Control System

The CMCS provides the functionalities needed to support the real-time and near-real-time data-processing tasks that are essential to control the mission (Fig. 3). One of the main drivers for its design is the fact that Cluster is the first multiple-spacecraft mission to be controlled by ESOC. In particular, the CMCS must support four spacecraft simultaneously during the Launch and Early Orbit and Transfer Orbit Phases (LEOP/TOP) and two during the subsequent Mission Operations Phase (MOP). This is achieved by exploiting the remotely controlled Redu and Odenwald ground stations. In addition, the CMCS receives and distributes the entire Cluster telemetry data stream.

Most spacecraft and payload operations are pre-planned and executed from the onboard time-tagged queue. Nominal real-time

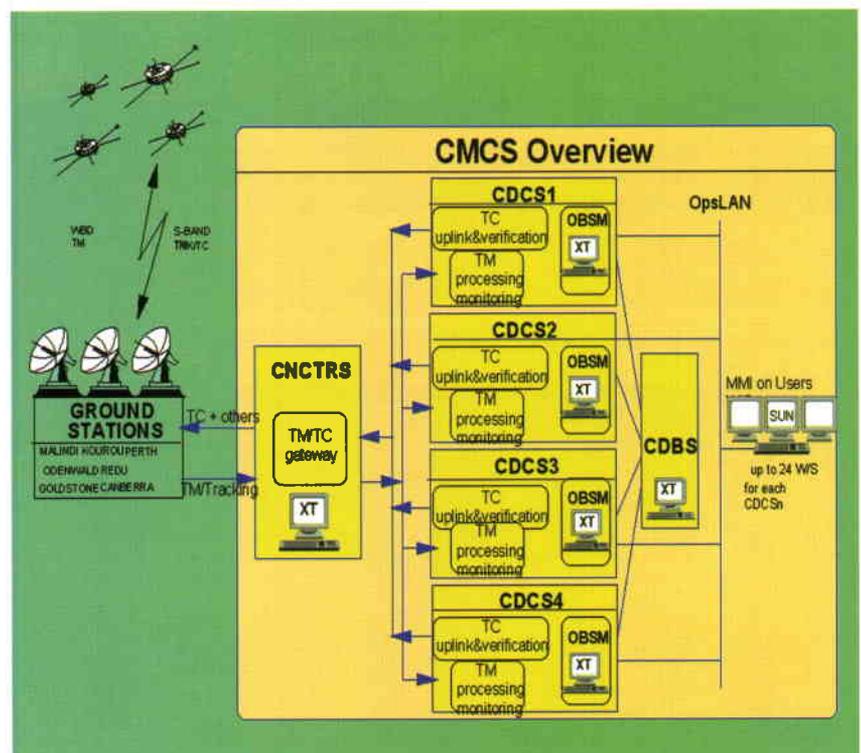
operations are limited to the acquisition of on-line and stored telemetry data of all types – housekeeping, memory dumps, science – the former generated at fixed time intervals and the latter recorded during the non-coverage periods and dumped to the ground station during the real-time contact periods, and the uplinking to the onboard memory of time-tagged commands for the execution of all pre-planned platform and payload operations. In addition, real-time operations are also used for special situations like complex payload software maintenance and contingencies.

The main CMCS functionalities, all of which are supported by a sophisticated and homogeneous graphical user interface, are as follows:

Ground-station interfacing and control

The Cluster Network Controller and Telemetry Receiver System (CNCTRS) performs the ground-station interface and control functionalities. It includes facilities for telemetry reception, telecommand transmission, range and range-rate measurements, and ground-station scheduling for the two unmanned stations. The CNCTRS receives the telemetry as delivered by the ground-station equipment and, after having run some basic checks, 'stamps' it with the Earth Reception Time (ERT). It then passes the housekeeping telemetry to the relevant Cluster Dedicated Control System for more specific processing, whilst the science telemetry data are delivered to the Cluster Data Disposition System.

Figure 3. The Cluster Mission Control System (CMCS) architecture



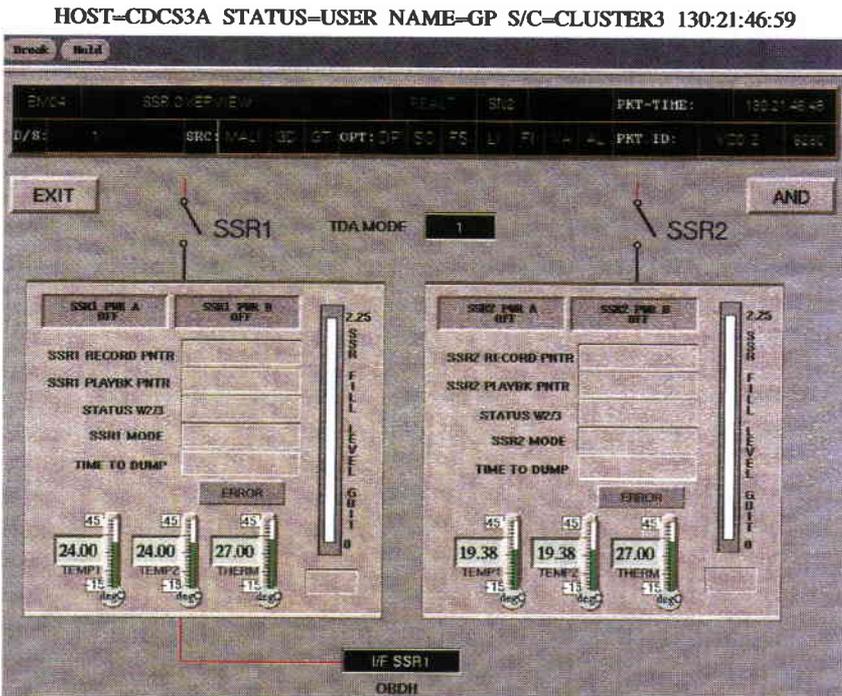


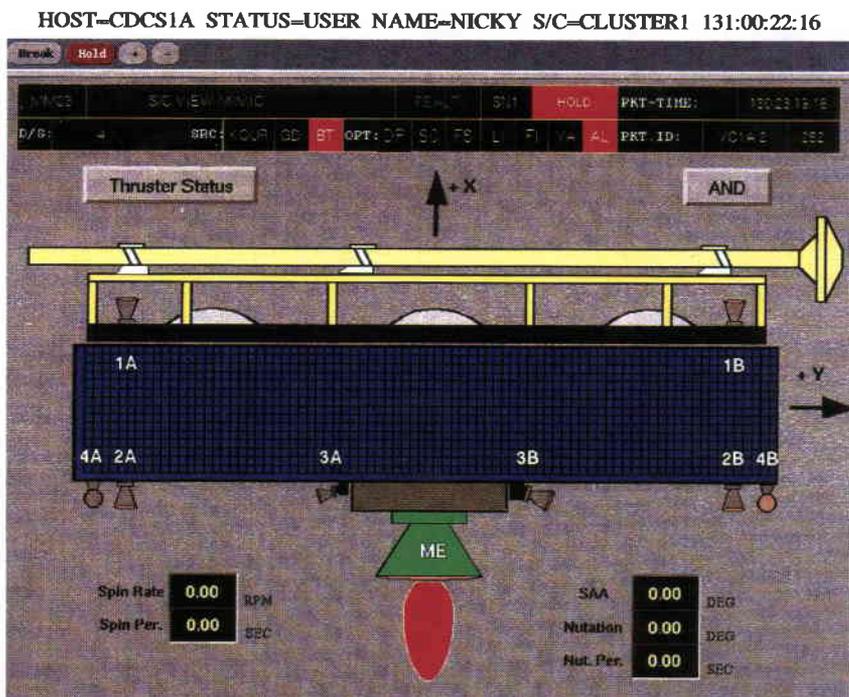
Figure 4a. Mimic display of the solid-state recorder

Furthermore, the CNCTRS gathers all the telecommands sent from the CDCSs and forwards them to the relevant ground station. The CNCTRS is also used for acquiring and locally storing range and range-rate measurements made at the ground station, which are made available to the Flight Dynamics System.

Housekeeping telemetry processing

Each of the four Cluster Spacecraft Dedicated Control Systems (CDCSs) performs the spacecraft monitoring and control functions and onboard software maintenance for a specific spacecraft. Each CDCS handles

Figure 4b. Mimic display of part of Cluster's attitude and orbit control subsystem (AOCS)



housekeeping data, special Cluster event messages and memory-dump data. The spacecraft housekeeping and science telemetry are time-stamped with UTC with a measurement error of less than 2 ms. Parameters can also be processed using calibration curves to convert them into engineering and/or functional parameter values. The housekeeping telemetry is subsequently made available to the operations staff via the On-Line Monitoring System. It is also filed in so-called 'Short-Term History Files' covering the last 10 days of the mission, used for remote access and offline investigations by the flight-dynamics control team. The telemetry is also regularly transferred to the CLUSPEVAL system for long-term archiving.

Telecommand uplinking and verification

The CDCSs also support the telecommand chain, providing the spacecraft operators both with interactive manual commanding and automatic schedule uplinking capabilities. They are also responsible for performing the telecommand uplinking and on-board execution verification via returned telemetry.

On-board software maintenance

The On-Board Software Maintenance (OBSM) facility provides management and configuration control of all changes performed to the on-board software. It relies on the CDSN as its host.

Database management

The Cluster Database System (CDBS) is an offline system that supports all database functions. It is a single database in which the telemetry/telecommand characteristics for all four Cluster spacecraft are defined and maintained for the entire duration of the mission. It also allows the importation of the spacecraft manufacturer's assembly, integration and test database.

The CMCS is based on a distributed system architecture with six primary computers, each with a dedicated standby machine (yellow boxes in Fig. 3), linked by the operations local area network (LAN) and accessible only to the operations staff at ESOC. The CDDS provides the necessary secure connection between this operational LAN and the external world, including the Cluster scientific community, in order to support, for instance, payload command requests.

For monitoring and control purposes, telemetry data from within the CMCS database can be displayed in alphanumeric form, graphical form and as synoptic mimics, two examples of which are shown in Figures 4a,b.

The Cluster Data Disposition System

The main role of the CDDS is to deliver the mission data to the Cluster scientific community. This is performed via two distinct services provided by the system: the On-Line Data Delivery Service, which allows mission data to be delivered on request via an electronic network for quick-look purposes; and the Off-Line Data Delivery Service, which allows the offline production of recordable compact disks (CD-Rs), to be used as masters for the mass production of CD-ROMs containing all Cluster data.

The types of mission data that are made available by these two services are basically identical, and include housekeeping and science telemetry from all four Cluster spacecraft and all auxiliary data required to correctly process and interpret the telemetry.

Figure 5 is a schematic of the CDDS's interactions with the other Cluster systems and its main products. An important feature of the CDDS is that it provides a safe gateway for secure communication between the highly protected operations environment in ESOC and the external world.

On-line data delivery service

As shown in Figure 5, the CDDS receives housekeeping and science telemetry data in real-time from the ground stations via the front-end computer of the CMCS, whilst the auxiliary data comes from both the CMCS and the Flight Dynamics System (FDS), to which external users have no access because they are protected by the ESOC network security system (firewall). The CDDS stores this data

upon receipt and makes it available to users just a few seconds later. Only the last ten days of data are kept on-line.

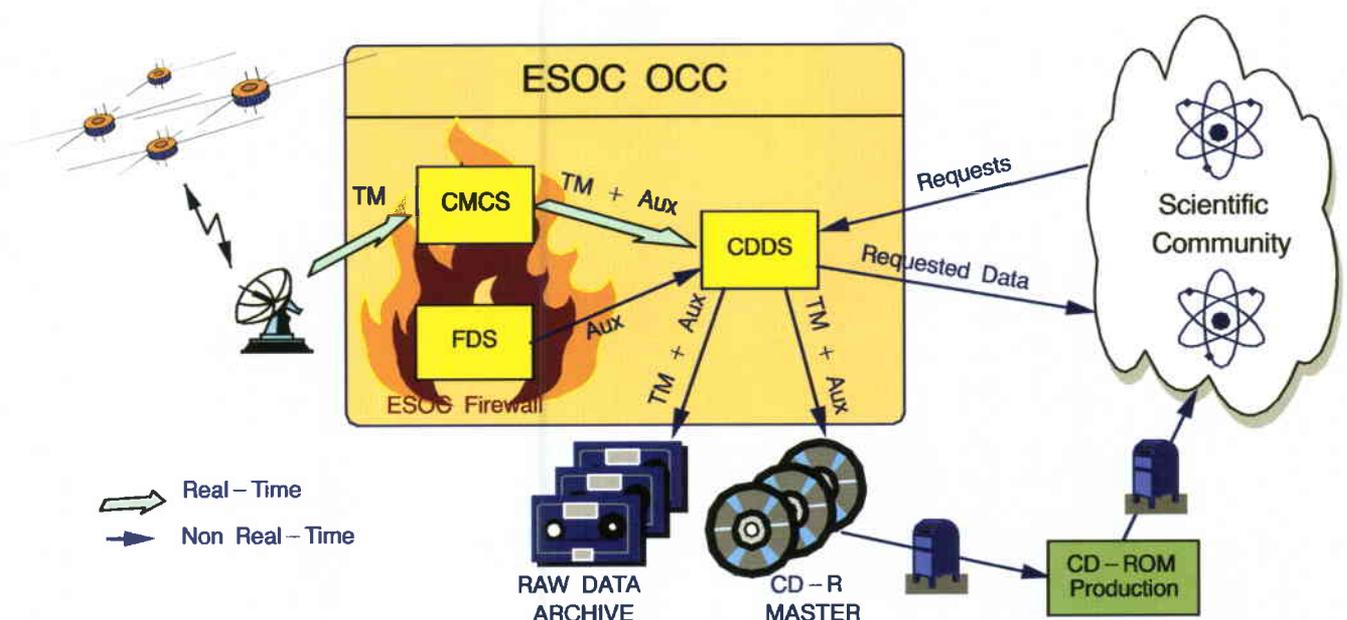
The on-line data-delivery service works as a client-server model, with no interactive interface for the user, just the exchange of request files and resultant data transfers. The user copies a request file from his own network node to his CDDS account, and the ensuing transfers are effected using FTP-based protocols. The data requested can be from three sources: telemetry data, auxiliary data or master catalogue data.

Off-line data delivery service

The off-line data delivery service is totally separate and asynchronous to the on-line service, although both use the same data pool that is available on the CDDS. This service is wholly controlled by ESOC and does not require any input from external users. As shown schematically in Figure 5, the CDDS stores all housekeeping, science-telemetry and auxiliary data on Recordable Compact Disks (CD-Rs), which are shipped by courier to an external manufacturer for duplication (in about 100 copies) onto Read-Only Memory CDs (CD-ROMs). The latter are then packaged and shipped to authorised members of the Cluster scientific community around the world.

Production of an average of two CD-ROMs per day is foreseen during the Mission Operations Phase, although the CDDS can support the production of up to four CD-ROMs per day on an exceptional basis. The set of CD-ROMs for any given day must be delivered to the scientific community within three weeks of the data's generation. This period includes the

Figure 5. Overview of the Cluster Data Disposition System (CDDS) and its environment



consolidation of orbit and attitude data (6 days), the production of the CD-Rs at ESOC (1 day), the shipment to the CD-ROM manufacturer (2 days), the CD-ROM replication (5 days) and, finally, the delivery of the CD-ROMs directly to the science community members (7 days).

A format compliant with the ISO 9660 level 1 standard is used for the CD-ROMs, so that the disks are readable on all common platforms, e.g. UNIX, VMS, PC and Macintosh.

Conclusions

The multi-spacecraft Cluster mission represents a considerable operational challenge, and all of the complex requirements associated with the novel mission characteristics and user requirements have been carefully analysed by ESOC. The resulting distributed computer system was chosen for several reasons:

1. The distributed architecture reduces the cost of both hardware and software.
2. The cost of procuring and maintaining several smaller computers (VAX stations) is significantly lower than that of a large computer capable of hosting the whole system.
3. Software licences are also usually cheaper for small computers. Furthermore, the distributed architecture allows the optimum use of licences across the system.
4. In the distributed architecture, each element is independent, and failure of one does not generally affect the others. Furthermore, the global system performance is not compromised by heavy resource usage by one element. This can be of particular importance for time-critical tasks, such as real-time commanding.
5. In the distributed architecture, off-line tasks are hosted on a dedicated computer. Important resource-hungry off-line tasks are thereby totally decoupled from the actual spacecraft operations and other time-critical tasks (e.g. database maintenance).

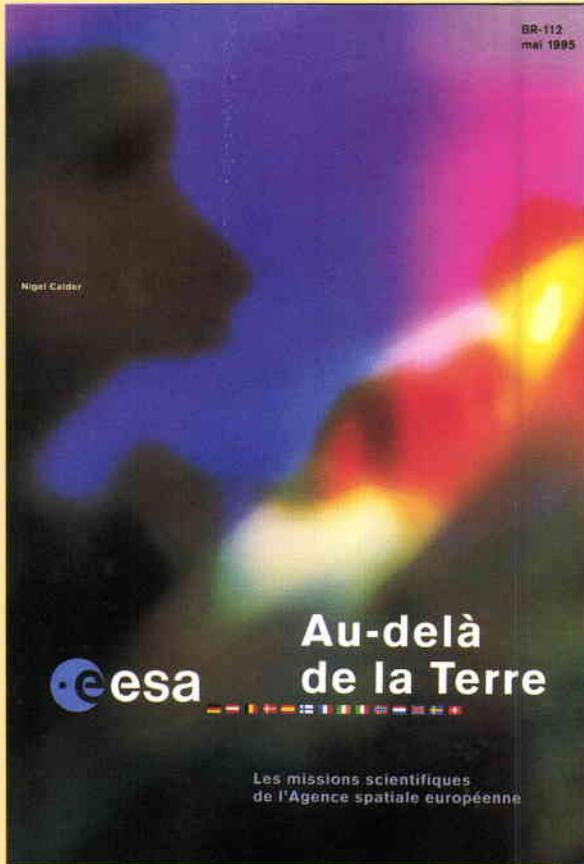
The experience gained in the Cluster preparation activities has shown that this distributed architecture for science operations provides greater flexibility and allows trade-offs to be made between the various elements of the overall system. This in turn allows the end-to-end data return to be optimised, as well

as leading to an overall reduction in project costs.

On the other hand, distributed systems call for clear definitions of the interfaces between the elements. Great effort has therefore been devoted to the definition, review and configuration control of these interfaces for Cluster. The science community have been encouraged to take an active part in their definition, review and testing.

On the assumption that the Cluster data-processing system will perform as well throughout the mission as it has during testing, ESOC's challenge for the future is to build on the novel experience gained to implement systems capable of meeting the needs of future, ever more challenging science missions.

esa



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 Cluster On-Board Software Maintenance Concept

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Introduction

The Cluster on-board software will handle primary spacecraft control, as well as the science data acquisition and formatting. To ensure safe operations and service continuity, the On-Board Software Maintenance (OBSM) concept that will be employed allows in-flight modification of the running software, through an incremental model based on patches. New programs are compared to the current software on board and the differences are converted into memory-load commands. Four independent versions of the on-board software will be maintained - one per spacecraft - with multi- and inter-spacecraft handling for the common functionalities.

The Cluster mission will be operated from ESOC. In addition to the mission challenges imposed by the simultaneous operation of four coordinated spacecraft, ESOC will be responsible for maintaining the software of the On-Board Data Handling (OBDH) subsystem from the time of launch until the end of the mission, which is nominally two and a half years. This on-board software maintenance capability provides a powerful means of adapting the behaviours of the four Cluster spacecraft to the real-time status of the hardware of each and to any operational difficulties that they might encounter during their operating lifetimes

The necessary OBSM tools have been set up at ESOC to support the production of the software updates and their uplinking to the four spacecraft, and to keep track of the prevailing configurations. In addition, ESOC has developed several application programs that will facilitate routine Cluster operations.

On-board software and operations

Why on-board software maintenance?

With recent generations of spacecraft, complex onboard software has emerged as a key component between the ground control facilities and the spacecraft platform and payload being operated, by offering a high level of spacecraft autonomy and flexibility. This software can be modified or even redefined during the mission, whereas most other on-

board subsystems are confined within the limits of pre-defined configurations.

The need for On-Board Software Maintenance can arise at any time, from immediately after launch if the spacecraft's post-launch status calls for operational adaptations, until the end of the mission when ageing of the in-orbit hardware leads to a greater probability of failures. Even if these OBSM services are not used regularly, an adequate infrastructure must be available on the ground throughout the mission to correct, add to or re-design the on-board software whenever the need arises.

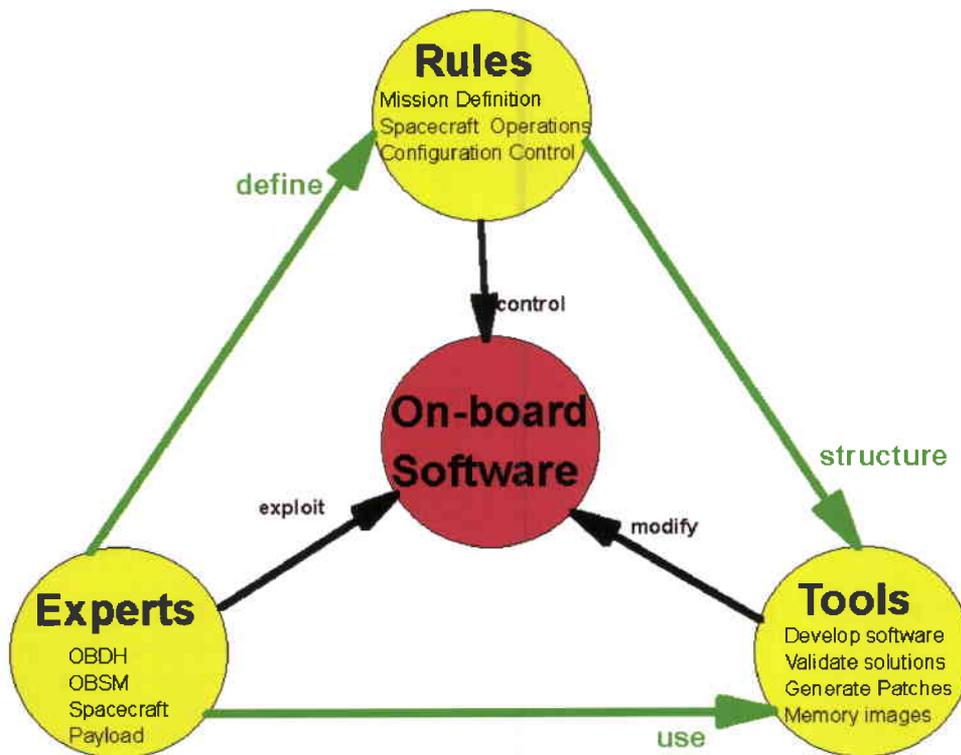
New programs must be uplinked to the spacecraft during the mission in order to adapt the OBDH's behaviour to the prevailing status of the spacecraft hardware and any operational difficulties that are encountered, and sometimes to satisfy additional requirements for the benefit of the user community or for operational safety reasons.

The operational environment

The software on-board the spacecraft is used by the spacecraft operator to run the mission according to specific rules (Fig. 1). These rules are prescribed flight and control procedures prepared by ESOC for each space mission, incorporated in the Flight Operations Plan, and adapted during flight as necessary. OBSM calls for specific flight control procedures for adding or modifying on-board functionality, or for restoring a known safe status. As such OBSM activities can change the OBDH subsystem's overall behaviour, configuration rules are introduced to control the successive software versions.

The OBSM tools have to support both the production of new software and its uplinking to the OBDH subsystem, whilst also ensuring safe integration of the new elements with the flight software originally delivered by the spacecraft manufacturer and keeping track of what is actually loaded on-board at any given

Figure 1. On-board software and operations



time. An OBSM workbench integrated into the operations environment has to include a compiler and software development environment (SDE), a software validation facility (SVF), a generator for patch telecommands, and a mission database of “memory images”. The latter are files representing, on the ground, the contents of the spacecraft’s on-board computer memory (programs and data) at any time during the mission.

ESOC’s role

Industry cannot be expected to provide all of the expertise or to maintain at their premises all of the tools that might be needed at very short notice at any time during the routine phase of every space mission, some of which can last for ten years or more. Keeping on-board software experts from industry on standby at ESOC throughout such missions would be just too expensive, not to mention the difficulties that would be encountered when missions are extended or terminated at short notice. Another alternative of buying off-the-shelf development tools from the OBDM manufacturer would neither guarantee the timely availability of adequate OBSM facilities nor the availability of the requisite expertise. Such development tools are not necessarily suitable for software maintenance and tend to be geared to hardware and software configurations far removed from the ESOC norm in terms of standards. Moreover, the spacecraft operator must be totally familiar with the on-board software and its current configuration, making close integration of the software tools within the

ESOC environment mandatory. Hence, it is desirable to have an autonomous OBSM infrastructure within the Control Centre itself, where the operations rules are defined and routinely applied. Within ESOC, the Mission Operations Department is responsible for OBSM, and the OBSM engineer forms part of the Flight Control team.

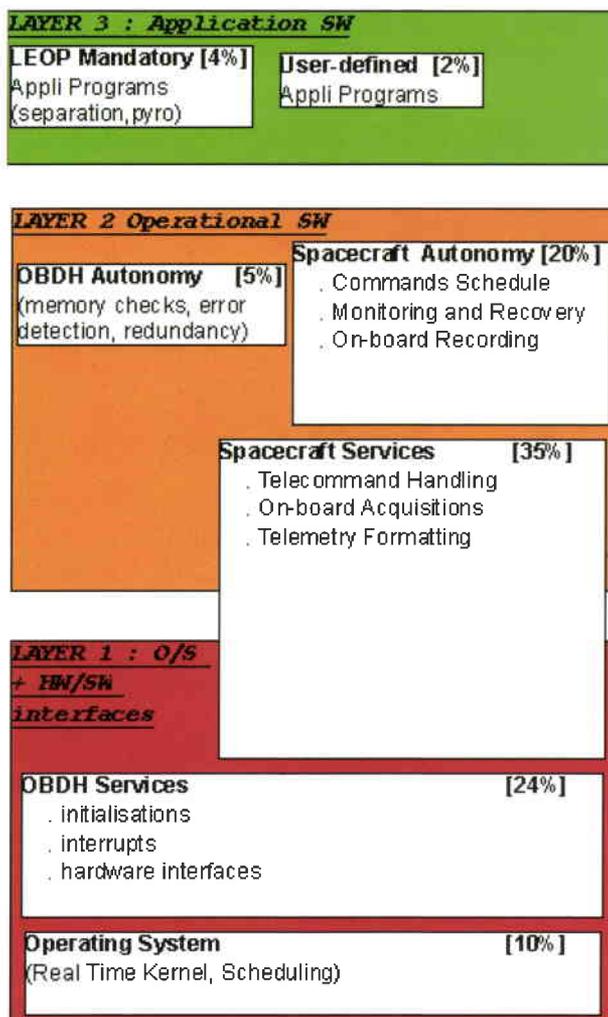
The choices for Cluster

This scientific mission involves four classical spin-stabilised spacecraft, each with its own ESA “standard” OBDM subsystem, running 72 kB of flight software. The scope of the OBSM is limited to maintenance of the OBDM software, the payload computers being the responsibility of the scientific investigators.

Prior to launch, the spacecraft manufacturer Dornier (D) is responsible for any adaptations of the on-board software. Any updates needed after the final delivery and prior to launch will be provided in the form of software patches, which ESA can decide to apply or not after test and trade-off with operational workarounds.

ESOC will be responsible for the Cluster OBSM from the moment of launch and a support contract for the Launch, Commissioning and Mission Phase (Phase-E/F) has been established between ESA and the Cluster OBDM supplier Laben (l). During the launch and commissioning of the spacecraft platform, Laben’s OBDM experts will be available at ESOC. Thereafter, ESOC will be in the front line for the duration of the mission, with the

Program Instructions [54 kB]



Program Constants [18kB]



Figure 2. On-board layering of Cluster software

contractor providing second-line OBSM support based on its reference knowledge of the multi-layered Cluster OBDDH software and hardware and its development (Fig. 2). All implementation, compilation, linking and configuration-control tasks will be under ESOC's responsibility.

The OBSM concept for Cluster

Three major features of the OBSM concept for the Cluster mission are: the ability to modify programs whilst they are running; the ability to distribute common software elements to several spacecraft; and the routine maintenance of operations data.

Live program patching

The OBSM concept originally defined by ESOC assumes a global and linear process. New programs and modifications to programs are written in ADA in a Software Development Environment (SDE), compiled and linked to the current flight code. The resulting complete new executable image is then delivered to the Cluster Dedicated Control System (CDCS) where a history of the on-board memory

contents is stored. The new contents are then compared with the current status of the memory and the differences, i.e. the software upgrade, are systematically converted into memory patch telecommands ready for uplinking.

The Cluster OBDDH software has to run continuously to ensure spacecraft survival, but the available on-board resources do not allow the running of two software versions - one active and one being loaded or modified - simultaneously. The existing software therefore has to be upgraded whilst it is running, which excludes recompilation and linking of the whole flight source code at ADA level, since the resulting executable image might be completely different and then impossible to load.

The global OBSM concept has therefore been transformed into an incremental model based on patches, which requires a deeper knowledge of the flight software image delivered by the OBDDH manufacturer. This reference image is always reloaded from PROM if a reboot occurs, and it will remain the basic framework to which all new software must be attached throughout the Cluster mission (Fig. 3).

As new instructions added to or replacing old code will become active immediately they arrive on-board, the patching procedure must take into account the detailed logic of the program being modified in order to ensure a clean transition. In addition, independent program units can be registered as application programs in the built-in task scheduler, and activated later.

Multi-spacecraft facilities

Certain code upgrades, for instance new functions defined by ESOC, will be common to the Cluster fleet and will need identical implementation. For sound configuration control, such software items to be loaded into all four spacecraft must come from a single source. Other potential software upgrades like those compensating for hardware failures on individual spacecraft will, by definition, be spacecraft-dependent and will therefore have to be created and maintained in an environment protected from interferences with the OBSM environments of the other spacecraft.

The principle of four independent on-ground OBSM environments handling four independent computers in flight has been amended to allow inter-spacecraft copying of the contents of memory patch telecommands. It will therefore be possible to distribute a

program produced in the development environment to one, two, three or all four spacecraft. However, dumped memory images will be unique to each spacecraft and cannot subsequently be exchanged.

OBSM data-handling support

OBDH reconfiguration tasks like the reprogramming of telemetry acquisition or recording tables can easily be carried out with the OBSM patching tools. Using the multi-spacecraft facilities, such tables can be reprogrammed identically on all four spacecraft, as long as no divergence in on-board hardware imposes different configurations on different spacecraft. Also, when performing OBDH

check-ups, OBSM comparison tools will facilitate the automation of large data verifications between a memory dump and the expected pattern. Data maintenance will be even easier than program maintenance because the values modified on-board will generally be passive or can be de-activated during the time of the change. This facility will provide an opportunity to exercise the OBSM procedures and tools, so that when live program patching is eventually required basic confidence in the techniques will have already been established and all efforts can be focused on defining and validating the necessary software modifications.

AREA	Item	Address	Size
PROGRAM Memory (executable code)		0000	36864
<div style="border: 1px solid black; padding: 2px; margin-bottom: 2px;">don't touch</div> <div style="border: 1px solid black; padding: 2px; margin-bottom: 2px;">modifiable</div> <div style="border: 1px solid black; padding: 2px;">free use</div>	Operating system and Real Time Kernel	0000	768
	Hardware interface routines	03BD	385
	On-Board Monitoring handler	08C0	642
	Separation handler	0B23	837
	Telecommands handler	1B1E	804
	Telemetry handler	1F1B	1878
	Constants	6A10	9151
	<i>FREE -> User Application programs</i>	8DCF	250
	<i>FREE -> Corrective Code Extensions</i>	8E66	168
	Checksum	8F70	90
	WORKING Memory (dynamic)		9000
	Variables	9000	197
	Scheduling Table	90C5	288
	Variables	91E5	1661
	Telecommand buffers	9862	1303
	Variables	AB65	6861
	<i>FREE</i>	C632	206
	Telemetry Acquisition Tables and Buffers	C700	13413
	Variables	FB65	1955
	<i>FREE</i>	10308	1273
	Stack	10800	2048
	TABLE Memory (user buffers)		11000
	Time-Tag Commands (Master Schedule)	11000	6000
	Macro-Commands	12770	2048
	On-board recorded Telemetry	12F70	250000
PROTECTED Memo (against power loss)		6C000	4096
	OBDH status and Data Quality Flags	6C000	2
	Command Buffers	6C002	3508
	<i>FREE</i>	6CDBA	581
	Mirror part	6D000	4096
PERMANENT Memo Original Flight Software in PROM		F0000	36864

Figure 3. Main memory areas

Figure 4. Primary OBSM tools

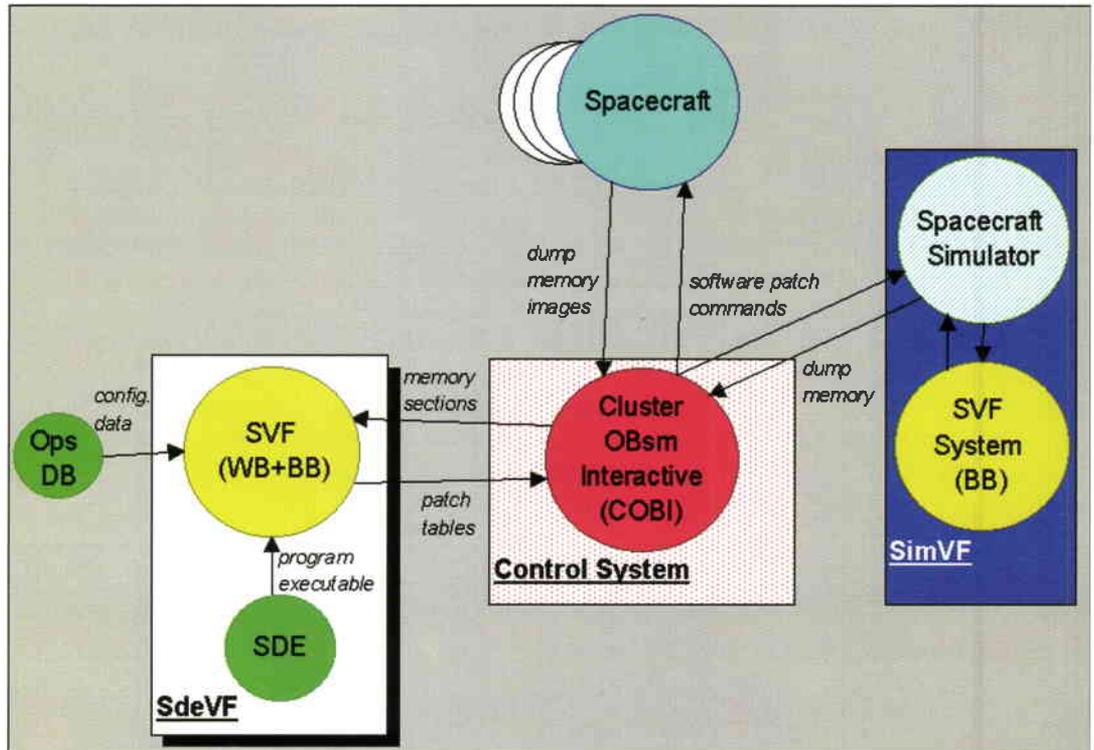
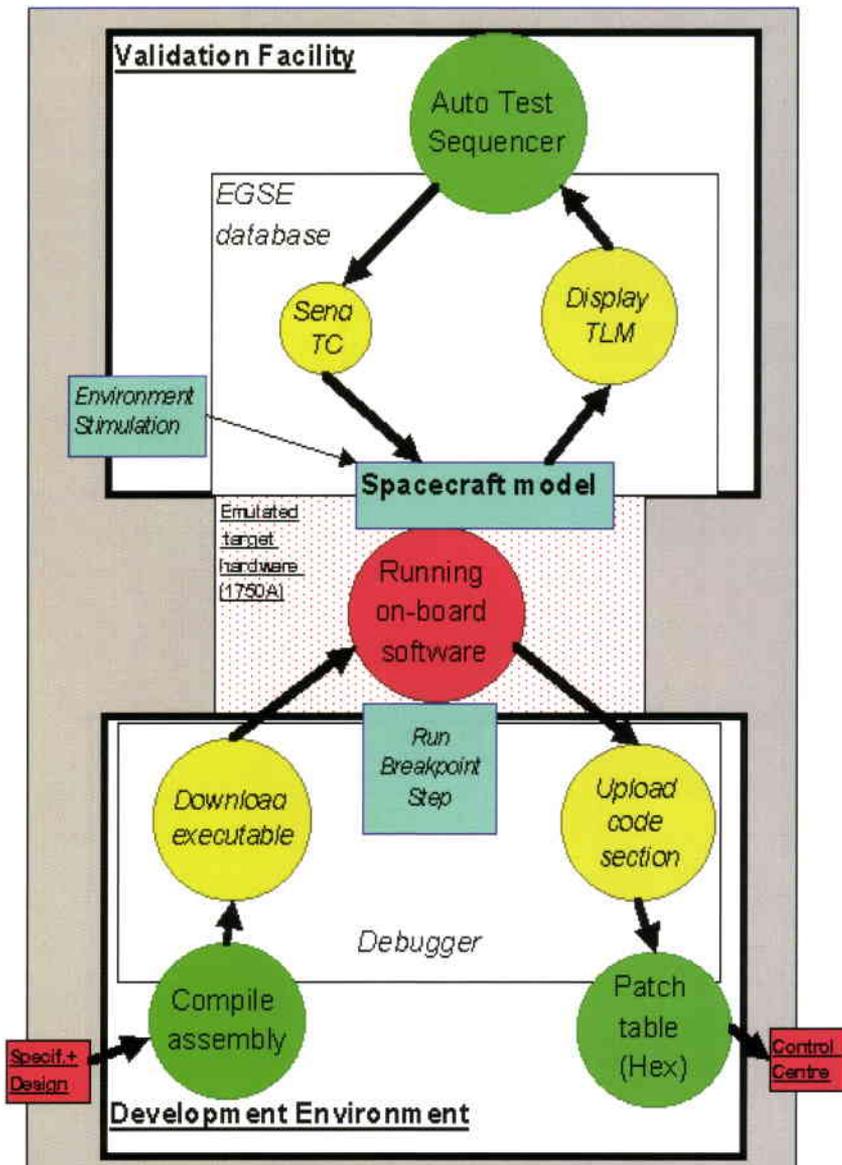


Figure 5. A single tool with which to develop and validate



Tools and on-board software validation

The primary OBSM tools for the Cluster mission are shown in the schematic of Figure 4. The two Software Validation Facilities - labelled SdeVF and SimVF - correspond to the two types of real-time requirements during the validation of new software, as explained below.

Software Development and Validation Facility (SdeVF)

An innovative Software Development and Validation Facility has been provided to ESOC by ESTEC as the result of seeking a cost-effective approach to serve both the Soho and Cluster missions. This facility offers a unique trade-off between low-level and high-level validation tools, combining two major validation strategies: software debugging on target hardware, and telecommand/telemetry consistency checking (Fig. 5).

At one level, the SdeVF serves as a development environment, including a 1750A Assembler compiler, for writing application programs and patches in Assembler. New programs and corrections can be immediately downloaded to the emulated target hardware, a 1750A microprocessor identical to that embedded in the Cluster OBDH, on which the rest of the flight software is already running. As from the coding step, therefore, this analytical tool helps in taking care of integration constraints, like available memory space, timing, performance and existing code.

At the next level, the SdeVF serves as a validation facility, with which the primary

interaction of the on-board software with its spacecraft environment can be checked. Cluster-specific functions simulate the OBDH hardware items like the telecommand decoder and the telemetry frame generator. The spacecraft outside the OBDH is simulated by a logic derived from the database of the Electrical Ground Support Equipment (EGSE): the telemetry reflects the status of devices switched on or off by telecommands. The evolution of analogue parameters like temperatures can be simulated stepwise, devices can be failed to a blocked status, etc. The simulated spacecraft is operated through the EGSE telecommand and telemetry interfaces in an interactive mode.

With its test sequencer, the SdeVF provides a major step towards the automation of software validation in that it is possible to program interactively every verification in a test scenario. The whole set can then be replayed by the test sequencer in a matter of hours to provide a formal go/no-go verification for the acceptance of a new on-board software release.

Interactive OBSM

Control tools used at ESOC to handle memory images and patch commands for the Agency's two ERS remote-sensing spacecraft have been adapted for Cluster, resulting in the Cluster OBsm Interactive (COBI) facility noted in Figure 4. COBI supports the on-ground representation and maintenance of the software images on-board the four Cluster spacecraft (Fig. 6) in four distinct environments - one per spacecraft - with inter-spacecraft

facilities. As most configuration control is performed on memory images, the on-board configuration of each of the four spacecraft must always be known by the ground so that it could be reconstructed at any time if needed. The memory images are obtained from memory dumps, the interpretation of which is facilitated by symbol tables.

Telecommands are constructed within COBI to modify the on-board software. Patch command sequences are obtained by comparing new memory sections or programs defined and validated on the SdeVF with actual on-board memory contents. The differences are converted into memory load commands, ready for uplinking. Only small portions of the memory (e.g. 1%) are affected each time, as all modifications respect the structure and address mapping of the reference flight code.

Simulator-based Validation Facility (SimVF)

This is a mode of the Cluster simulator in which the OBDH software model is replaced by a hardware emulation, as in the SdeVF, with a 1750A microprocessor identical to that in the Cluster OBDH running the flight software. The SimVF combines the real - and modifiable - on-board software with a full spacecraft simulation. It is operated from the Control Centre through the operational ground environment (Fig. 7), via a simulated ground station.

Operational validation of new on-board software can thus be reliably carried out using the SimVF. The behaviour of the OBDH, including software as OBSM intends to modify

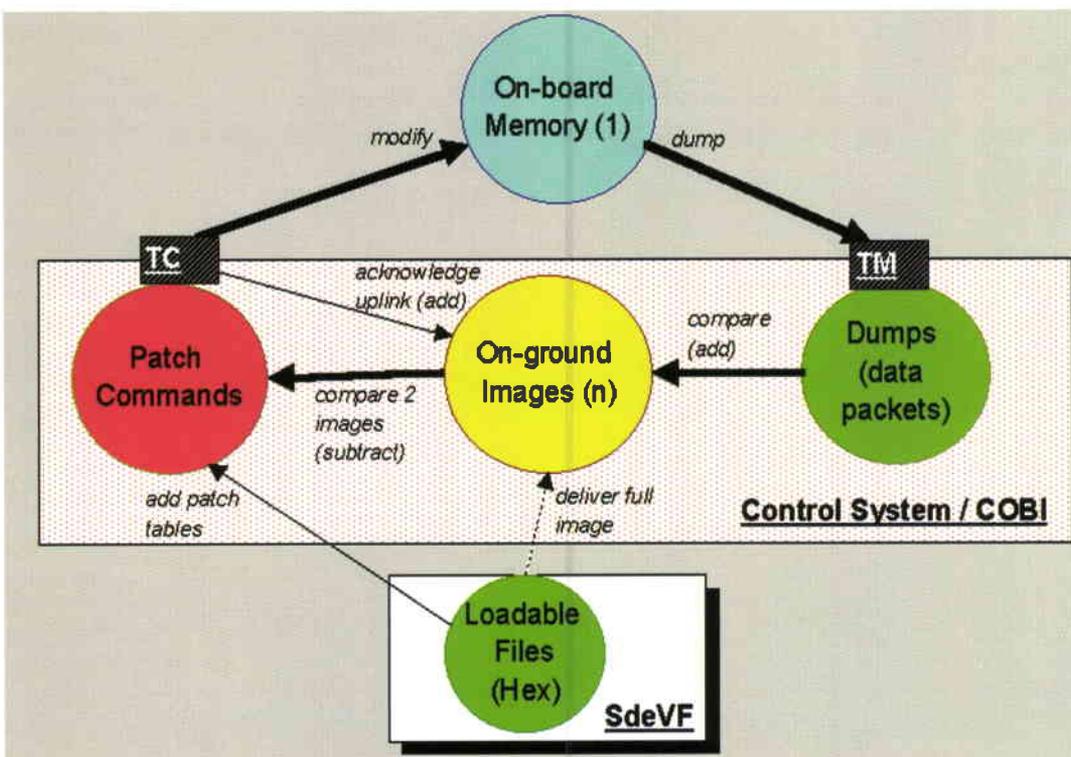
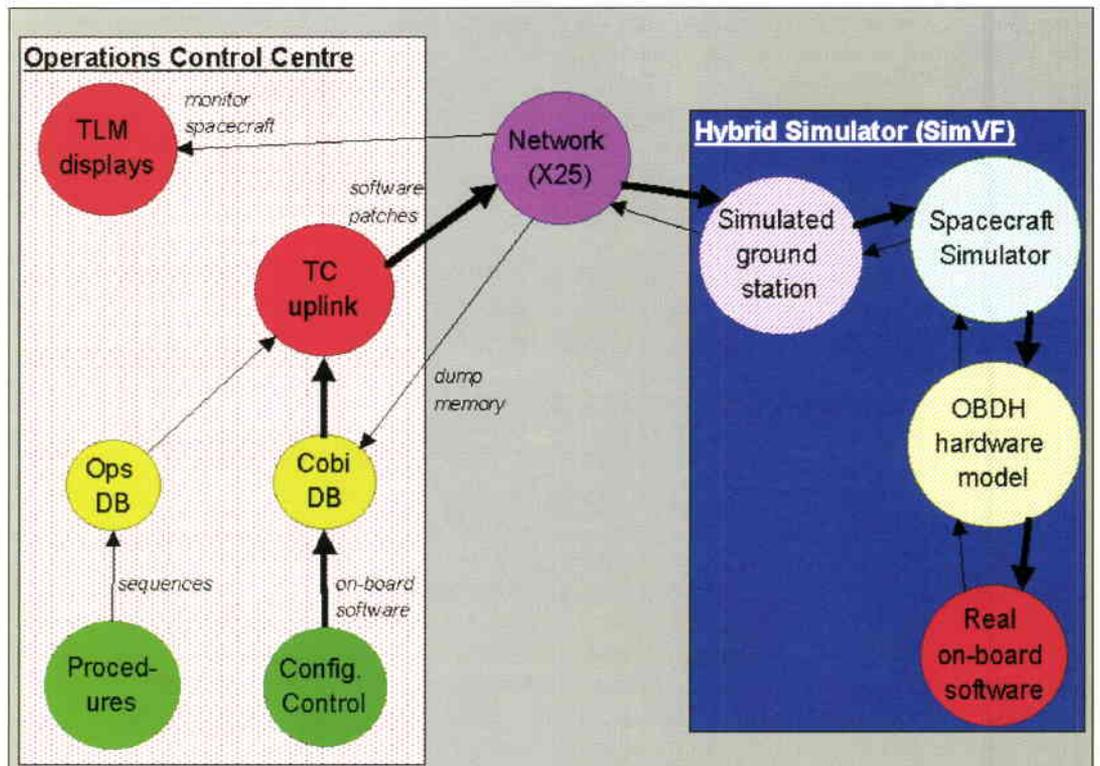


Figure 6. The image modification loop

Figure 7. Operational validation



it, is testable at system level within the modelled spacecraft. The robustness of the modified system can be assessed by executing operational procedures that involve the upgraded functionality.

The SimVF also supports OBSM procedure validation. As the installation of new software modifications has to take place in a continuously running software environment that ensures spacecraft survival and cannot be interrupted, such rehearsals are mandatory!

Conclusion

On-board software maintenance activities of the type described here have already been successfully carried out during the pre-launch phase of the original Cluster project in 1996. ESOC was able to successfully apply off-the-shelf patches provided by the spacecraft manufacturer and to add application programs

to improve operational capabilities beyond those included in the original design. ESOC is therefore certainly ready to fulfil its role in providing operational On-Board Software Maintenance for the Cluster fleet of four spacecraft in simultaneous operation.

With the current trend towards standardisation of on-board computer systems, the efforts described here are undoubtedly a good investment for the future. The new software maintenance and validation techniques and procedures that have been devised for Cluster are already being applied for ESA's Huygens and XMM missions, providing further confidence in ESOC's abilities to meet the needs of ESA's ever more demanding space missions for many years to come.

Optical Communications in Space – Twenty Years of ESA Effort

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Introduction

Twenty years ago, in summer 1977, ESA placed a technological research contract for the assessment of modulators for high-data-rate laser links in space. This marked the beginning of a long and sustained ESA involvement in space optical communications. A large number of study contracts and preparatory hardware development followed, conducted under various ESA R&D and support technology programmes. In the mid-1980's, ESA took an ambitious step by embarking on the SILEX (Semiconductor laser Intersatellite Link Experiment) programme, to demonstrate a pre-operational optical link in space.

In summer 1977, ESA placed the first technological study contract in the domain of intersatellite optical links. Now, twenty years later, a major milestone has been reached with the SILEX laser terminals having been flight tested for integration with their host spacecraft. At the same time, ESA is preparing itself for a new challenge: the potential massive use of optical cross links in satellite constellations for mobile communications and global multimedia services. This is an opportune moment to look back at the past twenty years of ESA effort in laser communications, to take stock of the results achieved and to reflect on ways to face the challenges of the future.



Figure 1. Laboratory breadboard model of CO₂ laser transceiver system

SILEX, which will be in operation in the year 2000, has put ESA in a world-leading position in civilian optical intersatellite links. While SILEX formed the backbone of ESA's optical communications activities in the recent past, additional R&D activities were undertaken to develop attractive second-generation systems, particularly for the commercial satellite market. Indeed, at the turn of the century, literally thousands of intersatellite links — radio-frequency (RF) and optical — are expected to be in operation in commercial multi-satellite constellations providing mobile communications, video conferencing and multimedia services. The race is on for the European laser communication industry to enter this lucrative market. Optical technology offers too many advantages in terms of mass, power, system flexibility and cost, to leave the field entirely to RF. With the heritage of twenty years of technological preparation, European industry is well positioned to face this burgeoning demand for commercial laser terminals.

The early days

When ESA started to consider optics for intersatellite communications, virtually no component technology was available to support space system development. The available laser sources were rather bulky and primarily laboratory devices. ESA selected the CO₂ gas laser for its initial work. This laser was the most efficient and reliable laser available at the time and Europe had a considerable background in CO₂ laser technology for industrial applications. ESA undertook a detailed design study of a CO₂ laser communication terminal and proceeded with the breadboarding of all critical subsystems which were integrated and tested in a complete laboratory breadboard transceiver model (Fig. 1).

This laboratory system breadboarding enabled ESA to get acquainted with the intricacies of coherent, free-space optical communication.

However, it soon became evident that the 10 micron CO₂ laser was not the winning technology for use in space because of weight, lifetime and operational problems.

