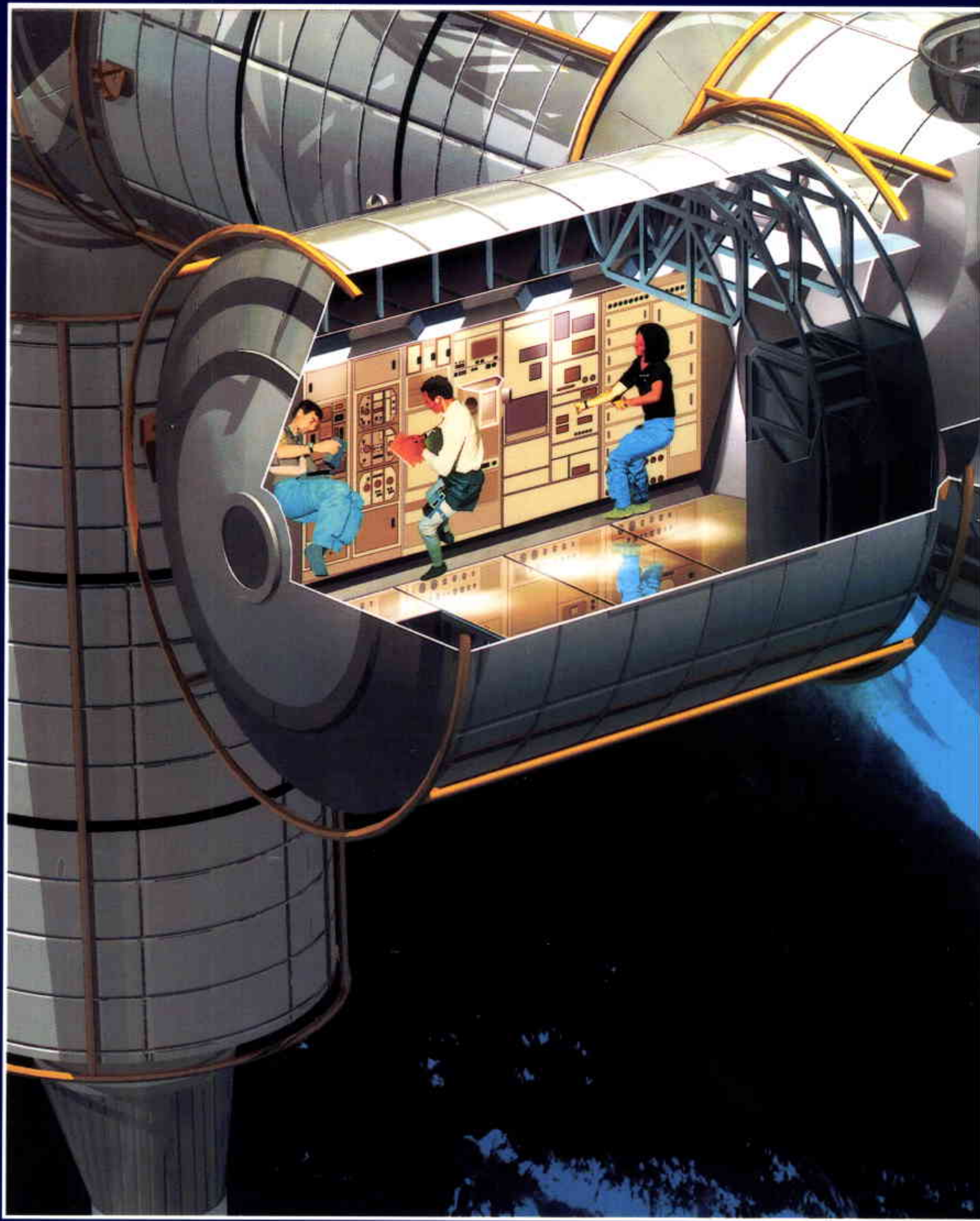
# esa bulletin

number 90 - may 1997



European Space Agency
Agence spatiale européenne

## european space agency

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(b) by elaborating and implementing activities and programmes in the space field;
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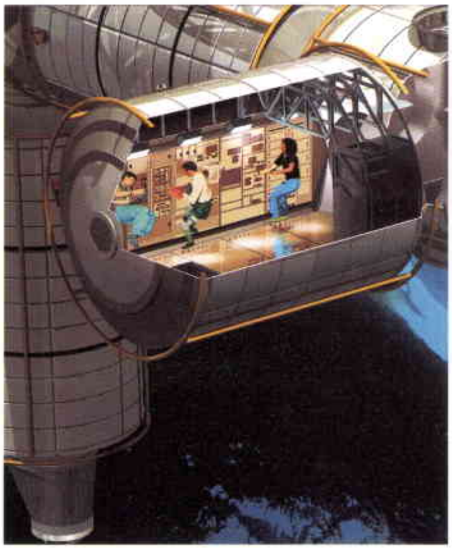

Cover: Artist's impression of the Columbus Orbital Facility (COF), by D. Ducros. See article on page 6.



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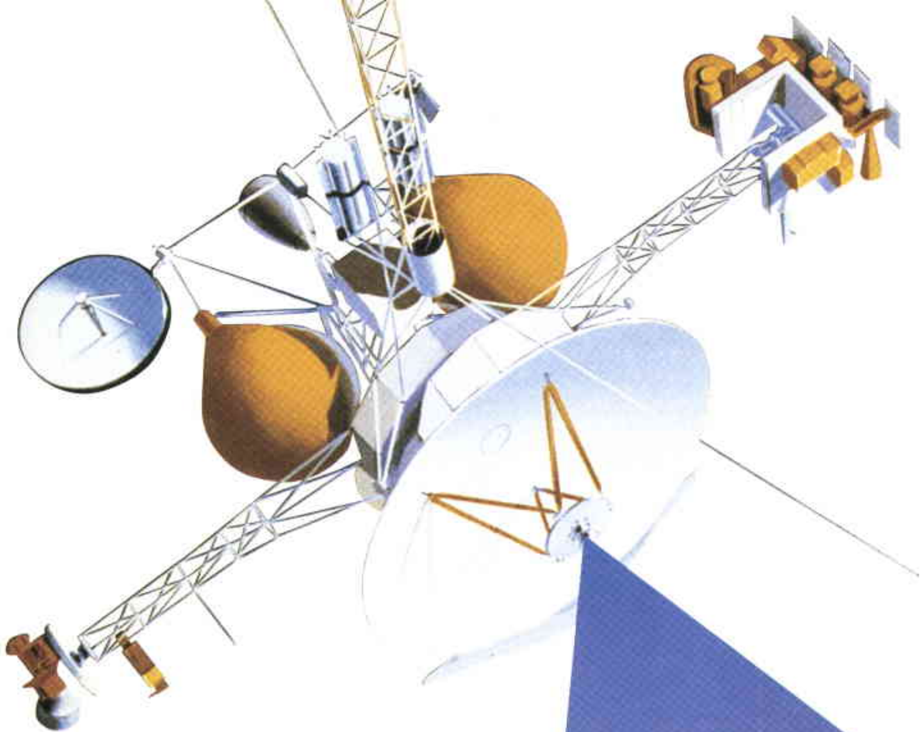


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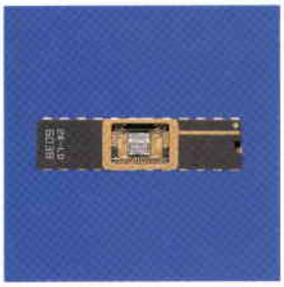

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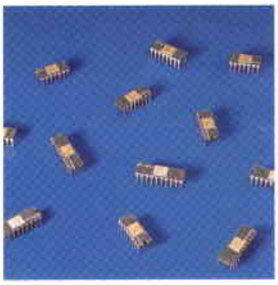

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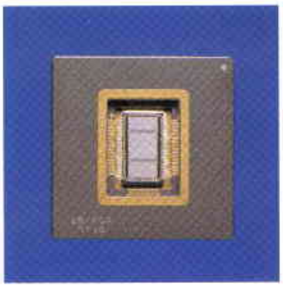

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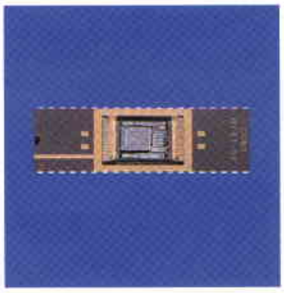

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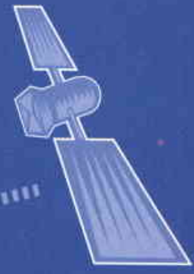


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# The Microgravity Facilities for Columbus Programme

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**The Microgravity Facilities for Columbus Programme was formally initiated in January 1997. However, most of the necessary preparatory activities had already been started over the last few years, building on the Agency's more than two decades of experience in conducting microgravity experiments in space. The Programme is the main ESA contribution to the utilisation of the International Space Station and the experiments that will be carried out in its facilities will provide a much-needed boost to the European scientific community. Equally importantly, they will greatly increase the competitiveness of European Industry by fostering innovative research, which is a major priority for both ESA and the European Union as we approach the new millennium.**

## Introduction

The European participation in the International Space Station Programme was confirmed at the ESA Council Meeting at Ministerial Level in Toulouse in October 1995. In the framework of this participation, the Ministers approved several elements, including the development of the Columbus Orbital Facility (COF) and the programme to develop the facilities required for conducting microgravity experiments in the COF. The latter development effort is known as the 'Microgravity Facilities for Columbus (MFC) Programme'.

Microgravity research covers a wide range of activities such as fundamental physics, solidification physics (e.g. crystal growth, metallurgy), physical chemistry, fluid science, biology, biotechnology, human physiology and medicine. Until 1996 the microgravity effort was funded only via the European Microgravity Research Programmes EMIR-1 and -2. In January 1997 the MFC programme has been initiated, complementing EMIR-2; it covers the development of a set of multi-user microgravity facilities to be accommodated in the International Space Station, i.e. in the Columbus Orbital Facility [COF] and, via Cooperative Agreements with NASA, in the US Laboratory. The objective of the MFC Programme is to have, following the launch of the COF, the four disciplines (i.e. material and fluid sciences, biology and human physiology) constantly present on the International Space Station to maximise the return to the European scientists (Fig. 1).

The MFC Programme is the most important European contribution to the Space Station's utilisation and it will continue throughout the Station's lifetime, the first phase covering the years 1997 to 2003. It is anticipated that the Programme will give a strong boost to Europe-wide research and development efforts in the above-identified fields, because of the novelty of the research to be carried out and the possibility to run long-term experiments on the Station rather than the short-term experiments typical of the earlier Spacelab missions.

## Programmatics

The first phase of the MFC Programme (1997-2003) includes:

- the development of the following multi-user facilities:
  - the Biolab, to be launched in the COF
  - the Fluid Science Laboratory (FSL), to be launched in the COF
  - the European Physiology Modules (EPMs), to be launched in the COF
  - the Material Science Laboratory (MSL), which will be composed of two facilities, one to be accommodated in the US Laboratory and one in the COF.

Figure 2 shows the above facilities, together with their planned launch dates.

- the development of experiment hardware related to the above multi-user facilities (e.g. experiment containers for Biolab and fluid science, cartridges for material science, etc.)

- the preparation of the second-generation modules and facilities (e.g. another type of furnace, a bioreactor, new physiology equipment, upgraded diagnostics, etc.).

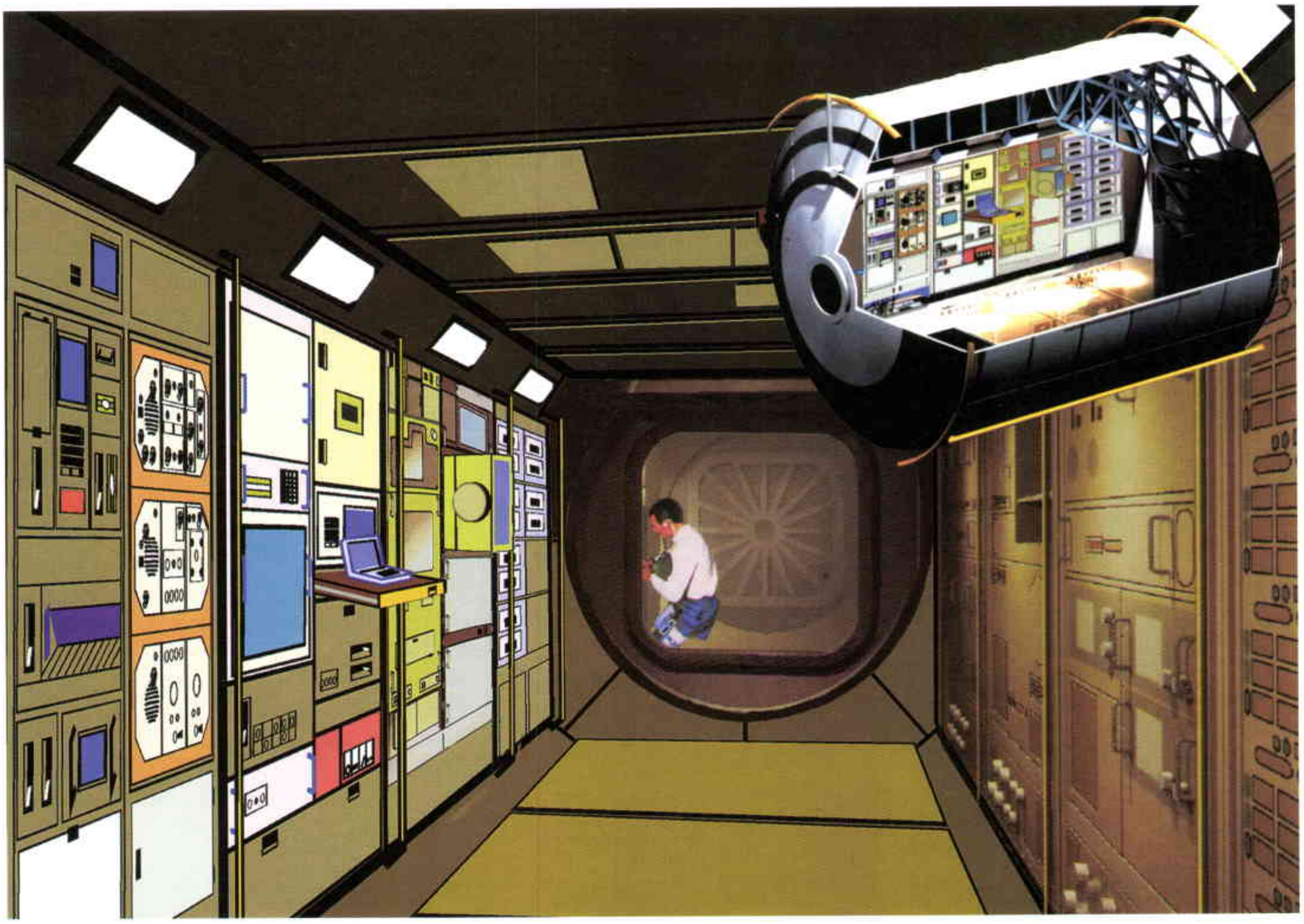


Figure 1. The MFC facilities: a view inside the Columbus Orbital Facility (COF)

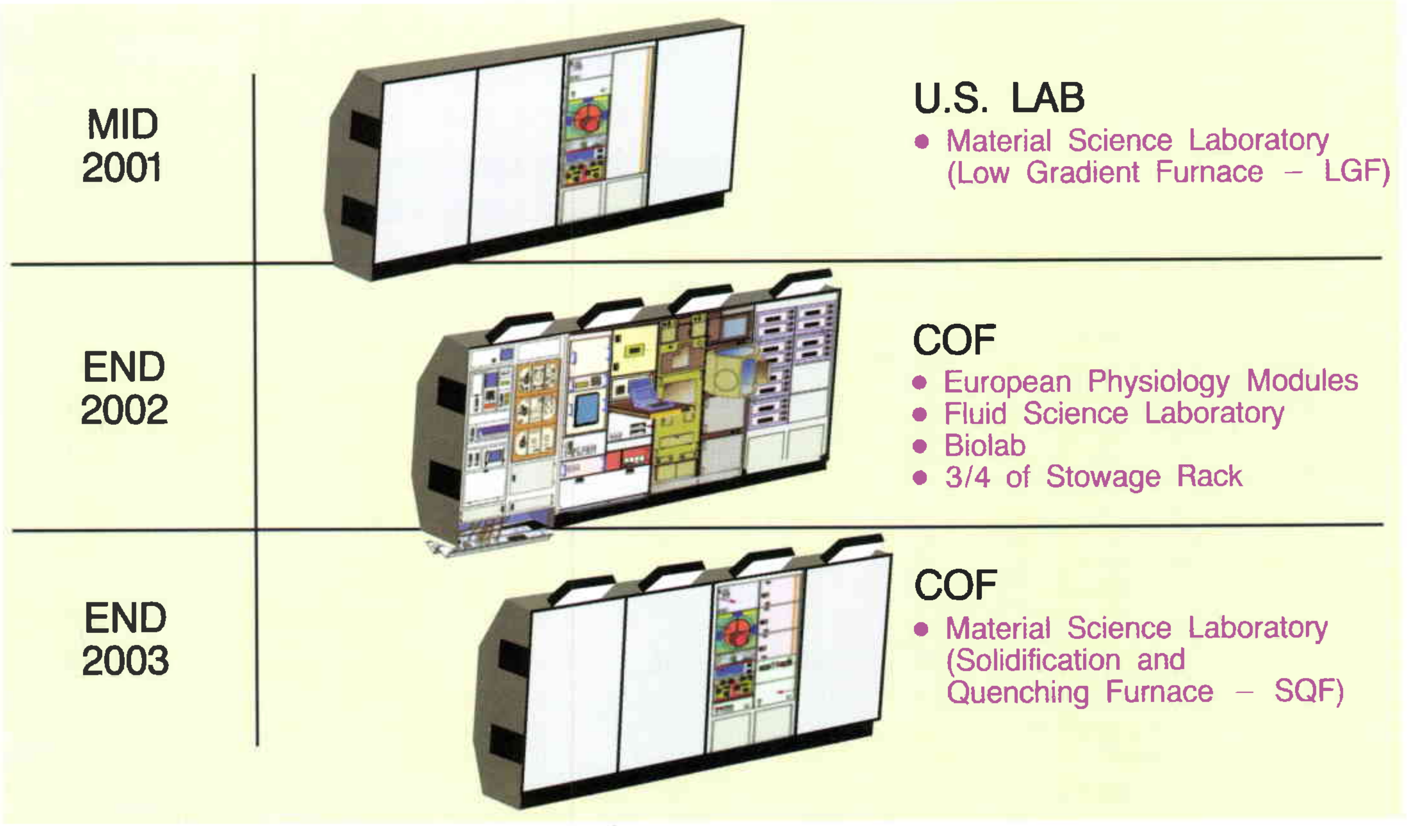



Figure 2. The MFC facilities and their launch dates

The activities required to support the scientific operation of the MFC facilities will be covered by the next phase of the MFC Programme.

The multi-user facilities will be modular in design to allow for upgrading and easy refurbishment and repair because of the long-term operations foreseen in the Space-Station era. The facilities are presently all in the development (Phase-B) stage, with the exception of the EPMs, which will shortly enter the design (Phase-A) stage.

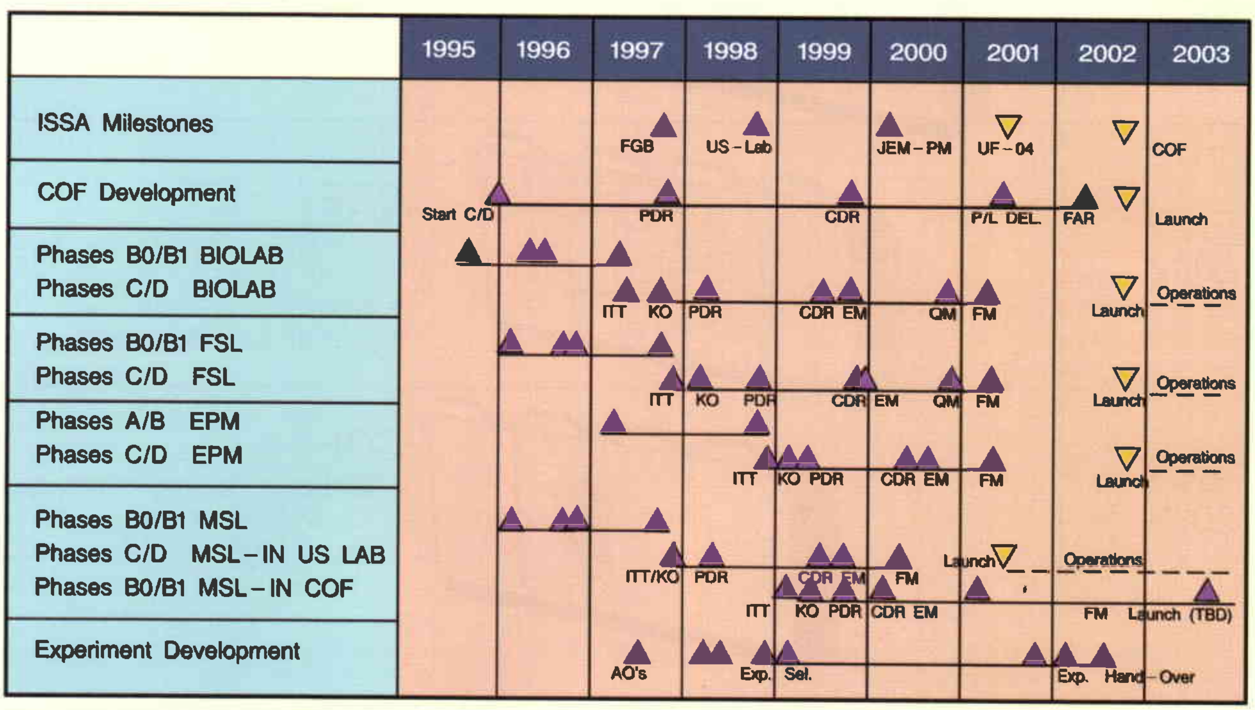
Each facility is supported by a dedicated science team that will follow its development and advise the Agency on its best scientific use. A major challenge of the Programme is to ensure that the scientific performances of the facilities respond to the scientists' needs. To achieve this, the scientists are attending all of the main design-phase reviews, and they have access to the critical breadboards (e.g. for Biolab the microscope and the observation system, for FSL the interferometric diagnostics) for testing purposes.

The maximum of synergy with the Agency's Technology Programmes has been sought in order to reduce development costs (e.g. experiment-container technology for Biolab, heater technology for MSL). The ESA approach has been to minimise the cost of experiment development by incorporating complex features in the facility design (e.g. advanced diagnostics). This serves to increase both the number of proposals submitted and the eventual scientific return. The experiments to be carried out in each facility will be selected from the proposals received in response to the relevant Announcements of Opportunity (AOs).

Three multi-user laboratories, as indicated above, are planned for launch inside the COF by the end of the year 2002 (Fig. 1). Together with these laboratories, there will be an allocated stowage volume (e.g. one quarter of the stowage rack for each facility) to upload a minimum set of spares for the initial maintenance, as well as the requisite experiment hardware (containers, cartridges, etc.). In the framework of the Space Station Agreements with the USA, ESA is allocated 51% usage of the COF, which is equivalent to five racks. The baseline composition for the first COF utilisation phase is: the Biolab, the Fluid Science Laboratory, the European Physiology Modules, a Stowage Rack and a European Drawer Rack. The MFC Programme will use up to 75% of the stowage volume allocated to ESA in the COF for the first launch, given that the Drawer Rack and one quarter of the Stowage Rack are not assigned to the MFC Programme.

The development schedule for each facility is indicated in Table 1. All facilities with the exception of the MSL in the US Lab. will make use of the Japanese International Standard Payload Racks (ISPRs) and also the Standard Payload Outfitting Equipment (SPOE) (e.g. standard payload computers, smoke sensors,

Table 1. The MFC development schedule




FSL= Fluid Science Laboratory; EPM= European Physiology Modules; MSL= Material Science Laboratory

*Table 2. MFC facilities scientfic/technical features*

| | BIOLAB | MSL | FSL | EPM |
|---|---|---|---|---|
| Research Field | • Cell culture<br>• Micro-organisms<br>• Small plants<br>• Small invertebrates<br>• Mechanism of radiation damage in cells and tissue | • Solidification physics<br>• Composite materials<br>• Crystal growth<br>• Measurement of material properties | • Bubble formation and growth<br>• Condensation phenomena<br>• Thermophysical parameters<br>• Directional solidification | • Metabolic functions<br>• Cardiovascular<br>• Muscular/skeleton system<br>• Neuroscience |
| Automation | Complete experiment execution including analysis by using handling mechanism | Complete experiment execution including analysis | Experiment execution including analysis | When feasible to shorten experiment set-up and teardown times |
| Telescience | All automatic features can be altered from ground | All automatic features can be altered from ground | All automatic features can be altered from ground | Experiment procedures can be modified at any time |
| Advanced Diagnostics | • Microscope<br>• Spectrophotometer | • Seebeck effect<br>• Sample resistance (electrical)<br>• High-res. thermocouples<br>• Peltier Pulse Marking | • Particle image velocimetry<br>• Thermographic mapping<br>• Interferometric observation | • Analysis on-board of blood, urine and saliva |
| Modularity/Serviceability | • Modular design of the facility<br>• Experiments in standard container box | • Modular design of the facility<br>• Furnace module can be replaced in orbit | • Modular design of the facility<br>• Experiments in standard container box | • Modules can be exchanged and operated in other space Station locations |
| Experiment Container | 60x60x100mm$^3$; standard | 20-30mm 1) | 400x270x280mm$^3$ | N/A |
| Box/Cartridge Size | 130x133x170mm$^3$; large | 120mm 2) for LGF 3)<br>250mm 2) for SQF 4) | | |

1) Diameter of heated cavity 2) Length of heated cavity 3) Low Gradient Furnace 4) Solidification and Quenching Furnace

remote power distribution unit, etc.) developed through the Utilisation Programme. Table 2 indicates the scientific/technical features for all facilities. It is planned to present the main features of these facilities on the World Wide Web to increase awareness of the possibilities that will be offered to the science community once they are operational.

## The Biolab

*Scientific objectives*

Life-science experiments in space are aimed at identifying the role that microgravity plays at all levels of life, from the organisation of a single cell to the nature of gravity resisting and detecting mechanisms in the more highly developed organisms, including man. Whilst the effects of microgravity on man will also be investigated by other facilities (e.g. EPMs), it is also important to start the investigation with the smaller elements of the biological structure. At the science community's request, ESA has always had a strong involvement in supporting (e.g. with Biorack on the Space Shuttle and Biobox on a Russian carrier) the investigation of biological samples. The scientific results from these flights can certainly influence our everyday lives, particularly in the areas of immunology, bone demineralisation, cellular signal transduction and cellular repair capabilities. Such results could eventually have a strong bearing on critical products in the medical, pharmacological and biotechnological fields.

With a view to continuing this research work in future years, in 1988 ESA initiated scientific/feasibility studies for the definition of a facility known as the 'Biolab' which could support biological research during the Space Station era.

In view of the results achieved to date, the ESA Microgravity Advisory Committee (MAC) has recommended continuing the life-science research by focussing on a well-defined list of fields, including the following related to biology:
- regulatory mechanism of proliferation and differentiation at cellular level, including gametogenesis
- role of cytoskeleton
- early development events
- mechanism of radiation damage in cells and tissue
- repair of cells and tissue damage
- perception and signal transduction in plant tropisms and taxes.

The current Biolab concept is that of a multi-user facility for conducting biological experiments of the above type in the COF on cells, micro-organisms, small plants and small invertebrates. The design respects the MAC's recommendations, the outcome of the scientific and feasibility studies (e.g. Phase-A) performed, the experience gained from facilities flown previously, and the requirements of and possibilities offered by the utilisation of the Space Station.

*Facility description*

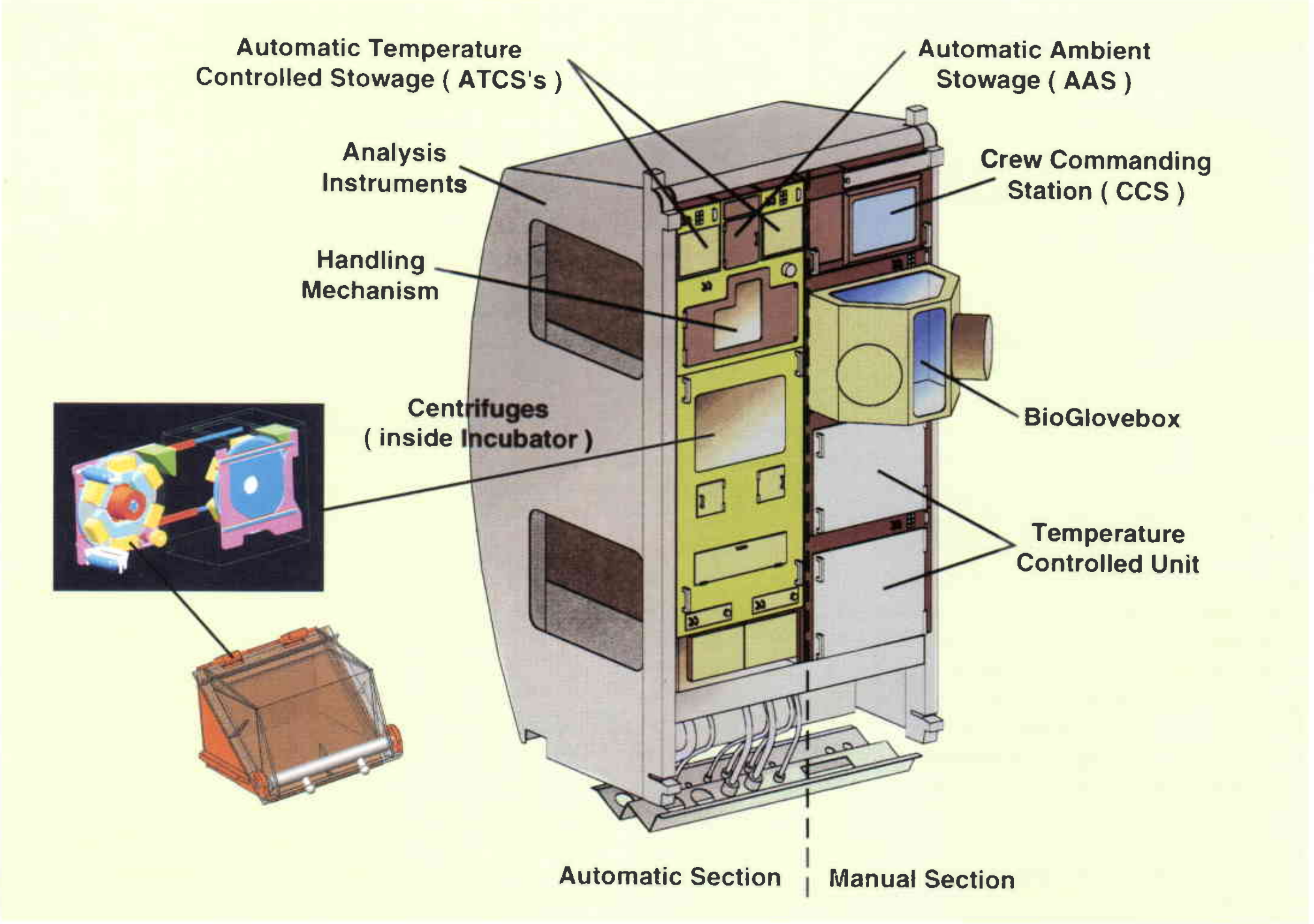
The Biolab facility (Fig. 3) is integrated into an International Standard Payload Rack (ISPR) and will be flown to the Space Station as part of the initial payload complement of the COF, into which it will already be integrated on the ground.

Biolab is divided physically and functionally into two sections: the automatic section in the left side of the rack, and the manual section in the right side of the rack. In the automatic section, also known as the 'Core Unit', all activities are performed automatically by the facility, after manual sample loading by the crew. By implementing such a high level of automation, the demand on crew time is drastically reduced. The manual section, in which all activities are performed by the crew themselves, is mainly devoted to sample storage and specific crew activities.

The biological samples are contained in standard 'Experiment Containers' (Fig. 3) which have standard external interfaces with the Biolab, an approach that has been well proven with the Biorack. The internal volume available to experimenters is 60 x 60 x 100 $mm^3$ for the standard container, but a larger one is also available.

The main features of the Biolab are as follows:
- Automation: by virtue of the advanced capabilities of the handling mechanisms, entire experiments can be performed with no crew involvement, including the automatic sampling, storing and analysis of samples.
- 1-g reference conditions: taking advantage of the two centrifuges located inside the same incubator, the 0-g and the 1-g experiments can be performed simultaneously, under identical environmental conditions, to identify the influence of gravity.
- Flexibility: the standard Experiment Container concept, and the controlled environmental conditions allow a wide variety of experiments to be performed, with only simple experiment hardware needing to be developed by the scientists themselves.

**Figure 3. The Biolab's design, with one centrifuge extracted and its experiment container**



- Modularity: the design of the facility allows in-orbit corrective and preventive maintenance, with potential upgrading of facility elements.
- Telescience: All the automatic features of Biolab can be controlled from the ground, giving the scientists the possibility to interact actively with their running experiments.

*Biolab operations*
The biological samples, with their ancillary items, will be transported from the ground to Biolab either already in the Experiment Containers, or in small vials if they require transportation and storage temperatures as low as -80° C, taking advantage of the ESA-developed Freezer [MELFI]. Once in orbit, samples already in Experiment Containers will be manually placed into the Biolab facility for processing, while those transported at -80° C will need to be prepared in the Bioglovebox.

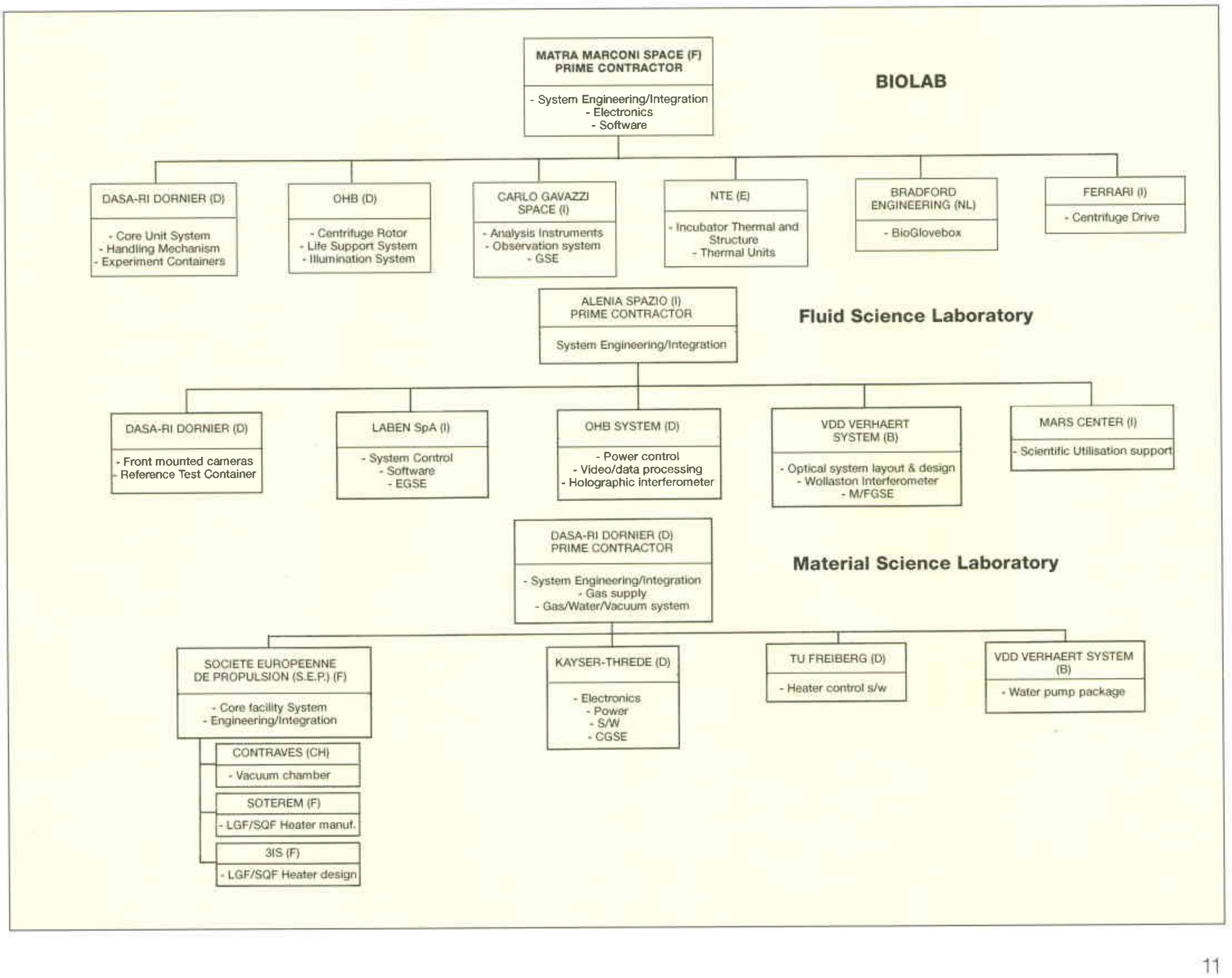
Once the manual loading has been completed, the automatic processing of the experiments can start. These experiments will be run in parallel on the centrifuges, one in 0-g and the other one in 1-g for reference. At the end of the experiment, the Handling Mechanism will transport the samples to the diagnostic instruments provided by Biolab. With the aid of teleoperations, the scientist on the ground will be able to interact with this preliminary analysis process. Typical experiment durations can be between a few days and a few months.

*Industrial organisation/status*
The Biolab design study (Phase-B) is currently being carried out by a consortium of industries led by Matra Marconi Space of Toulouse (F) (see Table 3). It will be completed this Spring, while the facility's main development phase (Phase-C/D) is planned to start in the second half of 1997.

*Challenges*
While the individual subsystems of the Biolab facility do not present a major technological challenge, the integration of the numerous subsystems into such a limited volume as an ISPR is indeed a difficult task. Much attention is therefore being paid to ensuring that all of the subsystems fit together well to form a homogeneous facility.

The challenge of the high level of automation has been met by developing a fully

**Table 3. Industrial participants in the MFC Multi-User Facilities Phase-B activities**



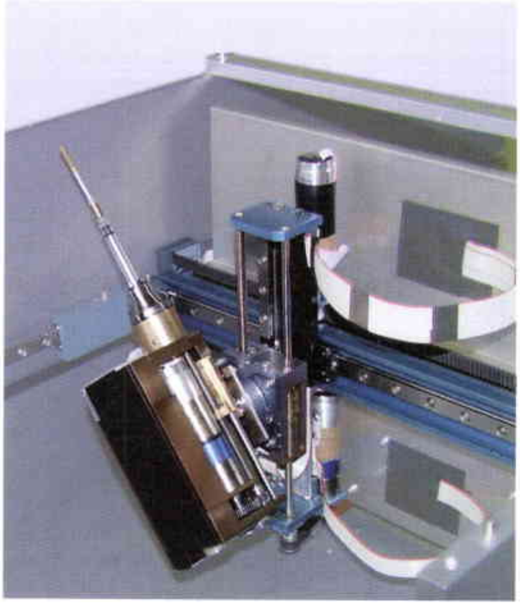


**Figure 4. Handling-Mechanism breadboard for Biolab**

representative Handling Mechanism breadboard (Fig. 4), including its interfaces with a functioning breadboard of the Automatic Temperature Controlled Stowage (ATCS).

## The Material Science Laboratory

*Scientific objectives*

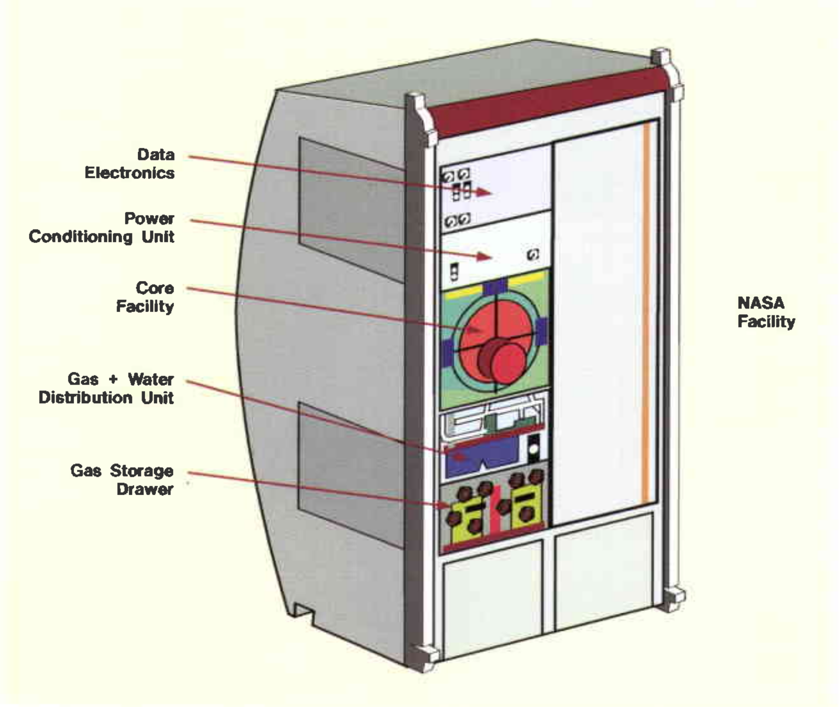
Material Science experiments in space are aimed at providing us with a clear understanding of the behaviour of crystallisation and solidification phenomena in microgravity, these phenomena being studied in conjunction with precision measurements of specific thermophysical properties (e.g. temperature, resistivity, etc). Research in this field is important to obtain data useful for ground-based process optimisation and to understand phenomena critical for ground-based production.

The Agency has flown various types of furnaces on its Eureca free-flying platform (e.g. Automatic Mirror Furnace [AMF], Multi Furnace Assembly [MFA]) as well on the Space Shuttle (e.g. Advanced Gradient Heating Facility [AGHF]). In order to be able to continue such material-science research work in the Space Station era, the Agency started the definition of the Material Science Laboratory. Four priority areas of research were identified by the Microgravity Advisory Committee:

- solidification physics
- measurement of thermophysical properties
- crystal growth by zone melting
- crystal growth by Bridgman techniques.

Eight furnaces were initially examined in two conceptual studies, but cuts in Space-Station resources and budget limitations reduced the final number under study to two: the Solidification and Quenching Furnace (SQF), and the Low Gradient Furnace (LGF).

**Figure 5. The Material Science Laboratory in US Lab configuration**




The MSL was required to adopt a highly modular design concept, thus alleviating the limitations imposed by budgetary and carrier constraints by offering increased flexibility for heater reconfiguration in orbit. In this way, most of the scientific objectives for the MSL can be satisfied within the scope of the present development effort.

All activities involved in the definition and design of the MSL elements are regularly monitored by a scientific advisory team, which also supported the redirections of effort described above.

*Facility description*

The MSL is highly modular in concept, with the greatest level of modularity incorporated in the facility 'infrastructure modules' offering the environment, intelligence, and resources for the operation of scientific 'Furnace Modules'. At present, two such infrastructure modules are being developed:

- Facility 1, to be accommodated in half of an International Standard Payload Rack (ISPR) within the US Module of the Space Station
- Facility 2, representing an autonomous facility utilising one ISPR within the Columbus Orbital Facility (COF).

The two infrastructure modules are presented schematically in Figures 5 (US Lab-based configuration) and 6 (COF-based configuration). There is a high degree of commonality between the two facilities and a kernel composed of gas, power, vacuum and 'furnace modules' has therefore been defined to minimise development costs.

The operational flexibility demanded by the science comes in at the level of the 'furnace modules', each of which is characterised by a specific heater arrangement with dedicated thermal performance. They are therefore being designed with a specific group of scientific experiments in mind. However, the utilisation of any such module is not restricted to the 'target' science, but they are open to any scientist who can make use of their specific performances.

The development logic of the Material Science Laboratory is presented in Figure 7.

Two furnace modules are under detailed study under the present MSL Phase-B contract:
- The Low Gradient Furnace (LGF) is targeted for Bridgman Crystal Growth experiments and it is presently planned to be accommodated in the MSL in the US Lab. The position of the cartridge containing the experiment sample is fixed and the heater can be moved at different speeds over the length of the cartridge. This configuration is intended to provide the very stable processing conditions required for crystal growth experiments. As noted above, it is expected that other scientists will also find these specific heating conditions useful. At present, for example, US scientists are proposing to use the LGF for diffusion experiments on silicon and germanium alloys.
- The Solidification and Quenching Furnace (SQF) is optimised for metallurgical experiments requiring large thermal gradients and fast quenching of samples. It is presently planned for the MSL in the COF. This module features one heating zone similar to LGF, but with lower requirements on thermal stability. However, the requirements for the energy density transmitted by the booster heater are significantly higher for the SQF. Another key feature of the SQF is the water-cooled cooling zone which can be coupled to the experiment cartridge via a liquid-metal 'sleeve' around the cartridge.