Towards the end of the 1970's, semiconductor diode lasers operating at room temperature became available, providing a very promising transmitter source for optical intersatellite links. In 1980, therefore, ESA placed the first studies to explore the potential of using this new device for intersatellite links. At the same time, the French national space agency, CNES, started to look into a laser-diode-based optical data-relay system called Pastel. This line of development was consequently followed and resulted in the decision, in 1985, to embark on the SILEX pre-operational, in-orbit optical link experiment.

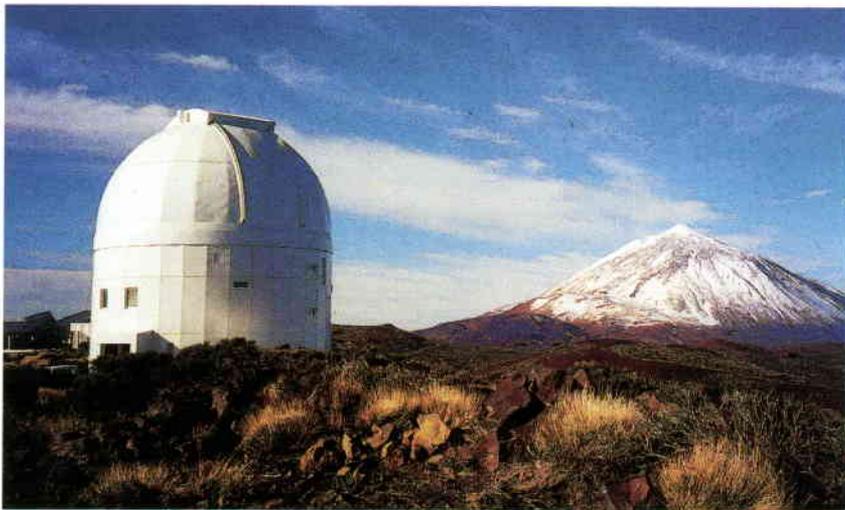


Figure 2. SILEX/Artemis Optical Ground Station on Tenerife, Canary Islands

SILEX

SILEX is a free-space optical communication system which consists of two optical communication payloads to be embarked on the ESA Artemis (Advanced Relay and TEchnology MISSION Satellite) spacecraft and on the French Earth-observation spacecraft SPOT-4. It will allow data transmission at 50 Mbps from low Earth orbit (LEO) to geostationary orbit (GEO) using GaAlAs laser-diodes and direct detection.

The SILEX Phase A and B studies were conducted around 1985, followed by technology breadboarding and predevelopment of the main critical elements which were tested on the so-called 'System Test Bed' to verify the feasibility of SILEX. A detailed design phase was carried out in parallel with the System Test Bed activities up to July 1989. At that time, the development of SPOT-4 Phase C/D was agreed with an optical terminal as passenger. This was an important decision since it made a suitable partner satellite available for the ESA data-relay satellite project;

the stage was therefore set to start the main SILEX development effort in October 1989.

In March 1997, a major milestone was reached in the SILEX programme: both terminals underwent a stringent environmental test programme and are now ready for integration with their host spacecraft. However, due to the agreed SPOT-4 and Artemis launch dates, it is likely that the in-orbit demonstration of the overall system will not start before mid-2000. Consequently, the GEO terminal will need to be stored after the completion of the spacecraft testing. The first host spacecraft (SPOT-4) is planned for launch in February 1998. The launch of Artemis on a Japanese H2A is delayed for non-technical reasons until February 2000. Apart from launching Artemis, Japan is participating in the SILEX programme with its own laser terminal, LUCE (Laser Utilizing Communications Equipment), to be carried onboard the Japanese OICETS satellite (Optical Inter-orbit Communications Engineering Test Satellite), set for launch in summer 2000.

Optical ground station on Tenerife

As part of the SILEX in-orbit check-out programme, ESA started to construct an optical ground station on the Canary Islands in 1993 (Fig. 2). This station, which will be completed by the end of 1997, simulates a LEO optical terminal using a 1-m telescope, allowing the performances of the GEO optical terminal on Artemis to be verified. The optical ground station will receive and evaluate the data transmitted from Artemis and will simultaneously transmit data at optical wavelengths towards Artemis. In addition to its primary objective as the SILEX in-orbit check-out facility, the optical ground station will also be used for space-debris tracking, lidar monitoring of the atmosphere and astronomical observations.

Towards smaller optical user terminals

SILEX has been a vital developmental step for Europe since it will provide inflight testing of a pre-operational optical link in space. The programme has stimulated the development of many new space-qualified optical, electronic and mechanical equipment items and technologies which can now form a core for future optical terminals. However, with its mass of 157 kg and electrical power consumption of 150 W, SILEX is hardly an attractive alternative to an RF terminal of comparable transmission capability.

One must bear in mind that the SILEX terminal had to be dimensioned using the limited laser diode power available at the end of the 1980's,

namely 60 mW average power at 830 nm. The result was a 25 cm telescope aperture, both on the LEO and the GEO terminal (Fig. 3). Indeed, for reasons of design and equipment commonality, it was decided to have identical LEO and GEO terminals to save on overall programme cost. The large telescope diameter obviously puts very stringent requirements on the pointing, acquisition and tracking (PAT) subsystem and related components.

For an Inter-Orbit Link (IOL) user terminal to be attractive, it is important to keep mass, interface requirements to the host spacecraft and cost to a minimum. Realising this, and anticipating the need for small data-relay LEO user terminals, ESA launched a programme in January 1992 for the development and manufacturing of an elegant breadboard of a Small Optical User Terminal (SOUT). Working outside the SILEX programmatic constraints, the SOUT programme no longer had to consider identical LEO and GEO terminals but could concentrate on developing a truly

asymmetric system using a smaller LEO transmitter with reduced constraints on the spacecraft. The SOUT terminal was specified for a data rate of 2 Mbps and was based on GaAlAs laser-diode technology with a SILEX-compatible wavelength and polarisation plan.

The SOUT terminal (Fig. 4) includes a number of innovative features. The mechanical interface to the spacecraft comprises an anti-vibration mount (soft-mount) which acts as a low-pass filter to the spacecraft microvibration spectrum. This reduces the bandwidth requirements for fine pointing, allowing a single Charge Coupled Device (CCD) sensor to perform both acquisition and tracking functions. The SOUT activities were successfully completed in December 1994, demonstrating that a compact terminal can be realised with a mass of about 25 kg.

After the successful completion of the SOUT programme, the UK supported the idea to adapt the SOUT terminal concept for low-data-

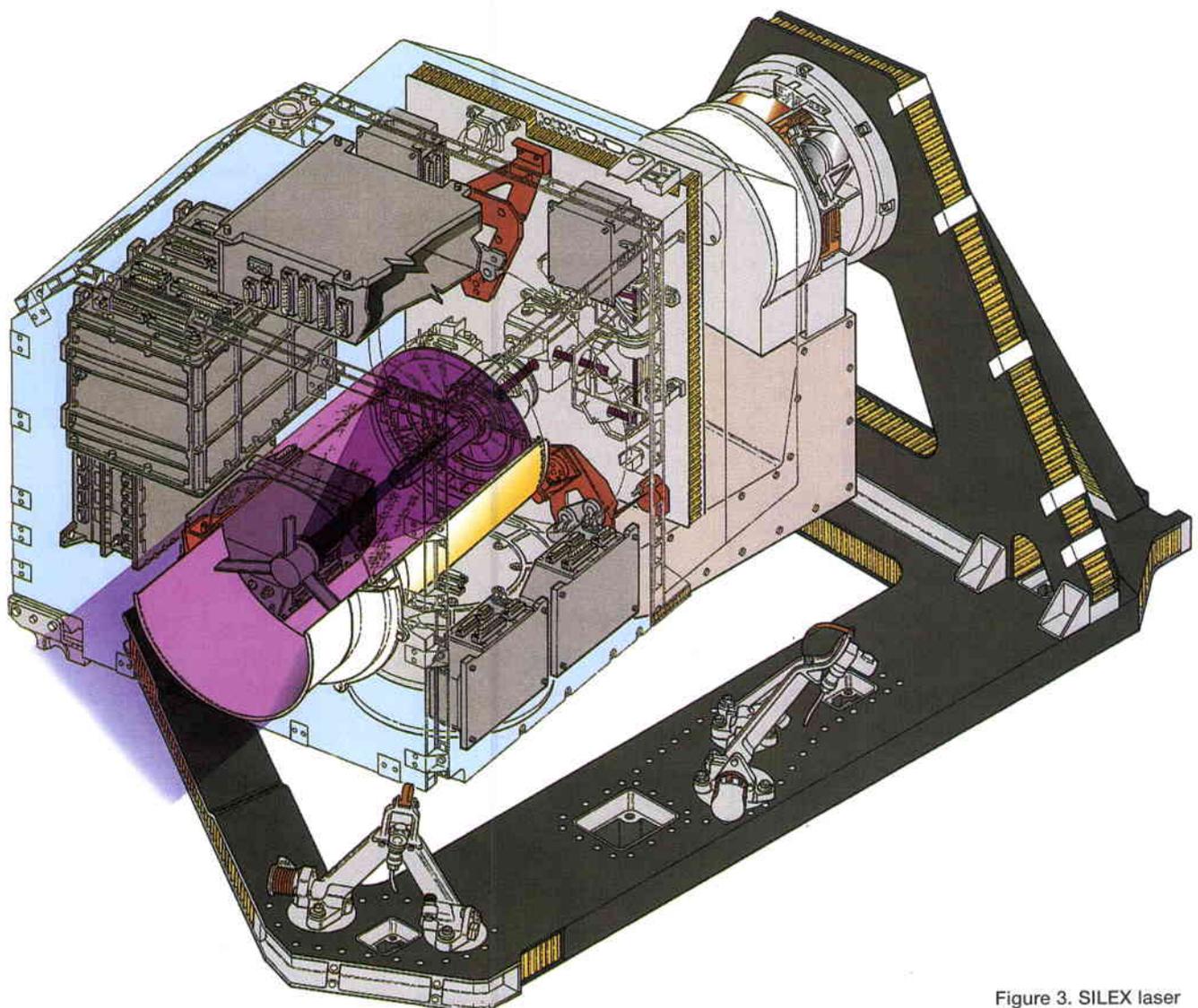


Figure 3. SILEX laser terminal

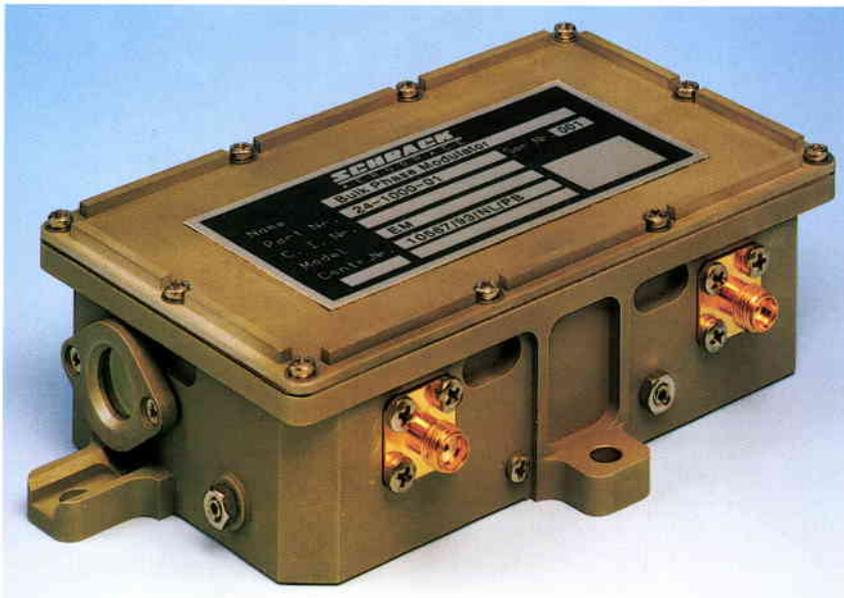
Figure 4. Small Optical User Terminal (SOUT)

rate cross links between two communication satellites in geostationary orbit. The name SOUT was changed to SOTT, the first 'T' standing for 'Telecommunication' instead of 'User'. A contract was awarded to Matra Marconi Space (UK) at the beginning of 1995 under the ARTES-4 partnership programme, which is 50% co-funded by industry, to study the changes that would be necessary to convert the SOUT terminal to the SOTT terminal. The communication capacity was increased with the help of Maser-Oscillator-Power-Amplifier (MOPA) laser diodes. Presently, the SOTT programme is still continuing but directed towards new market needs requiring a 1 Gbps data rate and GEO-GEO link distances up to 83 000 km, such as in the Hughes Spaceway system.

Coherent laser communication systems

In its search for smaller and more efficient laser terminals, ESA continued to investigate other advanced system concepts and technologies. Direct-detection, semiconductor laser-diode technology, as applied in SILEX, is appropriate for moderate-data-rate systems; however, there are physical limits to the achievable laser power and detector sensitivity. Optical direct detection receivers using state-of-the-art Avalanche Photo Diodes (APD) require about 50 photons/bit to achieve a Bit Error Rate (BER) better than 10^{-6} . On the other hand, coherent systems, based, for instance, on Nd-YAG laser radiation, are highly promising for high-data-rate systems. There is no principle restriction to the achievable laser power and detector sensitivity can almost reach the theoretical quantum limit. Since 1989, therefore, ESA has placed strong emphasis on the development of Nd-YAG laser-based coherent laser communication systems and related hardware technologies.

Figure 5. Phase modulator for Nd-YAG laser radiation



As part of this effort, two parallel system design studies were initiated in 1989 for the 'Design of a Diode-Pumped Nd:Host Laser Communication System'. Funding difficulties within the ESA ASTP-4 programme prevented a full hardware implementation of such terminals, but a number of critical technology elements were breadboarded and tested, including a diode-pumped Nd-YAG laser, a multi-channel coherent optical receiver and an electro-optic phase modulator (Fig. 5). Initially, Germany and Italy were primarily supporting this work; Italy subsequently withdrew and Germany continued the activities under the German national SOLACOS (Solid State LASer Communications in Space) programme.

The coherent Nd-YAG laser communication effort also stimulated the investigation of advanced concepts such as optical amplifiers in fibre-optic and/or semiconductor technology and the possibility of synthesising the input/output aperture of the terminal with the help of an array of smaller sub-apertures, coherently coupled together. Optical phased arrays provide laser communication systems with the inertia-free and hence ultra-fast, beam scanning ability needed for accurate beam pointing, efficient area scanning and reliable link tracking in the presence of spacecraft attitude jitter. The feasibility and efficiency of this concept has been demonstrated, and an

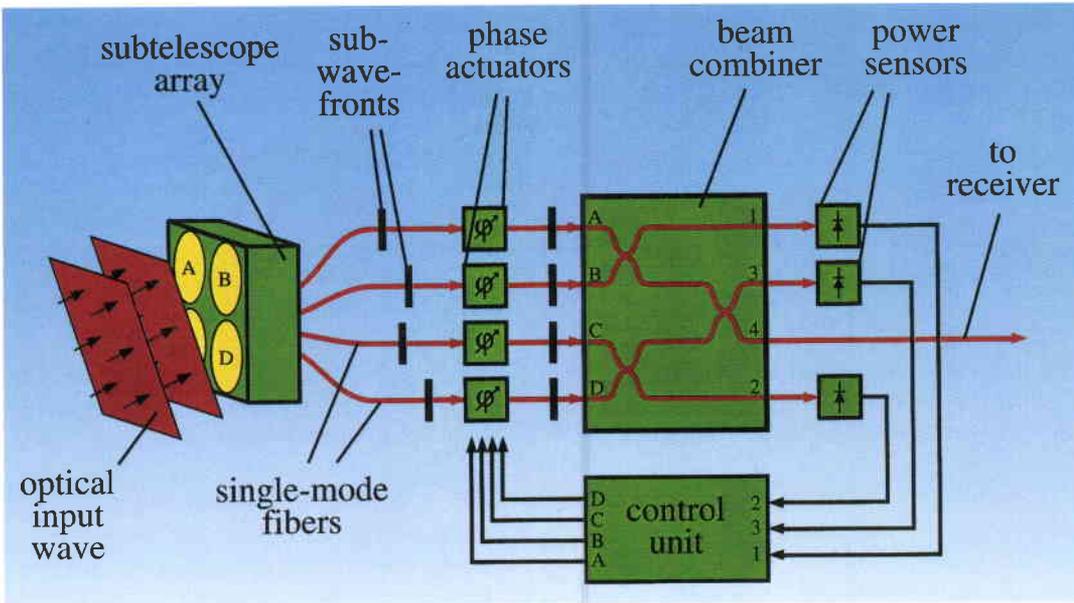
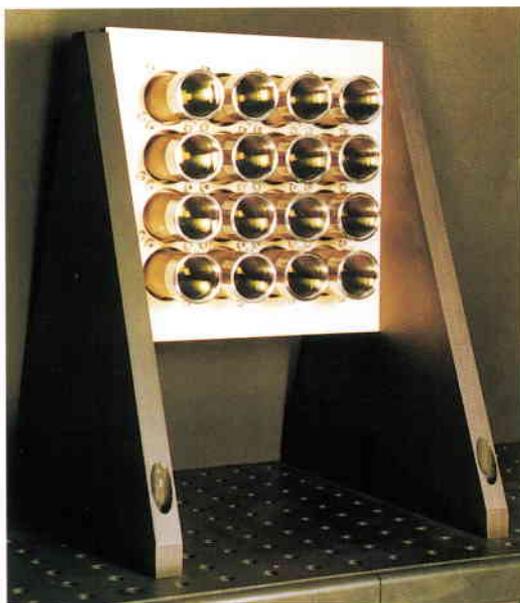


Figure 6a. Schematic of the optical phased array



optical phased array with 16 telescope subapertures of 3-cm diameter is presently in development, along with an integrated-optics phase control unit (Fig. 6a,b).

Figure 6b. Demonstrator model of the 16-telescope front-end unit

Laser terminals for commercial systems

Up to the early 1990's, ESA's optical communication activities were dominated by the data-relay scenario. Over time, however, some potential future users of a data-relay service disappeared and the interest in a near-term development of second-generation user terminals dropped considerably. On the other hand, a new class of potential users of optical intersatellite links emerged with the intended deployment of extensive satellite networks for mobile communications and interactive multimedia services.

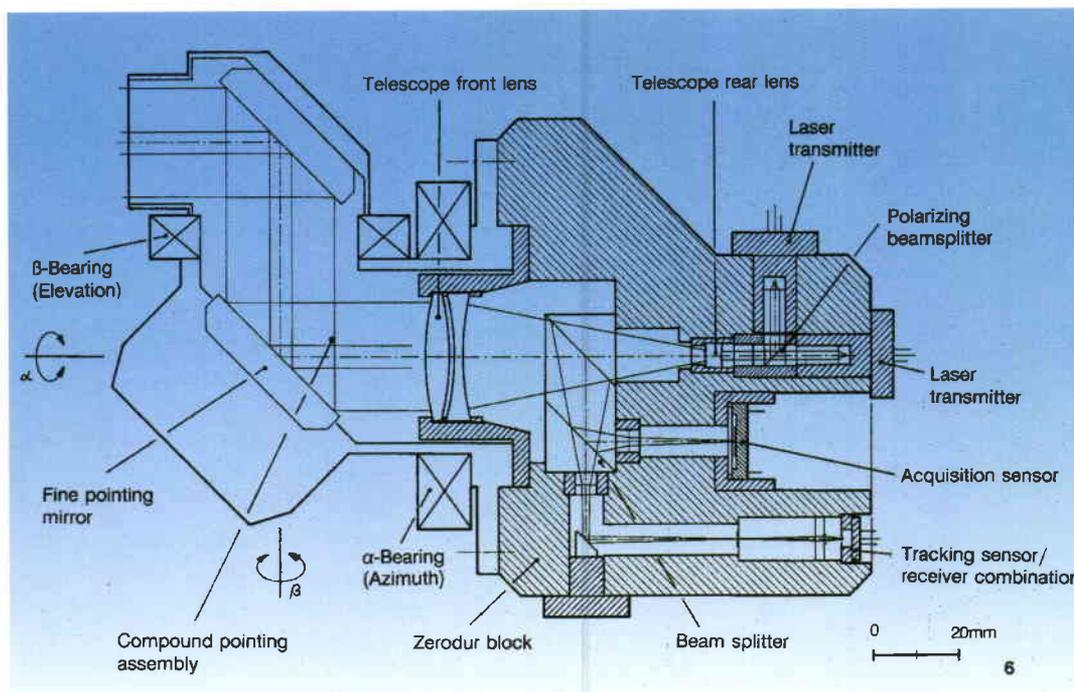


Figure 7. Monolithic Mini Optical Terminal (MOMOT)

Driven by these new perspectives, ESA started internal studies in 1991 to investigate possible design solutions for the compact laser terminals potentially needed by such commercial satellite constellations. One of the initial results was MOMOT, the Monolithic Mini Optical Terminal. The MOMOT optical head is essentially a monolithic glass block which fully compensates for thermal expansion effects and supports all optical and electro-optical elements. By using novel diffractive optical technologies and advanced principles of microsystem design, a very compact and lightweight design became feasible (Fig. 7).

In April 1996, ESA placed a contract with an industrial team led by Oerlikon-Contraves Space (CH) for the design, realisation and testing of a demonstrator of a compact and lightweight optical terminal for short-range

terminals), the cost issue becomes a dominant factor. To be attractive for these systems, optical ISL terminals, like SROIL, will have to be made very compact and robust, and be designed for mass production.

Following a Critical Design Review held in March 1997, go-ahead was given to produce a demonstration model of the SROIL terminal by summer 1998. To achieve ultimate system miniaturisation, highest transmit data rates and sufficient growth potential to also comply with extended link ranges, the SROIL terminal was designed using a laser-diode pumped Nd-YAG laser transmitter in conjunction with a coherent detection receiver. A two-axis pointing assembly in front of the 3.5 cm aperture telescope allows the SROIL terminal to achieve almost full hemispherical pointing (Fig. 9). The communication subsystem is designed as a

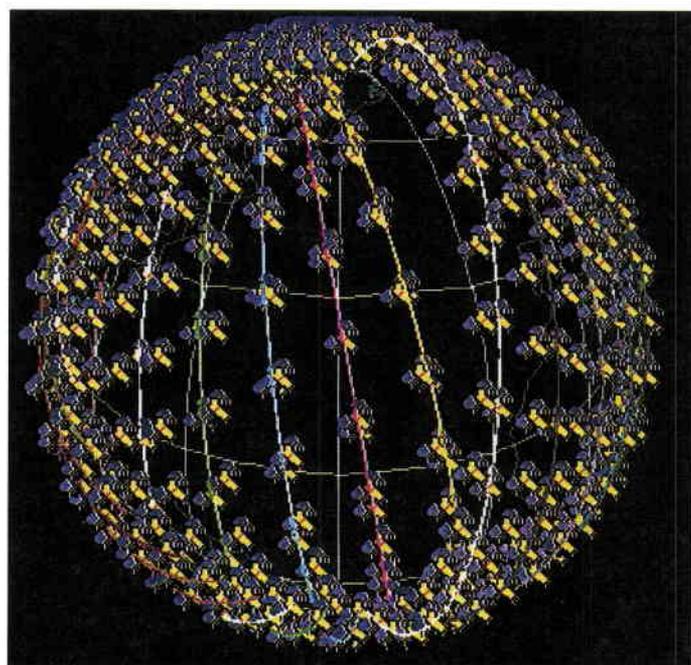
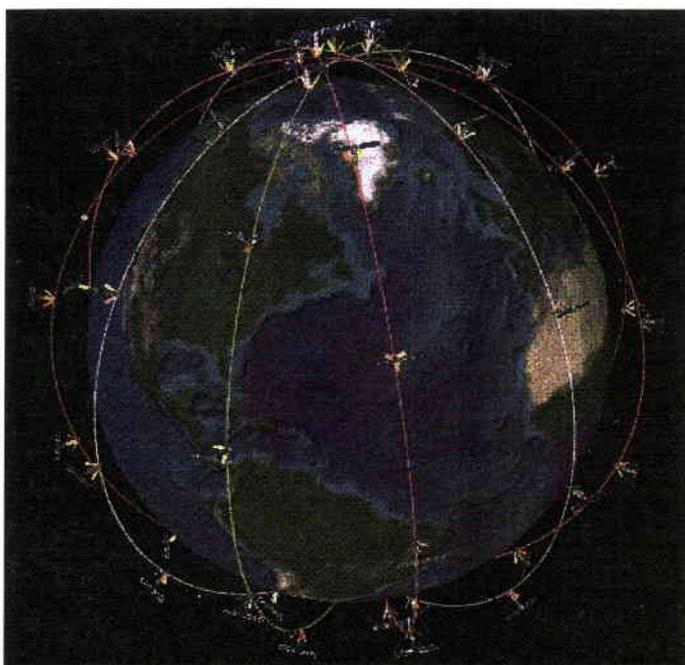


Figure 8. Examples of commercial LEO satellite constellations: Iridium (66 satellites), Teledesic (840 satellites)

intersatellite links (SROIL). To be responsive to the projected market opportunities, the SROIL terminal was required to be capable of servicing the following mission classes:

- cross links between low-Earth-orbiting satellites in global satellite networks for mobile communication (IRIDIUM) and fixed-station data highways (Teledesic), such those depicted in Fig. 8
- cross links between co-located telecommunication satellites in geostationary orbit
- cross links between widely spaced geostationary satellites as proposed in ESA's On-Board Processing System or in the Spaceway system from Hughes.

Considering the huge number of satellites involved in some of these configurations (e.g. 840 satellites for Teledesic, each carrying 8 ISL

BPSK (Binary Phase Shift Keying) homodyne system for a data rate of 1.5 Gbps. Due to the homodyne detection scheme the communication signal is recovered at baseband, which considerably simplifies the communications electronics design.

The terminal consists of two units, the optical head and the electronics unit. The optical head comprises the optics unit (Fig. 10) with beam forming optics, the laser unit, the actuators and sensors of the PAT subsystem, and some related electronics. The electronics unit comprises the PAT processor, the terminal controller, the communication electronics and the DC/DC converter.

Today, the problem of acceptance of optical free-space communication in the commercial

payload market is not so much a technical one but rather the lack of its convincing in-orbit demonstration to the commercial satellite communications community. Consequently, various scenarios for a potential in-orbit demonstration are currently being studied as part of the SROIL contract.

Conclusion

Twenty years of technology endeavours, sponsored by ESA and other European space agencies, has put Europe in a leading position in the domain of space laser communications. The most visible result of this effort is SILEX, the world's first launch-ready civilian laser communication system. With this vast technological base at hand, European industry is well prepared to face the challenge of meeting the current demands for optical intersatellite links in the emerging multimedia, Global Information Infrastructure (GII) satcom market. The question that remains is primarily one of how space industry is able to adapt its practices and put the required resources into place. The sheer number of terminals required, and the short times to market involved, will call for a paradigm shift in the way space products are manufactured. Old methods of space hardware design and qualification will have to be replaced by production-oriented, commercial manufacturing practices, with designed-in rather than tested-in quality and reliability. It is ESA's hope that European industry will succeed in these endeavours and thereby be able to reap the fruits of the past twenty years of developmental effort. 



Figure 9. Mock-up of Short-Range Optical Intersatellite Link (SROIL) terminal

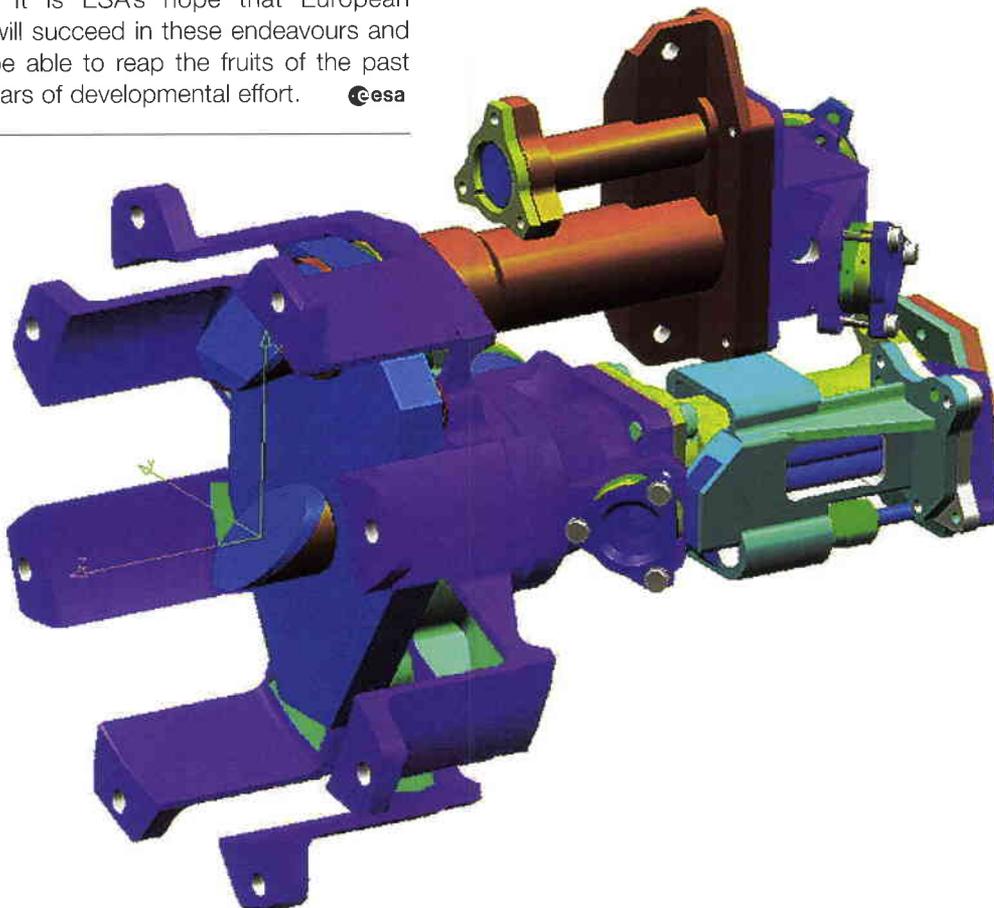


Figure 10. Optical subassembly of SROIL terminal

The Artemis Programme

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Data Relay Mission

Satellites in a Low Earth Orbit (LEO) are restricted in their ability to communicate with the ground because of the limited contact time. Artemis' location in the geo-stationary orbit will make it possible to relay data from a LEO satellite to Europe while over a large portion of the globe (Fig. 1).

Not only does a data relay service extend the duration of contact time between a LEO satellite and the ground, it also allows the data

Following the conclusion of a major collaboration with the Japanese space agency NASDA and the achievement of several major development milestones, Artemis is on course for launch by the Japanese H-IIA launcher in the winter of 1999/2000.

Artemis, presently in Phase-C/D with Alenia Aerospazio (I) as Prime Contractor, will carry out two main missions for data relay and L-band mobile communications.

to be delivered directly to the 'door-step' of the LEO satellite's management organisation. For example the SPOT-4 telemetry and remote-sensing data will be received in Aussaguel near Toulouse close to the operations control centre and image processing centre, while for Envisat data will be received directly at the processing centre at ESRIN, in Frascati (I).

The Artemis data relay payload provides feeder links between Artemis and the ground and inter orbit links (IOLs) between Artemis and the spacecraft in LEO. The feeder links operate at 20/30 GHz, while the inter orbit links can operate at S-band (2 GHz), Ka-band (23/26 GHz) and optical frequencies.

The feeder link, S-band and Ka-band payload elements jointly comprise the SKDR (S/Ka-band Data Relay) payload while the optical IOL payload element is called 'SILEX' (Semiconductor/Intersatellite Laser Experiment).

SKDR

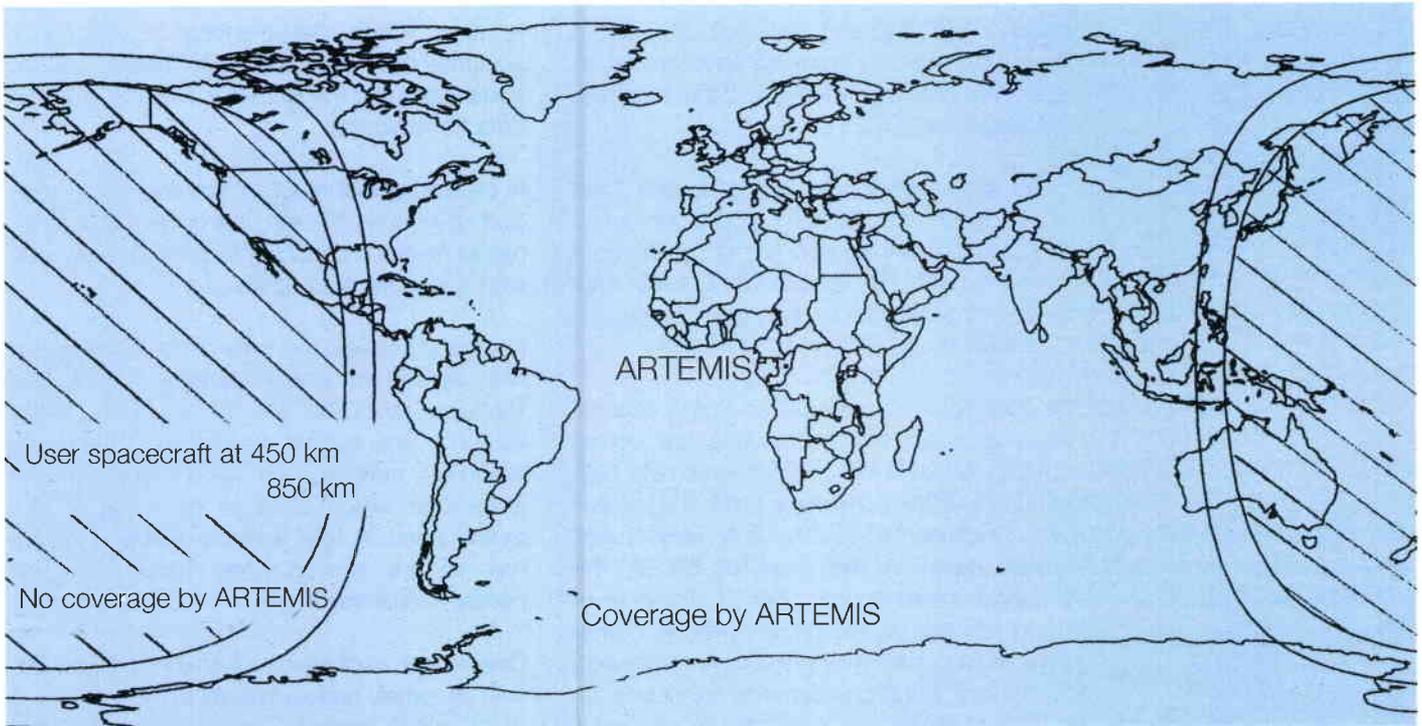
The SKDR payload frequency translates, filters and amplifies the signals passed through it. The section of the SKDR payload used for the forward and return S-band IOLs has a bandwidth of 15 MHz in both directions. The section used for the forward Ka-band IOL has a bandwidth of 30 MHz, while the section used for the return Ka-band IOL has one channel of 30 MHz and two channels of 230 MHz bandwidth.

The centre frequency of these channels can be set to a range of values since the local oscillators are all settable to frequency synthesisers locked to a common 10 MHz highly stable master oscillator. The channels all have a minimum amplitude and group delay ripple across their bandwidth and a minimum phase noise, implying the channels will hardly distort the signals passed through them.

This is a significant characteristic of the SKDR payload since it conserves the resources consumed by the spacecraft in LEO for receiving and transmitting data via Artemis.

The engineering model of the SKDR payload (Fig. 2) has been successfully tested. The flight model is being integrated and some sections of it have also been successfully tested.

Artemis is equipped with one IOL antenna having a feed capable of operating at S-band and Ka-band. The IOL antenna is an offset parabolic reflector antenna with a 2.85 m aperture. The antenna is steered in the direction of the LEO spacecraft by rotating the reflector around its focal point by means of a pointing mechanism controlled by an on-board computer. The computer controls the antenna pointing either in open or closed loop mode. In open loop mode the pointing direction is derived from a pointing table loaded by ground command into the computer. In closed loop



mode the antenna acquires the LEO spacecraft using a pointing table, and then it corrects the pointing direction and tracks the LEO spacecraft based on error signals derived from the higher order electromagnetic modes in the antenna feed and pre-processed by a track receiver.

When the IOL operates in S-band, the antenna pointing is always performed in open loop, while for a Ka-band IOL the antenna may be pointed in open loop or in closed loop.

To assist the LEO spacecraft in tracking Artemis an unmodulated wide beam beacon signal is broadcast by the latter at 23.540 GHz.

The engineering model of the IOL antenna has been successfully tested and an extensive testing of the closed loop tracking system has been completed. The flight model of the IOL antenna and its tracking systems is being manufactured and tested at unit level.

SILEX

SILEX is the world's first civil intersatellite data relay system using lasers as carriers for the signal transmission. Two SILEX terminals have been developed and built; one will be launched on the French SPOT-4 Earth observation spacecraft at the beginning of 1998, the other aboard the Artemis satellite.

The two terminals will allow the image data of SPOT-4 to be transmitted at a data rate of 50 megabits per second (Mbps) via the Artemis feeder link to the SPOT-4 earth station near Toulouse. In addition to the data transmission

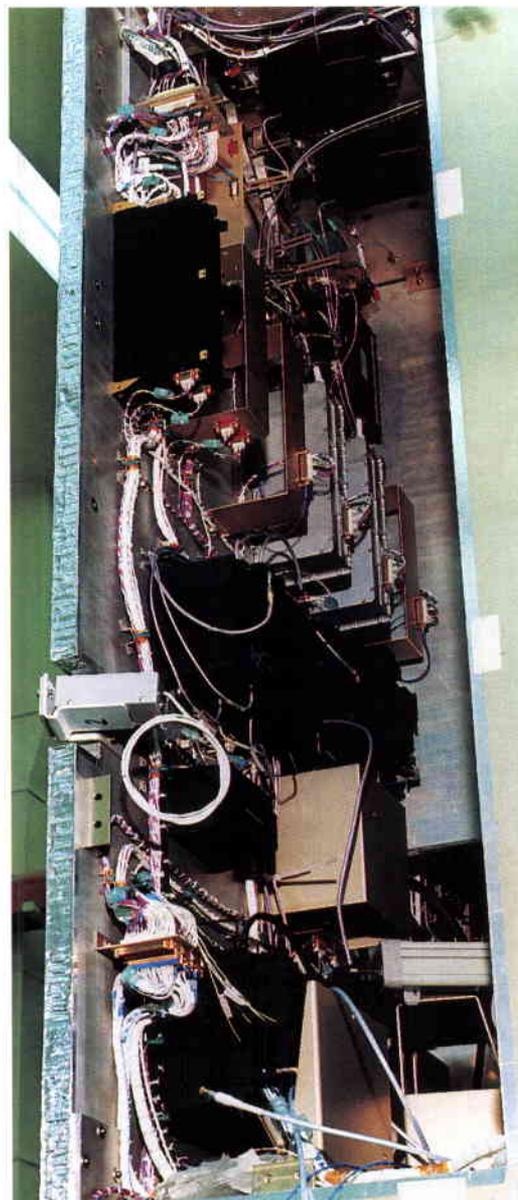


Figure 1. User spacecraft coverage from Artemis

Figure 2. Part of the north panel with the engineering-model SKDR return repeater

between SPOT-4 and Artemis, the SILEX terminal on board Artemis will also support an experiment between Artemis and the Japanese LEO spacecraft OICETS.

During this experiment, the data rate from OICETS to Artemis will also be 50 Mbps but, in addition, there will also be an optical link from Artemis to OICETS. Via the latter, a link data stream of 2 Mbps can be sent from the ground via Artemis to OICETS.

The principal advantage of using optical wavelengths for the intersatellite link stems from the capability to obtain extremely high 'antenna' gains with relatively modest apertures and, consequently, to use only very limited carrier power. In the case of SILEX, the 50 Mbps transmission over a distance of 42000 km can be performed with an optical power of about 60 mW only. As an 'antenna', SILEX uses a 25 cm-diameter telescope on both terminals which provides an 'antenna' gain of well above 100 dB.

The disadvantage of these extreme antenna gains is the very narrow width of the transmitted beams and, therefore, the need for very accurate pointing. The communication beam of SILEX has a width of about 8 μ rads or about 0.5 mdeg. This results in an illuminated zone of less than 400 m diam. at a distance of 42000 km. To avoid intolerable power losses, the optical beam must be pointed towards the partner with an accuracy of few micro-radians. At this extreme accuracy even the micro vibrations present in normal spacecraft, generated by the operation of the various mechanisms, are disturbing and need careful correction in the pointing loops of the terminal.

Prior to establishing the optical link, the position of the partner spacecraft is not well known. In the case of SILEX, the partner will be in a zone of uncertainty which is seen from 42000 km under an angle of 5500 μ rads. Since the optical communication beam has a width of only 8 μ rads, a search manoeuvre has to be performed. For this purpose the GEO terminal on Artemis is equipped with an optical beacon which generates, by means of 19 laser diodes, an optical power of typically 10 W which is transmitted within a beam of 750 μ rads. To find the partner spacecraft in the 5500 μ rads zone, the beacon beam is scanned over the zone of uncertainty until the partner is illuminated by the beacon signal. In this case, the LEO terminal will detect the optical signal and will, in turn, transmit its narrow beam signal towards Artemis. When Artemis detects the LEO signal it will stop scanning its beacon and will centre its transmission direction towards the LEO

terminal. Once the pointing is sufficiently accurate both communication beams will be transmitted and the system is ready to start the data transmission.

In order to establish the optical link over a large part of its orbit, the terminal on board SPOT-4 has to have the capability to point its telescope over a large angular range.

For this purpose a two axes gimbal mechanism was developed which carries not only the telescope but also the whole optical head including the optical transmitters, receivers, pointing mechanisms and the control electronics which have to be close to the optical head. In total a mass of about 100 kg has to be moved over nearly the full hemispherical coverage.

One further particularity of an intersatellite link with extremely narrow beams is the need for a point-ahead system. As noted above, the optical beam at the partner satellite has a width of less than 400 m. The relative velocity of the two spacecraft is, however, between 0 and 7000 m/s. Taking into account the time needed by the optical signal to travel twice over the distance of 42000 km, the spacecraft would be far out of the optical beam when the light arrives at the place where it was two light travel times ago. For this reason it is important to know the orbital parameters of both spacecraft exactly. This point-ahead angle changes continuously during one orbit and has to be updated at short intervals. This procedure requires continues data processing and a very accurate pointing mechanism whose bandwidth can, however, be relatively low. In contrast, the mechanism which provides the fine pointing accuracy of the incoming beams has to have a high bandwidth of several hundred Hertz.

Both terminals are now fully integrated. The LEO terminal (Fig. 3) was delivered to SPOT-4 in March and the GEO terminal to Artemis in June 1997.

To allow for a proper check-out in orbit of at least the GEO terminal, an optical ground station has been built in Tenerife on the Canary Islands where viewing conditions are among the best in the world. This station is equipped with a one metre telescope which simulates a LEO terminal. Together with the feeder link station in Redu (Belgium), it will be possible to perform a realistic bi-directional data relay experiment involving both optical data links.

Data Relay Users

In parallel with the development and

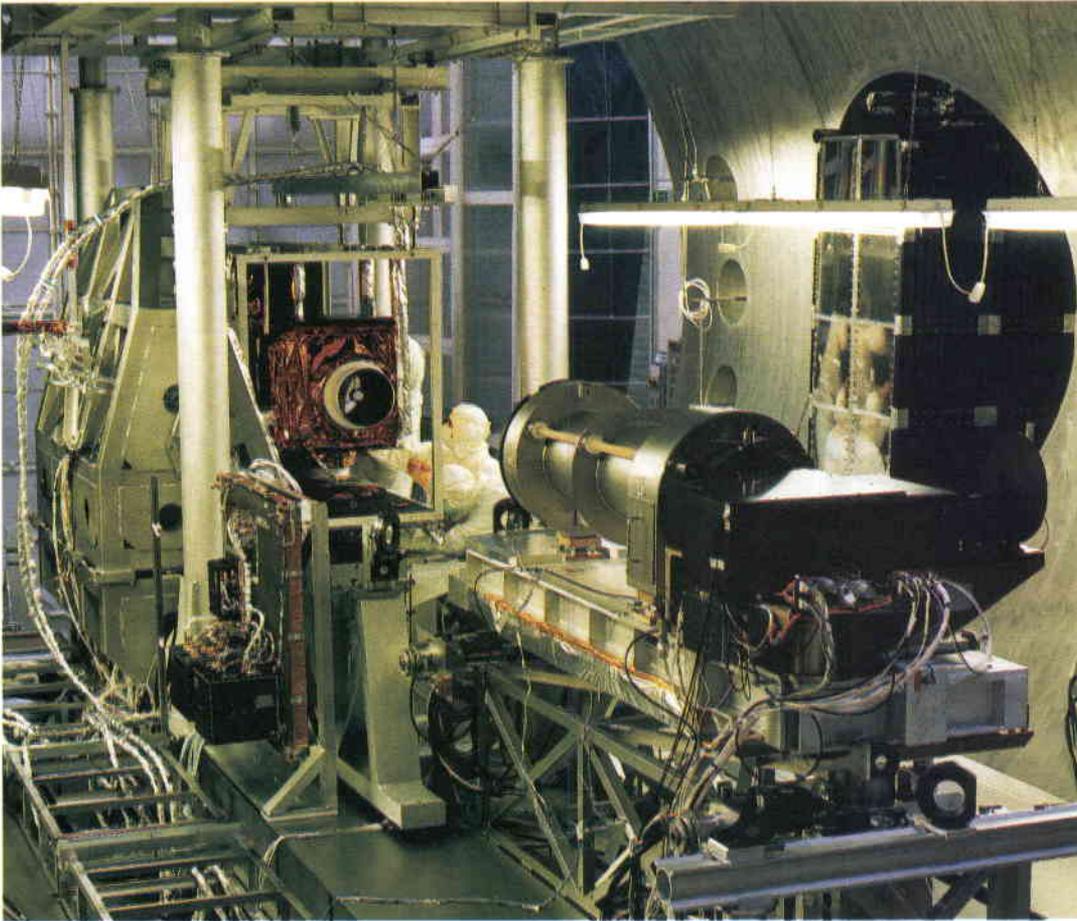


Figure 3. SILEX flight-model terminal to be accommodated on SPOT-4, under test at Centre Spatial de Liège (B)

manufacture of the Artemis data relay elements, preparations are under way with the users of the data relay services.

The main initial European data relay users are SPOT-4 and Envisat. As described above SPOT-4 will carry a SILEX optical terminal and will communicate via Artemis with its control centre in Toulouse. SPOT-4 will also use Artemis for relaying its telemetry signal through an S-band IOL.

Envisat will use Artemis to relay its instrument data to the ground via a Ka-band IOL. The Ka-band terminal has been described in detail in ESA Bulletin No. 88, November 1996.

As part of a collaboration agreement with NASDA, ESA will make part of the Artemis data relay capacity available to Japan. NASDA is planning to use this capacity to provide data relay services to several of their satellites including ADEOS-2, a remote-sensing satellite, and JEM, the NASDA module of the International Space Station, in addition to the OICETS optical experiment described above.

The L-band Land Mobile Payload (LLM)

In addition to the data relay payload, Artemis carries a payload which supports the communication of mobile users with fixed partners located anywhere in Europe, North

Africa and the Near East. The LLM payload is fully compatible with the EMS payload already developed by ESA and flown onboard the Italsat-2 spacecraft, thereby also providing full redundancy for its mission.

The LLM payload receives the signals transmitted by the fixed users at Ku-band (14.2 GHz) and transmits them at L-band (1550 MHz) to the mobile users. This link is called the forward link. The return link establishes the connection from the mobile user at L-band (1650 MHz) to the spacecraft and at Ku-band (12.75 GHz) from the spacecraft to the fixed user. About 400 bi-directional user links can be established simultaneously.

Since the bandwidth at L-band is a very scarce resource, it is mandatory to make efficient use of the available frequencies. Therefore, the use of Surface Acoustic Wave (SAW) filters was selected. These elements allow two adjacent channels to be positioned next to each other with only 200 kHz guard band between them, enabling a 90% use of the spectrum when the total bandwidth is split into 1 MHz channels and a 97.5% use of the spectrum when the channels have a nominal bandwidth of 4 MHz.

To simplify the coordination of the operation with other satellite systems using the same

frequency band the total installed nominal bandwidth of 15 MHz was subdivided into three 1 MHz channels and into three groups of 4 MHz channels. Each channel can be shifted individually and independently from each other within the available 29 MHz band in steps of 0.5 MHz.

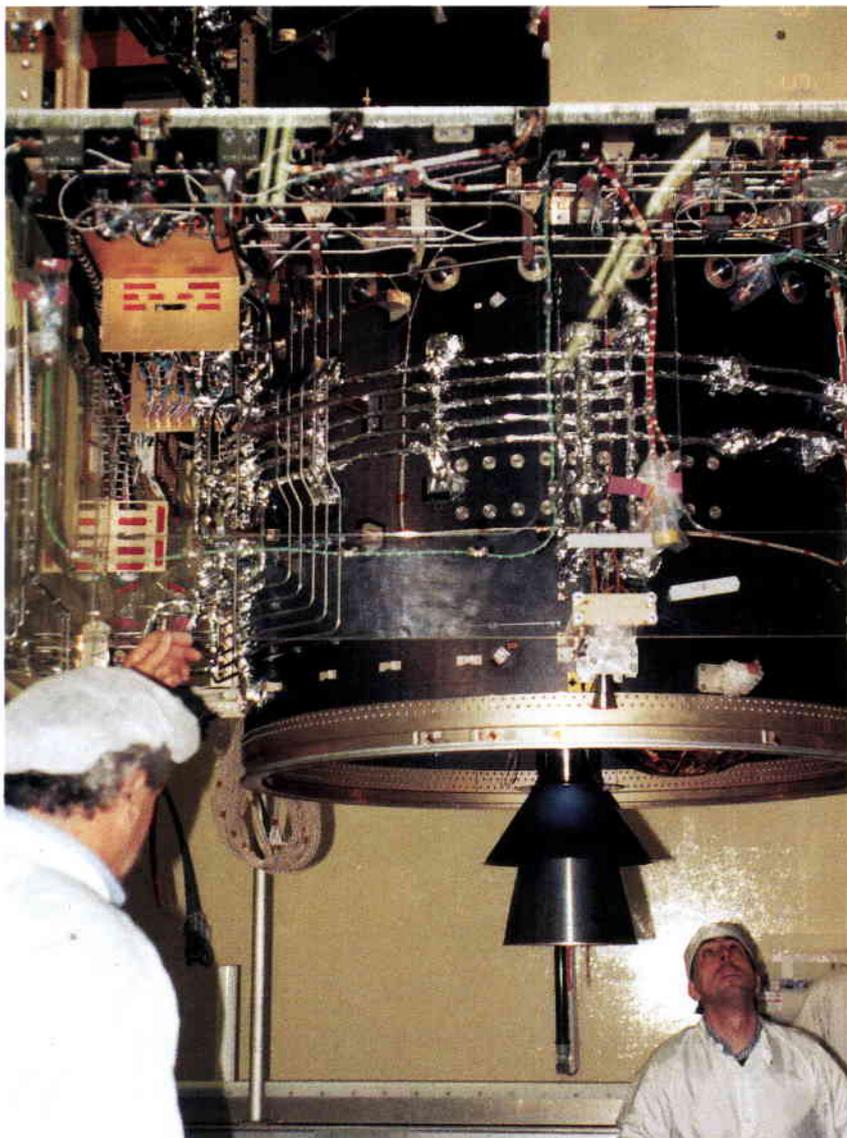


Figure 4. Lower part of the central cylinder of the flight-model spacecraft with the Liquid Apogee Engine

To allow a high number of users to exploit the payload simultaneously, it is essential to simplify the mobile user terminal on the ground and to ensure that the EIRP (equivalent isotropic radiated power) per individual user signal is high and also that the total EIRP, i.e. the sum of all signals, is high. This can most economically be achieved by increasing the antenna gain which in turn requires the generation of spot beams on the satellite. The LLM payload provides one large beam covering the whole of Europe, North Africa and the Near East, but also provides three spot beams together covering the same area on the Earth.