Additional furnace modules could be developed by NASA or other national entities to meet other specific scientific requirements.

It is a key feature of the Material Science Laboratory that all furnace modules can be

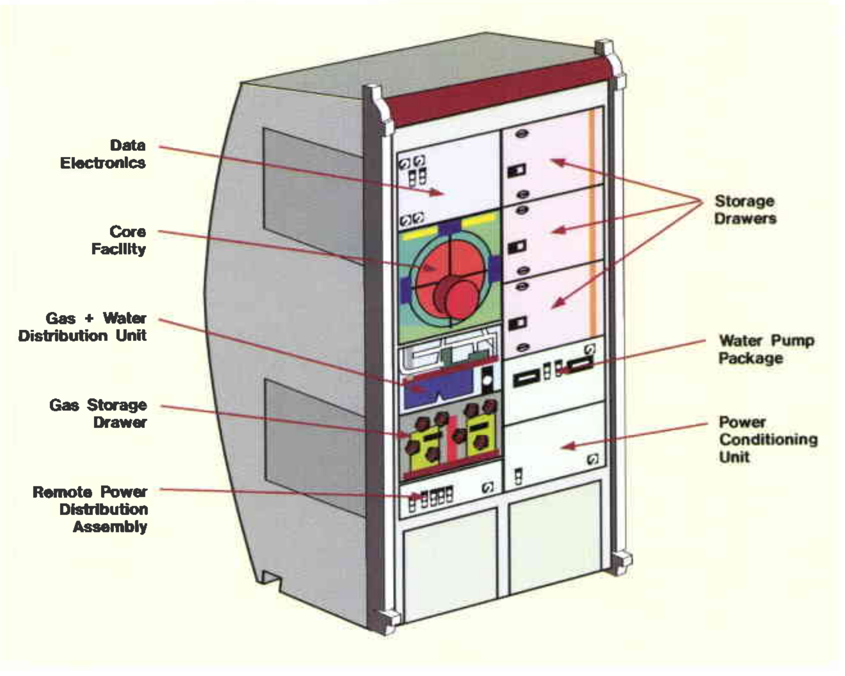



**Figure 6. The Material Science Laboratory in COF configuration**

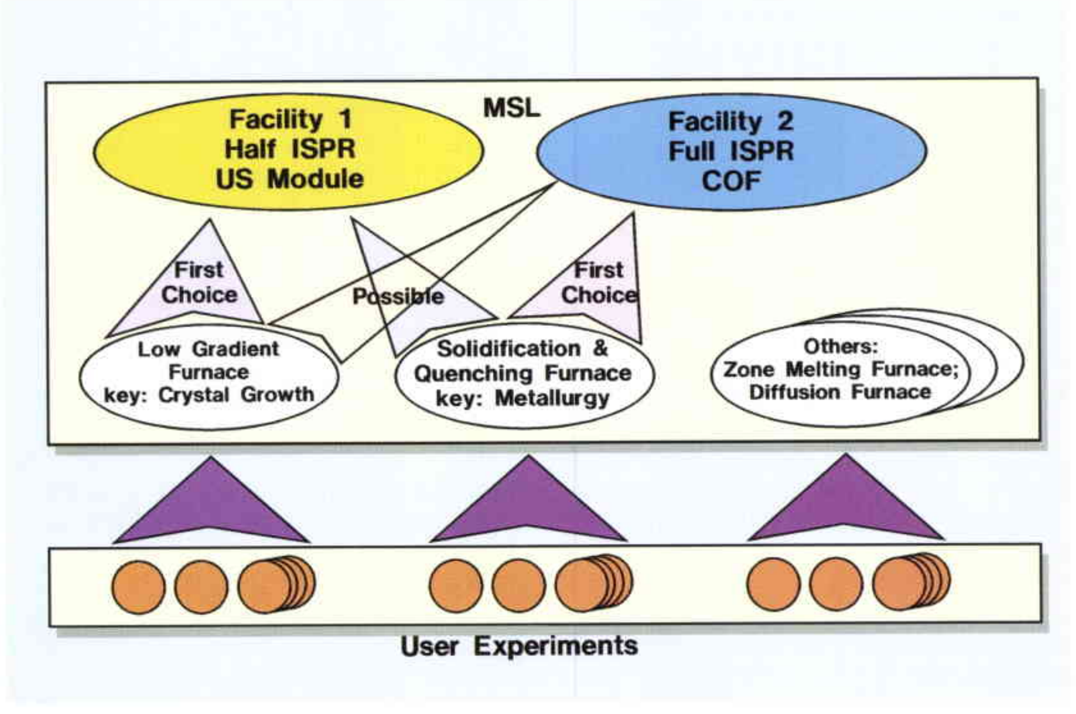



**Figure 7. The Material Science Laboratory Development Logic.**

integrated in orbit into either of the facility infrastructures. This capability is at the heart of the MSL modularity concept, since it enables the flight configuration to be reconfigured according to changing scientific requirements and programmatic constraints. For example, the LGF is currently being planned to be integrated into Facility 1 at launch, while the SQF is planned to reside in Facility 2. However, should the programmatic boundary conditions change, then this allocation could be reversed at relatively short notice, or both furnace modules could even be operated sequentially in either facility infrastructure. The maximum operating temperatures of both the LGF and SQF are set at 1600° C, with restricted operation above 1500° C. The temperature stability of the LGF heaters will be better than ± 0.02 K, while for the SQF ± 0.2 K is considered sufficient. Both furnaces are designed to achieve high radial uniformity of heating (less than 1 K effective temperature variation over the circumference), and the LGF additionally requires homogeneity of the 'central' heaters of better than 1K over 80% of the heater length.

**Figure 8. Typical furnace cartridge (AGHF facility)**

The diameter of both the LGF and SQF heater cavities is set at 30 mm, and they vary in length from 250 mm (SQF) to 120 mm (LGF 'cold' cavity). For the SQF, the diameter of both the insulating zone and the liquid metal ring adapter can be varied to allow the processing of experiment cartridges with diameters down to 10 mm. This is necessary for the generation of large thermal gradients in highly-conducting materials. A typical experiment cartridge is shown in Figure 8 (AGHF cartridge). Diagnostics and stimuli are embedded in the facility infrastructures and are thus independent of the choice of furnace module. Typical diagnostics are the Seebeck Voltage Measurement and the Peltier element and thermocouples.

*MSL operation*

The experiment cartridges will be loaded manually (by the astronaut) into the MSL facility. The facility will then perform automatic verification of the predefined experiment processing parameters and of its own configuration. Experiment processing will take place in a vacuum of better than $10^{-4}$ mbar. After positive verification, the facility will introduce a holding time to enable the scientist and ground crew to update the processing parameters if desired. After this holding period, the processing and ground crew will receive continuous (subject to ground-link coverage) scientific data and information on the facility's health. If so wished, the process can be modified on-line at any time during processing. However, the facility will reject commands which are incompatible with the current processing conditions or would violate the allocated resources. The process will terminate automatically and the facility will perform an automatic final health check. If this is successful, the facility will allow the processing chamber to be opened for another manual sample exchange or for furnace reconfiguration (e.g. exchange of LGF with SQF). After each experiment processing, the process chamber is to be cooled down and flushed with argon gas. The actual experiment run time can vary between a matter of hours and several days.

*Industrial organisation/status*

The current Phase-B activities are being led by DASA RI-Dornier from Germany (Table 3 shows the Phase-B industrial team for all MFC multi-user facilities). They will be completed this Autumn, while the Phase-C/D for MSL in the US Laboratory is planned to start by the end of 1997 or early 1998.

*Challenges*

One of the major challenges for the MSL lies in the development of Facility 1 for cooperative utilisation with NASA, since both NASA and ESA have furnace development programmes in progress and the scientific objectives are very similar. Also technically the coordination of facility resources and interfaces in the new environment of the Space Station requires major efforts from both Partners.

New technical challenges arise from the long durations of facility operation on the Space Station which are unprecedented for microgravity payloads. This problem is particularly relevant for MSL due to the limited lifetime of most items exposed to high temperatures. The modular design of MSL is expected to dramatically improve its in-orbit servicing, and the technical feasibility of most servicing operations in a flight rack environment has been demonstrated. Figure 9 shows a breadboard used for the definition of servicing. However, much work remains to optimise the MSL design for both reliability and servicing and to demonstrate that both requirements combine to support safe and scientifically meaningful operation over the projected lifetime of the facility.

Last but not least, the optimisation of MSL performance remains a continuous challenge. Thus technology development has been initiated to extend the upper temperature limit of the MSL furnaces to 1800° C. SQF is expected to be the first furnace to benefit from this. On the diagnostics front also, efforts are being made to advance and improve the maturity of the design. The current study to validate the performance of the Seebeck diagnostics for the LGF (i.e. for insight into the nature and dynamics of solidification processes), which CNES is conducting under ESA funding, is a prominent example of this.

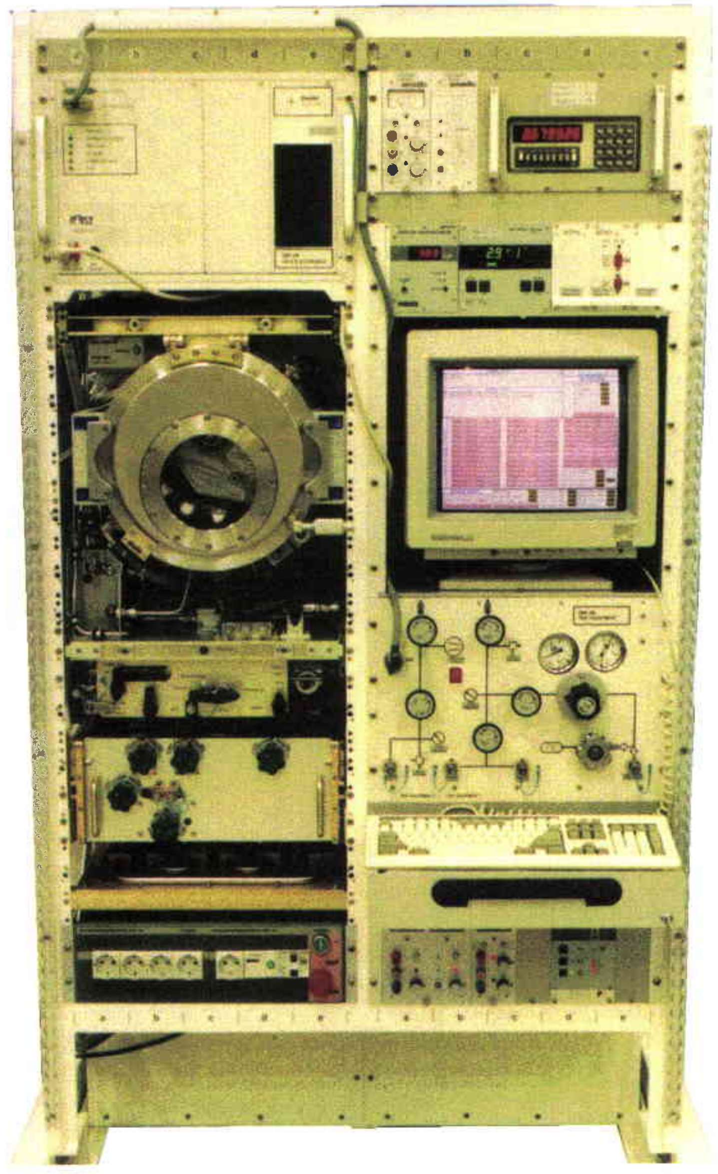


Figure 9. Breadboard used for the definition of Material Science Laboratory servicing.

## The Fluid-Science Laboratory

*Scientific objectives*

Fluid-science experiments in space are designed to study dynamic phenomena in the absence of gravitational forces. Under microgravity conditions, such forces are virtually eliminated, including their effects in fluid media (e.g. gravity-driven convection, sedimentation and stratification, and fluid static pressure). This allows one to study fluid dynamic effects that are normally masked by gravitation, e.g. the diffusion-controlled (rather than convective-flow-dominated) heat and mass transfer in crystallisation processes; their absence resulting in reduced defect density.

The absence of gravity-driven convection eliminates the negative effects of density gradients (inhomogeneous mass distribution), which always arise on Earth in processes involving heat treatment, phase transitions, diffusive transport, or chemical reactions (i.e. convection in earthbound processes is perceived as a strong perturbing factor, the effects of which are seldom predictable with great accuracy and dominate heat and mass transfer in fluids).

The ability to control such processes is still limited; their full understanding requires further fundamental research by conducting well-defined model experiments for the testing and development of related theories under microgravity. This will allow the optimisation of manufacturing processes on Earth and improvement of the quality of such high-value products as semiconductors.

ESA has already been involved in the study of fluid-science phenomena under microgravity conditions for several years, notably with the BDPU (Bubble, Drop and Particle Unit) facility which has already been flown several times on Spacelab missions with important results. The Microgravity Advisory Committee has now recommended research priorities for the future scientific work to be carried out on the Space Station using the Fluid Science Laboratory, these being:

- flows and instabilities induced by surface tension gradients and thermal radiation forces
- double diffusive instabilities (coupling between heat and mass transfer)
- interfacial tension and adsorption
- mechanisms of boiling
- critical-point phenomena
- crystal growth
- directional solidification.

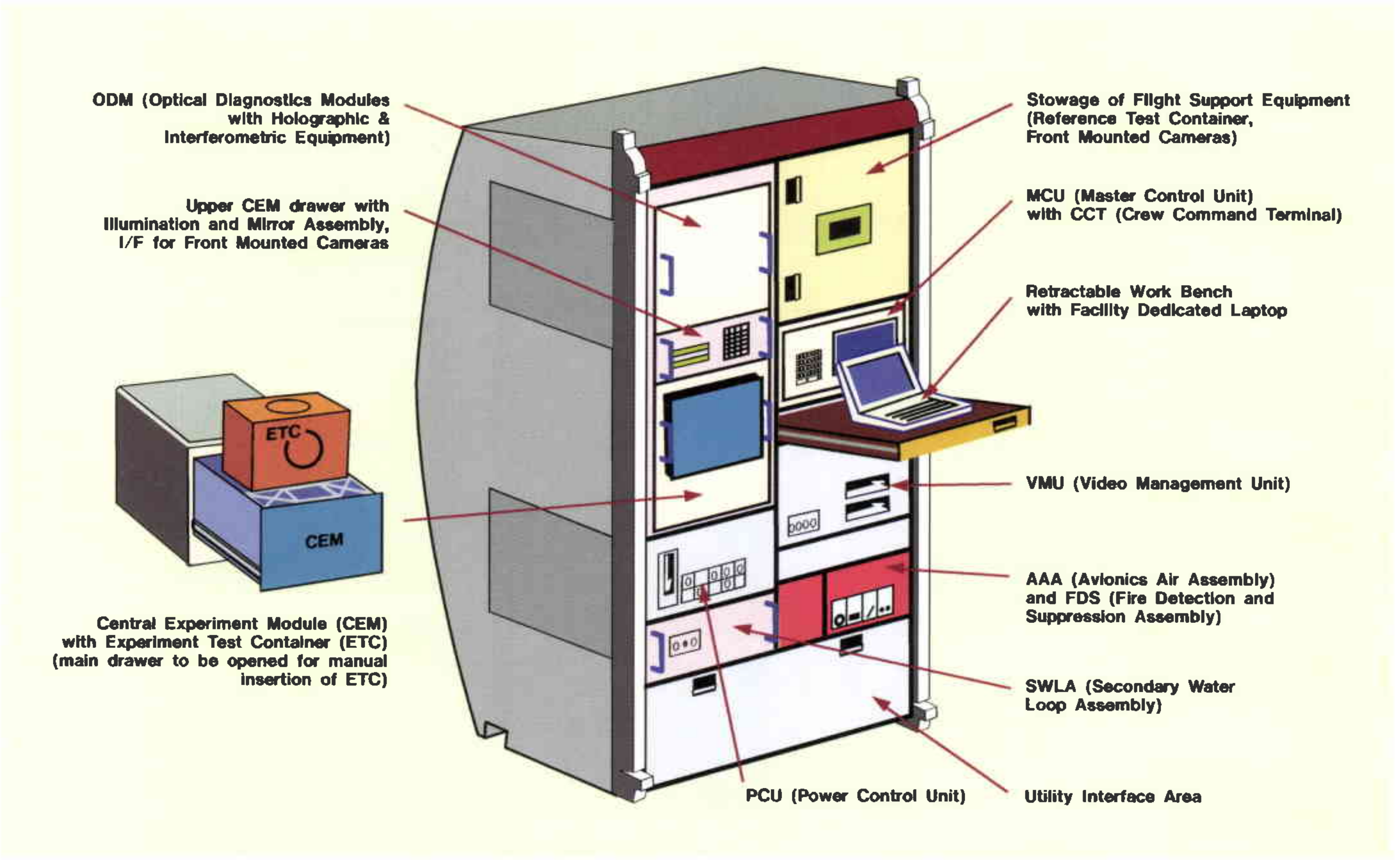



**Figure 10. the Fluid Science Laboratory's design with its experiment test container**

Two of the above-mentioned items are also relevant to the Material Science field (crystal growth, directional solidification), but the approach is different and complementary.

*Facility description*

The Fluid Science Laboratory (Fig. 10) is integrated into an International Standard Payload Rack (ISPR) and will be flown in the ESA COF as part of the initial COF payload complement. The kernel of the Facility is made up of the Optical Diagnostics Module (ODM) and the Central Experiment Module (CEM), into which the Experiment Test Containers (ETC) are sequentially inserted and operated. Together, these Modules represent the core of the experiment-dedicated facility, which is complemented by the functional subsystems for system and experiment control, power distribution, environmental conditioning, and data processing and management.

In order to cope with the experiment observation requirements, the optical diagnostic equipment includes:

- visual observation in two axes [with direct registration (electronic imaging and photographic back-up), background, sheet, and volume illumination with white light and monochromatic (laser) light sources]
- particle image velocimetry [including the possibility to use liquid-crystal tracers for simultaneous velocimetry and thermometry]
- thermographic (infrared) mapping of free liquid surfaces
- interferometric observation by means of a holographic interferometer [Wollaston/ Schlieren mode combined with shearing mode, Electronic Speckle Pattern Interferometer (ESPI)]

The design implements modularity by applying a drawer concept for all subsystems. This serves to facilitate in-flight reconfiguration of the system and the science protocols and supports scheduled maintenance as well as contingency activities. To this end, a Reference Test Container (RTC) is carried along as flight-support equipment providing reference functions, interfaces, and optical targets for calibration, interface re-verification, and potential trouble-shooting.

*Facility operation*

For each experiment or experiment category, an individually developed Experiment Test Container (ETC) will be used (the provisional planning foresees only a limited number of ETCs for the first FSL mission increment). Stored in the COF Stowage Rack during non-operational phases, each ETC will be manually inserted by the crew into the CEM drawer, where it will undergo an experiment and diagnostics calibration cycle prior to any process activation. Each ETC, with its standard dimensions of 400 x 270 x 280 $mm^3$, provides ample volume for the accommodation of the actual fluid cell and the process stimuli and control electronics (Fig. 11). It may additionally be equipped with dedicated experiment diagnostics complementary to the standard diagnostics provided within the facility itself as described above.

The control concept for system and experiment operation provides for alternative modes comprising fully autonomous experiment processing even during certain communication outage phases, semi-autonomous processing of defined experiment subroutines, and fully interactive step-by-step command keying. All operating modes can be activated either by the flight crew or from the ground, thus ensuring the possibility of quasi-real-time teleoperation ('telescience'). Typical experiment durations will vary between a few hours and a few days.

*Industrial organisation/status*
The currently running Phase-B, led by Alenia Spazio (I), will be completed by the second half of 1997, with the Phase-C/D planned to start in early 1998. Table 3 identifies the industrial teams for the Phase-B of all MFC multi-user facilities.

*Challenges*
Major challenges exist in the area of the optical diagnostics (convertible interferometers), the combination of which represents a new approach. Being highly susceptible to thermo-mechanical dilation, the alignment, alignment stability, and active alignment control of the optical path between and within the interferometers and the object cell within the Experiment Test Container require thorough optical end-to-end analysis and corresponding breadboarding for identification and verification of adequate design solutions. The breadboard foreseen in this respect comprises the whole facility core element. The science team will make use of this breadboard to test different diagnostic techniques.

Much attention is also being paid to the microgravity perturbation potential inherent in the secondary water cooling subsystem, to which the ETCs will be directly connected. This subsystem was introduced to provide a decoupling of the facility kernel control from the COF primary cooling loop, as its temperature variation and flow fluctuations might induce unacceptable perturbations for certain fluid-science experiments. The essential part of the secondary cooling loop will therefore be breadboarded, including the pumps and simulated valve switching, in order to determine the perturbation level to be expected and to test design solutions for corresponding suppression and damping.

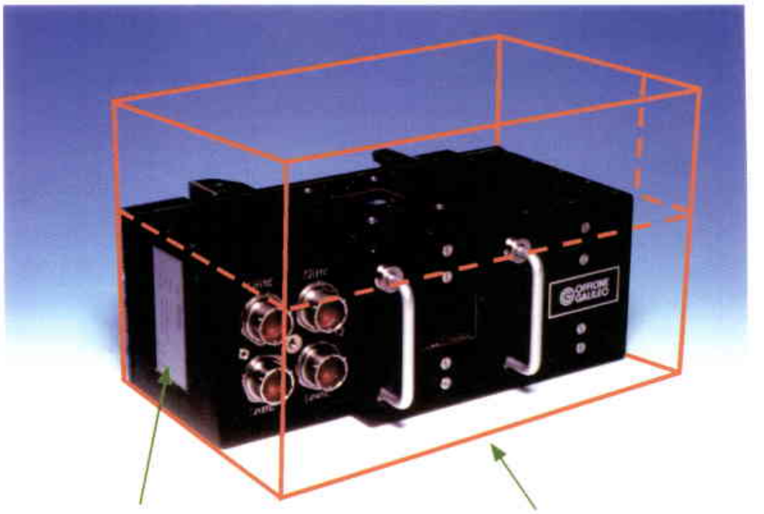



**Figure 11. Comparison of FSL and BDPU experiment test containers**

## The European Physiology Modules

*Scientific objectives*
Investigations of the effect of microgravity on the human body have been conducted for many years and ESA in particular has successfully flown related facilities on several Spacelab missions (e.g. Sled, Anthrorack, etc). For the International Space Station, the Agency's Microgravity Advisory Committee, in conjunction with the Life-Sciences Working Group, has identified the following as being the priority research areas:

- impairment of muscle structure and function
- impairment of bone remodelling and decalcification
- ventricular performance and regulation of blood pressure and volume
- endocrine components of fluid balance and kidney function
- regional interstitial fluid dynamics
- lung ventilation / perfusion and chest-wall dynamics
- multi-sensory integration and neuronal adaptation
- otolith organ and space adaptation syndrome.

These research fields have important applications back on Earth for the treatment of cardiovascular, respiratory and neurological diseases, as well as for diseases that primarily affect elderly people (e.g. bone decalcification). The European Physiology Modules (EPMs) facility to be launched inside the COF will support a broad selection of the above research.

*Facility description*

It is planned that the EPMs facility will incorporate instruments from various programme sources, including the Agency's EMIR-2 and national programmes in particular. A preliminary list of candidate instruments to be considered for incorporation within the EPMs facility will be compiled following consultation with representatives of the respective agencies of the Member States. A Facility Science Team, consisting of representatives of the scientific user community, will be established to follow the EPMs facility's development from its Phase-A onwards in order to advise the Agency on science-related matters connected with its development.

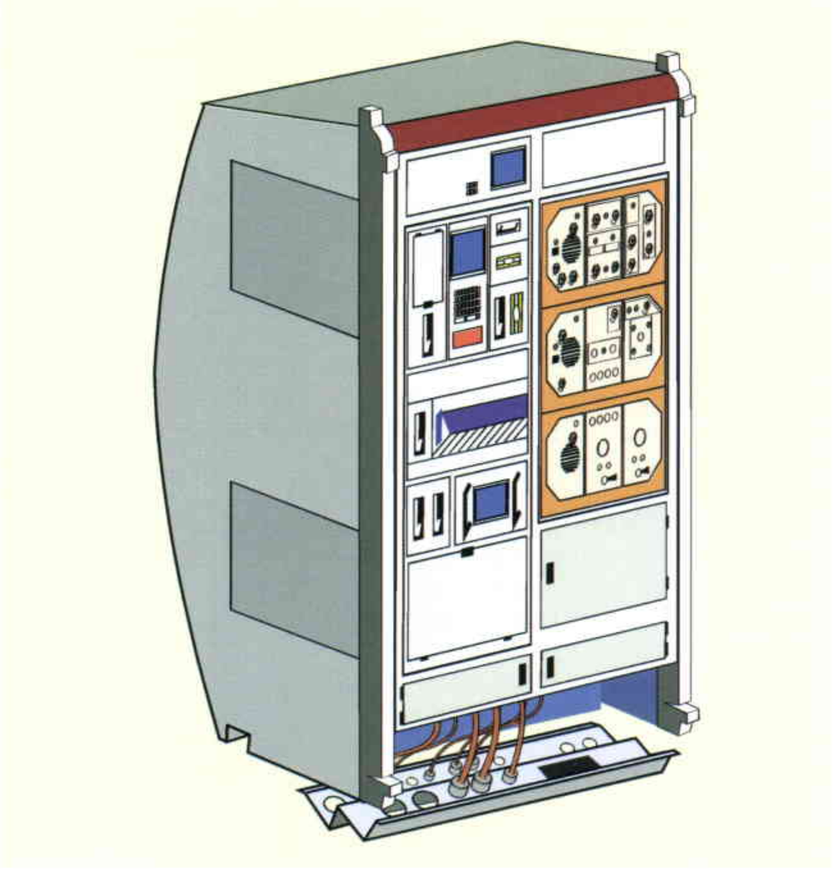


**Figure 12. The European Physiology Module's design**

An important aspect of the EPMs facility design will be the adoption of a modular accommodation approach, allowing later exchanges of instruments and hence updating of the facility's capabilities (Fig. 12).

The preliminary list of potential candidate instruments includes the following :

- The Advanced Respiratory Monitoring System (ARMS) is designed to support respiratory/pulmonary and cardiovascular research and is a further development of the RMS-II device that was flown on the Euromir-95 mission (Fig. 13). Both RMS-II and ARMS are based on the photo-acoustic gas-analysis technique, supplemented for the measurement of oxygen concentrations with a paramagnetic sensor. The main improvement in the ARMS over the RMS-II lies in the number of gas components whose concentrations can be measured. The ARMS will also provide an improved respiratory flow determination capability. The ARMS will incorporate a Gas Supply System (GSS) for storing and metering the special respiratory and gas analyser calibration gas mixtures.
- The Advanced Bone Densitometer (ABDM) is planned to be a further development of the Bone Densitometer (BDM) that was flown on Euromir-95. The BDM characterises changes in the structure and mineralisation state of a bone via related changes in the propagation properties of ultrasound through that bone. Changes in the ultrasonic propagation properties observed during orbital flight are then cross-correlated to more directly physiologically related bone properties through comparative measurements before and after the mission. It has become apparent, from the BDM's use in the Euromir-95 programme (Fig. 14), that the factor limiting its sensitivity is the accuracy with which the ultrasonic transducers can be relocated on the subject's heel bone at the time of each repeat measurement. This difficulty would be overcome if the instrument recorded a two-dimensional cross-sectional image of the heel bone, allowing ultrasonic data from the same spot to be compared each time. The ABDM will incorporate this capability.
- The purpose of the Bio-Medical Analysis System (BMAS) is to perform on-board analyses of blood, urine and saliva samples

**Figure 13. The Euromir-95 RMS-II experiment.**

for a wide range of parameters, with particular emphasis on hormones. Such an approach has the following advantages over the storage of the samples until they can be analysed back on Earth:

- it reduces the demand on frozen-sample storage volume
- it provides a rapid turn-around in the results of the analyses
- it overcomes the problem that exists for some of the parameters that the bio-fluid degrades rapidly as far as analysis for those parameters is concerned, even when stored in a frozen state.

The BMAS design will be based on the use of commercial analytical instruments.

- An Off-Axis Rotator (OAR) has been developed, as part of the Vestibular and Visual Stimulation system for the NASA Neurolab Spacelab mission. The OAR is designed to provide a linear acceleration stimulus to the subject's vestibular organs, via the centrifugal acceleration created by off-axis rotation of the test subject.
- An advisory team was established in 1996 as an adjunct to the Agency's Life Science Working Group, to advise the Agency with regard to the instrumentation that should be planned for the Space Station era to support the neuroscience disciplines. This 'Neuro-Science Topical Team' will present its recommendations to the Agency shortly.
- Other modules developed nationally will be considered following consultation with National Space Agencies.

*Facility operation*

The astronauts will serve as both the test operators and the test subjects, and this will often require two of them to be involved at the same time. They will follow well-defined procedures for each experiment and the principal investigators on the ground will be able to view the data being generated, allowing them to make changes in real-time. Typical experiment durations will vary between a few days and a few months.

*Industrial organisation/status*

The Phase-A study for the EPM facility will be a competitive tender action, with the Invitation to Tender (ITT) to be released in the second half of 1997. The Phase-B design effort will be initiated in 1998, while the full development process will start only in 1999.

*Challenges*

The main challenge will be to select a homogeneous and complementary set of instruments for the facility, trying to avoid overlap with instrumentation being placed within the Space Station by the other Space Station Partners.

**Scientific operation of the facilities**

In order to optimise facility design, the science teams, astronauts and user representatives will be involved in the development phases. Final acceptance of the FSL, Biolab, MSL and EPMs is planned to take place using the Rack Level Test Facility (RLTF), which will simulate all the COF interfaces. The MSL will be delivered to NASA for integration into the US Lab following its preliminary acceptance in Europe. The FSL, Biolab, MSL and EPMs will be integrated into the COF and launched with it.

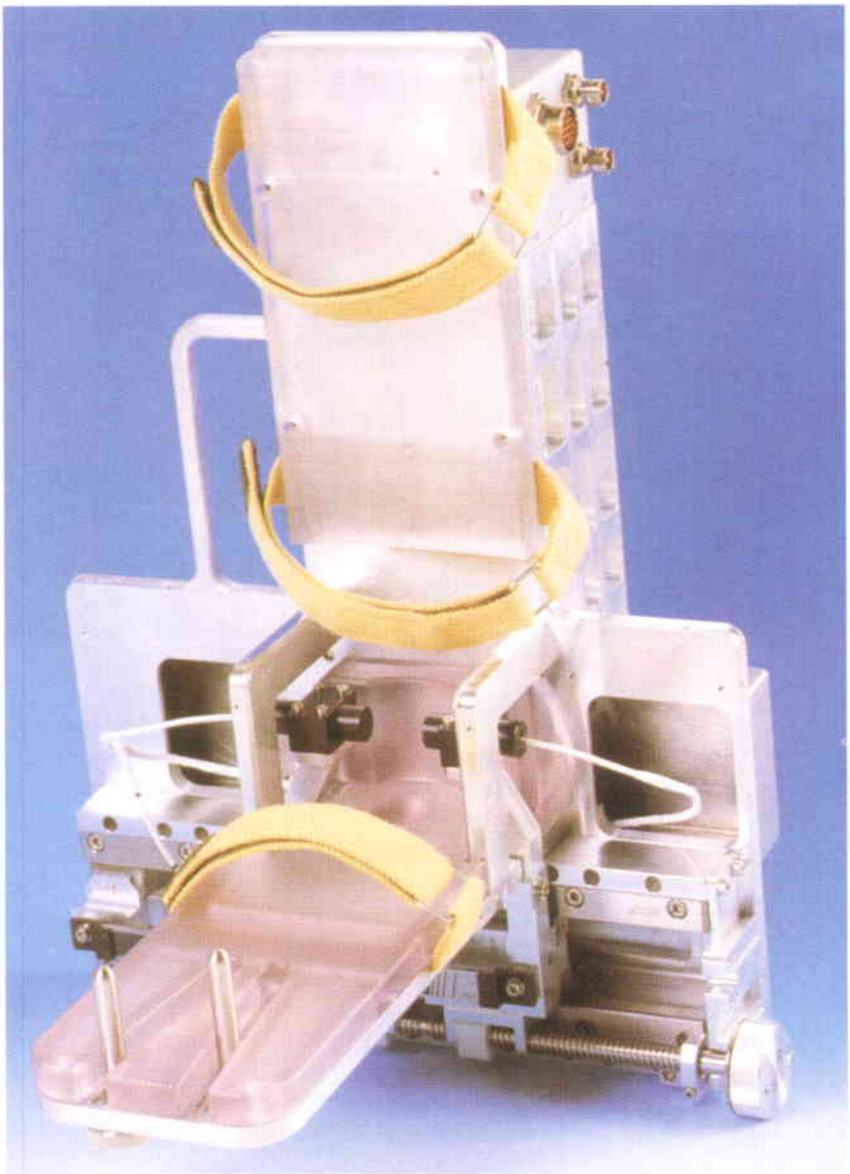


**Figure 14. The Euromir-95 BDM experiment**

The experiments to be executed in each laboratory will be selected on the basis of an Announcement of Opportunity which will be released in time to prepare the actual experiments (e.g. test containers for FSL and experiment Container for Biolab, cartridges for MSL, experiment procedures for the EPMs).

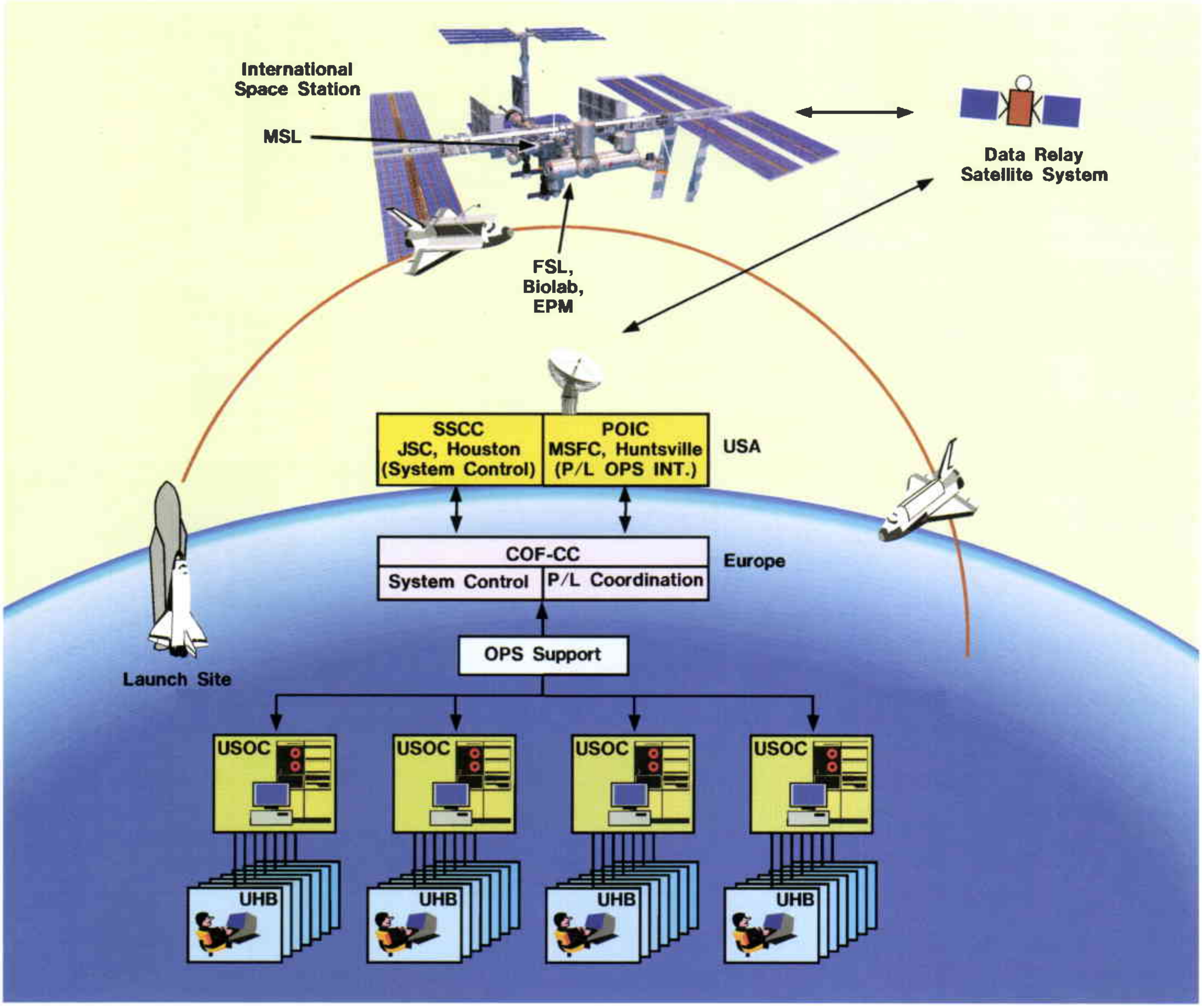



**Figure 15. Science Operations for the Multi-User Facilities**

Figure 15 shows a scenario for the scientific operation of the multi-user facilities. Each laboratory is expected to be operated scientifically from a dedicated Facility Responsible Centre (FRC) that will serve as the main interface between the users of each facility and the appropriate Payload Control Centre (e.g. the COF or the US Lab). These FRCs will also prepare the timelining for the experiments and perform the first level of troubleshooting should problems occur during the facility's operation. The prime contractor for each facility will be available to support a second level of troubleshooting and provide sustaining engineering support.

Experiments may be executed from the User Home Bases (UHBs) which will primarily be universities and research centres, with overall coordination by the FRC. This decentralised payload processing is seen as the most efficient approach for Columbus Utilisation implementation.

Each mission increment will lasts three to six months and the selection of successive complements of experiments will follow a similar schedule. The equipment required to carry out the experiments selected will be uploaded by the Mini Pressurised Logistics Module (MPLM) carried by the Space Shuttle. The MPLM will be the standard logistic carrier for uploading and downloading in the Space Station era.

The Space Station will offer many unique capabilities for microgravity experiments, including long flight durations, good data-gathering capabilities (statistics), reconfigurability, telescience operation and automation capabilities. The last feature is particularly important given the restricted crew time available for carrying out the wealth of scientific experiments that are being planned.

# The Ariane-5 Cryogenic Main-Stage Development Tests

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**The Ariane-5 launcher development programme was given the go-ahead at the Meeting of the ESA Council at Ministerial Level in The Hague in September 1987. Development of the cryogenic main stage, the launcher's core stage, represented a significant shift in scale compared with that of the cryogenic stages previously developed in Europe: the H8 and the H10. One of the key milestones in developing the new stage was the test firings at the ELA-3 launch facilities in Kourou, French Guiana. The data from the first 37 seconds of Ariane flight 501 on 4 June 1996 have been analysed to determine how the stage behaved in flight.**

**Figure 1. Lift-off of Ariane flight 501 on 4 June 1996**

## The context and organisation of the tests

After various studies and deliberations, it was decided to divide the cryogenic-stage test firings into three main campaigns:

- A battleship (BS) test campaign, using a dedicated thrust-frame and engine representative of the flight configuration, and industrially produced tanks to some extent functionally representative of flight tanks but incorporating wide structural margins (dual walled stainless-steel cylindrical sections and separate bulkheads). The functional electrical equipment was housed together in an electrical bay providing easy access.
- A development (M) test campaign, using a stage representative of a flight stage apart from a few details: no safety subsystem, no passivation or neutralisation system, since these items would contribute nothing to the tests and might even cause serious problems.
- A qualification (Q) test campaign, in a configuration similar to the M tests, but using flight-standard equipment.

Two major decisions were taken in 1989 concerning these tests:

- All testing would be done at ELA-3, so as to test stage operations in a real environment at the earliest opportunity.
- M and Q testing would be done on the same stage, except that any equipment whose internal definition changed significantly would be replaced. This decision had been necessary for budgetary reasons.

Taking into account the location of the testing and sequence of objectives – in particular, that the prime objective of the battleship tests was to ensure that the propulsion system functioned properly – the organisational arrangements were as follows:

- Prime contractors for tests:

| | |
|---|---|
| BS and M: | SEP |
| Q: | Aerospatiale |

- Stage prime contractor: Aerospatiale
- Tests conducted by: CNES ground subdirectorate

## The test campaigns in Kourou

*The battleship campaign*

The battleship campaign started on 2 September 1994 with the test review. This important meeting, at which all parties involved in the main-stage programme examined the preparation status of the specimen and test facilities, gave the go-ahead to start the


Figure 2. The battleship (BS) and M stages

campaign. The first test (BS1.1) subsequently took place on 23 September, but, due to a number of problems, first-stage ignition did not take place until 17 November during BS2.2. This test completed an arduous phase which made particularly heavy demands on both the ground and launcher teams. The outcome, however, was an outstanding success, with 281 seconds of perfect operation, proceeding entirely as planned.

What had happened between BS 1.1 and B52.2? The answer is simple: for the first time, a stage and all associated ground facilities, including all hardware/software features, had to be operated simultaneously. Various problems arose and these quite naturally gave rise to procedural changes, which had to be fully validated before operational application. In addition, the engine's launcher-side hydrogen feed valve failed to open and had to be replaced. Thereafter, the campaign proceeded without any major anomalies.

The last test took place on 27 January 1995, completing a fine run of successes, namely four long-duration test firings without any serious problems coming to light.

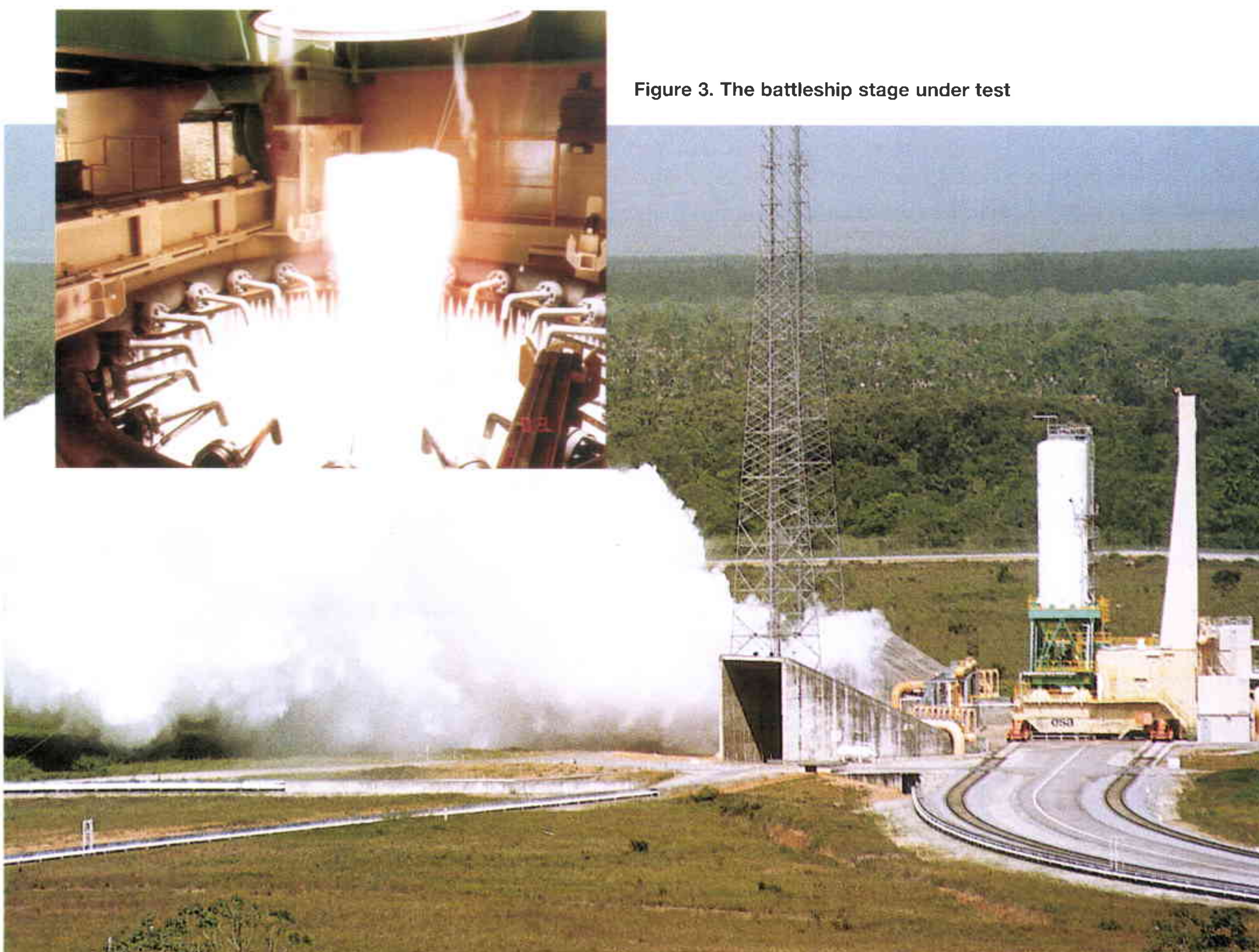


Figure 3. The battleship stage under test

The successful battleship campaign thus validated stage operations from both the onboard and associated ground facilities viewpoints. It validated the ground safety systems, thus allowing a stage (the MQ - see below) to be set up for testing in its flight configuration. It also provided confirmation that the stage preparation teams were able to carry out operations to tight deadlines, while keeping to the stringent quality assurance rules that govern all our activities. Last but not least, the campaign verified that the stage design was functionally viable and reliable.

*The development campaign*

The development (M) campaign started on 20 April 1995 with the test review. The first test was delayed by a serious accident in which two technicians sadly lost their lives, a tragedy that deeply shook the entire space community.

The first test took place on 22 May. It did not get as far as the test firing, essentially due to ground operations software malfunctions in the real environment. The following test scheduled for 30 May was halted during the engine start-up sequence by an incorrect parameter specification in the flight program. The next test took place successfully on 16 June. The stage operated perfectly for the planned firing duration of 589 seconds.

The campaign then entered a difficult phase. The ground operations software was still undergoing modifications to handle the 501 launcher after the main-stage test phases. Some of these modifications were integrated into the operational system, and rightly so, since it is always very worthwhile testing the latest version of a system at the earliest possible point - especially one as complex as a synchronised launch sequence. The main-stage M test campaign therefore had to allow for the secondary objective of validation of the full-scale ground/onboard/software system. Thus, the M2 test on 3 July did not go through to engine ignition. After a break in the campaign, which was used to carry out further validation, the M3 test likewise failed to produce a successful conclusion. Two major incidents required fairly substantial work on the stage: an oxygen leak detected during M3 had to be sealed, which could only be done from inside the tank itself, and a burst high-pressure oil line feeding the flight control actuator system called for an intricate repair operation to replace the affected equipment.

Testing was then able to resume and the M3.2 test took place on 23 October. During the 620 seconds of burn time, the stage functioned wholly satisfactorily. Next came the M4 test (592 seconds) on 7 November, followed on 23 November by the M5 test (623 seconds), the last in the campaign.

A number of incidents and accidents had punctuated the campaign, reinforcing the belief that ground/launcher system operations of this type are particularly complex. This complexity, which is only to be expected of a system of this scale, is such that any modification, however innocuous it might appear, has to undergo very extensive validation phases. The campaign also showed that for activities such as ours in which all systems are interdependent, no simulation will replace actual-scale testing, which will always be essential. Last but not least it showed that test incidents – which are not necessarily abnormal (testing would not be necessary if it was absolutely certain that there was nothing to learn!) – play an important part in securing system reliability.

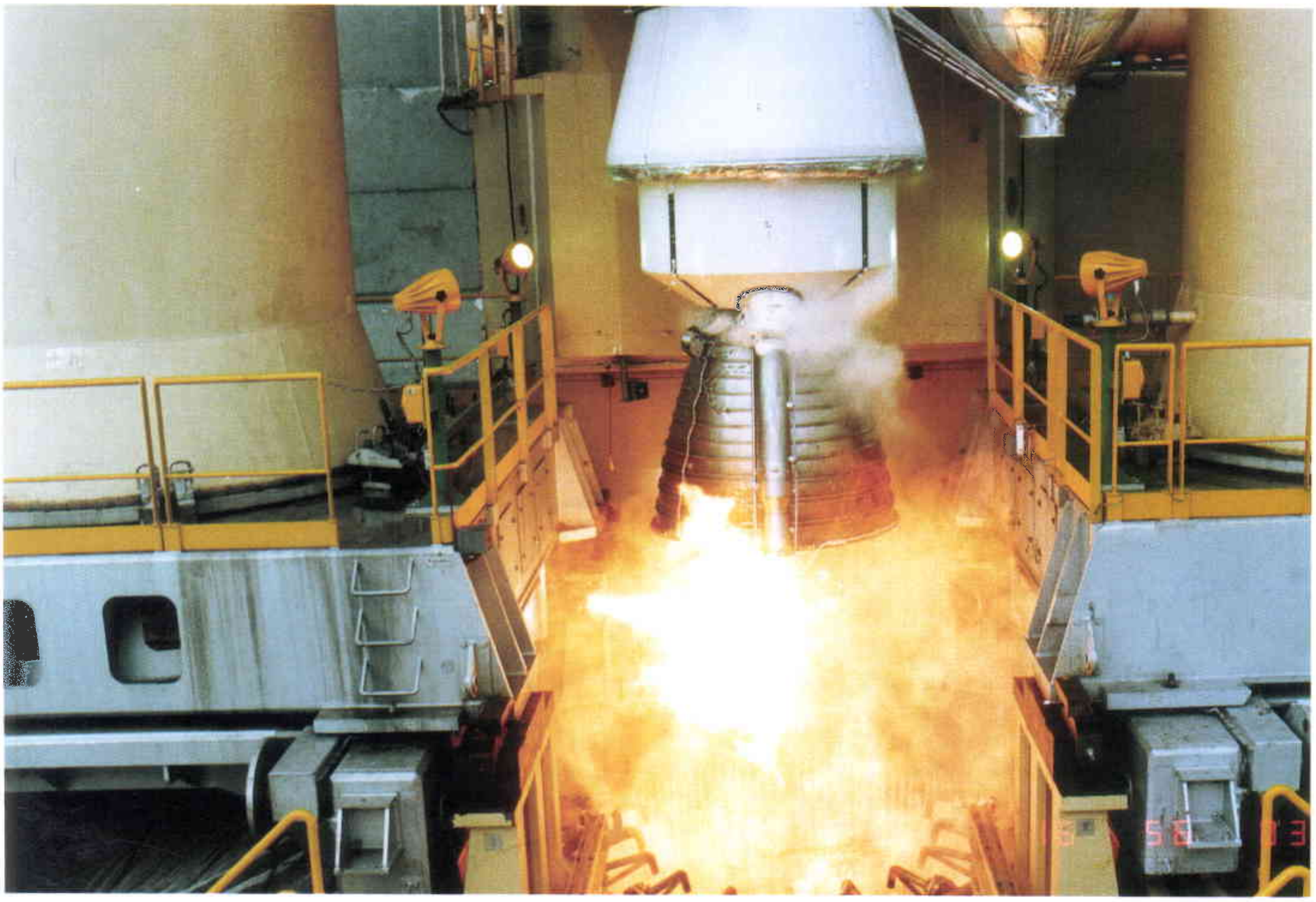
*The qualification campaign*

The qualification campaign started on 1 December 1995 with the test review and lasted just over a month. It actually involved two tests: the Q1 test which took place on 15 December and lasted 628 seconds: and the Q2 test of 594 seconds duration, which took place on 6 January 1996.

The Q2 target H0 was the same time as the flight 501 H0. Apart from the stage test objectives, Q2 also helped demonstrate that the launch teams could handle a long countdown, under the same conditions as the flight 501 countdown would occur. Q2 thus completed the lengthy phase of main-stage testing in French Guiana. The MQ stage used for the M and then the Q tests – after the replacement of some equipment – clocked up over 3600 seconds of running time, i.e. about six times its nominal burn time.

*Flight 501*

The 501 main-stage ignition sequence proceeded perfectly and electrical system operations were wholly satisfactory. As far as the pogo phenomenon was concerned, vibration levels were close to those recorded during the development (M) tests. Large and constantly increasing pressure fluctuations in the actuators were detected as from 20 seconds onwards, due to a phenomenon known as buffeting, but this does not cast doubt on the functioning of the stage. Overall, the main parameters of the command system were close to those forecast. The thermal environment in the stage bay was cooler than during M testing, but this had no impact on overall equipment functioning. The Vulcain engine functioned perfectly.



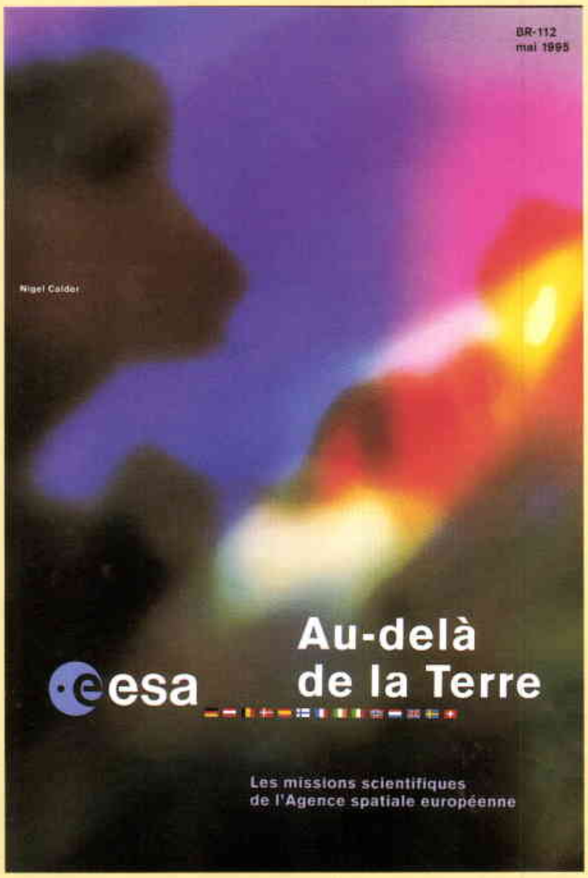
**Figures 4a,b. The M stage (left) and its testing (above).**

## Conclusion

The cryogenic main-stage test firings were carried out over a period of almost a year and a half; between September 1994 and January 1995. These tests revealed some difficulties in mastering stage operations, primarily at the start of the battleship campaign and during the development test campaign. More specifically, most of the difficulties arose during the synchronised sequence – the final phase of the countdown involving combined electrical and fluid commands.

Onboard functioning did not reveal major difficulties; a few incidents such as the liquid-oxygen line feedthrough leak or a burst in an engine actuator unit line disrupted the development test campaign, but these problems were overcome and corrected without any great impact on overall scheduling.

Finally, it should be noted that the decision to conduct the stage testing at ELA-3 was vindicated by the Ariane flight 501 final countdown to lift-off, both of which proceeded very well and without interruption, apart from weather-related problems.




# 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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# New Forms of Contributions to ESA's Optional Programmes: In-Kind Deliveries

**M. Ferrazzani**
Legal Affairs, Directorate of Administration, ESA, Paris

**The evolution in the general political and financial environment in which ESA's Programmes are conducted has prompted the Agency's Member States to consider new forms of financial constraint for contributions to the Optional Programmes. The debate is well under way on the issue of national 'contributions' to ESA Optional Programmes outside the usual scheme of financial contributions provided for by the Convention, and it has already produced some interesting and innovative schemes. Also, the Council meeting at Ministerial Level on 4 March 1997 (reported in ESA Bulletin No. 89), in its Resolution on the Agency's industrial policy (Chapter III), indicated the need to examine these issues with a view to establishing rules applicable to 'In-Kind Deliveries' (IKDs).**

## Introduction

The current situation calls for an in-depth analysis of the issue of national in-kind deliveries to ESA Optional Programmes with respect to their effects in terms of risk, legality, decision making and programme management. The somewhat diverse examples presented here are representative of the history of this type of activity within programmes conducted under the ESA system. The ensuing synthesis is an attempt to summarise the present situation regarding programme rules and practices and to identify questions to be answered and programmatic guidelines needed for the correct presentation and management of these issues in the future.

## Previous cases

*Meteosat*

In the Arrangement between the Member States and ESRO for the Meteosat Programme in 1972, it was recognised that ESRO would "make use of the result of the studies already covered under the French national programme, and of certain facilities and personnel of CNES". Detailed conditions were then agreed in an ESRO/CNES Agreement. This formula was implemented by ESRO (later by ESA) with a specific ESRO project team in charge of the execution of the programme, based at the CNES Toulouse Centre, and with CNES personnel made available free of charge at the specific request of ESRO, plus functional support. Contracts for carrying out the project were concluded initially by ESRO and later by ESA.

*Remote-Sensing Preparatory Programme*

The Declaration on a Preparatory European Remote-Sensing Satellite Programme provided that, for the purposes of the programme:

"Germany and France shall make available to the Agency, free of charge, each within the area concerning it, the results of studies and development work undertaken at national level, identified by the Executive and recognised by the Participants as being of direct interest to the Preparatory Programme and of a value equal to, or greater than, the difference between the 'direct costs' contributions actually paid, and the contributions of the other participants".

The Programme was actually carried out between 1979 and 1982 on this basis. This allowed both Germany and France to each contribute to external costs at a minimal level of 50 000 AU whilst other participants were contributing substantially towards them but with provision for a guaranteed 100% geographical return.

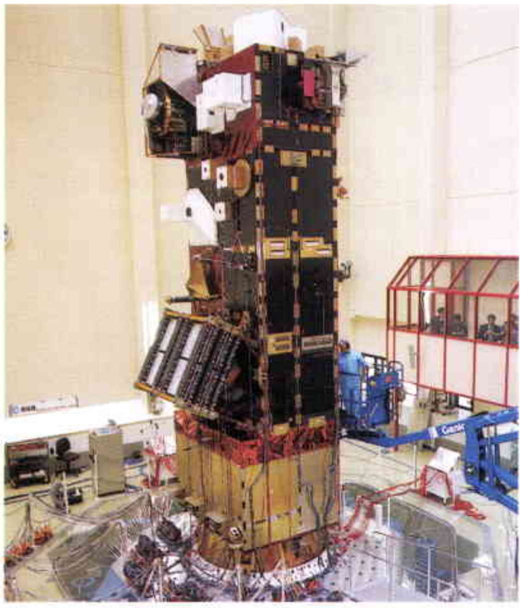
*Ariane*

The Arrangement on the Ariane Programme signed in September 1973 delegated programme management to CNES. This Arrangement was accompanied by an ESRO/CNES Agreement, whereby CNES was to provide a team (free of charge, except for mission costs), place contracts and so on. This was followed by the Resolution on the Ariane promotion series and the Declarations on the following programmes based on Article V.1(b) of the Convention, which were always supplemented by an ESA/CNES Agreement. Much the same provisions are used for the Agency's overall responsibility and CNES's technical and financial management.

*Hermes*

The starting point was the Europeanisation of the programme proposed by France involving a preparatory programme, the development programme proper, a Declaration and an ESA/CNES Agreement on the management scheme. Much the same provisions were used for the respective roles of the Agency and CNES, the arrangements for reporting technical information, and in this case the setting-up of an 'integrated' team at the CNES Centre in Toulouse (F).

*Envisat-1*
Germany proposed that certain tasks included in the content of the POEM-1 Declaration, and included in the Envisat-1 Programme element funding, be funded by a special cash contribution from Germany on the explicit condition that contracts of the corresponding value be assigned to its national industry. These tasks are Ground Segment/Payload Data Segment items managed by ESA on behalf of Germany. Germany recognised that "the elements developed with this national funding are considered to be part of the Envisat Programme, and in particular part of the approved Ground Segment concept". This special German contribution amounts to approximately 5.5 MAU (including an element reserved for ESA management costs).



Risk factors, as well as management aspects, remain under the close scrutiny of ESA, in accordance with additional arrangements established between ESA and DARA. Considering these special circumstances, this Envisat case cannot merely be likened to the previous cases of national works contributed in-kind, but has to be regarded rather as a special financial contribution by Germany outside the criteria of the Programme Declaration and its envelope. This extra contribution has also been made in the spirit of easing the impact of the existing under-subscription of the financial envelope. In this respect, it does not have a direct parallel with earlier events and should not be confused with a typical in-kind delivery. In fact, the accepted documents explicitly mention that this "special contribution offered by Germany remains outside the financial envelope".

*Artes-9*
The Artes Programme participants have defined and have subsequently subscribed to Element 9 of the Artes Programme, covering works related to the GNSS (Global Satellite Navigation System). The relevant Appendices A and B to the Artes Declaration have inserted in the Programme the concept of 'In-Kind Deliveries' (IKDs), funded nationally outside the ESA programme framework, and put at the disposal of the ESA programme through a grant in-kind and transfer of ownership. The legal status of such an IKD is explained in the Artes-9 Implementing Rules, approved by Council on 20 July 1995. A precise description of each of the agreed IKDs is added to the Appendix B before being included in the programme's work planning.

The Artes-9 Implementing Rules regulate in detail, within the General Implementing Rules of Artes, the special cases of in-kind deliveries and the related activities, including the administration and charging of ESA internal costs covering management and monitoring activities within the programme. This heavy regulatory exercise was necessary in order to incorporate this novel approach. In this case, important portions of the programme are intended to be contributed by Participating States, as in-kind deliveries, accompanied by some financial contribution to cover internal costs and other programme activities. Therefore, for the first time in an ESA Optional Programme and in a very new programme approach, a substantial part of a project consists of a coordination of national activities, or development works to be undertaken nationally, with a view to a European coherence for unified ultimate use and exploitation.

**Other cases**
This list is not intended to be exhaustive, but is rather a series of examples chosen to illustrate past practice in ESA's Programmes and its evolution. Based on past experience and accepted practice, the following should not be considered as national in-kind deliveries:

- the coordinated test facilities, where the Agency has a classical contractual relationship with these facilities (see Agreements with CNES, IABG, IAL based on a policy agreed by Council)

- the national space programmes sometimes carried out in close coordination with some Agency activities under cooperative Agreement with ESA
- nationally funded and developed instruments destined to fly on an ESA spacecraft on the basis of a selection process known as an 'Announcement of Opportunity'. This practice has been developed in the Science and Earth-Observation Programmes on the basis of specific requirements by some well-identified scientific groups and institutes which are also able to develop hardware. This activity is purely national and is accepted by ESA for meeting the mission objectives, well established at the outset by common agreement between the Participating States on the basis of rules approved by Council (see Rules concerning Information and Data adopted in December 1989).

**Definition and legal analysis**
In attempting to arrive at a 'uniform' definition of an IKD on the basis of ESA's experience to date in this domain, it might be identified as:

*"Goods transferred or services rendered to the Agency by a Member State and falling within an agreed programme content, not being funded by means of Article XIII of the Convention, but contributed by the Participating State free of charge to the Agency for the purpose of the programme in question".*

In order to identify issues associated with such a method of participating in ESA programmes, and analyse its impact on the Agency's framework and management practices, this definition has to be measured against the basic assumptions and elements of the Agency's system vis-a-vis the following points :

*a. The Convention*
An IKD, as described above, in essence 'deviates' from applying one of the fundamentals of the Agency's system, as formulated in the Convention. In lieu of financial contributions, as provided for in Article XIII of the Convention, such alternative schemes allow for voluntary and free grants from Member States, which do not have the same obligatory character towards other States as exists today in the commitments entered into by virtue of the provisions of the Convention, and accordingly expressed for each Optional Programme in a Programme Declaration. The nature and effect of a Delegation's commitment outside the framework of a Programme Declaration cannot guarantee the same level of commitment afforded under an international treaty obligation, such as that deriving from the provisions of the Convention. In fact the ESA Convention, as an international treaty between States, has been duly ratified and published as a domestic law of each Member State. Because of the ratifications, financial provisions contained in the Convention now constitute part of national laws and administrative procedures concerning the commitments and payments of financial contributions to the Agency. An IKD, deriving from the intention of one Delegation at programme level, is not covered by any provision of the Convention and therefore not guaranteed by a national ratification law, and may not be regarded as having the same power and legal security on the part of the national administration.


There is an obvious difference here which cannot be avoided by any ESA internal decision or text approved by Delegations of Member States. However, a new Optional Programme containing in-kind deliveries should be transparent and have the same character as other ordinary commitments towards ESA Programmes. To achieve this, the IKD needs to be defined and included already at the Programme Proposal stage and subsequently inscribed clearly in the Enabling Resolution approving the Programme and in the Declaration constituting the multilateral agreement between Participating States. The modalities of its execution need to be set in the Implementing Rules, thus implying the conclusion of a government-level agreement between ESA and the State concerned. Any IKD proposed by a Participant after the entry into force of the Declaration and not yet included in the work content would require an addition to the Programme content and also some adaptations to the Implementing Rules. Most of these decisions will have to be taken by unanimous vote of the Participating States. However, not all of the legal risks explained above may be avoided with such an alternative solution.

*b. Cost overruns*

In cases of cost overruns beyond the cumulative costs assumed in an agreed initial envelope, there is provision for the obligation of each Participating State to contribute to a level of 120%, beyond which any State may withdraw from the Optional Programme.

IKDs could be regarded as a way of fulfilling programme content without fully subscribing to the financial envelope. This has the indirect effect of creating structural deficits within the envelope, by diverting financial resources out of the programme envelope towards national investments. Such a solution has the disadvantage of leaving the Agency with the problem of managing an incompletely financed programme and also avoiding the normal allowance of a cost-overrun margin for the investment in question. The different obligations of States are also obvious here. Whatever the attitude taken by the national investment covering the IKD, there is still the risk of a cost overrun with the IKD and, because of their mutual interest in the total programme's success, *in fine* all of the other Participating States might end up bearing the additional cost to complete the programme.

In order to avoid this situation, a clear-cut separation has to be made between IKDs and the overall financial envelope: the ESA financial envelope should only contain funding for internal costs plus ESA-initiated industrial contracts. Such an envelope will then be 100% financed without any deficit, and the usual 120% rule can then easily be applied for its original purpose. IKD elements would have to be announced and committed to in the same Declaration and Financial Annex, but on a separate basis, outside the ESA financial envelope. Cost overruns on IKDs would then be solely the responsibility of the providing entity. An efficient project would need to keep full control of the programme content entrusted to it, with full management authority for each of the elements composing it. This would minimise, although not eliminate, the cost overrun risk for the programme.

*c. Programmatic risk*

A project including in-kind deliveries will inevitably involve more programmatic risk, because of the work items initially falling, either partially or even totally, outside the general management and supervision of the ESA project manager. There may be schedule impacts, and therefore cost consequences, for the remaining normal portion of the programme, and hence eventual financial responsibilities to be assumed by other Participating States.

The debate to date within ESA has shown that several Delegations refuse to accept solidarity towards this kind of programmatic risk, seeing the desirable solution in the case of a Participating State's non-compliance with its responsibility to deliver in time as a corresponding obligation to provide alternatives to the programme. These 'alternatives' would need to be fully understood and accepted by the other Participants, thereby causing some delay in the decision-making process. In any case, this solution does not complete the programme as planned and may cause disappointments and cost increases for the other participants.

*d. Internal costs*

The Agency's financial system, set up with the explicit approval of the Member States, has established a refined system for charging internal costs to the programmes and the activities approved under Article V of the Convention. The Agency's budget structure and charging policy for all mandatory activities and optional programmes are defined by Articles 11 and 12 of the Financial Regulations, which have recently been revised to reflect a new charging policy approved by Council. There is as yet no explicit rule or alternative system, nor any special financial provision, for the case of a national delivery in-kind.

As the price tag of each IKD activity will have to be known at the start of the programme, the ESA charging policy for internal costs could be applied, so that the general overheads need not increase substantially. This has already been done in the case of Artes-9, the programme currently most affected by the IKD concept.

For the future, therefore, special criteria need to be considered for insertion into the Financial

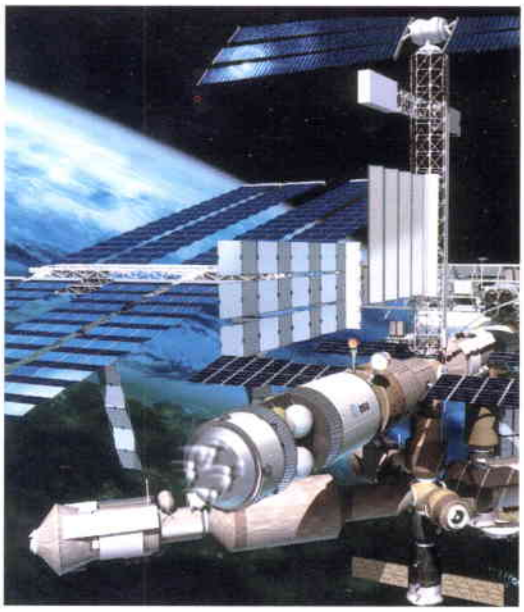
Regulations to cover this point. Such criteria might allow various rate levels to be applied, depending on the return of the development work, service or other activity. The cost of reproduction or the recurrent price of the IKD should form the basis for the calculation. Also, for such activities which can be likened in a way to external customer activities, a handling charge has to be levied as a fair percentage so as not to favour this approach unduly, and not to encourage such a regime compared with the classical method of contributing to the Agency's programmes. The 'income' from this handling charge because of the programme management cost involved, may appropriately be credited to the Programme concerned and not to the General Budget as in the case of external customers.

*e. Industrial Policy*
Participating States in an Optional Programme could view IKDs as a method of guaranteeing the granting of a portion of work to a given industry identified in advance, outside the normal procedures in force at the Agency. This could tempt Delegations to try to circumvent the competition provided for in the usual system, or else to distort that competition by granting a national contract which would be executed prior to the ESA competition and thereby pre-empt the subsequent situation. The prevailing delicate balance would be compromised. As such activities are not funded by the usual financial contributions and not covered by the usual ESA contracts, they would not be included in the calculation of the global industrial return of the Agency's programmes, although they would be regarded as an official part of its activities.

The situation could be clarified if, at the start of a programme, Participating States clearly and unanimously separate and define what is to be managed by ESA and what is not. Activities not managed by ESA would remain outside the Agency's programmes and responsibility as regards industrial-policy considerations. All IKDs should be evaluated against the industrial return of the country offering them: IKDs counted as part of the industrial return of a country would have the effect of increasing the industrial work foreseen for that country. If on the other hand, IKDs were to be omitted from industrial-return statistics, they would be carried out over and above the 'normal' share of work that should go to that country. Clearly, this would provide an incentive to offer more and more IKDs, either to have critical work done at home, or to move the project in the direction sought by the donor country, or simply as a means of avoiding competition.

*f. Contracts*
In the case of the inclusion of an IKD in a traditional ESA procurement contract, we would have the situation of a procurement contract for the total activity not being totally funded by ESA finances. ESA would be committed to pay for work rendered, and services for which it does not have fully guaranteed financial backing, because of the non-binding character of the national delivery in-kind, or special financial contribution. This situation has to be analysed further on a case-by-case basis, not least in view of national laws that could still hold ESA liable for the total.

The 'contribution-in-kind' may be the result of a national item (intellectual property, knowhow/design, software or hardware) that has already been developed or partially developed. In such a case it is likely to figure in the industrial development as 'Agency-furnished equipment' and the Agency takes responsibility for any technical shortfall, inadequacy or lateness. The firm concerned will try to avoid responsibility in its contract with the contributing State, and will have sufficient ammunition to do so (including externally imposed interfaces).



If the contribution is only financial, then a contract will have to be placed with the firm identified, and this will presumably involve development. The only way that the programme can maintain its technical and programmatic integrity is to incorporate the work within the prime contract, subject to both the technical and managerial controls of the ESA Project Manager and the Prime Contractor, and the ESA contract conditions, despite national and industrial resistance to this control.

Several of these problems can be solved by drafting appropriate contractual terms, but it would be necessary to:

- Ensure that the 'contribution' meets the technical requirements of the programme. This is best done either by incorporating it fully within the development contract, or having it fully as a 'national' and then 'Agency'-furnished complete element on the basis of cooperative arrangements for this purpose included in the programme, undertaken as such by a Member State.
- Require the contributing Member State and the industry concerned to fully guarantee the quality of the product and the consequences of performance not being met, even by means of a financial-liability clause or penalties.

This will probably involve an interlocking series of agreements, and care will have to be taken that all cross-links between the parties are complete. If there are any gaps, then it will almost certainly be the Agency which bears the risks, consequences and subsequent costs. The situation may be aggravated by differences in applicable laws in the countries concerned.

*g. Intellectual Property Rights (IPRs)*

If the IKD is taking place under the scheme of a national procurement contract, its legal terms and conditions may well be under different rules to those of the General Clauses and Conditions for ESA Contracts. The rights and obligations being created in such a contract might be distant from the ESA policy in the field of intellectual property for space research, as provided in Article III of the Convention and applied consistently in ESA contracts. Since such an in-kind delivery should in any case fall within the objectives, scope and content of an ESA Programme, there would again be a diversity of results. Also the terms of access to the IPR and results may prejudice future uses of such information by ESA for subsequent space programmes. The Intellectual Property rules for the IKD should as a minimum ensure access to, and sharing of the technology "in order to facilitate the exchange of scientific and technological information" pertaining to space research technology and application within the Member States as provided by Article III of the ESA Convention and by the ESA Council document on Information and Data (ESA/C(89)95, rev.1). Member States have to understand and accept this general principle in the same spirit as when they signed the ESA Convention, and ensure that it is respected in every national contract aimed at preparing an IKD for future inclusion in the ESA framework.

**Conclusion**

In conclusion, there is no reason to reject the IKD principle as such, but some work still needs to be done within the Agency to accommodate these innovative methods of contributing to ESA Programmes. However, we have to recognise the complexity and the exceptional nature of the approach. The debate now in progress, and also the Council Resolution at Ministerial Level, recognises the need to establish Agency-wide guidelines for the future for IKDs. In order to be incorporated sensibly into the Agency's programmes on a realistic scale, IKDs will need to:

(a) embrace work packages that are technically identified and clearly specified within an established system design, not constituting part of the core activity of the project nor a critical item of the system
(b) be easily harmonised with the industrial-policy baseline decided for the programme
(c) be in compliance with the system design without requiring complex or costly design solutions
(d) be integrated promptly into the total work plan
(e) be allocated a financial value to the programme, assessed by the Executive and accepted by the Programme participants
(f) be committed by the contributing State on the basis of an irrevocable, free-of-charge grant in-kind and full transfer of ownership to the Agency by means of a binding agreement at governmental level. Such commitment shall include the general responsibility of the Member State towards ESA for the time of delivery and quality of the work. Depending on the requirements of the programme, the Agreement shall specify the terms of ownership and other rights. The providing entity shall have to plan for replacement deliveries or other forms of replacement, in cases of unforeseen difficulties.

On the basis of this analysis, it might be prudent to introduce into the Agency's legal framework some ground rules, guidelines or code-of-conduct commensurate with the above-defined issues associated with in-kind deliveries. The objective would be to have these guidelines approved by the Member States to govern all ESA Programmes in such cases and then used as a reference when drafting legal texts such as Resolutions, Declarations and Implementing Rules (completed by detailed financial provisions), therefore allowing greater security, transparency and flexibility in each new Optional Programme.

# Droit de l'espace, mythe et réalité

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Merci lecteur de n'avoir pas sauté cet article et passé à un autre; peut-être avez-vous été retenu par une certaine curiosité mêlée d'un peu d'ironie amusée. Le droit de l'espace! Vraiment on ne sait quoi inventer, veut-on mettre des feux tricolores sur les orbites ou un poste douanier sur la Lune? D'ailleurs qui pourrait légiférer sur l'espace, les corps célestes, et de quel droit? Parce que nous sommes des êtres 'intelligents', plus développés que les bactéries qu'on semble retrouver dans les cailloux provenant de Mars? Mais pourquoi une assemblée auguste de petits hommes verts ne pourrait pas élaborer son propre droit de l'espace, régissant y compris la Terre? Le rêve pour le juriste, un conflit de lois extra-terrestres!

**Le Traité sur l'espace aura bientôt 30 ans. Il n'est plus la seule source de droit: à côté ont fleuri des réglementations techniques, des accords bilatéraux ou multilatéreaux entre gouvernements ou entre agences nationales, sans oublier les divers accords de démilitarisation de l'espace et les contrats. C'est en quelque sorte le trop plein, le manque de coordination et de vue d'ensemble. Aussi aujourd'hui on ne peut plus se limiter à la lecture du Traité de 1967. Le mythe a été dépassé par les réalités mais reste essentiel: c'est de cette fusion entre mythe et réalité que pourra apparaître un droit de l'espace plus rigoureux.**

Mais voilà, l'homme a proliféré sur cette petite planète bleue 'comme une orange' et n'a de cesse de forger des règles pour gouverner les relations avec ses congénères, pour régir le territoire sur lequel il va régner, imposer ses lois sur l'espace terrestre, maritime et aérien. Liberté ou souveraineté? Lecteur seras-tu étonné d'apprendre que Rome avait avancé l'idée que la propriété du sol s'étendait jusque dans les cieux et aux enfers? Normal, au delà c'était le royaume des dieux. Mais Gagarine nous a informé qu'il n'avait pas rencontré Dieu lors de son voyage orbital! (il aurait dû regarder en lui-même et non par le hublot).

Si on ne peut être propriétaire de l''éther' (comme on disait au début de ce siècle) et de l'air, les machines volantes du début du siècle et de la première guerre mondiale ont donné à croire que l'homme pouvait en être souverain, pouvait dresser des frontières, réglementer l'exercice de cette activité nouvelle. Par là, l'homme visait à étendre le domaine d'application des lois nationales. Qu'avaient fait Christophe Colomb et les autres découvreurs de nouveaux mondes en établissant de nouvelles frontières? Dès lors, les Etats se sont mis d'accord pour déclarer que l'Etat sous-jacent a la souveraineté sur l'espace aérien au-dessus de son territoire. Restait l'espace au-dessus de la haute mer et d'autres territoires en dehors de souveraineté nationale. D'où l'établissement des 'libertés de l'air' nécessaires au commerce international, ou de dispositions sur la responsabilité internationale des Etats ; nul besoin de se préoccuper pour savoir jusqu'à quel niveau cette 'souveraineté' existait.

Mais ne voilà-t-il pas qu'on se permet de lancer des objets artificiels, dotés d'un système de propulsion et qui peuvent même emporter un homme, faire des observations. Le droit de l'espace naît le 4 octobre 1957 avec Sputnik, et les Nations Unies s'en saisissent.

La première question que l'on va se poser, c'est bien sûr (dans la ligne de la doctrine existante), cet espace, qui n'est pas aérien, au fait comment l'appeler, 'outer space', c'est commode, mais c'est mal traduit en français par 'extra-atmosphérique', d'autres utilisent l'expression d'espace 'cosmique' ou 'extérieur'. Cet espace, certains vont même jusqu'à le découper en tranches.

Cet espace — qu'on ne sait appeler, mais pourquoi ne pas simplement dire 'l'espace', l'espace aérien n'étant lui qu'un élément de l'ensemble, cet espace à qui appartient-il donc? Qui dispose d'un droit de souveraineté? Voilà la question qui, en 1958, tracassait le monde juridique. On finit par comprendre que si on s'essaie à prolonger à la verticale les frontières nationales, on arrive à une situation ressemblant à celle de spaghettis que vous essayez d'extraire de votre assiette: tout se mélange. Aussi, après avoir essayé bien des théories savantes, on arrive à la conclusion que cet espace extra-atmosphérique, eh bien, ne peut faire l'objet d'appropriation nationale par quelque moyen que ce soit; aucune limite, supérieure ou inférieure n'est fixée et on s'intéresse aux activités conduites dans cet espace. Son exploration et son utilisation sont dites libres, par tout Etat sans discrimination, quel que soit son niveau de développement, pourvu bien sûr qu'il ait les ressources nécessaires (développer un lanceur ou se procurer un lancement, développer un satellite, disposer de stations de contrôle, d'une base de lancement, ce n'est pas donné à tous les Etats). L'issue est de proclamer que toutes ces utilisations se font au bénéfice de l'humanité toute entière. Mais celle-ci, le sait-elle et comment va-t-elle percevoir ces bénéfices?

Un autre sujet de préoccupation: l'utilisation militaire, pacifique, non agressive, quid des satellites espions (le satellite n'est-il par un super U2?), des satellites anti-satellites, etc. Alors on distinguera entre la Lune, les autres corps célestes, qui sont démilitarisés. Ouf pour les petits hommes verts et tant pis pour la 'guerre des étoiles'. Bien sûr on pourra y employer du personnel militaire (rendu libre sur Terre). Par contre, pour ce qui concerne la Terre, les écologistes seront heureux d'apprendre qu'on s'interdit toute utilisation d'armes de destruction massive (ce qui laisse quand même pas mal d'autres armes non interdites, aux survivants de dire si ce fut une destruction massive ou pas).

On se préoccupe alors y compris des astronautes 'envoyés de l'humanité toute entière', encore elle mise à contribution, ce qui n'évite pas que les astronautes partent avec passeports et visas, et bien sûr des dommages causés par des objets spatiaux sur Terre, sur mer, dans l'espace aérien et dans l'espace, dommages entre deux satellites, un satellite et un aéronef. Mais quel est le responsable, auprès de qui vais-je me plaindre si le ciel me tombe sur la tête? Quelle est la loi applicable, le tribunal compétent, et en plus s'il s'agit d'un débris, et d'un débris radioactif? Vous avez le choix, il faut déterminer l'Etat de lancement. Maintenant qu'on va pouvoir lancer depuis une plate-forme en haute mer! Vos papiers: quelle est votre immatriculation, votre assurance? Si Molière était là, les Plaideurs seraient à moderniser. De toute façon, on se calme, on se calme: en droit international, ça se dit 'on se consulte'. Pas de brouillage nuisible, pas d'interférence, c'est normal.

Tout ceci nous amène à une Déclaration en 1963 sur les principes régissant les activités des Etats, base du grand Traité sur l'espace entré en vigueur le 10 octobre 1967, à des Accords complémentaires, sur les astronautes, sur la responsabilité internationale pour dommages, sur l'immatriculation des objets spatiaux, sur la Lune puis à des principes concernant la radiodiffusion directe, l'observation des ressources terrestres, les sources d'énergie nucléaire, la notion de bénéfice.


Le Traité sur l'espace va donc sur ses 30 ans; il n'est plus la seule source de droit. A côté ont fleuri des réglementations techniques comme celles de l'UIT sur les fréquences, les positions en orbite, et surtout des accords bilatéraux ou multilatéraux soit entre gouvernements, entre agences nationales, avec les Organisations internationales conduisant des activités spatiales qui prennent une place de plus en plus grande mais quelque peu ignorées dans le droit de l'espace stricto sensu (comme ESA, Eutelsat, Eumetsat, Arabsat, Intelsat, etc.). Bien sûr, citons les accords sur la Station spatiale internationale de 1988 revus en 1997, sans oublier les divers accords de démilitarisation de l'espace et bien sûr les contrats.

De nouveaux sujets sont traités dans ce droit positif: les services commerciaux de lancement, brevet et copyright, accès aux informations scientifiques et techniques et distribution de ces informations, jusqu'au droit pénal. De nouvelles formules apparaissent ('cross-waiver' en matière de responsabilité), ou des faiblesses subsistent (en matière de règlement des différends) de nouveaux sujets de droit, en particulier les entités privées. D'où de nouvelles réglementations nationales (contrôle et autorisation des activités privées). Le droit du commerce spatial en quelque sorte. On va même s'interroger sur l'opportunité d'établir une Organisation mondiale de l'espace. Dans un sens, c'est le trop plein, le manque de coordination et de vue d'ensemble. Aussi aujourd'hui on ne peut se limiter à la lecture du Traité de 1967. Le mythe a été dépassé par les réalités mais reste essentiel; c'est de cette fusion entre mythe et réalité que pourra apparaître un droit de l'espace plus vigoureux.

# The Reform of the Agency's Budget Structure and Charging Policy

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**In all enterprises, be they governmental institutions or commercial companies, the charging of services provided to internal customers and the allocation of general overheads represents a difficult issue. The charging or allocation of these costs and overheads to cost centres, activities, programmes or products is the subject of permanent and sometimes difficult discussions.**

**A balance has to be struck between a fair charging or allocation of costs and overheads and a system that is simple enough to be operated and understood by everyone and that provides the transparency required to make it acceptable to all. A support user must know exactly what price he is going to pay for a service and how that price (including the constituent cost elements) has been built up. Only if the prices charged for internal services are based on true cost and general overheads allocated on an equitable basis, can both parties, the support provider and the support user, gain in the long run. In addition, a well-functioning cost accounting system is a necessary tool to control internal costs efficiently and thereby manage internal resources properly.**

## Introduction

The Agency's present budget structure and charging policy have been in force since 1983. During that time reform proposals have been discussed by ESA's Administrative and Finance Committee (the AFC is composed of representatives of all Member States and Canada) on several occasions without reaching a consensus to implement changes. By 1995, the shortcomings of the present system had become so apparent that the Council meeting at Ministerial Level in October that year adopted a Resolution that "underlined the need to define and to implement a new charging policy …….. and to achieve its entry into force by 1 January 1997", or by 1 January 1998 at the latest. The agreement of Member States that a reform of the system was needed was due to the necessity to reduce the Agency's indirect expenditures and therefore to implement a charging policy tailored to better controlling and managing internal costs, and to the shortcomings of the present system described in detail below.

The Director General therefore submitted to the AFC in March 1996 a proposal for a comprehensive reform of the Agency's budget structure and charging policy. This proposal was examined by the AFC throughout 1996 and finally adopted by Council at its meeting in December 1996. The new structure and charging policy will apply as from the 1998 budgets onwards.

## Shortcomings of the present system

Under the present charging policy, the support expenditures and overheads are composed of:
- Administrative Support and Site Services (105 MECU in 1997) recharged pro-rata to staff expenditure
- Variable Support Costs (83 MECU) recharged on the basis of usage
- General-Purpose Investments and Fixed Support Costs, representing some 100 MECU in 1997, of which 50% are financed by the General Budget and 50% recharged pro-rata to the use of Variable Support Costs.

The main shortcomings of this system are that:
1. The overhead recharge for Fixed Support Costs and Investments is recharged pro rata to the actual use by programmes of the Agency's capacities and facilities. This overhead, in addition to the support costs based on consumption of support units, acts as a strong disincentive to use the Agency's internal existing support capacity. This surcharge has increased strongly over the last two years due to reduced support requirements and would reach unsustainable levels because of the reduced mission model and the trend for programmes to place some support activities outside the Agency. This increasing

overhead percentage has increasingly become a major factor in decisions by programmes not to use available internal capacities, thereby reinforcing the under utilisation of existing support capacity and also leading to the creation of additional or even duplicate capacity outside the Agency.

2. The costs associated with the use of support facilities and capacities are recharged to the users without considering their level of utilisation. The unit rates are therefore varying from one year to the next as a function of this level of utilisation. The overhead rates are also unstable and the sometimes substantial cumulative variations make it difficult to estimate these expenditures at the beginning of a programme, although they have an influence on the cost-to-completion at a time when participating States are facing very constrained budgetary situations.

3. Exceptions to the existing rules decided in the past, mainly in favour of the Scientific Programme and programmes undertaken for third parties, have partly destroyed the logic of the present system and reduced its visibility and transparency, thus raising the question of its validity.

**Objectives and constraints of the reform**

When the Executive began, with the support of the consultancy firm Price Waterhouse, to study reform of the ESA charging policy, the objectives assigned to the project were to define a system that should:

- be equitable and transparent
- change behaviours in both the Programme and Support Directorates with the objective of reducing costs
- use actual resources utilisation/requirements as a basic principle ('cause-and-effect or the-user-pays' principle)
- allow more stable overhead and unit rates
- create an incentive for programmes to use the Agency's existing support capacity (facilities, expertise pools).

Given the unique nature of the Agency's functioning, several constraints were to be respected:

- the current Level of Resources for Mandatory Activities 1996 - 2000, approved by Ministers in 1995 in Toulouse, had to be strictly respected
- the present purchasing power of the Scientific Programme had to be preserved as far as possible
- variations in the present overall contribution profiles of Member States had to be kept to an absolute minimum
- the impact on the cost-to-completion of the Optional Programmes had to be marginal
- finally, the system had to be practical and simple enough to be understood and operated efficiently.

Maximising the benefits of the new charging policy whilst at the same time respecting the above constraints was a difficult challenge, especially considering that any proposed reform needed to be approved by a two-thirds majority of ESA Member States.

**New budget structure and charging policy**

The proposal for a new budget structure and charging policy should not be seen in isolation, but rather as one of the elements of the Agency's on-going Transformation Programme. The new charging policy has therefore been developed in coherence with a broader cost-management system with the overall objective of providing improved costing information to support management decision-making. It quickly became obvious that a simple adjustment of the present system would not be sufficient and that there was a need for a complete reform of the budget structure and charging policy.

The new concepts that have been defined in close consultation with the ESA Member States can be summarised as follows:

*Corporate costs*

This new Basic Activity output regroups the costs for the basic sustaining activities of the Agency, i.e. those relating to activities deemed essential, of common interest and (more or less) independent of the level of the Agency's programmes. This output will be totally financed by contributions within the General Budget.

The main expenditure items of Corporate Costs are the Agency's top management and basic administrative infrastructure, running costs not directly attributable to programmes, investments, maintenance and operation of the basic administrative data-processing systems and their related communication costs, the Audit Commission and the Agency's basic technical capability, including activities contributing to the framework of an efficient support capacity, e.g. standardisation, technical overseeing, development of analytical tools, technical assessments, reviews and studies, ensuring that the Agency can rely on a minimum level of know-how in critical technical areas.