The size of the spot beams is constrained by the fact that a solid reflector of only 2.8 m

projected aperture could be accommodated on the spacecraft. The L-band power stage applies a butler-like matrix concept. This configuration allows a relatively high efficiency which is independent of the actual traffic distribution over the antenna coverages.

Satellite Platform

The Artemis platform evolved from previous European telecommunication spacecraft and, hence, is largely based on a classical 3-axis stabilised geostationary concept. The platform has been designed not only to accommodate the payload elements of the Artemis mission but, with minor modifications, also those of other missions.

The platform's central propulsion module (Fig. 4) houses the three propellant tanks (two chemical and one xenon), the liquid apogee engine, the pressurant tanks and the bulk of the pipe-work feeding the reaction control thrusters. The east panel carries the L-band antenna and feed, the west panel the inter-orbit link antenna. The north and south panels are the prime thermal-control radiation areas which accommodate the bulk of the electronic equipment, particularly the highly dissipative units. The Earth-facing panel carries the optical payload (SILEX), TTC antenna, feeder link antenna, as well as various attitude and orbit control sensors. The two batteries are mounted on separate radiator plates, one on the north face and one on the south.

Structure

The structural design has followed a largely classical approach utilising aluminium honeycomb material. However, the central cylinder is aluminium honeycomb skinned with carbon fibre. The primary structure provides the load path to the launch vehicle interface and comprises the central cylinder, main platform, propulsion platform and four shear panels. The major elements of the secondary structure are the north and south radiators, the east and west panels and the Earth-facing panel.

The structural model qualification test campaign has been successfully completed and the complete flight structure has now been delivered.

Thermal Control

The satellite thermal control also follows a classic approach using primarily passive techniques employing optical solar reflectors on radiator surfaces and multi-foil insulation blankets on the majority of the remaining external surface. In addition, the efficiency of the main radiators is enhanced by the use of heat pipes which are uni-directionally mounted

under highly dissipative and/or sensitive equipment.

An innovative aspect of Artemis is the employment of a thermal technique to measure the amount of on-board chemical propellant.

Although already successfully tried on other ESA telecommunications spacecraft, Artemis will be the first spacecraft to have the method designed in from the start. The method has therefore dictated, to some extent, the thermal design around the propellant tanks and dedicated calibration tests are to be performed during the spacecraft solar simulation tests.

Equipping of the flight spacecraft with the thermal hardware is presently progressing well and the analysis campaigns are at an advanced stage. The subsystem will be proven during dedicated solar simulation testing in early 1998.

Power Generation

Power is generated by two identical solar array wings each of four panels made from CFRP (Carbon Fibre Reinforced Plastic) sandwich. Each wing is supported by a yoke, which is attached to the spacecraft via drive mechanisms located on the north and south faces.

The array is partially deployed in transfer orbit by cutting the Kevlar cables of the hold-down mechanism. Full deployment is achieved on reaching geostationary orbit.

The array is designed to deliver just under 3 kW of power during equinox after 10 years in orbit.

The flight solar array wings and drive mechanisms have been built and successfully tested and are now in storage awaiting integration at satellite level.

Power Storage

Power storage is achieved with two identical 23-cell nickel-hydrogen batteries, each with a nominal capacity of 60 Ah. They are equipped to deliver just over 1800 W during eclipses of up to 72 minutes duration at a depth of discharge, with no cell failures, close to 75%.

The flight cells have already been manufactured and are expected to be assembled into batteries by the autumn of 1997.

Power Conditioning and Distribution

The spacecraft power is distributed via a single, fully regulated 42.5 V bus.

Excess power from the solar arrays is shunted by the Solar Array Regulator which also

controls the start of battery charging at the end of eclipse.

The Battery Regulator Unit controls and regulates the power bus during battery discharge, regulates the battery charging and monitors the main battery parameters (voltage, temperature, pressure, current).

The Pyro and Knife Drive Unit, as the name implies, drives all the on-board pyrotechnic devices for appendage release and initiation of the propulsion subsystem.

A Thermal Control Unit provides automatic heater switching based on pre-set thresholds and also conditions the output of temperature sensors. The heater control has a ground override facility.

Each power line is protected individually as close as possible to the power source using redundant fuses. This is managed by the Power Protection and Distribution Unit.

The nominal operation of the subsystem has been successfully confirmed on the engineering model (EM) spacecraft.

The flight hardware has already been built, tested and delivered.

Unified Propulsion System (UPS)

The UPS is a conventional bi-propellant system comprising a single 400 N Liquid Apogee Engine (LAE) and a set of 10 N Reaction Control Thrusters (RCT). The latter are configured into two identical redundant branches, each of eight thrusters.

The UPS will be used for apogee boost, longitude control, wheel off-loading, any re-location manoeuvres and re-orbiting at the end of life. Inclination control will be performed by the Ion Propulsion Subsystem (IPS).

The propellant is stored in two 700 litre Cassini-shaped tanks, one containing the mono-methyl hydrogen fuel and the other the nitrogen tetroxide oxidiser. The total bi-propellant to be loaded will be about 1538 kg. The propellant tanks are pressurised by helium stored in three smaller spherical tanks.

The LAE operates in a pressure regulated mode at about 15.7 bar. Once artemis is in the required orbit the LAE will be isolated and the RCTs will then operate for the remaining spacecraft life in blow-down mode.

All the flight hardware has been delivered and integrated on the flight model spacecraft.

Ion Propulsion Subsystem (IPS)

The Artemis platform will be the first ESA satellite to fly electric propulsion technology operationally. It will be used for inclination control throughout the satellite's lifetime.

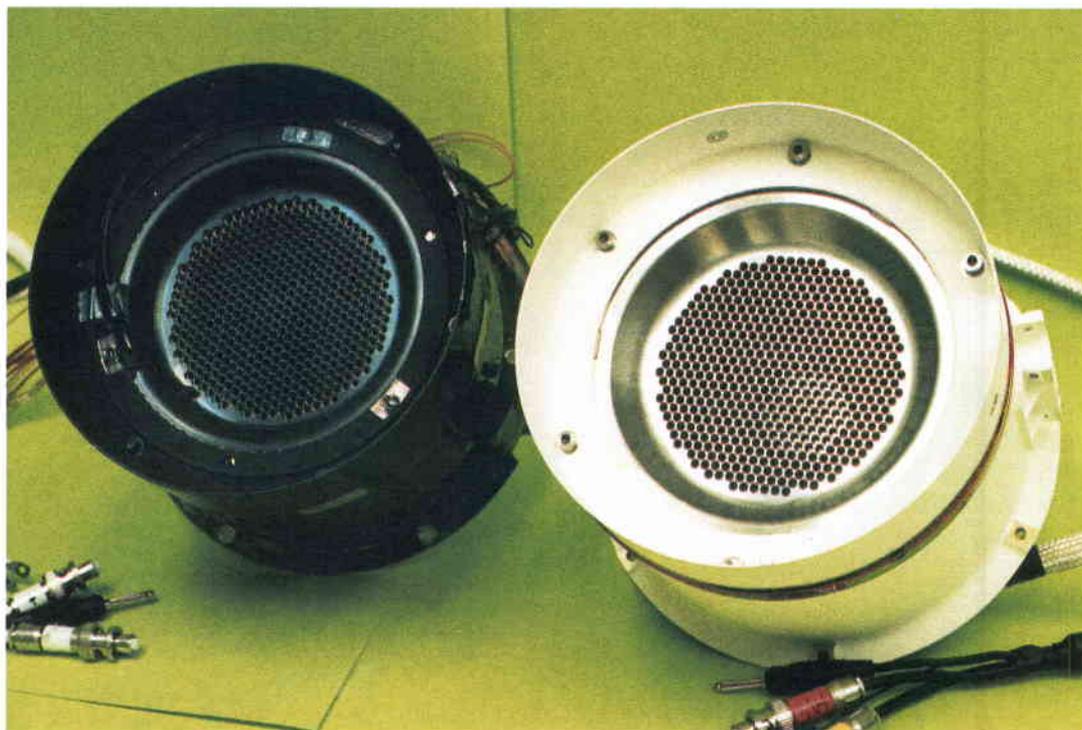
The IPS consists of two thruster assemblies, one mounted on each of the north and south faces. Each assembly comprises an Ion

This effort is now beginning to reap rewards as the individual equipment items successfully negotiate their qualification testing and flight unit delivery gets underway.

Integrated Control and Data System (ICDS)

The ICDS is the other major novel platform area of Artemis. It departs from the more traditional

Figure 5: Engineering model of the Radio Frequency Ion Thruster, courtesy of DASA



Thruster Alignment Mechanism upon which two redundant thrusters from different sources are mounted; a Radio-frequency Ion Thruster (RIT) from DASA (Fig. 5) and an Electro-bombardment Ion Thruster (EIT) from MMS.

Each thruster has its own power supply and control equipment as well as its own flow control/propellant monitoring units. There is a common propellant supply and distribution assembly. The propellant used is xenon, of which 40 kg is loaded on the satellite.

The main characteristics of this propulsion technology are its high specific impulse (3000 sec) and low thrust level (20 mN), in contrast with chemical propulsion. In the case of Artemis, this results in a net mass saving of about 60 kg which can be advantageously used elsewhere within the satellite.

In operation the system draws about 600 W of power, which is mainly supplied directly from the solar array, augmented later in life by the batteries.

A vast amount of development work has been performed to bring this subsystem to maturity.

independent architecture of the On-Board Data Handling (OBDH) and the Attitude and Orbit Control (AOC) subsystems. This subsystem utilises a centralised processing architecture which not only supports both the aforementioned functions but also includes a Fault Detection, Isolation and Recovery function (FDIR). The ICDS offers the different spacecraft equipment data collection and command distribution over the standard OBDH bus either by direct connection to this bus or through dedicated interface equipment.

In addition to the On-Board Computer Unit (OBCU) and the dedicated interface equipment mentioned above, the subsystem also includes the more traditional inventory of reaction wheels, momentum wheels, Sun sensors, infrared Earth sensors, gyros and supporting electronics.

Development Programme

Artemis has followed a three-satellite-model development strategy. Structural and mechanical integrity has been demonstrated with a structural model (Fig. 6) which has successfully been subjected to acoustic and sine vibration testing at qualification levels,

while an engineering model of the satellite has been used to verify the electrical compatibility of all of the satellite equipment.

Integration of the flight model spacecraft is now underway. Late in 1997 the fully integrated spacecraft will be transported to ESTEC for environmental testing. By late 1998 Artemis will be ready for storage awaiting the start of the launch campaign.

Launcher

As part of a broad cooperation programme between NASDA and ESA, it has been decided to launch Artemis on the Japanese H-IIA launcher. This launcher is an improved version of the existing H-II and will be able to deliver 2 tons of payload into geostationary orbit. Its design is based on a first stage made of a liquid hydrogen/liquid oxygen engine providing 110 tons of thrust and two solid-rocket boosters providing 230 tons of thrust each. The second stage, based on a liquid hydrogen/liquid oxygen engine, provides 14 tons of thrust.

Compatibility studies between Artemis and H-IIA started in 1996 and are continuing in 1997. The environmental levels foreseen from H-IIA are similar to those of Ariane-5 for which Artemis was originally designed. A preliminary coupled-load analysis based on a simplified spacecraft and launcher mathematical model has been run and the results are being analysed and compared with the results from Artemis structural model tests.

The launch campaign will start at the end of 1999 with the shipping of the spacecraft to the airport in Kagoshima. From there it will be carried by boat to Tanegashima, a small island in the south of Japan. The operations at the launch site will start with a final check-out of the spacecraft. It will then be loaded with its propellant, in a dedicated area, and a few days before the launch it will be mated to the launcher itself. The full assembly will then be rolled out from the final assembly building to the launch pad some 8 hours before lift-off.

Conclusion

The launch of Artemis, with its circa 3.1 tons of lift-off mass and just under 3 kW of DC power, from Tanegashima in Japan at the beginning of the year 2000 will mark the start of the ESA data relay system which, together with the large number of activities on the users space and ground terminal front, will ensure that Artemis is only the start of ESA's data relay adventure.

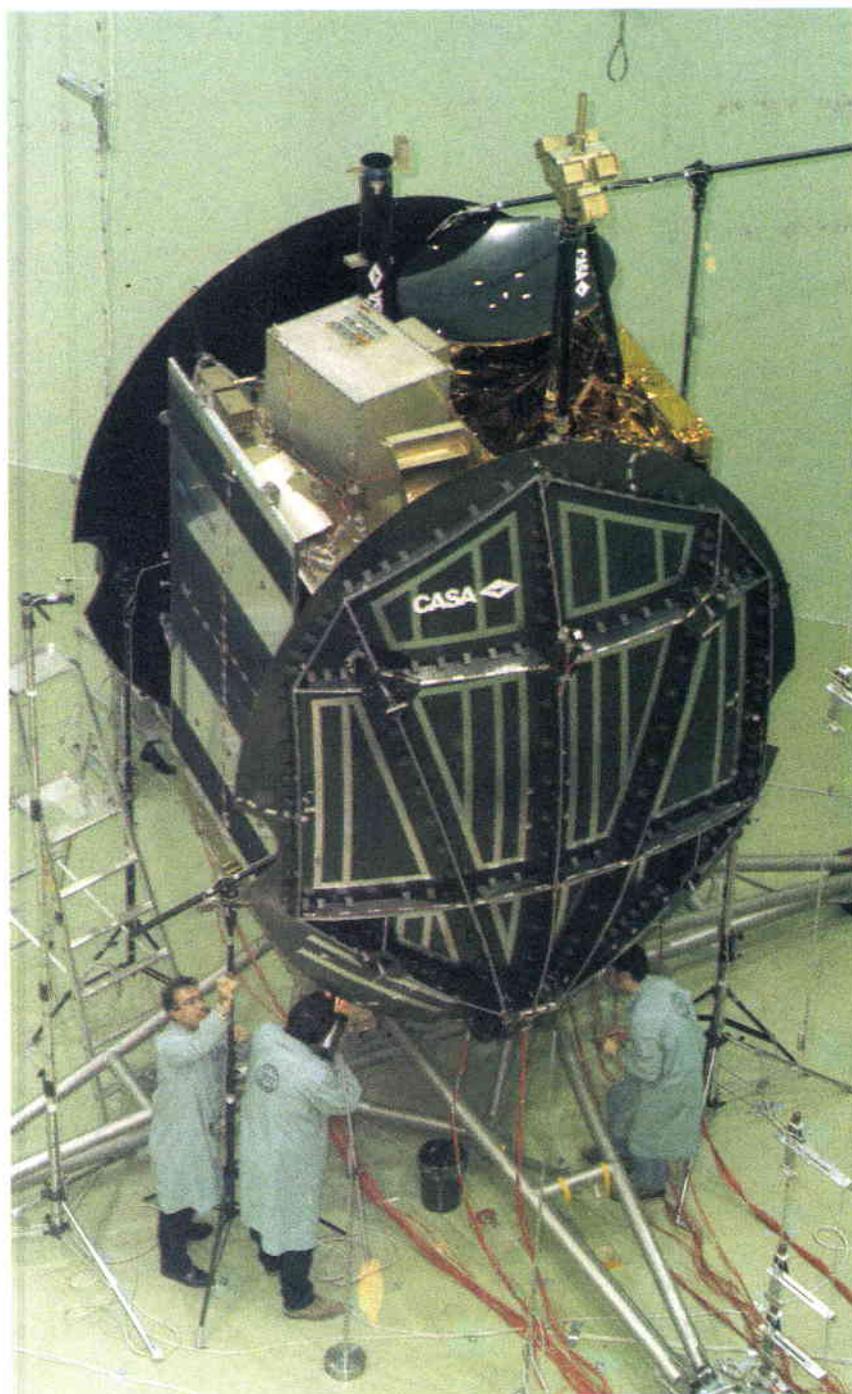


Figure 6. The Artemis structural model under test

Innovations for Competitiveness

— A Workshop Synthesis

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Introduction

This Workshop was organised as an initial response to specific recommendations made by the ESA Council, the European Union (EU) and the ESA Long-Term Space Policy Committee (LSPC), for the promotion of competitive and sustainable growth of the European space sector and the related role of innovation with respect to policies, methods, techniques, industrial organisation and financing.

The ESA Workshop on 'Innovations for Competitiveness' (held 20-22 March 1997, ESTEC, Noordwijk) elaborated on a number of important considerations for the future of the European space sector. Topics reviewed and discussed included innovative approaches relating to strategy, processes, products and services being explored by space agencies, the European Union, international organisations, industry, financial institutions and research centres. The Workshop also produced recommendations for an 'Action Plan' with specific tasks for the various players in the European space sector.

It has been recognised that without a major effort in innovation in industrial practices, organisation and R&D, the European space sector will stagnate and lose its competence as well as its competitiveness in comparison to the continued increase in efficiency and initiatives of, in particular, the USA and Japan. This European effort should include the setting up of strategic poles and should be guided by strategic initiatives for long-term objectives (Fig. 1).

Europe needs a coordinated, comprehensive, realistic and evolutionary space policy which takes into account public, commercial and defence space activities. Space initiatives are now assuming a global dimension, leading to a balanced responsibility between the public and private sectors.

The Workshop focused on:

- the understanding of trends towards future potential markets and other space applications

- the understanding of the bottleneck factors limiting competitiveness or preventing programme implementation
- the understanding of how innovation can contribute to the world-wide competitiveness of the European space industry, through the development of an industrial structure appropriate to market requirements and supported by a modern financial base and new financing schemes
- the coherence, efficiency and prioritisation of the various technology development efforts performed by ESA and its Member States, the EU, the space industry, research centres and academia.

Strategic Planning and Innovation

Europe needs to devote more effort to thinking 'strategically and innovatively'.

Factors leading to success are core capabilities in organisational, technical and economic domains, and institutional leadership. This implies exploiting those opportunities which manifest themselves and preparing for the future. It is, therefore, important to test the space community's capabilities and help develop demand which will create markets.

Innovation has to be oriented towards successful production, assimilation and exploitation of novelty in the economic and social spheres. Innovation is related to technology, to the definition of related systems and services, their financing and their implementation. Innovation should also contribute to shortened production time and decreased cost as well as to the reduction of risks associated with a given service or activity.

There is a noticeable innovation deficit in Europe, which, in spite of its internationally acknowledged scientific and technical excellence, launches fewer new products, services and applications than its main competitors. The primary contributors to this situation are the relatively low number of

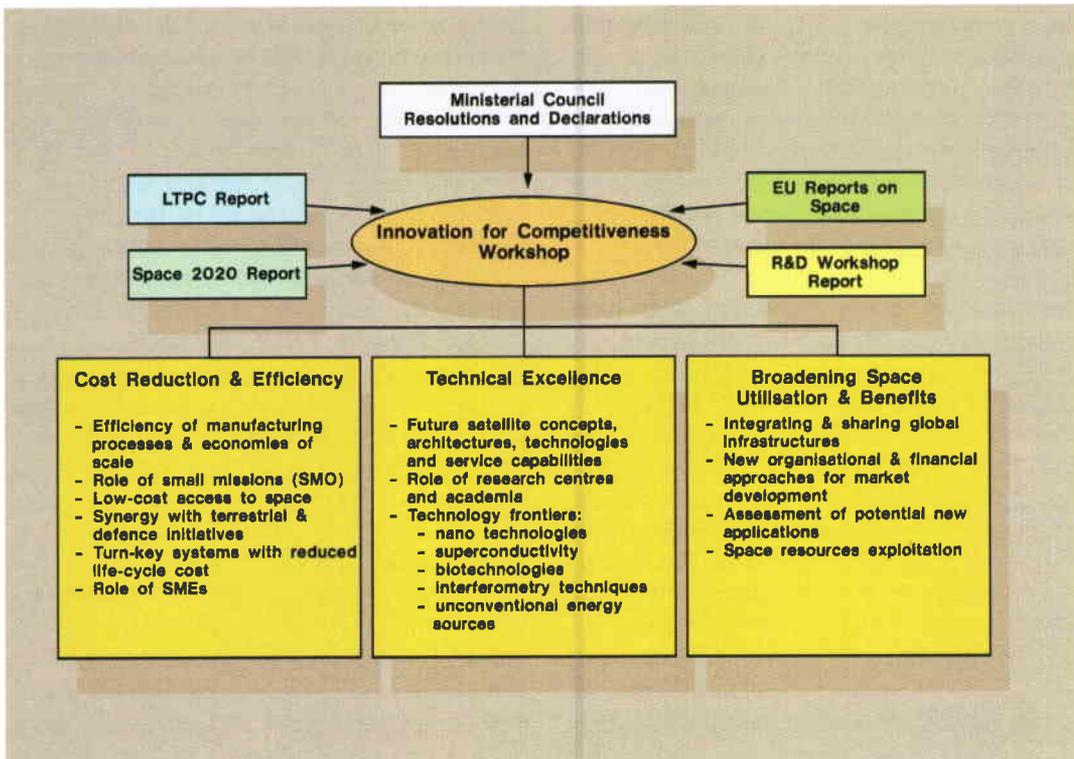


Figure 1. Strategy initiatives for long-term objectives

researchers and developers, insufficient R&D expenditure, the wide diversity in regulatory and social conditions, the difficulty in mobilising private capital, and the presence of cultural and legal barriers restricting the movement of persons and ideas.

The European Commission has drawn up a 'First Action Plan for Innovation', as the starting point for an ambitious, long-term innovation policy for Europe. The plan identifies three key areas for action: fostering an innovation culture, setting up a regulatory and financial framework, and gearing research more closely to innovation. Space technology is an area specifically identified for such actions.

Overview of the Market and the Users

The new environment for space applications is characterised by definite trends toward internationalisation, globalisation, deregulation and liberalisation, by a growing overlap between the civil and military sectors, and by growth potential in developing markets and potentially related economies of scale.

In this new environment, the most significant commercial space market is in the world-wide telecommunications business for mobile and personal communications, multimedia and broadcasting. The revolutionary approach of semi-autonomously deployed inter-communicating satellites in low Earth orbit (LEO) no longer raises major doubts about its financial viability and the space segment proper is just a minor portion, in comparison with end-user services. The recent decision by the

World Trade Organisation to liberalise communications world-wide by 1998 creates an urgent need for industry to become competitive within that time frame. It is expected that European society as a whole will undergo major transformations due to the shift from analogue to digital standards for broadcasting and due to the massive spread of digital technology.

Europe's active participation in future world navigation and transport management systems is both fundamental and urgent for the European space industry.

One thing that is increasingly apparent (long recognised in other industries) is that a change in perception of just who the users are is required. They should be seen not simply as short-term prospects, but rather as long-term prospective markets. End users are interested in services with a certain quality level (such as time lines or cost) and not in raw data or spacecraft per se. In any event, space data still has problems due to its being perceived as expensive and difficult to access. A new culture needs to be fostered which enhances the value of such data and makes it easier for the customer to use. While the means needed to provide the services are important to space industry and space agencies, they are not to users. Furthermore, potential users have to be made aware of the capabilities of space systems, what products are possible and how to use them properly. In addition, they have to get used to those products which might trigger a demand.

The multiplicity of Earth Observation applications ideas in agriculture, land use statistics, urbanisation, regional planning, environment monitoring, risk and disaster management, coastal monitoring, surface water watching, and cartography is affecting a variety of business sectors and will lead to a rapid expansion of the user community.

There is a willingness of industry to co-fund developments in this field and there is also a significant under-exploited military-to-civilian synergy. The return on investment in the Earth Observation market exists, but it is still difficult to quantify. The economic potential of this market is still hindered by a lack of coherent organisation, by the insufficient number of operational services, by conflicts about data policy, as well as by the inability to provide solutions tailored to user requirements (particularly in terms of revisit time, quality, and repeatability). This clearly suggests the need for lower-cost innovative approaches in the space segment.

An impressive potential exists for economic growth and employment in the space business, based on the demands of the developing global information society. The market for space-derived services could expand space industry sales by a factor of ten over the next decade, while government needs are expected to remain at the same level or even decrease (Fig. 2).

Space is also experiencing a new trend towards a 'service-on-demand' type of business, emphasising the early transition of R&D results into practical applications. Turnkey services, based on secure market prospects and featuring profitable returns, are becoming of strategic importance as well as driving company mergers.

Scientific missions and space exploration (including man in space) should motivate major advances in a broad range of frontier technologies which will constitute the backbone of tomorrow's industrial competitiveness. Advanced and leading-edge technology products should be developed for visionary programmes while serving the purpose of winning new users, increasing productivity, decreasing costs and lead times ('Faster, Cheaper, Better' approach), and with more focus on payload instrument technology. Greater use of small satellite solutions may lead to a different mix of long-term and short-term missions from which both industry and scientists would benefit.

R&D should be aimed more and more (although not exclusively) at supporting industry in its commercial enterprises. In the medium term, the space sector would be driven by complex infrastructures of low cost satellites and by the development of cheaper, more efficient launchers and launching policies tailored to small missions.

New Roles and Partnerships

New relationships in the space business world are leading to the establishment of partnerships in the form of 'extended enterprises', teaming governments and industry, as well as producers and suppliers, together.

In their evolving role, space agencies are expected to provide technical and financial support to industry in a twofold fashion: by sharing risks for the pre-competitive R&D phase, when new technical ground is to be broken, and also by actively promoting emerging and potential applications which could expand the market of space products (e.g. by replacing current Earth-bound services). Space agencies, together with

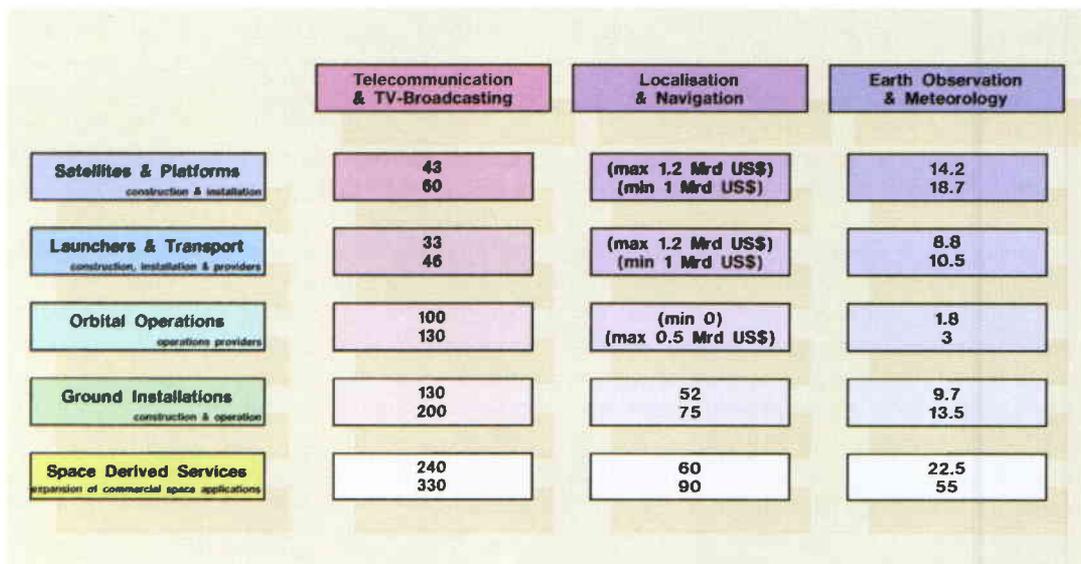


Figure 2. Projected market in US Dollars for space-derived services, 1996-2006 (Courtesy of DARA)

industry and research centres, should play the major role in developing product- and market-oriented R&D strategies aimed at demonstrating the economic and commercial value of emerging applications of space technology and novel services which would not otherwise capture the interest of potential investors. They should do so taking into account the complex dynamic interactions between socio-economic and technological factors.

Partnerships between space agencies and industry should be characterised by long-term commitments until a new service has secured a place in the market, and should entail a financial commitment for all parties. Embryonic proposals put forward in that sense should be formalised in the form of pilot projects. There is also a clear urge, on the part of European industry, to come to an institutionalised and comprehensive consultation mechanism between space agencies and industry in order to correctly focus R&D on areas with the most promising return on investment.

A new kind of institutional leadership is demanded from space agencies in terms of focused vision and strong technology management.

Dispersion of European space development initiatives leads to duplication of effort and scattering of resources. The innovation process should be supported by a framework integrating the contributions of ESA, EU, industry, operators, academia, users, financiers, governmental and public institutions — each with a clearly defined role. This provides the European space industry, ESA and the European Commission with a context in which to optimise the exploitation of the available human capital, capabilities and infrastructure.

In particular, more synergy between programmes, and a more dynamic relationship between the EU and ESA are advocated. A more coherent link between ESA's programmes and those under the EU's Fourth and Fifth Framework Programmes should be achieved. The way in which effective common work in R&D is to be organised practically at programme level still needs to be formalised. It is currently hindered by a set of incompatible rules, about which discussion is ongoing. A positive example is the cooperation between the EU, ESA and Eurocontrol on second-generation navigation systems, as proposed within the Fifth Framework Programme.

The scale of space activities should be

expanded by fostering synergy and cooperation with defence and other civilian terrestrial developments. New technical, managerial and financial approaches from outside the space industry have to be considered. Comparisons should be made with best practice in firms which are outside the space sector but which share some common environmental characteristics with space companies. Promoting and facilitating the dual use of technology and two-way technology transfer between the space and non-space fields is regarded as of great importance to increase return on investment in key areas such as high performance materials, electronic components, detection and positioning equipment, advanced mechanical, optical and energy storage systems, software, and computers. Industry is expected to play a major role in promoting and expanding technology transfer.

Non-space industry is often unaware of opportunities offered by space. Also, it may be difficult for newcomers to enter the space business regardless of their technical proficiency. In terms of applications, potential terrestrial users are often deterred from entering the space business by the high cost and long lead times typical of this market. Hence there is a need to ease access to space considerably for all potential new contributors.

A fundamental role which may be played by governments to stimulate innovation is in the domain of regulations and licensing. Judicious regulatory intervention may open new markets (such as in the case of environmental protection). At the same time, a process of deregulation initiated in carefully selected key areas may foster a blossoming of innovative applications (as in the case of GPS).

A broader involvement of small and medium sized enterprises (SMEs) and research centres in space R&D and project predevelopment needs to be envisaged. SMEs must be assisted in the process of absorbing scientific and technical expertise and converting it into practical applications. Research institutions are in need of support in order to be able to market their inventions.

Finally, a clear commitment of agencies to the training process (of their own staff and of industry) is regarded as a paramount contribution to innovation.

Innovation in Industry

Europe can benefit from the anticipated expansion of the commercial space business in

the next decade only if the necessary initiatives are taken, first and foremost by the European space industry. Companies should adopt new methods to increase their effectiveness and to be able to provide products and services at the right time and at an affordable price. Space-based services should be initiated by industry as a result of strategic marketing, initial private investment, and sound business planning (Fig. 3).

Issues such as industry consolidation, vertical integration, and international cooperation are vital to the industry's global competitiveness. Over the last three years, space industry throughout Europe has been undergoing a very significant restructuring process. The number of large companies that can act as prime contractors has decreased as mergers have taken place. Those same large companies tend to broaden the range of their activities by increasing the vertical integration of their businesses, e.g. by buying into the operator segment. These combined trends are perceived as a potential threat to smaller enterprises.

Preserving the much needed diversification in the industrial sector, by maintaining a correct balance between large prime contractors capable of competing on the world-wide market, subsystem equipment suppliers with unique expertise, and a network of innovative SME businesses, would tend to limit the amount of vertical integration that may be achieved.

The structure of the current European space

industry has been largely shaped by the geographical-return constraints which have often characterised past space programme development in Europe, and which are perceived as having hindered competition and as making European industry less effective. In the restructuring process, geographical-return rules should be replaced by service-oriented strategic partnerships, providing long-term chances for survival of smaller firms and expansion on the global market. An 'extended enterprise' arrangement of this kind should be neither the forced mating induced by the need to win a competitive action, nor a loose handshake. Rather, the concept of 'partnership sourcing' should be implemented, focusing on cooperation within the supply chain and with the dual goals of minimising the total value-chain cost and improving quality through information exchange, partner development, and joint problem solving.

Strategic teaming arrangements will be generated by the need to face international market pressure; these may differ from teaming arrangements created by the actions of ESA, acting as a regulator of industrial policy. The trend of industrial groupings spreading their activities over several Member States should help meet the legitimate concern for a fair overall geographical return.

A company's innovative capabilities will determine its future competitive advantage (in time, cost, performance or value) and overall growth potential. To date, no industrial group, and few companies, have established innovation as a competitive advantage. The

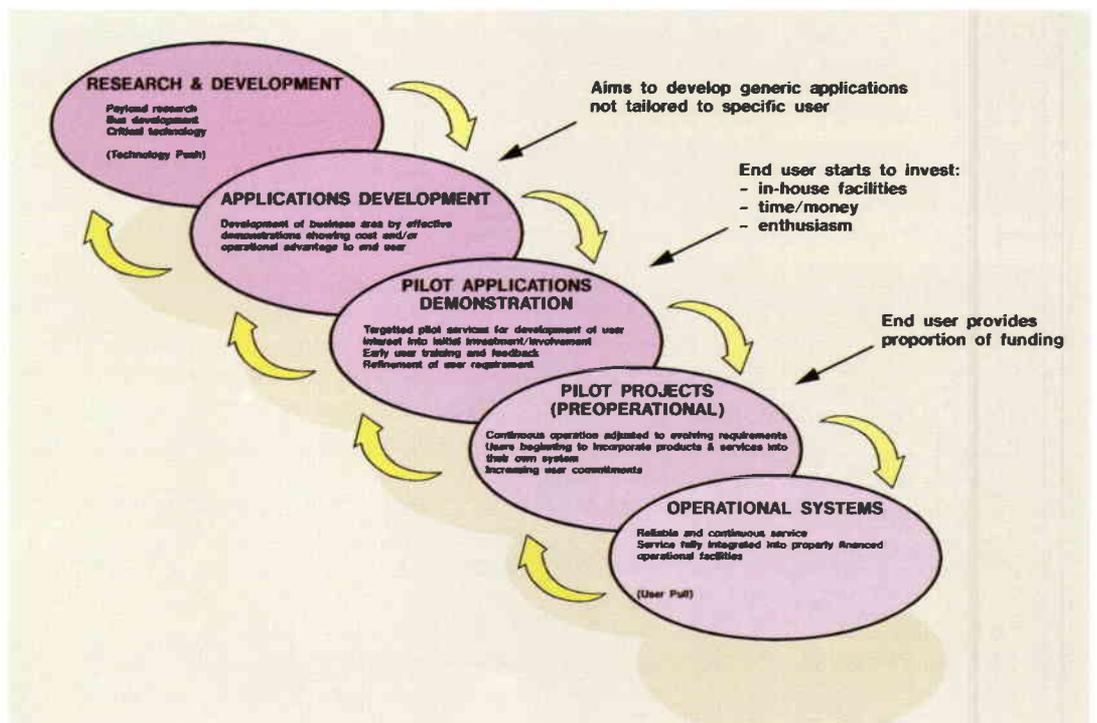


Figure 3. Business development model (Courtesy of ESYS)

next round of competitive repositioning will be based on innovative capabilities, since there are definite limits to creating shareholder value through mere cost cutting (such as lowering head counts and increasing efficiency). The strategic perspective must be shifted from the current emphasis on cost-driven enhancements to revenue-driven improvements for growth.

Innovation must be a process that can be counted on to provide repetitive, sustainable, long-term performance improvements. As such, it need not depend on great breakthroughs in technology and concepts, which tend to be rare. Rather, it could be based on bold evolution through the establishment of know-how, application of best practices, process effectiveness and high standards, performance measurement, and attention to customers and professional marketing. The most effective way to improve a company's innovation performance is to address company-specific core activities (market understanding, technology management, product planning, product development) by investing time and resources to implement best practices, and by measuring the increase in innovation performance.

An integrated monitoring system covering the technical, cost and schedule performance aspects of a space project is a prerequisite for effective project management. The concept of 'benchmarking' is a way of assessing the performance of a business by objective measurement against the best practice in the sector. It enables a company to concentrate efforts on improvement in areas of weakness, to monitor progress continually, and to set increasingly higher standards. The use of European benchmarking standards (ECSS) for quality and engineering management is of obvious advantage, and must become routine in this domain.

It is difficult for outsiders to measure the innovative performance of enterprises, since most companies will tend to shroud their most competitive assets under some degree of secrecy, and commercial confidentiality will prevent full disclosure of global study results. However, the innovative power of companies may be generically estimated on the basis of such parameters as the number of international patents filed by each company or, even better, the number of patents per company employee. It is evident from such data that, although European companies are generally in a good position (8 of the first 20 companies in the world in terms of number of patents), space-related enterprises fare much worse. Also, it is

evident that innovative power resides essentially with SMEs.

Innovation in the National Agencies

It is generally agreed that a global European system is the only viable framework in which innovation for competitiveness may effectively be developed (hence bridging the gaps between national and European, public and commercial bodies). National agencies in Europe are already taking steps toward innovation. These initiatives show a large amount of commonality even if one observes some important points of divergence. The inevitable deviations need to be taken into account by ESA to achieve harmonisation at European level.

CNES (F) prepared a Strategic Plan in 1996, with the aim of maintaining France as one of the driving forces behind European space activities. CNES intends to develop a partnership with French industry, to support it in strengthening its competitiveness and winning new markets. In the partnership scheme, industry concentrates on production, export and marketing, while CNES draws on its specific capabilities in basic research, advanced studies and system trade-offs, the introduction of innovative technologies, and demonstration in orbit.

ASI (I) has prepared a National Space Plan for 1998-2000, which is substantially in line with the above views and perspectives. ASI's Automation and Robotics Programme is an example of how innovation can be implemented in the 'access to space' process. This makes maximum use of commercial off-the-shelf technology in order to reduce the time to orbit (e.g. car manufacturing robot controllers for the A&R Programme), by involving non-space companies. ASI underlines the role of research centres as being fundamental for triggering innovation.

DARA (D) has reacted to the present competitive environment issues by investigating current status and available options with Germany's major space industries. DARA sees its role as one of supporting the relevant industrial initiatives as far as technical progress, national economic growth and employment are concerned. Support to industry is to be granted through market development. DARA also stresses the need for Europe to focus on sectors which hold the greatest promise for return on investment, rather than trying to compete with the USA across the full spectrum of space activities.

In the UK, BNSC and its largest partner, the

Department of Trade and Industry, have placed increasing emphasis and resources, in recent years, on encouraging British industry to improve its competitiveness with initiatives like the 'Inside UK Enterprise' scheme aimed at exchanging best practice know-how between companies (e.g. between novices and experts, small and large firms, space and terrestrial concerns). In particular, the concept of 'partnership sourcing' is being actively promoted across British industry.

NIVR (NL) supports Dutch industries through national space programmes. Innovative products are being developed in the framework of space technology projects, managed by NIVR. In recent years, NIVR has promoted new developments in the areas of informatics, mechanisms, simulation, propulsion and bioprocessing, with potential applications not only in space projects but also in military and civil projects.

Other space agencies have their own specific approaches designed to achieve a more efficient national space industry. For instance Finland, through TEKES, manages an effective scheme of technology transfer from government-sponsored R&D to application by small firms. Since space activities are only marginal in such schemes, benefits stemming from synergies become strikingly evident, with returns 10-20 times the initial investment and numerous jobs created both directly and indirectly.

SMEs in the Global Competition

International competition has undergone profound changes in recent years, with traditional trade no longer following conventional patterns. In addition, regional trading blocks and multinational companies (MNCs) are now shaping global economic activities.

This development has a number of consequences for SMEs which have many difficulties in achieving critical size and an efficient cost structure. In other words, SMEs have problems reaping economies of scale. In an open market regime very often the average yearly turnover of an SME is similar to a typical single order intake. This, in turn, creates economic instability within the company, which is aggravated by the barriers put up by large companies, dominating 2/3 of the global market.

SMEs, therefore, must observe these changes more closely in order to maintain their competitive and innovative potential. Clustering is a promising strategy for achieving this goal,

by bundling of economic activities, specific skills, as well as economic and scientific traditions within a region in order to gain competitive advantages. Clustering or networking between SMEs, or SMEs and MNCs, could enable them to gain a competitive edge over large companies. This could work to advantage in the space field where:

- sophisticated technologies developed for the non-commercial space market cannot be used in a competitive way for non-space applications
- prime contractors are under extreme competitive pressure
- European space industry follows the USA's 'merger path' to increase price-related competitiveness.

Because the space market is dominated by large firms, alternative and/or survival strategies have to be developed for SMEs. This has an impact on industrial strategies and on European and national industrial policy as well. On the industrial side, SMEs may either follow a 'niche strategy' (focus on their specific competitiveness factors such as overall speed, specific know-how and technology, tailor-made products, and by being more service oriented than their large rivals) or a 'cooperation strategy' by clustering among SMEs and possibly with MNCs. This would create value chains and areas of competence in addition to the competitive edges in the individual companies and it would also underline the links between a firm's strategies and government policies, thus supporting the integration of the European space industry.

The Relationship Between Research Centres and Industry

The competitive position of the European economies is linked to their ability to generate technological innovations to counterbalance the lower labour costs of newly industrialised countries.

To remain competitive in space, Europe must improve the efficiency of its R&D base — this can be done by improving the relationships between science and industry. However, new interaction between research labs and industrial firms requires a change in attitude on both sides. Research has a central role to play in making innovation possible and knowledge generated through research activities can be considered as an intermediate input to the process cycle. Research is a product with quality determining its usefulness. However, the research sector lacks the capability to market its products, while the industrial sector often lacks the capacity to express its needs. This situation needs to be improved and links

between universities and research centres on the one hand and the industrial sector on the other need to be strengthened. EU initiatives which draw industrial firms and research organisations together for specific programmes are a step in the right direction.

Firms must invest in basic research to create the capability to recognise, assimilate and exploit knowledge produced elsewhere. Firms are efficient at generating direct economic effects when they are open to the best basic research teams. One way to get the latter is by creating a network of companies. Networks offer a way to share knowledge between scientific institutions and private firms. The presence of a university in such a networked consortium has a beneficial effect on the generation of economic effects, while increasing participation of research labs in R&D programmes is beneficial to all members of a network, specifically large companies. Technological innovation is often enjoyed locally and thus the physical proximity between research centres and industry favours a rapid interchange of information, knowledge, personnel and know-how.

The Long Term

'Long-term' in space generally refers to mission opportunities being analysed and studied today but which are far from realisation. Typical examples are energy from space and utilisation of the Moon's resources. Among the issues relating to long-term space policy are:

- Why does it seem to be so difficult to move forward?
- What are the barriers to progress and what do we lack?

Fundamental points which must be considered include the lack of strategy and the need to identify convincing benefits for major problems of mankind (Fig. 4). For instance, the world's population is expected to double in the coming decades and the most pressing needs of the next century will still be material ones — ranging from the provision of food to energy generation, taking into account human health and the protection of the biosphere. Could space resources eventually be used to help eliminate shortages on Earth and remove biosphere risks?

One of the main hurdles to the large-scale utilisation of space is the immense cost of today's space launching and transportation systems. Ways to overcome this have to be found. Innovative approaches to low-cost access to space have to be found bearing in mind that recovery of development costs is a major factor in commercial enterprises. For

example, a number of international launch operators could share non-recurring costs and thereby reduce the prices of future (re-useable?) launchers.

The ISS (International Space Station) could represent an essential test bed for technologies and project management methods applicable to even bolder and more innovative space initiatives, such as lunar and planetary exploration (both robotic, and manned):

- In-orbit assembly operations, which may also be extensively developed in the context of the ISS, will constitute the core capabilities of future exploration initiatives. These operations will need rendezvous and docking systems, in-orbit fuel and cargo transfer, etc. Europe may get started in this direction from its already planned contribution to the ISS represented by the ATV, by increasing its basic capabilities and using it as a flexible technological test bed during each of its routine missions to the ISS.
- Tether systems may be used on and around the ISS for a multitude of applications (from capsule reentry initiation to 'zero fuel' ISS reboost). The European early start in this domain should be exploited and innovative initiatives proposed.
- Reentry capsules (for material samples and for crews) will play a fundamental role not only for the ISS, but also in lunar and planetary exploration. Europe has carried out extensive preparatory studies and has basic technology background in the field, which should be exploited.

In terms of organisation and management, the likely evolution of the ISS is towards the innovative concept of delegating operations and utilisation to the care of an industrial consortium, thereby allowing the public agencies to concentrate on research and development. Although this will represent only a privatisation stage and may not yet evolve into a truly commercial enterprise, given the potentially limited nature of the market concerned, it will definitely constitute a fundamental model for future enterprises (e.g. re-useable launch vehicle operations and ventures in space resource exploitation).

For the longer term, the central role of the continued presence of humans in space, so much evident in American space programmes, should be restated. Humans play a unique role in space exploration and utilisation by effectively complementing the performance of robotics. Their presence in space reaffirms the striving of mankind for expansion beyond Earth. Last but not least, a manned space

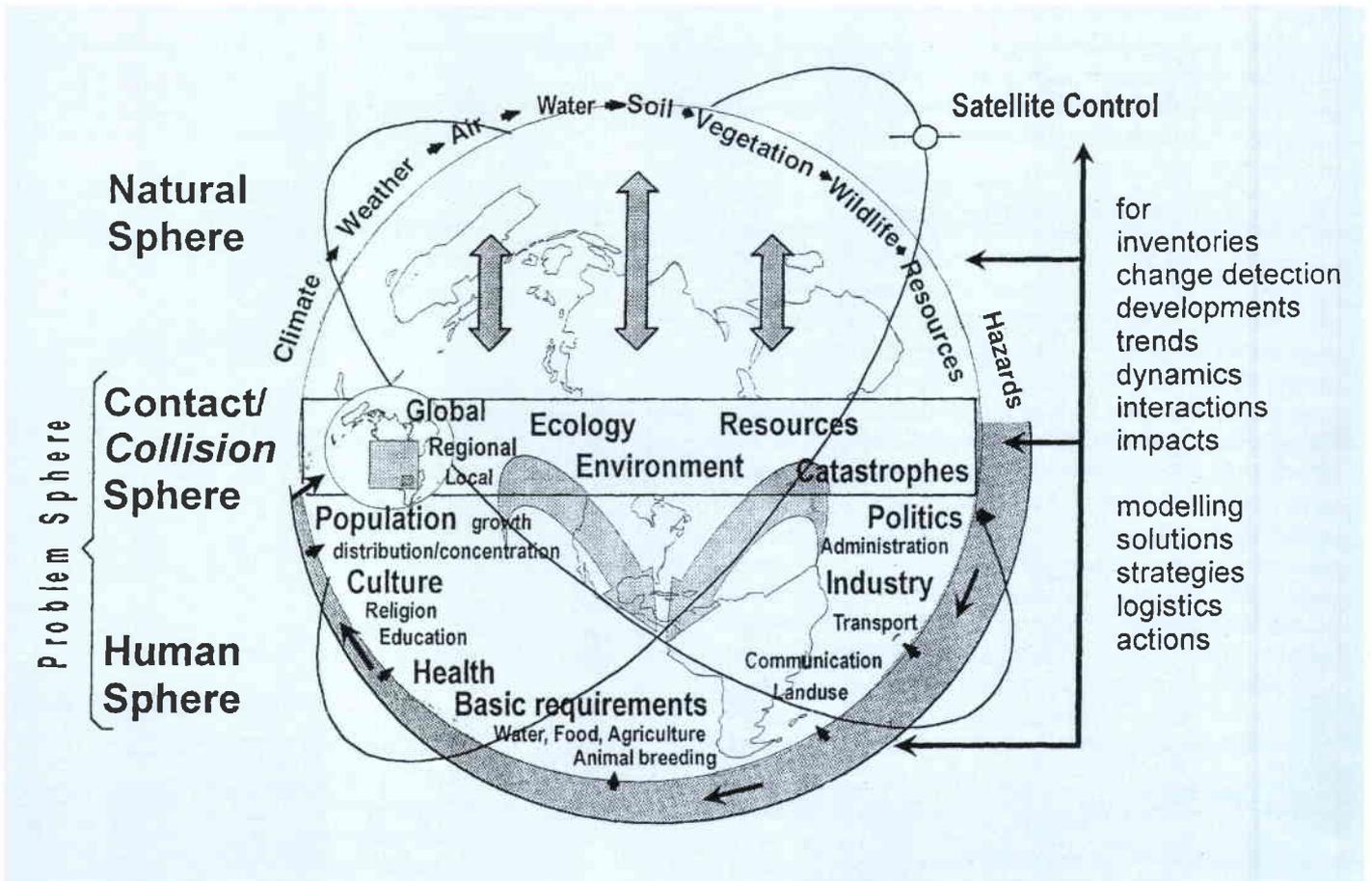


Figure 4. The global system (Courtesy of GEOSPACE)

programme is most effective in ensuring public support and involvement, including useful incentives to technical and scientific education.

Ultimately, it is hoped that the ISS experience, combined with drastically reduced launch costs, will lead to leapfrog innovations based on mass access to space, enabling such new initiatives as space tourism. A measure of the dramatic amount of advancement which is needed in this domain is given by the fact that jump-starting mass access to space is estimated to require a further reduction of one order of magnitude in launch costs, even from the currently projected operational cost levels for a true, fully re-useable launch vehicle.

The Investors and Market Makers

Market-oriented applications are still not a dominant component of space activities, with a share of about 30% in Europe and only 10% in the USA. However, commercial growth in the telecommunications, multimedia and navigation markets is likely to ensure parity in Europe within five years, and commercial dominance thereafter. This effect is even more noticeable when full account is taken of the combined applications between space and the home, the car and in business. Small companies and entrepreneurs are able to feed off a rich cocktail of technology developments to attract venture capital and to acquire long-

term financial support for potentially well managed, bold programmes. Venture capital is far scarcer in Europe than in the USA and is seldom used to finance technological innovation, a problem which extends into European space programmes. For historical and structural reasons, a significant gap exists between the European space R&D communities and the commercial market, as well as the users of space applications.

Private capital is becoming increasingly more important for financing both application and market-driven space activities in Europe. The emergence of large, commercially funded space projects requires a novel look at how new space initiatives can be funded.

It is clear that the international market for commercial telecommunications can attract investment from corporate and financial investors. The financial 'engineering' needed to take advantage of venture capital at the early stage, and other sources of funding throughout a project's life, are reasonably well understood and frequently used for US projects. Investor confidence focuses particularly on a proven management team and an associated business plan. Investment is primarily targeted at high-growth activities such as satellite telecommunications, but not at public funded and embryo markets — such as Earth

observation — where the corresponding growth is not yet assured.

There is no lack of capital for space projects in the international markets, nor a lack of professional financial expertise in Europe. Emphasis should be placed on improving investors' knowledge of space technology and the associated opportunities and risks. Similarly, space entrepreneurs must learn more about the essential characteristics sought by potential investors when looking at high-growth projects.

A proposal to create a venture capital fund in Europe comparable to Space Vest in the USA stimulated considerable debate. It was concluded, however, that financial market makers will readily create such funds when a ready stream of projects emerge which are perceived to meet the needs of public or commercial customers. The potential interest of the European Union in offering financial support through its 'Communication on Space', published in December 1996, has been noted.

In conclusion, ESA, in its role as 'technology' provider, has to keep in mind that:

- innovative space-based service concepts will rely on 'advanced technologies' only if the overall competitiveness and financial results justify it
- the R&D planning process has to be adapted to the business plan and to the financial concepts of the specific service. Here a common educational process (technologists, entrepreneurs and bankers) should be initiated
- innovative legal frameworks have to be set up to allow for a deregulated space environment, helping to create confidence for space management in the financial and investment sector.

It appears that there is a lack of 'governmental money' to finance space-based business, but no lack of money on the financial markets per se. However, the space community has yet to learn how to tap it.

Conclusions

In today's competitive environment there is the need to demonstrate the economic and commercial value of emerging applications of space technology and to identify those skills needed to strengthen European industrial competitiveness. Space agencies, industry and research centres should develop research vision and technology strategies targeted to exploring the uncertain dynamics of emerging markets and user communities, anticipating the interaction between socio-economic and technology thrusts. This requires the ability to

perform a high-level synthesis of multidisciplinary trends encompassing applications, science, technology, economics, finance, manufacturing processes and industrial organisation.

More effort is needed in terms of:

- the provision of turnkey services based on strategic and more secure market prospects
- the development of high technology products capable of winning new users, increasing production, decreasing the cost and delivery time, integrating high levels of essential information and autonomy (better, faster, cheaper)
- larger investment in payload technologies, driven by global goals rather than by spread objectives
- the introduction of performance-based incentive clauses for timely delivery and quality products
- the replacement of geographical-return rules and other political constraints by strategic partnerships, providing greater probability of long-term survival in a global context
- establishing a framework supporting the innovation process; the major players should elaborate a joint plan with a clear assignment of responsibilities. This plan should include the role of ESA, the EU, industry, operators, research centres and universities, user organisations, financial institutions, governmental and public institutions
- the elaboration of a strategy for improving the European space sector on the basis of such innovative elements as:
 - product and market-oriented R&D
 - service-oriented partnership programmes
 - introduction of the leading-edge technologies into visionary programmes. 

ISS-VIEW: A Software Tool for External Science Payloads Attached to the International Space Station

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The International Space Station

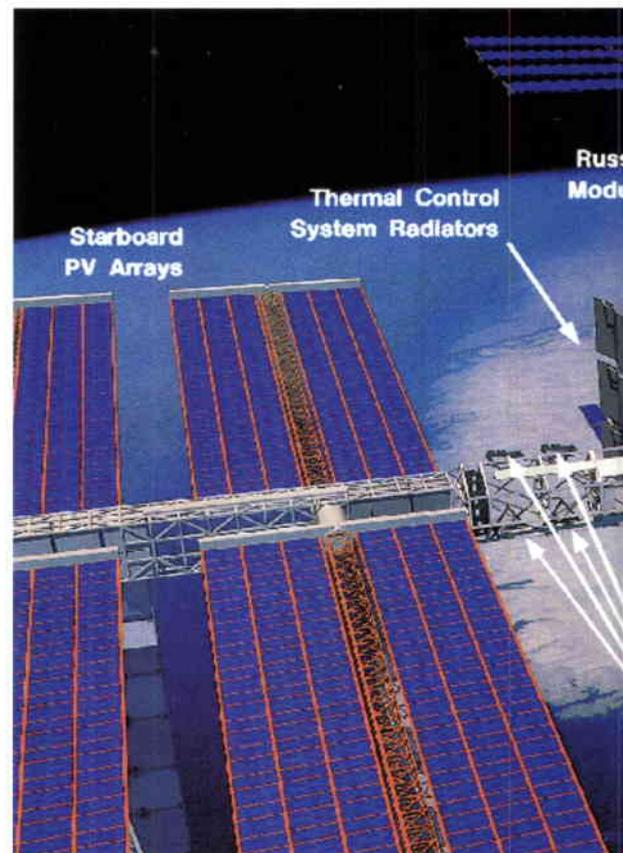
The International Space Station (ISS) will be a large permanently manned space platform capable of supporting long-duration scientific and technology research projects in space. Traditional microgravity disciplines such as the

science of materials and fluids, human physiology, biology, chemistry and biotechnology will benefit considerably from the long-term availability of such a facility with a gravity-free environment. Earth remote sensing and space science too will be able to take

In the framework of the Agreement for the Early Utilisation of the International Space Station (ISS), ESA has negotiated with NASA to have early flight opportunities for European payload instruments prior to the launch of the Columbus Orbital Facility, in exchange for the delivery to NASA of a set of items that constitute the early European contributions for the utilisation of the International Space Station.

One of these early European contributions is the Hexapod positioning/pointing system, which is being developed under the responsibility of ESA's Directorate of Manned Spaceflight and Microgravity to provide a pointing platform for the NASA Stratospheric Aerosol and Gas Experiment III (SAGE III) instrument. Hexapod and SAGE III are designed to be accommodated on an ISS Express Pallet and have a five-year design lifetime. They will be launched with Space Shuttle flight UF-4 at the beginning 2002.

The ISS-VIEW software tool has been developed to support the mission analysis and to define the observational windows for Hexapod/SAGE III, but it can also be used for other instruments. For example, it also allows one to predict astronomical or Earth-target observing opportunities for Express Pallet payload instruments from their actual mounting locations on the Space Station Truss. In addition to the orbital and attitude parameters of the Station, ISS-VIEW is also able to take into account the field-of-view restrictions imposed by both the fixed and movable elements of the overall Space Station assembly.



advantage of the availability of such a large platform in low Earth orbit with frequent access opportunities.

The ISS (Fig. 1) is the biggest international space enterprise ever and is the result of the combined efforts of the United States, Russia, Japan, Canada and Europe. The European contribution is provided through the ESA Programme for European Participation in the International Space Station, funded by 10 ESA Member States*. It is the biggest manned space programme ever undertaken by ESA. The Station will provide the space infrastructure needed to carry out experiments in both pressurised and unpressurised environments (further information can be found in the ESA Guide for European Users, ESA SP-1202, available from ESA Publications Division). The first assembly elements are scheduled to be launched in 1998, starting an assembly sequence that will take about half a decade. The permanent habitation of the Station by a crew will, however, already start some six months after the launch of the first element.

Dedicated platforms called Express Pallets will accommodate external payload instruments at four locations on the starboard side of the Space Station Integrated Truss Assembly, inboard of the solar arrays. Two Express Pallet mounting locations will offer zenith-oriented viewing, and the other two locations will be

nadir-oriented. Each Express Pallet will provide the interface infrastructure (six adapters) and the resources needed to accommodate several smaller payload instruments.

Figure 2 shows the segment of the Station's Truss (known as segment S3) that will host the Express Pallets, and two Pallets are shown accommodated on top of it. Figure 3 shows the Express Pallet architectural concept, with square boxes representing the payload instruments that can be accommodated on the six Express Pallet Adapters.

On the basis of the ESA/NASA Agreement on Early Utilisation, in exchange for the Hexapod's delivery to NASA European users will benefit from early flight opportunities for their instruments on these Express Pallets.

SAGE III and Hexapod

The NASA Stratospheric Aerosol and Gas Experiment III (SAGE III) is the fifth in a series of spaceborne Earth remote-sensing instruments developed at NASA's Langley Research Center. The industrial contractor for its development is Ball Aerospace (Boulder, Colorado). SAGE III will use both solar and lunar occultation techniques to perform the spectrometric measurements needed to monitor the global distribution of aerosol and gas constituents in the Earth's atmosphere. Three flight units will be produced, each one adapted to fly on a

* Belgium, Denmark, France, Germany, Italy, Netherlands, Norway, Spain, Sweden, and Switzerland.

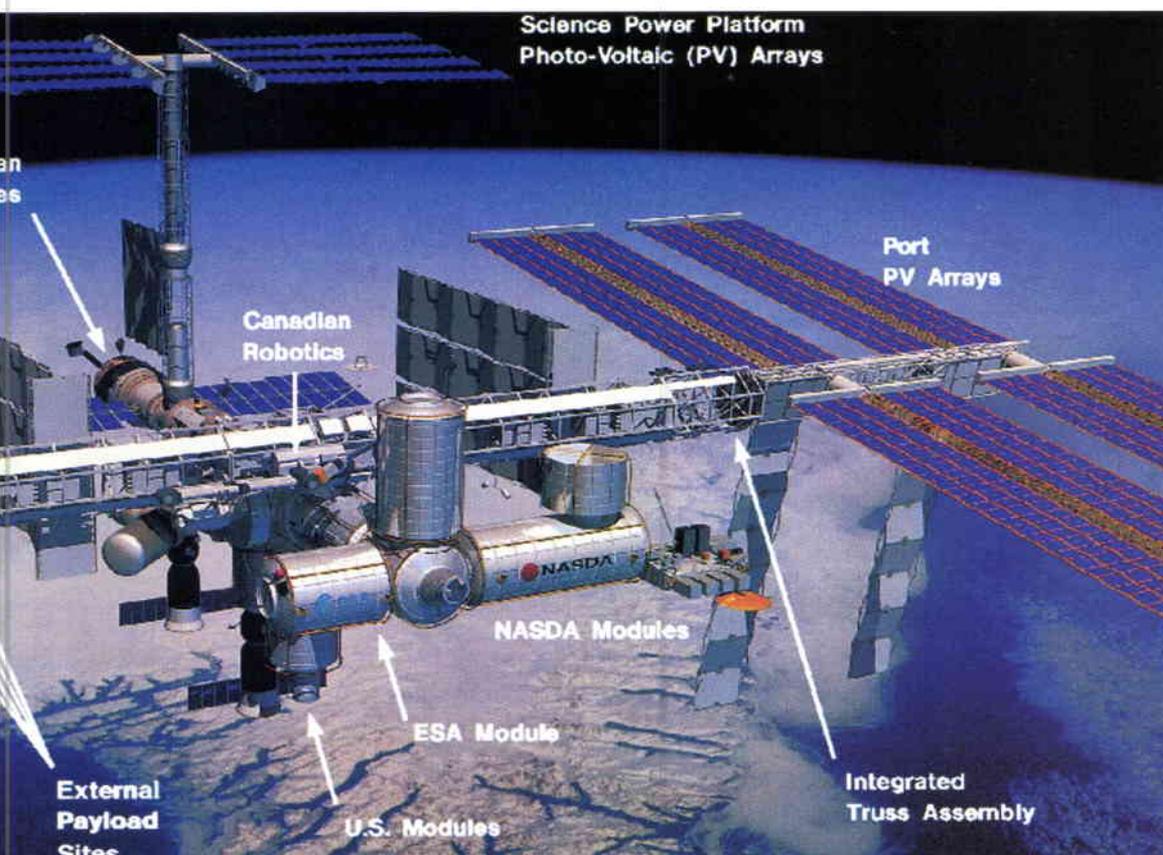


Figure 1. The International Space Station

different spacecraft carrier. One of these units will be flown on the ISS, mounted on the Hexapod pointing system developed by ESA.

Hexapods are positioning/pointing devices that are able to control the six degrees of freedom (positional and rotational) of a rigid body in three-dimensional space. They are frequently used in several types of ground applications, ranging from high-accuracy applications in optics and manufacturing machinery, to dynamic applications in car/flight-dynamics simulators and active anti-vibration mounts.

Hexapods are typically composed of six linear actuators (legs) arranged in the shape of three trapezia and interconnected by means of 12 universal joints to a lower and an upper mounting plate. The payload is normally accommodated on the upper mounting plate and the lower mounting plate is fixed to the hosting carrier. Computerised coordinated control of the lengths of the six legs allows the relative displacements and attitudes of the upper and lower mounting plates to be precisely controlled.

The pointing device for SAGE III will be the first European space mechanism based on the Hexapod principle. Following preliminary feasibility assessments, the Hexapod Project underwent a Pre-Phase-B pre-development activity (contractor ADS Italia) lasting from December 1994 until October 1995, which included the prototyping and testing of several linear actuator options, and a Phase-B design study, completed in March 1997 (prime contractor Alenia Spazio, with ADS Italia and Carlo Gavazzi Space as subcontractors), which included the breadboarding of a development model with full functionality (Fig. 4), and extensive testing activities.

Hexapod and SAGE III will be mounted on a nadir-oriented ISS Express Pallet.

Pointing/viewing from the ISS

Nominally, the International Space Station will operate in a 90 min orbit with very low eccentricity and 51.6 deg inclination, in a local vertical - local horizontal attitude fixed with respect to the local nadir and the direction of motion. Tracking a target from the Station requires relatively high pointing rates for relatively short periods. The rates for tracking

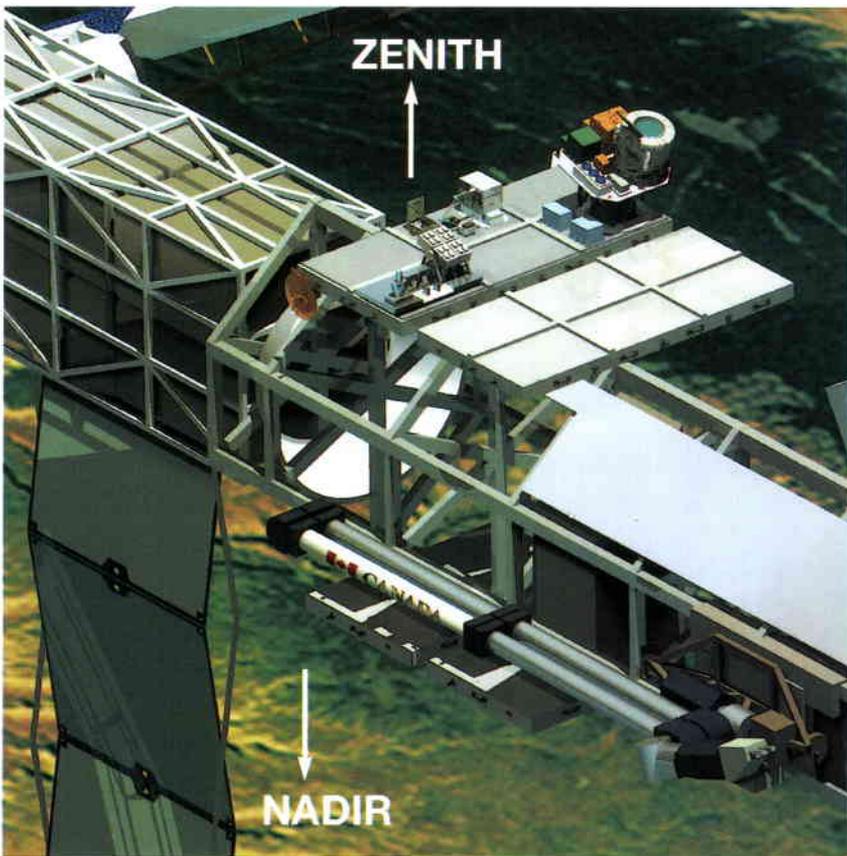
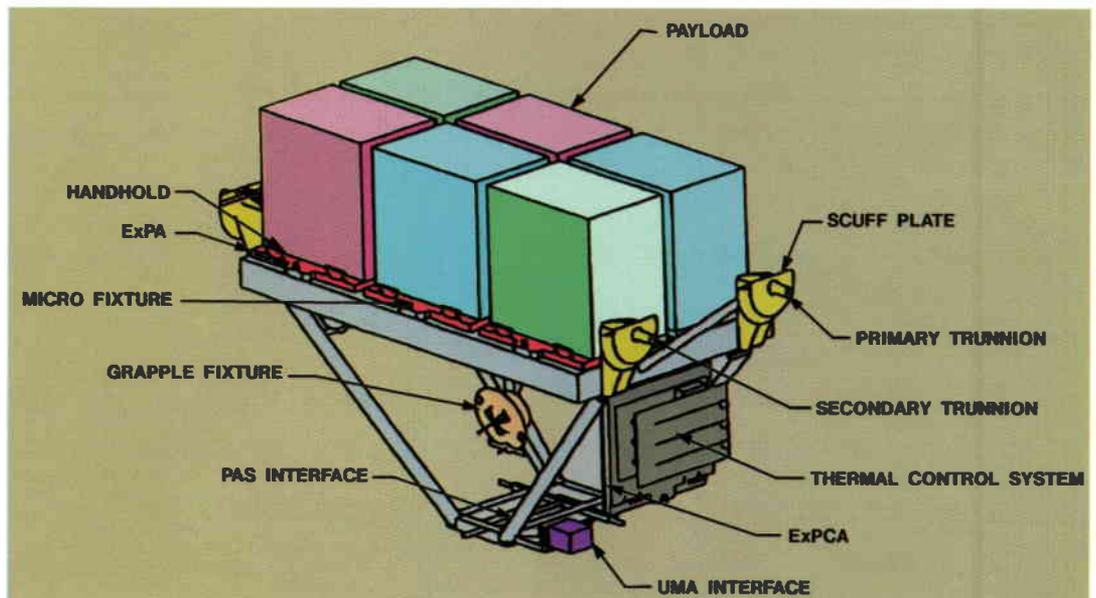


Figure 2. The zenith- and nadir-facing Express Pallets, attached to the Station's truss structure



Figures 3. Express Pallet architectural concept

the Sun or a star are typically in the order of 0.07 deg/sec, and the viewing time for a 60 deg viewing range for a celestial source lying in the orbital plane is 15 min/orbit. This time increases for sources located away from the orbital plane.

The actual field of view will be very much limited by various obstructions associated with the Station's structure, which introduces constraints on the visibility of the payload targets. The fixed parts of the Station assembly will intrude into the payload fields of view in such a way that their profile may change as the Station's configuration evolves over time during the assembly sequence. Obstructions from the solar arrays and radiators will impose important limitations on the fields of view from the Express-Pallet mounting locations (Fig. 5). The field-of-view obstruction caused by the solar arrays and by the radiators will also be time-dependent. In order to maximise energy generation, the solar arrays will normally be rotated during the day both around their axis and around the Truss to maintain perpendicularity to the Sun; at night they will be aligned with the Station's flight direction to reduce drag. The radiators will also turn to optimise heat rejection.

Temporary field-of-view limitations will be caused by re-supply vehicle docking, by the movements of robotic manipulators, etc. Other obstructions may be mission-dependent, such as the presence of large payload facilities. These complications, combined with the short-duration visibility of many of the targets - which will call for relatively high tracking rates, particularly if they are located on the Earth's surface - mean that accurate mission analysis and observation planning for the remote-sensing and space-science instruments that will be operating from the Station are of critical importance.

All in all, therefore, the Station's complex configuration, combined with the regularly changing geometry of its moving parts, imposes the use of sophisticated software tools for accurately predicting the visibilities of specific targets of interest.

Observations from Hexapod/SAGE III will require unobstructed viewing of the Sun and the Moon during sunrise (moonrise) and sunset (moonset), i.e. when the Sun's (Moon's) light passes through the terrestrial atmosphere prior to entering the SAGE III spectrometer. It is precisely to identify these opportunities that ISS-VIEW has been developed (by CARSO of Italy, under the supervision of the Hexapod prime contractor).

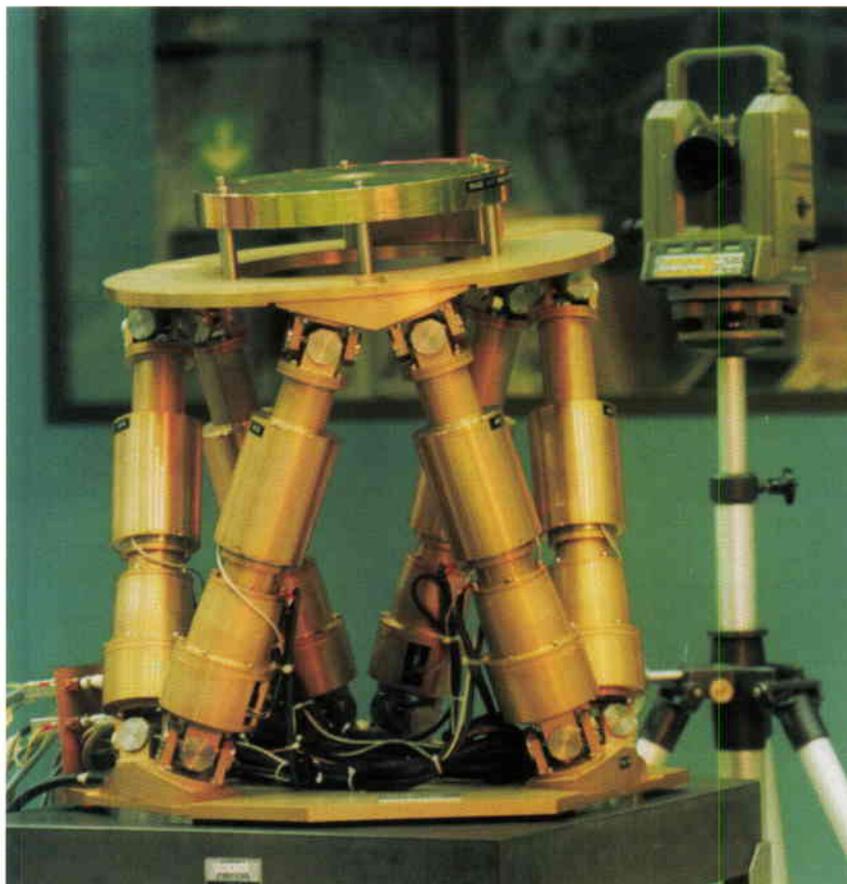


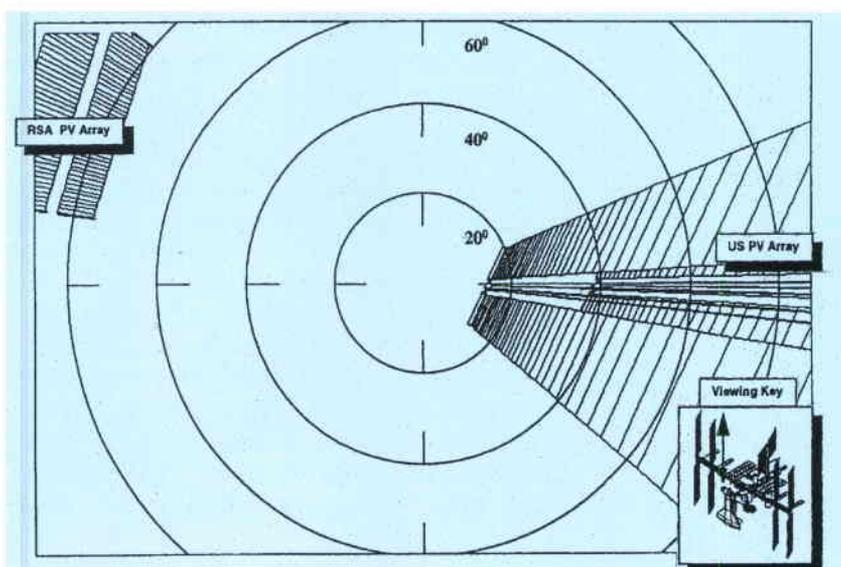
Figure 4. The fully functional Hexapod development model

ISS-VIEW

ISS-VIEW has been developed as a software tool primarily to support the engineering analysis and the mission planning for Hexapod/SAGE III. However, it has been conceived in such a way that its use can be generalised to other Earth-observation, solar and astronomy payload instruments mounted on either the upper or lower Express Pallets of the ISS.

It is possible with ISS-VIEW to simulate the payload observations by using a polar display showing the hemisphere of observational

Figure 5. Zenith-looking field-of-view from the Express Pallet



interest. The payload instrument is assumed to be in the centre of the polar display; the entire spatial sphere is represented, with the hemisphere behind the instrument displayed at a lower resolution. ISS-VIEW simulations include modelling of the profiles of the ISS fixed and moving obstructions as a function of the Express Pallet payload position and of time. The key data of the analysis run, such as time, attitude, obstruction/observation periods and target positions, can be recorded as outputs for the user.

Background

Precursors of ISS-VIEW are the UVS-VIEW and the GLO-VIEW software tools developed for two Space Shuttle Hitchhiker pointing instruments UVSTAR and GLO, respectively. The latter were part of the International EUV Hitchhiker (IEH) experiment flown in 1995 on Shuttle flight STS-69 and are planned to fly a second time (five flights in total) in August 1997 on STS-85. GLO is a University of Arizona (Tucson) programme, while UVSTAR is a collaborative effort by the Universities of Trieste and Arizona. GLO-VIEW and UVS-VIEW are used to help scientists predict available observing windows, thereby assisting in the effective planning of both observation and mission strategies.

With UVS-VIEW and GLO-VIEW, the centre of the display is the Space Shuttle's -Z axis (out of the bay). The viewing horizon is the Space Shuttle envelope as seen from the Hitchhiker bridge. The entire spatial sphere is shown, with the +Z hemisphere (the one behind the Space Shuttle bay) represented at lower resolution.

When UVS-VIEW or GLO-VIEW are started, after the initialisation phase (in which they read the input data files), they switch into a graphical mode to display the spherical map, and the Mission Elapsed Time clock starts running. Current Mission Elapsed Time and Space Shuttle attitude are shown to the user. The Earth or space targets selected are displayed; Earth, Sun, Moon, Jupiter, and the spacecraft velocity vector direction are always shown by default. The Earth's night and sunlit limbs and the terminator are also indicated.

The ISS-VIEW package

ISS-VIEW, developed under an ESA contract, retains many features of its UVS-VIEW precursor. The major modifications introduced consist of several improvements to the package's man/machine interface and adaptations to take into account the particular configuration and attitude characteristics of the International Space Station. It allows observers to simulate observing windows, to plan target

sequences, and to select instrument pointing criteria. The software simulation results can be recorded, and the user also has a playback facility.

Running ISS-VIEW requires an IBM-compatible 386, 486, or Pentium computer running DOS 3.1 or higher. Both standard VGA and Super VGA cards are supported. The software can be made available to users upon request.

The modelling of the Space Station consists of the envelope (mask) of the Station 'horizon', represented in a polar geometry, as seen from one of the lower (or upper) Express Pallets. The mask model takes into account both the fixed parts of the Station and the main moving parts: the US and Russian solar arrays and the radiators. The simulation also takes into account the fact that during the day (i.e. during the part of orbit when the Station is exposed to the Sun) the US solar arrays rotate both around their axis and around the Truss in order to remain perpendicular to the Sun's direction. The modelling also considers the movement of the Russian solar panels to track the Sun, and the rotations of the radiators to optimise heat rejection.

ISS-VIEW can be easily modified to account for the presence of additional mission-dependent Space Station obstruction sources (e.g. large payloads like the Materials Exposure Facility), and if necessary the time-dependent profiles of robotics arms and docking vehicles can also be introduced. Changes in the Station's geometry can be programmed into a specific file modelling the Station mask (ISS.MSK). Different masks are provided for instruments mounted on the upper and lower Express Pallets.

The centre of the graphical display is the instrument Z-axis (zenith-nadir direction for Earth-oriented instruments; the opposite direction for sky-oriented instruments); the hemisphere behind the instrument is shown at a lower resolution. The current Observation Elapsed Time and Station attitude are displayed on the screen. The default display includes the Sun, the Moon, Jupiter, the Earth's centre and the Station velocity vector. The Earth's limb is represented, with dark blue used to indicate the night limb and bright blue the sunlit limb. When visible, the terminator is shown as a bright yellow line. Earth latitude and longitude lines (if selected for display) are shown at 5 or 10 deg intervals, facilitating correlations with specific points on the Earth's surface. The auroral oval is also displayed, as a green line or as an oval, when it is visible; it is calculated for a height of 100 km and so it

appears slightly above the Earth's limb. Other command-line options include the possibility to select the stars displayed, based for instance on the intensity of their ultraviolet emission. The program can be run in either interactive or automatic mode.

To facilitate its use, ISS-VIEW has an online Help feature.

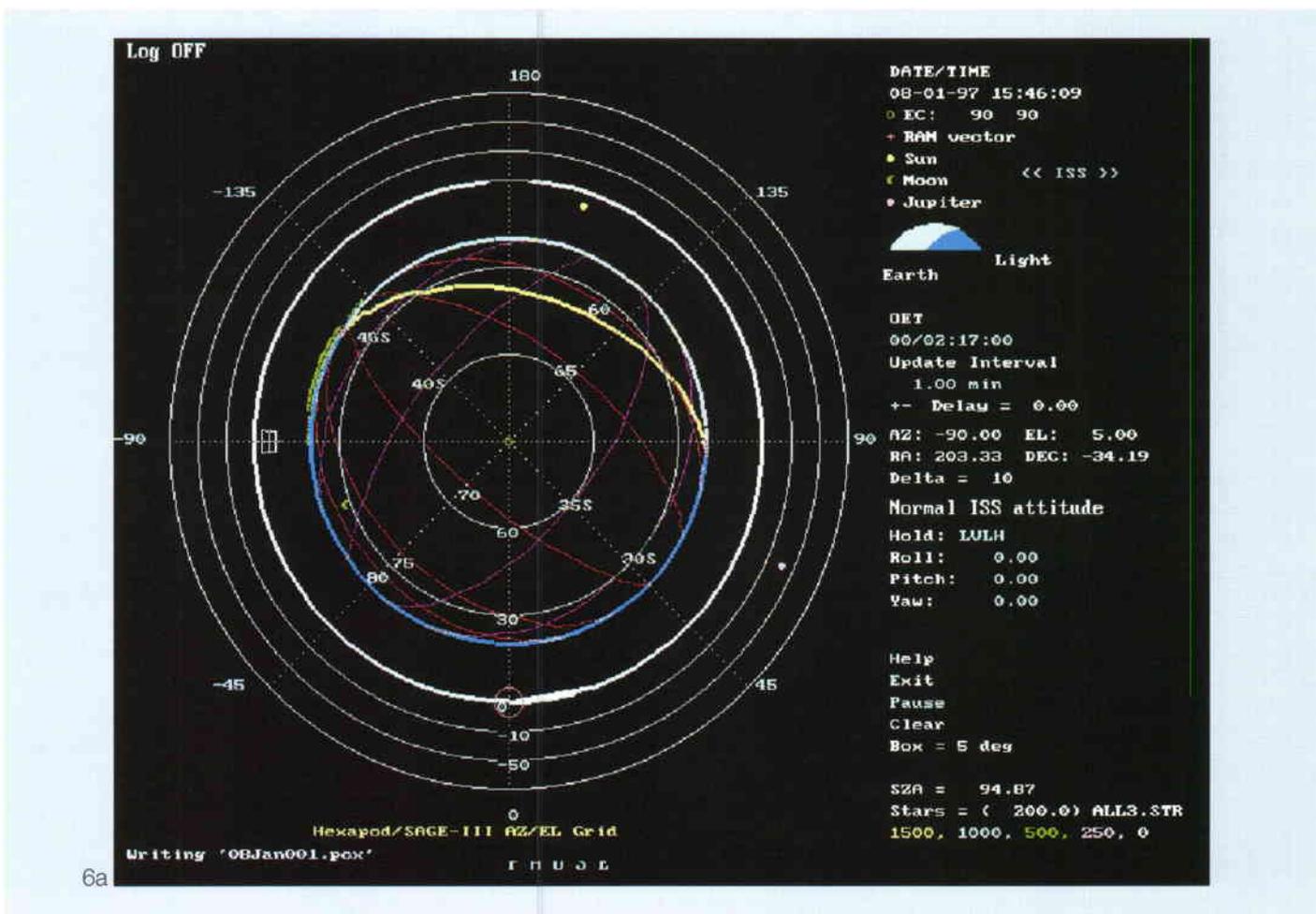
ISS-VIEW for Hexapod/SAGE III

Mounted on one of the lower Express Pallets of the ISS, and suitably aligned by Hexapod, SAGE III will use the solar/lunar occultation technique to perform spectrometric measurements to monitor the global distribution of aerosol and gas constituents in the Earth's atmosphere. Sun- or moonlight will be collected via an aperture near the nadir end of the instrument. A scan mirror directs the collected light to a telescope, which focuses it at the entrance slit of a spectrometer. Light entering the spectrometer is reflected by a folded mirror to a spherical holographic grating, which disperses first-order light onto a Charge-Coupled Device (CCD) detector. The CCD will record eight different spectral channels of science data. A ninth data channel is provided by the zero-order light, appropriately filtered; in this case the detector is a photodiode.

Observations from Hexapod/SAGE III require unobstructed viewing of the Sun or the Moon during sunrise (moonrise) and sunset (moonset). Once the target has been detected and acquired, the SAGE III azimuth pointing system will keep the instrument locked onto the target's vertical centroid whilst the elevation mirror starts scanning at constant angular velocity until it scans off the source disk, and then reverses scan direction. In the sunrise (moonrise) case, SAGE III will then continue to scan the light source disk through the atmosphere from the moment when the disk is in an apparent position tangential to the Earth's surface, until the moment it reaches an apparent altitude of 300 km (the opposite sequence will apply for sunset/moonset). Observations made when the source disk has a tangent height of between 150 and 300 km (i.e. when the incoming light does not pass through the Earth's atmosphere) will be used to obtain the unattenuated source intensity for instrument self-calibration.

To illustrate the application of ISS-VIEW for Hexapod/SAGE III operations, Figures 6a-d present a sequence of ISS-VIEW displays for different viewing situations. Figure 6a shows the unobstructed sky as seen by an observer looking at the Earth from the same orbit as the

Figures 6a-d. Sequence of ISS-VIEW displays for different viewing situations



International Space Station. In Figures 6b-d, the Space Station masks are as seen from one of the lower Express Pallets, where Hexapod/SAGE III is to be accommodated. The mask used in Figure 6b refers only to the fixed parts of the Station - basically the pressurised elements and the Truss assembly. In Figures 6c-d, the Space Station 'horizon' includes the obstructions generated by the rotating panels (solar arrays and radiators) of the station and also the Materials Exposure Facility, as an example of a mission-dependent temporary obstruction, assumed to be accommodated on an Express Pallet adjacent to Hexapod/SAGE III. Figures 6c and d refer to sunrise and sunset, respectively.

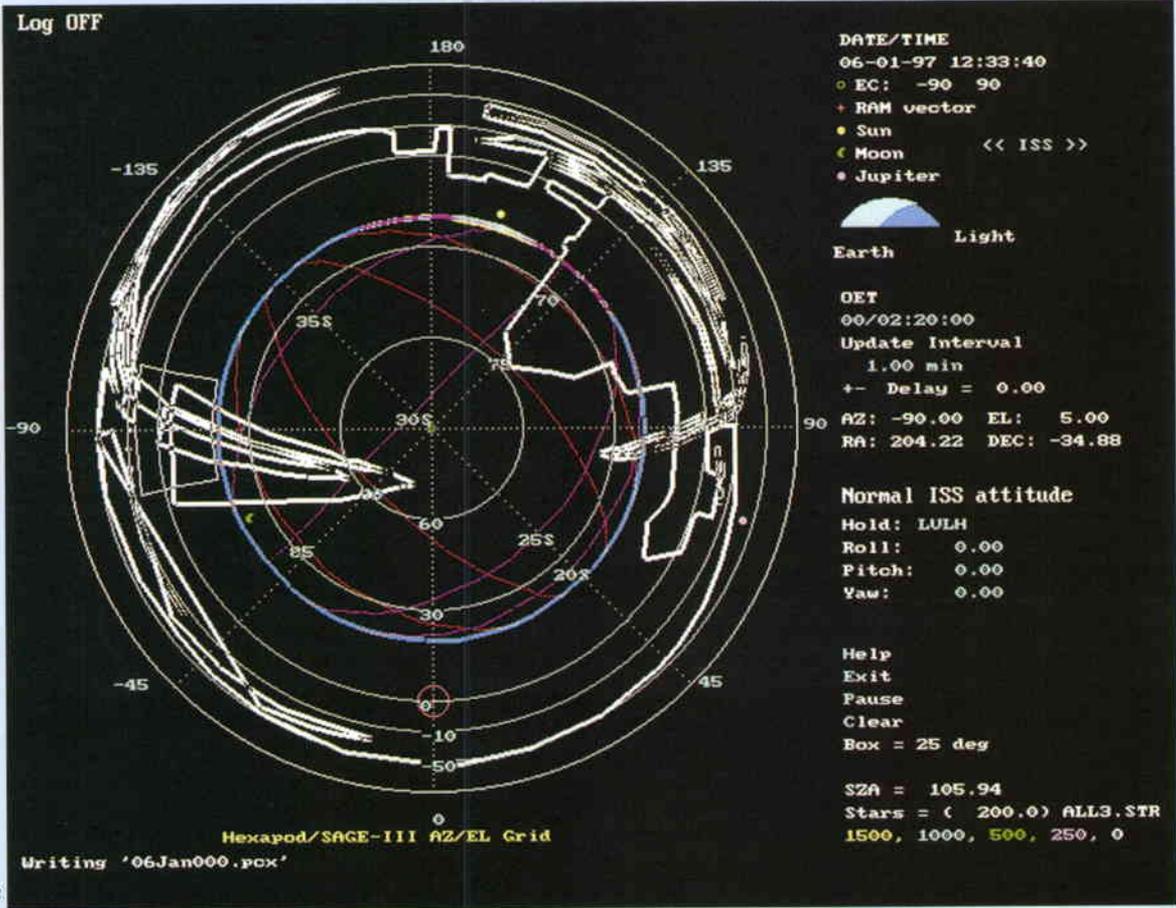
Figure 6a is intended to illustrate the unobstructed-sky view as seen from a free-flying spacecraft that looks towards nadir (centre of the graphical display) from the same orbit as the International Space Station. The heavy white circle is the observer's horizon. The hemisphere behind the observer, lying outside the horizon circle and represented at lower resolution, contains the Moon (green crescent) and Jupiter (magenta circle). The Sun (yellow circle) is on the horizon and illuminates part of the Earth (marked in bright blue). The terminator is visible as a bright

yellow line. The Earth's night limb is represented in dark blue. The latitude and longitude lines are displayed on the Earth's surface in red and magenta, respectively, at 5 deg intervals. The auroral oval is visible near the South Pole as a projected green oval. The direction of the Space Station's velocity vector is indicated by a red cross surrounded by a circle; it fixes the X-axis direction and has (0, 0) azimuth and elevation coordinates.

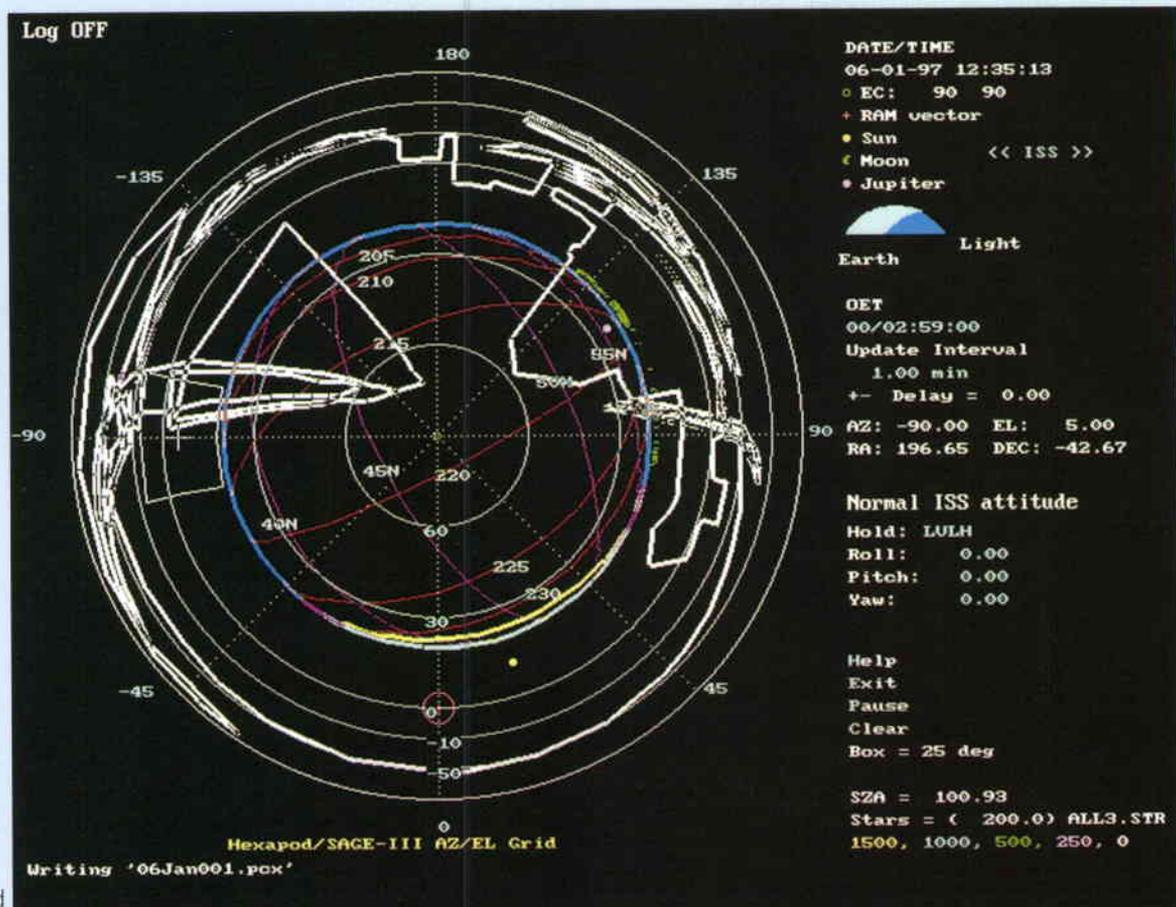
In the simulation of Figure 6a the observer's viewfinder is assumed to be 5 deg wide, represented by the 5 deg field-of-view box pointed according to the azimuth and elevation coordinates reported on the right side of the display (Az = 90 deg, El = 5 deg). The corresponding inertial coordinates of right ascension and declination (RA and Dec) of the centre of the field of view are also reported on the display. For the sake of greater clarity, no stars have been represented. The Log-Off sign in the top left corner indicates that the data are not being recorded. Other self-explanatory information is given on the right side of the display.

In Figure 6b, the fixed elements of the Station (as foreseen at assembly completion) are shown as seen from Hexapod/SAGE III (which



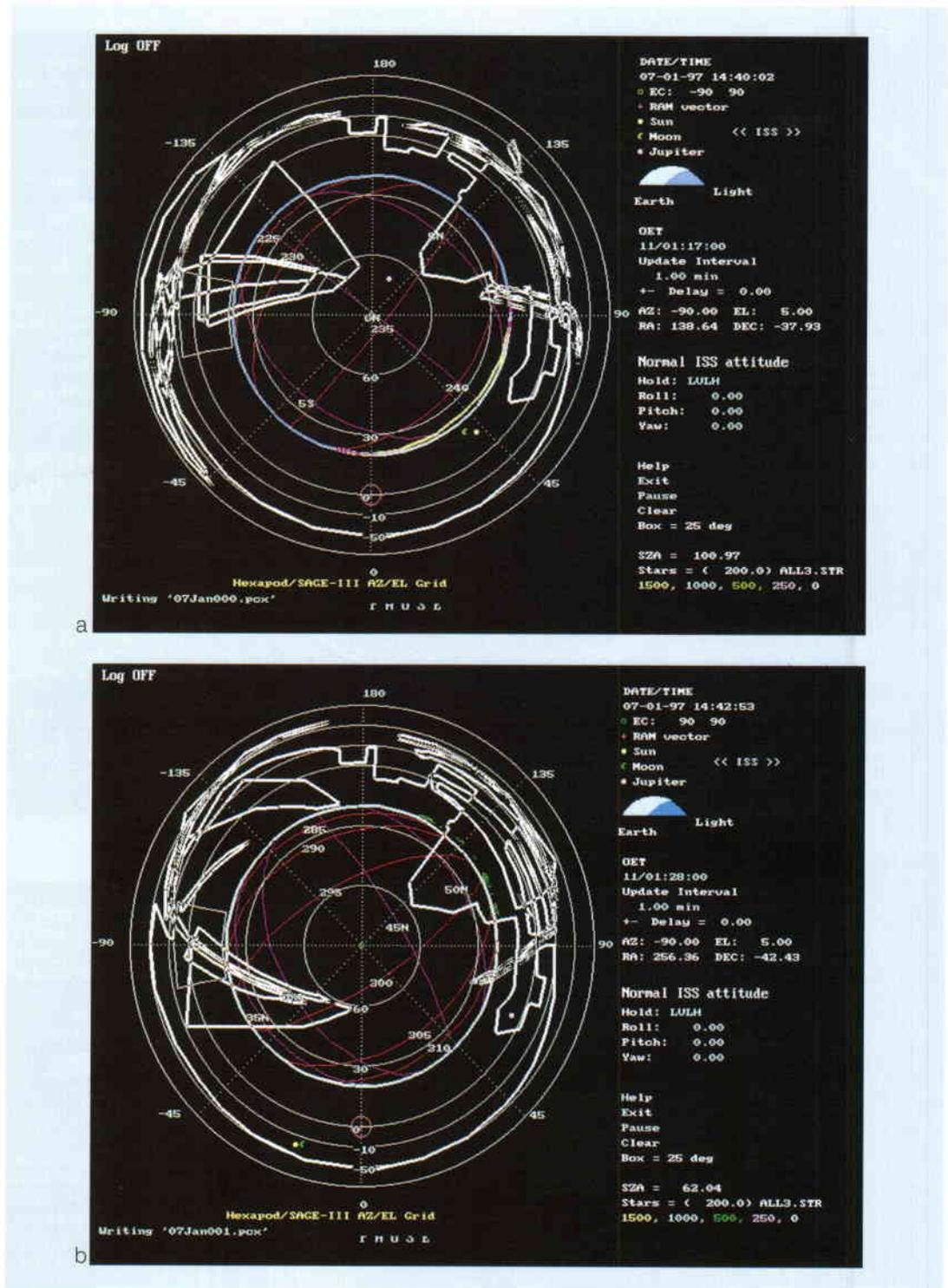


6c



6d

Figures 7a,b. Effect of precession caused by changing ISS orbit's ascending node from 109.6 to 169.6 deg



is at the centre of the display). Under the proposed orbital conditions, the full Earth is now dark and the Sun is illuminating its other side.

Figures 6c,d represent the sky obstruction with the full profile of the Station, including solar arrays, radiators and with the Materials Exposure Facility present. The simulations have been run for sunrise and sunset, respectively, when SAGE III performs its spectrometric measurements. Here a 25 deg-wide field-of-view box has been used. The attitude file used for the simulations shown in the sequence of

Figure 6 has a local vertical - local horizontal hold with constant zero roll, pitch and yaw angles. Like its predecessor UVS-VIEW, ISS-VIEW allows one to select several different attitudes (although in reality the Station will not use all of them). However, as a further improvement introduced in ISS-VIEW, it is possible to simulate the Station torque equilibrium attitude also, adding amplitude and frequency periodic perturbations around the nominal local vertical - local horizontal attitude.

These simulations have been performed with a given set of orbital parameters for the

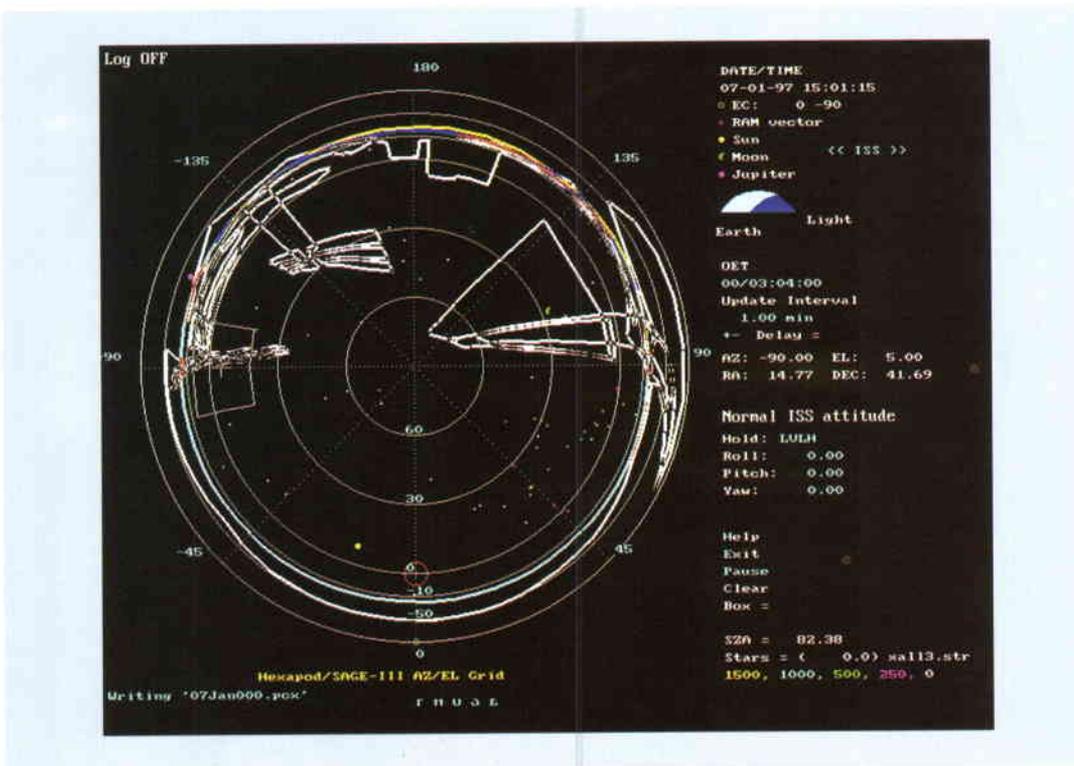


Figure 8. Typical field-of-view for solar/astronomy payloads from the upper Express Pallet

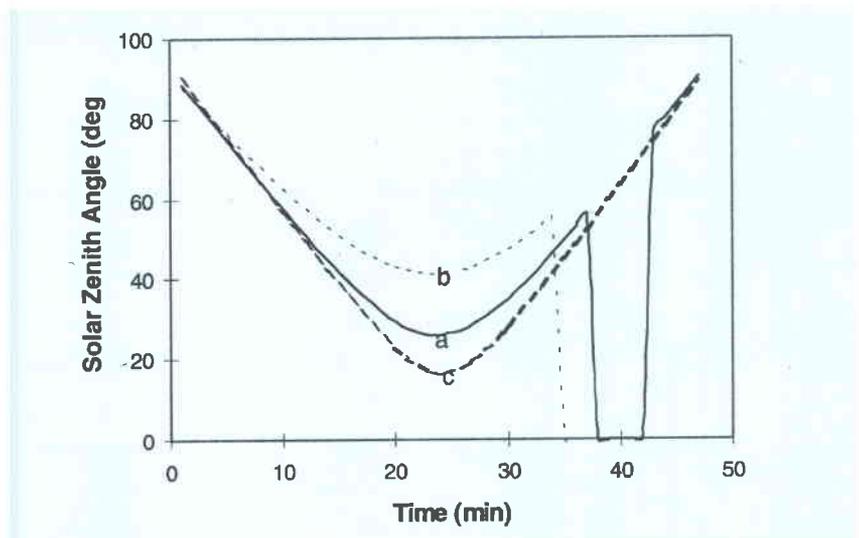
International Space Station. It should be noted, however, that given updated knowledge of detailed orbital parameters, different sets of inputs can be selected for ISS-VIEW runs.