A simulation based on the 1997 Budget shows that Corporate Costs would represent some 80 MECU this year.

*Site services and office automation*
This new support output regroups the costs for site services (expenditures for building maintenance, communications, canteens, cleaning, security, etc.) and for office automation.

Total expenditure for site services will be recharged at establishment level (thus improving transparency) pro-rata to the number of staff (ESA staff and contractor staff on-site). Total expenditure on office automation will be regrouped and recharged at Agency level pro-rata to the number of staff (ESA staff and contractor staff on-site).

The projected rates for 1998 are of the order of 20-25 kECU per head for site services, and 3 kECU per head for office automation.

*Administrative support*
This new support output regroups the costs of staff that are responsible for the day-to-day administrative support to all activities and programmes of the Agency, including Finance, Personnel, Contracts and the Publications Division. Total expenditure for administrative support, including its share of site services and office automation, will be recharged at Agency level pro-rata to manpower costs. The projected recharge rate for 1998 is of the order of 35% of the manpower costs.

*Technical and operations support*
This new support output will include expenditures for the technical support capacity which are generated by activity and programme requirements comprising:
- support manpower, specifically required to support programme activities
- facility operating costs generated by operating the support facilities at the request of programmes and the maintenance necessitated by operating those facilities.

The main areas of support expertise comprise:

- at ESTEC:
  product assurance; data handling; power supplies; structures; telecommunications; maintenance and operation of ESTEC Test Centre facilities

- at ESOC:
  preparation of the ground segment and operations; operations for the Agency's programmes; software development; computer services

- at ESRIN:
  design, development and operation of databases; data-processing applications.

Recharges for Technical & Operations Support, including its share of site services and office automation, to all users will be made according to usage on the basis of unit prices. Unit prices for facility usage will include manpower, consumables, spares and the operating maintenance for these facilities. Unit prices will remain stable throughout the years due to the introduction of the concept of 'capacity support' (see below).

*Technical infrastructure and capacity support*
The new Technical Infrastructure support output will include expenditures for:
- new capital investments which are of common utility for the Agency's activities and programmes on the basis of the Agency's Investment Plan
- the basic maintenance (including maintenance investments) of technical support facilities to ensure that they may be used within a reasonable delay
- related staff and associated expenditure
- the Agency's annual contribution to the Coordinated Test Facilities (Intespace in France, IABG in Germany and IAL in Belgium).

A Technical Infrastructure Review Board will analyse the future support requirements of programmes and their impact on the Agency's support capacity. This Board will report to the Director General and propose:

- for each major facility and support service, whether it:
  - shall be maintained due to programme requirements in the near future
  - shall be maintained (and possibly mothballed) due to future requirements or for other reasons (e.g. facility is unique in Europe)
  - shall be (partially) suppressed

- or whether a new investment should be foreseen due to forthcoming requirements and, if so, whether it would be a general-purpose investment or a specific-to-project investment.

Thus, all parties concerned will participate in these decisions, which will have a direct bearing on the overheads that will ultimately be charged to programmes and projects for which they have the overall responsibility.

The usage of Technical & Operations Support will be recharged to users on the basis of unit prices that are calculated on the assumption of a 'nominal capacity' and 'nominal cost', i.e. the total number of technical units that could, under normal circumstances, be produced per year by the unit concerned and the total annual cost associated with operating the facility or service at nominal capacity.

The expenditures for existing essential technical support capacity which is not used to its nominal capacity during the financial year, but which is retained due to future requirements in the framework of the European Space Policy, will be financed under the Capacity Support output. In particular, in all cases where a facility or service will be used at below-nominal level, it will cover the difference between the planned/actual total cost required to operate the facility or service and the planned/actual recharges to users based on the unit prices calculated on the basis of a 'nominal capacity' as explained above, if these costs are unavoidable. The total amount of this output has been strictly limited by ESA Council to 10 MECU.

The total expenditures of Technical Infrastructure & Capacity Support, outputs including their share of recharges for site services and office automation, will be recharged at Agency level to all programmes, pro-rata to their Direct Expenditure ( projected rate for 1998 is of the order of 6.5% of the Direct Expenditure of programmes).

In order to preserve the purchasing power of the Scientific Programme, as requested by the Council at Ministerial Level in Toulouse on 20 October 1995, this Programme will be recharged under Technical Infrastructure & Capacity Support on the basis of only one third of its direct expenditures for the present Level of Resources, with a review of this situation foreseen by mid-1998.

Considering that the Ariane Programmes are financing all of their investments, including those of a general-purpose nature, the ESA Council decided to exempt all on-going Ariane Programmes from recharges for Technical Infrastructure & Capacity Support. The Ariane-5 ARTA and Evolution Programmes will be charged with 20% of the Agency's annual contribution to the Coordinated Facilities.

**The reform in the overall context of the Transformation Programme and the next steps**

As noted above, the new charging policy has been developed in parallel and in coherence with the implementation in ESA of a new Analytical Cost Management System (ACMS). The overall objective of this cost-management system is to provide improved costing information to support management decision making, and to meet the following objectives in particular:

- provision of an improved tool for managing cost
- greater transparency in costing
- support to the planning and resource allocation process
- facilitate a culture that encourages cost control, with the aim of achieving savings
- a better understanding of cost behaviour
- a clear understanding of the utilisation of the Agency's support capacity.

In addition, the Council meeting at Ministerial level in Toulouse in October 1995 highlighted the need to reduce the Agency's costs over the next three years. In order to achieve these savings, there is a need for increased visibility of the right financial and non-financial information for management to support its decision making. The ACMS is therefore an important element for controlling and efficiently reducing costs in the years to come.

The ACMS is effectively a framework of modern management techniques and generally accepted best practices in the public sector and industry, and is designed to enable ESA to meet the key cost management needs identified above.

The aims of a costing system (ACMS) and of a funding system (the new charging policy) are different. The ACMS is a management tool with the primary objective of controlling and managing costs, while the role of the charging policy is to distribute the support expenditures and overheads as Indirect Expenditures to programmes with full transparency and on a fair basis. However, important parts of the cost-management system and the charging policy are closely interrelated, e.g. the concept of Corporate Costs and Capacity Support.

There are also further advantages to establishing links between the two systems in order to:

- avoid unnecessary duplication of administrative work
- have Programmes and Basic Activities benefiting in a fair way from the results achieved in cost management
- have a charging policy supporting the efforts made in cost management.

The ACMS system will provide the Agency's management with a multitude of data that go far beyond those needed for the charging policy through the introduction of 'cost centres'. A generalised cost-centre system at Agency level will make sure that the people with key cost-management responsibilities have the right information and incentives to carry out their role to the maximum benefit of the Agency.

It will provide improved transparency in how costs are built up and as such will create cost-consciousness and foster change. Cost-centre managers will be responsible and accountable for the technical management of the cost centre, the use of its resources, the overall quantity and quality of the services provided, for providing appropriate information to support the charges made to service users, reporting on the performance of the cost centre and ensuring the appropriate utilisation of the capacity of the cost centre.

The introduction of cost centres within the Agency will allow their managers to manage their budget at the appropriate level, to establish draft budgets and implement approved budgets at cost-centre level, and to determine the cost of individual activities. This information will be used to determine the total cost of support entities and to calculate realistic unit prices.

A trade-off has been made in order to define the level of detail needed for a fair charging policy given the need to have a concept that is easy to operate both during the budget-preparation cycle and during the financial year for budget implementation.

The implementation of the proposed ACMS system will provide greater visibility and control over how and by whom costs are incurred within the Agency, and for which activities and programmes. The outputs of the ACMS will provide a sound basis for a more equitable policy in the way in which the Basic Activities and the Programmes are funded by Member States.

**Conclusion**

The main advantages expected from the recently approved new budget structure and charging policy for the Agency are:

- the increased transparency achieved by regrouping all basic sustaining costs of the Agency (Corporate Costs), all costs needed to maintain and upgrade the Agency's common facilities/expertise (Technical Infrastructure), by measuring under utilisation of support capacity (Capacity Support) and by recharging Site Services costs at establishment level
- an increase by some 70% in overheads recharged on the basis of actual utilisation, and as a consequence a decrease in overheads charged on the basis of a cost attribution key
- reduced and more stable rates, thereby increasing the incentive to use the existing facilities and capacities of the Agency.

According to generally accepted best practices, a cost-accounting system must be based on accruals and not on cash. For legal and practical reasons, the accounting system of the Agency is based on cash accounting. With the arrival of AWARDS, the Agency's future financial system, accruals will be available in addition to information on payments made. Accruals could be defined as prices for work carried out and accepted by the Agency and for which the information has been made known by the contractor to the Agency, e.g. as a cost report, invoice, milestone report, etc. Whether the Agency's financial system will in future be completely based on accruals remains to be seen, but the tools necessary for such a reform will be available when the AWARDS project is implemented.

In an ideal world, cost accounting equals budgetary accounting and cost accounting is based on accrual accounting and includes amortisation of assets. The new budget structure and charging policy of the Agency, as approved by Council, is a first step in this direction. ESA not being a commercial enterprise, changes in cost-accounting techniques cannot be implemented at the same pace as in private organisations. However, considering the increased budgetary pressure that the Agency is facing, the support of modern accounting techniques and analytical tools is more and more necessary. Full transparency on costs and the right tools for capacity management is one of the main objectives of the already achieved and still on-going reforms in the Agency's financial and management structure.

The overall aim is to make the Agency more cost efficient and easier to manage, and to reduce response times to changing requirements.

# 1977-1997: Twenty Years of Software Engineering Standardisation in ESA

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**Almost exactly twenty years ago, in May 1977, ESA's Board for Software Standardisation and Control (BSSC) was established. Since that time, the BSSC has produced a highly successful software engineering standard, first issued in 1984, which has been applied extensively in ESA. This article describes the development and validation of ESA Software Engineering Standards, as well as a version of the standards for use in small projects - the so-called PSS-05 "lite." The results of comparing the ESA Software Engineering Standards with international standards such as ISO 9001/9000-3 and ISO 12207 are summarised. Work in progress is discussed, in particular the production of a guide on the application of PSS-05-0 in projects using object-oriented technology, together with future plans.**

## How the ESA Software Engineering Standards came to be written: a brief history

The origin of the ESA Software Engineering Standards goes back to the software development circumstances in the Agency in the mid 1970s. At two of its main support establishments, ESA was embarking on a number of ambitious projects involving the development of large amounts of software. At ESTEC these were mainly for the design and implementation of spacecraft, and, at ESOC, for the support of spacecraft operations and data processing. A number of these developments were in application areas which were new to the Agency at the time. The staff involved in software development were often brilliant engineers, able to find innovative solutions to problems. However, they were not used to working in a project environment with rigorous cost and schedule constraints. Each followed his own methods and there was little project discipline.

One of the founders of the ESA Board for Software Standardisation and Control, its first Chairman, and a co-author of this article, joined the Agency in 1975 and was nominated as project manager of a very critical software development activity at ESOC, namely to support a mission, the launch of which was imminent. The ground system involved a spacecraft control system, and extensive facilities for processing and other handling of the payload data. It was evident that the project was late. In addition, there were major hardware and operating system problems. While the developers were desperately waiting for improvements on the hardware side, an initial idea was to reduce requirements and to proceed directly with the implementation of only those requirements essential for the launch of the satellite. But what were the requirements? There were no written requirements - at best, some could partly be retrieved from minutes of meetings. All the rest were in the minds of the project engineers. How could cost and schedule be guaranteed under these circumstances? This was a project manager's worst nightmare!

The first reaction to the situation was the decision to stop any further development and require the software engineers to put into writing their understanding of what the requirements were. This was a very unpopular decision, particularly since the management hierarchy was sceptical of a radical measure such as suspending development on a high-profile project which was already late. However, it worked - with the list of written requirements, it was possible to select those needed for launch and then proceed with the development of a minimal system. The remainder of the system was completed when the satellite was already in orbit. Thus, disaster was averted.

Then came the second reaction, "We never want to find ourselves in this situation again!". This is the seed from which the BSSC, and consequently, the ESA Software Engineering Standards grew.

Problems similar to these were also experienced at ESTEC, and little by little, other software managers came to the conclusion that an effort had to be made to define a methodology which would enable:

a) the development of a product based on requirements defined by the users of the system, and not solely on the developers' wishes,
b) a rigorous testing of the system before its release for operation,
c) the execution of a project according to tight cost constraints and rigorous schedule control. In this regard, it must be noted that launch delays are extremely expensive and it is simply unacceptable to delay a launch because of delays in the development of software components, whether these are on board the spacecraft or in the ground system.

The next battle was to establish the need to set up a group of software experts to define the methodology. In 1977 an agreement was finally reached, and the Board for Software Standardisation was nominated by the ESA Director General. However, many staff had an odd image of this Board as more of an informatics police squad, chasing and booking errant software developers for infringements of software engineering laws. For this reason, the words "and Control" were added to the name of the Board. In fact, the BSSC's emphasis has always been on the production of standards - never having had the resources to act in a "policing" role.

The initial reactions to the BSSC were rather negative. A frequent comment was, "Our software is special, and therefore we need special methods, so thanks, but no thanks," or words to that effect. One project manager even asserted, "Our software is very large, so we don't need any special methodology."! The initial target given to the Board was to complete its work within three months, which only goes to emphasise the generally poor understanding of the software engineering discipline at the time.

In spite of this discouraging environment and unrealistic schedule, the meetings of the Board were very constructive from the beginning. A conscious decision was taken to disregard the opposition, to concentrate on a realistic targets and to seek the help of the few supporters in ESA.

As an initial realistic task, it was decided to define the software life cycle and its phases. This resulted in initial guidelines for the procurement of software, issued at the beginning of 1978. These had the immediate and very beneficial effect of establishing a common terminology. Managers, engineers, administrators and legal experts were then able to speak the same language, using terms such as "user requirements", "software requirements", "architectural design" and "detailed design" as a part of their common vocabulary.

The next step was to produce a set of documents, each covering one specific phase of the software life cycle. These documents became known as "pink documents", after the colour of paper on which they were printed. In each of them the major milestones and the practices applicable in the phase were defined. Useful information was derived from other software engineering standards, most notably those of the Institute of Electrical and Electronic Engineers (IEEE), used as a primary source of terminology and definitions.

As the standards were put into use, people started to realise their benefits and opposition gradually decreased. By the end of 1982, a full set of documents was available covering the complete software life cycle. This set was adopted as the standard for all software development in the Agency. Two years later, all of the pink documents were bound together in a single volume. An extensive survey was carried out in which comments and improvement proposals were solicited from ESA, the aerospace industry and the software industry. This led to the first complete version of the ESA Software Engineering Standards (called ESA BSSC (84)1, Issue 1), a single slim volume identifying a relatively compact set of some 200 mandatory practices as well as recommended practices and advisory material. After a three-year period during which the complete set of standards was extensively used, a further review and update took place resulting in a fully mature standard which was then published as ESA PSS-05-0, Issue 1, January 1987, consequently becoming part of the ESA System of Procedures, Standards and Specifications (PSS). The ESA PSS series covers all applicable ESA engineering and product assurance standards. PSS-05-0 Issue 2 appeared in February 1991, again following an extensive review and update process.

Following Issue 2, work started on a comprehensive set of guides giving detailed advice on all aspects of the standards. These were published as PSS documents between 1991 and 1995. The PSS-05-0 Document Tree is shown in Figure 1.

The PSS-05-0 standard and guides, Software Engineering Standards and Software Engineering Guides, respectively, have been republished by Prentice-Hall in the context of ESA's Technology Transfer Programme.

A number of organisations from outside the space domain have adapted these standards

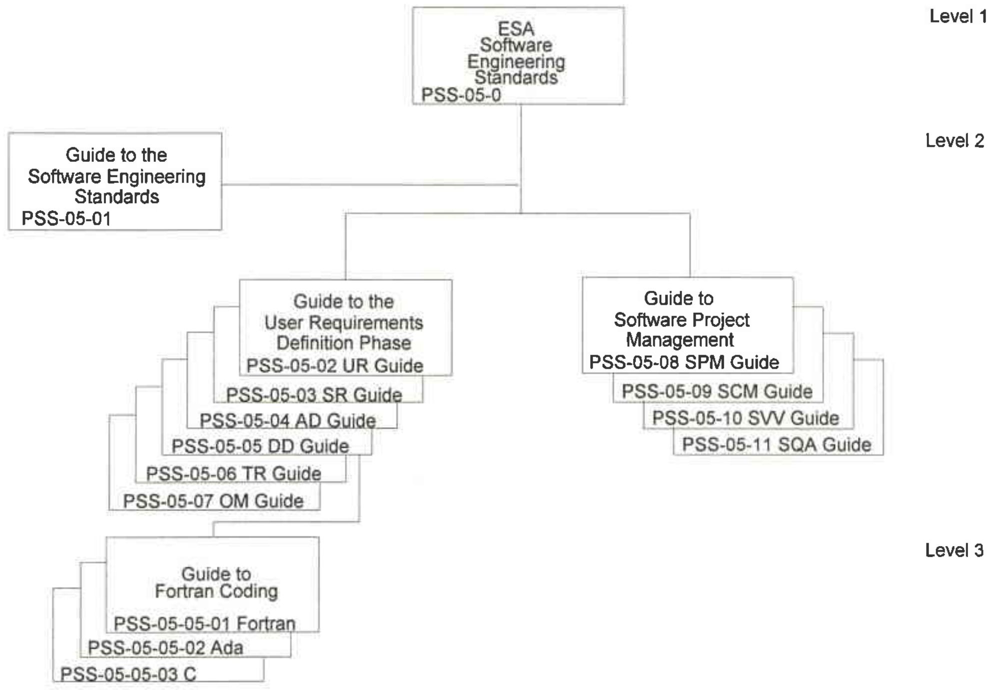



**Figure 1.The PSS-05-0 Document Tree**

for their own use since the Prentice-Hall publications. These include DERA (who have developed a standard for system engineering based upon the Software Engineering Standards), CERN, JRC and GSI, just to mention a few. Additionally, a Software Engineering Standards User Group (SESUG) has been set up outside the Agency to serve the interests of the groups' organisations.

**ESA's Board for Software Standardisation and Control (BSSC)**

ESA's Board for Software Standardisation and Control (BSSC) was formally established in May 1977 in an "Instruction from the Director General of ESA" (ESA/ADMIN(77)18, May 1977).

*BSSC responsibilities*

The BSSC is responsible for:

- Establishing and maintaining engineering standards for the procurement, development and maintenance of software. *Its work in this area was described in the previous section.*
- Verifying that the standards thus established are made applicable to software development activities in the Agency. The *BSSC verifies application of the PSS-05-0 standards through a procedure involving the scrutiny of contracts with a software content. These rather limited controls have succeeded remarkably well in helping to instil a software standards "culture" within the organisation.*
- Acting as liaison with the Agency's Legal Affairs department concerning the safeguarding of intellectual property rights relating to software. *For software developed for operational purposes under ESA contract, the software remains the intellectual property of the Agency. Under the terms of ESA's Convention, industry or government agencies within the ESA Member States have the right to free licences for such software. Charges are negotiated for software licences issued outside the ESA Member States. The signature of a BSSC representative is required on each licence application. In practice, this means that the BSSC's involvement is largely that of observer in the licence preparation process.*

Another task appears in the BSSC Terms of Reference, namely the establishment of an Agency-wide library of application software. However, local specialist software libraries already exist within the Agency and are maintained by their users directly. Supervision of an Agency-wide library involving extensive effort to provide user support, version control, up-to-date documentation etc., simply turned out to be an impractical proposition within the rather modest staffing envisaged.

*Membership*

The BSSC currently has 7 members, all of whom work part-time on the committee. Mr C. Mazza was the chairman from 1977 to 1995. Since 1995, the committee has been co- chaired by Mr M. Jones (ESOC) and Mr U. Mortensen (ESTEC).

## An outline of the ESA Software Engineering Standards

*The PSS-05-0 standard*

The PSS-05-0 standard describes the processes involved in the complete life cycle of a single software project from its inception to the retirement of the software. The standard is split into two parts:

1. The production process, based on life-cycle models, has 6 phases as follows:
   - User Requirements (UR) Definition Phase,
   - Software Requirements (SR) Definition Phase,
   - Architectural Design (AD) Phase,
   - Detailed Design (DD) Phase,
   - Transfer (TR) Phase,
   - Operations and Maintenance (OM) Phase.

The phases are each defined in terms of inputs, outputs and activities. Figure 2 shows these phases, inputs and outputs schematically.

The way in which these phases are put together is referred to as a "life-cycle model". The simplest is the waterfall model, in which the phases follow one another in sequence. PSS-05-0 does not prescribe any particular model, but it suggests three life-cycle models: waterfall, incremental and evolutionary. Figure 2 in effect corresponds to the waterfall model. The incremental model, which splits the detailed design phase into manageable chunks, is shown in Figure 3.

2. The procedures used to manage a software project. These are divided among four management activities:
   - Software Project Management,
   - Software Configuration Management,
   - Software Verification and Validation,
   - Software Quality Assurance.This is the process of checking that the Standards are properly followed. It is thus an activity within a project, rather than a responsibility of an outside body (such as the BSSC)

As mentioned earlier there are some 200 mandatory practices. These are split roughly equally between the product standards and the procedure standards. The text defines what has to be done and gives some advice on how to follow the practices. This makes PSS-05-0 easily readable and readily applicable. Templates are provided for all the major documents, plans and forms.

PSS-05-0 does not prescribe any particular software engineering method or tool. Each project manager is left to decide which methods and tools are to be used, although it is mandatory that appropriate methods be adopted. Such methods would include, for example, software requirements analysis methods and design methods.

*PSS-05-0 "lite"*

PSS-05-0 can be too heavy if used for small projects. Here, "small" means a project for which one or more of the following applies:
- less than two man years of development effort,
- a single development team of five people or fewer,

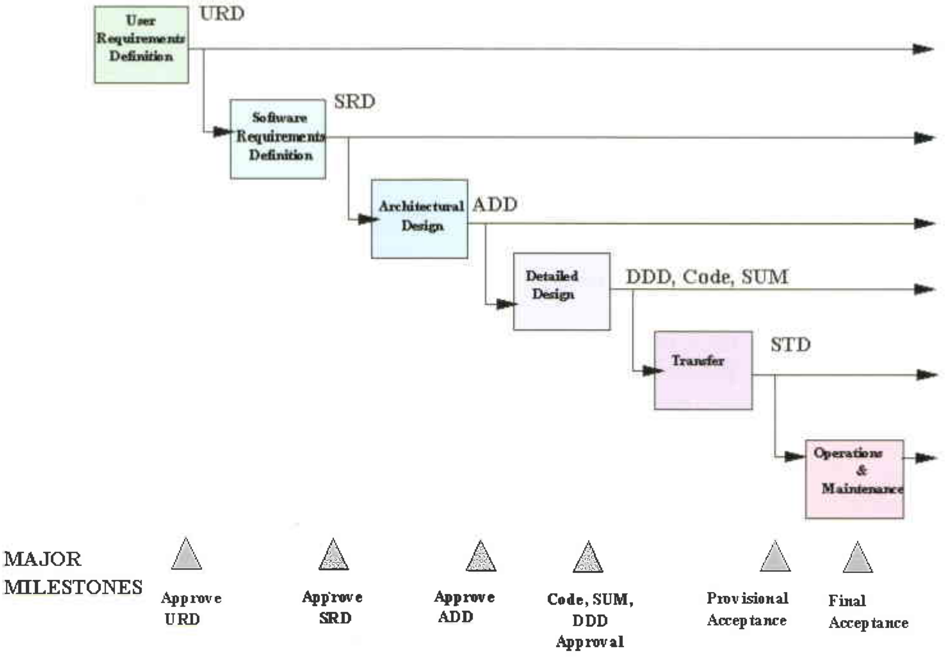



Figure 2. The PSS-05-0 production process

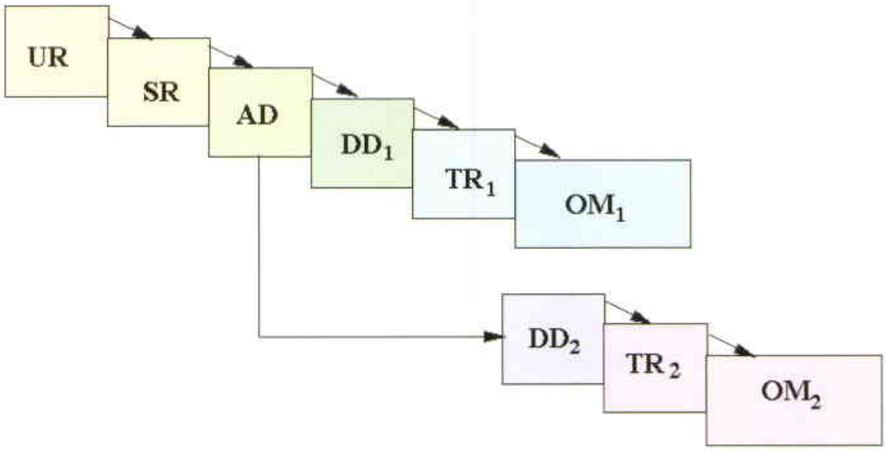



Figure 3. Incremental development lifecycle

- fewer than ~ 10 000 lines of source code (excluding comments).

Experience shows that simplifications are possible for such projects. In PSS-05-0 "Lite", known more formally as the *Guide to Applying the ESA Software Engineering Standards to Small Projects* (BSSC(96)2), a number of strategies suitable for small projects producing non-critical software are described, along with possible ways of tailoring the mandatory requirements to these small projects. This includes the possibility of combining and simplify the various management documents.

**PSS-05-0 and International Standards**

The BSSC has made comparisons of PSS-05-0 with two major international standards: ISO 9000 and ISO/IEC 12207. Initially, the reason for this was to determine to what extent the practices of the ESA Software Engineering Standards could be used to implement the requirements of these other standards. Another benefit of the comparisons was a greater understanding of the other standards and the identification of potential improvements to the ESA Software Engineering Standards.

The technique used to carry out this type of comparison is to list the requirements of the standard being compared and identify which ESA Software Engineering Standards products or processes result in compliance. The relation between PSS-05-0 and ISO 9000 is illustrated by the diagram in Figure 4. The large circles represent the set of requirements in ISO 9000 and the mandatory practices in PSS-05-0.

Categories of compliance are as follows:

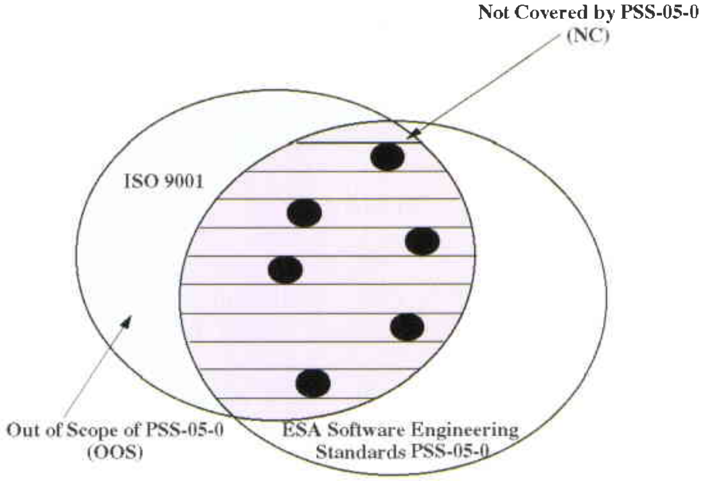
- ***compliant (hatched region):*** those ESA Software Engineering Standards practices which ensure conformance to the ISO standard,
- ***out-of-scope (unhatched regions):*** requirements of the ISO standard which are out of the scope of the ESA Software Engineering Standards because the later has different objectives,
- ***non-compliant (filled circles):*** those requirements of the ISO standard which are in the scope of the ESA Software Engineering Standards but are not covered.

*PSS-05-0 and the ISO Quality Standard (ISO 9000)*

The report BSSC(96)1 documents the comparison of PSS-05-0 and ISO 9001 and its associated software guide ISO 9000-3.

ISO 9001 is the internationally accepted standard for quality assurance for all manufacturing and production industries. The standard defines the requirements that suppliers must fulfil to ensure that they deliver quality products. ISO 9001 applies to all types of products: hardware, software, processed materials and services. ISO 9000-3 is the accepted interpretation of the ISO 9001 requirements for software products. ISO 9001 and ISO 9000-3 both state what has to be done

Figure 4. Relationships between ISO 9000 and PSS-05-0



rather than how. Organisations themselves are responsible for defining how to fulfil the ISO requirements. Organisations can obtain ISO 9000 accreditation by a process involving independent audits of its practices and projects.

ESA PSS-05-0 defines a set of practices for making software products. These practices can be used to implement the requirements of ISO 9001.

BSSC(96)1 demonstrates that:
1. the ESA Software Engineering Standards are an excellent basis for a software quality management system,
2. the ESA standards cover virtually all the requirements related to software development. It is shown that organisations which develop, supply and maintain software can cover approximately two thirds of the requirements in ISO 9001 using the ESA Software Engineering Standards. The majority of the requirements not covered are not related to software development,
3. the ESA standards do not contradict those of ISO 9001.

Examples of ISO 9001 certified quality management systems exist based upon the ESA Software Engineering Standards.

*PSS-05-0 and the ISO Software Engineering Standard (ISO/IEC 12207)*
The ISO Software Engineering Standard ISO/IEC 12207 was published in 1995. It is a comprehensive high-level standard, which supplies a framework against which organisations can check their existing standards. It is also permissible to tailor ISO/IEC 12207 to an organisation's specific needs by removing, adding or extending requirements. A comparison of PSS-05-0 with ISO/IEC 12207 has been carried out using the same approach as that for ISO 9000. The broad conclusions are that for the ISO/IEC 12207 processes which are within the scope of PSS-05-0 (such as development), PSS-05-0 comprises very good coverage and there are no conflicts. The details will be in a report to be issued shortly as BSSC(97)1.

**On-going work**
Work is on-going in a number of areas:
- PSS-05-0 and object-oriented methods,
- coding guides,
- software based on Commercial-Off-The-Shelf software (COTS),
- software process improvement.

For reasons of brevity, and because work in the last two areas is in a very early stage, we restrict the discussion to the first two items only.

*PSS-05-0 and object-oriented methods*
What are object-oriented methods? While PSS-05-0 does not prescribe any particular development method, it reflects, to a certain extent, the methods prevalent at the time it was written. These were mostly based on functional decomposition, in which a top-down breakdown of the functions of the system is made. Data is separated from functions and handled individually, e.g. in data flow diagrams or data structure specifications. In the early 1990s, object-oriented methods began to become popular, and since this time have evolved through application in many different software projects. They are now replacing the functional decomposition methods; most of the recent computer science or information technology graduates have been trained in these techniques and one or more of the associated computer languages. Object-oriented thinking has also penetrated outside the software engineering community: for example the various tables, queries, forms, etc., in the widespread database package Microsoft Access, are objects. Object-oriented methods are much more mature than they were even 4 or 5 years ago, although there is still room for growth.

In contrast to functional decomposition, data structures and functions in object-oriented methods are grouped together into classes. The data attached to a class are called the attributes and the functions performed within the class are called methods or services. Broadly, the advantages of object-oriented methods are:
- the analysis corresponds more closely to the application domain,
- they are continuous, i.e. the design (physical model) is an elaboration of the requirements analysis model (the logical model),
- object-oriented methods use the concept of inheritance which, if properly used, permits the building of reusable software.

Can PSS-05 be applied to projects using object-oriented methods? A guide is under preparation which explains the application of PSS-05-0 in conjunction with object-oriented (OO) methods. The preliminary results of this work prove that PSS-05-0 can be applied without difficulty to projects using object-oriented methods and only the wording of a few of the mandatory practices referring to functions or functional breakdown (in the SR and AD phases) need modification. In addition, given the more continuous nature of OO development, recommendations will be given on matters such as determining the end of a phase, which (among other things) is related to the content and level of detail of the modelling carried out in the various development phases.

Some OO methods have recommended feedback loops between analysis, design and implementation phases. These would appear to be excluded by the life-cycle models covered in PSS-05-0. However, from a management viewpoint, it is essential to maintain the PSS-05-0 concept of well-defined development phases, each terminated by a verifiable milestone. This discipline is essential for the successful development of software systems, especially large ones, and fully borne out by the experience on ESA projects following PSS-05-0 and using object-oriented methods.

This general conclusion is almost certainly applicable to any good software engineering standard. It is also important to point out that if a method cannot be used with the organisation's software engineering standard, it should not be used at all - otherwise the method becomes a pretext for anarchy.

*Coding guides*

C++ and C have taken over as the languages of choice for most new software implementations in the ground segments of space projects. For on-board software, Ada or C are the programming languages normally used by ESA projects. C++ and Ada are object-oriented or object-based languages, associated with the object-oriented methods discussed earlier.

Coding guides on C/C++ and Ada are in preparation, the initial work of drafting the guides having been delegated to working groups made up of specialists in these languages. These coding guides are expected to be issued as BSSC pink documents in 1997.

**Conclusions**

It should be clear from this article that PSS-05-0 is a very successful standard. The BSSC has played an important role in promoting it, both through its various publications and through its responsibility in monitoring its application. PSS-05-0 has served to create a common software engineering culture in ESA.

It is also clear from experience that developing such a standard is a lengthy process (it took 7 years to reach the maturity of BSSC(84)1), and acceptance by the community also takes time. This acceptance should not be taken for granted — an unworkable standard cannot be imposed. Developers of new software engineering standards should take note.

**The future**

In June 1994, ESA Council adopted a resolution which confirmed the Agency's commitment to transfer the present PSS system of ESA space standards to a new system of standards under preparation by the European Cooperation for Space Standardisation (ECSS). ESA, European national space agencies and European space industry are represented in the ECSS. The PSS system of standards is a mandatory input to the preparation of the ECSS standards. The ECSS system of standards covers management, product assurance and engineering standards, specifically for space projects. In ECSS, software engineering standards form a branch of the engineering standards. The ECSS standard for software engineering, ECSS-E-40, is currently in preparation. ECSS-E-40 will be a high-level requirements-oriented standard, in effect a tailoring of ISO/IEC 12207 for space projects. Unlike PSS-05-0, it reflects the specifics of space projects, for example the relationship between the space system development cycle and the software development cycle.

As a result of the ESA Council decision, no new issues of PSS documents will be released, although existing PSS standards remain in force until the relevant ECSS standards are available or adopted. This, of course, also applies to PSS-05-0 which remains in force and will be maintained as the mandatory standard for all ESA software projects until such time as ECSS-E-40 is approved for application in the Agency. A plan will be prepared for the introduction of ECSS-E-40. It is anticipated that this will include tests using the ECSS-E-40 standard in selected ESA projects. A detailed standard, practice-oriented, at the level of, for example, the current ESA Software Engineering Standards, would be expected as a requirement for the implementation of ECSS-E-40. It would also be expected that other organisations (e.g. national space agencies, space industry) might use their own standards as implementations of ECSS-E-40.

It should be noted that within the Agency there will be a continuing need for a PSS-05-0 type standard for much of the software development in the Agency which is not directly part of a space project, e.g. ground infrastructure software, administrative software and technology studies.

# The In-Orbit Testing of the European Mobile Services Payload on Italsat-2

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**The European Mobile Services (EMS) payload was launched on board Italsat-2 in August 1996. The payload, which is partly experimental, consists of one forward and one return transponder. The forward transponder is able to receive voice and data communications transmitted in Ku-band from fixed ground stations and transmit them to earth mobile terminals in L-band. After the satellite had reached its allocated position in geostationary orbit, it was commissioned by Nuovo Telespazio with the assistance of ESA engineers for the EMS payload**

## Introduction

For some years the Directorate of Telecommunications has maintained a specialised satellite-monitoring facility, which has proved extremely useful on numerous occasions for evaluating communications satellite performance. This facility, known as the Backup Satellite Support System (BSSS), has enabled ESA engineers to analyse satellite telemetry data received either directly from antennas located at ESTEC or via a PSTN line, using analogue modems, from the Redu (B) and Fucino (I) ground stations. The facility has been used over the years for the on-station monitoring of both the Marecs and ECS series of satellites, as well as for the initial In-Orbit Testing (IOT) of, and the later control/recovery operations for the Olympus spacecraft in May 1991.

Figure 1. The BSSS installation

Currently, such systems are in use at ESOC, ESTEC and the Redu station, as well as at other non-ESA sites. They have been kept up-to-date in hardware and software terms and are maintained in a state of readiness for immediate use as and when needed. Its unique combination of capabilities and flexibility made the BSSS the perfect facility to support the Italsat EMS payload In-Orbit Test (IOT), for which additional BSSSs were procured from Polygon Control Systems.

Given that the IOT was planned to take place from the Redu ground station, it was decided to locate the monitoring facility there also to provide direct availability of the EMS information needed to conduct the tests. The BSSS's role was to:
- process and monitor all of Italsat's telemetry parameters
- archive the telemetry data and provide convenient retrieval capabilities
- present the processed telemetry data in the form of alphanumeric-, graphic-, hexa-decimal and synoptic displays
- provide a protocol-based interface to IOT test computers in order to dynamically exchange test data via the Local Area Network (LAN).

**System configuration**

The BSSS installation (Fig. 1) used during the IOT consisted of two off-the-shelf PCs, one acting as a data server (hereafter called the 'Server') and the other as a processing and monitoring work station (known as the 'Master'), with an X.25 link for data transfer between the two (Figs. 2a,b). In fact, it was decided to use two such systems for the EMS IOT in order to have full redundancy. The Italsat telemetry data was input to the Server in the form of a NRZ-L coded serial data stream at a bit rate of 1024 bit/s. The format of 16 frames, each 128 bytes in length, implied an update interval of 16 seconds.

*Server station*

The tasks performed by the Server included:
- synchronisation with the incoming serial data stream
- buffering, when necessary, of up to 15 minutes of unprocessed (raw) telemetry data
- various checks on the Italsat format (i.e. satellite identifier, format- and frame counters)
- displaying the raw telemetry format in hexadecimal form, including the identification of bad-quality data.

*Master station*

The following tasks were performed by the Master station:
- support of alphanumeric (AND), graphical (GRD), hexadecimal (HEX), out-of-limit (OOL), mimic (MMD), and parameter observation (POD) displays
- processing and monitoring of the raw telemetry data received from the Server
- archiving and provision of retrieval facilities
- export of processed telemetry data in various ways
- maintenance of the satellite database
- provision of database management tools.

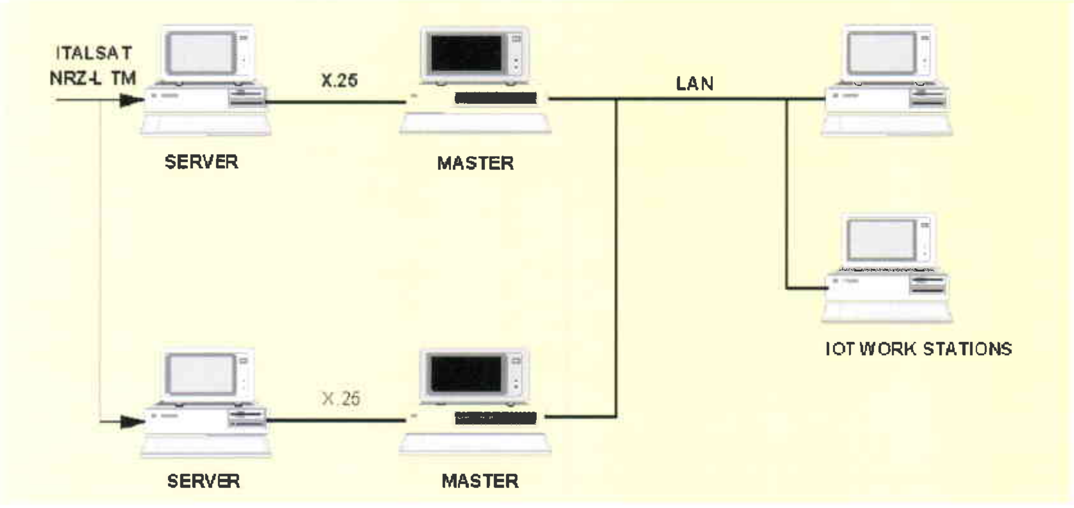


Figure 2a. IOT system hardware configuration

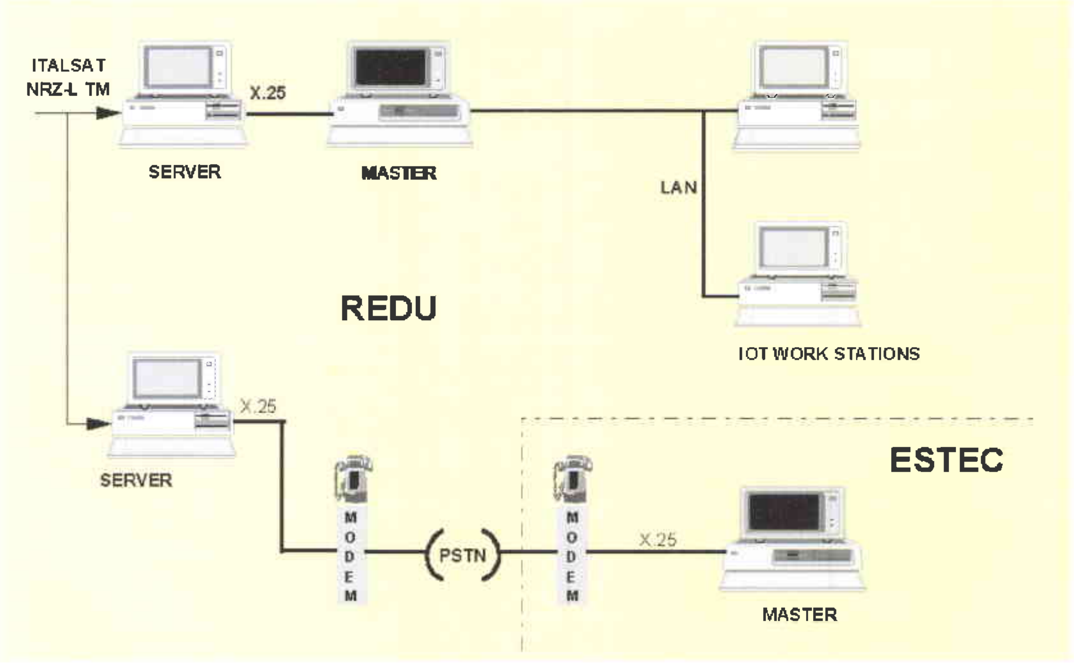


Figure 2b. Post-IOT system hardware configuration

*Database management tools*
As the BSSS is fully compliant with the database syntax used by ESA, the Italsat database built by ESOC could be used during the In-Orbit Testing. Several tools have been developed to simplify the database's maintenance, including: (i) a Database Editor that presents the database information in a context-sensitive manner; (ii) a Mimics Editor that provides an interactive means of generating the static elements of mimic displays; (iii) a Parser/Pre-compiler, which allows the coupling of parameters and mimic objects with real-time data. Figures 3 and 4 show examples of mimic displays used during Italsat's in-orbit testing.

Figure 5 shows a typical database update cycle. The BSSS Desktop application handles all real-time-related tasks, as indicated in Figure 6.