Figures 7a,b show the effect of precession by changing the ascending node of the orbit from 109.6 deg to 169.6 deg.

ISS-VIEW for solar/astronomy payloads

The zenith-oriented Express Pallets on the Space Station will mostly be used by payload instruments that need to view large parts of the sky, such as solar and astronomy instruments. Figure 8 shows an example of the field-of-view capabilities (zenith direction) from the upper Express Pallets. In the top/left part of the hemispherical display, we can identify the mask shapes of the Russian elements, with their solar arrays. The Sun and other celestial bodies are visible from the Express Pallet mounting location when they are above the line of the Space Station mask (which is a sort of local horizon).

Figure 9 gives the visibility of the Sun at three different selected Observation Elapsed Times. The parameter that measures the Sun's visibility is the solar zenith angle, i.e. the angular distance, measured on the geocentric celestial sphere, between the right ascension and the declination coordinates of the station and the Sun. Three solar-zenith-angle curves are plotted in Figure 9. Curves (a) and (b) have been calculated starting at Observation Elapsed Times of 02/04:24.:00 and 10/03:44:00, respectively. They both show the



effect of obscuration by the Russian solar arrays and their supporting structures. Curve (c) has been calculated at an Observation Elapsed Time of 11/02:53:00 with a change in the value of the ascending node angle to simulate the precession.

Figure 9. Visibility of the Sun at three different Observation Elapsed Times

Conclusion

ISS-VIEW is a valuable new tool for supporting mission analysis and planning activities for Earth-observation and solar/astronomy instruments to be operated from the International Space Station. The simulation software includes knowledge and display of Earth latitude and longitude, and hence it can also be used to make visibility predictions for targets located on the Earth's surface. 

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Prodex — The First 10 Years

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Introduction

In June 1986 the ESA Council adopted a resolution for the creation of the optional programme called Prodex (PROgramme de Développement d'EXperiences scientifiques).

The Prodex Programme was created at a time when several ESA Member States were limited in the funding of experiments and instruments for ESA missions desired by universities and other scientific institutions. Furthermore, Prodex has the advantage of being able to expand ESA's sphere of operations since it is also available to non-Member States, thereby attracting the interest and support of other countries, especially those with which ESA has entered into cooperation agreements. The Prodex Programme Office fulfils the role of coordinating experiment development and awarding industrial contracts

The concept for this programme was originated by the well known Swiss scientist Prof. Johannes Geiss, and the Head of the Swiss Delegation to Council, Dr. Peter Creola. The stimulus was based on the fact that within Switzerland, which did not have a national space agency, only very limited funding and no long-term commitment could be secured from the Swiss National Science Foundation for the development of space hardware. It was therefore conceived that an ESA experiment development programme, to which Switzerland could contribute, would have a twofold benefit. Firstly this type of programme would enable Swiss scientists to develop ESA-selected experiments, and secondly it would trigger other funding sources, thereby increasing the opportunities for participation in ESA scientific missions.

Not surprisingly, Switzerland was the first Member State to join the Prodex programme, on 8 October 1986. Subsequently, Ireland joined in August 1987, Belgium in June 1988, Norway in June 1989, Austria in June 1991 and Denmark in June 1994. The programme, open to the participation of non-Member

States, has also been joined by Hungary, whose participation was unanimously approved by ESA Council in March 1996.

Objectives and Conditions

As outlined in the ESA Council Declaration of 1986, the main objectives of the Prodex Programme are:

- To provide funding for the industrial development of scientific instruments or experiments, proposed by Institutes or Universities in the Participating States, that have been selected by ESA for one of its programmes in the various fields of space research (science, microgravity, earth observation, etc).
- These scientific instruments or experiments are defined to be either hardware or software projects, the development of which shall be carried out in collaboration with the industry of the Participating States such as to help to improve relations between scientific and industrial circles.
- The instruments and experiments prepared at national level shall be selected by ESA in accordance with its own rules and procedures, i.e. in strict competition with the instruments and experiments from other Member States. No instrument or experiment not selected by ESA shall be funded under this programme.

To manage this programme, a small team, the 'Prodex Programme Office' staffed by the authors of this article, was established at ESA/ESTEC. Hierarchically, the Head of the Prodex Office reports directly to the Director of Scientific Programmes and, in parallel, interacts directly with the Delegations of the Participating States on all Prodex matters. ESA Council monitors and controls the execution of

Summary of the Prodex Implementing Rules

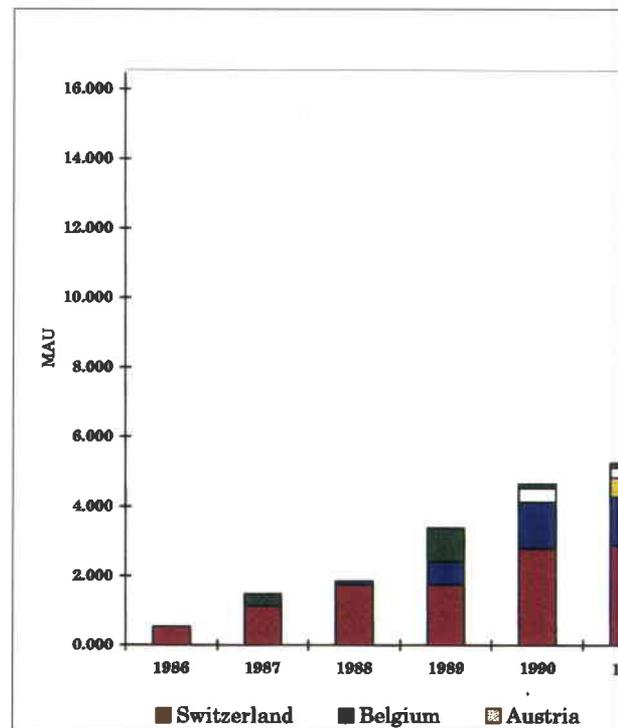
The Agency (ESA) is responsible for the evaluation and selection of the scientific instruments or experiments according to the rules and procedures in force. The Participating States shall inform the Agency of their agreement to finance within Prodex the proposals selected by the Agency. Once an instrument or experiment has been selected and its financing secured, the Agency concludes an arrangement with the institute or university concerned which defines the specific modalities needed to develop the respective instrument or experiment. It will, in particular, fix the total projected cost of the instrument or experiment which shall be spent in principle within the territory of the Participating State and will assure that no less than 50% of these projected costs will be spent through industrial contracts within the territory of the Participating State. The Agency will conclude and manage industrial contracts in cooperation with the respective institutes and universities. Upon request, the Agency will give scientific advice.

The contracts for the development of the selected instruments or experiments are awarded in accordance with the rules and procedures in force, but call for tenders are restricted to the industries of the Participating State that has decided to finance the corresponding instrument or experiment. Each Participating State shall provide the Agency, over a period of five years, with a financial envelope broken down into annual slices. Any surplus on each individual slice shall automatically be carried forward to the following year. Ten percent of each annual slice is reserved for covering the costs of the Agency, i.e. the running of the Prodex office. The updating of the annual slices will take into account the changes in economic conditions. Each Participating State may notify the Agency of increased financial envelopes and annual slices during the course of each year.

The Agency, acting on behalf of the Participating State, shall be the owner of the assets produced under Prodex for a period of 5 years after delivery. During that time, however, and by request of the Participating State, the assets funded by the Participating State will be put at the disposal, free of charge, to the selected institute or university. After a period of 5 years, this institute or university shall become the owner of the said instrument or experiment.

The Prodex Programme is an open programme. ESA Member States can become Participating States subscribing to the declaration and to the present rules in force provided that all other Participating States agree. Non-Member States may apply to take part in Prodex. In such cases the Director General shall submit the application to the Council, whose approval of it must be unanimous and arrived at in agreement with the Participating States, which shall unanimously determine the terms for participation by the acceding State.

The rules may be revised by unanimous decision of the Participating States. Any amendment shall be referred to the Council for approval.



the Prodex Programme and approves the annual budget, which is summarised in Figure 1 and Table 1.

The Implementing Rules, as approved by ESA Council, define the conditions governing the execution of the Prodex Programme and describe the means of interaction between the Participating States and ESA.

Institute Agreements

Following the selection of the instrument or experiment, an 'Institute Agreement' is established. This agreement outlines the responsibilities of the institute concerned, describes the interaction with the Prodex Programme Office, and is used in the preparation and placement of any financial commitments made by the Agency (ESA) to the university or institute.

An 'Institute Agreement' lays down the following rules:

- The Institute defines the objectives and content of the projects to be developed and nominates a person to be responsible for the development of the instrument or experiment.
- The Institute prepares the statement of work and specifications for the industrial contracts. These are agreed by the Agency. For these contracts the Agency's general clauses and conditions shall apply. These contracts are managed by the Prodex office.
- The Institute prepares a financial plan for the

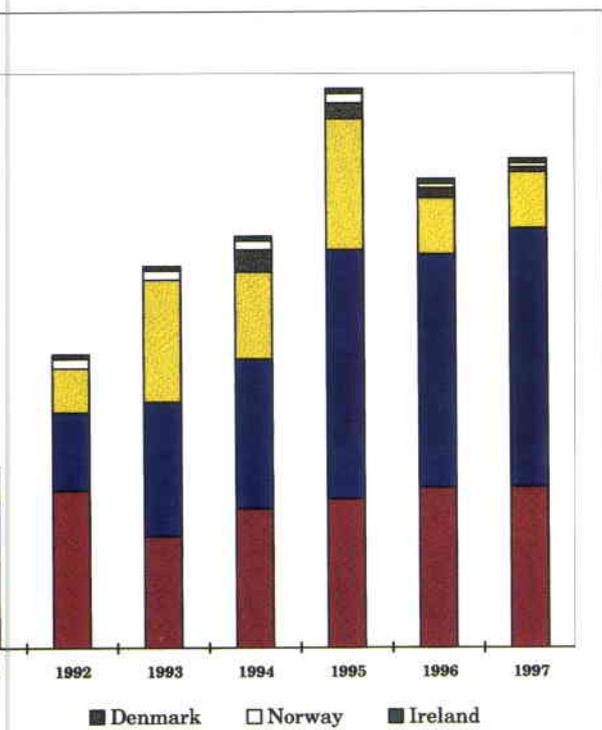


Figure 1. Evolution of the Prodex budget since 1986

Table 1. Contributions to Prodex in MAU (million accounting units) per year / per country

	Switzerland	Ireland	Belgium	Norway	Austria	Denmark
1986	0.53					
1987	1.13	0.35				
1988	1.74		.012			
1989	1.74	0.97	.069			
1990	2.80	0.12	1.33	0.40		
1991	2.87	0.13	1.41	0.29	.055	
1992	4.54	0.13	2.24	0.28	1.26	
1993	3.22	0.14	3.85	0.26	3.51	
1994	4.01	0.13	4.28	0.25	2.52	0.64
1995	4.30	0.14	7.15	0.27	3.76	0.45
1996	4.62	0.13	6.70	0.12	1.61	0.30
1997	4.64	0.14	7.41	0.12	1.62	0.14

implementation of the project to be carried out under its responsibility. This plan shall contain expenditure estimates in the form of planned payments in the following categories: contracts with industry, purchase of equipment, salaries, etc. This financial plan shall be updated every year. Actual expenditure and cost-to-completion is reviewed annually and the financial plan is adjusted accordingly.

- The Institute participates in the evaluation of the industrial proposals, progress meetings and reviews with the contractor. When the goods or services are delivered the Institute will be invited to agree to their acceptance.
- The Institute is responsible for the delivery of its part of the scientific instrument or experiment either to the Principal

Investigator or directly to the Agency for integration in the spacecraft.

Figure 2 is a schematic of the interaction between the institutes, industry and the Prodex Programme Office.

Practical Implementation

Following the selection of an experiment by one of the Agency's Programme Boards (SPC, PB-EO, PB-MG, etc.), the Delegation of the supporting country informs the Prodex Programme Office of its agreement to finance the experiment from its contribution to the Prodex budget. Subsequently, the Programme Office prepares the 'Institute Agreement' and invites those responsible for the experiment to prepare a financial plan which, after approval by the respective Delegation, governs the development of the experiment.

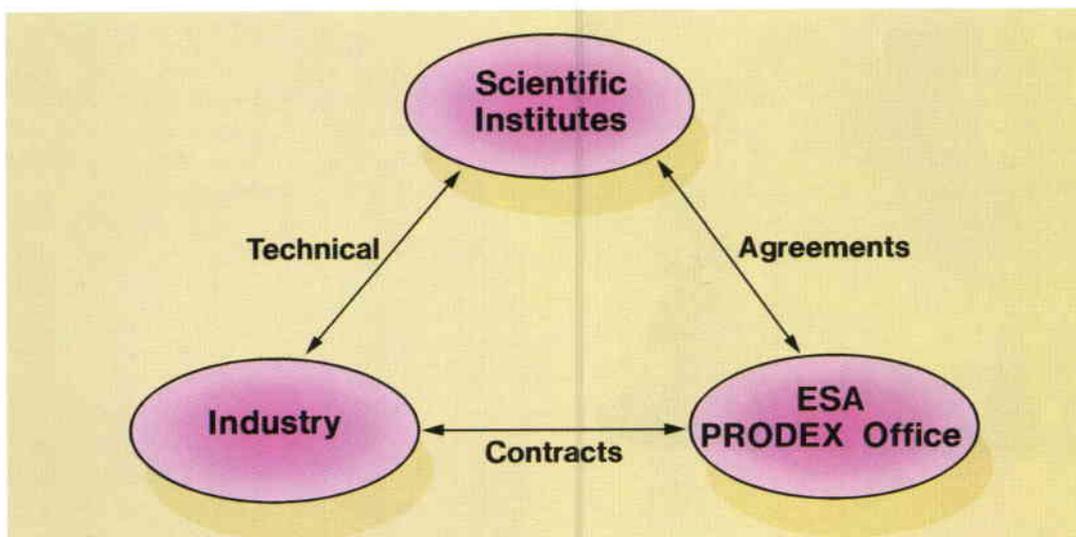


Figure 2. The principal lines of interaction within Prodex

Figure 3. The Extreme Ultraviolet Imaging Telescope (EIT) for the SOHO mission (courtesy of Spacebel and Centre Spatial de Liège)

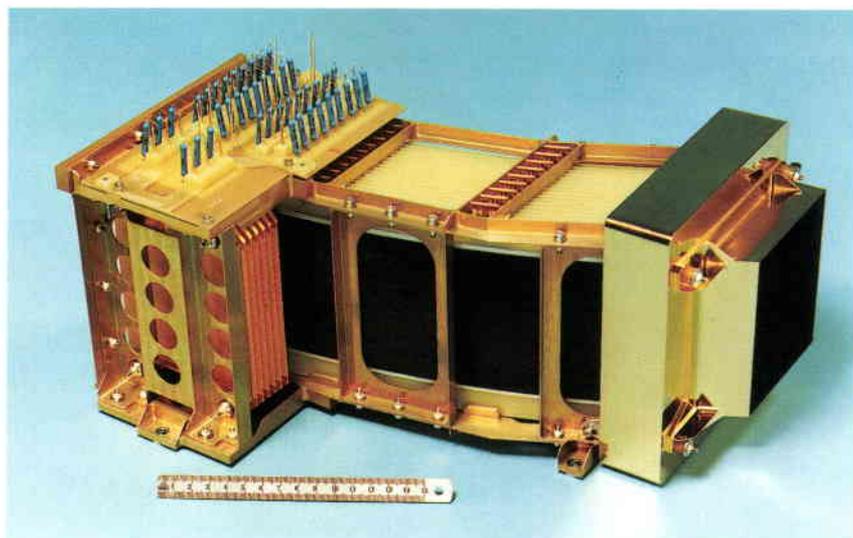
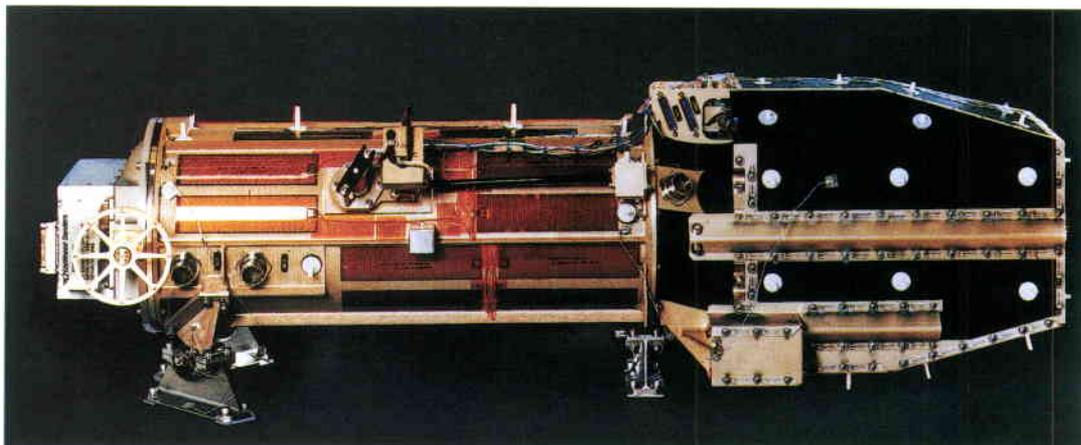


Figure 4. The entrance system of the CELIAS experiment for the SOHO mission (courtesy of Contraves and University of Bern)

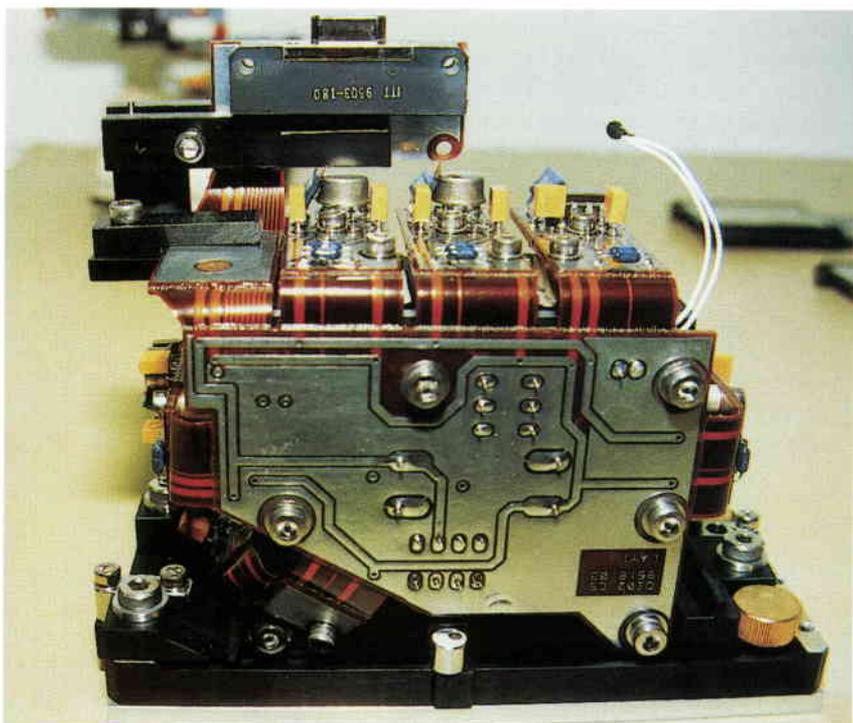


Figure 5. The Polarisation Measurement Device of Envisat's Sciamachy instrument (courtesy of OIP and the Belgian Institute for Space Aeronomy)

Once the statement of work and specifications are prepared by the institute, they are reviewed by ESA-staff, i.e. representatives of the Prodex Office, the contract officer, a representative of the project for which the experiment has been selected and technical experts, as required. The experiment representative participates in this review process.

The industrial procurement process follows normal ESA rules and regulations. Once a contractor is selected, the technical management of the industrial development activities is shared with the experiment representative. Progress meetings and reviews are attended by all interested parties (as per the review process), with the exception of the contract officer who attends only in cases of contractual disputes. Once industrial development is completed, the experiment representative is invited to accept the final hardware product.

The annual budget of the Prodex Programme is established based on the financial envelope provided by the Participating States. This follows the normal ESA budget structure. Care is being taken to ensure that at least 90% of the annual slice of funding is used for external expenditure on experiment development, thereby keeping the internal ESA costs to an absolute minimum. To provide as much flexibility as possible in the Prodex Programme, it has been agreed that any surplus from the annual slice will automatically be carried forward to the following years.

To allow the various institutes to benefit from ESA's standing procurement agreements with suppliers, large pieces of equipment are purchased by ESA and delivered to the institute.

The financial expenditures are controlled by the Prodex Programme Office and presented to the Delegations on a regular basis. During these meetings, the Delegations are also informed of

technical progress made. Each Delegation has full visibility of expenditures made from its contribution to the Prodex budget.

The Delegations of the Participating States also meet on an annual basis to discuss issues of mutual interest, including any necessary updates to the Implementing Rules, new members and so forth.

Achievements

The first experiment financed by the Prodex Programme, a diffusion cell culture chamber for the Space Biology Group of the ETH in Zurich, flew as a mid-deck experiment on the Space Shuttle in 1987. This was soon followed by the contributions that Swiss, Belgian and Irish experimenters provided to the EIT (Fig. 3), CELIAS (Fig. 4), VIRGO, UVCS and COSTEP experiments for the SOHO mission.

Developments in the Prodex Programme are not limited to experiments for missions in the Science Programme, but are also included in Microgravity and Earth Observation Programmes. Examples of experiments for these programmes are:

- The Polarisation Measurement Device (Fig. 5) that is part of the Sciamachy experiment for the Envisat mission.



- A Bioreactor (Fig. 6) which has been flown twice on the Shuttle, and medical equipment to study the astronauts' physiology which has been flown both on the Shuttle and on the MIR station.
- With data obtained from ERS-1 and ERS-2, application software has been developed to

Figure 6. The space Bioreactor flown twice on the Space Shuttle (courtesy of Mécanex, IMT and the ETH Space Biology Group)



Figure 7. ERS-1 image of the Viking Bank in the North Sea acquired on 10 August 1995. It is a section of a low-resolution (100 m) image produced for near real-time delivery to the pollution control authorities. The bright points in the image are oil rigs. The black areas emanating from them are probably waste water or drilling fluid (courtesy of TSS and ESRIN)

Table 1. Institutes and industries currently involved in Prodex activities

Country	Institutes	Industries
Austria	Laser Station, Graz Space Research Inst., Graz	Schrack Aerospace, Vienna Joanneum Research, Graz Austr. Res. Centre, Seibersdorf
Belgium	Vito, Mol IRMB/KMIB, Brussels Micro-g Research Centre ULB, Brussels Medical Faculty ULB, Brussels Physics Dept. VUB, Brussels Royal Observatory, Brussels IASB/BIRA, Brussels CRI/ULB, Brussels Centre Spatial de Liege Inst. d'Astrophys., Liege Lab. Biol. Mol., Liege Lab. Dermatology., Liege Material Science Dept., Leuven Astronomy Dept., Leuven Engineering Dept., Leuven Medical Dept., Leuven IMEC, Leuven Lab. Phys. Nucleaire, Louvain-la-Neuve Lab. Phys. Chimie, Louvain-la-Neuve Lab. Télécom/Det., Louvain-la-Neuve Physics Dept., University of Gent	Verhaert D & D, Antwerp Sparnex, Antwerp Cosurvey, Brussels SAS, Brussels Spacebel, Liège AMOS, Liège OIP, Oudenaarde Union Minière, Olen
Denmark	Danish Met. Institute, Copenhagen	CRI, Birkerød
Ireland	St. Patrick's College, Maynooth Trinity College, Dublin DIAS, Dublin University College, Dublin	Sp.Tech., Maynooth ERA-Maptec, Dublin
Norway	Astronomy Dept, Univ. of Oslo NDRE, Kjeller, Oslo NERSC, Bergen NILU, Tromsø	Spacotech, Tromsø Tromsø Sat. Station
Switzerland	Space Biology Group, ETH, Zurich Astronomy Dept, ETH, Zurich Lab. Solid State Phys., ETH, Zurich Lab. Biomechanics, ETH, Zurich Physics Institute, Bern PMOD/WRC, Davos Univ. Medical Centre, Geneva Geneva Observatory Paul Scherrer Inst., Villingen Neuchâtel Observatory,	Contraves, Zurich HTS, Wallisellen Mécanex, Nyon Kistler, Winterthur Brusag, Stâfa CIR, Gals INTEC, Bern CSEM, Neuchâtel IMT, Neuchâtel AEO, Siebenen de Marco Eng., Geneva SF, Emmen

help us to understand Arctic ice formation, detect oil spills in the open sea (Fig. 7), etc.

The Prodex Programme has become very popular within the Participating States and their scientists are appreciative of the support that the programme provides. Additionally, funding for experiments is not limited to those selected for ESA missions but is also available for missions co-funded by ESA and other missions for which ESA's scientific interest has been recognised by the respective Programme Board or by Council.

Industry has also found the Prodex Programme to be a profitable experience. One of the programme's most helpful achievements has been to facilitate dialogue and cooperation between universities and private industry. The resulting synergy of knowledge helps in optimising the application of new techniques and in building industry's competitiveness, both in space-related and non-space-related activities.

The institutes and industries currently involved in Prodex Programme activities are listed in Table 2.

Due to its flexible, open-minded and pragmatic approach, the Prodex Programme has become an ideal tool for allowing potential future Member States to become more familiar with ESA procedures and practices. This is of particular interest for countries with whom ESA has signed Cooperation Agreements, such as Greece, Poland, Portugal and Rumania. In particular, Hungary has recognised the benefit of this unique opportunity by seeking to become a Participating State member in the Prodex Programme, a request that the ESA Council has unanimously accepted. 

Eureca Re-Flights: Opportunities for Very-Low-Cost and Cost-Efficient Space Missions

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Introduction

Currently, most governments involved in space exploration have significantly reduced funding for unmanned space missions. In order to be able to conduct meaningful space activities despite this shortage of funds, many new 'low-cost' approaches have evolved, including:

- the 'small satellite' approach
- the 'increased on-board autonomy' approach
- the 'reduced mission return' approach
- the 'accept increased risk' approach
- the 'reduced mission duration' approach.

In the world-wide search for the lowest cost (and hopefully most cost effective) approach for undertaking space missions, several strategies have recently been recommended by various parties. This article addresses these approaches in addition to the so-called 'use what you have' alternative which suggests flying science- and technology-oriented space missions using readily available facilities, i.e. the 'Eureca system'. Its technical and cost advantages in comparison to, for example, the 'small satellite' approach are discussed, concentrating on the optimal usage of currently restricted funds for the generation of new in-orbit mission products rather than building further space and ground segment elements

In the overall competition for retaining or obtaining work, low-cost missions are often offered without addressing the overall cost-efficiency. This means that funds are used for new in-orbit or ground facilities or, as is the case of some small satellites, for generating data which has already been measured during earlier missions, rather than developing novel and, as yet unavailable, mission products. Such mission products include:

- data products (e.g. science, Earth observation, astronomy)
- sample products (e.g. material samples, biological samples, crystal samples)
- technology products (e.g. in-orbit performance validation, space qualification, acquisition of experience)
- services (e.g. communications, data relay, provision of refined mission products to end users, bringing sample products or entire space facilities back to Earth).

The success of a mission can be measured by the quantity, quality and timely delivery of its products. Such measurements, if honestly applied, are also suitable for determining the overall cost efficiency of a mission. This would require:

- a judgement of the degree of novelty and/or utility (i.e. value) of mission products
- a systematic definition, before launch, of the mission products in terms of their quantity, quality and time of delivery, together with the required degree of mission exploitation
- relating the entire project life-cycle cost to the anticipated mission products.

Seen from this perspective it is obvious that the greatest cost efficiency for any mission is achieved when we maximise the overall return of useful products and the mission success probability while minimising appropriate life cycle cost. Cost efficiency is thus not dependent on the size of a mission (e.g. small or large satellites). The size of a satellite or mission is mainly a function of the required mission product characteristics and of the associated production capacity as well as a function of available funds to satisfy either the full demand or only a part of it.

Nearly all of the previous traditional European missions were in this sense very cost-efficient since full mission success (98.5% or higher) was achieved even in cases where severe satellite in-orbit anomalies occurred.

Nevertheless, triggered mainly by reduced financial resources and by the higher demands of an increasingly broader product user community, there is a strong requirement for more frequent flight opportunities with shorter lead times to launch, at significantly lower cost than traditional projects. Obviously, cost reduction must be achieved in all areas, such as the satellite procurement process (e.g. implement simplest design, use available elements), the launch cost (e.g. minimise mass) and the ground segment and mission operation

costs (e.g. use of available infrastructure, off-line versus on-line control).

Potential solutions for more frequent, short-notice and low-cost missions are:

- The 'small satellite' approach. Its advantages are short lead times to launch, low overall life-cycle cost per mission, and thus a less dramatic impact in the case of mission loss. This approach, however, limits the overall mission return by imposing severe restrictions on the payload mass and the mission product generation capacity, and often suffers from the 'accept high risk' and 'accept low-cost efficiency' mentality. It also involves demands for funds for the development of new miniaturised units.
- The 'use what you have' approach, which is based on the re-utilisation of available flight-proven space and/or ground infrastructure elements. In addition to a high mission success probability, its advantages are that satellite and ground segment procurement costs are minimised and that short lead times to launch can be achieved for projects with overall payload capacities similar to traditional projects. Disadvantages are that launch costs remain as high as for traditional projects and that financial contributions to the industrial satellite development process

would be somewhat reduced. Overall, this approach would concentrate the utilisation of available funds on the mission product provision process, i.e. to the benefit of the customer community.

With reference to the latter 'use what you have approach', Europe possesses a powerful, high-tech and flight-proven retrievable carrier, Eureca, which was designed for at least five flights, and an existing ground segment infrastructure for its in-orbit operation. So far, the system has been used for one 11-month mission (from 31 July 1992 - 1 July 1993) which was a big success from a mission-product and technology-return point of view. The reuse of the Eureca system for future missions offers significant advantages in terms of technical capabilities, reliability, fast turn-around, low-cost and overall cost-efficiency compared to most of the other low-cost approaches.

The low-cost alternative

Eureca background

Eureca (European Retrievable Carrier) was developed by Deutsche Aerospace (DASA) under ESA contract as a re-usable, multi-disciplinary platform for microgravity, science and technology missions. Its design life was based on at least five flights, each lasting from several months to nearly one year, and an on-

Figure 1. The release of the European Retrievable Carrier (Eureca) from the Space Shuttle on 2 August 1992



ground turn-around time of maximum two years. Eureca is launched and retrieved by the US Space Shuttle. Bringing Eureca back to Earth following its first mission proved to be an invaluable contribution not only to payload and mission product owners, but also to technical areas dealing with in-orbit performance validation and, in particular, with the identification of the causes of in-orbit anomalies. The results of spacecraft in-flight anomaly investigations often point to several potential failure sources which can be sufficient for workaround mission continuation, but only post flight on-ground investigations can unambiguously identify the real causes. Results of this nature from the first Eureca flight have provided important contributions for the improvement of other satellites prior to their launches !

Eureca's flight was controlled from the ESA/ESOC Mission Control Centre in Darmstadt, Germany throughout all phases (i.e. launch and early orbit phase (LEOP), commissioning, payload utilisation, rendezvous and retrieval) using its multi-project ground segment infrastructure. The Eureca-1 payload included sixteen active instruments (six for microgravity research, two for space radiation research, five for space science research, three for technology demonstrations) and a number of entirely passive payloads. Overall, a degree of mission exploitation close

to 100% was achieved throughout the experimental phase.

The control methodology used encompassed mission planning, pre-programming of on-board activities for up to 60 hours ahead in the on-board master schedule, on-board autonomous execution of all activities listed in the master schedule, storage of data products and appropriate housekeeping telemetry in the on-board mass memory, on-board autonomous fault management, dumping of mass memory data content during ground station passes, transmission of dumped data to the OCC and, finally, provision of science data to investigators via a dedicated Data Distribution System (DDS). Eureca and its payload were kept continuously productive although the Mission Control Centre was on-line with the spacecraft for less than 6% of the total in-orbit time. This first mission also provided significant experience in collaborating with NASA's Shuttle Control Center in Houston (JSC) during Eureca's deployment and retrieval.

Eureca system capabilities

The baseline Eureca-2 mission is a 6 to 9 month stay in a 51.6 degree inclination orbit at an altitude of around 500 km. Such a mission provides opportunities for multi-disciplinary science, for in-orbit technology investigations and flight-qualification activities. A first Eureca re-flight could be arranged for as early as the

Table 1. Eureca on-board characteristics

Total spacecraft mass:	~4500 kg
Payload mass:	1000 kg
Payload power:	1000 W average, 1.5 kW peak
Orbit control:	hot gas system, Earth pointing mode
Orbit inclination:	28.5 or 51.6° depending on Shuttle mission
Orbit altitude:	440 to 600 km, altitude and eccentricity adjustable within fuel budget constraints
Attitude control:	hot or cold gas system with Sun and Earth sensors, gyros, accelerometers
Attitude: Sun inertial pointing: (capability for att. offset [roll around Sun vector] by bias TC)	$\pm 1^\circ$ (3 sigma), (actual performance during 1st flight $\pm 0.45^\circ$)
Attitude measurement accuracy:	$\pm 0.25^\circ$ (3 sigma)
Microgravity:	$<10^{-5}$ g for $f < 1$ Hz linear for $1 \text{ Hz} < f < 100 \text{ Hz}$ $<10^{-3}$ g for $f > 100 \text{ Hz}$
ESP dimensions:	70 x 70 cm ²
Orbital operational temperature:	0 to 40°C (active payload cooling/heating capability)
Orbital non-operational temperature:	-10 to 40°C
On-board data storage capacity:	13 Mbytes (11.3 for payload, 1.7 for housekeeping)
Ops. pre-programming in on-board master schedule:	up to 60 h ahead
Packet telemetry:	payload, housekeeping (system and payload), event messages
Packet telecommand:	high/low level commanding as desired
Flight application programmes:	generic infrastructure for subsystems and payload operations control, command expansions and fault detection, isolation and recovery

second half of 1999.

The science possibilities encompass microgravity research with a number of facilities (e.g. AMF, MFA, PCF, ERA) used during the first Eureka flight, or other science payloads (e.g. for Sun or Earth observation, astronomy, particle impact research, space physics, etc.) compatible with the Eureka infrastructure and its orbital environment.

Essential characteristics of the Eureka space and ground segment available for payload support during future missions are listed in Tables 1 and 2. In many respects, this existing infrastructure offers significantly more powerful support functions than can reasonably be expected with a small-satellite approach. Currently, no other approach could facilitate such a powerful support infrastructure with such a short turn-around for flying a multitude

Table 2. Eureka payload operations support characteristics

Reliable procedurised mission control	- timelines, flight control and contingency recovery procedures (for degraded situations adjustable post launch)
Mission planning	- long term 3-6 months ahead - medium term 1 month ahead - short term 3 days ahead, final command schedule ready for uplink - optimal resource utilisation for payload operations - conflict resolution (priorities, time, disturbances) - maintenance of all functions/services required for payload utilisation (orbit, attitude, power, thermal, data storage, communications, life-time management, etc.)
Telecommand schedule uplinking	- operations pre-programmed on-board for up to 60 h ahead (use of up to three 10 min pass windows per day)
Data delivery	- on-board storage of payload and housekeeping data - delivery of real-time and event message data from spacecraft to Operations Control Centre (OCC) - dump of on-board stored data to ground station (use of 3-4 pass windows per day) - delivery of dumped data from station to OCC (post pass) - delivery of payload data together with OCC-generated auxiliary data to Data Distribution System (DDS) < 24 hours after on-board generation
Monitoring/control	- continuous on-board real-time performance surveillance for platform and payload housekeeping - autonomous on-board execution of activities in master schedule - on-board event message generation (for nominal events and anomalies) - on-board fault recognition and recovery (single failure in a platform function is normally recovered without significant effect on payload activities) - real-time performance surveillance on ground (~7 passes per day, each of up to 12 min in duration) - off-line assessment of spacecraft performance for periods outside ground contact - determination of overall mission achievement and systems adjustments/tuning in case of under-performance - anomaly identification, contingency recovery operations, fault management and appropriate mission and procedure adjustments in case of non-recoverable failure effects
Logistics support	- interfacing/reporting with/to customer society (investigators) - preparation and adjustment of flight operations procedures and appropriate telemetry, telecommand and mission planning databases - provision and maintenance of required ground facilities (OCC, stations, communications) - delivery of all sample products and return of entire payload to investigators after mission termination - validation of systems and procedure adjustments by means of simulation prior to actual use - software maintenance (ground segment and on-board software) and updating, if required, throughout the mission

of complex payloads over an extended period. There is also the important advantage with Eureca that all payloads are returned at the end of the mission to their owners for post-flight assessment and/or reuse on later flights. This is a particular advantage for technology validation/demonstration payloads.

Cost aspects

Since the Eureca infrastructure has already been paid for by Member States, the costs for a re-flight would be limited to satellite refurbishment and payload integration activities, the launch and retrieval flight services, the ground segment activation, the operations preparations for new payloads, and mission operation services. The turn-around time between project approval and launch would be approximately 2 years, the anticipated degree of mission exploitation could be as high as 98% and data products could be available to payload owners within less than 24 hours if so required.

The Eureca re-flight approach allows a reduction in the cost of flying complex, ambitious and demanding payloads to around 100 KECU per kg of payload. In other words, financing authorities would be able to provide payload owners with a flight opportunity for e.g. 100 kg of payload for only 10 MECU. This is approximately 20 times cheaper than the traditional approach. This price could be further reduced for subsequent flights, depending on the degree of repair required between flights.

The life-cycle costs for a number of small satellites (launch masses between 200 and 400 kg) currently being pursued in Europe are between 200 and 325 KECU per kg of payload, i.e. more than twice the projected Eureca cost.

However, there remains the fact that one Eureca flight costs approximately 3 times as much as one of the above-mentioned small satellites. Nonetheless, approximately 10 or more such small satellites would have to be flown to achieve the mission-product return of a single Eureca flight. Eureca's significantly superior payload support infrastructure, overall high mission success probability and the value of the post-mission payload return must also be factored in. Clearly, building even a small simple satellite around each payload is not necessarily the most cost-efficient approach. It does, however, ease the task of funding authorities and creates a new industrial marketing field, whereas the 'use what you have' approach concentrates the spending on providing mission products, which is perhaps the primary objective of space undertakings.

Commercial Eureca re-flights

A commercially funded science/technology mission using the Eureca system is presently being pursued by Daimler-Benz Aerospace (DASA Bremen) in an attempt to overcome the current lack of government funding for such a mission.

This commercial approach foresees recovering mission costs mainly by payload flight ticket sales or equivalent arrangements. The flight ticket price is based on a pro-rata sharing of on-board resources – e.g. mass, telemetry, command/control operations, power, orbit/attitude control – between payloads.

Further information about the possibilities offered and projected costs associated with this proposed commercial Eureca re-flight opportunity can be obtained from:

Daimler-Benz Aerospace AG
Space Infrastructure
Attention : Mr Wolfram LORK
P.O. Box 28 61 56
D-28361 Bremen
GERMANY
Tel. (49) 421 539 5870
Fax (49) 421 539 5074
E-mail Eureca@ERNO.DE

Conclusion

An alternative low-cost and cost-efficient approach has been described, together with its technical advantages. Even compared with small satellites, this approach could reduce payload flight costs by a factor of 2 or more. It also meets other requirements such as having a short lead time to launch, a high mission success probability and a post-flight payload return to investigators. It is therefore a serious low-cost alternative for missions in the low-Earth-orbit environment.



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MegSat1 satellite launch: 1999

Second Announcement of ESA/CNES Workshop: **Applications of Pyrotechnics in Spacecraft** ESTEC, Noordwijk, The Netherlands 18 - 19 November 1997

Experience and knowledge are the keys to reliable and safe pyrotechnics in spacecraft. To improve information flow in this critical technology, the third user-oriented Workshop on Applications of Pyrotechnics in Spacecraft is planned for November of this year.

Following specialist presentations, time will be available for questions and discussion to explore the topics more fully. Opportunities for further discussion will be provided by several coffee and lunch breaks. Topics raised during informal discussions will be welcomed for inclusion in the group discussions. The tentative Programme is shown below, but the plan is flexible to allow improvements and additions.

Tuesday 18th November 1997, 09:00-17:30. Topics will include: Properties of Pyrotechnic Compositions, Laser Ignition, Simulation, Valves and Fasteners for Cutting.

Wednesday 19th November 1997, 08:30-16:45. Topics will include: Shock Test and Measurement, Release Nut Development, Aims, R&D, Product Assurance and Standards.

No fees are payable for this ESA/CNES Workshop.

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email: confburo@estec.esa.nl



CENTRE NATIONAL D'ETUDES SPATIALES

Interactive Multimedia Services on Internet

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Introduction

Multimedia

Multimedia technology has already been around for quite some time, but with the accelerated pace of development that it has enjoyed in the last few years it can be now safely said to be a part of our daily lives, both at work and in the home. It finds application in fields ranging from encyclopedias to catalogues, from games to video clips, allowing computers to display to users information in a form that is not only textual, but can include sound, moving pictures, or both.

expansion, which can be attributed mainly to the appearance of the World Wide Web with its "browsers", has spawned a whole new range of communication techniques, all of which are characterised by :

- the ease with which information can be accessed
- the possibility to "navigate" from one document or item to related ones, following so-called "hyperlinks" (predefined connections between related information items)
- the ease with which information can be published.

Multimedia and the Internet

Whilst it is still largely true that the type of data currently prevalent on the Web is text and still images, there is clearly a definite need to be able to use the same infrastructure/data networks to exchange multimedia data, including sound and moving pictures. A non-negligible part of this perceived need finds its origin in the requirements of advertising: many "service providers" are financed (also) by commercials, and it is well-known to the advertisers that moving images have a much stronger impact on the viewer than any other form of communication.

It is already possible today using the Internet to listen to music and to radio news, to view short video sequences, and to talk to remote users by means of special applications that emulate the functions of a normal telephone. Nevertheless, it is also true to say that the use of multimedia information via a network is still restricted to more or less experimental applications. This, together with the trend towards more extensive use of multimedia information, has created an opportunity that developers are pursuing very actively.

Consequently, the technological area that lies at the intersection of Internet and multimedia is today the object of much interest and intense development, financed - sometimes with

The combination of multimedia technology and Internet is currently attracting a considerable amount of attention from developers and potential users alike. However, although many new products are being announced and marketed, the majority of the information on the Web still consists of just images and text, and the few "multimedia" items are in reality only short video clips with little interactive functionality.

Our prototype implementation of an interactive multimedia system, based on the integration of commercial products, provides some original functions for enhanced user interaction, whilst still maintaining complete compatibility with the rapidly evolving context of the Web. It also allows the same "product" to be delivered over connections of different capacity by selectively decreasing the bandwidth dedicated to the video part of the data.

Up to now, the medium of choice for this technology has been the CD-ROM: due to its high capacity it is able - to a certain extent - to meet the needs of digital audio and video, it is stable and reliable and, last but not least, the cost of the device required to read it is low. As a result, the CD-ROM has become the most widely used medium for the delivery of multimedia material.

Internet

In the same few years, another phenomenon has drastically changed the way in which information is distributed, namely the development of digital data networks, and particularly the extraordinary expansion of the Internet, "the network of all networks". This

sizable investments - both by the Information Technology (IT) industries and by those whose focus is entertainment: film, television, and radio production, and music recording companies.

The eventual end result of all of the effort that is being devoted to this field is still somewhat difficult to predict. What can already be observed is the very rapid pace in the development of new products, which are often marketed or distributed via the Internet itself.

Open issues

All of the development effort notwithstanding, a certain number of problems remain that hinder more extensive use of multimedia data on Wide-Area Networks (WANs). The most significant of these is certainly constituted by the severe bandwidth limitations of the networks: while recent technologies, such as ATM, allow bandwidths of hundreds of megabytes on any length of link, the majority of Internet users are still connected via a dial-up telephone line and a modem capable of operating at 28.8 kbit/s at most. It is also not unusual for other bottlenecks to occur between the user and the service provider, especially at times of heavy traffic, which slow down the overall speed of the link even further. Another closely related problem is the low predictability and high variability of the overall data rate that can be achieved at any particular time on a given link.

The result is that the Internet user wanting to access video material will need the patience to wait for a long time before the whole file is downloaded, and will then be rewarded with the disappointing experience of a video lasting a few seconds and displaying a picture barely larger than a postage stamp.

In addition, the possibility for interaction with the video clip will generally be limited to start/stop commands, such as can be found on a domestic video recorder

Development goals

ESRIN is responsible for all of ESA's non-operational data-processing activities, including the distribution to external users of the Earth-observation data collected by the Agency's various remote-sensing satellites. In line with the overwhelming general trend, the Web is the medium of choice for the distribution of most of this data. To date the vast majority of the data consist of text and images, but the requirement to support multimedia applications will certainly grow as user expectations increase and the available technology allows it.

Requirements

To gain first-hand experience of the requirements in terms of infrastructure and the potential of multimedia technology, it was decided to carry out a small study and prototype development effort focussing on multimedia data distribution over local and geographical networks. The contract to perform the study was awarded to Cap Gemini (I), following the Agency's usual competitive call-for-tender procedure.

The requirements that were defined for the prototype system implementation include:

- access to multimedia material through local and Wide-Area Networks
- good quality video, as users are accustomed to the high resolution of today's displays and are likely to be turned away by low quality
- "streaming" (i.e. display of the video as it is received), to avoid delays between the user command and the start of the video experienced when the file has to be completely downloaded first
- good interactivity, which is considered a key factor for the professional (as opposed to entertainment) use of multimedia data, and is in any case essential if the audio/video material lasts more than a few minutes.

A more general overall requirement for the implementation was to maintain openness to the integration of new products, avoiding ad hoc and proprietary solutions.

Prototype system

Approach

In the first phase of the activity, a fairly detailed state-of-the-art analysis was performed, supported by some early breadboard implementations, to define the best technical approach for the project. Given the requirements fixed by ESRIN, this had to comply with the general guidelines to:

- identify and exploit the most promising technologies and products on the market
- develop only those components required for the implementation of the functions not yet supported by the off-the-shelf products.

Given the rapid evolution in this general area of technology, it was decided to follow a "rapid application development" approach that would allow the system's design to exploit emerging products, and this contributed greatly to the eventual successful outcome of the overall activity.

The application chosen for the demonstration of the system's capabilities was a general presentation of ESA activities, based on

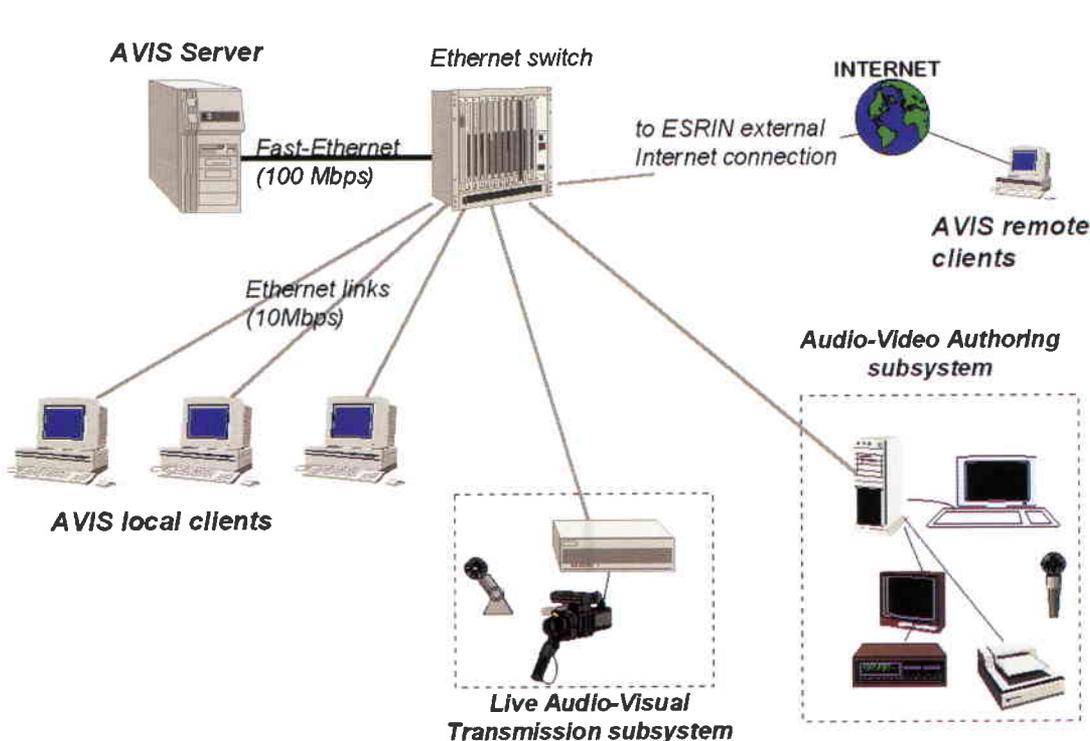


Figure 1. General architecture

existing public-relations material for various missions. The material was chosen on the grounds of its ready availability, and also because the information contained in it is sufficiently interrelated to allow meaningful navigation, thereby demonstrating the interactive capabilities of the underlying system.

Technical solution

The prototype system is completely integrated with the WWW technology, and the client application is indeed a normal Web browser to which specific "plug-ins" (functional modules that interface in a predefined way with the core software) have been added. This approach, which required a change to the initial direction of the work, was chosen after an analysis of the state-of-the-art in order to take advantage of the Web phenomenon (then in its infancy), and to guarantee easier future integration with other ESRIN Web-based applications used for the various data-distribution services.

Two classes of service are foreseen, which reflect the two situations of a user connected to the server via the public Internet (typically via a 28.8 kbit/s dial-up connection), or via Intranet (normally a Local Area Network, or LAN). In the first case, the use of video material is precluded by the bandwidth limitations of the connection. Consequently, the system only provides high-quality audio, which can be integrated and synchronised with text, still images, and animations. In the second case, the system also supports high-quality video, whilst the ability to integrate and synchronise it with other types of material remains unchanged.

The architecture of the prototype consists of a server acting both as a Web and multimedia server, connected with the local client workstations via a switched Ethernet LAN, and accessible from remote stations via the public Internet.

It is also possible to include a live television broadcast in the multimedia material accessible on the server. While this option is not one of the deliverables of the project, it has been successfully demonstrated via the integration of a real-time MPEG video compression card. The authoring of the application (graphics, animations, audio and video editing) is performed on a PC-based station, equipped with an MPEG video compression card (not real time, to allow better quality at affordable cost), and commercial authoring software (Adobe Premiere for the video, and Macromedia Director for the animations).

MPEG was chosen as the format for the video data as part of the general policy to favour public standards over proprietary ones in the hope of maintaining openness towards new developments. The term "hope" is used because, in a domain as active and as broad as Internet, one cannot exclude the possibility of a proprietary standard becoming the "de facto" choice at some stage. MPEG 1 was chosen in preference to MPEG 2 because of the latter's greater bandwidth requirement and the definitively higher cost of the hardware and software required for authoring and displaying MPEG 2 files.

The MPEG 1 compression allows the visualisation of full-motion (30 frame/s) video with quarter-screen format and very good resolution. A full-screen display is usually still fairly good, but is more sensitive to the quality of both the source material and the compression process. In the prototype system as implemented, it is foreseen to equip the client workstations with a hardware decoding card, which allows the quality to be maintained even with less powerful PCs. In the near future, the need for a dedicated decompression card will disappear, as the newer generations of processors will provide good software decompression.

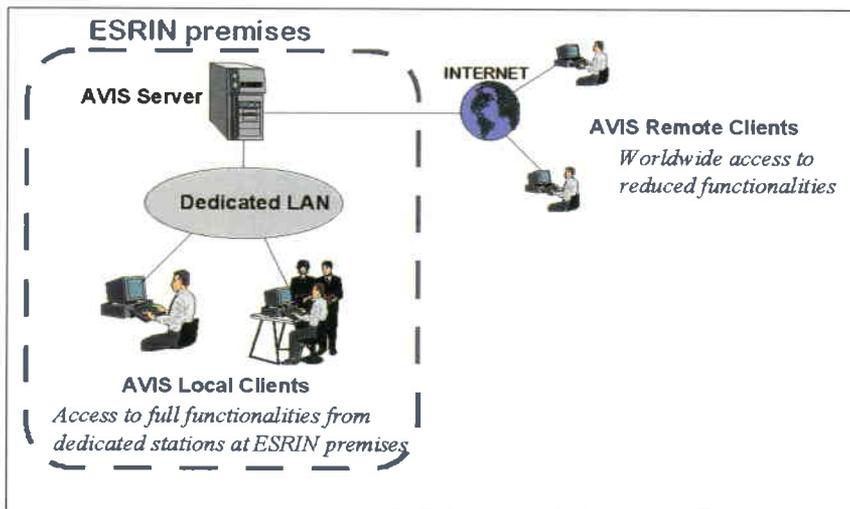


Figure 2. Multimedia-capable Web client

The commercial product chosen for the audio streaming function is RealAudio by Progressive Networks. Two complementary approaches have been followed for the distribution of video data:

- the use of a commercial product Streamworks by Xing Technologies, which has the desired capability of adapting the same video material to the transmission through channels of different bandwidth; this is achieved by reducing, in an intelligent and configurable way, the quality of the video that is actually transmitted (e.g. by reducing the frame rate) and at the same time maintaining the quality of the audio
- the use of standard protocols for access on the LAN (UDP, NFS) to the video stream by a specific component developed as part of the project in the form of a plug-in for the browser; this plug-in handles both the display of the data and the interaction with the user.

User interaction

The functionality supporting the interaction with the user is very high compared with that for the customary Web applications. In addition to the usual browsing and navigation functions, it is possible to:

- synchronise the display of new HTML pages with the audio stream, by using a skip-to function to go to predefined positions in a video sequence using controls of the type found on a normal video recorder
- display, at the user's request, information relating to the content at any specific moment of a video sequence; this further information may itself contain pointers to other items of information
- skip from a predetermined position in a video sequence to other points or sequences
- select the language of choice for the subtitles during the display of a video stream.

The plug-in developed to carry out these functions is based on Java and Javascript for the management of the on-screen controls and the interactivity with the user, and on the MCI standard interface (Multimedia Common Interface) for the integration of the multimedia drivers.

One interesting feature of the system, which is a direct result of the design choices that were made, is the ability to provide the same navigation paths for both classes of service foreseen. In the case of access via a low-bandwidth channel, the video material is simply replaced with a selection of stills extracted from the video itself, which remains synchronised with the original audio stream in unaltered quality.

Conclusion

In addition to providing an interesting technical solution to the problem of the development of interactive applications for the distribution of multimedia data over the existing telecommunications network infrastructure, the prototype system's capabilities suggest some very interesting potential applications for this multimedia technology integrated with Internet, such as teaching, self-paced training, entertainment, etc.

As the system has been designed from the outset based on the most widely used standards and using commercial components, it is "open" to the integration of future new technologies and products. One possible further development could be integration with the emerging services for data distribution via satellite (e.g. Direct PC™). These systems promise to overcome the bandwidth limitations of the current Internet by exploiting the technology and infrastructure that is being put in place to support direct satellite broadcasting of digital television.

Use of the ECU in Major ESA Procurements

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What is the ECU ?

The ECU is a basket of currencies weighted approximately according to the European Union's (EU) Member States' relative share of the European Community's Gross National Product (GNP) and in intra-community trade.

In October 1995, the ESA Council determined that as of 1 January 1997, ESA should implement an 'All ECU System' with the financial contributions from Member States, the Agency's budget and the contracts placed with industry all to be in European Currency Units (ECU). It was, however, decided to facilitate a smooth changeover by means of a transition period lasting from 1997 to 2000, during which existing contractual commitments in National Currencies (NC) will be phased out.

In 1978, the Heads of State of the European Community decided to introduce a European Monetary System (EMS) with the ECU as its central element. The objective was to establish stability between the currencies of the EU's Member States and, ultimately, to facilitate the introduction of a single European currency, named the EURO, in 1995. The ECU is a precursor of the EURO.

The Maastricht Treaty determined that there would need to be a liberalisation of capital movements in the EU, a coordination of financial policies of Member States and an adherence to certain economic convergence criteria relating to a maximum permitted percentage of public debt, price stability, exchange rate stability and interest rate levels. Subject to meeting these criteria, all EU Member States would enter into European Monetary Union (EMU), with the possible exception of Denmark and the UK who negotiated an opt-out agreement should they choose not to join.

The introduction of a common currency is seen by many as an essential complement to the EU single market.

The European Commission's proposals regarding the changeover to the EURO are

contained in its Green Paper 'Practical Arrangements for the Introduction of the Single Currency' which also details the advantages of a single currency, which include cost-savings in currency transactions. The EC estimates that the annual transaction costs relating to currency exchanges within the EU are around 25 billion ECU, or 0.4% of the EU's GNP. It cites the example that if one were to be given 1000 units of any EU Member State's currency and then proceed to visit every Member State, changing the currency at each border but not making any purchases, then one would be left with only 500 units at the end.

The present programme for EMU's introduction is stated in the Green Paper and can be summarised as follows :

- at the beginning of 1998, the European Council will decide which Member States meet the convergence criteria and thus qualify for participation in the single currency
- at the beginning of 1999, conversion rates for the NC of participating EMU States to the EURO will be permanently fixed. The EURO will be the single currency, but the NC can still be used until 2002
- by 30 June 2002, all bank notes denominated in the former NCs will be replaced by EURO bank notes.

'All ECU system'

In anticipation of the ESA Council decision which had been under discussion for some time, ESA has progressively been placing contracts in ECU, rather than in the NC of each contractor.

Although ESA has acquired substantial experience in placing contracts and sub-contracts in various currencies, the systematic and general use of the ECU constitutes a new challenge which requires the adaptation of a number of specific aspects of the ESA procurement procedure and the way contract prices are established and negotiated with industry.

It must be emphasised that in contrast to ESA's purely internal 'Accounting Unit' (AU), the ECU is a basket of currencies which is tradable and convertible, and which has a recognised value in financial markets. Contracts can consequently be formally and legally concluded in ECU, whereas this was not possible in Accounting Units.

The ECU as a foreign currency

Using the ECU in industrial contracts is, however, not without its difficulties. One such complication is encountered by ESA contractors who generally incur cost in NC and, consequently, must deal with the ECU as a foreign currency. For pricing purposes the estimated cost in NC must be converted to the ECU in order to submit proposals. Once a contract is negotiated and placed, there is a subsequent time when the ECUs received by the contractor have to be converted into one or more NCs unless the receipts in ECU can be applied to settle some other commitment in ECU of the contractor concerned.



Figure1. Bank notes of the national currencies of ESA Member States

The procedure used for the conversion from NC to ECU and then from ECU back to NC has been a major topic for discussion and negotiation between ESA and its contractors, since the conversion can result in losses or in windfall gains, especially during times of financial turbulence. The aim of ESA in conceiving and developing conversion procedures is to minimise their impact. The most desirable result is that both the negative and positive effects are neutralised for all parties, without an excessive increase in administrative effort. In addition, the nature and extent of financial risk must be defined, the

party which will assume it determined and the cost conditions ascertained.

The nature of ESA's business

The nature of ESA and its activities is such that there is an inherent and inevitable complexity in its operations which is not applicable to most other organisations. In the context of the introduction of the ECU, the following factors have to be considered:

- ESA has fourteen Member States, some of which have traditionally more stable and stronger currencies than others.
- Not all ESA Member States are members of the European Monetary System (EMS).
- ESA's programmes are of a research and development nature, and in consequence:
 - the achievement of payment milestones may be delayed as a result of performance delays
 - a wide range of price types are applied including Firm Fixed Prices (FFP), Fixed Prices with Variation (FPV) and various cost-reimbursement, often with cost-sharing, arrangements.
- ESA's contractors range in size from large international companies that can support sophisticated treasury operations, to small companies who lack such specialist expertise.
- ESA's budget has been under great pressure, and therefore it is particularly important to avoid significant price increases and to cover for exchange rate risks.

Establishing contract prices in ECU

ESA's preference is to place FFP contracts in ECU if satisfactory prices can be agreed, particularly for smaller contracts of relatively short duration. For such smaller contracts experience has shown that there is no great difficulty in negotiating FFPs. In some cases, FFPs have also been agreed for major programmes.

With all price types, including fixed prices, ESA has full transparency of the detailed estimated cost including the number of hours per labour category, the rates and overheads applied, details of non-labour costs, and the ECU conversion rate applied. The conversion rate and/or any possible provisions in the quoted price relating to exchange rate risks are then subject to assessment and negotiation in the same way as other elements of the price.

Traditionally, there has been a mixture of FPV, FFP and cost reimbursement with cost sharing arrangements for larger programmes of relatively long duration and high values. In a number of such contracts placed in ECU, ESA

originally introduced currency adjustment mechanisms with respect to the exchange rates between NC and the ECU at various stages of the contract cycle. However, whilst by this means valuable experience was gained in dealing with large ECU contracts, and significant currency losses or gains were avoided, it was considered that this approach was not consistent with the long-term objectives of placing all contracts in ECU.

In line with ESA Council policy and with the development of a new overall approach for ESA major procurements, it was therefore decided to request total binding commitments in ECUs

countries with currencies having a tendency to strengthen against the ECU, the situation has become somewhat more complicated.

ESA has investigated this matter in some depth over the years in the context of a working group with industry coordinated through Eurospace, an ESA Council working group, discussions with experts from the European Commission, discussions with banks and other financial institutions, and bi-lateral discussions with contractors.

From the latter, it is evident that large international companies with treasury sections,



Figure 2. Proposed EURO coins

without such adjustment mechanisms in order to avoid constant uncertainty about the final prices of contracts.

Since it is based on a basket of currencies, the ECU is relatively stable and there is also a damping effect on changes in the exchange rate between the currencies included in the basket and the ECU itself. Furthermore, the fact that many of the currencies included in this basket are also participating in the CMS has an additional stabilising effect.

However, certain of the currencies which are in the ECU basket but outside the EMS have shown significant fluctuations against the ECU. Over the last year some traditionally weak currencies have considerably strengthened against the stronger currencies, reversing the general trend at least temporarily. Thus, whilst a few years ago the concept of fixed prices in ECU could be much more easily accepted by companies from countries with a currency having a tendency to depreciate vis à vis the ECU and less easily accepted by companies in

which have had experience in dealing in foreign currencies, are often able to make satisfactory financial arrangements to protect against currency losses — at least for contracts of relatively short duration. However, this protection is more difficult and expensive to achieve for contracts of longer duration. It has also been noted that in a few cases, international companies find the ECU to be a convenient basis for financial accounting at the corporate level. It is also clear that the overall problem of dealing in ECUs will reduce as its use becomes more widespread, not least because in some cases companies will have financial commitments in ECU which can be met by receipts in ECU, thus avoiding the need for additional ECU/NC conversions.

Placing contracts in ECU has also raised certain specific issues for ESA some of which, though substantial progress has been made, are not yet fully resolved. These issues include:

- the price comparisons of competitive offers in ECU
- the use of appropriate price-variation

- formulae and indices
- the use of the ECU in cost reimbursement contracts
- the procedure for making payments in ECU.

Price comparisons

Price comparisons of competitive offers in ECU present no formal or practical problem. Clearly, in principle, industry from countries with a comparatively depreciated currency can present more attractive ECU prices. However, this is simply one element of the overall competition and, in the case of FFPs, not without risk since such a currency can regain comparative value while the contractor remains committed to its total price in ECU. The system is, however, still easier to manage than the previous one based on AU exchange rates.

Price variation formulae and indices

With reference to the more difficult problem of finding appropriate variation formulae and reference indices for price-variation formulae, ESA has initiated an activity with EUROSTAT* to express indices in ECU.

As mentioned previously, ESA uses FFPs for most long-running major programmes. This means fixing the price at a defined economic baseline, subject to variation by the application of a price variation formula. Such formulae contain a fixed element not subject to change, a labour element and a material/non-labour element, the coefficients of each reflecting the estimated cost details making up the price.

Historically, ESA's budgets have been updated by applying the appropriate Wiesbaden statistics (as issued by the Wiesbaden Institute). Contract prices, including the target cost for cost-reimbursement with cost-sharing prices, have been updated by applying the appropriate national indices (as issued by various national statistical offices).

However, it is not logical to apply these national indices for prices expressed in ECU because they have a distorting effect. For example, if a country is experiencing a high rate of inflation it can be expected that this will be reflected in both the labour and non-labour indices. It can also be expected that over a period of time the high rate of inflation will have an impact on the exchange rate by weakening the currency. Thus, by applying the national indices as they stand, a company will benefit from a corresponding increase in the price in ECU and then benefit again when converting the ECU into a weakened NC. For companies in countries with low inflation, the reverse situation applies.

The solution would have been to use indices expressed in ECU, but the only official indices of this type in existence were those of consumer prices in Member States issued by EUROSTAT.

ESA therefore initiated discussions with EUROSTAT to investigate the possibility of preparing the indices in ECU. This was achieved without much difficulty. The main tasks involved were some software development, administrative support to obtain the base indices from the national statistical offices, and a final publication of the data.

Applying this method in updating ESA's budget is a relatively simple exercise. The data (comprising about 80 indices) is available electronically and the calculations are required only twice per year (in January for the sketch budget and in June for the budget exercise proper).

For contracts placed with industry, the exercise is much more time consuming. There are more than 200 separate indices which have to be obtained from the different statistical offices

Figure 3. The agreed symbol for the EURO



and the calculations have to be made and published each month.

The 1997 ESA budget has been produced using the indices in ECU produced by EUROSTAT. The first publication of the contract indices was in February 1997 and they are now freely available through EMITS**. These indices, in ECU, can now be substituted for the national indices in price-variation formulae which will then be applied to the Milestone Payment Plan or to the Development Cost Plan (DCP). It is expected that these indices will be applied in all new contracts incorporating FFPs, this being considered to be a fair and logical approachfully consistent with ESA's established practices.

* EUROSTAT is the statistical service of the European Commission based in Luxembourg

** EMITS = ESA's 'Electronic Mail Invitation to Tender System'

Cost reimbursement contracts

It is inevitable that costs will be incurred and monitored in NC. Thus whilst the limit of liability and the target cost will be expressed in ECU, the main points of issue are the means by which the recorded cost in NC is converted to ECU for the purpose of payment, and the method for updating the target cost for the purpose of comparison of total incurred cost against the updated target cost.

The intention with respect to payments is that the contractor will report costs incurred in NC on a monthly or quarterly basis, according to the contract requirements. These costs will be converted to ECU using a predetermined, provisional exchange rate specified in the contract. Payment will be claimed on this basis. Once the final costs in NC have been established (following an audit by ESA), the definitive amount to be reimbursed in ECU will be calculated by applying the monthly average spot rates for the ECU. The amounts derived will be compared to the amounts paid on a provisional basis and any necessary adjustments made.

The target cost in ECU will be updated in the same way as previously — by the addition of the agreed prices for 'class A' changes and by the application of a price variation formula, now incorporating indices in ECU, to the DCP.

Payments in ECU

ESA has given considerable attention to the general problem of delayed payments, especially for SMEs* and lower-level contractors. ESA has traditionally made direct payments to lower level contractors to avoid both exchange rate losses and to speed up the payment process. Given the hierarchy of contractors often found on major programmes, ESA's ETIS** system has made a major contribution in giving visibility on payment claims at all levels of the contractual hierarchy and accelerating payments.

The removal of possible exchange rate losses to the Prime Contractor as a result of the introduction of the ECU facilitates a delegation to the Prime Contractor to make all payments to his consortium. However, to ensure timely payment, this would require prior agreement of the members of the industrial team on an appropriate internal payment procedure.

Conclusion

Notwithstanding the fact that it has as many as fourteen Member States, each with its own currency, ESA had found the means to be able to place contracts and subcontracts in each participant's NC, thus avoiding the risk of



Figure 4. Some proposed EURO bank notes of different denominations

companies losing or gaining significant amounts due to currency fluctuations and without having to accept provisions in contractor prices to cover the risk of currency fluctuations.

Nevertheless, the fact of there being so many different currencies introduced additional complexity in major contracts, often involving the currencies of all Member States, and there was often the need for retroactive adjustments of Member States' contributions as a result of currency fluctuations.

Therefore, both as a European organisation and as a major procurement Agency, it was appropriate for ESA to move towards placing its contracts in ECU as other European Institutions are also doing.

Experience gained over the years in placing a number of contracts in ECU has provided valuable experience and highlighted the issues to be addressed. The presently proposed approach for different price types is considered to be both reasonable and practical.

Thus, when the time comes to make the transition from the ECU to the EURO, ESA should be well prepared and the overall process of placing contracts in EUROS will be more straightforward.

 Cesa

* SMEs = Small and Medium-sized Enterprises

** ETIS = ESA's 'Tele-Invoicing System'

ESA Around the World

— Relations with Developing Countries and Emerging Space Powers

K. Bergquist & V. Hood

International Relations, ESA, Paris

Introduction

Why does ESA have relations with developing countries? What can a research and development agency, in the forefront of technology, have to offer countries where the overriding daily need is enough to eat? Where should ESA intervene with its limited resources? When should ESA stand aside?

This is the first article in a series of four* intended to acquaint the reader with the range of activities undertaken by ESA International Relations. Faced with unique political environments which call for diverse methods in the handling of events and encounters, International Relations has the invariable and ultimate aim of promoting ESA's image abroad.

Why, what, when and where are all valid questions which face International Relations in determining its yearly Plan of Action for approval by ESA's Member States. Given the limited means available both in manpower and resources, priorities have to be established. Once these are established, the means to act have to be found either within the existing budget or by joining forces with other national or international institutions to achieve the desired goals.

Why does ESA have relations with Developing Countries?

In 1975, while ESA was in its infancy, relations with developing countries were still limited. An agreement was entered into with Brazil for the use of their ground station in Natal to track ESA's new Ariane launcher, at the time still in the development stage. A bilateral agreement already existed between ESA and the Indian Space Research Organisation (ISRO) for mutual cooperation. Additional bilateral agreements were made with Indonesia and Iran.

In 1978 Meteosat was launched. Since its coverage zone included Africa and the Near-East, a small budget of 200 kAU was allocated to enable ESA to promote the use of Meteosat

in countries outside its Member States. A portable ground station was purchased to enable ESA to demonstrate the effectiveness of its newest satellite. In cooperation with the World Meteorological Organisation (WMO), training courses were held, especially in Africa, to help new users take advantage of Meteosat data as an additional tool to assist development. ASECNA, a regional organisation for safety of air traffic navigation, regrouping Francophone countries in West Africa and the Malagasy Republic, were quick to see the advantages of Meteosat data for their task.

AGRHYMET, another regional organisation in West Africa centred on the Niger, recognised the advantages of using Meteosat data for agricultural applications. The United Nations joined ESA and WMO in the organisation of further training courses and several meteorologists from Africa were taken for on-the-job training in ESOC to enable a hands-on experience in the use of satellite data. By the time Meteosat passed from ESA to EUMETSAT, there were some fifty ground stations using Meteosat data in Africa.

In the meantime, ESA was preparing its remote sensing satellite programme ERS, the French were building SPOT, CEOS (the Committee for Earth Observation Satellites) was established as a result of a Canadian initiative, and a decision was taken to inform the developing world of the advent of a new generation of remote-sensing satellites to join the American Landsat series. The Economic Commission for Africa created the African Remote Sensing Centre, which is perhaps better known by its French acronym CAT (Conseil Africain de Télédétection). ESA was granted observer status by CAT and received more requests than could be handled to provide training courses. A solution was found through the provision of regional training courses given alternately in English and in French at the Regional Centre for Services in Surveying, Mapping and Remote Sensing (RCSSMRS) in Nairobi, and the

* 'ESA Around the World'

1. ESA's Relations with Developing Countries and Emerging Space Powers
2. ESA's Relations with the Space Powers in the Developed World
3. ESA and Europe
4. International Relations in Perspective

Regional Remote Sensing Centre (CRTO) in Ouagadougou. CNES and ESA combined forces in this training venture using experts in the various domains from ESA's Member States.

In South America, SELPER, an organisation of remote-sensing experts, was created as a Brazilian initiative. SELPER expressed interest in the advent of SPOT and ERS and requested training courses in advance of satellite deployment. ESA organised the first regional training course on ERS in Buenos Aires in 1987, and in 1988 CNES and ESA joined forces to provide a regional training course in Mazatlan, Mexico covering SPOT (launched in 1986) and ERS (launched in 1991). These training courses were a success and thereafter regular regional courses were organised on an annual basis by CNES and ESA, joined by DLR after the deployment of ERS.

Through the initial use of Calls for Experiment proposals for ERS and the provision of data on a case by case basis, ESA encouraged hands-on use of ERS satellite data, thus increasing the community of users. As the local expertise increased, trainees were accepted for specific advanced courses in Europe, e.g. at the University of Milan for interferometry and the University of Sheffield for data analysis.

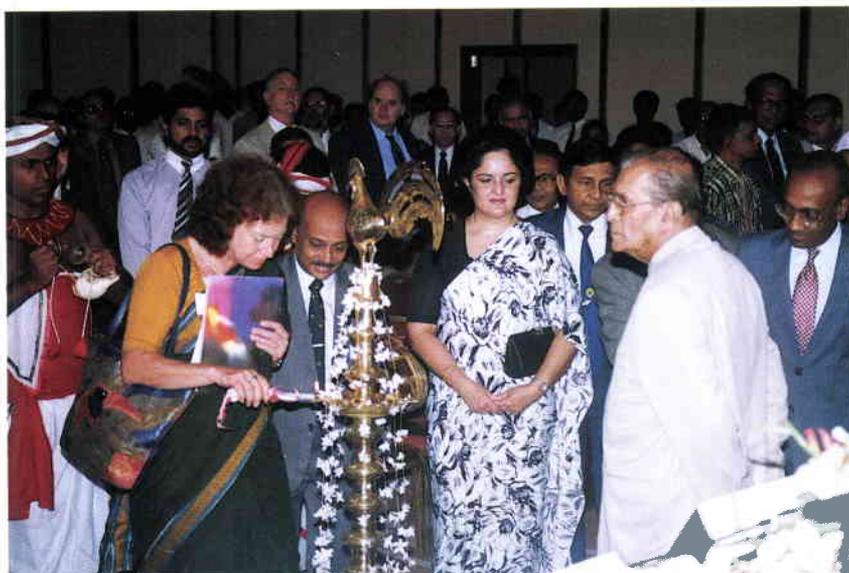
Attracted by the potential of ERS for data acquisition in traditionally cloud-covered areas, four ASEAN countries — the Philippines, Malaysia, Thailand and Indonesia — requested assistance from the European Commission (EC) to promote the use of ERS radar data in South-East Asia. In the EC/ESA/ASEAN project, the EC provided the seed money to upgrade the Thai ground station and provide a meteorological ground station for Malaysia; ESA gave the data free of charge; and the EC and ESA combined to support training courses and assistance from European experts. The project ended in 1996. Building on its success, a second project is in the pipeline, this time involving all the ASEAN countries.

Turning now to telecommunications, after OTS was launched in 1978 ESA became increasingly involved in definition studies for regional telecommunications satellites, especially in Africa. African telecommunications engineers visited ESTEC in The Netherlands for on-the-job training on a case by case basis, sponsored either by ESA or by the International Telecommunications Union (ITU). In 1982 the United Nations held a conference devoted to space applications of Developing Countries — UNISPACE'82. ESA Member States offered five fellowships per year, through the United

Nations, to be used for on-the-job training at ESA establishments: one in meteorology, one in remote sensing and three in telecommunications-related subjects.

Increased contact with the United Nations Office for Outer Space Affairs (OOSA) led to ESA and the UN combining their efforts in holding regional courses on space applications both regionally and in ESRIN. To these was added a regional course on basic space science, which has now been run successfully for six years.

The answer to the question "Why does ESA have relations with Developing Countries?" is now evident. It has been, and continues to be, to promote the use of ESA's satellites worldwide where this use can be an effective tool in helping people in Developing Countries advance their own resources.



What can a research and development agency, in the forefront of technology, have to offer countries where the overriding daily need is enough to eat?

Information on natural resources is sadly lacking in many of the poorer Developing Countries. Satellites can provide an inexpensive means of locating natural resources, allowing the country in question to exploit them. The European Commission (DG VIII) came to ESA for technical assistance in providing satellite data to researchers in the Sahel for the "Freedom from Hunger Campaign". The Commission allocated funds for the operation of ESA's Maspalomas station to acquire Landsat and later SPOT data for researchers in the Sahel. The United Nations Food and Agriculture Organisation (FAO) have successfully used Meteosat data to detect and destroy sites of locust breeding in Africa, thereby saving crops.

Inauguration ceremony for a new telescope at the Arthur C. Clarke Centre in Sri Lanka, January 1996



Mr K.-E. Reuter, Head of ESA's Cabinet, and Mrs Wang Xiuting, Director General of Foreign Affairs, CNSA, preparing for the visit of ESA's Director General to China, May 1996

Many of the globe's natural hazard areas tend to be in Developing Countries. Satellites can play a useful role in disaster management, e.g. determining flooded areas, ascertaining the extent of earthquake damage using remote-sensing satellites and, via communications satellites, permitting swift establishment of emergency communication, an essential factor in disaster relief.

Where should ESA intervene with its limited resources and when should it stand aside?

ESA's Council, at its 1992 Ministerial Level meeting in Granada, urged ESA's Director General to look for further ways and means to make data available for use by Developing Countries. As a result, ESA's International Relations Committee set up an ad hoc Working Group on Developing Countries. This group produced a report entitled 'A World Wide Approach: ESA Linking to Developing Countries'. One of its recommendations was

that a Coordination Group on Developing Countries should be established within ESA to bring forward recommendations which would fulfil this requirement. The group was formed with the furtherance of ESA Council Resolution ESA/C/CXVI Res.1 Final, adopted on 22 February 1995.

This coordination group is currently studying the possibilities for ESA to further develop relations with Developing Countries in the short, medium and long term. It is also seeking the answer to "When should ESA stand aside?" The group is contacting aid agencies belonging to its Member States as well as other international organisations to investigate what is already being done and where, in order to avoid duplication of effort, and to apply ESA's resources to the best advantage.

ESA's relations with emerging space powers

Brazil, China, India and, to a lesser extent, Argentina qualify as emerging space powers in their own right. Here, ESA takes a different approach, one geared towards technical assistance, exchange of personnel and, faced with diminishing resources available for space activities in the foreseeable future, attempts to define areas where resources could be combined.

This leads to discussions on future plans, possibilities of joint satellite projects, using satellite data from various sources to mount a pilot project for disaster mitigation and possibilities of an interactive regional series of systems for global navigation. Possibilities for European industry are also actively explored, not only with the emerging space powers, but also in expanding economic areas of the world. With this factor uppermost in its mind, International Relations has already organised two 'Euro-Latin American Space Days' conferences in Latin America, one in Brazil and one in Argentina. This year the third will be held in Mexico. In June 1998, a similar conference will be organised in Singapore entitled 'Euro-Asian Cooperation in Space'.



Participants in the International Seminar on the Use and Applications of ERS in Latin America; Viña Del Mar, Chile, November 1996



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

In Orbit / En orbite

PROJECT	1995		1996		1997		1998		1999		2000		2001		COMMENTS										
	J	F	M	A	M	J	J	A	S	O	N	D	J	F		M	A	M	J	J	A	S	O	N	D
SCIENCE PROGRAMME	IUE	[Green bar from Jan 1995 to Sep 1996]																							TERMINATED SEPT. 1996
	SPACE TELESCOPE	[Green bar from Jan 1995 to Dec 1999]																							LAUNCHED APRIL 1990
	ULYSSES	[Green bar from Jan 1995 to Dec 1999]																							LAUNCHED OCTOBER 1990
	ISO	[Green bar from Jan 1995 to Dec 1999]																							LAUNCHED NOVEMBER 1995
	SOHO	[Green bar from Jan 1995 to Dec 1999]																							LAUNCHED DECEMBER 1995
APPLICATIONS PROGRAMME	MARECS - A	[Green bar from Jan 1995 to Aug 1996]																							RE ORBITED AUGUST 1996
	MARECS - B2	[Green bar from Jan 1995 to Dec 1999]																							LEASED TO NUOVA TELESPIAZIO
	METEOSAT-4 (MOP-1)	[Green bar from Jan 1995 to Dec 1999]																							LIFETIME 5 YEARS
	METEOSAT-5 (MOP-2)	[Green bar from Jan 1995 to Dec 1999]																							LAUNCHED MARCH 1991
	METEOSAT-6 (MOP-3)	[Green bar from Jan 1995 to Dec 1999]																							LIFETIME 5 YEARS
	ERS - 1	[Green bar from Jan 1995 to Dec 1999]																							HIBERNATION SINCE JUNE '96
	ERS - 2	[Green bar from Jan 1995 to Dec 1999]																							LAUNCHED APRIL 1995
	ECS - 1	[Green bar from Jan 1995 to Dec 1999]																							RE-ORBITED DECEMBER 1996
	ECS - 4	[Green bar from Jan 1995 to Dec 1999]																							LAUNCHED SEPT 1987
	ECS - 5	[Green bar from Jan 1995 to Dec 1999]																							LAUNCHED JULY 1988

Under Development / En cours de réalisation

PROJECT	1995		1996		1997		1998		1999		2000		2001		COMMENTS										
	J	F	M	A	M	J	J	A	S	O	N	D	J	F		M	A	M	J	J	A	S	O	N	D
SCIENTIFIC PROGRAMME	CLUSTER II	[Green bar from Jan 1995 to Dec 1999]																							RELAUNCH MID-2000
	HUYGENS	[Green bar from Jan 1995 to Dec 1999]																							LAUNCH OCTOBER 1997
	XMM	[Green bar from Jan 1995 to Dec 1999]																							LAUNCH AUGUST 1999
	INTEGRAL	[Green bar from Jan 1995 to Dec 1999]																							LAUNCH APRIL 2001
COMM. PROG.	ROSETTA	[Green bar from Jan 1995 to Dec 1999]																							LAUNCH JAN. 2003
	DATA RELAY SATELLITE (DRS)	[Green bar from Jan 1995 to Dec 1999]																							PROGRAMME UNDER REVIEW
EARTH OBSERV. PROGRAMME	ARTEMIS	[Green bar from Jan 1995 to Dec 1999]																							LAUNCH EARLY 2000
	EARTH OBS. PREPAR. PROG. (EOPP)	[Green bar from Jan 1995 to Dec 1999]																							
	ENVISAT / POLAR PLATFORM	[Green bar from Jan 1995 to Dec 1999]																							LAUNCH MID-1999
	METEOSAT TRANSITION PROG.	[Green bar from Jan 1995 to Dec 1999]																							LAUNCH AUG./SEPT 1997
MANNED SPACE & MICROGRAVITY PROGRAMME	MSG-1	[Green bar from Jan 1995 to Dec 1999]																							LAUNCH OCTOBER 2000
	COLUMBUS (COF)	[Green bar from Jan 1995 to Dec 1999]																							LAUNCH MID-2002
	ATV	[Green bar from Jan 1995 to Dec 1999]																							LAUNCH MARCH 2002
	ERA	[Green bar from Jan 1995 to Dec 1999]																							LAUNCH JULY 2000
	DMS (R)	[Green bar from Jan 1995 to Dec 1999]																							LAUNCH DEC. 1998
	ARD	[Green bar from Jan 1995 to Dec 1999]																							LAUNCH MARCH 1998
	FREEZER	[Green bar from Jan 1995 to Dec 1999]																							
	GLOVE BOX	[Green bar from Jan 1995 to Dec 1999]																							
	HEXAPOD	[Green bar from Jan 1995 to Dec 1999]																							
	EMIR 1 & 2	[Green bar from Jan 1995 to Dec 1999]																							
	MFC	[Green bar from Jan 1995 to Dec 1999]																							
	EUROMIR-E	[Green bar from Jan 1995 to Dec 1999]																							
	LAUNCH PROG.	ARIANE-5 DEVELOP.	[Green bar from Jan 1995 to Dec 1999]																						
ARIANE-5 EVOLUTION		[Green bar from Jan 1995 to Dec 1999]																							FIRST LAUNCH EARLY 2003

- DEFINITION PHASE
- MAIN DEVELOPMENT PHASE
- OPERATIONS
- ▲ LAUNCH/READY FOR LAUNCH
- ADDITIONAL LIFE POSSIBLE
- ▼ RETRIEVAL
- ▤ STORAGE

Ulysse

A l'issue de plus de six ans et six mois d'une exploitation scientifique hautement satisfaisante, le fonctionnement d'Ulysse demeure excellent. Premier véhicule spatial à avoir survolé le pôle nord du Soleil, en 1994, puis son pôle sud, en 1995, Ulysse est maintenant bien engagé dans la deuxième phase de sa mission d'exploration. Le but ultime de cette nouvelle phase de la mission, dénommée 'mission d'étude du maximum d'activité solaire' est l'étude des régions polaires du Soleil à une période d'intense activité de l'astre. Ses temps forts correspondront à un nouveau survol de chacun des pôles, en 2000 et 2001.

Au début du mois de septembre 1997, Ulysse sera situé à 5 degrés nord au dessus de l'équateur solaire, à une distance de l'astre équivalant à 5 UA. La phase actuelle de l'orbite d'Ulysse, alors que la sonde approche de son aphélie, est caractérisée par une modification relativement lente de sa latitude et de sa distance radiale. De ce point d'observation quasi-stationnaire aux basses latitudes, Ulysse est bien placé pour surveiller les caractéristiques transitoires du vent solaire tels que les éjections de masse coronale (CME) qui se sont échappées du Soleil et ont dépassé l'orbite terrestre. Un certain nombre de CME sont étudiées en collaboration avec d'autres sondes (par exemple SOHO et Wind), y compris la CME qui est arrivée au niveau de la Terre à la mi-janvier 1997, dont on a beaucoup parlé, et qui a peut-être été à l'origine des dommages causés à un satellite de télécommunications.

L'équipe scientifique d'Ulysse, qui continue d'être très productive, peut s'enorgueillir à ce jour de plus de 600 publications. Outre le grand nombre d'articles parus sous signature individuelle dans la littérature spécialisée, Ulysse a fait l'objet de 8 publications coordonnées. La dernière est un vaste recueil des publications décrivant les résultats obtenus pendant le voyage de pôle à pôle et le survol du pôle nord, qui ont fait l'objet d'un numéro spécial de la revue 'Astronomy and Astrophysics' en décembre 1996.

Il a été recommandé de retenir les neuf propositions reçues en réponse à l'avis d'offre de participation (AO) au 'Programme Ulysse réservé aux chercheurs invités' et les chercheurs



invités ont été officiellement accueillis au sein de l'équipe scientifique d'Ulysse lors de la dernière réunion du groupe de travail scientifique qui s'est tenue à l'ESTEC en avril.

ISO

L'exploitation de l'Observatoire spatial dans l'infrarouge, ISO, continue de donner toute satisfaction. Le satellite, ses instruments et son secteur sol fonctionnent à la perfection. Certains résultats scientifiques d'ISO retiennent fort l'attention des spécialistes. ISO a en effet détecté de l'eau dans nombre des objets sur lesquels il a pointé ses instruments et notamment dans les planètes géantes de notre système solaire, autour des étoiles nouvelles, dans le linceul des étoiles à l'agonie, et à proximité du centre de notre galaxie.

La capacité d'ISO à observer au pied levé des phénomènes astronomiques inattendus a été récemment démontrée de façon flagrante. Début avril, le satellite italo-néerlandais BeppoSAX a détecté une intense bouffée de rayons gamma. Ces énigmatiques 'sursauts gammas', ne durant que quelques dizaines de secondes, constituent actuellement un mystère impénétrable pour les astronomes qui ne sont pas d'accord sur leur origine. C'est pourquoi il est important pour eux de pouvoir procéder à des observations aussi vite que possible une fois qu'un tel

Ulysses

phénomène a été signalé. Moins de 40 heures après que l'alerte a été donné, la caméra et le photomètre d'ISO entreprenaient une inspection détaillée de la zone entourant le lieu supposé de l'émission.

Une deuxième manoeuvre de maintien à poste (correction d'orbite) a été menée à bien le 14 mai à 0h30 TU. Le système de commande par réaction à hydrazine a été 'mis à feu' pendant 3 minutes et 12 secondes, ce qui a modifié la vitesse du satellite de 0,7 m/s et a remonté son apogée de quelque 20 km. On a ainsi mis fin à la dérive du satellite en direction de l'est et induit une légère dérive vers l'ouest. Une troisième manoeuvre (qui sera probablement la dernière) est prévue pour le 11 décembre 1997.

Pendant cette manoeuvre, on a pour la deuxième fois mesuré directement la quantité d'hélium liquide restant à bord d'ISO, qui revêt un intérêt critique étant donné que c'est ce qui détermine la durée de vie d'ISO en orbite. Pour procéder à cette mesure, on a injecté une quantité précise de chaleur dans le liquide au moyen d'un corps chauffant et on a mesuré l'augmentation de température en résultant. Les mesures de mai 1997 indiquent qu'il reste 116 kg d'hélium liquide à bord d'ISO. En rapportant ce résultat à celui de septembre 1996, on peut estimer qu'ISO aura épuisé ses réserves d'hélium liquide le 10 avril 1998 (à 2,5 semaines près). Ces 10 mois de vie supplémentaires par rapport aux 18 mois que prévoyaient les spécifications sont infiniment précieux au plan scientifique, non seulement parce qu'ils augmentent le nombre des observations possibles mais également parce qu'ils permettront à ISO de consacrer du temps à l'inspection de la région du Taureau/Orion, l'une des pouponnières d'étoiles où se produisent les phénomènes les plus violents de notre Galaxie.

Cluster II

Suite à la décision d'approuver la mission Cluster II, prise le 3 avril par le Comité du programme scientifique (SPC), le contrat

Ulysses

Ulysses, with more than six and a half years of highly successful scientific operations behind it, continues to perform extremely well. Following the first-ever passes over the Sun's northern and southern polar regions in 1994 and 1995, Ulysses is now well into the second phase of its exploratory mission. The ultimate goal of the new mission phase, referred to as the 'Ulysses Solar Maximum Mission', is the study of the Sun's polar regions under conditions of high solar activity, culminating in a second set of polar passes in 2000 and 2001.

By early September of this year, Ulysses will have reached a position 5 degrees north of the solar equator at a distance of 5 AU from the Sun. The current phase of the Ulysses orbit, as the spacecraft approaches aphelion, is characterised by relatively slow changes in latitude and radial distance. From this quasi-stationary, low-latitude vantage point, Ulysses is well-placed to monitor transient solar-wind features such as Coronal Mass Ejections (CMEs) that have moved out from the Sun, past the orbit of Earth. A number of CME events are being studied in collaboration with other spacecraft (e.g. SOHO and Wind), including the well-publicised CME that passed the Earth in mid-January 1997, possibly causing damage to a telecommunications satellite.

The Ulysses science team continues to be prolific, with more than 600 publications to date. In addition to many individual papers in the literature, there have been eight coordinated publications. The latest is a comprehensive collection of papers describing the results obtained during the pole-to-pole transit and northern polar passage that appeared as a special issue of *Astronomy and Astrophysics* in December 1996.

All nine proposals that were received in response to the ESA Announcement of Opportunity (AO) for the Ulysses Guest Investigator Programme were recommended for selection, and the Guest Investigators formally joined the Ulysses science team at the last Science Working Team meeting, held at ESTEC in April.

The Cluster fleet
La flottille Cluster

ISO

Happily, all continues to go very well with the in-orbit operations of ESA's Infrared Space Observatory (ISO) satellite. The spacecraft, the instruments and the ground segment all continue to perform excellently. Some of ISO's scientific results receiving very detailed attention are its detections of water in many different targets, such as in the giant planets in our solar system, around newly-forming stars, in the envelopes of dying stars, and around the centre of our galaxy.

In early April, the capability of ISO to respond fast to unexpected astronomical events was graphically demonstrated. The Italian-Dutch satellite, BeppoSAX, reported detecting an intense burst of gamma rays - these enigmatic 'Gamma Ray Bursts', lasting only a few tens of seconds, are currently one of astronomy's greatest puzzles as there is no consensus as to what they are. Thus observations as soon as possible after the initial detection are critical. Within 40 hours of notification, ISO was making detailed observations with its camera and photometer of the area around the suspected position.

The second station-keeping (or orbit-correction) manoeuvre was successfully conducted on 14 May at 00.30 UT. A 'burn', lasting 3 minutes and 12 seconds, was made using the hydrazine reaction control system. This altered the satellite's velocity by 0.7 m/s and increased the

apogee height by some 20 km. The result is that the eastward drift of the satellite has been stopped and a small westward drift induced. The third (and probably last) manoeuvre is being planned for 11 December 1997.

During this manoeuvre, a second direct measurement was made of the quantity of liquid helium coolant remaining on-board ISO. This is of critical interest as it determines ISO's in-orbit lifetime. The measurement was made by using heaters to inject a precisely-known quantity of heat into the liquid and by measuring the temperature increase. This May measurement gave a remaining mass of 116 kg. Combining the results of the May 1997 and September 1996 measurements yields a best estimate of 10 April 1998 (± 2.5 weeks) for the exhaustion of ISO's liquid helium. This additional lifetime, some 10 months above the required 18, is of great scientific value, not only because of the increase in the number of observations to be made, but specifically because it permits ISO to spend time examining the Taurus/Orion region of the sky, one of the most exciting and violent regions of star birth in our Galaxy.

Cluster II

Following the Science Programme Committee's (SPC) decision on 3 April to approve the Cluster II mission, the prime contract with Dornier Satellitensysteme (D) has been successfully kicked-off. Procurement of long-lead items has been initiated and detailed discussion with all subcontractors has started.

The Cluster II mission consists of four identical spacecraft, which will be launched at approximately the same time: the Phoenix spacecraft, built from spares from the original Cluster programme, and three new satellites. At the time of the Cluster II decision, integration of the Phoenix spacecraft had just been completed and it had successfully passed all functional and electromagnetic (EMC) tests. The Phoenix programme was then halted and its environmental test phase will now be held nearer the launch date.

The payload for the original Cluster mission was funded directly by the



de maîtrise d'oeuvre attribué à Dornier Satellitensysteme (D) a démarré. L'approvisionnement des éléments à long délai de livraison a commencé et des discussions détaillées ont été engagées avec la totalité des sous-traitants.

La mission Cluster II consiste en 4 véhicules spatiaux identiques qui seront lancés à peu près au même moment : il s'agit de la sonde Phénix, construite à partir des pièces de rechange du programme Cluster initial, et de trois nouvelles sondes. Au moment où la décision de réaliser Cluster II a été prise, l'intégration de Phénix venait de prendre fin et la sonde avait été soumise avec succès à tous les essais fonctionnels et électromagnétiques (EMC). Le déroulement du programme Phénix a ensuite été stoppé de manière à ce que la phase des essais d'ambiance se tienne à une date plus rapprochée du lancement.

La charge utile de la mission Cluster initiale avait été financée directement par les Etats membres. Cependant, étant donné que les budgets nationaux sont déjà entièrement engagés à court terme, le SPC a demandé à l'Agence de financer partiellement les instruments scientifiques européens de Cluster II.

En liaison avec la proposition de lancement des sondes Cluster II par Soyouz, des études au niveau système sont conduites avec l'aide du Consortium Starsem. La base de référence actuelle consiste à faire appel à l'étage supérieur Fregat dont le vol inaugural aura lieu en 1999. Les quatre véhicules spatiaux Cluster seraient lancés deux par deux à la mi-2000, les deux lancements se tenant à environ un mois d'intervalle.

Le système sol (ESOC, JSOC et CSDS) a été mis en attente mais des effectifs en nombre réduit ont été maintenus afin d'assurer une certaine continuité et également d'étudier les nouveaux scénarios de lancement. L'augmentation des ressources qui sera nécessaire lorsque le lancement approchera est en cours de définition afin d'en limiter le plus possible les coûts.

The XMM satellite

Le satellite XMM

XMM

L'intégration du modèle structural et thermique du véhicule spatial progresse de façon satisfaisante. Tous les éléments nécessaires ont été livrés à Dornier (D). L'ensemble plan focal, entièrement assemblé, a été intégré à l'élément supérieur du tube du télescope. Ce 'module supérieur' complet est prêt à être soumis aux premiers essais d'alignement et d'étanchéité à la lumière.

L'intégration des conduites du système de pilotage par réaction (RCS), chez BPD (I), est terminée et le sous-ensemble complet est arrivé chez Dornier qui doit poursuivre son intégration avec le reste des éléments du module de servitude. La livraison des modèles d'identification au niveau équipements se poursuit.

Les essais de recette du sous-système de commande d'attitude et de correction d'orbite (AOCS) sont en cours chez Matra Marconi Space (GB). L'intégration du modèle électrique du satellite se poursuit en parallèle chez Dornier.

Les performances des deux premiers modules de vol des miroirs testés chez CSL (B) sont très bonnes et confirment les résultats escomptés. La campagne d'essai du premier module est maintenant terminée. Le deuxième module a été livré à l'Institut Max Planck (D) pour la

campagne d'étalonnage du réseau et du détecteur de vol de l'expérience RGS, campagne qui se déroulera dans l'installation Panter.

Les travaux de développement du secteur sol progressent conformément au plan établi et la réunion finale de la Commission de revue de définition/conception du secteur sol, qui s'est tenue en juin, a donné des résultats satisfaisants.

La redéfinition de l'orbite d'XMM est définitivement terminée : l'orbite retenue est inclinée de 40° vers le sud.

Le contrat de lancement d'XMM a été officiellement signé le 16 juin.

Intégral

Alenia, maître d'oeuvre du véhicule spatial, a travaillé à la préparation de la revue de conception détaillée devant faire suite aux revues de niveau inférieur qui se sont tenues chez chacun des sous-traitants. Le dossier a été livré et la revue devrait s'achever début juin. Les premières livraisons de logiciel et d'équipements de soutien sol électriques nécessaires à un stade précoce du programme pour aider les équipes travaillant sur la charge utile sont terminées.

Au cours de la période de référence, les équipes Charge utile ont respecté les



Member States. However, as near-term budgets had already been fully committed, the SPC requested the Agency to partially fund the European scientific instruments for Cluster II.

System studies relating to the proposed Soyuz launch for Cluster II are being conducted with the help of the Starsem Consortium. The present baseline is to use the Fregat upper stage, which will have its maiden flight in 1999. The four Cluster spacecraft would be launched in mid-2000 in two pairs on separate launches approximately one month apart.

The ground system (ESOC, JSOC and CSDS) has been put on hold with reduced manpower, in order to maintain some continuity and also to study the new launch scenarios. The build-up of resources needed nearer to the launch is currently being defined with a view to minimising costs.

XMM

The integration of the spacecraft's structural and thermal model is progressing well. All of the necessary elements have been delivered to Dornier (D). The focal-plane assembly is fully assembled and mated with the upper element of the telescope tube. This complete 'upper module' is now ready to undergo the first alignment and light-tightness tests.

Integration of the Reaction Control System (RCS) pipework at BPD (I) has been completed and the complete subassembly has arrived at Dornier for further integration with the remaining elements of the service module. Deliveries of engineering models at equipment level are continuing.

Acceptance testing of the Attitude and Orbit Control (AOCS) subsystem is in progress at Matra Marconi Space (UK). Integration of the electrical model of the spacecraft is proceeding in parallel at Dornier.

The measured performance of the first two flight mirror modules tested at CSL (B) is very good and confirms the high expectations. The test campaign for the first module is now complete. The second module has been delivered for the RGS experiment flight detector and grating calibration campaign at the Max Planck Institute's Panter facility (D).

The ground-segment development work has progressed according to plan and the final Ground Segment Definition/Design Review Board meeting was successfully completed in June.

The redefinition of XMM's orbit has been finalised, with the adoption of a southerly orbit with an inclination of 40°.

The XMM launch contract was formally signed on 16 June.

Integral

The spacecraft prime contractor Alenia (I) has been busy preparing for the Detailed Design Review, following lower-level reviews at each subcontractor. The Data Package has been delivered and the review is expected to be completed by early June. The first deliveries of electrical ground-support equipment and software needed early in the programme to support the payload teams have been completed.

The payload teams met key milestones during the reporting period. The contractor for the spectrometer anti-coincidence system has been selected and is expected to meet the required delivery dates. The contract with the Imager prime contractor has been clarified and full development-phase support should now be available, but the payload schedule nevertheless remains tight.

A first round of preliminary studies regarding the launch of Integral on the Proton vehicle has been completed and the results are promising. The technical interfaces between the spacecraft and the launcher have been clarified and the feasibility of a shorter coast phase has been demonstrated.

Definition of the ground segment is progressing. The allocation of specific NASA or European ground stations is still under review, and so the project is proceeding on the basis of generic ground-station performance.