**Evolution**
The successes achieved with the Backup Satellite Support System over the past years have prompted ESA to support the development of the next generation of low-cost satellite telemetry data monitoring and commanding facility manufactured by Polygon Control Systems®, called SatView™. Running under the MS-Windows NT™ operating system, it has inherited many of the proven features of the BSSS, but some significant

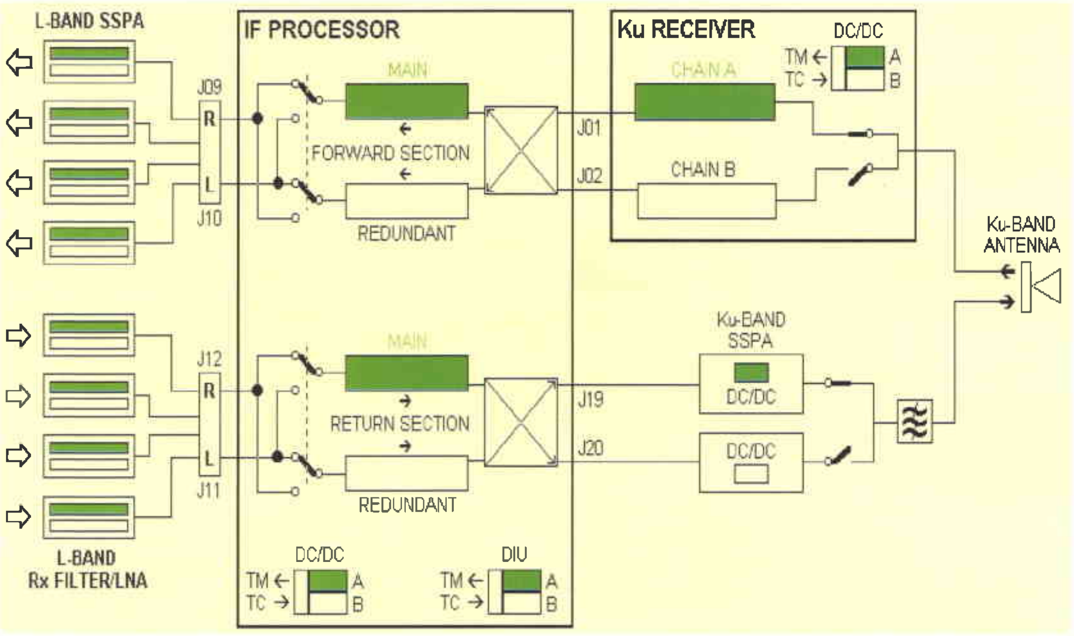


Figure 3. Mimic display of the Italsat EMS payload

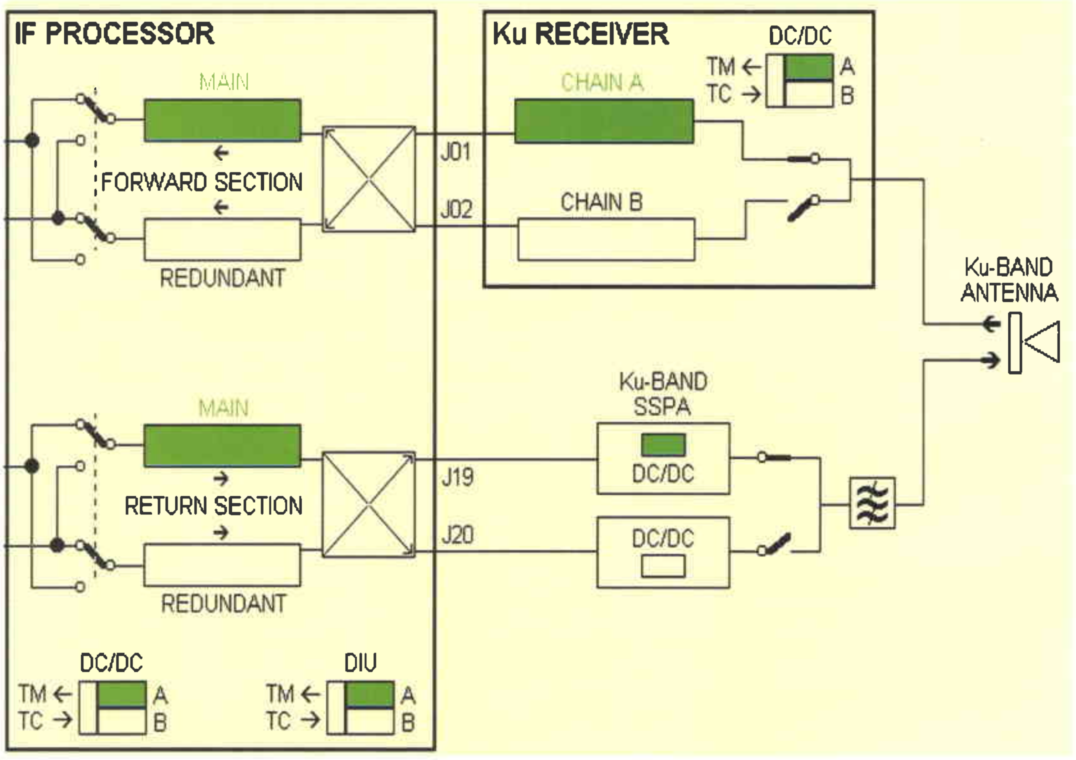


Figure 4. Mimic display of the Italsat EMS IF processor

extensions are also being added:
- Packet Telemetry Standard: Through the integration of special third-party hard- and software, SatView™ conforms with this telemetry data standard.
- Relational Database: SatView™ uses the MS-SQL™ Server as its satellite database management tool.
- Account Management: The tight integration with the MS-Windows NT™ account management services prevents unauthorised use of SatView™.
- Security Profiles: Modifiable security profiles allow user-dependent access privileges.
- Report Generation Facilities: SatView™ provides the capability to schedule and generate reports automatically.
- Mailing Facilities: Normal or event-driven messages can be generated and mailed by SatView™.
- Event Logging: All events are archived by category and can be retrieved at a later time.

It is intended to use SatView™ in the in-orbit testing of Artemis, as well as for its on-station operation.

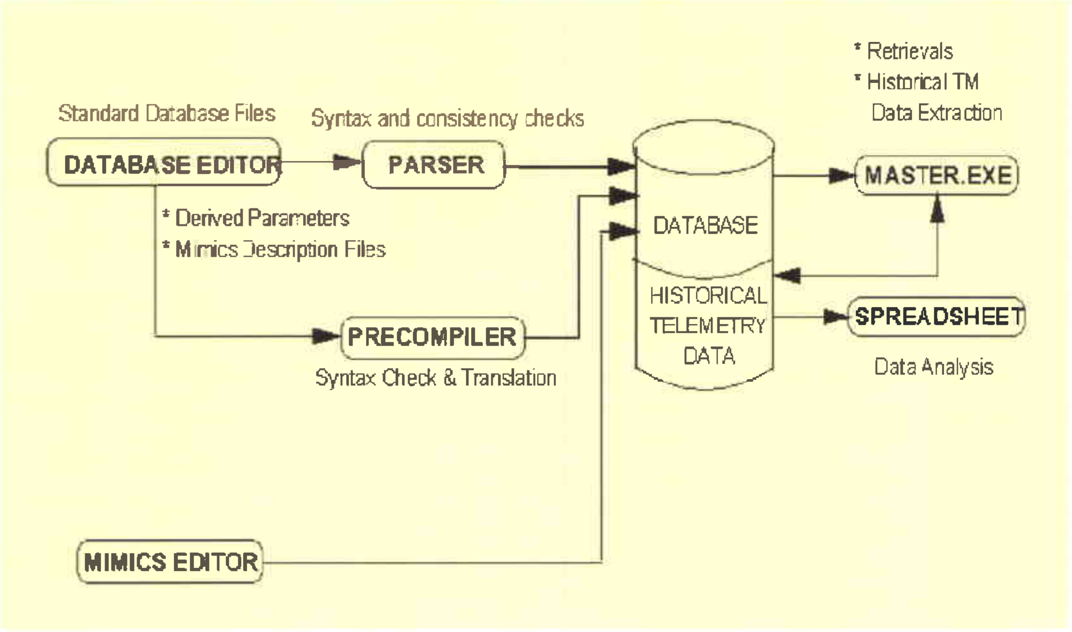


**Figure 5. A typical database update cycle**

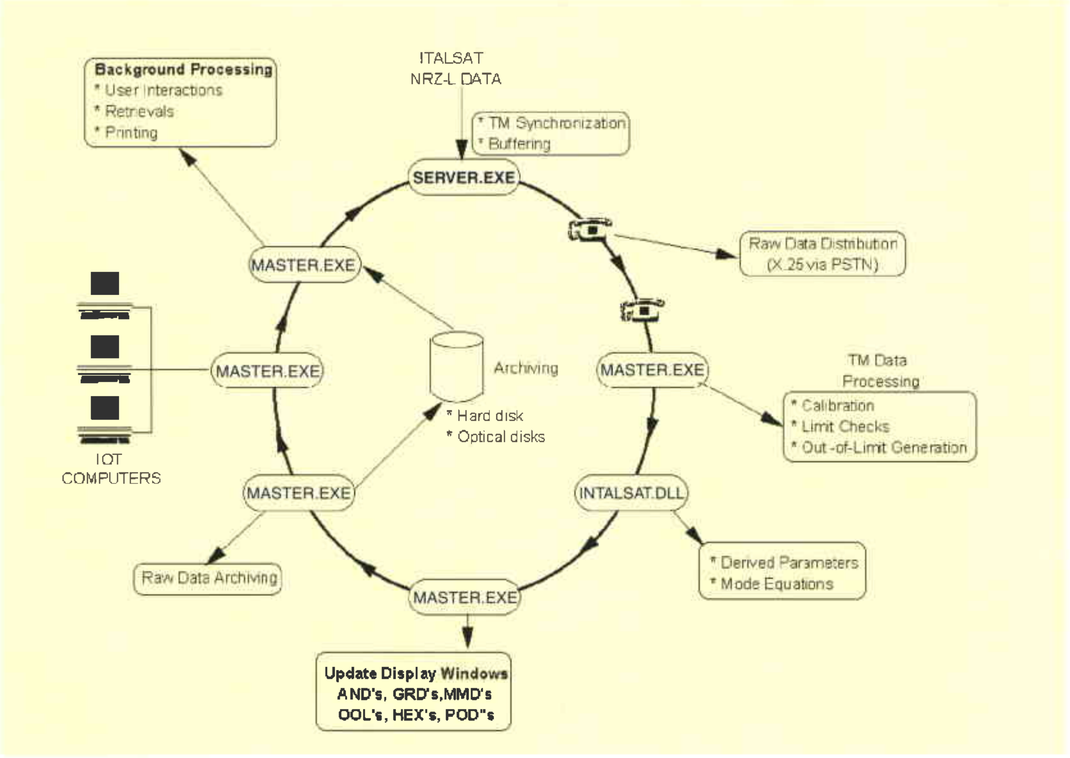


**Figure 6. The BSSS Italsat real-time monitoring**

# Secondary Lithium Batteries for Spacecraft

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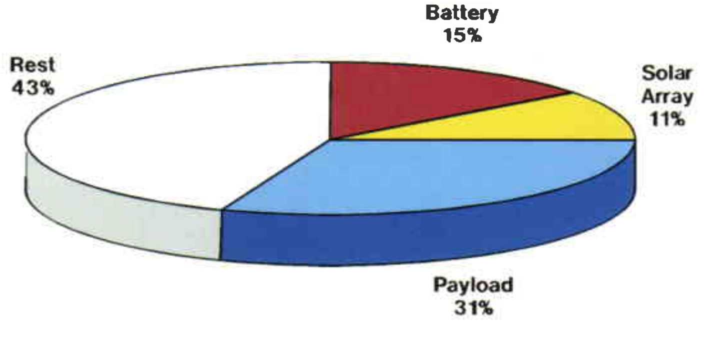
**Whilst some small satellites have design lives of only a year or two, for the majority of larger spacecraft they range from 7 to 15 years (GEO) and 3 to 6 years (LEO) and the trend is for these mission durations to increase. The batteries used must achieve 1000 to 33 000 cycles without failure and without any possibility for maintenance. This is considerably in excess of the cycle lives demanded by most terrestrial battery applications and it is the cycle life requirement that has to date confined spacecraft to the use of the well-proven alkaline battery technologies, nickel-cadmium and nickel-hydrogen. However, even when used to 80% of their available capacity, these technologies offer useful mass energy densities of no more than 24 and 36 watt-hours per kilogramme (Wh/kg) respectively at battery level (i.e. taking into account the mass of the battery packaging). The latest lithium-carbon technology promises to revolutionise the world of space batteries in terms of cost/performance factor.**

## The current state of the art

The majority of spacecraft are Earth-orbiting and undergo between 90 and 5500 eclipses per year. The former figure is typical of a geostationary (GEO) telecommunications satellite, whilst the latter is typical of a satellite in low earth orbit (LEO) such as an earth-observation spacecraft. During eclipse, electric power has to be supplied by batteries which are recharged by the solar panels when the spacecraft re-emerges into sunlight. In addition, there are some instances when batteries are called upon to provide peak power in sunlight periods. As can be seen from Figure 1, the existing state-of-the-art batteries (nickel-hydrogen) are heavy, constituting 15% of the dry mass of a typical communications spacecraft and nearly half the mass of the entire payload. Clearly, any mass that could be saved by the use of lighter batteries would allow a corresponding increase in the amount of useful payload equipment. Looked at another way, the use of lighter batteries can be very cost-effective when one remembers that launch costs (GEO) are typically of the order of $50000 per kilogramme. Nickel-hydrogen batteries supplanted the previously-used nickel cadmium batteries because of their mass advantage despite their much higher cost and larger volume.

Figure 1. Dry-mass breakdown for large telecommunications spacecraft using nickel-hydrogen batteries (courtesy of British Aerospace)




## Lithium secondary batteries — a long time coming but now definitely here

It has long been realised that there are a number of cell chemistries that should be capable of achieving better than 100 Wh/kg at battery level (based on 100% of capacity). One such class are cells using lithium as the negative electrode and a non-aqueous electrolyte. There is a large range of candidate positive electrode materials. Although work on these types of cells has been continuous since the early seventies, successful commercial application of rechargeable lithium cells has been extremely limited because of the poor cycle life that has been achievable (at most a few hundred cycles) and to some extent because of concerns over safety. (In contrast lithium primary cells have found extensive application, though safety concerns limit their domestic use in large capacity versions).

The poor cycle life was due to the difficulty of re-plating lithium onto the negative electrode during recharge. A significant proportion of the lithium re-plated during each cycle is not adequately integrated into the electrode and can no longer be discharged. Hence the loss in capacity. Again it has long been realised that this might be overcome by switching from the use of metallic lithium as the negative electrode to another material which could 'dissolve' lithium in a solid structure in which the lithium atoms are nevertheless mobile (one of the authors worked on this approach in the late seventies). The problem was that the mass of lithium which could be reversibly dissolved into the materials that were tried was too small compared to the mass of the electrode, negating most of the energy-density advantage one was trying to obtain.

A major breakthrough was achieved by Sony when, in 1991, it introduced cells in which the lithium metal was replaced by a layered-structure carbon electrode into which lithium ions can pass reversibly and in large quantity (roughly one lithium atom per six carbon atoms). This idea had been tried in the past without success, but the breakthrough was in finding the right form of carbon and the necessary pre-treatments for it to function reversibly. The use of carbon in place of lithium metal still does not come without penalties. It results in a reduction of about 0.3 volts in cell potential and it adds to the mass of the negative electrode. Fortunately, developments in positive electrode materials had shown how to compensate for this voltage disadvantage and, perhaps still more importantly, opened the way to simpler cell manufacture.

Unlike the negative electrode, positive electrodes have nearly always been 'solid solution electrodes' in which lithium ions are free to move within a layer structure, usually a transition metal oxide or sulphide. The content of lithium ions can be varied over a wide range of composition because the lithium ion charge can be balanced by the variable charge of the transition metal ions. Earlier lithium cells were made in the charged state, i.e. by combining lithium-metal negative electrodes with positive electrodes containing no lithium. As the cell was discharged, the voltage associated with the positive electrode fell as lithium ions were introduced.

The breakthrough in positive electrodes came from a UK Atomic Energy Authority (now AEA Technology) programme, as part of which J. Goodenough at Oxford University devised a new class of positive solid solution electrode materials that were already lithium-containing as synthesised. Combined with the new carbon positive electrodes, this brought two important advantages. Firstly, it enabled cells to be assembled in the discharged state so that it was no longer necessary to handle metallic lithium (or the still very air- and water-sensitive lithium-carbon compound) during manufacture. This greatly simplified the manufacturing process. Secondly, when lithium was removed from the positive electrodes during charge, the voltage associated with the electrode increased, largely compensating the voltage penalty associated with the negative.

Any cells based on lithium-carbon negative electrodes and solid solution positive electrodes are referred to as lithium-carbon or lithium-ion cells. The latter name refers to the fact that the cell can be regarded as a concentration cell in which lithium remains in the form of ions and the voltage is due to the difference in chemical activity between the positive and negative electrodes. The operation of such a cell is shown diagramatically in Figure 2. They are now under vigorous development by most major battery manufacturers around the world and especially in Japan for use in portable electrical equipment such as computers, power tools and for electric vehicles. In fact, lithium-ion cells are not restricted to graphite as the anode host to the lithium ions, and alternatives are also under development.

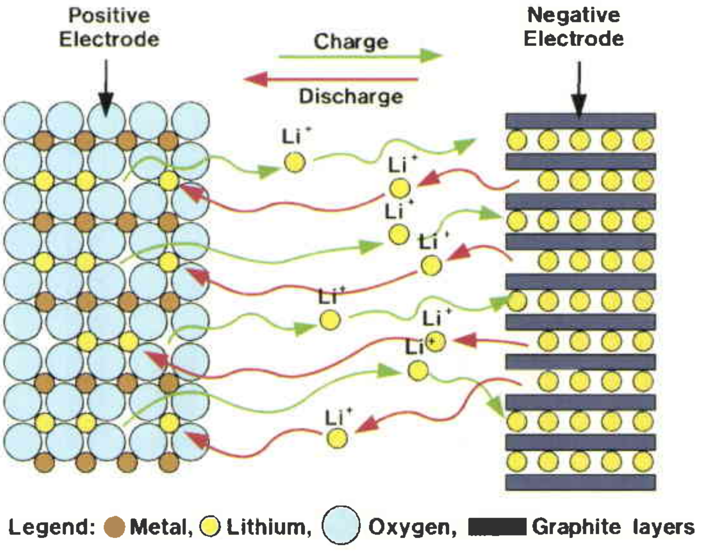



Figure 2. Schematic of the lithium-carbon/ion cell's operation (courtesy of AEA Technology)

A further development, begun in the early eighties, has been to replace the liquid organic electrolyte with a lithium-ion-conducting polymeric electrolyte. This opens up a way to fabricate all solid-state batteries and to further save on battery mass by obviating the need for the battery container to provide mechanical strength as well as hermeticity. Thin-card geometries are attractive with this technology and it also makes more feasible the fabrication of bipolar batteries where a number of couples are stacked in series within the same package.

The down side of this approach is an increase in electrolyte resistance, especially at lower temperatures, which reduces the cell's rate capability compared to a liquid-electrolyte cell of the same geometry.

## Prospects for lithium secondary batteries in space

Typical lithium-carbon cell (deep) cycle lives currently reported are still quite modest at around 1000 to 2000 cycles. This is nevertheless sufficient to be worthy of serious consideration for GEO spacecraft as well as for limited-life small satellites. These are also the space applications which are growing the most rapidly and account for the vast majority of spacecraft to be launched in 1997. In short, the opportunity to halve the battery mass on these spacecraft at a cost which should not exceed that of the current state of the art is too attractive to pass over. Figure 3 compares the projected masses and volumes of lithium-carbon batteries with those of current technologies. It can be seen that the lithium-carbon battery is projected to be very compact, especially compared to current-generation independent pressure vessel (IPV) nickel-hydrogen batteries.

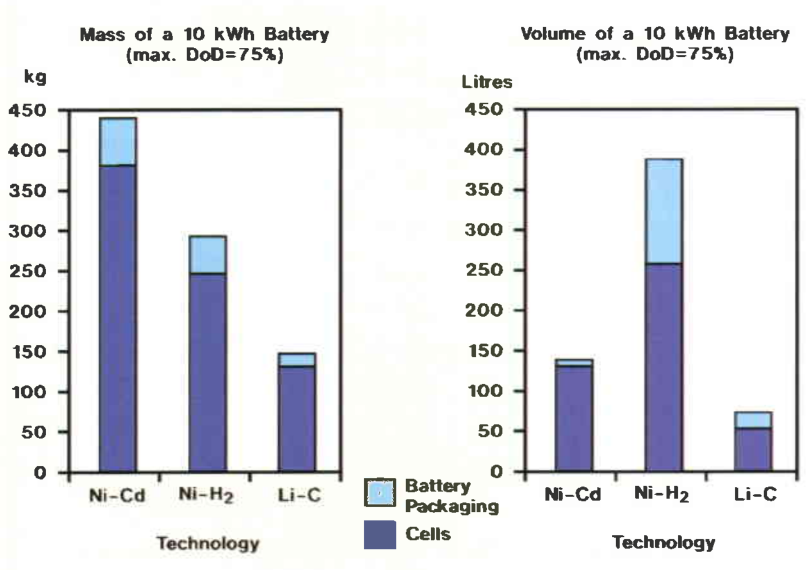



**Figure 3. Mass and volume of lithium-carbon batteries compared to current technologies Data are for IPV $Ni$-$H_2$ and cylindrical cell Li-C (courtesy of SAFT)**

Another advantage is that these cells have a voltage 2.5 to 3 times that of the alkaline cell technology, thus reducing the number of cells required per battery by the same ratio. Yet another valuable feature for certain space applications is their 'magnetic cleanliness'. The electrode substrate employed in nickel-cadmium and nickel-hydrogen batteries is of course nickel, a (ferro-)magnetic metal. This excludes them from use aboard scientific spacecraft carrying experiments involving sensitive magnetometers. There have been a series of ESA spacecraft in this category: Heos, Geos, Giotto and, most recently, Cluster. All have had to use silver-cadmium batteries, which although having quite a good energy density (around 70 Wh/kg at battery level), have poor storage and cycle life performances. The requirements of Cluster are in fact quite close to the limits of this technology. Lithium-carbon cells need not contain ferromagnetic materials and have already demonstrated superior performance to silver-cadmium. Whilst this type of application is not commercial, use of lithium-carbon should allow longer missions and increase the scientific return.

The excellent storage life expected for lithium-carbon might also make it attractive for powering certain deep-space probes and planetary landers where there is a requirement for a limited number of recharges. The current alternative, silver-zinc, which has been chosen for the US Mars Pathfinder mission, suffers from the disadvantage of having a limited storage life once it has had its electrolyte added. To get around this limitation, cells with remote activation have been designed in the past, but at considerable penalty in cost, mass and complexity. Lithium-carbon would not require such measures. The technology would be particularly valuable if it could be designed for operation at lower temperatures, down to -20°C or below.

## Development of lithium-carbon technology for space

As an important part of its Technological Research Programme (TRP) and in collaboration with CNES, ESA started a development of lithium-carbon (organic electrolyte) cells for space applications at SAFT (F) in 1994. The small (7 Ah) prototype cells were subsequently evaluated in the European Space Battery Test Centre at ESTEC (NL) and gave encouraging results. The second phase of the development is currently in progress. Here the target is to produce qualifiable cells in the 40 to 100 Ah range, suitable for future telecommunications spacecraft. These cells are also baselined for flight aboard Stentor, a technology-demonstration spacecraft (Fig. 4) which is due to be launched in 2000. The development is building on the manufacturer's much larger programme for the future electric-vehicle market, which will require cells of similar capacity. The development and qualification of a complete battery system for large geostationary spacecraft features prominently in the new ESA Technology Plan for 1997-9.

As mentioned earlier, another promising area of application is the 'small-sat' market. Here, battery capacities in the region of 2 to 5 Ah are sufficient, a size already available commercially from certain Japanese manufacturers for portable electronic equipment. In this field, low cost is all-important so an attractive approach is to use commercial cells rather than the traditional approach of using cells built especially for space applications in small numbers and at high cost. The STRV 1 C and D spacecraft, due to be launched together in 1998, will use battery modules containing Sony commercial cells (Fig. 5), and ESA is embarking on a General Support Technology Programme (GSTP-2) at AEA Technology (UK) aimed at scaling up this modular concept to cover small-to-medium size applications and to meet the more stringent reliability and lifetime requirements that go with them.

ESA thus regards these two development programmes as complimentary. Together, they cover most space applications not requiring more than, say 5000 charge-discharge cycles, a modest increase over the current capability of this technology and one which stands a good chance of being reached within the frame of the parallel terrestrial developments.

To cover deep-space needs, it is intended in the future to investigate improving cell performance at lower temperatures. Whether the cycle life can be improved sufficiently to meet long LEO mission requirements is as yet unknown. Laboratory evaluation of the lifetime of current commercial cells as a function of depth of discharge, temperature and charge control are planned at ESTEC in order to understand which factors most influence cycle life.

**Figure 4. The Stentor technology-demonstration spacecraft (courtesy of CNES)**

Within its ASTP-4 programme, ESA also has an ongoing activity at Danionics (DK) for the development of a lithium secondary battery in which the liquid electrolyte is replaced by a lithium-ion conducting polymer. For space applications one has to trade off the advantage of ruggedness against the lower expected rate capability of this configuration. There are, however, reasons to hope that a polymer electrolyte may allow a greater cycle life to be achieved which would be an important advantage. A prototype polymer electrolyte

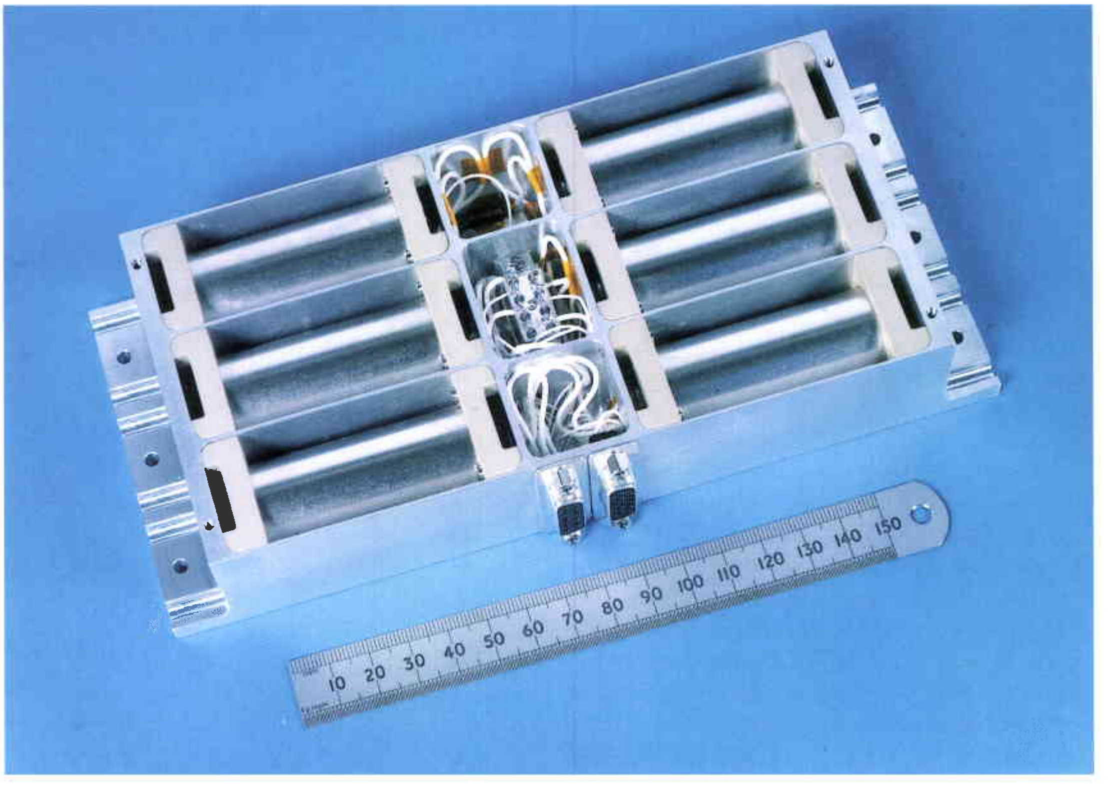


**Figure 5. A six-cell battery module for STRV (courtesy of AEA Technology / BNSC)**

battery from this programme is due for delivery to ESTEC later this year for life-testing.

Life-cycling provides information not only on the 'graceful' degradation in performance that inevitably accompanies cell ageing, but also on possible premature failure modes. Whilst most of these can be eliminated by good manufacturing control, it is sometimes impossible to reduce the risk to such low levels that it can be ignored. Part of any space-battery design is a failure mode and effects analysis (FMECA), which has to include all conceivable ways in which a battery and its cells and other components may fail and to assess the impact of each of these failure modes on the battery's subsequent performance. To meet reliability requirements, a battery design may have to include appropriate means for minimising the impact of a failed cell. In the case of nickel-hydrogen, for example, it is usually necessary to provide means for bypassing a cell that fails in open circuit. This sort of information for lithium secondary cells is only beginning to become available, yet is essential for optimising the design of a space battery.

Charge control of lithium-carbon batteries is an important aspect of the technology, and initial conceptual and breadboard studies at ETCA (B) (part of the Agency's MSTP programme) are nearing completion. Charge control is important because of a fundamental difference between lithium secondary batteries and the presently used alkaline systems. Both nickel-cadmium and nickel-hydrogen cells are capable of accepting significant overcharge without damage. Overcharging results in generation of oxygen at the positive electrode, but the design of the cells allows this oxygen to recombine chemically at the negative electrodes, preventing an excessive buildup of pressure that would otherwise occur in a sealed cell. There is therefore no net change in the cell as a result of overcharge, except for the heat generation which accompanies the recombination reaction.

Whilst overcharging a battery wastes energy, a limited amount of overcharge is beneficial because it ensures that all of the cells, connected in series within the battery, reach full charge at the end of the charging period. There is always the risk that some cells will have or will develop a greater self-discharge or leakage current than others so that without overcharge and over a large number of cycles these cells can 'run down', eventually reducing the useful capacity of the battery to levels insufficient to meet the needs of the payload during eclipse. Lithium secondary cells in contrast do not possess such a 'safe' overcharge reaction mechanism. Small amounts of overcharge can irreversibly damage a cell's subsequent performance and excessive overcharging can lead to the buildup of internal pressure leading to bursting. It is therefore not certain that it will be possible to maintain all cells in a battery at the same state of charge without additional means to adjust the state of charge of individual cells.

The high round trip efficiency (the useful energy recoverable on discharge divided by the energy required to charge) of lithium carbon (typically >90%) is another advantage compared to the currently used batteries which have efficiencies nearer to 80%. This results in a halving of the heat generation in the battery. Together with the somewhat higher maximum temperature of operation (probably about 40°C unless the cycle life turns out to be unduly compromised), this means that the thermal design of lithium-carbon batteries will be less critical and there should be additional mass savings to be gained in battery thermal-control elements such as battery radiator plates.

Battery thermal control is often critical because the batteries are usually one of the greatest sources of heat dissipation onboard a spacecraft, but also have one of the smallest allowable temperature ranges of operation. Battery thermal control would therefore be further simplified if the temperature range of operation of lithium batteries turns out to be larger than for nickel-cadmium and nickel-hydrogen (typically -5 to +25°C). At the moment, however, it is not sure what the practical lower temperature limit for lithium-carbon batteries is going to be.

## Conclusions

It is an exciting time in the space battery field. Lithium-carbon promises to revolutionise space batteries, providing a much bigger step up in performance than that which was achieved in the switch from nickel-cadmium to nickel-hydrogen. GEO spacecraft using this technology will have a significant competitive edge over those using nickel-hydrogen. It should also provide a considerable cost/performance advantage for small satellites, as well as improve mission capability for certain scientific spacecraft. In the interests of maintaining European competitiveness, it is essential that the greatest possible effort be made to qualify this technology for space as quickly as possible.

# Satellite Navigation Using GPS

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**The Global Positioning System (GPS) is currently being used for a wide variety of applications. A GPS receiver aboard a spacecraft can provide the means for autonomous navigation and also allows a very accurate reconstitution of the trajectory of the spacecraft when onboard recorded measurements are combined with ground-based measurements.**

**This article outlines some of the basic concepts involved and presents the activities that the European Space Operations Centre is carrying out in the field of satellite navigation using GPS.**

## Introduction

The launch of the first Sputnik triggered the initial challenge in satellite navigation: the determination of the characteristics of the orbit of the satellite, using the variations in the signal that was being radiated by the satellite. Within a short time the idea of using the inverse process was developed: if, by knowing your position you could determine the orbit of a satellite, then it should also be possible to use the signal transmitted by a satellite in a known orbit, in order to determine your own position. This concept was implemented in a series of satellites sponsored and operated by the US Armed Forces. Firstly, the Transit satellites were deployed, then the Timation and finally, the NAVSTAR GPS system.

The focus of these programmes was to provide the military forces of the US and its allies with precise positioning capabilities. In response, the Soviet Union also developed and deployed similar Global Navigation Satellite Systems (GNSS): Tsikada and GLONASS.

From the very beginning it was realised that these systems could also be used for a wide range of scientific and other civil applications. New tracking methods that were not foreseen by the original developers of the systems, like carrier tracking, were proposed and, as soon as it was possible, successfully tested and used.

One of the applications that was soon envisioned was the use of GPS for navigation of spacecraft. The first onboard receiver was installed and flown in a Landsat satellite even before the complete GPS constellation was deployed. Since that time, more receivers have been flown on satellites, at first as a demonstration of increasingly precise uses and now as the main operational means of navigation.

## The NAVSTAR Global Positioning System

The NAVSTAR Global Positioning System, usually called GPS, consists of three components: a space segment of GPS satellites, a control segment that monitors and operates those satellites and a user segment that employs GPS receivers to observe and record transmissions from the satellites and perform position, velocity, attitude and time calculations.

*The GPS space segment*

The space segment is based on three-axis stabilised satellites orbiting in near-circular orbits with a period of half a sidereal day and an inclination of 55 degrees. There are six orbital planes, each with four satellites. This constellation provides global coverage with more than four satellites in view at all times.

The significance of the visibility of at least four satellites is that the GPS system is intended to allow instantaneous real time determination of the user position (3 variables) and the time of the fix (one more variable). Previous positioning systems, like the methods used in the Transit and Tsikada systems, were based on the processing of several passes of data (requiring hours to days) and did not provide the instantaneous solutions that GPS (or GLONASS) offers.

The GPS satellites carry very stable atomic clocks that are used to derive the ranging signals. The basic signal for civil use, L1, has a frequency of 1575.42 MHz and is modulated with a Clear Acquisition (C/A) Pseudo Random Noise (PRN) code at 1.023 MHz that is different for every satellite. The signal is also modulated with a 10.23 MHz Precise (P) code that is usually encrypted and only available to authorised users. Additionally, there is a 50-bit-per-second modulation which is used to transmit the satellite ephemerides (predicted orbit and clock) and other information. Authorised users also have access to the Precise code on a second frequency, L2, which allows users to correct for ionospheric propagation delays. Some receivers are able to measure the delay between the signal in the L1 frequency and the L2 frequency without access to the P code. There are plans to add, in future satellites, another frequency for civil users so they can easily correct for ionospheric delays.

*The GPS control segment*
The GPS control segment tracks and monitors the signal from the GPS space segment and estimates the orbits and clock behaviour of the satellites. This information is uploaded to the satellites so it can be transmitted to users.

*The GPS user segment*
The GPS user segment can perform two basic measurements of the GPS signals. The first method compares the C/A or P code that it is receiving with a locally generated copy in order to compute the transmission delay between the satellite and the receiver. This measurement is called pseudo-range. Pseudo-ranges to four or more satellites can be used to determine the position of the user once the position of the GPS satellites has been obtained using the ephemerides of the navigation message.

The second and more precise method is to obtain the difference in phase between the received carrier signal and a receiver-generated signal at the same frequency. This measurement is known as the carrier phase observable and reaches millimetre precision. However, it lacks the accuracy of the pseudo-range because once the tracking is started, the phase can only be identified with an ambiguity of an unknown number of times the carrier wavelength (about 19 cm for L1).

**Use of GPS for spacecraft navigation**
The number of applications and users of the GPS system has exploded in the last years, well beyond any expectations. The latest receivers are inexpensive, small, offer very good performance and are easy to use.

One of the first scientific applications of GPS was to precisely determine the position of fixed ground antennas in order to study the dynamics of the Earth surface. It was soon realised that in order to obtain the best results it would be necessary to compute very precise orbits the GPS satellites. A number of groups

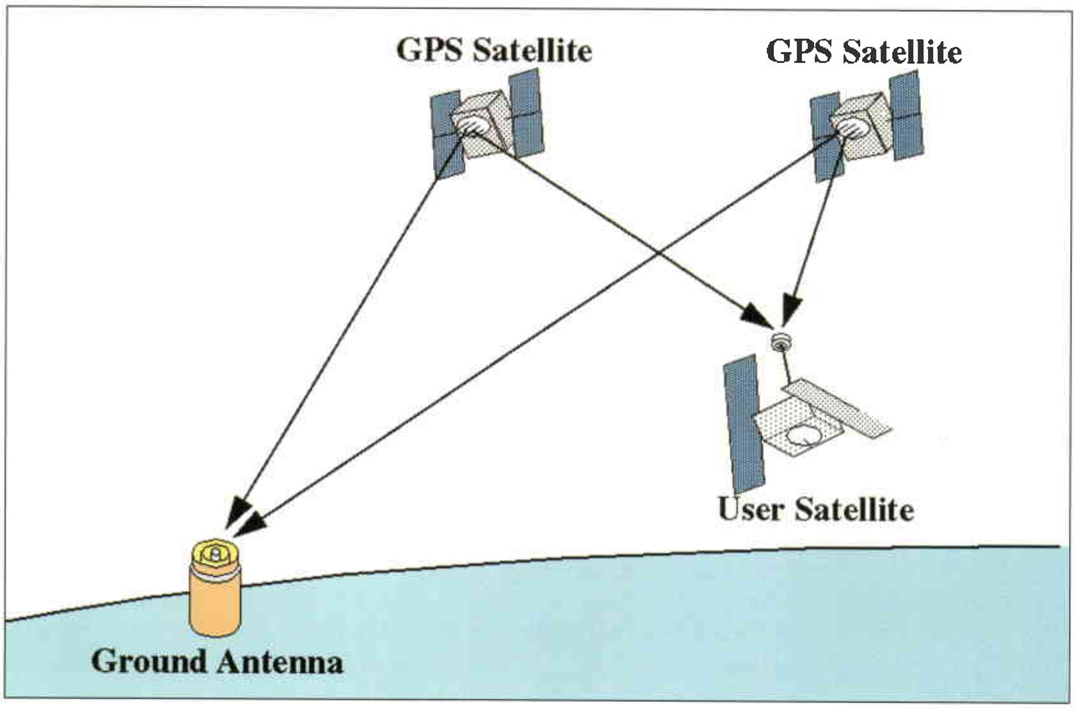


**Figure 1. Common observability of GPS satellites by ground and onboard receivers allows a better determination of the satellite orbit**

started doing this and, as a result, the first orbits that were precisely obtained using GPS were those of the GPS satellites themselves.

GPS has many advantages for the tracking of satellites orbiting the Earth. It provides unsurpassed observability since low-Earth satellites are able to track six or more GPS satellites, with tracking arcs amounting to about half of the user satellite orbit. This cannot be achieved by any ground-based tracking station. This ability also renders the method robust. There is a high level of redundancy because orbits can be determined with as few as two GPS satellites being tracked at any one time. When four satellites are being tracked, GPS allows for real-time autonomous determination of the position of the satellite, with an accuracy equivalent to that obtained with non-precise ground tracking methods. If a precise dual- frequency receiver is used and data is processed together with ground-based data, GPS possibly provides the best accuracy that can be achieved in precise orbit determination.

The first user satellite to fly a precise GPS receiver was the TOPEX/Poseidon altimeter satellite. Since then, other satellites have been flown with different types of receivers. Table 1 details the different applications for a GPS receiver aboard a spacecraft.

ESA has been involved in GPS activities since the late eighties with the development of space-qualified GPS and GPS/GLONASS receivers, the ESOC activities which support spacecraft navigation and, recently, within the ARTES programme, the European Geostationary Navigation Overlay Service (EGNOS). EGNOS will complement the GPS system in order to provide European users with increased availability, integrity and accuracy for real-time applications such as aircraft navigation.

It is foreseen that ESA will participate in the development of future Global Navigation Satellite Systems (GNSS) that may replace GPS, GLONASS and their augmentations for such purposes in the future.

GPS has been proposed as the tracking or scientific instrument for several ESA spacecraft. It is the main positioning instrument envisioned for the Automated Transfer Vehicle (ATV), both for absolute navigation and for navigation relative to the International Space Station. The ATV Rendezvous Pre-development (ARP) programme is being carried out to validate methods for relative navigation that will be used for ATV, including relative GPS navigation. Other spacecraft for which a GPS receiver has been proposed include several of the Earth Explorer candidates and other future observation and scientific satellites (Metop, STEP).

**ESOC involvement in GPS activities**

Within the European Space Agency, ESOC is responsible for the operation of ESA spacecraft. This includes the flight dynamics activities needed to achieve and maintain their desired orbit and attitude. In order to fulfil this task, ESOC began to prepare itself to support ESA missions that might use the GPS system as soon as GPS was proposed for spacecraft navigation.

ESOC had an excellent opportunity to do so by contributing to the success of the International GPS Service for Geodynamics (IGS). Scientists were proposing to install a permanent network of precise ground-based GPS receivers that would allow the monitoring of the movement of the Earth's surface in order to better understand plate tectonics and local deformations that are the cause of earthquakes. The data from these receivers could be processed in order to obtain precise orbits for the GPS satellites that would be used by geodesists in regional deformation studies. Additionally, within the IGS Terms of Reference was a provision of support for other applications, including scientific satellite orbit determination. The assets which ESOC could contribute to the IGS were its network of

**Table 1. Applications of a GPS receiver for space navigation**

**Current uses:**

- To determine the position and velocity of a satellite.
- To accurately determine the time of observations from other tracking or scientific instruments.
- To determine the attitude of a satellite. This can be accomplished by comparing the measurements obtained from different antennas.
- To collect GPS measurements that will allow a precise reconstitution of the orbit of the satellite.
- To collect GPS measurements that can be used to reconstitute the characteristics of the medium travelled through by the signal: ionosphere and troposphere.

**Future uses:**

- The relative navigation of two spacecraft (currently being validated).
- The tracking of the launch and early-orbit phases of rockets.
- The tracking of re-entering spacecraft, even to the point of autonomous landing.

ground stations in which receivers could be installed and its expertise, supported by in-house developed software, in precise orbit and geodetic parameter estimation.

The first receiver was installed in Maspalomas (Spain) in June 1992 (Fig. 2). Receivers have also been installed in Kourou (French Guyana) in July 1992, Kiruna (Sweden) in July 1993, Perth (Australia) in August 1993, Villafranca (Spain) in November 1994 and Malindi (Kenya) in November 1995. Precise estimation software was extended to include GPS measurement types for both ground-based and spacecraft-borne receivers. We have been providing data and increasingly precise GPS products for the last five years. Currently we provide:
- raw measurement data from six ground stations,
- precise orbits of the GPS spacecraft,
- Earth orientation parameters (polar motion, length of day),
- station coordinate solutions for those stations included in our analysis,
- GPS satellite clock information.

ESOC is currently an active IGS Analysis and Operational Data Centre and is especially involved in discussions to extend the IGS to use space-borne receivers.

### The ESA GPS TDAF

The ESA GPS Tracking and Data Analysis Facility (GPS-TDAF) has been developed in order to support the GPS activities carried out by ESOC. It includes a network of ground GPS receivers, the necessary communication interfaces to allow the remote operation and data downloading from ESOC, and the processing and analysis software needed to format the data and to obtain the precise products (Fig. 3). The system is highly automated, and includes an easy to operate interface for the retrieval and the processing of the data (Fig. 4). The GPS-TDAF is currently being extended to process GLONASS data and to include real-time monitoring capabilities that may be needed to support critical operational phases like rendez-vous.

Figure 2. Pillar-mounted GPS antenna and pillar in Maspalomas, Spain

Other recent developments are:
- The calculation of global and locall ionospheric models that can be used to correct one-frequency ranging and altimeter data.
- The implementation of a sequential filter to estimate spacecraft trajectories using the precise products obtained by the IGS analysis activities.

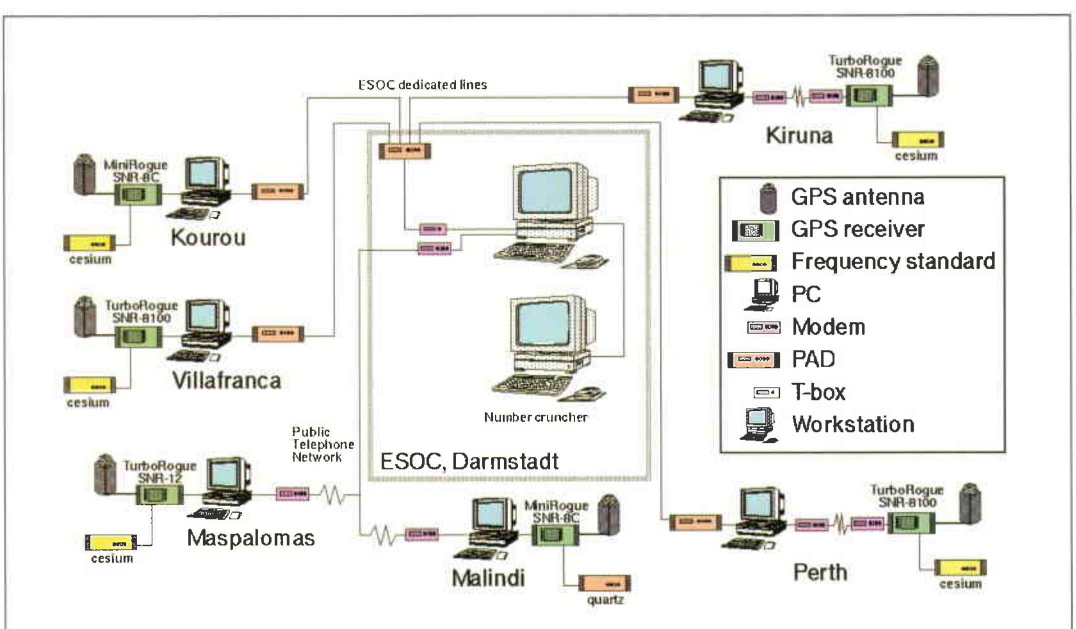


Figure 3. Current configuration of the GPS-TDAF

## Role of the ESA operations ground segment in GPS navigation

The driving reason for implementing a GPS-TDAF in ESOC was to provide ESA with the capability to support the navigation of satellites equipped with GPS receivers. This support involves the following activities:

*Support of critical real-time GPS applications*
GPS has been proposed as the absolute and relative positioning system for spacecraft going to the manned International Space Station. For this application it is clear that the ground segment cannot be in-the-loop for the calculation of real-time trajectories of the spacecraft involved because of the unavoidable delays that this will create. Still, the ground segment has a role in monitoring the integrity of the signals that are to be used for critical operations.