Rosetta

The design phase (Phase-B) started on 3 March with Dornier Satellitensysteme (D)

as prime contractor, after agreement had been reached on the contractual aspects of Phase-B and the main development phase (Phase-C/D).

The Invitations to Tender (ITTs) for the first two major procurements at system level were released in May, according to plan (i.e. major subcontractor avionics and platform).

The Experiment Conceptual Design Reviews have been conducted for all instruments, with no major technical problems being identified.

Definition of the ground requirements has started and is progressing according to plan.

Artemis

Satellite

The Artemis structural model is currently in testing at CASA (E) to verify that the micro-vibration environment of the spacecraft is compatible with the requirements of the Silex optical communications terminal.

Integrated system testing and tests to demonstrate electromagnetic compatibility and robustness to electrostatic discharges have been successfully carried out on the engineering-model spacecraft. Activities using this development model have now been completed.

The flight-model primary structure, fully equipped with the propulsion subsystem, has been delivered by BPD (I) to Alenia Aerospazio in Rome for satellite-level integration activities. The main elements of the S-band/Ka-band data-relay repeater have also been delivered to Alenia by Bosch Telecom (D) and Alcatel Espace (F).

Silex LEO terminal

The Silex LEO terminal has been integrated on Spot-4 for satellite-level testing.

Ground segment

The Design Review for the Artemis operational ground segment has been completed and full development is now underway.

étapes clefs. Le contractant du système anti-coïncidence du spectromètre a été retenu et devrait respecter les dates de livraison requises. Le contrat de maîtrise d'oeuvre de l'imageur a été clarifié et tout le soutien voulu devrait maintenant être disponible pour la phase de développement mais le calendrier de réalisation de la charge utile reste très juste.

En ce qui concerne le lancement d'Intégral par Proton, les résultats de la première série d'études préliminaires, qui vient de prendre fin, sont prometteurs. Les questions liées aux interfaces techniques entre véhicule spatial et lanceur ont été clarifiées et la faisabilité d'une phase de vol balistique plus courte a été démontrée.

La définition du secteur sol progresse. Mais l'affectation de stations sol NASA ou européennes spécifiques est encore à l'examen de sorte que le projet avance sur la base de caractéristiques techniques génériques.

Rosetta

La phase de conception (phase B) a commencé le 3 mars sous la maîtrise d'oeuvre de Dornier Satellitensysteme (D), un accord étant intervenu en ce qui concerne les aspects contractuels de la phase B et de la phase de développement principale (phase C/D).

Les appels d'offres (ITT) des deux premiers grands approvisionnements au niveau système (contrats de sous-traitance relatifs à l'avionique et à la plate-forme) ont été publiés en mai, conformément au plan établi.

Les revues de définition conceptuelle des expériences conduites pour tous les instruments n'ont pas fait apparaître de gros problèmes techniques.

La définition des impératifs du secteur sol a commencé et se déroule conformément au calendrier.

Artemis

Satellite

Le modèle structurel d'Artemis subit actuellement des essais chez CASA (E) où l'on vérifie que les microvibrations sont

compatibles avec les exigences du terminal de télécommunications optiques Silex.

Le modèle d'identification du satellite a subi avec succès les essais du système intégré ainsi que les essais de démonstration de la compatibilité électromagnétique et de la résistance aux décharges électrostatiques. Les activités impliquant ce modèle de développement sont maintenant achevées.

La structure principale du modèle de vol, entièrement équipée de son sous-système de propulsion, a été livrée par BPD (I) à Alenia Aerospazio à Rome qui est responsable des activités d'intégration au niveau du satellite. Les principaux éléments du répéteur du relais de données en bandes S-Ka ont également été remis à Alenia par Bosch Telecom (D) et Alcatel Espace (F).

Terminal Silex LEO

Le terminal Silex LEO a été intégré au satellite Spot-4 pour les essais au niveau du satellite.

Secteur sol

La revue de conception du secteur sol pour les opérations d'Artemis est achevée et les travaux de développement ont été lancés.

EOPP

Stratégie future

Dans la perspective de la session du Conseil qui se tiendra au niveau ministériel en 1998, l'ESA a créé un groupe de travail stratégique sur l'observation de la Terre qui a été chargé de réfléchir et de préparer une stratégie applicable aux programmes futurs. Ce groupe est composé de représentants des principaux acteurs européens sur la scène de l'observation de la Terre. Parallèlement, un groupe de travail industriel ad hoc vérifiera le point de vue de l'industrie pour ce qui est des futurs programmes d'observation de la Terre. Le groupe de travail stratégique remettra son rapport en octobre.

Programmes futurs

Lors du Conseil directeur du programme d'observation de la Terre, réuni le 27 mai, les onze Etats membres qui participent à l'Extension 2 de l'EOPP se sont mis d'accord pour engager le programme

avec seulement 46,21% des souscriptions, à titre de mesure provisoire et exceptionnelle. Cette décision a permis de lancer quelques activités nouvelles mais cette mesure ne suffit pas pour engager les études de phase A du programme d'exploration de la Terre. La situation sera de nouveau examinée en septembre.

Les travaux de préparation des programmes d'exploration et de surveillance de la Terre ont commencé à l'Agence.

Campagnes

Le dernier atelier EMAC s'est déroulé du 14 au 16 avril ; l'atelier POLRAD a eu lieu le 29 avril. L'atelier correspondant pour INDREX est en préparation.

Plate-forme polaire/Envisat

Système Envisat-1

La revue critique de conception (CDR) du système 'Mission Envisat' (EMS) a été menée à bon terme ; elle confirme que les plans de conception, de développement et d'intégration sont conformes aux exigences de la mission.

La définition de la politique en matière de données a bien progressé. L'avis d'offre de participation relatif à l'exploitation des données scientifiques et à des projets pilotes est en préparation.

La première réunion de préparation du plan des opérations de haut niveau (HLOP) s'est tenue en avril ; les participants à ce programme étaient représentés par leurs experts auprès du DOSTAG.

Les responsables du programme ont créé un site Envisat sur l'Internet qui fournit des renseignements détaillés sur la mission. On peut y accéder à partir de la page d'accueil de l'ESA.

Plate-forme polaire (PPF)

La revue de conception critique de la plate-forme polaire a été menée à bon terme dans le cadre de la revue de conception critique du système 'Mission Envisat' (EMS). L'ensemble des travaux de développement est bien avancé et, d'une façon générale, satisfaisant. On a repéré

EOPP

Future strategy

In order to prepare for discussions at the Council Meeting to be held at Ministerial Level in 1998, an ESA Earth Observation Strategy Task Force has been established to reflect on and prepare a strategy for future programmes. It includes representatives of the main European players in Earth Observation. In parallel, an Industrial Ad Hoc Working Group will ascertain industry's point of view regarding future Earth-observation programmes. The Strategy Task Force's report will be available in October.

Future programmes

At the Earth Observation Programme Board meeting on 27 May, the eleven countries participating in EOPP Extension 2 agreed to initiate the programme with just a 46.21% level of subscription, as a temporary and exceptional measure. This has allowed some new activities to be initiated, but is not yet sufficient for initiating the Earth Explorer Phase-A studies. The situation will be reviewed in September.

In-house work has been started on the preparation of both the Earth Watch and Earth Explorer Programme elements.

Campaigns

The final EMAC workshop took place on 14 - 16 April and that for POLRAD on 28/29 April. The corresponding workshop for INDREX is in preparation.

Polar Platform/ Envisat

Envisat-1 system

The Envisat Mission System Critical Design Review (EMS-CDR) has been conducted successfully, confirming that the design, development and integration plans are compliant with the mission requirements.

Significant progress has been achieved in the definition of the Data Policy. The Announcement of Opportunity for scientific data exploitation and pilot projects is in preparation.

The first meeting for the preparation of the High Level Operations Plan (HLOP) was

held in April, with the programme participants represented by their DOSTAG-committee experts.

An Envisat Web site has been established which provides detailed mission information. It is accessible via the ESA Home Page.

Polar Platform (PPF)

The Polar Platform Critical Design Review (PPF-CDR) has been successfully completed within the framework of the Envisat Mission System Critical Design Review (EMS-CDR). The overall development status is well advanced and generally satisfactory. Few problems were identified and these are currently being resolved.

The spacecraft structural-model activities have been successfully completed. The vibration tests were conducted at ESTEC (NL) using the newly developed HYDRA test facility (longitudinal axes), and the Multi-Shaker (lateral axes). Following final alignment checks, the spacecraft was then shipped back to the prime contractor, Matra Marconi Space (Bristol, UK), where the refurbishment of the Payload Module structure to flight standard has been initiated.

Following its integration at Matra Marconi Space in Toulouse (F), the flight-model Service Module was delivered to Matra Marconi Space in Bristol.

The engineering-model (EM) activities have continued with the mating of the flight-model Service Module with the Payload Module equipped with five EM instruments or breadboard models. Integration of the flight-model Payload Equipment Bay is continuing at DASA/Dornier (D).

Envisat-1 payload

All engineering-model instruments have been delivered for integration onto the Polar Platform EM payload model, with the exception of MERIS and ASAR. The MERIS EM model is expected to be delivered at the beginning of July, closely followed by the Central Electronic Assembly (CESA) of the ASAR instrument.

Following the EMS-CDR, a number of actions were initiated with industry to fully resolve a few non-compliances. Emphasis is now focussing on flight-model instrument manufacture and testing. A large number of flight-model

subassemblies have been delivered and integration of the flight-model instruments has begun.

Envisat-1 ground segment

The Payload Data Segment (PDS) Detailed Design Review was successfully held in parallel with the EMS-CDR. The Flight Operation Segment (FOS) and Payload Data Segment (PDS) development efforts are progressing according to plan.

Simulated payload data have been delivered for the acceptance testing of the PDS front-end and the ASAR processors, which are nearing development completion and factory acceptance testing.

Expert Support Laboratories (ESLs) are assisting the Agency by providing valuable guidance in the PDS processor development. They provide reference test data as well as answering specific PDS contractor questions. MIPAS Level-2 ESL documentation is planned to be delivered in July, allowing the corresponding PDS processor development to be kicked-off.

Turning to the Processing and Archiving Centre (PAC) activities, the development effort for the French PAC (F-PAC) has begun. Finalisation of the Statements of Work for the other PACs is in process.

Meteosat Second Generation

The Preliminary Design Review (PDR) for the SEVIRI (Scanning Enhanced Visible and Infrared Imager) scanning assembly is still in progress and the SEVIRI scheduling remains on a critical path.

The satellite primary structure for the Structural and Thermal Model (STM) has been delivered to the prime contractor Aérospatiale in Cannes (F), where the various subsystems and equipment items will be integrated during the rest of the year.

The development of the MSG-1 spacecraft and the procurement of MSG-2 and -3 are on schedule, with engineering and thermal/mechanical-model production in progress at equipment and subsystem level. The launch of MSG-1 remains on schedule for October 2000, with MSG-2 to be launched in 2002 and MSG-3 to go into storage in 2003.

quelques problèmes qui sont en cours de résolution.

Les activités relatives au modèle structural du satellite ont été menées également à bon terme. Les essais en vibrations ont été conduits à l'ESTEC (NL) au moyen de la nouvelle table vibrante hydraulique (HYDRA) (axes longitudinaux) et du système multiple de vibration (axes latéraux). Après la dernière vérification des alignements, le satellite a été réexpédié chez le maître d'oeuvre, Matra Marconi Space (Bristol, Grande-Bretagne), où ont commencé les travaux de remise en état de la structure du module de charge utile pour qu'elle soit conforme aux normes de vol.

Après son intégration chez Matra Marconi Space à Toulouse (F), le module de vol du module de servitude a été livré à Matra Marconi Space à Bristol.

Les activités relatives au modèle d'identification (EM) se sont poursuivies avec l'adaptation du modèle de vol du module de servitude au module de charge utile équipé de cinq modèles d'identification ou de modèles de laboratoire des instruments.

L'intégration du modèle de vol de la case à équipements de la charge utile se poursuit chez DASA/Dornier (D).

Charge utile d'Envisat-1

Tous les modèles d'identification des instruments ont été livrés pour intégration sur le modèle d'identification de la charge utile de la plate-forme polaire, à l'exception de MERIS et d'ASAR. Le modèle d'identification de MERIS devrait être livré début juillet, rapidement suivi par l'ensemble électronique central (CESA) de l'ASAR. Au terme de la revue de conception critique (CDR) du système 'mission Envisat' (EMS), un certain nombre de mesures ont été prises avec l'industrie pour résoudre définitivement quelques problèmes de non conformité. Désormais, l'accent est mis sur la fabrication et les essais des modèles de vol des instruments, un nombre important de sous-ensembles ont été livrés et intégrés aux modèles de vol des instruments.

Secteur sol d'Envisat-1

La revue de conception détaillée du système de gestion des données de charge utile (PDS) a été menée à bon

terme, parallèlement à la CDR de l'EMS. Les travaux portant sur le secteur des opérations en vol (FOS) et sur le système de gestion des données de charge utile (PDS) progressent conformément au calendrier.

Des données de charge utile simulées ont été fournies pour les essais de recette des équipements frontaux du PDS et des processeurs ASAR dont les travaux de développement sont en voie d'achèvement et qui devraient être soumis aux essais de recette en usine.

Les laboratoires de soutien spécialisé (ESL) apportent leur concours à l'Agence en lui fournissant des conseils précieux relatifs aux travaux de développement des processeurs du PDS. Ils fournissent des données d'essais de référence et répondent à des questions spécifiques du contractant du PDS. Les documents ESL de niveau 2 du MIPAS devraient être livrés en juillet, ce qui permettrait d'engager les travaux de développement de ce processeur.

Pour ce qui est des activités portant sur les Centres de traitement et d'archivage (PAC), la PAC française a commencé ses travaux de développement. Les descriptifs de travaux des autres PAC sont en voie d'achèvement.

Météosat de deuxième génération

La revue de conception préliminaire (PDR) du dispositif de balayage de l'imageur visible et infrarouge amélioré non dégyré (SEVIRI) suit son cours. Le calendrier de réalisation du SEVIRI reste sur le chemin critique.

La structure primaire du modèle thermique et structural (STM) du satellite a été livrée à Aérospatiale (maître d'oeuvre) à Cannes (F), où les différents sous-systèmes et équipements seront intégrés d'ici la fin de l'année.

Le développement du satellite MSG-1 et l'approvisionnement des satellites MSG-2 et MSG-3 avancent conformément au calendrier. La production du modèle d'identification et des modèles thermique et mécanique suit son cours au niveau des équipements et sous-systèmes. Le

calendrier est maintenu : lancement de MSG-1 en octobre 2000 et de MSG-2 en 2002, et entreposage de MSG-3 en 2003.

Métop

Au mois de juin, le niveau des souscriptions à la phase de développement (phase C/D) s'est révélé insuffisant pour autoriser la mise en route des activités anticipées nécessaires au maintien du coût du programme et au respect de son calendrier. Cette situation pèse lourdement sur le programme, dont la survie est menacée si la Belgique, l'Espagne, la France et la Grande-Bretagne ne confirment pas les souscriptions qu'elles avaient officiellement annoncées.

La demande de prix (RFQ) relative à la phase C/D de Métop a été envoyée début avril. L'industrie prépare maintenant son offre, qu'elle doit remettre cet été. Compte tenu de la situation du programme, elle entrera en phase d'hibernation dès qu'un point final aura été mis à l'offre de phase C/D.

Météosat

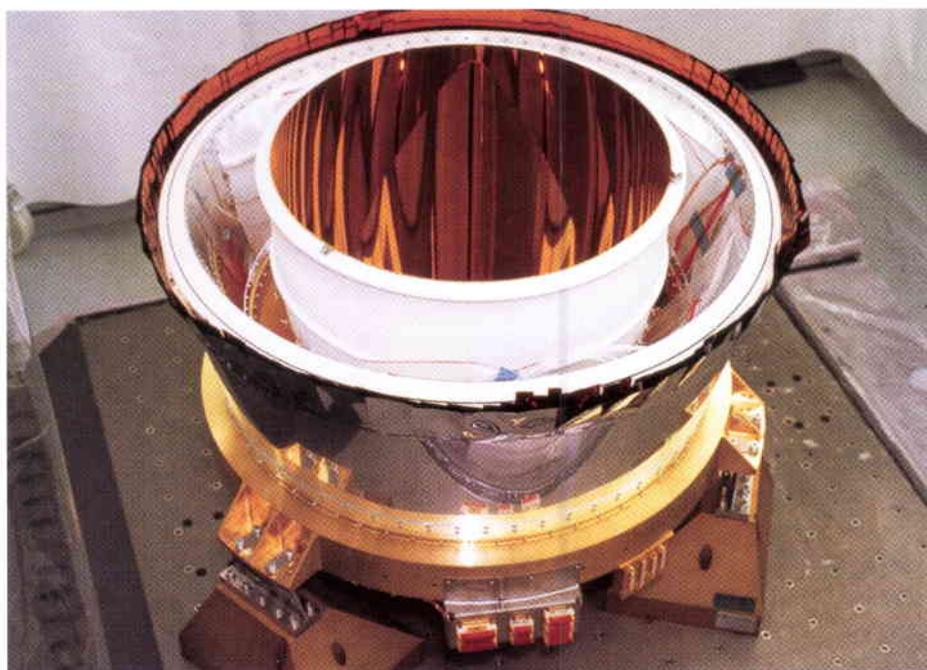
Le satellite du Programme Météosat de transition (MTP) est entièrement intégré. Les principaux essais d'ambiance sont tous terminés, de même que les derniers essais de fonctionnement. Le satellite sera bientôt expédié vers le site de lancement.

Bien que sa date de lancement n'ait pas été confirmée, le satellite sera transporté à Kourou début juillet pour un lancement entre fin août et mi-septembre.

Une fois sur orbite, le satellite sera exploité par Eumetsat et fournira régulièrement les cartes météorologiques de l'Europe que nous recevons actuellement de Météosat-5, Météosat-6 jouant pour sa part le rôle de réserve en orbite. Ces deux satellites ont également été construits au titre de contrats d'approvisionnements de l'ESA.

ERS

La prolongation des activités opérationnelles d'ERS (phase E1) a été approuvée. Le déficit de financement dû au retard de



The Meteosat SEVIRI instrument's passive cooler

Le refroidisseur passif de l'instrument SEVIRI de Météosat

Metop

As of June, it has proved impossible to achieve the level of subscription for the Metop main development phase (Phase-C/D) needed to allow the release of those advanced activities seen as necessary to preserve the programme cost and schedule objectives. The consequent effects on the programme are critical and its survival is threatened, unless formerly announced subscriptions by Belgium, France, Spain and United Kingdom materialise.

The Metop Phase-C/D Request for Quotation (RFQ) was released in early April. Industry is currently preparing its offer for submission in late summer. In response to the programmatic situation, industry will be entering a hibernation phase as soon as the Phase-C/D offer is complete.

Meteosat

The Meteosat Transition Programme (MTP) spacecraft has been fully integrated and all the major environmental tests have been completed. The final performance testing has also been completed.

Although a launch date has not yet been confirmed, the spacecraft will be transported to Kourou in early July,

allowing a launch between end-August and mid-September.

Once launched, the spacecraft will be operated by Eumetsat to provide the regular weather pictures over Europe which are currently being provided by Meteosat-5, with Meteosat-6 as the in-orbit spare. Both these spacecraft were provided under ESA spacecraft supply contracts.

ERS

The extension of ERS operations (Phase-E1) has been approved. Subscriptions still outstanding from Belgium, Italy and Spain threaten full continuation of operations due to insufficient financial coverage.

ERS-2 satellite operations remain stable with continued high availability of payload science data. Uploading of a software patch for the satellite platform, providing improved surveillance and recovery in case of attitude-control anomalies, is imminent. Close monitoring of the gyro package, following the recent unit failure, has shown that the remaining five gyros are stable and that satellite pointing is within requirements. It is anticipated that, based on the evaluation of the remaining gyros, a piloting triplet selected for the next period should allow almost full recovery of the pointing performance that was achieved with the original gyro configuration.

ERS-1 is being maintained as a back-up for ERS-2. ERS-1's performance, particularly that of the attitude and orbit control, thermal and power subsystems, remains stable. The payload check-out performed in the third week of May showed that instrument functionality is unimpaired.

ERS-1 will be re-activated for special campaigns over Japan and Australia planned for July/August this year.

International Space Station Programme (ISS)

Columbus Orbital Facility (COF)

The COF preliminary design phase is nearing completion. Many equipment-level and subsystem-level PDRs have been successfully concluded, and the system PDR is planned for the fourth quarter of this year. The overall configuration mock-up has been assembled and is being evaluated for subsystem, harness and piping layout, access and maintainability. This mock-up will be put into a neutral-buoyancy facility this summer for crew activity tests. Several equipment breadboards and development models have been completed and are under test. The technical and programmatic aspects of possibly adding an External Payload Accommodation capability to the COF are under study.

Consolidation of the industrial consortium to reflect the final levels of Member State contributions to the Programme has been completed. Rider 1 to the Prime Contract incorporating all amendments has been signed by both parties.

Following a re-assessment of the overall Space Station Assembly Sequence, necessitated mainly by funding problems in Russia, all of the International Partners have participated in a Space Station Control Board (SSCB) to baseline a revised Station Assembly Sequence (up to

souscription de la Belgique, de l'Italie et de l'Espagne compromet toutefois la poursuite des opérations.

L'exploitation d'ERS-2 reste stable, la charge utile continuant de fournir des données scientifiques dans de bonnes conditions de disponibilité. On doit très bientôt charger un logiciel de correction destiné à la plate-forme du satellite, mais aussi améliorer la surveillance et la correction des anomalies pouvant survenir dans le contrôle d'attitude. Un suivi minutieux des gyroscopes, après la panne de l'un d'entre eux, a montré que les cinq unités restantes sont stables et que le pointage répond aux impératifs. A partir de l'évaluation des gyroscopes restants, les trois unités de pilotage choisies pour la prochaine période devraient autoriser le rétablissement quasiment complet des capacités de pointage obtenues avec la configuration originale.

ERS-1 sert de satellite de réserve pour ERS-2. Son fonctionnement, notamment en ce qui concerne le contrôle d'attitude et la correction d'orbite ainsi que les sous-systèmes thermiques et de puissance, reste stable. La vérification de la charge utile réalisée dans la troisième semaine de mai a montré que les instruments ont conservé toutes leurs caractéristiques de fonctionnement.

ERS-1 sera réactivé pour des campagnes spécifiques qui doivent avoir lieu au-dessus du Japon et de l'Australie en juillet-août 1997.

Station spatiale internationale (ISS)

Élément orbital Columbus (COF)

La phase préliminaire de conception du COF est en voie d'achèvement. De nombreuses revues préliminaires de conception ont été menées à bien aux niveaux équipements et sous-systèmes et la revue au niveau système est prévue pour le quatrième trimestre de cette année. La maquette de configuration générale a été assemblée et est en cours d'évaluation en ce qui concerne l'agencement, l'accès et la facilité de maintenance des sous-systèmes, faisceaux de câbles et tuyauteries. Cette maquette sera placée cet été dans une piscine d'immersion pour tester certaines activités d'équipage. Des montages table et des maquettes de développement de plusieurs équipements ont été réalisés et

sont en cours d'essai. Les aspects techniques et programmatiques de l'intégration éventuelle d'un système d'installation de charges utiles externes sur le COF sont à l'étude.

La consolidation du consortium industriel visant à refléter les niveaux définitifs de contribution des Etats membres au programme a été achevée. L'avenant 1 au contrat de maîtrise d'oeuvre incluant tous les amendements a été signé par les deux parties.

Après une réévaluation de l'ensemble de la séquence d'assemblage de la Station spatiale, rendue nécessaire notamment du fait de problèmes de financement de la Russie, tous les partenaires internationaux ont participé à une réunion de la Commission de contrôle de la Station spatiale (SSCB) afin de définir une nouvelle séquence de référence pour l'assemblage de la Station (jusqu'à la mi-2002). La séquence des vols qui suivront fait l'objet d'une évaluation multipartite détaillée, l'un des principaux objectifs étant le lancement du COF vers la Station par la Navette spatiale au second semestre 2002. La SSCB envisage de se réunir à nouveau en septembre/octobre afin d'établir un calendrier de référence de tous les vols d'assemblage après la mi-2002.

Dans le cadre de l'accord de compensation signé avec la NASA au sujet du lancement du COF, une lettre d'habilitation a été signée entre l'ESA et l'Agence spatiale italienne (ASI) donnant à l'industrie l'autorisation d'engager les travaux de développement des éléments de jonction no. 2 et 3. L'industrie a également été autorisée à entreprendre la production d'un équipement DMS supplémentaire et à assurer le soutien technique continu de l'installation de vérification des logiciels de la NASA.

Véhicule de transfert automatique (ATV)

La demande de prix (RFQ) relative à la phase de développement principale (phase C/D) a été envoyée officiellement le 19 mars au maître d'oeuvre Aérospatiale (F), qui doit soumettre sa proposition début septembre. L'Exécutif a pour objectif de présenter la proposition de contrat correspondante à la réunion du 26 novembre du Comité de la politique industrielle de l'Agence (IPC). Il se propose également de prolonger l'actuel contrat de phase B2 de mars à fin-novembre afin de

préserver le calendrier de la phase C/D en lançant des activités anticipées au titre de cette phase et pour assurer la continuité de l'équipe industrielle.

En ce qui concerne les interfaces de la Station spatiale, un événement majeur est intervenu avec la signature par l'ESA, la RKA et la NASA du document tripartite définissant les capacités et la mission de l'ATV.

Le deuxième vol de démonstration de l'ARP a été mené à bien dans le cadre de la mission STS-84 de la Navette. Il ressort, en première analyse, que les objectifs essentiels de la mission ont été atteints, bien que certaines données de l'expérience GPS soient manquantes. Cette anomalie est en cours d'analyse.

Véhicule de sauvetage des équipages/ Véhicule de transport d'équipages (CRV/CTV)

Compte tenu des progrès considérables qui ont été accomplis dans la définition du CRV/CTV de type corps portant grâce à une excellente coopération avec la NASA, une proposition visant à poursuivre ces activités en coopération jusqu'à fin 1998, parallèlement à l'achèvement de l'étude de CTV de type capsule, a été présentée au Conseil directeur des programmes spatiaux habités. Celui-ci a approuvé la réorientation des études CTV en cours afin de prendre en compte la poursuite de la coopération ESA/NASA jusqu'à fin 1997, une décision définitive devant être prise en septembre en ce qui concerne les travaux à exécuter en 1998. La revue des impératifs système (SRR) du concept de capsule CTV a été menée à bien en avril.

Démonstrateur de rentrée atmosphérique (ARD)

Les activités de qualification de l'ARD ont été menées à bon terme en avril. L'ARD sera maintenu en état opérationnel jusqu'à ce que les activités de préparation du lancement puissent reprendre, ce qui dépend de la date définitive retenue pour le vol Ariane-503.

Opérations et secteur sol

Les données opérationnelles et les caractéristiques de fonctionnement de l'ATV, ainsi que les besoins annuels de l'ESA en matière de charge montante et descendante, ont été intégrés par le Centre spatial Johnson de la NASA dans une analyse de trafic avec une flotte mixte. Le rapport d'étude, publié en avril, inclut

mid-2002). The sequence of flights thereafter is under detailed multilateral evaluation, with one of the major goals being the launch of COF by the Space Shuttle to the Station in the second half of 2002. The SSCB plans to meet again in September/October to baseline all assembly flights after mid-2002.

In the context of the COF launch barter agreement with NASA, an enabling letter has been signed between ESA and the Italian Space Agency (ASI) giving industry an Authorisation to Proceed with the development of ISS Nodes 2 and 3. Industry has also been authorised to begin the production of extra DMS equipment and to perform sustaining engineering for the NASA Software Verification Facility.

Automated Transfer Vehicle (ATV)

The main development phase (Phase-C/D) Request for Quotation (RFQ) was formally released to the prime contractor Aérospatiale (F) on 19 March, and the Proposal submission is now targeted for early September. The Executive's objective is to present the associated Contract Proposal to the 26 November meeting of the Agency's Industrial Policy Committee (IPC). The Executive plans to extend the current Phase-B2 contract from March to end-November in order to secure the Phase-C/D schedule by starting advanced C/D activities and to ensure industrial team continuity.

In terms of Space Station interfaces, a key event has been the signature of the trilateral decision paper by ESA, RSA and NASA on the ATV's capabilities and mission.

The second ARP demonstration flight has been completed successfully in conjunction with the STS-84 Shuttle mission. Initial indications are that the essential mission objectives have been achieved, but with some data loss occurring in the GPS experiment. This anomaly is under investigation.

Crew Rescue Vehicle/Crew Transfer Vehicle (CRV/CTV)

Taking into account the considerable progress made in the definition of the lifting-body CRV/CTV, thanks to excellent cooperation with NASA, a proposal for continuing this cooperative effort through the end of 1998, in parallel with completion of the capsule-type CTV study, has been presented to the Manned Space Programme Board. The latter endorsed reorientation of the on-going CTV studies to accommodate continuation of ESA/NASA cooperation until the end of 1997, with a final decision concerning work in 1998 to be taken in September. The System Requirements Review (SRR) for the CTV capsule concept was successfully completed during April.

Atmospheric Re-entry Demonstrator (ARD)

The ARD qualification effort was successfully completed in April. The ARD will be kept operational until the launch-preparation activities can be resumed, which is dependent on the final date established for the Ariane-503 launch.

Lifting-body concept for CRV/CTV

Concept de type "lifting body" pour CRV/CTV

Operations and ground segment

ATV operational and performance data and annual ESA up-/download requirements have been used by NASA/JSC as inputs to a Mixed Fleet Traffic Analysis. The study report, released in April, shows the ATV integrated with all other ISS Fleet resources. Based on this data, a preliminary ATV manifest has been generated as an input to the ESA/RSA implementation arrangements.

A definition study of the COF/ATV Operations Control Functions and Facilities was begun in April, as well as a study related to the definition of the associated ground communications infrastructure.

The following month, the detailed definition study for the COF/ATV Operations Support Functions and Facilities was also kicked-off. Each study will take approximately six months.

Utilisation

Since the finalisation of the Memorandum of Understanding (MOU) with NASA on Early Opportunities on Space Station for Europe and the subsequent issue by ESA last December of the Announcement of Opportunity (AO) for External Payloads to 6000 addressees in all ESA Member States, the Executive has received notifications of interest from about 150 potential proposers.

In the context of the discussions with NASA concerning the pressurised Early Opportunity payloads, it has been agreed to implement the Protein Crystallisation Diagnostic Facility (PCDF) and the Modular Cultivation Facility (MCF) as Express Rack payloads.

Astronauts

The major mission event of late was the participation of ESA Astronaut J.-F. Clervoy in the STS-84 Shuttle mission from 15 to 24 May. This was the first time that an ESA Astronaut had been assigned as Payload Commander aboard a Shuttle docking with the Mir space station. The fact that the experienced Russian Astronaut Elena Kondakova was also a member of the same crew underlined the truly international nature of the STS-84 mission.

Early deliveries

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

The Russian Service Module team has



l'ATV dans l'ensemble des composantes de la flotte de l'ISS. A partir de ces données, un manifeste préliminaire de l'ATV a été établi comme document de référence pour les arrangements d'exécution ESA/RKA.

Une étude de définition des installations et fonctions de contrôle opérationnel COF/ATV a démarré en avril, ainsi qu'une étude portant sur la définition de l'infrastructure sol correspondante de télécommunications. Le mois suivant, l'étude de définition détaillée des installations et fonctions de soutien opérationnel COF/ATV a également été lancée. Chacune de ces études durera environ six mois.

Utilisation

Depuis la mise au point définitive du Mémorandum d'accord (MOU) avec la NASA sur la possibilité pour l'Europe de participer à l'utilisation initiale de la Station et la publication par l'ESA, en décembre dernier, de l'avis d'offre de participation (AO) relatif à des charges utiles externes, qui a été envoyé à 6000 destinataires dans tous les Etats membres de l'Agence, l'Exécutif a reçu des avis d'intention d'environ 150 candidats potentiels.

Lors des discussions avec la NASA relatives aux charges utiles pressurisées entrant dans le cadre de l'utilisation initiale, il a été décidé que l'installation de diagnostic pour la cristallisation des protéines (PCDF) et l'installation de culture modulaire (MCF) seraient montées sur bâti express.

Astronautes

Le principal événement récent a été la participation de l'astronaute de l'ESA J.-F. Clervoy à la mission STS-84 de la Navette du 15 au 24 mai. C'était la première fois qu'un astronaute de l'ESA était affecté en qualité de commandant charge utile à bord d'une Navette chargée de s'amarrer à la station spatiale Mir. Le fait que l'astronaute russe Elena Kondakova ait également fait partie de l'équipage souligne le caractère véritablement international de la mission STS-84.

Livraisons à court terme

Système de gestion de données pour le module de service russe (DMS-R)

Il a été demandé à l'équipe du module de service russe d'apporter des modifications supplémentaires au logiciel DMS-R. Plutôt que d'utiliser intégralement les services du

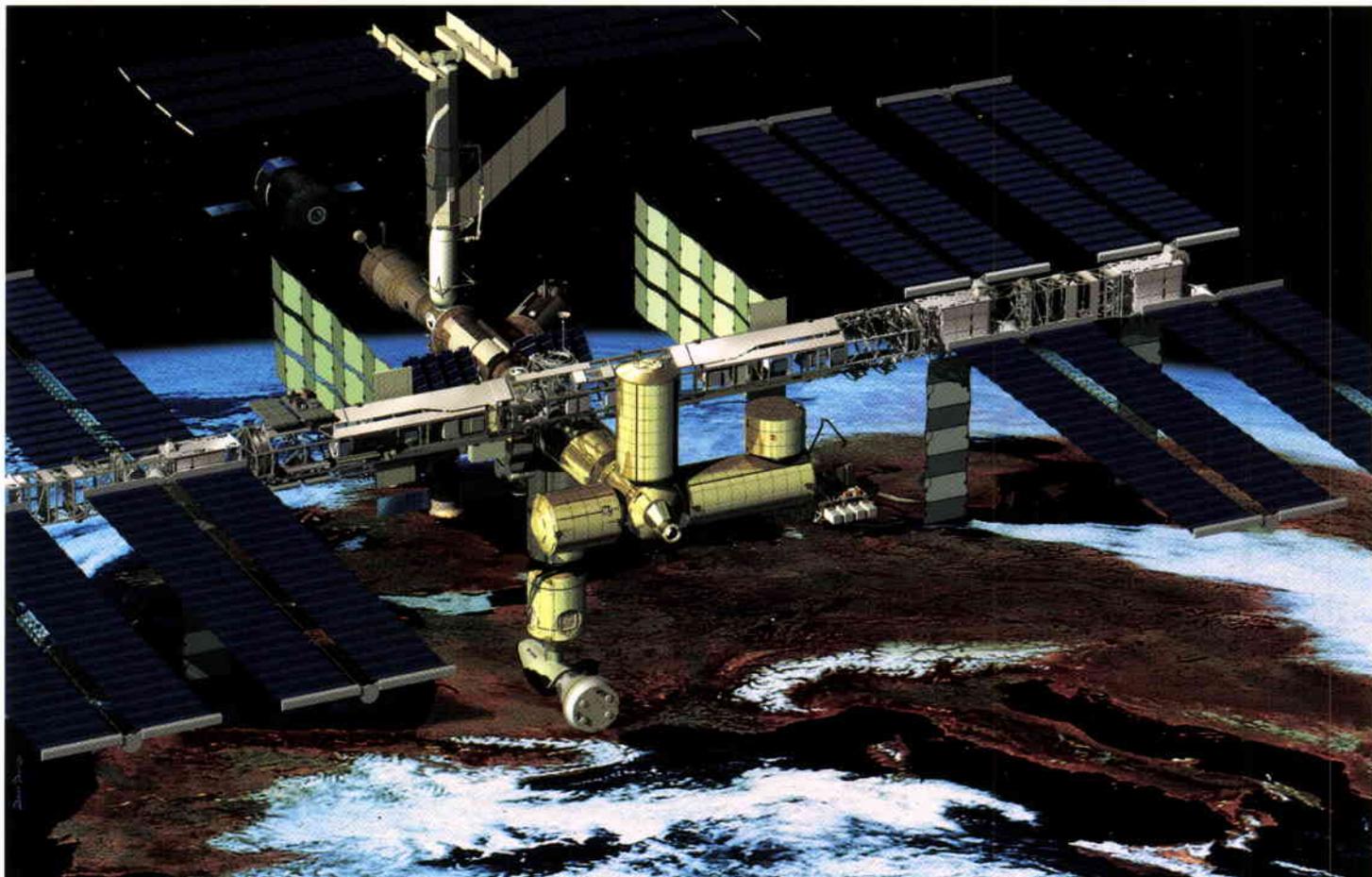
système logiciel DMS-R, l'équipe a choisi de concevoir elle-même ces services en réutilisant une part importante des éléments de logiciels mis au point pour un satellite russe afin de préserver le calendrier du module de service.

L'ensemble du matériel des modèles de qualification et d'identification a été réalisé et le programme de qualification suit son cours, son achèvement étant prévu fin juillet. La fabrication de l'unité de vol a également été lancée et la livraison devrait pouvoir s'effectuer en août, comme prévu.

Compte tenu du report à décembre 1998 de la date de lancement du module de service, le programme de soutien technique, qui prend fin trois mois après le lancement du laboratoire américain aux termes de l'arrangement ESA/RKA, doit maintenant être prolongé de huit mois.

*Bras télémanipulateur européen (ERA)
Le retard de lancement de la plate-forme russe science et énergie (SPP), prévu*

*The International Space Station
La Station spatiale internationale*



requested additional DMS-R software changes. Rather than fully using the DMS-R software system services, they have opted to build these services themselves by reusing significant amounts of software developed for a Russian satellite, in order to safeguard the Service Module schedule.

All qualification- and engineering-model hardware has been manufactured, and the qualification programme is proceeding towards its planned completion by the end of July. Flight-unit manufacture has also been initiated, and the agreed delivery date of August remains feasible.

In view of the new launch date of December 1998 for the Service Module, the engineering support programme, which according to the ESA/RKA Arrangement terminates three months after the US Lab. launch, must now be extended by eight months.

European Robotic Arm (ERA)

The launch delay for the Russian Science and Power Platform (SPP), per Revision C of the Assembly Sequence, is eight months with respect to the current baseline. The consequences of this delay, together with the impact of the earlier change of launch vehicle from Proton to Shuttle are under review with industry, and a revised and consolidated plan for the completion of ERA development will be established during the summer.

At industry level, the manufacture of the subsystem engineering qualification models is progressing, with the first deliveries of hardware to the prime contractor. Assembly of the engineering model will lead to system functional testing by the end of the year, although there remains the potential for some delay due to design changes arising from the new launch configuration.

Laboratory Support Equipment (LSE)

The MELFI (Minus Eighty Degree Co-Laboratory Freezer) Preliminary Design Review (PDR) began in April with NASDA and NASA participating. The PDR kick-off meeting for the Microgravity Science Glovebox (MSG) was held in April at DASA in Bremen (D). The Request for Quotation (RFQ) for the Hexapod main development phase (Phase-C/D) was issued in April. The Invitation to Tender (ITT) for the Cryo-Freezer system has also been issued.

Microgravity

EMIR 1

The sixth and last flight of Biorack took place on the Shuttle mission to Mir from 15 May to 24 May. This STS-84 mission carried the Spacehab module, which contained not only the ESA Biorack but also the ESA MOMO instrument for the investigation of morphological transitions in model substances. Both instruments worked well. The Biorack carried not only the classical cell-biology experiments, but also an experiment on the vestibular biology of small amphibians and fish.

The Biopan, Biobox and FluidPac facilities are being prepared for flight on the Russian Foton 11 and Foton 12 capsules in September 1997 and November 1998, respectively.

Two short-duration sounding-rocket flights yielding 3 min of free-fall conditions are planned in November. The first one, Mini-Texus 5, will carry an experiment with a fluid at the critical point which will be submitted to oscillatory accelerations. The second, a Maser Technology mission, will flight-verify the new Maser service module with a technological experiment provided by CNES for studying the boiling and condensation of ammonia in microgravity.

EMIR 2

In conjunction with the STS-4 launch, negotiations were initiated with the Spacehab Corp. and NASA regarding ESA's participation in a possible additional series of three Spacehab missions to be carried out between 1998 and 2001. Candidate facilities for these flights are the Advanced Gradient Heating Facility (AGHF), the Advanced Protein Crystallisation Facility (APCF), the Morphological Transition in Model Substances (MOMO) facility, the Urine Monitoring System (UMS) and the Facility for Absorption and Surface Tension (FAST).

Discussions have continued with CNES regarding possible ESA participation, focussing on human-physiology research, in CNES missions to Mir scheduled for 1998 and 1999.

MFC

The Microgravity Facilities for Columbus Programme was formally started on 1 January (see Bulletin 90, pages 6-20).

It includes the following multi-user facilities: Biolab, Fluid Science Laboratory (FSL), Material Science Laboratory (MSL) and European Physiology Modules (EPM).

The Biolab design phase (Phase-B) was completed in May and the results of the breadboarding have validated the design. The main development phase (Phase-C/D) is planned to start in September/October.

The FSL's Phase-B is in progress and will be completed in September, with its Phase-C/D planned to start in March 1998.

The current MSL Phase-B will be completed by December 1997, and Phase-C/D is planned for the second quarter of 1998. The cooperation with NASA to accommodate the MSL inside the US Lab will be finalised by the end of the year.

The EPM's study phase (Phase-A) will start in October.

Ariane-5

Three important milestones in the schedule for the Ariane-502 planning have occurred:

- System Qualification Review, on 20-23 May
- Departure of the vessel transporting the launcher elements to French Guiana, on 30 May
- Start of the 502 launch campaign, on 16 June.

Due to a problem encountered with the liquid-oxygen turbo-pump of the Vulcain engine of the cryogenic main stage destined for Ariane flight 504 (which is identical to the one fitted on 502), it has been decided to replace the complete Vulcain engine with the one intended for the flight 503 launcher. This activity, which will take two weeks, has been incorporated into the detailed launch-campaign planning.

The Ariane-502 launch is currently planned for 30 September.

dans la révision C de la séquence d'assemblage, est de huit mois par rapport à la référence actuelle. Les conséquences de ce retard, ainsi que du remplacement du lanceur Proton par la Navette décidé antérieurement, sont analysées avec l'industrie et un plan révisé et consolidé relatif à l'achèvement du développement de l'ERA sera établi au cours de l'été.

Au niveau industriel, la fabrication des modèles de qualification et d'identification des sous-systèmes est en cours et le maître d'oeuvre a reçu les premières livraisons de matériel. L'assemblage du modèle d'identification débouchera sur des essais fonctionnels au niveau système d'ici la fin de l'année à moins d'un éventuel retard dû à des modifications de conception résultant de la nouvelle configuration de lancement.

Equipements de soutien de laboratoire (LSE)

La revue préliminaire de conception (PDR) du congélateur - 80°C MELFI a commencé en avril avec la participation de la NASDA et de la NASA. La réunion de lancement de la PDR concernant la boîte à gants de recherche en microgravité (MSG) s'est tenue en avril chez DASA à Brême (D). La demande de prix relative à la phase principale de développement (phase C/D) de l'Hexapod a été envoyée en avril. L'appel d'offres (ITT) pour le congélateur cryogénique a également été diffusé.

Microgravité

EMIR 1

Le sixième et dernier vol du Biorack a eu lieu du 15 au 24 mai dans le cadre de la mission de la Navette à destination de Mir. Cette mission, dénommée STS-84, emportait le module Spacehab, qui contenait non seulement le Biorack de l'ESA, mais également l'instrument MOMO mis au point par l'Agence pour étudier les transitions morphologiques sur des substances modèles. Ces deux instruments ont bien fonctionné. Le Biorack comportait, outre les expériences classiques de biologie cellulaires, une expérience sur la biologie vestibulaires de petits amphibiens et de poissons.

Les installations Biopan, Biobox et FluidPac sont en cours de préparation

pour être embarquées sur les capsules Photon 11 et Photon 12, respectivement en septembre 1997 et en novembre 1998.

Deux vols de fusées-sondes de courte durée, offrant 3 minutes de conditions de chute libre, sont prévus en novembre. Le premier, Mini-Texas 5, emportera une expérience avec un fluide au point critique, qui sera soumis à des accélérations oscillatoires. Le second, qui s'inscrit dans le cadre d'une mission sur la technologie Maser, servira à vérifier en vol le nouveau module de service Maser au moyen d'une expérience fournie par le CNES pour étudier la vaporisation et la condensation de l'ammoniac en microgravité.

EMIR 2

En liaison avec le vol STS-4, des négociations ont été engagées avec Spacehab Corp. et la NASA au sujet de la participation de l'ESA à une éventuelle série supplémentaire de trois missions Spacehab, qui auraient lieu entre 1998 et 2001. Les installations envisagées pour ces vols sont le four à gradient de haute technologie (AGHF), l'installation de cristallisation des protéines de pointe (APCF), l'expérience de transition morphologique sur des substances modèles (MOMO), le système de contrôle des urines (UMS) et l'installation d'étude d'adsorption et de tension de surface (FAST).

Des discussions se sont poursuivies avec le CNES au sujet d'une éventuelle participation de l'ESA, axée sur la recherche en physiologie humaine, à des missions du CNES sur Mir, qui doivent avoir lieu en 1998 et 1999.

MFC

Le programme d'installations de recherche en microgravité pour Columbus (MFC) a démarré officiellement le 1er janvier dernier (cf. Bulletin 90, pp. 6-20). Il englobe les installations multi-utilisateurs suivantes : Biolab, laboratoire de science des fluides (FSL), laboratoire de science des matériaux (MSL) et modules de physiologie européens (EPM).

La phase de conception (phase B) du Biolab s'est achevée en mai et les résultats d'un montage table ont validé la conception. Il est prévu de lancer la phase principale de développement (phase C/D) en septembre/octobre.

La phase B du FSL est en cours et

s'achèvera en septembre, la phase C/D devant démarrer en mars 1998.

La phase B du MSL, qui est en cours, s'achèvera d'ici décembre 1997 et il est prévu de lancer la phase C/D au deuxième trimestre 1998. La coopération avec la NASA visant à installer le MSL à l'intérieur du laboratoire américain sera finalisée d'ici la fin de l'année.

La phase d'étude (phase A) de l'EPM débutera en octobre.

Ariane-5

Trois étapes importantes ont été franchies dans le calendrier de préparation du vol 502 :

- revue de qualification système : 20-23 mai
- départ du navire transportant les éléments du lanceur en Guyane : 30 mai
- démarrage de la campagne de lancement 502 : 16 juin.

En raison d'un problème rencontré sur la turbo-pompe à oxygène liquide du moteur Vulcain de l'étage principal cryotechnique du vol 504 (identique à celui du vol 502), il a été décidé de remplacer la totalité du moteur Vulcain du vol 502 par l'exemplaire destiné au vol 503. Ces travaux, d'une durée de 15 jours, ont été pris en compte dans le calendrier détaillé de la campagne de lancement.

Le lancement d'Ariane 502 est prévu pour le 30 septembre.

ISO Finds Water in Distant Places

Water is the medium of life and ESA's cosmic water diviner continues to detect it in a wide variety of sources, most recently in the cosmos where it was previously unknown. Astronomers using ESA's Infrared Space Observatory, ISO, have found water vapour in dark clouds lying towards the centre of the Milky Way. They calculate that water is abundant in our Galaxy.

Equally striking is ISO's discovery of water vapour in the outer planets, Saturn, Uranus and Neptune. As those chilly planets cannot release water from within, they probably have a supply of water coming from elsewhere in the Solar System.

Since ISO went into orbit at the end of 1995, it has used its unique power of analysing infrared rays coming from the Universe to identify water vapour and water ice near newborn and dying stars. It has also measured the water vapour steaming from Comet Hale-Bopp.

"Before ISO no instrument was capable of detecting water in so many places" comments ESA's Director of Science, Roger Bonnet. "To start revealing the cosmic history of the Earth's water is a big success for ESA and for the astronomers who use our unique infrared observatory. And ISO's discovery that water is commonplace in the Galaxy will encourage renewed speculation about life that may exist in the vicinity of other stars."

Water amid the stars

Primeval hydrogen atoms make water by joining with oxygen atoms that are manufactured within stars, in nuclear reactions occurring towards the end of a star's life. Oxygen from defunct stars enriches the Galaxy, and abundant hydrogen is available to react with it. Although the existence of water in interstellar space is not surprising, the Earth's moist atmosphere makes life difficult for any astronomer who wishes to spot water vapour in the Universe with ground-based instruments.

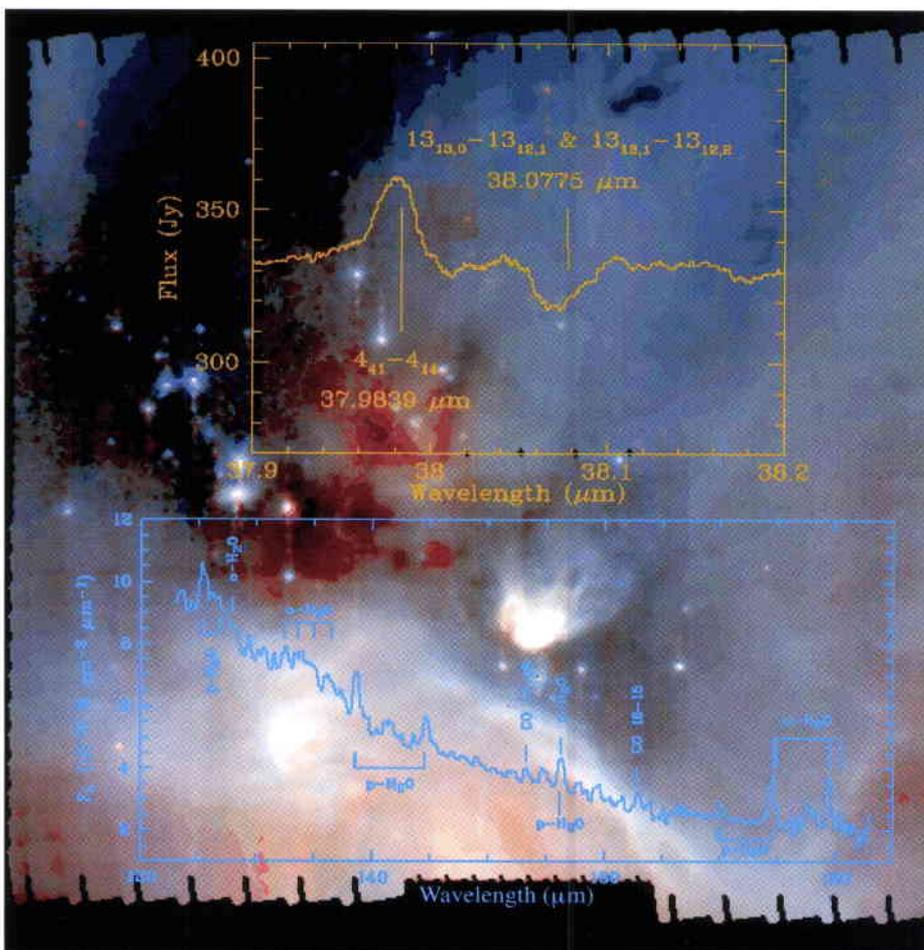
Observations from aircraft and balloons gave early hints of cosmic water, but thorough investigations had to wait for ISO's unhampered view from space. Three of the satellite's instruments, the Short Wavelength Spectrometer (SWS), the Long Wavelength Spectrometer (LWS) and the photometer ISOPHOT, operating in spectroscopic mode, take part in the hunt for water.