This can be accomplished using a ground network of GPS receivers that is able to track all the satellites that the orbiting spacecraft may use. The navigation data and observations of these precisely located ground stations can be processed in order to check their integrity and to estimate the error in the signal for each GPS satellite. Poorly performing satellites can be identified and the number of healthy GPS satellites observable by the user spacecraft during the critical operations can be predicted. This can also be done in real-time in order to detect satellite failures that can affect the navigation solution of the user spacecraft, so that the information can be delivered to Mission Control and the poorly performing GPS satellites can be excluded from the onboard computed navigation solution.

Another role of the ground segment will be to support the validation of the receivers and their correct functioning before critical operations are started. It can also assist in the fast re-start of receivers by providing up-to-date almanacs and other initialisation data.

ESOC has installed GPS receivers at six ground stations and it is developing a real-time communication system that will allow for the continuous monitoring of the GPS spacecraft visible from these ground receivers.

*Precise orbit determination using GPS*
GPS is one of the best types of tracking for Precise Orbit Determination of Low Earth Orbit satellites because it combines high accuracy with unsurpassed observability. The high accuracy is obtained by using the GPS carrier phase observable, free of ionospheric errors, when dual-frequency data is used. The observability is provided by the high number of GPS satellites that can be simultaneously tracked by an orbiting receiver.

ESOC has incorporated models for the most widely used GPS measurements in its Precise Orbit Determination software. This has been done both for the determination of the orbit of the GPS spacecraft and for the determination of the orbit of user spacecraft (spacecraft carrying a GPS receiver). The implementation has been validated using TOPEX/Poseidon data and the software is currently being used to support the ARP Flight Demonstrations. More information on these activities is given below.

*Determination of the orbits and clocks of the GPS satellites*
For some applications it is not necessary to simultaneously solve for the orbits of the GPS spacecraft and the user spacecraft. The orbits and clock biases of the GPS spacecraft can be precisely computed and then held fixed for the computation of the orbit of the user spacecraft.

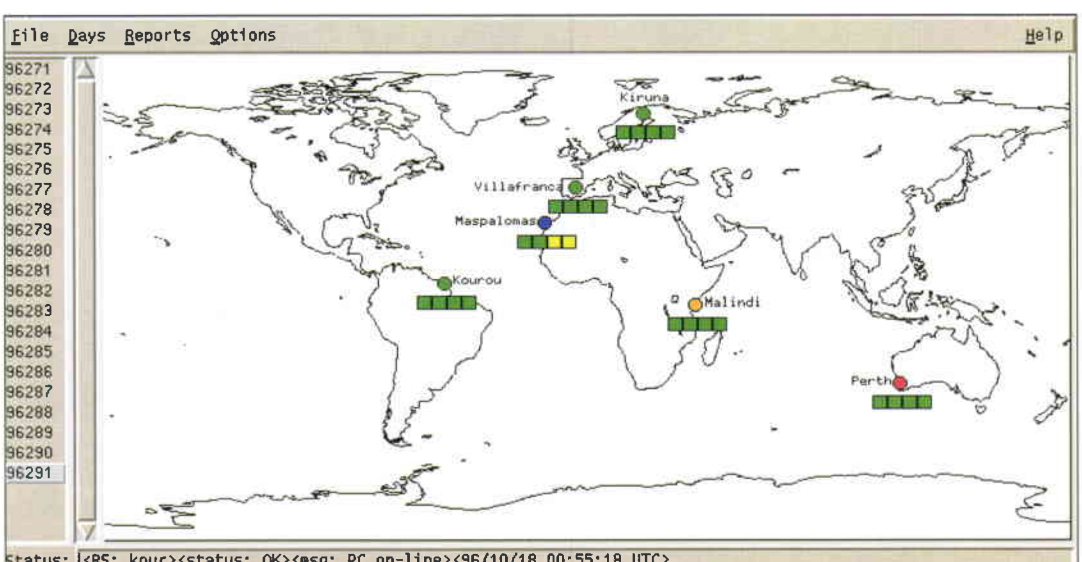


**Figure 4. Remote Station Control panel of the gPS-TDAF. This panel is used to monitor the daily retrieval tasks**

ESOC has been participating in the International GPS Service for Geodynamics (IGS) since its establishment, and producing precise orbit and clock solutions for the GPS satellites. These ephemerides are estimated to be accurate to about 10 cm.

Our GPS orbit determination software is also being used for feasibility and validation experiments for the ARTES-9 EGNOS project.

*Operational orbit determination using GPS*
The facilities implemented for Precise Orbit Determination can also be used for Operational Orbit Determination to produce a very accurate orbit prediction and to calibrate manoeuvres. This on-ground determined orbit can also be used during the spacecraft check-out to assess GPS-based onboard orbit determination.

For some applications it is not necessary to be able to produce a precise orbit prediction. In these cases the GPS-based onboard generated positions can be used on the ground as observables in order to determine the orbit that will be used for orbit control, mission planning and station visibility predictions. This process can also assess the quality of the onboard generated positions.

In this context, our GPS orbit determination software will be used operationally to determine the orbit of the Danish Ørsted geomagnetic research microsatellite.

*Geophysical parameter estimation*
Most of the activities listed previously are possible because networks of precise geodetic receivers are currently deployed to support these and other applications. For the most accurate applications, the position of the receivers in these networks has to be precisely determined, together with a number of other geophysical parameters. The accurate determination of the position of the ESA ground stations, the determination of Earth orientation parameters and the calculation of ionospheric calibrations can also support other projects that are not directly using GPS but need an accurate location of the position of tracking antennas and correction for ionospheric delays.

ESOC is contributing to the estimation of very precise station coordinate solutions that include the ESA ground stations, and through the IGS, also to the activities of the International Earth Rotation Service (IERS). We are currently testing the use of GPS derived ionospheric models in order to correct one-frequency ERS altimeter measurements as well as S-band ranging and doppler measurements used for the routine control of most spacecraft.

**TOPEX/Poseidon precise orbit determination**
TOPEX/Poseidon (T/P) is a joint US/French altimetric spacecraft launched in August 1992. The main scientific goal of this mission is to produce sea level maps to study ocean circulation and variability. Accurate orbit determination is vital to the success of this and other altimetric missions. In this case, the fundamental quantity measured is the geocentric height of the sea surface, obtained as the difference between the radial orbit position and the altimeter measurement proper. The orbit determination requirements for T/P were set to a very demanding 13 cm error budget for the radial position. In order to satisfy this challenge an unprecedented effort was made to improve the gravity model of the Earth and, to further guarantee the best possible results in orbit determination, several tracking systems were placed onboard: retroreflectors for Satellite Laser Ranging (SLR), a DORIS receiver, and an experimental precise GPS receiver. Effectively, this has made the T/P spacecraft a veritable orbit determination laboratory that allows intercomparisons between different tracking techniques.

T/P has been of unique importance for the validation of techniques for GPS-based satellite navigation. It is equipped with a high precision dual-frequency GPS receiver producing long cycle-slip-free carrier phase passes as well as pseudo-range measurements. It was launched when the GPS constellation was almost complete and when the IGS network of high precision GPS receivers had started to provide continuous globally distributed tracking data.

For our evaluation, a 10-day period was selected for the comparison of the orbit restitution capabilities of the three techniques: SLR, DORIS and GPS. For the GPS processing, T/P observations were used together with data from about 20 ground receivers from the IGS network. The orbit of the T/P spacecraft was then solved simultaneously with the orbits of the GPS spacecraft. The chosen data type was double-difference phase measurements involving two GPS satellites and two GPS receivers.

Comparisons were made to determine the ephemerides generated using only GPS and using a combination of SLR and DORIS, with external solutions obtained by the Delft University of Technology (DUT) and the Jet Propulsion Laboratory (JPL). The orbits show a remarkable agreement, with the difference in a radial direction in the order of 2 cm, and along track and cross track differences in the order of 5 to 10 cm.

These results demonstrate the capability of the GPS-TDAF to produce very accurate results when precise data collected onboard can be combined with on-ground collected data from a network of high precision GPS receivers.

**The ARP flight demonstrations**

ESA is developing the unmanned Automated Transfer Vehicle (ATV) that will serve as a logistic /re-supply vehicle for the International Space Station (ISS). The ATV will perform a number of manoeuvres in order to rendezvous and dock with the ISS. GPS is baselined as the main positioning system for the ATV. It will be used for autonomous absolute position determination and autonomous relative position determination with respect to the ISS. For autonomous absolute position determination the ATV will be equipped with a one-frequency GPS receiver that will provide position, velocity and time solutions. For autonomous relative position determination, the ISS will also be equipped with a GPS receiver that will provide GPS observables for transmission to the ATV. The ATV will process them together with its own GPS observables in order to determine its position and velocity relative to the ISS.

The ATV Rendezvous Pre-development (ARP) project covers the pre-development of rendezvous technologies critical to ATV. One of the aspects covered by this project is the validation of relative navigation using GPS observables. For this, three Flight Demonstrations (FD) are planned, in which the Space Shuttle will act as chaser and another spacecraft (Astrospas for FD1 and the Mir station for FD2 and FD3) will be the target. These spacecraft will carry one-frequency GPS receivers and will collect GPS data during the proximity operations. The data will be post-processed on the ground to validate the relative navigation algorithms.

The role of ESOC in these three ARP FDs is to compute reference trajectories (relative and absolute) for the spacecraft involved using all available measurements. These trajectories will then be used to compare with the results of the relative navigation filter. ESOC will obtain the trajectories using the following data:

- GPS observables (pseudo-range and phase) and onboard-derived positions from the two flying receivers.
- The ESOC precise orbit and clock solutions for the GPS satellites.
- Attitude data derived from the spacecraft Guidance, Navigation, and Control (GNC) system.

The data will be decoded and converted to an engineering format which will then be fed into a program which will produce the best estimate trajectories for the spacecraft. This program is called GPSBET (GPS Based Estimator of Trajectories) and it includes the following:

- Precise measurement models that use the GPS orbits and clocks computed by ESOC. The models include a centre of mass correction that is performed using the location of the particular antenna in the body-fixed axes and the attitude data.
- A multi-satellite orbit propagator that includes precise dynamic models and empirical accelerations.
- A Square Root Information Filter that processes all the information and produces filtered and smoothed estimates of the parameters.

We are currently processing data from the first ARP Flight Demonstration and we expect to achieve absolute positioning results with about 1 metre accuracy and even better relative-positioning accuracy.

**Conclusion**

The GPS system, originally deployed to allow very precise delivery of weapons, has demonstrated an incredible versatility of use for civil applications. GNSS systems are ideal to support many aspects of the navigation of spacecraft orbiting the Earth. They can support increased spacecraft autonomy and, when used together with ground-collected measurements, they provide unsurpassed accuracy. The ESA GPS-TDAF is already supporting validation activities for navigation of spacecraft using GNSS systems and will also be able to support preparations for a European contribution to future Global Navigation Satellite Systems.

Additional information on these activities, as well as links to other related World Wide Web sites, can be found under http://nng.esoc.esa.de/.

**Acknowledgement**

The development and operation of the GPS-TDAF has been possible thanks to the important contributions of C. García Martínez (GMV), J. Feltens (EDS) and M.A. Bayona (GMV), as well as those of S. Casotto and P. Duque and several trainees. Assistance of station and communications experts at ESOC and the ground stations is also gratefully acknowledged.

# SAR Mission Planning for ERS-1 and ERS-2

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**The mission planning activities which are performed at ESRIN in order to schedule data acquisitions for the Synthetic Aperture Radar (SAR) instruments on board of ERS-1 and ERS-2 (alone and in tandem) are described starting with their initial organisation and then their evolution based on experience and change in requirements. This is preceded by a short description of the ERS Ground Segment and an introduction which lists other key mission factors and summarises ESRIN's responsibilities in Earth Observation (ESA and Third Party Missions).**

**The major topics discussed are: user interface, user requests and their conflicts, baseline plans, data policy, mission guidelines; platform, sensors, ground segment and exploitation constraints; as well as planning tools, manpower needs, and interfaces with ground stations. The experience gained can be used for future missions in the identification of realistically achievable objectives, the definition of the offers to users, and the design of the mission planning system, in particular for user interfacing, mission planning tools and preparation of agreements with ground stations.**

## ERS Mission and Ground Segment

The ERS-1 and ERS-2 satellites, launched respectively on 17 July 1991 and 21 April 1995, currently represent a unique case of a dual remote sensing mission and have provided results beyond expectations, in particular for tandem data acquisition with a one-day difference. This provides data to many user categories such as real-time operators involved in meteorological, oceanographic and environmental applications, long-term research groups working off-line, commercial users, etc.

*Table 1. ERS-1 and ERS-2 On-board Instruments*

| Instruments | ERS-1 | ERS-2 |
|---|---|---|
| Active Microwave Instrument | | |
| SAR Image Mode | X | X |
| SAR Wave Mode | X | X |
| Wind Scatterometer | X | X |
| Radar Altimeter | X | X |
| Along Track Scanning Radiometer-1 | X | |
| Along Track Scanning Radiometer-2 | | X |
| Global Ozone Monitoring Experiment | | X |

The two satellites, carrying the set of instruments listed in Table 1 on board, have been exploited in the different mission phases listed in Table 2.

The ERS Payload Data Ground Segment, sketched in Figure 1 and providing SAR coverage as per Figure 2, is managed by ESRIN, via its Earth Remote Sensing Exploitation Division (RS/E), and is composed of:

- The ESRIN ERS Central Facility (EECF), located in Frascati, in charge of:
  - user interface and user support (training, promotion, documentation, tools, etc.),
  - monitoring of investigations and transfer of technology,
  - mission planning in conjunction with the Mission Management and Control Centre (MMCC) at ESOC,
  - ground stations' interface & coordination of National & Foreign Stations (NFSs: National = stations of countries participating in the ERS programme, Foreign = stations of non-participating countries),
  - planning and monitoring of production and delivery of near-real-time and off-line products,
  - generation and maintenance of a world wide inventory of acquired data,
  - coordination of the commercial Eurimage, Spotimage and Radarsat International Consortium (ERSC),
  - assessment of instrument behaviour and of related margins,
  - monitoring and control of ERS data and product quality,
  - management of the ground segment facilities and monitoring/control of related file routing,
  - maintenance of the "reference system" for the high- and low-rate fast delivery processing chains,
  - maintenance of data-processing software for the entire ground segment.

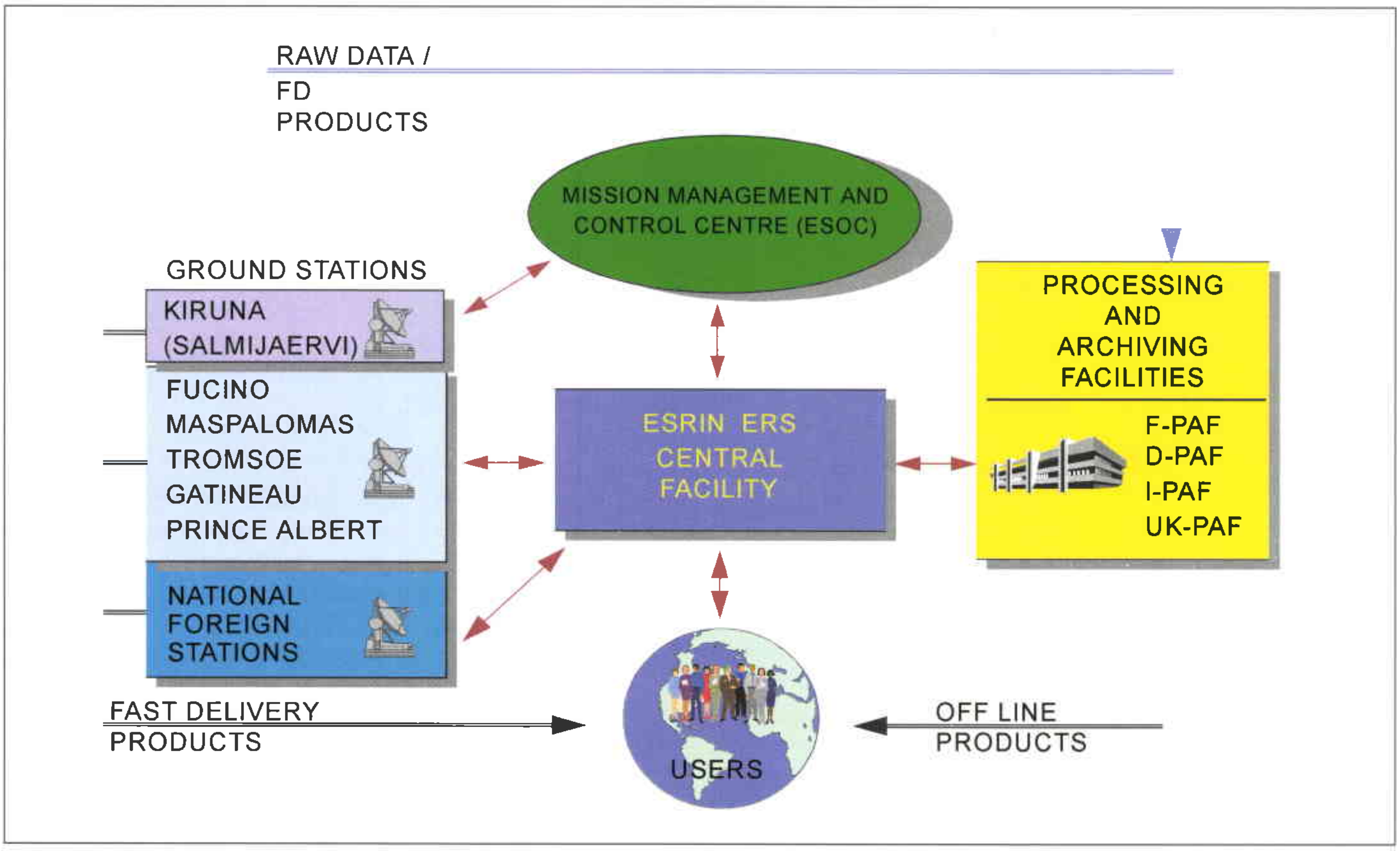
*Table 2. ERS-1 and ERS-2 Mission Phases*

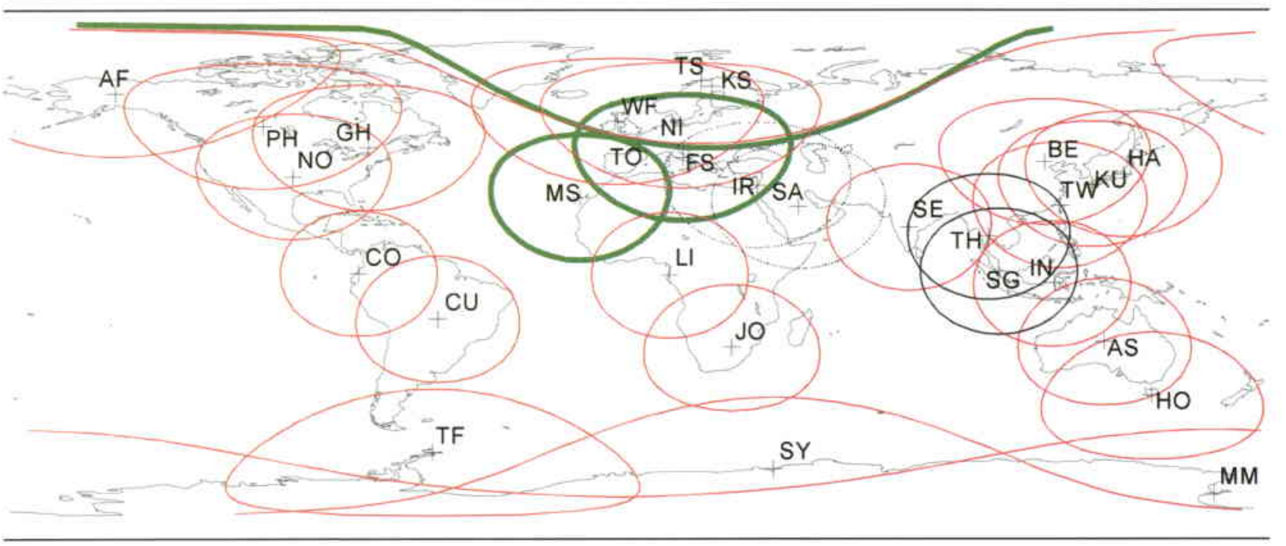
| Mission Phases | Start | Cycle | SAR Mission Objectives |
|---|---|---|---|
| **ERS-1** | | | |
| - Launch | 17-Jul-91 | | |
| - Payload switch-on & verif. | 17-Jul-91 | | |
| **A** Commissioning | 25-Jul-91 | 3 days | all instruments; until 10-Dec-91 |
| **B** Ice | 28-Dec-91 | 3 days | ice & pollution; interferometry possibility |
| **R** Roll-tilt (experimental) | 02-Apr-92 | 35 days | different SAR incidence angle (35°) |
| **C** Multi-disciplinary | 14-Apr-92 | 35 days | AO; land & ice mapping; consistent set in regular intervals |
| **D** 2nd Ice | 23-Dec-93 | 3 days | see Phase B |
| **E** Geodetic | 10-Apr-94 | 168 days | radar-altimetric mission; SAR as Phase C |
| **F** Shifted Geodetic | 28-Sep-94 | 168 days | 8 km shift vs. Phase E for denser grid |
| **G** 2nd Multi-disciplinary | 21-Mar-95 | 35 days | see Phase C |
| **G** Tandem | 17-Aug-95 | 35 days | interferometry & mapping |
| **G** Back-up | 2-Jun-96 | 35 days | |
| **ERS-2** | | | |
| - Launch | 21-Apr-95 | | |
| - Payload switch-on & verif. | 21-Apr-95 | 35 days | |
| **A** Commissioning | 02-May-95 | 35 days | SAR commissioning |
| **A** Tandem | 17-Aug-95 | 35 days | see ERS-1 Tandem Phase G |
| **A** Multi-disciplinary | 3-Jun-96 | 35 days | see ERS-1 Phase C |

***Note: 3 days = 43 orbits; 35 days = 501 orbits; 168 days = 2411 orbits***

- The ESA ground stations: Kiruna (Salmijaervi, Sweden), Fucino (Italy), Maspalomas (Canary Islands), Tromsø (Norway), Gatineau and Prince Albert (Canada). All stations but Kiruna, which is operated by ESOC and fully dedicated to ERS operations (including telemetry, tracking and control activities), are multi-mission and operate under ESRIN contracts. This network ensures acquisition of regional ERS SAR data and acquisition, processing and delivery of global ERS LBR data within three hours from sensing.

**Figure 1. ERS Payload Data Ground Segment**






(5° antenna elevation) ESA Stations — Stations with MoU ······· Other Stations * available during campaign periods

AF Fairbanks, Alaska, USA
AS Alice Spring, Australia
BE Beijing, China
CO Cotopaxi, Ecuador
CU Cuiabá, Brazil
FS Fucino, Italy
GH Gatineau, Canada
HA Hatoyama, Japan
HO Hobart, Australia
IN Parepare, Indonesia
IR Tel Aviv, Israel
JO Johannesburg, South Africa
KS Kiruna, Sweden
KU Kumamoto, Japan
LI * Libreville, Gabon, (Germany)
MM * McMurdo, Antarctica, (USA)
MS Maspalomas, Spain
NO Norman, USA
NZ Neustrelitz, Germany
PH Prince Albert, Canada
SA Rhyad, Saudi Arabia
SE Hyderabad, India
SG Singapore
SY * Syowa, Antarctica, (Japan)
TF * O'Higgins, Antarctica, (Germany)
TH Bangkok, Thailand
TO * Aussaguel, France
TS Tromsoe, Norway
TW Chung-Li, Taiwan
WF West Freugh, United Kingdom

**Figure 2. Network of all stations (ESA & NFSs)**

– A network of 27 NFSs which acquire ERS SAR data around the world (no on-board tape recorder for SAR) under the terms and conditions of a standard agreement.

– Four Processing and Archiving Facilities (PAFs), which are joint national / ESA endeavours to support / expand the applications of ERS data (SAR and/or LBR) through data archiving and off-line generation of precision products, in Brest (France, operated by IFREMER), Farnborough (UK, operated by NRSC), Oberpfaffenhofen (Germany, operated by DLR) and Matera (Italy, operated by the Italian Space Agency).

## Background

In this paper, the term "mission planning" indicates only those activities performed at ESRIN for planning SAR acquisitions. Other linked activities, such as planning of LBR instruments (mostly performed by default at ESOC) or production planning are not discussed.

SAR acquisition planning, even if a complex task, has not caused bottlenecks or problems for the ERS mission. The overall effectiveness of the ERS SAR mission was, or is, affected much more by:

– Experimental nature of radar data:
  - off-the-shelf tools to manipulate data are just emerging on the market,
  - application potentialities are still being demonstrated (research and promotion to be funded),
  - users are not yet familiar with radar image interpretation (training required).

– Data coverage and continuity:
  - possibility to plan, at short notice, special events (24 h service depends on funds),
  - high revisiting frequency is essential for operational applications,
  - data should be systematically acquired and archived long-term for future use,
  - NFSs should be encouraged to build and maintain a long-term data archive (data policy).

– Products:
  - reasonable quota should be defined for investigations (and budget allocated),
  - commitments for data from foreign stations should be carefully examined (contract vs. agreement?),
  - formats should be homogeneous across all generation facilities and, possibly, missions,
  - products should be tailored to user needs (e.g. fast delivery, low resolution, terrain corrected, etc.).

ESRIN is in charge of the planning and handling of the Earth Observation data from ESA and Third Party Missions (TPMs). For TPMs (e.g. Landsat and JERS-1), planning is limited to the collection of user needs, the definition of other potentially relevant acquisitions, the transmission of the resulting plan to the satellite operator, and the scheduling of ESA stations. On the other hand, ERS-1 and 2 SAR activity planning is far more complex because, over and above the number of on-board instruments and the parallel activities of two satellites, it must match user requirements (*user requests*), gathered through the *user interface*, and the *baseline plan* (derived from mission/data policies, anticipated user needs and contingency planning), with the system *constraints*. This activity is supported by a balanced combination of dedicated *planning tools* and manpower, and relies on interfaces with the ground stations. All these elements are discussed below, with a description of their initial implementation and their evolution in line with the experience gained and the changing requirements.

**User interface**

The user interface has been organised around three service desks: the ESA Help Desk (for information, documentation, tools, etc., to all users), the ERSC Customer Service (for commercial users) and the ESA Order Desk (for non commercial users); correspondence can be exchanged through fax, telephone, letter, e-mail, etc., as selected by the user.

Currently 3378 users are registered, of which only 922 have on-line access (mainly e-mail). Of the total number, 841 have submitted at least one user request (of these only 323 have e-mail). It is evident that normal correspondence media are still widely used. Their use will continue in the coming years especially in view of the opening of Eastern and African markets (telecommunication links to be set-up).

User interfacing for ERS was designed to serve a variety of user categories (see Table 3):

Table 3. Current number of users per user category

| *User Category* | *No. of Users* |
|---|---|
| AO / PP | 1113 |
| NA / FO | 32 |
| Planning | 7 |
| Commercial | 291 |
| ESA | 239 |
| No Project | 2140 |
| Total number of users | 3378 |

(some users belong to several user categories)

- investigators participating in ESA Announcements of Opportunity (AO) or Pilot Projects (PP),
- national and foreign stations,
- commercial/operational users or institutional organisations,
- others (calibration/validation, training, promotion, public relations, etc.).

The service was set-up to treat all users on an identical footing.

After the start of the mission, it was evident that interaction with users was more difficult and demanding than expected, despite the fact that some key documents describing the system had been prepared and widely distributed (some users had the impression that we could move the satellite wherever necessary). It became essential, particularly for planning, to improve the user's "visual" knowledge of the mission, and to ensure that the user and our service desks clearly understand each other. Therefore the graphical, simple and powerful Display ERS-1 SAR Coverage (DESC) tool, running on PCs, was developed and distributed. It was enhanced over time through valuable user feedback, up to the most recent Display ERS Swath Coverage for Windows (DESCW), which is multi-mission, supports quick-look display, provides on-line help, etc.

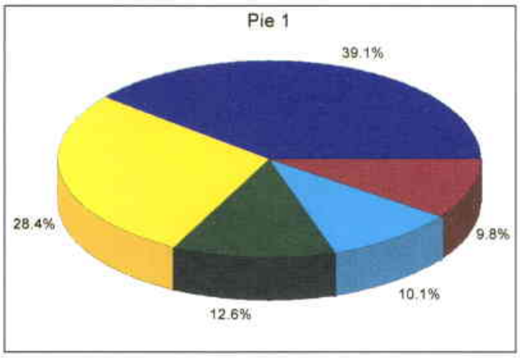
DESCW shows graphically the coverage of the various sensors in the future and/or in the past (through inventory search and filter). It is based on visibility files for possible future acquisitions and on compressed inventory files for past and planned acquisitions. The inventory files are either historical (past years) or updated weekly and are available online for free-of-charge downloading via FTP or Internet, together with the software and all supporting data. The entire software, the basic files, the help text, the inventory files (about 30 years of inventory data in total for ERS-1, ERS-2, JERS-1 and Landsat) take less than 4 Mbytes and, therefore, are also distributed on three PC diskettes on user request.

Over time, DESCW has been more and more used by our service desks and also by the mission planner, particularly to identify possible acquisition conflicts with other missions (the ERS mission planning system is not multi-mission), to derive rough indications useful for detailed mission planning and to quickly check future planning over small areas.

**User requests**

The system was designed to permit formalisation of user needs through user requests, which, for acquisition planning,

Figure 3. Total number of user requests per category




mainly define the area and time period of interest and can equally accurately identify single frames and very large acquisitions (e.g. the full station visibility area for some months).

Large sensing requirements must be submitted for planning about one month ahead of acquisition, limited requests up to five working days ahead and exceptional cases have been handled up to two to three working days ahead (uplinking of the spacecraft telecommands is done one day before the acquisition). User requests can be submitted and their status verified on-line through dedicated forms, via X.25 and VT200 terminals. Users are also actively informed via e-mail or fax of major status changes.

Figure 3 shows the total number of user requests per user category since mission start and Figure 4 shows their variation over time. It must be noted that:
- commercial requests are increasing (even if absolute value is still much below other categories),
- investigator requests are in line with the number of accepted projects,
- national and foreign stations without an exchange of fund agreement request large amounts of acquisitions (even with few user requests, since area and time range are wide),
- the complexity of the baseline planning is increasing (more specialised user requests).

A few months after exploitation started, it was realised that some NFSs and most of the investigators were submitting large acquisition requests, causing extra overheads in mission planning and a possible waste of satellite resources. Since most of the investigations had a production quota defined, the investigators were asked to limit their acquisition requirements to those which could be associated to a future product. This simple measure permitted a drastic reduction in the size rather than the number of user requests. However, when justified, the excess acquisitions were accepted within the baseline plan (see below).

The need to speed up the provision of information to users in case of sensor unavailability soon emerged (some users take in-situ measurements during satellite passes). Therefore, an automatic procedure was added to inform all affected users, immediately, via fax.

**Baseline planning**

Before the launch of ERS-1, it was realised that there was a need for an ESA baseline plan (a set of mission planner user requests) for the implementation of a data policy and mission guidelines (see Table 4 for the most relevant ones), and for the collection of data of potential commercial, operational or scientific interest. In particular, the mission guidelines, defined for each mission phase in the high level operations plan, influence planning over selected areas

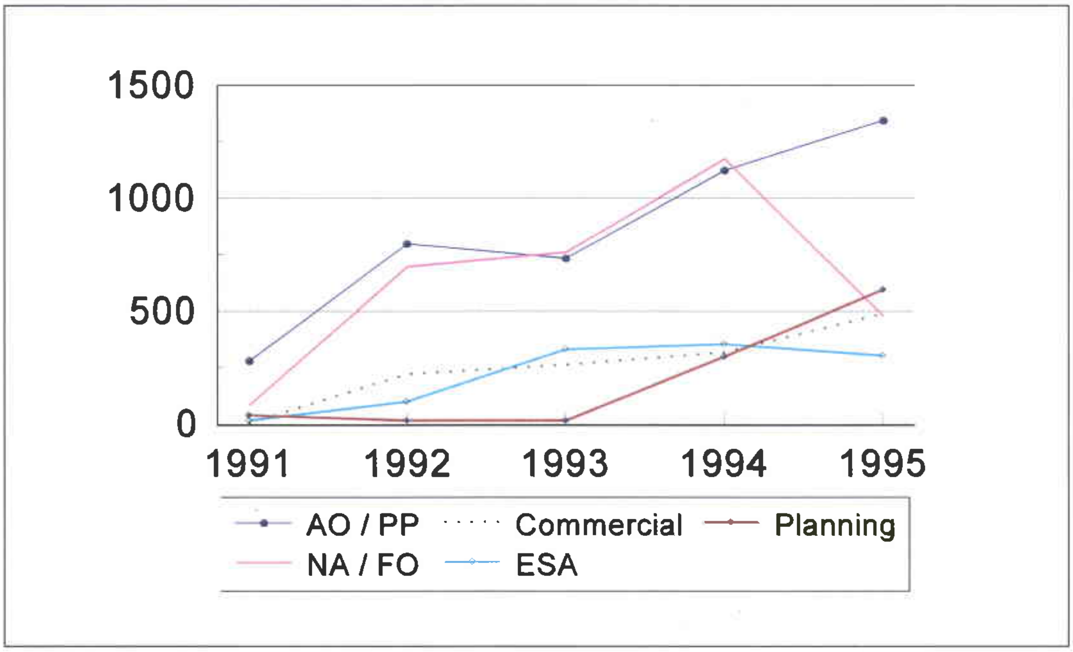



Figure 4. Number of user requests per user category vs. time

***Table 4. System Constraints***

*(- = initial; * = close to ERS-1 launch; / = not implemented; + = during exploitation)*

**Data Policy:**

- national stations (with signed agreement) can acquire data on a non-interference basis
- stations with approved agreement can request data acquisition (at no cost for national stations and for foreign stations with no-exchange of funds agreements)

**Mission Guidelines:**

- adhere to mission objectives (phase dependent)
- SAR has priority in descending passes, Wave and Scatterometer in ascending passes (night)
- solve conflicts applying priorities to the user categories and then to users according to past allocation

/ allocate acquisitions for AOs within the assigned quota, in a 6 months moving window, varying their priority according to remaining time, past allocation for country and application category
+ LBR activity has priority over SAR in ascending passes, every other cycle

**Platform and Sensor Constraints:**

- SAR can be activated only within visibility of a ground station (no HR tape recorder on-board)
- in each 100 min. orbit, SAR can be activated < 12 minutes in total, < 10 minutes per segment on descending passes, < 4 minutes in eclipse (in addition, merge gaps <30 seconds)
- maximum number of SAR on/off switches = 6 per orbit
- SAR imaging mode of AMI mutually incompatible with SAR Wave mode and Windscatterometer
- Windscatterometer must be switched on 128.2 seconds (850 km) before and after the site of interest

**Ground Segment Constraints:**

- take into account the real station visibility mask in planning SAR sensing
- instrument planning and Kiruna station scheduling must follow defined time constraints

* schedule SAR sensing from 5 to 2 degrees above horizon
* handle station unavailability at major subsystem level

+ adhere to ground station specific operational constraints, like: working hours (depending on campaign, country or religion), conflicts, available tapes, interval between adjacent passes, etc.
+ schedule all stations within visibility of planned segments, unless no agreement exists, unless there is a national or commercial request, or a natural disaster unless there is no hope to serve the user
+ schedule overlapping stations depending on reliability and on station or PAF processing capability
+ some stations report on acquisitions with a variable delay (even months, causing loss of replanning opportunities) and occasionally their reports are discovered to be incorrect
+ some MoUs signed later than expected or signature proceeding with difficulties
+ reduce number of HDDTs avoiding overlapping acquisitions and minimise night passes to save manpower

**Exploitation Constraints:**

* avoid bridging of specific segments (precise start flag)

/ monitor and control energy and thermal balances over and across orbits
/ handle SAR gain setting at user request level
/ permit planning of sensor modes (e.g.: OGRC / OBRG)
/ handle solar panel occultation of downlink antenna (changing over the year and with latitude)
+ 12 SAR minutes not per orbit, but from eclipse start to eclipse start (changing with seasons)
+ apply 'common sense' (strict application of HLOP rules prevents optimised use of resources)
+ assign higher priority to 'production requests' requiring new planning over 'acquisition only' ones
+ assign higher priority to requests over stations working in campaigns
+ change confirmed requests only in case of natural disasters or calibration needs
+ ensure proper and complete tandem planning (no multi-mission planning tool, user requirements might conflict with tandem mission, ground stations operational constraints more difficult to match, etc.)
+ keep to a minimum the number of IDHT on/off switches (from June 1996, to extend lifetime)
+ 'keep alive' scenario requires planning of at least two segments per day, about 12 hours apart

depending on the phase, while data policy has large impacts on data requests from NFSs.

The baseline plan became more defined and complex, being centred on acquisitions for:

- a mapping mission (build up consistent thematic data archives, anticipate future user needs, collect data for exceptional events and natural disasters, etc.),
- phase/season-dependent targets (monitor seasonal changes such as ice, ice boundaries and vegetation growth; collect full data sets over selected areas for applications like interferometry, change detection; etc.),
- system-related objectives (optimise instrument and ground segment utilisation, plan instrument calibrations, optimise acquisition over stations working on campaigns, etc.),
- large investigators' requests (follow moving targets like icebergs or ships, scan large areas for oil pollution or special phenomena, etc.),
- anticipated user requirements (those not yet formalised).

During the Tandem phase, data acquisition from both satellites was implemented through a special baseline planning considering:

- areas as large as station visibility for descending passes,
- small areas around steep slopes for ascending passes,
- stations' availability (linked also to signature of agreements)
- conflicts among stations due to SAR acquisition limits (in practice, only one station can be in full Tandem at any time along the same meridian),
- orbit maintenance manoeuvres (for best Tandem data, the orbits of the two satellites were made to cross around equatorial regions during winter and over the poles during summer),
- segments linked to user requests on one satellite and unavailable for Tandem on both satellites.

The baseline planning is currently kept to a minimum in order to extend satellite lifetime.

**Constraints**

Some of the system constraints (the major ones are listed in Table 4) are imposed by the physical characteristics of the instruments, spacecraft or orbit, while others are derived from ground segment and exploitation possibilities (of course, more detailed constraints are taken into account at ESRIN and ESOC). Some of the listed constraints make the planning process complex, their relative emphasis changing over time in relation to, for example, day/night, season, mission phase, etc.

The constraints marked with an asterisk in Table 4 were defined a few months before the ERS-1 launch, after a pre-release of the ESRIN mission planning system was delivered, and, therefore, induced late changes. Those with a slash were defined around the same period but were not implemented. The constraints marked with a plus have been encountered during exploitation.

**Planning tools and manpower**

The basic implementation of the ESRIN mission planning system was embedded in the development of the Central User Service (CUS) by MacDonald Dettwiler. In this type of core sub-system, the planning is based on user requests shared with other sub-systems (user request handling, order handling, production planning, etc.), while a specific set of tools (forms, graphics and reports) assists the planner in his activities.

Prior to the mission, ESRIN developed, in conjunction with Advanced Computer Systems, a mission analysis tool to verify possible use of SAR sensing in various mission scenarios (different launch dates and cycles). Since the major concern was related to the probability of acquisition conflicts, this tool was upgraded to test a simple algorithm for possible conflict resolution, reduction, or at least, identification. The problem was extremely simplified, generating for three key types of user requests, all the visible (by a ground station) orbit and frame combinations, with all their possible alternatives. The algorithm was designed to allocate acquisitions starting from the less critical orbits (those with more frames available and less requests) and propagating the effects to all involved user requests (the algorithm was designed to minimise conflicts and not to optimise planning, allocating the minimum number of sensing segments). The results were promising, since, on feeding the tool (which could also have been easily interfaced with CUS) with the available AO user requests, practically no conflict was detected. It was decided to verify CUS planning in practice before connecting this algorithm.

An analysis was made of the real conflicts experienced among user requests. From Table 5, related to Phase C, it is evident that the limited commercial (top priority) requirements could not cause conflicts, while investigators have larger conflict probabilities, even if, with a share of only 1/5 of the total allocation, other resources could have been freed for them if necessary. But this was not the case, since only 0.25% (5 out of 2024) of the requests were in conflict and therefore marginally descoped. During Phase D the percentage of requests in conflict grew to 1.75 % (13 out of 743), because the short repetition cycle (3 days) and phase (3 months) forced the grouping of large requirements from ice scientists over fewer orbits (43 against 501).

Currently, the orbit configuration for both satellites is as for Phase C, while large investigator requests are tending to decrease. Therefore, even fewer conflicts are being experienced.

Acquisition planning is currently performed at ESRIN by one contractor supervised by an ESA staff member (part time only), who ensures backup during working days, but also contributes to the preparation of planning documents, defines the detailed acquisition strategy in line with mission guidelines, sets-up the baseline plan, follows specific cases, contacts the stations for special arrangements, ensures correct reporting, etc. This manpower level is only just adequate and, consequently, in periods of a particularly higher load, such as during a Tandem mission, some low priority activities have to be descoped, deferred or cancelled (e.g. internal reporting, analysis of station reports, etc.). The use of an expert system would not have reduced the manpower requirements below this limit, since, in addition to the planner, there would have been a need for an expert-system specialist for adapting the rules according to the constantly varying mission needs (and possibly additional manpower for corrections and tuning).

**Interfaces**

Besides the internal ESA interface between EECF and MMCC for mission planning, the EECF has planning interfaces with acquisition stations, mainly for sending acquisition schedules and spacecraft ephemerides, and receiving acquisition reports. This loop is essential for user request satisfaction, since, in case of lost acquisitions, the sensing must be replanned if this is still acceptable to the user. This interface was defined in two documents, one for ESA stations and a simplified one for NFSs, both based on files exchanged through telecommunication links using two file transfer protocols (FTAM and FTSV) over X.25.

Table 5. Frames allocated during ERS-1 Phase C vs. user category (as of June 1996)

| *User Category* | *No. of Frames* |
|---|---|
| AO / PP | 66331 |
| NA / FO | 80028 |
| Planning | 171116 |
| Commercial | 1479 |
| ESA | 3305 |

When NFSs started to join the ground segment, few of them had interfaces in line with the specifications and new interfaces and procedures had to be quickly defined and implemented, based initially on telefax communication. Slowly, over the years, stations started to migrate towards online connections, but using their own preferred protocols. We therefore had to progressively add new protocols to our system in order to simplify our operations, but at the expense of complexity.

Table 6 shows the number of SAR frames acquired over all stations for both missions.

**Conclusions**

Due to the experimental nature of the mission, the complexity of the ground segment, as well as the political drive and sensitivity, it was not possible in the ERS SAR mission planning to anticipate many of the eventual ground-segment constraints and the evolution of requirements during the mission. Therefore, the planning system for future missions of this type should be designed starting with the basics and adding complexity over time, when the real constraints, requirements and possibilities are known. The initial system should be sufficiently flexible, and enough resources should be foreseen, for this expansion/adaptation.

Since the user is an integral part of the system, a large amount of information exchange is necessary. This should take place according to the user's preferred method(s) and possibly supported by a graphical, powerful and user-friendly tool, running in the most popular environment. This tool should be precise and comprehensive enough to also be used internally, in order to communicate with the user on the same basis. The resources (facilities and manpower) necessary for proper interaction should be carefully evaluated and allocated since they are essential to the reduction of problems and workload, and to the improvement of overall service quality.

The initial forecast of a practically conflict-free 12 minutes of SAR per orbit was confirmed by experience, verifying that the decision to implement neither an expert system nor a

*Table 6. Total SAR frames acquired worldwide for both missions (as of June 1996)*

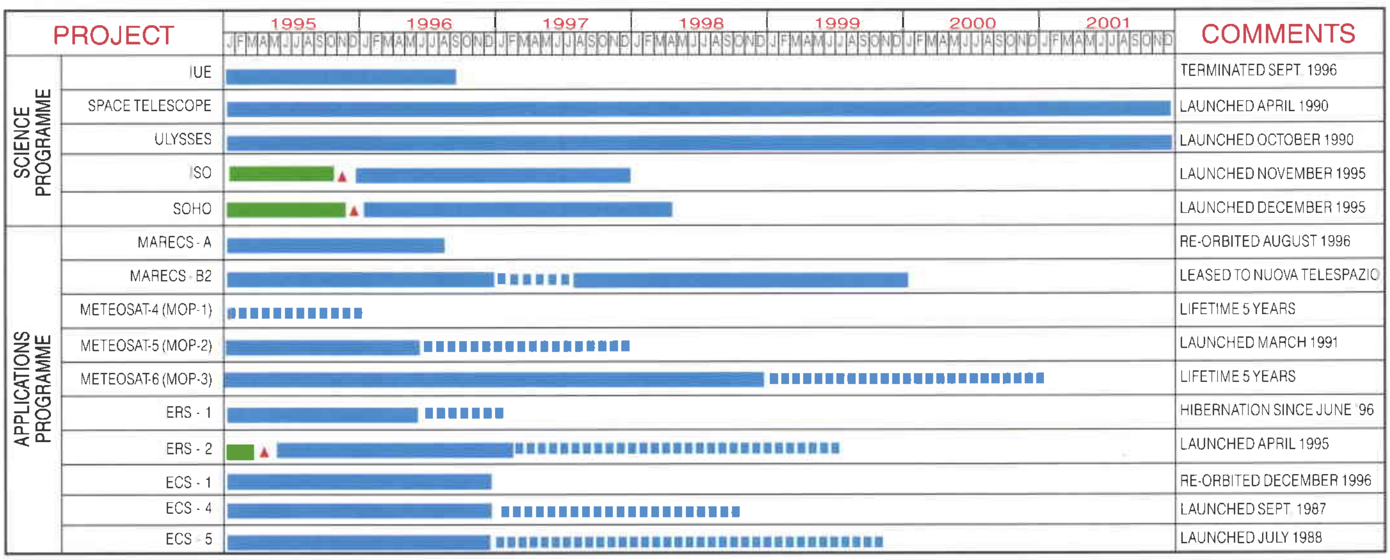
| | ERS-1 | ERS-2 | |
|---|---|---|---|
| **Ground Stations** | **Phases A-G** | **Phase A** | **Total** |
| Fucino | 99198 | 24536 | 123734 |
| Kiruna | 252740 | 38716 | 291456 |
| Maspalomas | 32559 | 6578 | 39137 |
| **Total ESA Stations** | **384497** | **69830** | **454327** |
| Aussaguel | 4843 | 0 | 4843 |
| Gatineau | 101314 | 12708 | 114022 |
| Libreville | 5975 | 3711 | 9686 |
| Neustrelitz | 3783 | 3320 | 7103 |
| O'Higgins | 37080 | 11247 | 48327 |
| Prince-Albert | 150371 | 19638 | 170009 |
| Tromsø | 215452 | 27996 | 243448 |
| West Freugh | 54119 | 6128 | 60247 |
| **Total National Stations** | **572937** | **84748** | **657685** |
| Alice Springs | 22372 | 5889 | 28261 |
| Bangkok | 5858 | 0 | 5858 |
| Beijing | 7834 | 4814 | 12648 |
| Cotopaxi | 7058 | 407 | 7465 |
| Cuiaba | 19445 | 3204 | 22649 |
| Fairbanks | 212328 | 18933 | 231261 |
| Hatoyama | 20874 | 0 | 20874 |
| Hobart | 3753 | 2661 | 6414 |
| Hyderabad | 24012 | 3961 | 27973 |
| Johannesburg | 5870 | 2919 | 8789 |
| Kumamoto | 18561 | 0 | 18561 |
| Norman | 2588 | 2287 | 4875 |
| McMurdo | 12851 | 12858 | 25709 |
| Parepare | 8395 | 2 | 8397 |
| Singapore | 2924 | 2765 | 5689 |
| Syowa | 6700 | 1183 | 7883 |
| Taiwan | 3990 | 1256 | 5246 |
| **Total Foreign Stations** | **385413** | **63139** | **448552** |
| **Grand Total** | **1342847** | **217717** | **1560564** |
| Distinct frames | 831824 | 152809 | 984633 |
| Distinct/Grand Total (%) | 61.94% | 70.19% | 63.09% |

special conflict resolution tool was correct. The absence of conflicts, and the variability of constraints and rules, make flexibility more important than plan optimisation, and favour mission planning based on natural rather than artificial intelligence (supported by powerful tools). A skilful mission planner can anticipate and resolve conflicts before they become critical, can judge new requirements against knowledge of the constraints, and can learn from the past and dynamically adapt procedures to the changing environment.

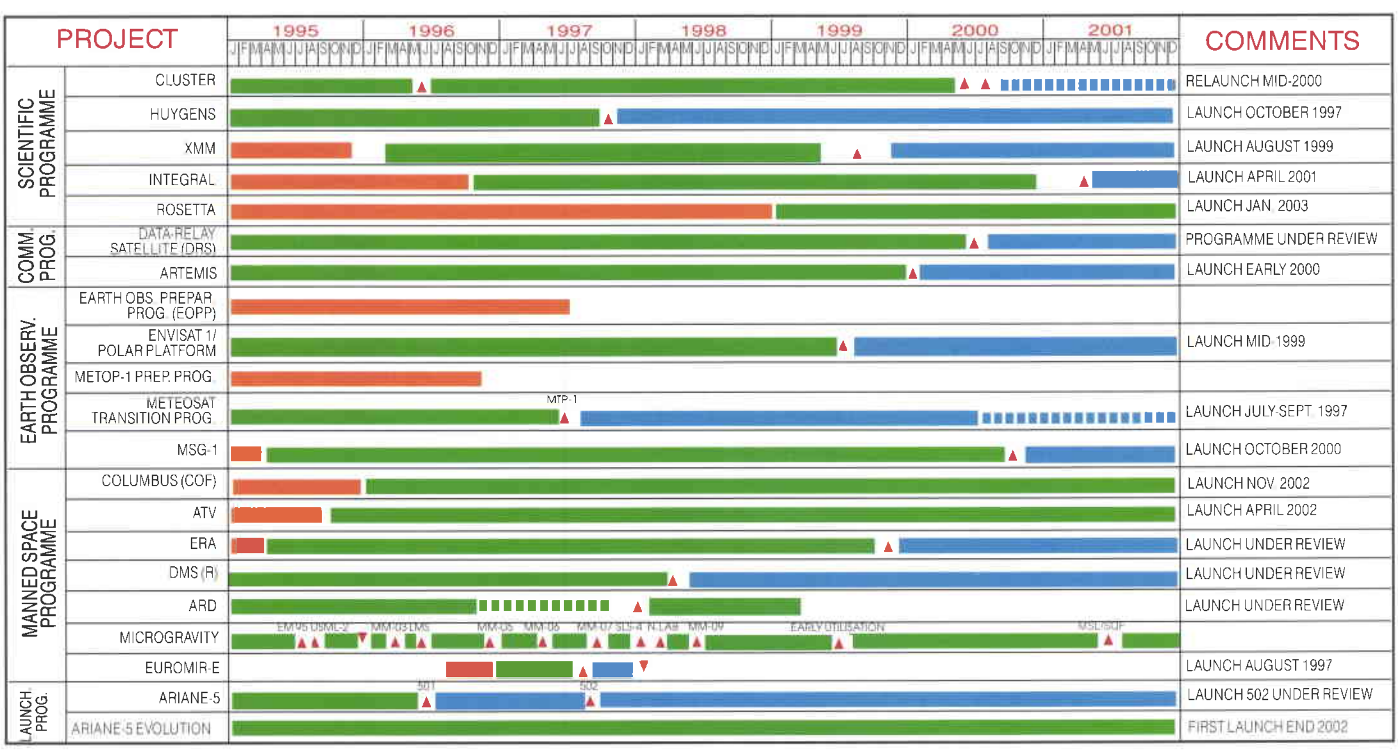
In conclusion, SAR mission planning has never been a limiting factor for the ERS mission. As has been shown, other factors have had a much greater overall impact.

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

## In Orbit / En orbite




## Under Development / En cours de réalisation




DEFINITION PHASE
OPERATIONS
MAIN DEVELOPMENT PHASE
ADDITIONAL LIFE POSSIBLE
LAUNCH/READY FOR LAUNCH
RETRIEVAL
STORAGE

# ISO

*L'Observatoire spatial dans l'infrarouge (ISO) de l'ESA continue à fonctionner de façon remarquable en orbite. Il suit des calendriers très serrés comprenant couramment 45 observations de haute qualité par jour. On compte déjà de nombreuses publications scientifiques sur les résultats d'ISO, et d'autres sont en préparation. En ce qui concerne les objets de notre propre système solaire, la caméra infrarouge (ISOCAM) d'ISO nous a par exemple transmis des images des comètes Hale-Bopp et Wirtanen, cette dernière étant retenue comme cible pour la mission Rosetta de l'Agence.*

*Le système de pointage d'ISO a été réglé avec précision après une série d'investigations, y compris un certain nombre d'essais menés sur le satellite en orbite. La précision absolue de pointage a été portée à environ 2 secondes d'arc (à comparer aux 12 secondes d'arc figurant dans les spécifications) et l'on espère parvenir à une précision encore plus fine de 1 seconde d'arc.*

*Par mesure de précaution, les activités du spectromètre LWS ont été interrompues le 28 novembre à la suite de plusieurs anomalies de fonctionnement de la roue permettant de sélectionner soit le réseau soit l'un des deux interféromètres Fabry-Perrot. Il a été procédé à une analyse détaillée des données de télémesure de l'instrument en orbite et à des essais sur le modèle de vol de réserve. Les dysfonctionnements en orbite ont été attribués à des modifications de distribution du lubrifiant basse température dans les cages de roulement à billes de la roue, ces modifications se traduisant par une perte de couple dans le mécanisme d'entraînement. Le mode de fonctionnement de la roue a été modifié de façon à rétablir le couple voulu, et les observations du LWS ont repris de façon satisfaisante le 31 janvier. Cette intervention n'a pas eu d'incidence sur les activités scientifiques ni sur le fonctionnement de l'instrument.*

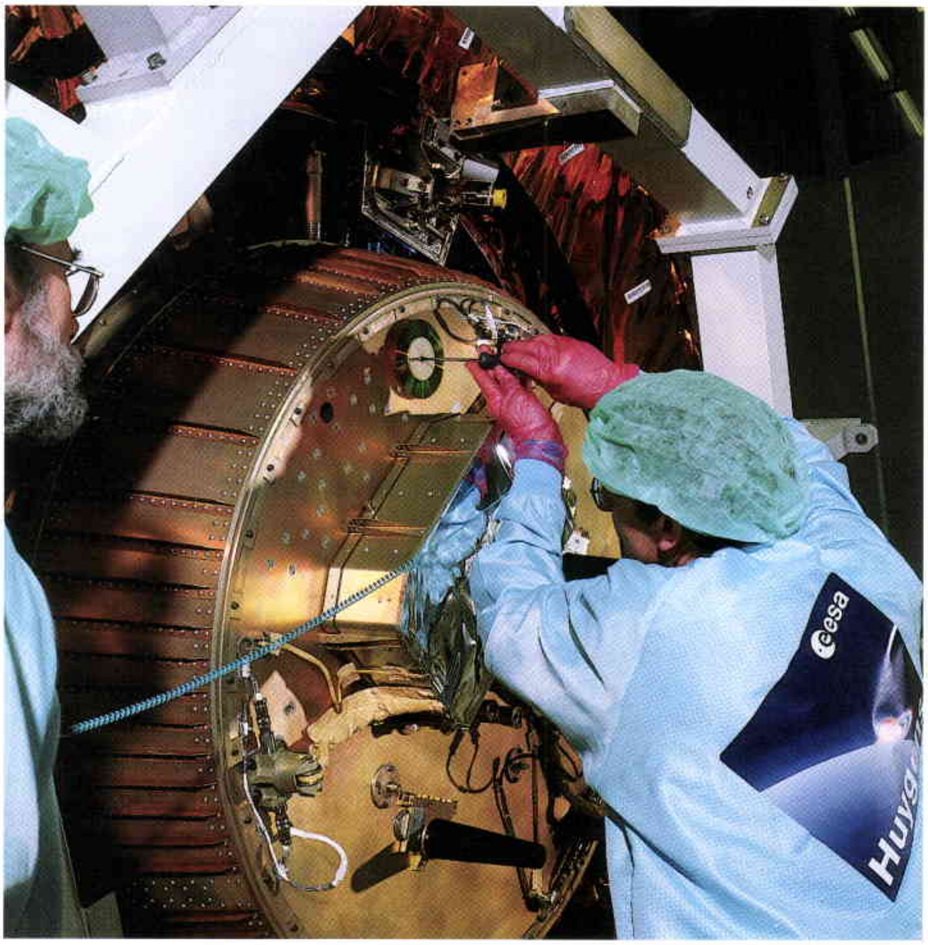
*L'examen par un groupe de pairs de la deuxième série de propositions de temps d'observation s'est achevé en novembre. Des recommandations ont été formulées sur un total approximatif de 1900 heures, réparties sur 330 propositions. Environ 6% de ce temps est alloué à l'étude du système solaire, 32% aux observations stellaires et circumstellaires, 21 % au milieu interstellaire, 28% aux systèmes extragalactiques et 13% à la cosmologie. De décembre à mars, les auteurs des propositions retenues ont fourni des détails complets sur leurs observations et certaines d'entre elles ont déjà été menées à bien par ISO.*

*Un calendrier détaillé est en cours d'élaboration pour l'exécution d'une manoeuvre de maintien à poste, prévue le 14 mai. Dans un même temps, il sera procédé à une deuxième mesure directe de l'hélium liquide restant afin d'estimer de façon plus précise la date à laquelle la réserve d'hélium sera épuisée. Selon les prévisions actuelles, l'hélium devrait arriver à épuisement en décembre 1997, ce qui prolongerait de six mois l'autonomie prévue dans les spécifications. Dans ces conditions, ISO connaîtra en septembre plusieurs éclipses pouvant atteindre une durée de 2 heures 40 minutes, soit le double de ce qui a été prévu lors de la conception. Il faudra donc imposer des restrictions particulières pendant cette période.*

# Huygens

*Les essais intégrés au niveau système et logiciel – vérification en ligne des interfaces avec le réseau sol de l'ESOC – sont les derniers essais système importants à avoir été conduits sur le modèle de vol de la sonde en Europe. Ils se sont tous déroulés de façon concluante, de sorte qu'il ne reste qu'à réaliser quelques essais mineurs au niveau unités et sous-systèmes et certains ajustements avant d'expédier la sonde au Centre spatial Kennedy pour les préparatifs du lancement.*

*La revue de recette pour le vol (FAR) de la sonde s'est traduite par une intense activité. Pour commencer, l'industrie a présenté les résultats des essais à l'Agence, y compris aux co-présidents de la commission de la FAR, et l'ensemble des données de la FAR ont été livrées en*



The Huygens flight Probe, with back cover removed.

*La sonde Huygens (avec bouclier arrière ouvert).*

## ISO

In-orbit operations of ESA's Infrared Space Observatory (ISO) satellite continue to run extremely smoothly. Very efficient schedules containing an average of 45 highly-graded observations per day are routinely carried out. Many scientific papers have been published with ISO results and more are in preparation. As examples of ISO results on objects in our own solar system, ISO's infrared camera (ISOCAM) has been used to take images of the comets Hale-Bopp and Wirtanen, the latter being the target of ESA's Rosetta mission.

ISO's pointing system has been fine-tuned after a series of investigations, including some in-orbit tests with the satellite. The absolute pointing accuracy has been increased to around 2 arcseconds (cf. specification of 12 arcsecs) and a further improvement to the 1 arcsec level is expected.

Operations with the Long Wavelength Spectrometer (LWS) were suspended on 28 November as a precautionary measure following a number of anomalies in the operation of its interchange wheel - which carries the two Fabry-Perots and an aperture for the grating mode. Detailed investigations were made on the existing telemetry from the in-orbit instrument, as well as tests on the flight spare model. The in-orbit malfunctions were attributed to changes in the distribution of the low-temperature lubricant in the ball races of the wheel assembly, leading to a loss of torque margin in the drive mechanism. The way in which the wheel is operated was changed so as to restore this margin and LWS observations were successfully resumed on 31 January. This change has no effect on the scientific operation or performance of the instrument.

The peer review of the second round of proposals for ISO observing time was completed in November. Recommendations were made for a total of about 1900 hours of time, spread over 330 proposals. About 6% of the time is for solar system studies, 32% for stellar and circumstellar observations, 21% for the interstellar medium, 28% for extragalactic systems and 13% for cosmology. In the period from December to March, successful proposers provided full details of their observations and some have already been carried out by ISO.

Detailed planning is underway for a station-keeping manoeuvre to be executed on 14 May. At the same time, a second direct measurement of the remaining liquid helium will be made in order to provide a more precise estimate of when ISO's helium will be exhausted. The current prediction of December 1997 is about 6 months longer than specified. This extended lifetime means that, in September, ISO will suffer eclipses with durations of up to 2 hrs 40 mins, about twice the design value. Special operational restrictions will be imposed during this period.

## Huygens

Integrated System Testing and Software Verification Testing - the on-line interface testing with the ESOC ground network - were the last major system-level tests to be carried out on the flight-model Probe in Europe. All such tests were successful and so just a few minor unit and subsystem tests and adjustments remained to be performed before the Probe is finally readied for shipment to Kennedy Space Center for launch preparations.

The Probe Flight Acceptance Review (FAR) activities have been intense, starting with an industry presentation of the Probe testing status to ESA, including the co-chairmen of the FAR Board, and delivery of the FAR data package, in January. The findings to date all point to a satisfactory conclusion to the Review, with flight Probe acceptance scheduled for 26 March. The Probe is due to be shipped to the launch site on 1 April 1997.

## XMM

Critical Design Reviews at equipment level were successfully completed during the last quarter and the team is currently delivering the equipment items to the prime contractor Dornier (D) for the integration of the electrical, structural and thermal models of the spacecraft. In parallel, assembly of the structural and thermal models has started with the integration of the reaction-control elements onto the service-module structure at BPD (I).

Significant progress has also been made on the X-ray optics. The flight mirror modules numbers one and two were delivered as planned in January and February 1997 by Media Lario (I). Optical and environmental testing of the first mirror module, conducted at CSL (B), has been completed and has confirmed the very good performance expectations. This model will now be X-ray tested in the PANTER facility (D), while the second module will in turn start its test campaign at CSL. All three structural/thermal models of the mirror modules have been completely tested and handed over to Dornier for spacecraft integration.

Optical testing of the X-ray instruments at the Max-Planck Institute conducted during the last quarter of 1996 using the mirror qualification model and engineering models of the detectors and gratings has been completed. The structural, thermal and engineering models of the instruments are being delivered to Dornier for spacecraft integration, and preparations are well underway for the calibration campaign for the X-ray instruments together with the flight mirror modules at the PANTER facility.

The user- and software-requirement documentation for the major elements of the ground segment have been finalised and the next milestone will be the completion of the architectural design.

XMM's orbit is currently being redefined to make the best possible use of the Ariane-5 launch vehicle's revised capabilities.

## Integral

Following the kick-off of the spacecraft's main development phase (Phase-C/D), the industrial team has proceeded with the detailed design activities. In parallel, negotiations have been held with the majority of the subcontractors to reach fixed-price agreements. Special emphasis has been placed on those payload items required early in the development cycle, ground-support equipment simulating the spacecraft, and the spacecraft data-processing electronic units.

The Instrument Baseline Design Review has been held. Instrument-specific issues were raised, but generally speaking payload definition has progressed *janvier. Tout semble indiquer à ce jour que la revue s'achèvera de façon satisfaisante, la recette étant prévue le 26 mars. La sonde doit être expédiée au site de lancement le 1er avril 1997.*

## XMM

*Les revues critiques de conception au niveau des équipements ont été menées à bien au cours du dernier trimestre et l'équipe procède actuellement à la livraison du matériel au maître d'oeuvre, Dornier (D), en vue de l'intégration des modèles électrique, structurel et thermique du satellite. L'assemblage des modèles structurel et thermique a démarré en parallèle avec l'intégration des équipements de commande par réaction à la structure du module de servitude chez BPD (I).*

*Des progrès significatifs ont été accomplis en ce qui concerne l'optique X. Les premier et deuxième modules miroirs aux normes de vol ont été livrés comme prévu en janvier et février 1997 par Media Lario (I). Les essais optiques et d'ambiance réalisés sur le premier module chez CSL (B) sont terminés, confirmant les excellentes performances escomptées. Ce module sera maintenant soumis à des essais en rayonnement X dans l'installation PANTER (D), tandis que l'autre abordera à son tour une campagne d'essais chez CSL. Les trois modèles structurels et thermiques des modules miroirs ont subi tous les essais prévus et ont été remis à Dornier en vue de leur intégration au satellite.*

*En ce qui concerne les instruments X, des essais optiques ont été menés à bien à l'Institut Max Planck pendant le dernier trimestre 1996 en utilisant le modèle de qualification des miroirs et des modèles d'identification des détecteurs et des grilles. Les modèles structurels, thermiques et d'identification des instruments sont en cours de livraison à Dornier en vue de leur intégration au satellite, et les préparatifs sont bien avancés en ce qui concerne la campagne d'étalonnage des instruments X avec les modules miroirs aux normes de vol dans l'installation PANTER.*

*La documentation sur les impératifs des utilisateurs et les exigences en matière de logiciel des principaux éléments du secteur sol a été mise au point. La prochaine grande étape consistera à achever la conception architecturale.*

*L'orbite de XMM est en cours de redéfinition, l'objectif étant d'exploiter au mieux les capacités révisées du lanceur Ariane-5.*

## Integral

*A la suite du démarrage de la phase de développement proprement dit (phase C/D) du satellite, l'équipe industrielle a procédé aux activités de conception détaillée. Des négociations ont eu lieu en parallèle avec la majeure partie des sous-traitants pour conclure des accords à prix forfaitaire. L'accent a été mis en particulier sur les éléments de la charge utile dont il faudra disposer au début du cycle de développement, les équipements de soutien sol permettant de simuler le satellite, et les unités électroniques assurant le traitement des données du satellite.*

*La revue de conception de la base de référence des instruments a suscité un certain nombre de questions propres aux instruments. Mais en règle générale, la conception de la charge utile a progressé de façon satisfaisante et les interfaces avec le satellite devraient être consolidées au cours de la revue 'satellite' en mai prochain.*

*Les négociations avec l'Agence spatiale russe (RKA) ont également évolué en ce qui concerne le lancement d'Intégral par une fusée Proton en échange de la fourniture de données scientifiques. Une étude détaillée est en cours sur les conséquences pour le satellite d'un lancement par un véhicule Proton et sur le partage des tâches au niveau 'lanceur' et 'satellite' qui en découlerait. Les conclusions de cette étude faciliteront la définition des documents d'interface et, partant, la signature du Memorandum d'Accord.*

*D'autres avancées ont été enregistrées avec la NASA en ce qui concerne la fourniture de stations sol. Bien que le passage escompté au réseau d'antennes puisse avoir des incidences sur Integral, les deux agences ont élaboré en commun une spécification générique des caractéristiques de fonctionnement des stations sol qui servira de base de travail dans la recherche d'un scénario approprié.*

## Artemis

### Satellite

*Le modèle structurel a passé avec succès l'épreuve des essais d'ambiance mécaniques au niveau qualification. Début février, avec le soutien technique et l'aide du personnel de la NASDA, il a été procédé à l'ESTEC (NL) à un essai d'interface avec l'adaptateur du lanceur japonais HII-A. Le modèle structurel a été expédié à Madrid où il doit subir chez CASA des essais en micro-vibrations destinés à mettre un terme au programme de qualification de la structure secondaire du satellite et où le matériel sera inspecté après les essais d'ambiance.*

*La campagne d'essais officielle du modèle d'identification démarre ces jours-ci par les essais système intégrés, qui seront suivis par des essais de compatibilité électromagnétique (EMC) et de décharge électrostatique (ESD).*

*La préparation thermique des panneaux de structure du modèle de vol est terminée et les panneaux sont prêts à être intégrés à l'unité au centre d'assemblage, d'intégration et d'essai (AIT) d'Alenia à Rome (I).*

*L'assemblage de la structure primaire du modèle de vol du satellite se poursuit par l'intégration du matériel de propulsion, du câblage, du matériel de régulation thermique correspondant et des instruments d'essai. Lorsque le sous-système de propulsion, intégralement assemblé, aura été testé, le modèle de vol d'Artemis sera livré à Alenia Spazio (I).*

### Terminal Silex LEO

*En ce qui concerne le terminal Silex sur orbite terrestre basse, le programme d'essais d'ambiance est achevé et le terminal a été livré à SPOT pour des activités d'intégration et d'essais au niveau satellite.*

## EOPP

### Programmes futurs

*Les ultimes engagements contractuels de la première extension du programme* satisfactorily and should allow the freezing of the interfaces to the spacecraft during the spacecraft review in May.

Further progress was made with the Russian Space Agency (RKA) regarding the provision of a Proton launcher in exchange for scientific data. A detailed analysis is currently being carried out to determine the precise implications for the spacecraft of a Proton launch and the appropriate sharing of tasks associated with the launcher and the spacecraft. The results of this study will facilitate the proper definition of the interface documentation and, subsequently, the signature of the Memorandum of Understanding.

Further progress was also made with NASA on the provision of ground stations. Although the planned changes to the antenna network may have implications for Integral, a generic ground-station performance specification has been jointly established which will serve as a baseline for finding a suitable scenario.

## Artemis

### Satellite

The Artemis structural model has successfully completed its mechanical environmental test programme at qualification levels. In early February, with the support of NASDA hardware and personnel, an interface test with the Japanese HIIA launcher adapter was performed at ESTEC (NL). The structural model is presently being transported to Madrid, where micro-vibration testing in the CASA facilities will complete the qualification of the spacecraft secondary structure and where hardware inspection after the environmental testing will take place.

The formal engineering-model test campaign is now starting with the Integrated System Test. This will be followed by the EMC/ESD test.

The thermal preparation of the flight-model structural panels has been completed and they are now available for unit integration at the Alenia AIT facility in Rome (I).

Flight-model spacecraft primary structure assembly is continuing with the integration of the propulsion equipment, harness, associated thermal-control hardware and test instrumentation. Once the fully assembled propulsion subsystem has been tested, the Artemis flight model will be delivered to Alenia Spazio (I).

### Silex LEO terminal

The Silex Low Earth Orbit terminal has successfully completed its environmental test programme and has been delivered to SPOT for integration and satellite-level testing.

## EOPP

### Future programmes

During the last quarter, the final contract commitments were made for the EOPP first extension programme. Although work initiated within that programme will continue until well into 1998, no further activities can be started until agreed by the Participating States or until subscriptions to the new slice have reached 80%. In particular, this financial problem is delaying the initiation of the Earth Explorer and Earth Watch programmes.

### Campaigns

All data acquisition from the 1996 campaigns has been successfully completed. Analysis of the data from the last three campaigns is still in progress. In particular, the data from the INDREX campaign have now been released by the Indonesian authorities and have been made available to the investigators.

## Polar Platform/Envisat

The Polar Platform/Envisat-1 mission is the most challenging ESA has ever undertaken in the Earth-observation domain. It will not only provide continuity with space-acquired ocean, land and ice data from ERS-1 and ERS-2, but will also gather information on atmospheric constituents and Earth-surface features that will be invaluable for future environmental research and applications.

The instrument payload is a combination of six ESA-developed instruments (EDIs) and three Announcement of Opportunity Instruments (AOIs).

Envisat-1 is planned to be launched by an Ariane-5 in mid-1999 into a Sun-synchronous, near-polar orbit in which it will circle our planet some 14 times per day. The mission is expected to provide continuous global data for at least five years.

Envisat's service module in the Large Space Simulator at ESTEC.

*Module de service d'Envisat dans le grand simulateur spatial à l'ESTEC.*

*EOPP ont été pris au cours du dernier trimestre. Bien que les travaux lancés dans le cadre de ce programme soient appelés à se poursuivre pendant une grande partie de l'année 1998, les nouvelles activités ne pourront être engagées que sous réserve de l'accord des Etats participants ou lorsque les souscriptions à la nouvelle tranche auront atteint le seuil de 80 %. Ce problème financier se traduit notamment par un retard dans la mise en route des programmes d'exploration et de surveillance de la Terre.*

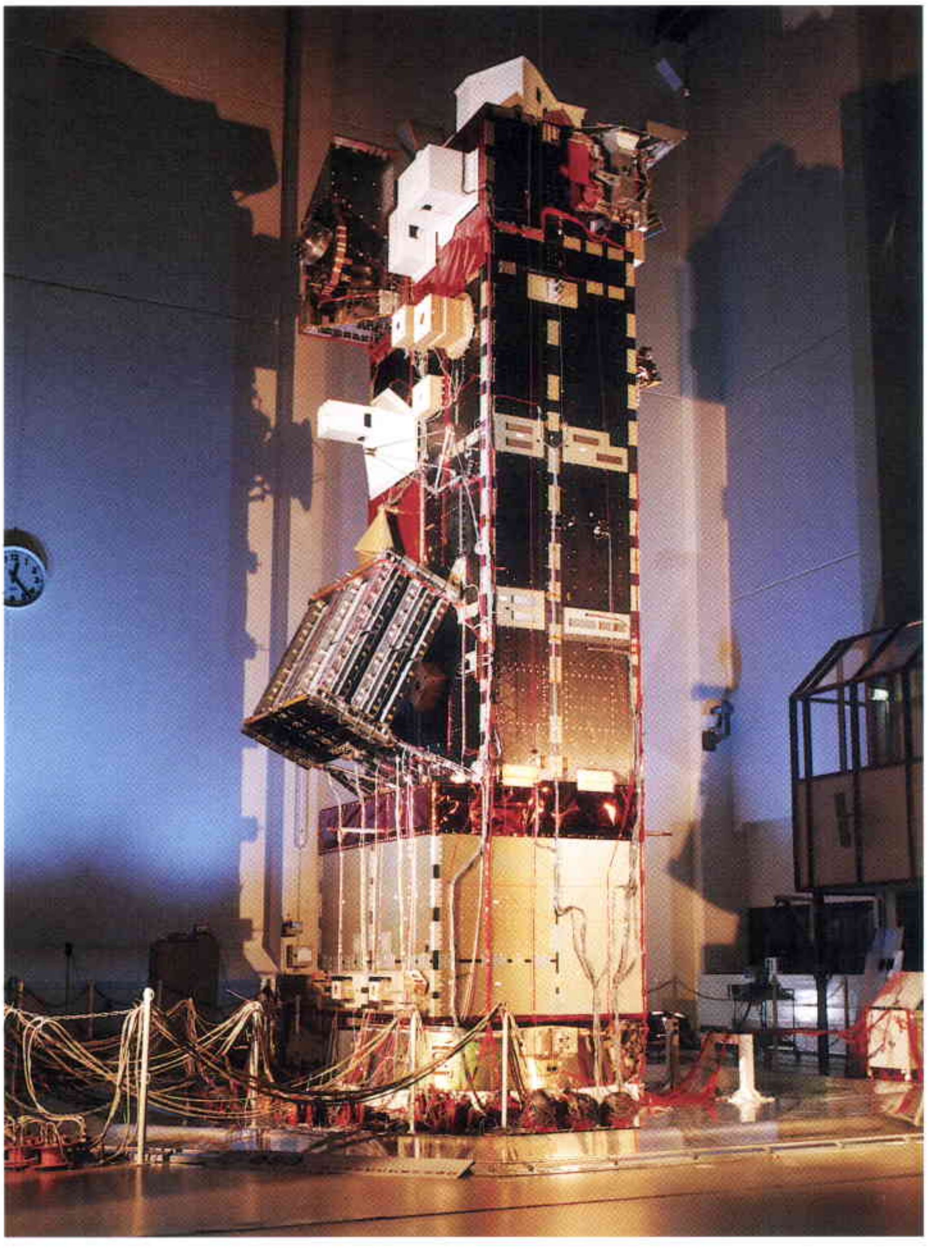
**Campagnes**
*L'acquisition des données des campagnes de 1996 est terminée. L'analyse des données des trois dernières campagnes est en cours. En ce qui concerne notamment la campagne INDREX, les données ont récemment été communiquées par les autorités indonésiennes et mises à la disposition des chercheurs.*

## Envisat/Plate-forme polaire

*Envisat-1/Plate-forme polaire est la mission la plus ambitieuse jamais entreprise par l'Agence dans le domaine de l'observation de la Terre. Elle assurera non seulement la continuité des données acquises par ERS-1 et ERS-2 au-dessus des océans, des terres émergées et des glaces, mais elle permettra aussi de recueillir des informations sur les composants atmosphériques et les caractéristiques de la surface du globe qui constitueront un précieux atout pour les futures recherches et applications dans le domaine de l'environnement.*

*La charge utile comprend six instruments réalisés par l'Agence (EDI) et trois instruments réalisés dans le cadre d'avis d'offre de participation (AOI).*

*Envisat-1 doit être lancé à la mi-1999 par une fusée Ariane-5. Placé sur une orbite héliosynchrone quasi-polaire, il accomplira environ 14 révolutions par jour autour de notre planète. Cette mission devrait nous fournir pendant au moins cinq ans un ensemble continu de données sur l'ensemble du globe.*



Envisat-1 in the ESTEC test facilities (HYDRA)

*Envisat-1 dans le centre d'essai le l'ESTEC (HYDRA).*

**Système Envisat-1**
*La revue critique de conception (CDR) du système 'mission Envisat' (EMS) a eu lieu en février. Ont été associés à cette revue les participants au programme, via leurs experts au DOSTAG, les fournisseurs des instruments AOI, les centres de traitement et d'archivage (PAC) et les représentants clés des groupes consultatifs scientifiques (SAG) chargés des instruments. L'Exécutif est convaincu que les objectifs de la mission pourront être atteints, sous réserve de confirmation par la CDR de l'EMS.*

*Les activités du Groupe de travail sur la politique en matière de données suivent leur cours. Les résultats préliminaires ont permis de préparer l'avis d'offre de participation relatif à l'exploitation des données scientifiques et de lancer des projets pilotes. L'élaboration du Plan d'exploitation de haut niveau (HLOP) a également démarré.*

**Plate-forme polaire**
*Les activités relatives au modèle structurel du satellite se sont poursuivies par des essais en vibrations dans l'axe longitudinal au moyen de l'installation HYDRA de l'ESTEC (NL). Des essais dans les axes latéraux sont actuellement réalisés au moyen du pot vibrant de l'ESTEC.*

### Envisat-1 system

The Envisat Mission System (EMS) Critical Design Review (CDR) took place in February, involving programme participants via their experts in DOSTAG, the providers of Announcement of Opportunity Instruments (AOIs), and the Processing and Archiving Centres (PACs), as well as the key representatives of the Instrument Science Advisory Groups (SAGs). The Executive is confident that the mission objectives can be met, subject to confirmation by the EMS-CDR.

The activities of the Data Policy Working Group are progressing. The preliminary results have permitted the preparation of the Announcement of Opportunity for scientific data exploitation and pilot projects to be initiated. Preparation of the High-Level Operations Plan (HLOP) is also being initiated.

### Polar Platform

The structural-model satellite activities have continued with axial vibration testing using the HYDRA facility at ESTEC (NL). The vibration tests are currently being completed with lateral-axes testing on the Multi-Shaker at ESTEC.

The engineering-model Payload Module system-level integration has progressed well at Matra Marconi Space (UK). Five engineering models/simulators of the instruments have been successfully integrated on the engineering-model Polar Platform, namely: the AATSR engineering model, the GOMOS breadboard, the MIPAS reduced engineering model, the RA-2 engineering model, and the SCIAMACHY simplified engineering model. The small number of problems encountered has confirmed the good engineering of the Polar Platform/instrument interfaces. Activities are currently being adjusted to accommodate a delay in the deliveries of MERIS and ASAR engineering models.

The flight-model Payload Equipment Bay (PEB) is under integration at DASA/DSS. The Service Module successfully underwent thermal-balance/thermal-vacuum testing in the Large Space Simulator (LSS) at ESTEC (NL) in December. The final Service Module acceptance tests will now be carried out at Matra Marconi Space (F) prior to the Module's delivery to Matra Marconi Space (UK) in April 1997.

The Polar Platform Critical Design Review is being conducted simultaneously in the framework of the Envisat Mission System CDR.

### Envisat-1 payload

Development of the Envisat payload instruments has passed a further milestone with the delivery of the RA-2 engineering model in December. Together with the MTSR, MIPAS, SCIAMACHY and GOMOS engineering models delivered earlier, five instruments have now been successfully integrated onto the engineering-model Polar Platform. All of them were integrated without major problems, with the use of standardised elements in the instrument design (the Remote Bus Interface) and unified Electrical Ground Support Equipment (EGSE) proving to be a valid and cost-effective engineering approach.

The results of the test campaign on the Polar Platform structural model, which is now almost complete, have generally confirmed the validity of the instrument mechanical design. In particular, adequate design margins have been demonstrated for the MERIS instrument and the ASAR antenna, which have been causes of concern in the past. For the GOMOS instrument, local reinforcement of the structure may still be required.

Work is also well in hand on the instrument flight models, for which all subsystems and equipment items are in manufacture and testing. Several flight-model units have already been delivered and integration of the flight-model instruments has started.

Integration of the first MERIS flight-model camera is nearly complete, and the MIPAS interferometer mechanisms have been fully tested and delivered to the instrument prime contractor. Integration of the AATSR, MWR and RA-2 instruments is also well advanced.

### Envisat-1 ground segment

The Flight Operations Segment (FOS) Critical Design Review was concluded successfully at the end of December. With the recent delivery of the RA-2/MWR, MERIS and AATSR ESL documentation, all Payload Data Segment (PDS) operational processor developments have been kicked-off, except that for SCIAMACHY which is planned to start later in 1997.

The PDS Detailed Design Review for version V-1 is going on in parallel with the Envisat Mission System Critical Design Review.

The Statement of Work for the PAC contracts is under final review. The kick-off of the PAC development activities is foreseen for April/May 1997 for those PACs that already have approved national financing for the development phase.

## Meteosat Second Generation

The SEVIRI (Scanning Enhanced Visible and Infrared Imager) telescope and scan assembly has been re-designed, the telescope has undergone a preliminary design review, and its engineering-model and mechanical/thermal-model equipment manufacture has been released to industry. The Preliminary Design Review (PDR) for the scan assembly is currently in progress. The SEVIRI scheduling remains on a critical path.

The development of MSG-1 and the procurement of MSG-2/3 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.

## Metop

The approval within ESA and Eumetsat of the combined EPS/Metop programme was significantly advanced by the opening for voting of the EPS Resolution by the Eumetsat Council in December. The opening for subscription of the ESA Metop-1 Declaration by the Agency's Director-General, also in December, and the approval at the March meeting of the Eumetsat Council of a bridging phase for the space segment also reflected the strong support that exists in Europe for this programme.

The Agency's Industrial Policy Committee (IPC), meeting in January, approved the

*L'intégration au niveau système du module de charge utile du modèle d'identification a bien avancé chez Matra Marconi Space (UK). Au modèle d'identification de la plate-forme ont été intégrés les modèles d'identification ou simulateurs des cinq instruments : les modèles d'identification de l'AATSR, du MIPAS (réduit), du RA-2 et du SCIAMACHY (simplifié), ainsi que le montage table du GOMOS. Ces travaux ont soulevé peu de difficultés, ce qui confirme la bonne qualité technique des interfaces entre la plate-forme polaire et les instruments. Les activités sont en cours d'ajustement pour tenir compte des retards de livraison des modèles d'identification du MERIS et de l'ASAR.*

*Le modèle de vol de la case à équipements (PEB) est en cours d'intégration chez DASA/DSS. En décembre, le module de servitude a passé avec succès l'épreuve des essais de bilan thermique et d'ambiance thermique sous vide dans le Grand simulateur spatial (LSS) de l'ESTEC (NL). Les derniers essais de recette du module de servitude seront entrepris sous peu chez Matra Marconi Space/F avant la livraison du module à Matra Marconi Space/UK en avril 1997.*

*La revue critique de conception de la plate-forme polaire est conduite simultanément dans le cadre de la CDR de l'EMS.*

### Charge utile d'Envisat-1

*La réalisation des instruments de la charge utile d'Envisat a franchi une nouvelle étape en décembre avec la livraison du modèle d'identification du RA-2. Si l'on y associe les modèles d'identification du MTSR, du MIPAS, du SCIAMACHY et du GOMOS, déjà livrés, cinq instruments ont été intégrés au modèle d'identification de la Plate-forme polaire. Cette intégration s'est faite sans problème majeur et force a été de constater que l'utilisation d'éléments standard dans la conception de l'instrument (coupleur de bus) et de matériel EGSE unifié constitue une approche techniquement valable, d'un bon rapport coût/efficacité.*

*Les résultats de la campagne d'essais réalisée sur le modèle structurel de la plate-forme polaire, quasiment terminé, ont confirmé dans l'ensemble la validité de la conception mécanique des instruments. Des marges de conception adéquates ont notamment été mises en évidence pour l'instrument MERIS et l'antenne de l'ASAR, qui avaient été des sources de préoccupation par le passé. En ce qui concerne le GOMOS, un renforcement local de la structure pourrait être nécessaire.*

*Les travaux sont également en bonne voie pour ce qui est des modèles de vol des instruments, pour lesquels tous les éléments des sous-systèmes et équipements sont en cours de fabrication et d'essai. Plusieurs modèles de vol des unités ont été livrés et l'intégration des modèles de vol des instruments a été mise en route.*

*L'intégration du premier modèle de vol de la caméra du MERIS est quasiment terminée et les mécanismes de l'interféromètre du MIPAS ont été intégralement testés et livrés au maître d'oeuvre de l'instrument. L'intégration des instruments AATSR, MWR et RA-2 a également bien avancé.*

### Secteur sol d'Envisat-1

*La revue critique de conception du secteur des opérations en vol (FOS) s'est conclue fin décembre. Avec la livraison récente des documents ESL AATSR, MERIS et RA-2/MWR, tous les travaux relatifs au processeur d'exploitation du système de gestion des données de charge utile (PDS) ont été engagés, à l'exception de l'activité relative au SCIAMACHY, qui doit démarrer plus tard en 1997.*

*Le revue de conception détaillée du PDS (version V-1) se déroule maintenant en parallèle avec la revue critique de conception de l'EMS.*

*Le descriptif des travaux intéressant les contrats des centres de traitement et d'archivage (PAC) fait l'objet d'une revue finale. Le lancement des activités de développement des PAC est prévu en avril ou mai 1997 pour ceux qui bénéficient déjà d'un financement approuvé au niveau national pour la phase de développement.*

## Météosat de deuxième génération

*Le télescope et le dispositif de balayage du SEVIRI (imageur visible et infrarouge amélioré non dégyré) ont été redéfinis, le télescope a fait l'objet d'une revue préliminaire de conception et la fabrication du modèle d'identification et des équipements des modèles mécanique et thermique a été lancée dans l'industrie. La revue préliminaire de conception (PDR) du dispositif de balayage est en cours. Le calendrier du SEVIRI reste critique.*

*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 des 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

*L'approbation du programme EPS/Métop, commun à l'ESA et à Eumetsat, a été sensiblement accélérée par l'ouverture au vote de la Résolution EPS par le Conseil d'Eumetsat lors de sa session de décembre. L'ouverture à souscription de la Déclaration Métop-1 par le Directeur général de l'ESA, également en décembre, et l'approbation par le Conseil d'Eumetsat, en mars, d'une phase de transition pour le secteur spatial attestent du soutien important dont ce programme bénéficie en Europe.*

*Le Comité de la politique industrielle (IPC) de l'ESA a approuvé, lors de sa réunion de janvier, l'envoi d'une demande de prix (RFQ) à l'industrie pour la phase C/D de Métop. L'élaboration de ce document en est déjà à un stade bien avancé et l'ESA et Eumetsat comptent le diffuser auprès des industriels fin mars, dans le cadre de leur responsabilité commune au titre du programme Métop.*

*La prochaine étape importante du processus d'approbation du programme consistera pour les Etats membres de l'ESA à faire le point sur l'état de leurs souscriptions et à décider de la marche à suivre pour ce qui est des activités industrielles anticipées de phase C/D. Il est indispensable de lancer rapidement ces activités pour n'affecter ni l'enveloppe financière ni le calendrier du programme.*

release of the Metop Phase-C/D Request for Quotation (RFQ) to industry. Preparation of this documentation is well advanced and ESA and Eumetsat, in the framework of their future joint responsibility for the Metop programme, intend to release it to industry at the end of March.

The next major step in the programme's approval will be the outcome of the ESA Member States' subscriptions and their agreement on how to proceed as far as advanced Phase-C/D industrial activities are concerned. An early start to these activities is essential to preserve the validity of the programme's cost and schedule envelopes. Industrial activities are 'on-hold' in the interim, awaiting the results of these deliberations.