Last year, for example, users of both SWS and LWS reported water vapour in the vicinity of the aged star W Hydrae, from which oxygen-rich winds blow into space. The bright infrared source GL 2591, surrounding a newly formed massive star,

This composite picture shows fingerprints of water vapour (labelled H₂O) in widely differing infrared wavebands, as registered by two instruments of ESA's space telescope ISO when it was trained on the elderly star W Hydrae. In a high-resolution spectrum from the Short Wavelength Spectrometer (SWS) the main water feature is the strong emission at wavelengths around 38 microns. The Long Wavelength Spectrometer (LWS) picked up a large number of strong water-vapour emissions at wavelengths from 122 to 183 microns.

The two spectra are overlaid on an image taken with the ISOCAM at wavelengths of 7 and 15 microns. It shows the dark star-forming cloud called Rho Ophiuchi, partially opened to view by the penetrating power of ISO's infrared 'eyes'. (Courtesy ESA/ISO and the ISOCAM, LWS and SWS Consortia)

In Brief



revealed to SWS hot and abundant water vapour. Jets of gas from very young stars can create luminous shock waves at great distances and LWS made the first detection of water vapour in such an object, HH-54.

Among the objects subsequently examined by LWS, IRAS 16293-2422 is a cosmic egg in the process of creating a star of about the same size as the Sun. Characteristic emissions from water vapour at 108, 113, 174 and 179 microns show up clearly. The water plays a practical part in starmaking. It helps to radiate away excess heat which could otherwise prevent the parent gas from condensing under gravity to make the star.

When ISO looks towards the centre of the Galaxy, which lies about 28 000 light-years away in the constellation of Sagittarius, it sees, not emissions of the characteristic wavelengths of water, but absorptions. These appear as dips in the infrared spectrum and tell of the presence of dark, cool clouds, called molecular clouds, which are the primary source of new stars. Very close to the true Galactic Centre is the bright infrared source Sagittarius B2 and it too shows the presence of water vapour.

In a programme of observations which began in the autumn of 1996 and is still continuing, ISO's Long Wavelength Spectrometer has made observations of such high precision that it distinguishes different molecular clouds on the way towards the Galactic Centre. The clouds are moving at different speeds relative to the Earth. They alter each water wavelength by the Doppler effect to produce a broad absorption line representing water vapour in the various clouds intervening between the Earth and the bright source Sagittarius B2. The detection by LWS of water molecules containing the rare, heavy form of oxygen, oxygen-18, helps astronomers to estimate the abundance of water.

Other watery clouds show up when ISO is pointed towards other dense regions of the Galaxy somewhat away from the Galactic Centre. There really is, in the words of an English poet, "Water, water everywhere".

A Spanish astronomer, José Cernicharo of the Instituto de Estructura de la Materia in Madrid, has played a prominent part in

this work. He is delighted by the results. "For the first time, we have a clear impression of the abundance of water in the Galaxy," Cernicharo says. "In relatively dense clouds, as many as ten percent of all oxygen atoms are incorporated into molecules of water vapour. Even more may be in the form of water ice. Water vapour is, after molecular hydrogen and carbon monoxide, one of the most important molecules in space. It plays an important role in the dynamic evolution of the gas inside the molecular clouds of our Galaxy, and hence in the formation of new stars."

The water supply of the outer planets

The water vapour in Saturn, Uranus and Neptune showed up in analyses of very accurate observations made with ISO's Short Wavelength Spectrometer during October and November 1996. A report to the world's astronomical community tells of a particularly clear water signature from Uranus, in distinctive infrared emissions at eight wavelengths between 28.43 and 44.19 microns. A preliminary analysis indicated that the water vapour exists in the giant planet's outer atmosphere, at a temperature around 0 deg C. ISO detected six of the same water 'lines' in the infrared spectrum of distant Neptune, and three in Saturn, which is closer than Uranus. The puzzle for planetary astronomers now is to figure out where the water comes from. These giant planets are a long way from the Sun. Uranus, for example, is twenty times farther out than the Earth and sunlight is feebler by a factor of 400. The planets have their own internal sources of heat and they are thought to contain plenty of water incorporated when the planets formed, but it would be difficult for water vapour to escape into the outer atmosphere. On the other hand, water in the form of ice is a major constituent of comets, which sometimes collide with the planets, as seen in the spectacular impacts of Comet Shoemaker-Levy 9 on Jupiter in 1994.

The leader of the ISO team that found the water vapour in the outer planets is Helmut Feuchtgruber of the Max-Planck Institut für Extraterrestrische Physik at Garching, Germany. He works at ESA's ISO operations centre at Villafranca, Spain. He sees the theoretical puzzle of the water vapour as being of great significance for planetary science.

"The upper atmosphere of the Earth is

very dry because water vapour rising from the oceans or the land freezes into clouds," Feuchtgruber comments. "We would expect the same kind of lid to seal in the water vapour of the outer planets. What we see in Saturn, Uranus and Neptune probably comes from an outside source. This has important implications for our theories of the origin and evolution of all planetary atmospheres, including the Earth's." Feuchtgruber and his colleagues are preparing a theoretical analysis of the likely origin of the water vapour in the outer planets, which they hope to publish soon.

European success story

Rated by a panel of American astronomers as 'the major infrared mission of the decade', ISO is a special achievement for ESA — and for Europe's astronomers and engineers. Advanced technology created ISO's extremely cold telescope capable of observing cool regions of the Universe. Multinational teams, with leaders in France, Germany, the Netherlands and the United Kingdom, developed the special scientific instruments. An Ariane 44P launcher put ISO into orbit on 17 November 1995.

ISO's supply of superfluid helium, which keeps the telescope and instruments cold, is expected to run out around the end of 1997, giving it a life several months longer than required in the original specification. Requests from the world's astronomers for observations with ISO have always far exceeded the available operating time even though the spacecraft's controllers at the Villafranca site supervise an average of 45 astronomical observations every day. esa

Hydrogen Cloud Around Hale-Bopp

A huge cloud of hydrogen surrounded Comet Hale-Bopp when it neared the Sun in the spring of 1997. Ultraviolet light, charted by the SWAN instrument on ESA's SOHO spacecraft, revealed a cloud 100 million kilometres wide and diminishing in intensity outwards (contour lines, Fig. 1). It far exceeded the great comet's visible tail (inset photograph).

Although generated by a comet nucleus perhaps 40 kilometres in diameter, the hydrogen cloud was 70 times wider than the Sun itself (yellow dot to scale) and ten times wider than the hydrogen cloud of Comet Hyakutake observed by SWAN on SOHO in 1996.

Solar rays broke up water vapour released from the comet by the warmth of the Sun. The resulting hydrogen atoms shone in ultraviolet light invisible from the Earth's surface (even a satellite's view of the Hale-Bopp cloud would be spoiled by hydrogen around the Earth). Stationed 1.5 million kilometres out in space, SOHO had a clear view.

SWAN is the brainchild of Jean-Loup Bertaux and colleagues at the Service d'Aéronomie du CNRS (F) and the Finnish Meteorological Institute. Tuned to see hydrogen, SWAN scans the sky and studies the solar wind's effect on hydrogen atoms coming from interstellar space.

Michael Combi of the University of Michigan studies gas outflow from comets – local sources of hydrogen – using SWAN's maps. The unique SWAN observations of Comet Hale-Bopp imply that the outflow of water vapour peaked at almost 50 million tonnes a day.



Full Schedule for Ariane-4 Launchers

The last three Ariane launches successfully placed a total of five telecommunications satellites into geostationary transfer orbit.

On Wednesday 16 April (23:08 GMT), Ariane V95 (type 44LP, equipped with two liquid and two solid propellant boosters) lifted off with Thaicom 3 (Thailand) and BSAT-1a (Japan).

On Tuesday 3 June (11:20 GMT), Ariane V97 (type 44L, equipped with four liquid propellant boosters) lifted off with INMARSAT 3F4 (International) and INSAT 2D (India).

On Wednesday 25 June (23:45 GMT), Ariane V96 (type 44P, equipped with four solid propellant boosters) was launched carrying INTELSAT 802 (International).

The next Ariane launch is scheduled for 7 August and will carry PanAmSat 6, an international telecommunications satellite, into orbit.



Conference on Space Debris Stresses International Cooperation

More than 200 experts from 18 countries took part in the 2nd European Conference on Space Debris organised by the European Space Agency in Darmstadt, Germany, on 17-19 March 1997.

The papers presented at this conference have helped the space community to take stock of the current status of space debris. Guidelines and recommendations were discussed as to the measures required in order to minimise the problems caused by space debris, mainly associated with the risk of collisions with operational satellites and the potential danger for manned space flights.

Radar and optical telescopes regularly track over 10 000 "man-made" objects, 8500 of which are duly catalogued (spent satellites, upper launcher stages and fragments). Only a small portion (5%) of the trackable objects are operational spacecraft. In addition, there is a large



Figure 1. SOHO/SWAN Lyman-alpha scan, 1 April 1997.

Main image: SOHO (ESA & NASA) and SWAN Consortium

Inset photo of comet: Dennis di Cicco and Sky & Telescope

amount of untrackable fragments (70 000-150 000) of only 1-10 cm in size which also pose a danger to operational spacecraft in Low Earth Orbit (LEO) and in the geostationary ring.

Experts speaking at the conference emphasised that unless action is taken, the amount of space debris will continue to increase. They indicated that prevention of further debris is the only way to achieve mitigation. Clean-up of existing space debris would be impractical and financially unfeasible.

ESA and other space agencies are already involved in solutions to space debris prevention. Current measures aim to avoid explosions in space by venting upper launcher stages and repositioning spent geostationary satellites to higher "disposal" orbits (also known as graveyard orbits). However, in the long-term, even these measures may not be sufficient. In densely populated regions, selective removal of large objects may be necessary and their disposal achieved through controlled atmospheric re-entry leading to total disintegration and vaporisation from friction and heat.

Long-life and/or large spacecraft (manned or unmanned) will require shielding for protection against space debris. For example, ESA's Columbus Orbital Facility, the European laboratory module that will be permanently attached to the International Space Station, will be fitted with special meteorite/debris aluminium shielding. Smaller spacecraft with a relatively short operational life already have basic protection in their design that, in general, provides adequate resistance.

The conference participants also stressed that the problems related to space debris can only be solved through international cooperation. The Inter Agency Space Debris Coordination Committee (IADC) will play a decisive role in defining cost-effective mitigation measures.

The results from this conference and the upcoming discussions within the IADC will provide a technical basis for deliberations on space debris to be held by the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS). 

ESA Highlights from the Paris Air Show

The 42nd Paris Air Show successfully took place at Le Bourget airfield (15-22 June), attracting aerospace professionals and enthusiasts from all over the world.

ESA featured a spectacular display inside a pavilion with a surface area of almost 1000 m², alongside a full-scale mock-up of Ariane-5. The display included: a functioning replica of a mission control centre, with engineers and scientists simulating the control and operation of satellites in orbit; a 'virtual reality' theatre staging 3-D images of the International Space Station; and a 1:10 model of the International Space Station suspended from the ceiling.

Additionally, an evocative depiction of the landscape of Titan – the largest moon of Saturn – was the backdrop for a full-scale test model of ESA's Huygens space probe, scheduled for launch in October of this year on board the NASA Cassini orbiter. Another area of the pavilion highlighted technology transfer from space to the motor industry and health sector.

A number of ESA Directors visited many of the exhibitions and held briefings for the press. These commenced with a press breakfast held by Jean-Marie Luton, ESA Director General and Antonio Rodotà, ESA Director General designate, on Monday 16 June. Further briefings regarding current and future programmes were given by R-M. Bonnet, Director of Science; R. Collette, Director of Application Programmes; F. Engström, Director of Launchers; J. Feustel-Büechl, Director of Manned Spaceflight and Microgravity.

ESA astronauts were also in attendance, captivating youngsters from ESA Member States during a specially held space class and lunch on Saturday 21 June. During the ESA astronauts' event on 18 June, Jean-François Clervoy made his first public appearance since returning to Earth following the STS-84 flight. 





Figure 1. The ESA Pavilion at the 42nd Paris Air Show, Le Bourget, 15-22 June

Figure 2. The ESA exhibition included a full-scale test model of ESA's Huygens space probe with a backdrop of Titan, Saturn's largest moon (right), a 1:10 model of the International Space Station suspended from the ceiling (left), and a mission control centre (centre back)

Figure 3. The D/MSM press conference with (from left to right) Mr H. Oser, Head of ESA Astronauts Centre, Mr J. Feustel-Büechli, Director of Manned Spaceflight and Microgravity, Mr F. Longhurst, Head of Manned Spaceflight Programme Department, Mr A. Thirkettle, Head of COF Projects Division, Mr P. Amadiou, Head of ATV/CTV Projects Division

Figure 4. The ESA Astronauts event featured a press conference with ESA European Astronauts Centre representatives and ESA/NASA STS-84 mission astronauts: (from left to right) Mr C. Noriega, NASA, Mr J-F. Clervoy, ESA, Mr H. Oser, Head of ESA Astronauts Centre, Mr C. Precourt, NASA, Mr E. Lu, NASA



3



4

Director-Level Appointments

New Director General takes over at ESA

Antonio Rodotà, of Italian nationality, has taken over as head of the European Space Agency as per 1 July. Appointed for a period of four years, he will see ESA into the 21st century, succeeding the French Director General, Jean-Marie Luton, who served as DG for nearly seven years.

At 61, Mr Rodotà has had many years experience in European industry. "It is a real challenge but interest in the space sector is increasing all over the world and I see a rosy future for ESA. It must adapt to the rapid changes that are taking place and must also continue to play its part in supporting industry. This collective effort will guarantee that it has a bright future".



Mr A. Rodotà, new ESA Director General

Director of Launchers term extended

At its last meeting held in Paris on 25 June, the ESA Council, on the recommendation of the Director General, extended the term of office of Mr Fredrik Engström, Director of Launchers, until the end of September 2000.



Mr F Engström, Director of Launchers

ESA's former DG Receives Commendation

On the occasion of a dinner in Paris on 25 June, Mr Jacques-Louis Lions, Professor at the 'Collège de France' and President of the French Academy of Sciences, presented Mr Jean-Marie Luton with the insignia of the 'Commandeur dans l'Ordre

National du Mérite' in the presence of ESA Council Delegates as well as Mr Antonio Rodotà, Mr Luton's successor as Director General and Professor Reimar Lüst, Director General of ESA from 1984-1990.



Mr K.-E. Reuter (left), ESA's Head of Cabinet, helps in the ceremonial decoration of Mr J.-M. Luton by Professor J.-L. Lions (right)

Director of Manned Spaceflight and Microgravity accepts contract renewal

Mr Jörg Feustel-Büechl, Director of Manned Spaceflight and Microgravity, has accepted ESA Council's 25 June offer of a further four-year mandate (to October 2002).

Mr Feustel-Büechl thus remains in charge of organising the European contribution to the International Space Station and the related ESA programmes, notably the Columbus Orbital Facility (COF), the Automated Transfer Vehicle (ATV), the European Robotic Arm (ERA), the European Astronaut Centre (EAC) and the Microgravity (life and materials science) Programme.



Mr J. Feustel-Büechl, Director of Manned Spaceflight and Microgravity

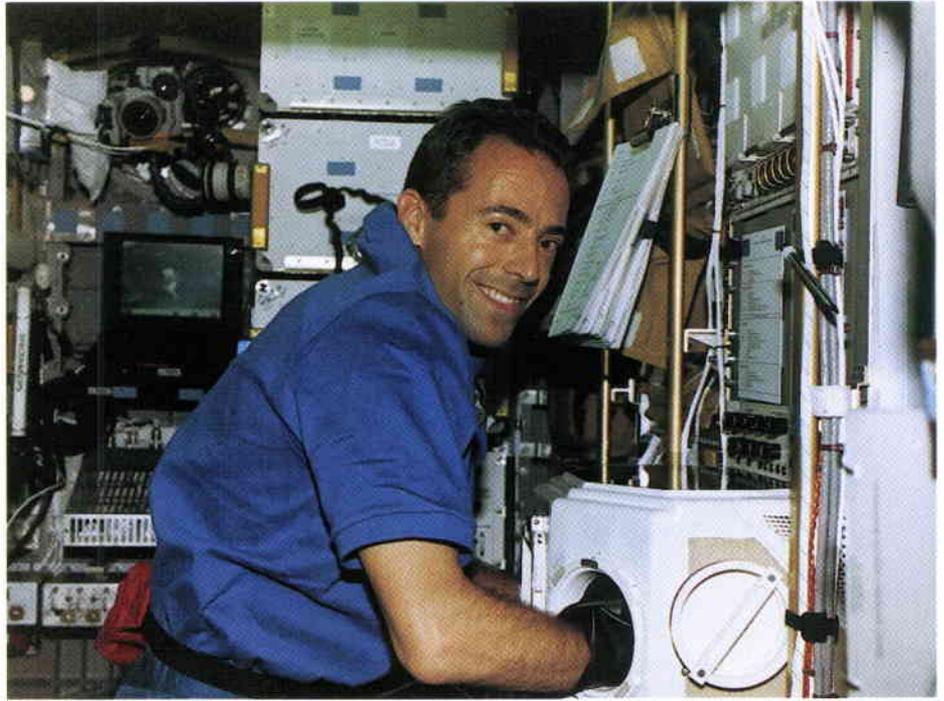
Atlantis Launches Europe on New Phase of Space Operations

The Space Shuttle Atlantis mission STS-84, carrying ESA astronaut Jean-François Clervoy, was launched on 15 May from Pad 39a at the Kennedy Space Center in Florida.

Clervoy, who has now completed two Space Shuttle missions, had a number of crucial tasks onboard, including monitoring systems performance at lift-off and during docking, activating Spacehab, coordinating the transfer of supplies to Mir and being prepared for any emergency work outside the complex. The other crew members were: Commander, Charles J. Precourt; Pilot, Eileen M. Collins; and Mission Specialists, Michael Foale, Carlos I. Noriega, Edward T. Lu, Elena Kondakova (Russian Cosmonaut).

During the STS-84 mission, Atlantis' crew spent five days docked to the Russian space station Mir. The STS-84/Mir-23 team transferred 7000 pounds of experiments, hardware, food and clothing to and from the Station. NASA astronaut Jerry Linenger was brought home after four months aboard Mir. He has been replaced on Mir by Mike Foale, who is scheduled to stay on the station until September this year.

The mission carried ESA's Biorack - one of the most successful and versatile space experimentation facilities - as well



ESA Astronaut Jean-François Clervoy (Mission Specialist 1 and Payload Commander on STS-84) working on one of the Biorack experiments in the Glovebox

as a solidification experiment called MOMO. The Biorack was the main science payload and housed a series of microgravity experiments from scientists in France, Germany and the United States. Those scientists will now begin to analyse the data collected during the mission.

During the Shuttle's approach and departure from Mir, new ESA-developed technology to be used in automated rendezvous and docking was successfully tested. Data from the experiment will help European engineers develop technology for ESA's unmanned Automated Transfer

Vehicle (ATV) which will approach and depart the International Space Station on regular supply missions early in the next century. The technology will be tested again on the next Shuttle-to-Mir mission (STS-86) in September.

After nine days in Space, the Space Shuttle Atlantis touched down at the Shuttle Landing Facility at Kennedy Space Center in Florida at 09h28 local time on Saturday 24 May.

After Atlantis' touchdown, Mr Jörg Feustel-Büechel, ESA's Director of Manned Spaceflight and Microgravity, hailed the mission as a great success for Europe. "This has been an excellent flight in terms of the valuable manned and technological experience that we have gained in preparation for our role on the International Space Station".

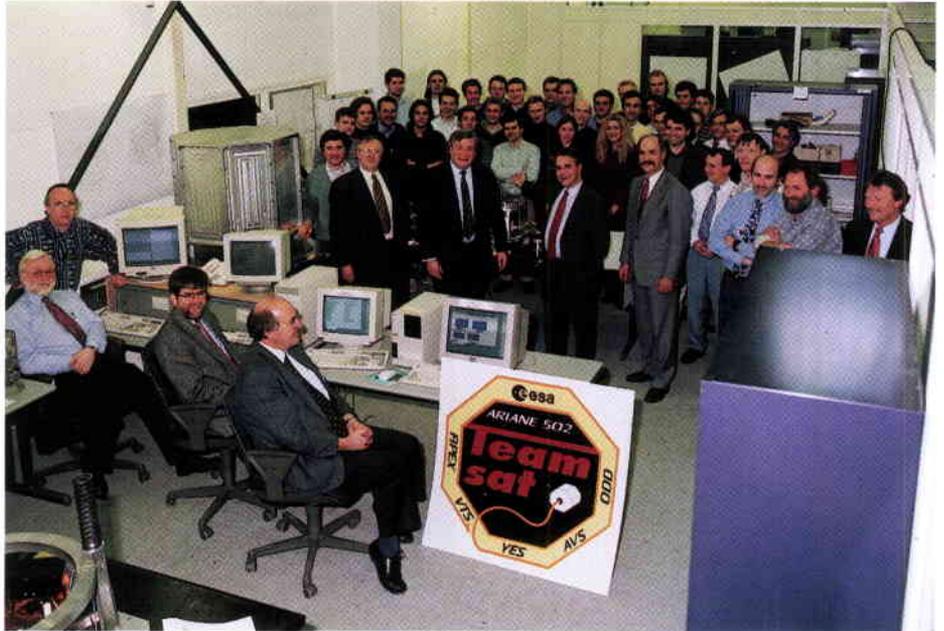


The STS-84 crew with the complete set of Biorack experiment hardware used for the flight. From right to left: Eileen M. Collins (Pilot), Carlos I. Noriega (Mission Specialist), Edward T. Lu (Mission Specialist), Elena Kondakova (Mission specialist, Russian Cosmonaut), Charles J. Precourt (Mission Commander), Jean-François Clervoy (Mission Specialist and Payload Commander, ESA Astronaut), Julia Bateman (Russian Interpreter). Not in the picture is C. Michael Foale who was carried up to Mir where he replaced Jerry M. Linenger who returned to Earth with the STS-84 crew

Ariane 502 Launch Campaign Begins

The Director General of ESA and the Chairman of CNES jointly gave the go-ahead for the Ariane 502 flight launch campaign to start on 16 June following the Flight Readiness Review (5-6 June).

Preparations are now under way at the Guiana Space Centre, Europe's spaceport at Kourou in French Guiana. Initial tasks include mechanical, fluid and electrical integration of the cryogenic main stage, the solid booster stage, the vehicle equipment bay and the upper stage of the launcher in the Launcher Integration Building. Preparatory work has also started in the Final Assembly Building on the upper composite – the Speltra, the fairing and the payload consisting of two technological instrument platforms, Maqsat H and B, and two satellites, Amsat P3D (an international amateur radio satellite) and TeamSat (ESA). The latter, built at ESTEC, consists of 5 European technology experiments. This ad hoc project was created in response to a flight opportunity with the second test flight of Ariane-5. The project team in-



volves over 40 young European engineers and students, supervised and supported by ESA staff.

Various tests and, in particular, flight programme functional simulations are continuing, leading up to a target launch date as from the end of September this year.



TeamSat was developed in ESTEC by young European engineers and students with the support of ESA staff. The team and staff are pictured here during a visit by ESA's DG. Standing behind the ground station equipment, from left to right are: Mr M. Bandecchi, TeamSat's project engineer and integration manager, Mr E. Slachmuylders, Mr D. Dale, Mr J-M. Luton, Mr W. Ockels, TeamSat's project manager. On one of the satellite panels (back left), all the names of the team members are engraved.

Mr. Rodotà Visits ESTEC

On 10 June, Mr Antonio Rodotà visited ESTEC for the first time after being nominated ESA Director General designate. Organised by Mr N. de Boer, Head of D/TOS Staff Office, the half day's activities succeeded in giving Mr Rodotà a broad impression of ESTEC and its facilities.



As a start to the programme, Mr Rodotà was given a tour of the ESTEC test facilities by Mr C. Stavrinidis, Head of Mechanical Systems Department.

This was followed by a visit to the Space Science laboratories accompanied by Mr M. Huber, Head of Space Science Department. Mr Rodotà was shown the Super Conducting Tunnelling Junctions (STJ) laboratory by Mr A. Peacock and the Midas laboratory by Mr R. Schmidt.

Mr L. Adams, Head of Radiation Effects and Analysis Techniques Unit, then guided Mr Rodotà through the Components laboratories concluding the tour of the ESTEC facilities.

A meeting with the Chairman of the ESTEC Staff Association, Mr D. Campbell and SAC representatives preceded an address to all staff during which Mr Rodotà outlined his vision for ESA in the coming years to an attentive audience.



ESA and RSA Initial 'Partnership Charter'

ESA and the Russian Space Agency (RSA) launched a 'Partnership Charter' – to expand the exchange of expertise between Russian and West European aerospace professionals – in the ESA Pavilion of the Paris Air Show on 16 June.

Mr Jean-Marie Luton, ESA's Director General, and Mr Yuri Koptev, RSA's Director General initialled the charter to which all organisations, institutes and industrial suppliers in the Russian and West European aerospace sectors are invited to subscribe. The partnership is also receiving active support from the European Commission, in the framework of its TACIS cooperation programmes with Russia.

The aim of the partnership is to strengthen the many links that have been developed in space cooperation over the past decade through the arrangement of exchanges of information on working methods and staff training.

The initial programme of activities, starting in the second half of this year, calls for seminars and presentations, specifically designed for high-level Russian personnel, on international law, industrial contracts and management of space projects. These will be held in Moscow and will be primarily run by the International Space University (ISU, Strasbourg, France) teaching staff, with expertise to be contributed by Western space industry professionals.

Seminars and round table discussions are also envisaged in fields in which Russia has outstanding first-hand experience (e.g. space transport, manned flight).

The overall cost of activities envisaged for 1997 amounts to some 200 000 ECU, to be shared by all the partners. 



Mr Jean-Marie Luton, ESA's Director General (left) and Mr Yuri Koptev, RSA's Director General (right) finalise the signing of a Russian-West European aerospace 'Partnership Charter'

Space Applications in the Mediterranean Region

Cooperation in space technologies between Europe and the Mediterranean countries made a significant step forward following a workshop on 'Space Applications in the Euro Med Region' held in Cairo, 26-27 May and promoted by ESA, the European Commission and the Arab Institute of Navigation. Some 250 officials and industrialists from the 12 Mediterranean countries* and the European Union (EU) attended.

The workshop highlighted space technology applications, emphasising their potential, costs and required skills by using real examples in the fields of telecommunications, remote-sensing and navigation. It is expected that a number of possible projects will stem from this workshop as Mediterranean partnerships or as potential candidates for cooperation with ESA and the EU, in the fields of risk management, Earth Observation networks and telecommunications.

* Algeria, Cyprus, Egypt, Israel, Jordan, Malta, Morocco, Syria, Tunisia, Turkey, Lebanon, Palestine



The workshop on "Space Applications in the Euro Med Region" discussed and demonstrated potential space application projects for Mediterranean countries

Potential areas of interest for ESA were identified as a result of this workshop. An extension of the EGNOS programme on global satellite navigation could be envisaged for the North African region and promoted together with activities in the fields of telecommunications such as telemedicine. Cooperation on Earth Observation could be strengthened where ESA already has a widely recognised expertise such as coastal zone management, water resources management and monitoring of water pollution with the use of ESA's ERS satellite data. 

HIPPARCOS Venice '97

"The winning card for Europe – and for Venice". That was how the Mayor of Venice, Massimo Cacciari, characterised research and development, in welcoming the world's astronomers to his city at the start of the Hipparcos Symposium (13-16 May). A major European contribution to advanced astronomy was celebrated in the 16th-Century monastery of San Giorgio Maggiore, on an island facing the main waterfront of Venice.

This unique Symposium was dedicated to the scientific results of the Hipparcos mission based on the analysis of data released to Principal Investigators during 1996 and early 1997. It also provided the

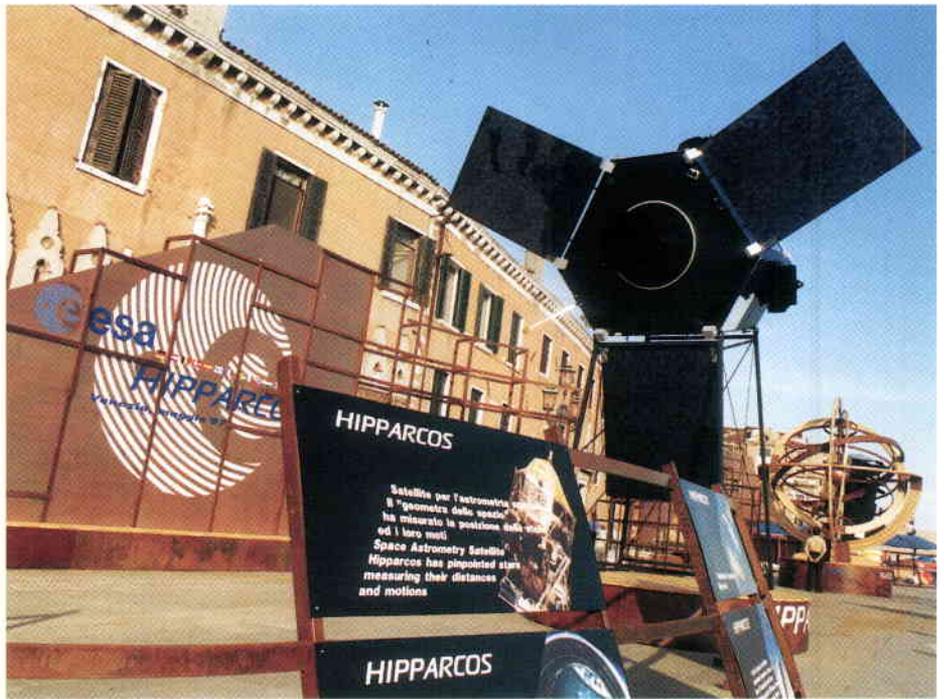
opportunity to present the Hipparcos and Tycho Catalogues to the scientific community. The Proceedings of this Symposium have already been published.

In a special opening session, the history of the European Space Agency's Hipparcos mission was described by 14 of the scientists and engineers most closely responsible for it. They summarised their efforts of 17 years to conceive, build and fly the satellite, and translate its observations into catalogues of the stars. Built for ESA by Europe's aerospace industry, and sent into orbit by an Ariane-4 launcher, the Hipparcos satellite scanned the sky for nearly four years, between 1989 and 1993, measuring angles between stars. Protracted calculations by multinational teams then produced the Hipparcos Catalogue giving the positions and motions of 118 000 stars with 100 times the precision of previous surveys. The accompanying Tycho Catalogue contains a million stars charted with lesser but still unprecedented accuracy.

High drama punctuated the years of patient work when, after its launch, Hipparcos failed to reach its intended orbit. "It was a real shock," said Dietmar Heger of ESA's European Space Operations Centre (Darmstadt). The initial prediction was that Hipparcos would last for only 9 months and accomplish only 5-10 % of its science programme. Quick action by the multinational teams extended the satellite's life, and ground stations, hurriedly recruited from around the world, enabled Hipparcos to fulfil its task of pinpointing the stars.

Many of the 240 participants gave their early conclusions during the 4 day Symposium, and over 100 scientific posters revealed the impact that Hipparcos data are going to have on astronomy. The results will affect many branches of astronomy from asteroids to cosmology, but most notably the theories of stellar physics and evolution.

The future of space astrometry research was also considered during the Symposium. Experts discussed plans for a super-Hipparcos for the 21st Century. GAIA, Global Astrometric Interferometer for Astrophysics, is a leading concept under study by ESA. It would carry two or possibly three pairs of mirrors spaced a few metres apart and orientated to look in different directions in the sky. The



In the foreground, ESA's Hipparcos satellite on display in Venice. Behind it is a model of an armillary sphere, used by Hipparchus (190-125 BC), the first modern astronomer, to determine the position of heavenly bodies, "thus bequeathing the heavens as a legacy to all mankind".

intended accuracy of star-fixing, to within about a billionth of a degree, makes GAIA an unprecedented engineering challenge. Other missions mooted include a German proposal, DIVA, for a small-scale interferometer which could be a step along the road to GAIA's development. DIVA would be able to chart a million stars with an accuracy three times better than that of Hipparcos. Furthermore, the Japanese have proposed a concept called LIGHT and NASA one called SIM.

The enthusiasm of the Hipparcos astronomers for GAIA is, however, not dampened by uncertainties in ESA's Long-Term Science Programme. The prospects for GAIA have to be seen in the context of present efforts by ESA's planners to secure a steady sequence of cornerstone missions, for which it may be a candidate.

At the close of the Celebration Session the President of the International Astronomical Union, Lodewijk Woltjer of the Observatoire de Haute-Provence, France, hailed Hipparcos as "a triple triumph" – for the scientific community, for European engineering, and for European cooperation. He reiterated the importance of continued scientific space missions for Europe.

The Hipparcos and Tycho Catalogues are available from ESA Publications Division in the form of a 16-volume hard-bound printed catalogue and a set of 6 CD-ROMs, as ESA Special Publication SP-1200.

The Proceedings of the Hipparcos Venice '97 Symposium are available from ESA Publications Division as ESA Special Publication SP-402.

For ordering information please contact:

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Awards for Valuable Contributions to the International Space Station

ESA has instituted a special award to honour those who are actively preparing the way, and creating the means for making the European contribution to the International Space Station (ISS) a reality. This award will be presented annually to a number of individuals selected in "appreciation of their dedication and outstanding performance which has made a significant contribution to ESA's participation in the International Space Station".

The first such award ceremony took place on a canal-boat cruise around Amsterdam on 15 July. In the presence of ESA's Director General, Antonio Rodotà, and representatives from other space agencies, embassies, and major industrial companies involved in the ISS Programme, ESA's Director of Manned Spaceflight and Microgravity, Jörg Feustel-Büechl, presented the award to the first four winners: Mr P.-G. Winters, Mr J.-B. Mennicken, Mr J. Zimmerman and Mr V. Nikolaev.

In his speech, Mr Feustel-Büechl thanked Mr Winters, who was Chairman of the ESA Council at the time of the Ministerial Council Meeting in Toulouse in October 1995, for the decisive role that he had played in achieving a positive decision on Europe's participation in the International Space Station Programme. Mr Feustel-Büechl also noted the fact that, as the Head of the Dutch Delegation to ESA, Mr Winters had been among the very first "confessors" who had joined the Programme, since the Netherlands were one of the protagonists of the so-called "Early Delivery Items" which paved the way for European participation in the early utilisation of the Station before the arrival of Europe's Columbus Laboratory.

In presenting the award to Mr Mennicken, Director General of the German Space Agency (DARA), Mr Feustel-Büechl thanked him for his active support of the International Space Station not only within the ESA decision-making bodies, but also vis-à-vis the decision-makers, the media and the public inside Germany, which is one of the major contributors to the ESA ISS Programme. He also underlined the fact that, in the light of all of the political priorities and financial constraints resulting from German reunification, Mr Mennicken could certainly not have had an easy task in this respect.

In giving the award to Mr Zimmerman, who had been NASA's European Representative for many years, Mr Feustel-Büechl explained that Mr Zimmerman had not only served as an ambassador for NASA in Europe, but he had also been a staunch advocate of Europe's views and position within NASA on numerous occasions. He therefore presented the award to Mr Zimmerman for his untiring support of NASA - ESA cooperation.

One of the essential ingredients of the International Space Station Programme is Russia's participation. Given that just a few years ago, the two space communities in the West and in the East were still largely separated from one another and the key players in the two communities had minimal contact, one can understand how important it was when the ISS partnership began for ESA to have "pathfinders" who could guide it in establishing closer collaboration within the Russian space community. One of these guides has been Viktor Nikolaev, who was honoured for his active involvement in fostering cooperation between Russia and Europe.



Mr P.-G. Winters



Mr J.-B. Mennicken

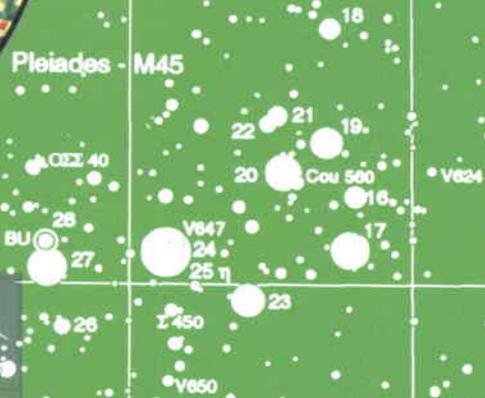
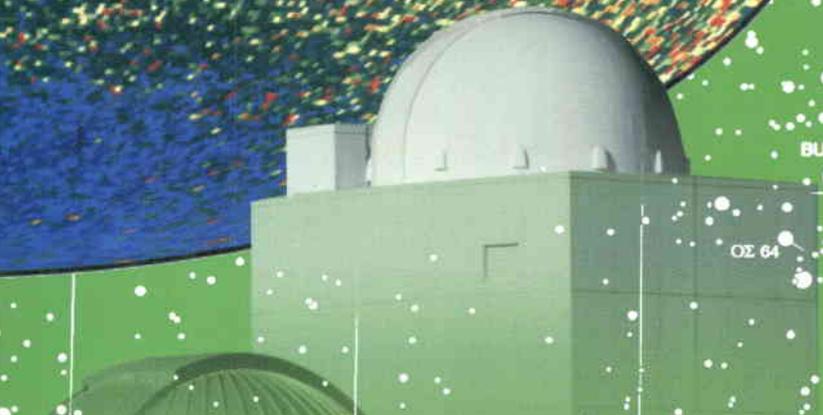
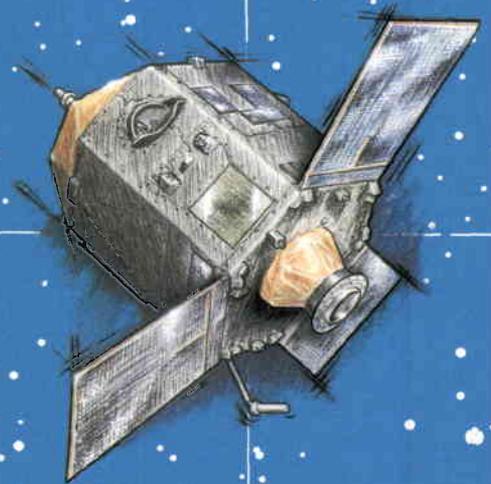
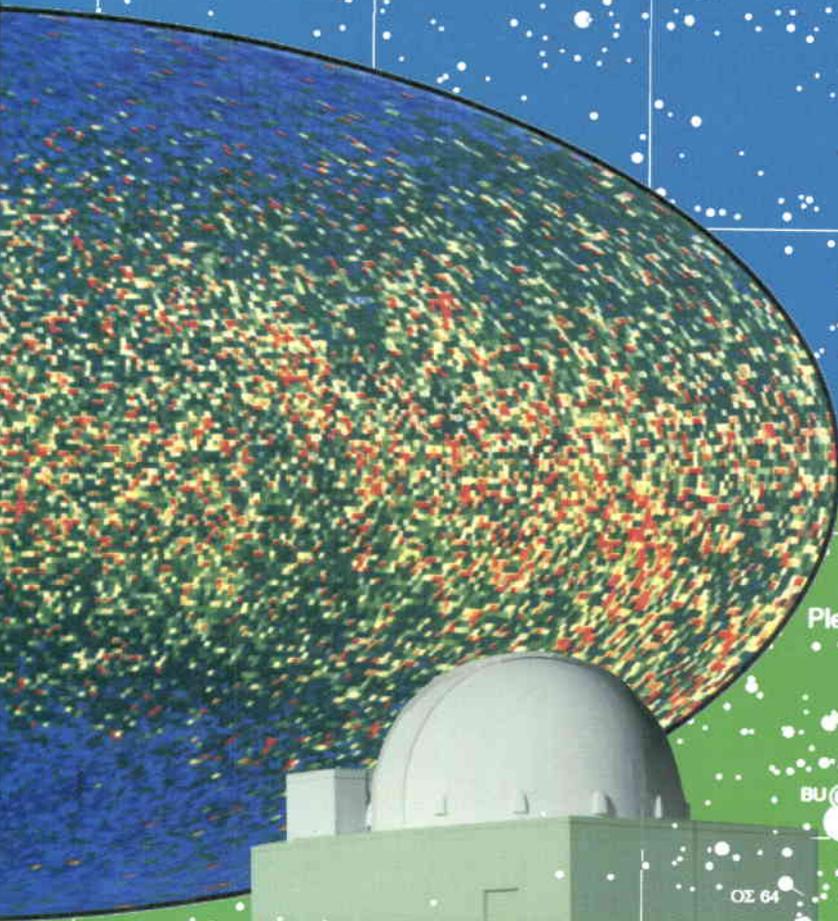


Mr J. Zimmerman



Mr V. Nikolaev

The Hipparcos and Tycho Catalogues





The Mission Products

The principal parts of the Hipparcos Catalogue are provided in both printed and machine-readable form. Tycho Catalogue results are provided in machine-readable form only. The printed volumes include a description of the Hipparcos and Tycho Catalogues and associated annexes, a description of the satellite operational phase, a description of the corresponding data analysis tasks, and the final data.

The definitive mission products are also released as a set of ASCII files on a series of CD-ROMs, which contain all of the printed catalogue information as well as some additional data. Auxiliary files containing results from intermediate stages of the data processing, of relevance for the more-specialised user, are also included.

The Hipparcos Mission

The Hipparcos space astrometry mission was accepted within the European Space Agency's scientific programme in 1980. The Hipparcos satellite was designed and constructed under ESA responsibility by a European industrial consortium led by Matra Marconi Space (France) and Alenia Spazio (Italy), and launched by Ariane-4 on 8 August 1989. High-quality scientific data were acquired between November 1989 and March 1993. The scientific aspects of the mission were undertaken by nationally-funded scientific institutes. All of the scientific goals motivating the mission's adoption in 1980 were surpassed, in terms of astrometric accuracy, photometry, and numbers of stars.

The global data analysis tasks, proceeding from nearly 1000 Gbit of satellite data to the final catalogues, were undertaken by three scientific consortia: the NDAC and FAST Consortia, together responsible for the production of the Hipparcos Catalogue; and the Tycho Consortium, responsible for the production of the Tycho Catalogue. A fourth scientific consortium, the INCA Consortium, was responsible for the construction of the Hipparcos observing programme. The production of the Hipparcos and Tycho Catalogues marks the formal end of the involvement in the mission by ESA and the four scientific consortia.

The Hipparcos and Tycho Catalogues

The final products of the European Space Agency's Hipparcos mission are two major stellar catalogues, the Hipparcos Catalogue and the Tycho Catalogue.

Each catalogue includes a large quantity of very high quality astrometric and photometric data. The astrometric data in the Hipparcos Catalogue is of unprecedented accuracy: positions at the catalogue epoch (J1991.25), annual proper motions, and trigonometric parallaxes, have a median accuracy of approximately 1 milliarcsec. The Hipparcos Catalogue includes annexes featuring variability and double/multiple star data for many thousands of stars discovered or measured by the satellite. The Hipparcos and Tycho Catalogues will remain the definitive astrometric stellar catalogues for many years.

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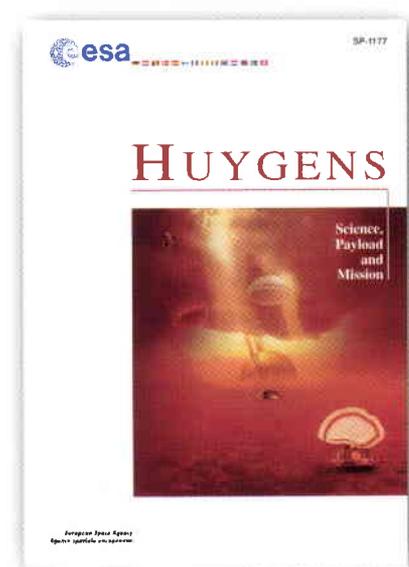
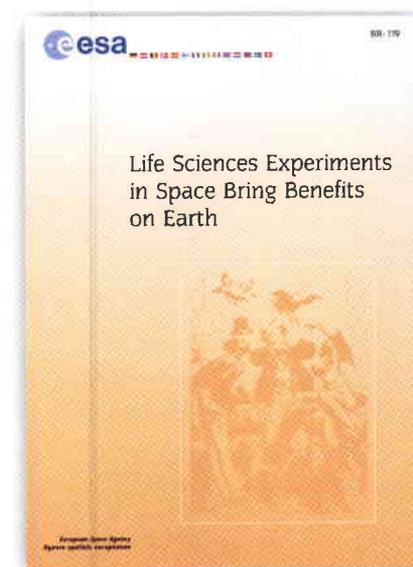
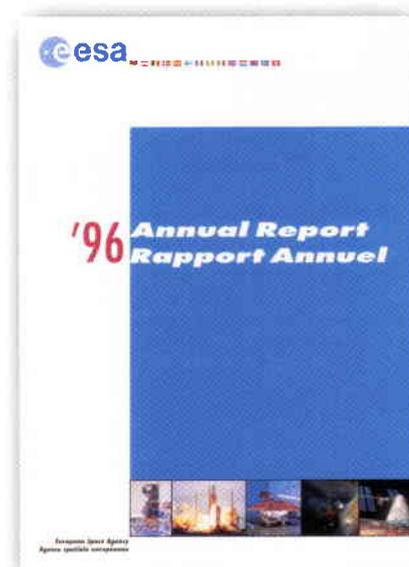
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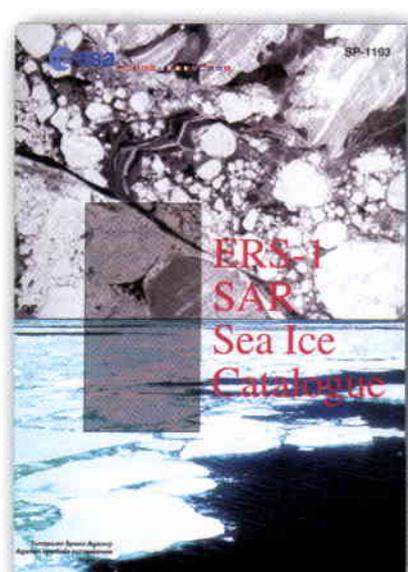
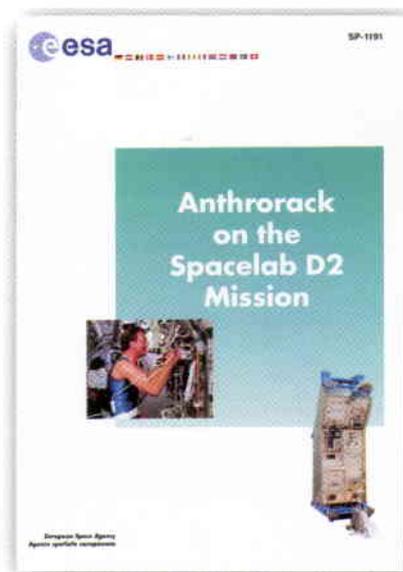
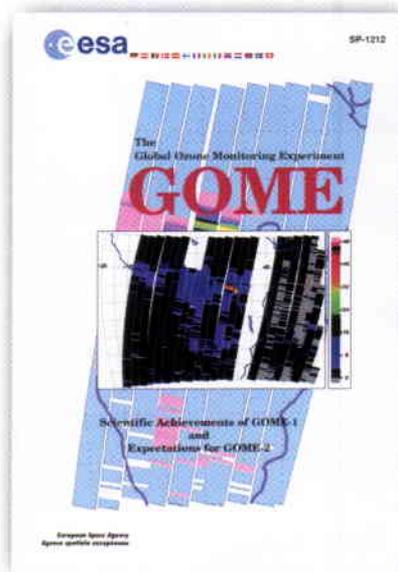
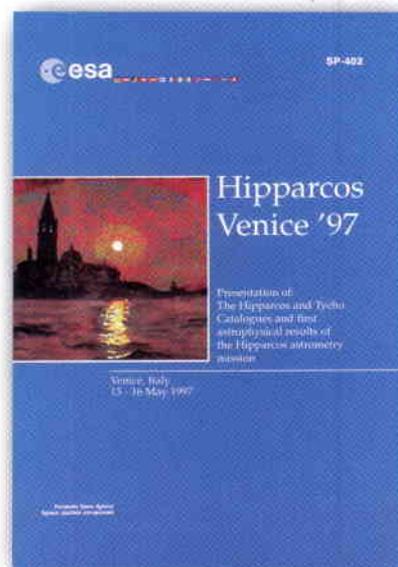
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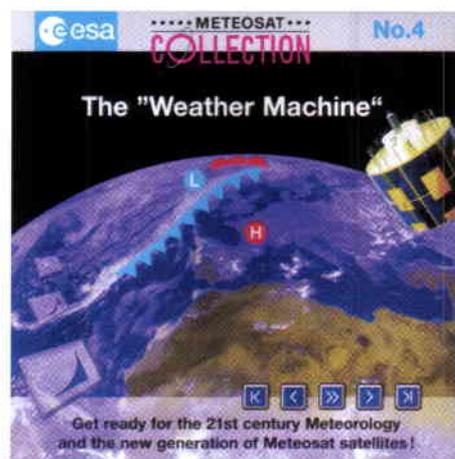
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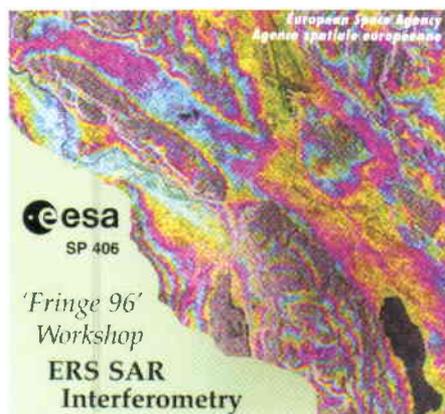
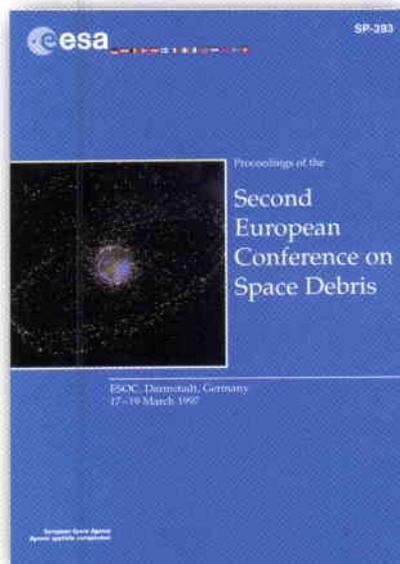
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