## Meteosat

The Meteosat Transition Programme (MTP) spacecraft has been fully integrated and all of the major environmental tests have been completed. The ground-system validation tests have also been successfully performed. In order to achieve a July launch, a replanning exercise is in preparation which may bring forward the start of the launch campaign by at least a month.

The MTP spacecraft will be the last of the Meteosat Operational Programme (MOP) design to be launched. Once launched, it 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 of these spacecraft were provided under ESA spacecraft supply contracts.

## ERS

The overwhelming attendance (over 700 participants) at the Third ERS Scientific Symposium, held in Florence on 17-21 March, reflected the fact that ERS-1 and ERS-2 data are now being actively utilised by a multitude of scientists and engineers working in a very broad range of disciplines. An increased emphasis on applications in the field of geophysical research since the last symposium was apparent. In particular, the newly emerging areas of disaster monitoring and hazard analysis attracted much attention and show interesting potential. Other highlights were the results reported from the 'tandem mission' of ERS-1 and ERS-2 providing SAR-interferometry, and the first very encouraging results from the new GOME instrument on ERS-2.

ERS-2 has continued to provide high-quality data combined with good data availability. ERS-1 is presently in hibernation mode and the periodic checkouts show that its performance levels remain high and it is therefore readily available for backup purposes.

There was a 36 hour interruption in ERS-2's service during the reporting period, due to a gyro failure that provoked a de-pointing of the satellite. The payload was automatically switched-off for safety reasons. After a careful analysis and subsequent recovery actions, however, service was resumed with the same high standard as before this anomaly. The exact cause of the failure is still being analysed with a view to reinforcing the onboard attitude-control algorithms to avoid such problems in the future.

The budget for the extension of ERS Phase-El will be presented to the Agency's Administrative and Finance Committee (AFC) in April, by which time subscriptions are expected to have reached an appropriate level.

## International Space Station Programme (ISS)

### Columbus Orbital Facility (COF)

Consolidation of the industrial consortium to reflect the final levels of contributions to the Programme has almost been completed with, in particular, the transfer of some equipment responsibilities from US to Member State countries being achieved. The project technical baseline (top-level specifications and plans) has been approved by the Agency, and the planning baseline is nearing finalisation. Agreement has been reached with NASA on the launch of the COF by the NSTS Orbiter, and a barter arrangement has also been agreed to offset this launch by a package of deliverable items from European industry to NASA, including two outfitted Nodes, a range of freezers and sustaining engineering support for some of the Early Deliverable Items (notably the Glovebox, MELFI Freezer and the Software Verification Facility). Discussions between NASA and the Russian Space Agency on the initial flights in the ISS Assembly Sequence will potentially have some effect on the overall launch schedule of the ISS in general, possibly including that of the COF.

### Automated Transfer Vehicle (ATV)

After the Procurement Proposal for Phase-C/D was approved by the Agency's Industrial Policy Committee (IPC) in September, a price estimate for that phase was submitted by the prime contractor, Aerospatiale, to ESA in November but proved to be far above the announced ESA target. Subsequently, a task force on Phase-C/D costs was set up between ESA and Aerospatiale and it identified substantial price-reduction possibilities. The Request for Quotation (RFQ) for Phase-C/D was then formally released to Aerospatiale on 19 March.

The first flight demonstration in the ATV Rendezvous Predevelopment Programme (ARP) took place in November 1996 (on STS-80) with the onboard GPS experiment in combination with the Orpheus SPAS programme from Germany. The GPS equipment worked satisfactorily and the flight-test results are currently being processed by Matra Marconi Space. Preparations for Flight Demonstration No.2 (GPS and Rendezvous Sensors onboard STS-84) are now in progress.

### Crew Rescue Vehicle/Crew Transfer Vehicle (CRV/CTV)

Signature of the Phase-B CTV study contract, to evaluate a capsule-type vehicle, took place in mid-September 1996 with a European Economic Interest Grouping (EEIG) made up of Aerospatiale, MAN Technologie and Alenia Spazio. A 90-day joint ESA/NASA study on possible cooperation on a lifting-body CRV/CTV derived from the NASA X-38 demonstration programme was completed. This was followed in early December by a reorientation of the Phase-B study after the Manned Space Programme Board had approved a first set of activities with respect to ESA/NASA cooperation until April/May 1997.

*Les travaux industriels sont provisoirement suspendus, dans l'attente du résultat de ces délibérations.*

## Météosat

*Le satellite du programme Météosat de transition (MTP) est entièrement intégré et les principaux essais d'ambiance sont tous terminés. Les essais de validation du système sol ont été menés à bien. Dans la perspective d'un lancement en juillet, il est procédé à un ajustement du calendrier qui pourrait avancer d'au moins un mois le démarrage de la campagne de lancement.*

*MTP sera le dernier satellite construit selon le concept des satellites MOP (programme Météosat opérationnel). Une fois sur orbite, il sera exploité par Eumetsat et fournira régulièrement les cartes atmosphériques 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'approvisionnement de l'ESA.*

## ERS

*Le succès (plus de 700 participants) du troisème symposium scientifique sur ERS, tenu à Florence du 17 au 21 mars, a apporté la preuve que les données d'ERS-1 et d'ERS-2 sont aujourd'hui activement exploitées par une multitude de chercheurs et d'ingénieurs travaillant dans des disciplines très diverses. Depuis le dernier symposium, il semble que les applications dans le domaine de la recherche géophysique suscitent un intérêt croissant. L'attention s'est portée en particulier sur les activités émergentes telles que la surveillance des catastrophes et l'analyse des risques, qui présentent des possibilités intéressantes. Ce symposium a en outre permis de souligner l'importance des données d'interférométrie SAR obtenues dans le cadre de l'exploitation en tandem d'ERS-1 et d'ERS-2 et de mettre en valeur les résultats très encourageants du nouvel instrument GOME embarqué sur ERS-2.*

*ERS-2 a continué à fournir des données de haute qualité dans de bonnes conditions de disponibilité. ERS-1 est maintenant en mode d'hibernation et les vérification périodiques montrent qu'il conserve d'excellentes caractéristiques de fonctionnement, de sorte qu'il peut être rapidement mis à contribution en cas de besoin.*

*Le service d'ERS-2 a été interrompu pendant 36 heures à la suite d'une panne de gyroscope qui a entraîné un dépointage du satellite. Pour des raisons de sécurité. la charge utile a été automatiquement mise hors tension. A l'issue d'une investigation minutieuse, l'anomalie a été corrigée et le service a pu reprendre avec le même niveau de qualité. Les recherches se poursuivent sur la cause exacte de la défaillance afin de renforcer les algorithmes de contrôle d'attitude de bord et d'éviter ainsi qu'une telle anomalie ne se reproduise.*

*Le budget de la prolongation de la phase E1 d'ERS sera présenté au Comité administratif et financier (AFC) de l'Agence en avril. D'ici là, les souscriptions devraient avoir atteint un niveau adéquat.*

## Programme de Station spatiale internationale (ISS)

**Elément orbital Columbus (COF)**
*Le processus de consolidation du consortium industriel, qui a pour objet de tenir compte des taux finals de participation au programme, est quasiment terminé, notamment en ce qui concerne le transfert de certaines responsabilités en matière d'équipements des Etats-Unis aux pays membres. La base de référence technique du projet (plans et spécifications de haut niveau) a été approuvée par l'Agence et l'élaboration du calendrier de référence est en passe d'aboutir. Un accord a été conclu avec la NASA sur le lancement du COF par la Navette spatiale américaine, en contrepartie duquel l'industrie européenne fournira à la NASA un certain nombre d'éléments, dont deux éléments de jonction équipés, plusieurs congélateurs et un soutien technique continu pour certains éléments à livrer à court terme (boîte à gants, congélateur MELFI et dispositif de vérification de logiciels, entre autres). Les négociations entre la NASA et l'Agence spatiale russe sur les premiers vols de la séquence d'assemblage de l'ISS pourraient avoir une incidence sur le calendrier de lancement de l'ISS en général, et du COF en particulier.*

**Véhicule de transfert automatique (ATV)**
*Le Comité de la politique industrielle (IPC) de l'Agence ayant donné en septembre son feu vert à la proposition d'approvisionnement de phase C/D, le maître d'oeuvre, Aérospatiale, a soumis en novembre à l'ESA un prix estimatif pour l'exécution de cette phase qui dépassait de beaucoup le prix-plafond fixé par l'Agence. L'Agence et Aérospatiale ont alors créé un groupe de travail chargé d'étudier les coûts de la phase C/D, qui a mis en évidence des possibilités de réductions de coût substantielles. La demande de prix relative à la phase C/D a ensuite été officiellement soumise à Aérospatiale le 19 mars.*

*La première démonstration en vol dans le cadre du programme de pré-développement du rendez-vous ATV (ARP) a eu lieu en novembre 1996 (lors de la mission STS-80), avec l'embarquement de l'expérience GPS associée au programme allemand Orpheus SPAS. L'équipement GPS a fonctionné de façon satisfaisante et les résultats des essais en vol sont en cours de traitement chez Matra Marconi Space. Les préparatifs de la deuxième démonstration en vol (GPS et détecteurs de rendez-vous à embarquer lors de la mission STS-84) progressent.*

**Véhicule de sauvetage des équipages (CRV)/Véhicule de transport d'équipages (CTV)**
*Le contrat de phase B du CTV relatif à l'étude d'un véhicule de type capsule a été signé à la mi-septembre 1996 avec un groupement d'intérêt économique européen (GIEE) constitué d'Aérospatiale, MAN Technologie et Alenia Spazio. L'étude de 90 jours entreprise en commun par l'ESA et la NASA sur une coopération possible à la réalisation d'un CRV/CTV de type corps portant dérivé du programme de démonstration X-38 de la NASA, a été menée à bien. Puis, début décembre, il a été procédé à une réorientation de l'étude de phase B après l'approbation par le Conseil directeur des programmes spatiaux habités d'un premier ensemble d'activités concernant la coopération ESA/NASA jusqu'à avril/mai 1997.*

*Comme prévu, des études ont été menées en parallèle sur une capsule CTV. Une revue intermédiaire des impératifs aura lieu pendant la deuxième quinzaine d'avril.*

Activities related to a capsule CTV were still performed in parallel as planned, and an Intermediate Requirements Review will take place in the first half of April. As far as the lifting-body studies are concerned, definition of a common core (e.g. shape) between a NASA-led CRV and a European-led CTV is in progress and concepts for cooperative scenarios are under discussion between the Agencies.

**Atmospheric Re-entry Demonstrator**
The ARD qualification tests have been completed. Validation of the launch sequence is about to start. Preparation of the acceptance test procedures and facilities has been initiated, as well as that for the storage needed until Ariane flight 503.

## Early Deliveries

**Data Management System for the Russian Service Module (DMS-R)**
The first Software Integration Facility has been delivered to Moscow and is being used intensively by the Russians to generate Service Module application software. A full EGSE Test Facility and the first engineering models of the DMS-R onboard computers are being prepared for delivery in March 1997. The potential Service Module launch delay will not have an impact on the ESA delivery milestones, but will require increased engineering support from Europe to cover the prolongation.

**European Robotic Arm (ERA)**
The change in launch vehicle (from the baselined use of a Russian launcher to that of the STS Orbiter) has continued to be a primary concern for the project. Mass problems associated with the Science and Power Platform (SPP) on which ERA is installed during launch necessitated a radical change to the launch configuration at the end of 1996, with attendant feasibility concerns. These have now largely been solved and the associated changes are being incorporated into the ERA design.

Due to persistent problems with the availability of a working ADA compiler for the THOR processor, it has now been decided to abandon this approach for the ERA onboard computer and to use the SPARC ERC-32 chip-based processor board instead, in common with the DMS-R project. The Man/Machine Interfaces have been reviewed by Russian experts and representatives of the ISS crew office. Both Russian cosmonauts and ISS astronauts contributed significantly to the review, which has put the ERA MMI designs on a more secure footing.

The ERA geometric model has been completed and is awaiting delivery to Russia, pending incorporation of late modifications which are expected due to the changes caused by the new launch configuration.

**Laboratory Support Equipment**
Signature of the MELFI (Minus Eighty Degree Celsius Laboratory Freezer) took place on 14 January (see Bulletin 89, page 129). In the MSG (Microgravity Science Glovebox) arena, preparation for the Preliminary Design Review continued, as well as the negotiation of the Phase-C/D contract.

The procurement of the Hexapod Phase-B development model continued to progress. Tests performed on each of the six linear actuators showed the performance of all six legs to be compliant with the design specifications.

## Utilisation

The Proceedings of the Space Station Utilisation Symposium held in Darmstadt (D) at the end of September were made available to the Space Station User Community in December (as ESA Special Publication SP-385, available from ESA Publications Division).

Further to the Agreement reached with NASA concerning the early opportunities on Space Station for Europe, in December the 'ESA Announcement of Opportunity for Externally Mounted Payloads during the Early Space Station Utilisation Period' was issued to some 6000 addressees in all ESA Member States, together with the 'ESA Life-Sciences Research Announcement'. Publication of these AOs (by ESA Publications Division as SP-1201 and SP-1210, respectively, in hard copy and on the World Wide Web) has to be seen as marking the real start of Space Station utilisation preparation.

The European Utilisation Board (EUB) had discussed the principles of user access to the International Space Station and reviewed the documentation to accompany the above AOs. The Space Station User Panel, at its meeting in November 1996, had issued recommendations with regard to payload selection, ISS access rules, interactive operations, and multinational research

*Pour ce qui est des études relatives à un corps portant, la définition d'un 'noyau commun' (forme, par exemple) entre un CRV réalisé sous la conduite de la NASA et un CTV réalisé sous conduite de l'Europe suit son cours et les deux agences examinent des scénarios possibles de coopération.*

**Démonstrateur de rentrée atmosphérique**
*Les essais de qualification de l'ARD sont terminés et la validation de la séquence de lancement sera bientôt mise en route. Les procédures et les installations d'essais de recette ainsi que l'entreposage de l'ARD jusqu'au vol Ariane 503 sont en préparation.*

**Livraisons à court terme**

**Système de gestion de données pour le module de service russe (DMS-R)**
*La première installation d'intégration de logiciels a été livrée à Moscou et les Russes s'en servent intensivement pour élaborer les logiciels d'application du module de service. Une installation d'essai complète des équipements électriques de soutien au sol (EGSE) ainsi que les premiers modèles d'identification des ordinateurs de bord du DMS-R sont en préparation en vue d'une livraison en mars 1997. Le retard qui pourrait être pris dans le lancement du module de service n'aura pas d'incidence sur les calendriers de livraison de l'Agence, mais l'Europe devra intensifier son soutien technique pendant la période correspondante.*

**Bras télémanipulateur européen (ERA)**
*La décision de changer de lanceur (remplacement du lanceur russe prévu à l'origine par la Navette américaine) a sérieusement préoccupé l'équipe du projet. En raison des problèmes de masse liés à la Plate-forme science et énergie (SPP) sur laquelle l'ERA sera installé pendant le lancement, il a fallu procéder fin 1996 à une modification radicale de la configuration de lancement, dont la faisabilité suscitait quelques craintes. Celles-ci ont, pour l'essentiel, été aplanies et les changements correspondants ont été incorporés dans la conception de l'ERA.*

*Compte tenu des problèmes persistants liés à la disponibilité d'un compilateur de travail AD pour le processeur THOR, il a été décidé d'abandonner cette approche en ce qui concerne l'ordinateur de bord de l'ERA et d'utiliser le processeur à puces SPARC ERC-32, également utilisé pour le DMS-R. Les interfaces homme/machine de l'ERA ont été passées en revue par des experts russes et des représentants du bureau des équipages de l'ISS. Des cosmonautes russes et des astronautes de l'ISS ont largement contribué à cette revue, ce qui a permis de sécuriser la conception de ces interfaces.*

*Le modèle géométrique de l'ERA est terminé et sera livré à la Russie lorsqu'on lui aura apporté les modifications de dernière minute auxquelles devrait donner lieu la révision de la configuration de lancement.*

**Equipement de soutien de laboratoire**
*Le contrat relatif au congélateur –80°C (MELFI) a été signé le 14 janvier (cf. Bulletin 89, page 129). En ce qui concerne la boîte à gants pour la recherche en microgravité (MSG), les préparatifs de la revue préliminaire de conception se sont poursuivis, de même que la négociation du contrat de phase C/D.*

*La procédure d'approvisionnement du modèle de développement de l'Hexapod (phase B) s'est poursuivie. Les essais réalisés sur chacun des six actionneurs linéaires ont attesté que les six pieds fonctionnent conformément aux spécifications de conception.*

**Utilisation**
*Les actes du symposium sur l'utilisation de la Station spatiale qui s'est tenu fin septembre à Darmstadt (D) ont été publiés en décembre à l'intention de la communauté des utilisateurs de la Station (cf. ESA SP-385, disponible auprès de la Division des publications de l'ESA).*

*A la suite de la conclusion d'un Accord avec la NASA sur la possibilité pour l'Europe de participer à l'utilisation initiale de la Station, l'ESA a lancé en décembre un avis d'offre de participation (AO) portant sur des charges utiles externes pendant la période d'utilisation initiale de la Station. Cet avis a été adressé à quelque 6000 destinataires dans l'ensemble des Etats membres, en même temps que l'avis d'offre de participation à des recherches en sciences de la vie (LSRA) de l'ESA. Il faut voir dans la publication de ces deux AO par la Division des publications de l'Agence (respectivement sous les références SP-1201 et SP-1210, sur papier et sur le World Wide Web) le démarrage effectif de la préparation de l'utilisation de l'ISS.*

*La Commission européenne de l'utilisation (EUB) a examiné les principes appelés à régir l'accès des utilisateurs à la Station spatiale internationale et passé en revue les documents d'accompagnement des AO précités. Lors de sa réunion de novembre 1996, le Groupe Utilisateurs de la Station spatiale a émis des recommandations en matière de sélection des charges utiles, de règles d'accès à l'ISS, d'opérations interactives et de projets de recherche multinationaux.* esa

# In Brief

## ESA's Hipparcos satellite revises the scale of the cosmos

The observable Universe may be about 10 percent larger than astronomers have supposed, according to early results from the European Space Agency's Hipparcos mission. Investigators claim that the measuring ruler used since 1912 to gauge distances in the cosmos was wrongly marked.

This ruler relies on the brightness of winking stars called Cepheids, but the distances of the nearest examples, which calibrate the ruler, could only be estimated. Direct measurements by Hipparcos imply that the Cepheids are more luminous and more distant than previously imagined.

The brightnesses of Cepheids seen in other galaxies are used as a guide to their distances. All of these galaxies may now be judged to lie farther away. At the same time the Hipparcos Cepheid scale drastically reduces the ages of the oldest stars, to about 11 billion years. By a tentative interpretation the Universe is perhaps 12 billion years old.

This estimate will provoke much comment and controversy, because the scale and age of the Universe is one of the touchiest issues in cosmology. The best hope for confirming or modifying the result now rests with studies using Hipparcos data on other kinds of stars.

European teams of scientists and engineers conceived and launched the unique Hipparcos satellite, which operated from 1989 to 1993. Hipparcos fixed precise positions in the sky of 120,000 stars (Hipparcos Catalogue) and logged a million more with a little less accuracy (Tycho Catalogue). Since 1993 the largest computations in the history of astronomy have reconciled the observations, to achieve a hundredfold improvement in the accuracy of star positions compared with previous surveys.

Slight seasonal shifts in stellar positions as the Earth orbits the Sun, called parallaxes, give the first direct measurements of the distances of large numbers of stars. With the overall calculations completed, the harvest of scientific discoveries has begun. Among those delighted with the immediate eruption into cosmology, from this spacecraft made in Europe, is ESA's Director of Science, Roger Bonnet.

"When supporters of the Hipparcos project argued their case," Bonnet recalls, "they were competing with astrophysical missions with more obvious glamour. But they promised remarkable consequences for all branches of astronomy. And already we see that even the teams using the Hubble Space Telescope will benefit from a verdict from Hipparcos on the distance scale that underpins all their reckonings of the expansion of the Universe."

Michael Perryman, ESA's Project Scientist for Hipparcos, anticipates a warm debate among astronomers. Should the Hipparcos Cepheid results be taken at face value, with all their implications for the size and age of the Universe? He remains confident that the issue will be settled by other results quarried from the Hipparcos data.

Further Hipparcos studies of variable stars are in progress. Also relevant to the distance scale are differing quantities of heavy elements present in stars of different ages, which can affect their luminosity. Any remaining confusion on this point will be dispelled by mainstream Hipparcos research devoted to the basic astrophysics of stars of different ages of origin, and at different stages of their life cycles.

"Until Hipparcos, the cosmic distance scale rested on well-informed guesses," Michael Perryman says. "The distances we now have, for stars of many kinds, provide for the very first time a firm foundation from which to gauge the distances of galaxies. The work has only just begun. If it should turn out that the Cepheids have given the final answer straight away, that might be surprising. But there will be no reason for astonishment when Hipparcos's direct measurements of stellar distances lead to a revised scale for the Universe."

The Hipparcos Cepheid scale was recently debated at the Royal Astronomical Society in London and at the annual meeting of the American Association for the Advancement of Science in Seattle. It will also be one of the hot topics at ESA's Hipparcos Symposium in Venice,13-16 May. The Venice meeting will celebrate the release of the Hipparcos and Tycho

Catalogues to the world-wide astronomical community. It will also offer the first overview of results obtained by the groups who have had early access to the data, by virtue of their contributions to the Hipparcos mission. The subjects range from the Solar System and the Sun's neighbours among the stars, through special stars and the shape and behaviour of the Milky Way Galaxy, to the link between the starry sky of Hipparcos and the wide Universe of galaxies and quasars.

Hipparcos information is accessible on the World Wide Web:
http://astro.estec.esa.nl/Hipparcos/hipparcos.html

**Hipparcos and Tycho Catalogues**
The final products of ESA's Hipparcos mission will be two major stellar catalogues – the Hipparcos Catalogue and the Tycho Catalogue – to be published in June 1977 by the 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.

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 to come. esa

# Cluster will fly again!

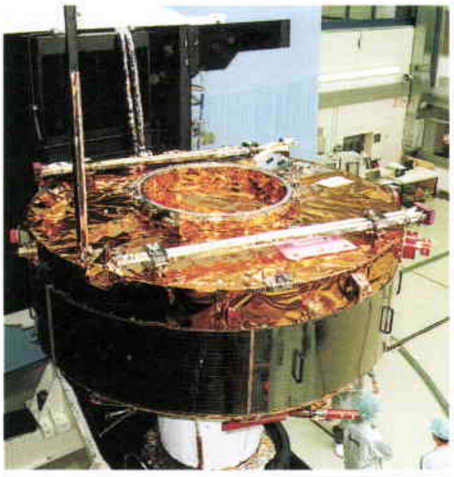
ESA's Science Programme Committee, during its meeting at ESA Headquarters in Paris on 3 April, has agreed on the reflight of a full Cluster mission by mid-2000. After months of intense negotiations and an impressive display of solidarity by all ESA Member States and the scientific community at large in support of the reflight, this mission to investigate the physical interaction between the Sun and our planet is back on track.

The original Cluster mission, lost on 4 June 1996 with the explosion of the first Ariane-5 demonstration flight, is being replaced by Cluster 2, comprising the Phoenix spacecraft (being built with spares from the four original Cluster satellites) and three identical new satellites to be built by a European industrial consortium led by DASA/Daimler Benz Aerospace (Germany).

The satellites will be launched in pairs by two Russian Soyuz launchers in mid-2000 within a short period of time to meet the orbital requirements of the mission. The launchers will be procured through the STARSEM consortium, a French/Russian joint venture.

The choice of the Soyuz launchers, together with major efforts on the part of ESA, the industrial consortium and scientific institutes all over Europe and the US, has enabled the additional Cluster mission cost to be kept down to 214 MECU. esa

*One of the four original Cluster spacecraft.*



# Successes with the Hubble Space Telescope

Excellent use of the Hubble Space Telescope continues to provide astronomers in ESA's Member States with a large share of the observing time. ESA has a 15% stake in the Hubble Space Telescope project, earned by providing the Faint Object Camera and the first two sets of solar power arrays, as well as helping to staff the Space Telescope Science Institute in Baltimore. Current European-led programmes account for about 22% of the observing schedule. European astronomers' work spans all aspects of astronomy, from the planets to the most distant galaxies and quasars. The following examples are just a few European highlights from Hubble's second phase, 1994-96.

**A scarcity of midget stars**
Guido De Marchi and Francesco Paresce of the European Southern Observatory at Garching, Germany, have taken sample censuses with the wide-field WFPC2 camera within six globular clusters- large gatherings of stars orbiting independently in the galaxy. They found that stars less massive and fainter than Sun-like stars are ten times more numerous in the Milky Way galaxy. However, they suggest that very faint stars are scarce, a finding which is significant for theories as to how the Universe originated.

Confirmation that very small stars are indeed scarce comes from Gerry Gilmore of the Institute of Astronomy in Cambridge (UK). He leads a European team that analyses long-exposure images in the WFPC2 camera, obtained as a by-product when another instrument is examining a selected object. The result is an almost random sample of well-observed stars and galaxies.

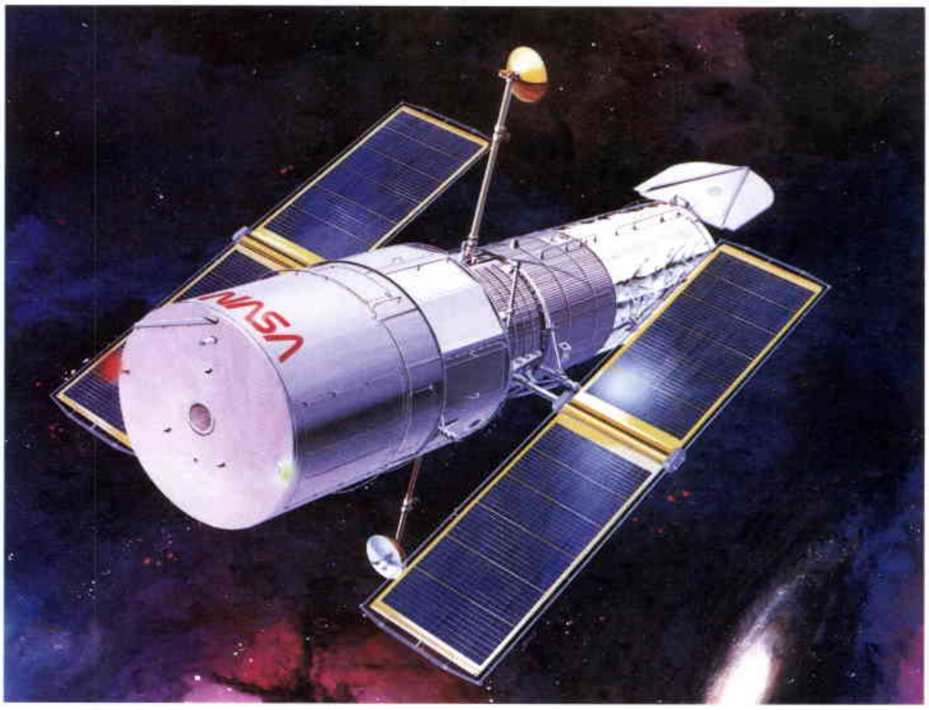
**Unchanging habits in starmaking**
A remarkable general conclusion is that the make-up of stellar populations never seems to vary. In dense or diffuse regions, in very young or very old agglomerations, in the Milky Way galaxy or elsewhere, the relative numbers of stars of different masses are always roughly the same. Evidently Nature mass-produces quotas of large and small stars irrespective of circumstances. This discovery will assist

astronomers in making sense of very distant and early galaxies.

Another surprise was spotted by Rebecca Elson of Gilmore's team. Long-exposure images of the giant galaxy M87, in the nearby Virgo cluster have shown that it possesses globular clusters of very different ages. Theory suggests that the clusters were manufactured during collisions of the galaxies that merged into M87, making it the egg-shaped giant seen today. If so, the absence of young globular clusters in the Milky Way may mean that our galaxy has never suffered a major collision.

**Accidents in the galactic traffic**
Brighter than a million suns, a quasar is the most powerful lamp in the Universe. Astronomers understand it to be powered by matter falling into a massive black hole in the heart of a galaxy. Mike Disney of the University of Wales, Cardiff, leads a European team that asks why some thousands of galaxies harbour quasars, in contrast to the billions that do not. In almost every case that he and his colleagues have investigated, using Hubble's WFPC2 camera at its highest resolution, they see the quasar's home galaxy involved in a collision with another galaxy. Though these findings are not conclusive, Disney says, "...the important thing is that we have wonderfully clear pictures to argue about. Quasar theories were mostly pure speculation before we had Hubble."

**The history of the elements**
Astronomer Dieter Reimers and his colleagues at the Hamburger Sternwarte use the Faint Object Spectrograph to analyse ultraviolet light from distant quasars, which they also examine by visible light from the ground. Through cosmic time, they trace the origin of elements like carbon, silicon and iron, from which planets and living things can be built. On its way to Hubble, the quasar light passes through various intervening galaxies and gas clouds, like the skewer of a kebab. Each object visited absorbs some of the quasar light, depending on the local abundances of the elements. As more and more objects are detected, an impression is formed of galaxies building up their stocks of elements progressively through time, by the alchemy of successive generations of stars.




Apart from primordial hydrogen, the second lightest element, helium, has also been abundant since the origin of the Universe. The first major discovery after Hubble's last refurbishment came from Peter Jakobsen of ESA's Space Science Department at ESTEC who, in January 1994, detected ionized helium in the remote Universe, by the light of a very distant quasar, 0302-003. Since then Jakobsen has looked for the ionized helium using other quasars. He now suspects that this helium mainly gathered in clumps, rather than scattered freely through intergalactic space. If so, it greatly increases the estimates of the total mass of ordinary matter in the Universe.

**Through a lens to the early Universe**
Natural lenses scattered through the cosmos reveal distant galaxies, and make an astronomical tool for Richard Ellis of the Institute of Astronomy, Cambridge (UK). The strong gravity of an intervening cluster of galaxies can bend the light from more distant objects, magnifying and intensifying their images. In one spectacular case, cluster Abell 2218 creates in Hubble's WFPC2 camera more than a hundred images of galaxies lying beyond it. Without the magnifying effect of the cluster, many of these remote objects would be too faint to study in detail.

**The cosmic scale**
The Hubble Space Telescope is being used to measure the Hubble Constant – both are named after Edwin Hubble who discovered, almost 70 years ago, that the galaxies are spreading apart. The Hubble Constant is the rate of expansion and the most important number in cosmology, because it fixes the size and the maximum age of the observable Universe.

Since the launch of the Space Telescope in 1990, two independent teams have tried to fix the constant but their answers disagree. American astronomers believe there is a high expansion rate which would make the Universe relatively young. A lower value for Hubble's Constant, implying an older Universe, comes from a mainly European team. According to Gustav Tammann of the latter team, "Time will tell us who is closer to the right answer."

**STS-82 Servicing Mission**
Many more important findings may result from the February 1997 Discovery STS-82 Hubble servicing mission, during which astronauts have significantly upgraded the scientific capabilities of the HST.

Work during spacewalks included the installation of two new state-of-the-art instruments. The crew has successfully replaced the Faint Object Spectrograph with the Near Infrared Camera and Multi-Object Spectrometer (NICMOS). The Goddard High Resolution Spectrometer was replaced with the Space Telescope Imaging Spectrograph (STIS).

Other tasks included maintenance to the Space Telescope to keep it functioning smoothly until the next scheduled servicing mission in 1999.

# New ESA Directors Appointed

Following the announcement by Mr Jean-Marie Luton, at the ESA Council Meeting last December, that he would not be seeking a third term of office as Director General, on 20 March the Council announced the appointment of Mr Antonio Rodotà as his successor for an initial period of four years. Mr Rodotà who is 61 years old and of Italian nationality, was previously Director of the Space Division of Finmeccanica (Italy), Managing Director of Quadrics Supercomputer World Ltd. (Italy/United Kingdom), and a Director of several other companies including Arianespace. A graduate of Rome University and an electronics engineer, Mr Rodotà began his career with Selenia (1966/80), followed by three years as Head of Compagnia Nazionale Satelliti (Italy). He subsequently moved to Alenia-Spazio in 1983, where he held a series of senior positions before becoming Chief Executive in 1995.

At their March meeting, Council, on the recommendation of the Director General, also appointed, for four-year terms of office:

– Mr David Dale, to the post of Director of Technical and Operational Support.

Mr Dale, 54 years old and of British nationality, has a degree in applied physics, together with diplomas in mechanical and electrical engineering. He was previously Head of ESA's Scientific Projects Department.

– Mr Hans Kappler, to the post of Director of Industrial Matters and Technology Programmes.

Mr Kappler, 55 years old and of German nationality, is a physics graduate of the Technical University of Munich. He was previously in charge of technology development at STN Atlas Elektronik in Germany.

– Mr Daniel Sacotte, to the post of Director of Administration.

Mr Sacotte, 51 years old and of French nationality, holds a "Diplôme d'Etudes Appliquées" in astrophysics. He was previously Deputy Director General, Administration, Finance and Human Resources, at Centre National d'Etudes Spatiales (CNES), in France.

Council also, again on the recommendation of the Director General, extended by two years the term of office of Mr Roger Bonnet, ESA's Director of Scientific Programmes, and asked Mr René Collette, who is currently Director of ESA's Telecommunications Programmes, to assume responsibility as from 1 April 1997 for the new Directorate of Applications Programmes, which will bring together all the approved Earth-observation and telecommunications programmes (other than the Earth-observation scientific programme).

Finally, the term of office of Mr Massimo Trella, ESA's Inspector General, has been extended by six months to enable him to complete his task as Co-Chairman of the Ariane-5 Qualification Review Board.

# SOHO's Sun at Christmas

An action-packed motion picture from ESA's solar spacecraft SOHO astonishes the experts and will enthral the public. It shows the Sun at Christmas sailing in front of the stars of the Sagittarius constellation and the Milky Way, while blowing its solar wind outwards in all directions around it. Another scene depicts the Sun swallowing a comet. In a subsequent, unconnected event, it emits a plainly visible puff of gas, in a large mass ejection.

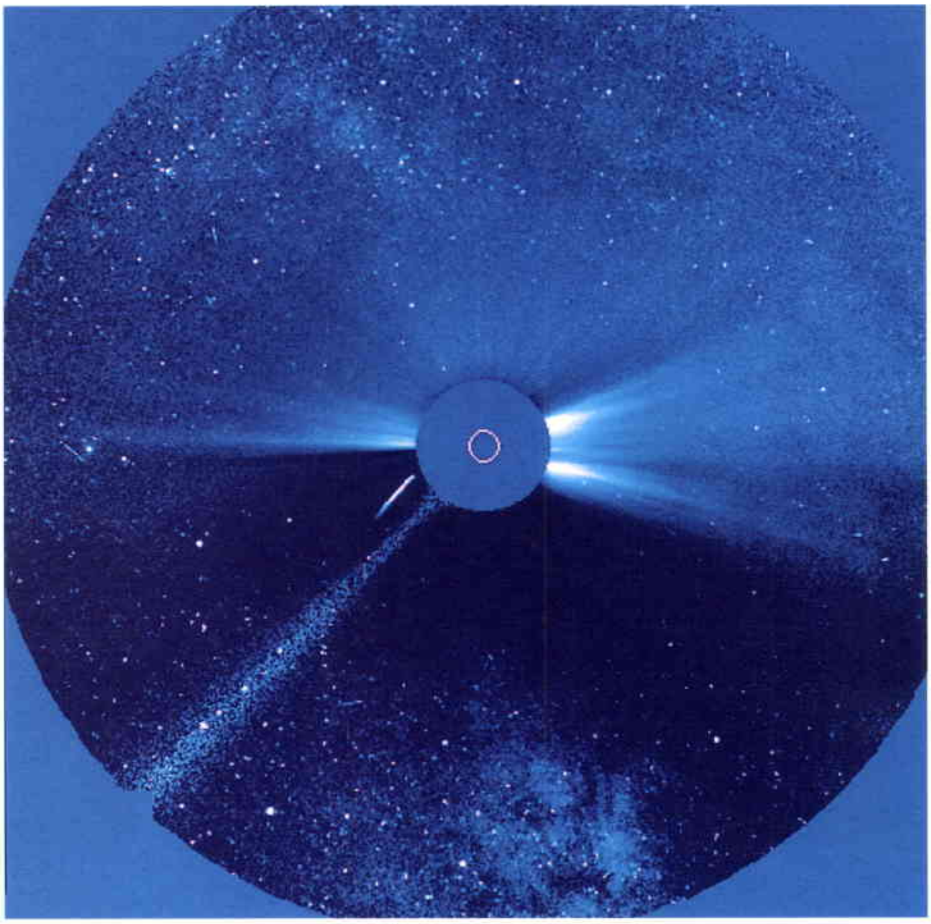
The remarkable images come from SOHO's visible-light coronagraph LASCO. It masks the intense rays from the Sun's surface in order to reveal the much fainter glow of the solar atmosphere, or corona. Operated with its widest field of view, in its C3 instrument, LASCO's unprecedented sensitivity enables it to see the thin ionized gas of the solar wind out to the edges of the picture, 22 million kilometres from the Sun's surface. Many stars are brighter than the gas, and they create the background scene.

The results alter human perceptions of the Sun. Nearly 30 years ago, Apollo photographs of the Earth persuaded everyone of what until then they knew only in theory, that we live on a small planet. Similarly the new imagery shows our motion in orbit around the Sun, and depicts it as one star among many – yet close enough to fill the sky with emanations that engulf us.

For many centuries even astrologers knew that the Sun was in Sagittarius in December and drifting towards the next zodiacal constellation, Capricornus. This was a matter of calculation only, because the Sun's own brightness prevented a direct view of the starfield. The SOHO-LASCO movie makes this elementary point of astronomy a matter of direct observation for the first time. The images are achievable only from a vantage point in space, because the blue glow of the Earth's atmosphere hides the stars during the day.

A special allocation of observing time, and of data transmission from the SOHO spacecraft, enabled the LASCO team to obtain large numbers of images over the period 22-28 December 1996. Since then, a sustained effort in image processing, frame by frame, has achieved a result of high technical and aesthetic quality. Only now is the leader of the LASCO team, Guenter Brueckner of the US Naval Research Laboratory, satisfied with the product and ready to authorize its release.

"I spend my life examining the Sun," Brueckner says, "but this movie is a special thrill. For a moment I forget the years of effort that went into creating LASCO and SOHO, and leave aside the many points of scientific importance in the images. I am happy to marvel at a new impression of the busy star that gives us life, and which affects our environment in many ways that we are only now beginning to understand."



*A scene from the SOHO Christmas video taken with the C3 coronagraph of the Large Angle Spectroscopic Coronagrahp (LASCO, Principal Investigator: G.E. Brueckner, Naval Research Laboratory, Washington D.C.). The angular diameter of the field of view is 16°; at the location of the Sun this corresponds to 42 million kilometers (or 28% of the distance between the Sun and the Earth). The structure in the lower left-hand quadrant results from the boom that holds the mask occulting the Sun's disk (whose diameter is indicated by the circle inside the mask).*

# Two additional successful Ariane launches

Ariane flights V93 and V94 were both successfully launched from the Guiana Space Center in Kourou on Thursday, 30 January, and Saturday, 1 March, respectively.

For V93, an Ariane 44L placed the Argentinian and American telecommunication satellites NAHUEL 1A and GE2 into geostationary transfer orbit.

The International Telecommunication Satellite Organisation's Intelsat 801 was placed into geostationary transfer orbit during V94 by an Ariane 44P version launcher.

# European satellite telecommunications technologies to improve maritime safety

ESA has contributed to the development of a faster, more reliable and more accurate satellite distress system for ships at sea, in the framework of a project promoted by Inmarsat, the global mobile satellite operator.

Called Inmarsat-E (for Emergency), this search and rescue system uses dedicated L-band channels (at 1.6 GHz) on the existing Inmarsat telecommunications satellites in geostationary orbit. Inmarsat is committed to offer this service within the Global Maritime Distress and Safety System, currently being implemented by the International Maritime Organization (IMO). Use of the Inmarsat-E system will be free of charge.

The continuing high number of losses of ships at sea and the progress in satellite technology have prompted IMO to adopt regulations requiring most ships to carry Emergency Position Indicating Radio Beacons (EPIRB), small transmitters (about 1 W in power) that a ship can trigger in an emergency. The signal is immediately received by the geostationary satellite and relayed down to a coastal Earth station equipped with dedicated and very sensitive receivers. The signal includes the identity of the ship, the type of alert and the ship's position evaluated from a GPS receiver built into the EPIRB (with an accuracy of 200 m). The digital receiver in the Earth station – typically a compact rack – is designed for fully unattended operation. The data is automatically relayed by the station to a search and rescue centre and, consequently, within a few minutes of the alert having been triggered, rescue operations can begin.

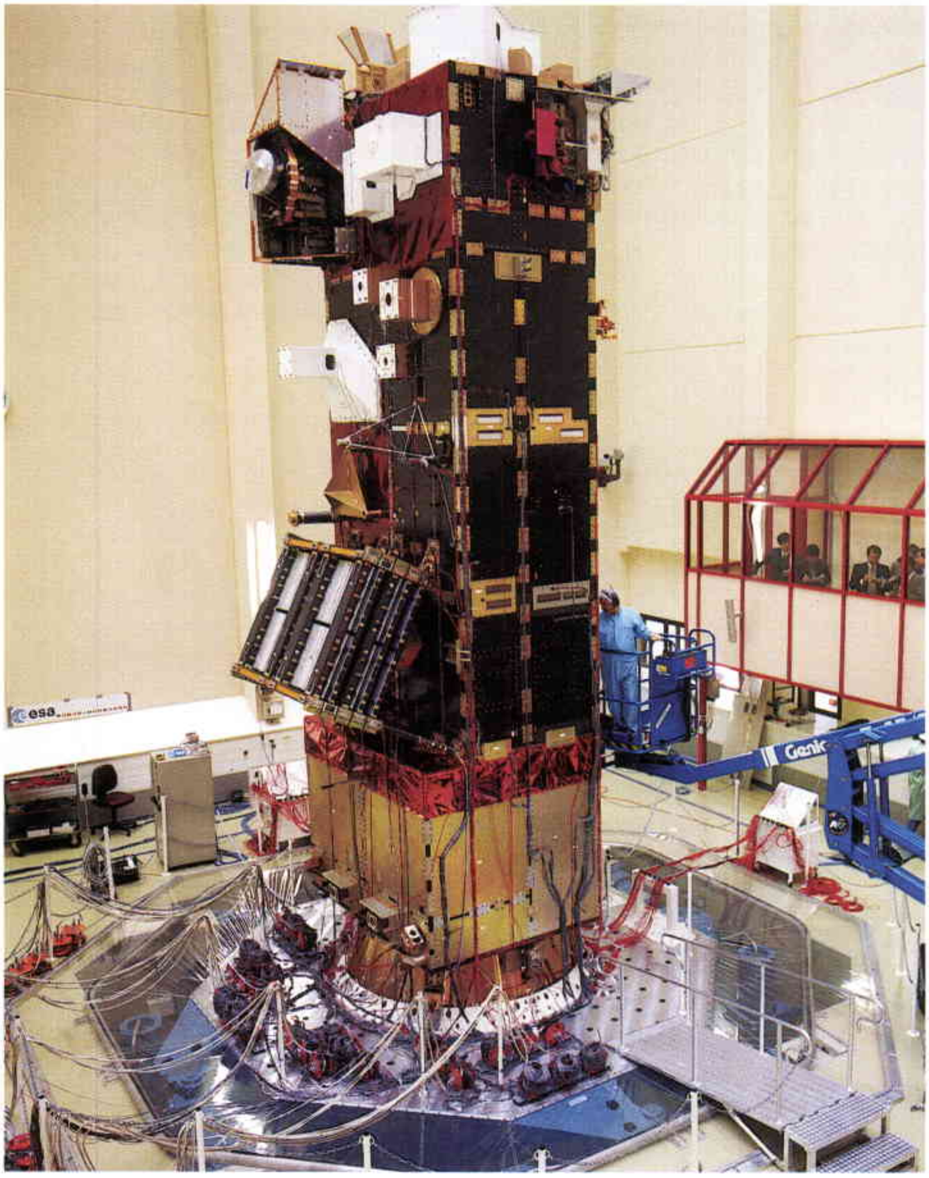
For the Inmarsat-E system, ESA has financed the development and the manufacturing of two sets of receivers (contracts were awarded to Nortel-DASA, Germany and Nokia, Finland), while the German Ministry of Transport purchased two other sets. Three receivers have been installed and are now operating in stations at Raisting (Germany), Niles Canyon (California) and Perth (Australia). The Inmarsat-E system was inaugurated worldwide on Thursday, 30 January 1997.

# First satellite test on the hydraulic shaker at ESTEC

A first series of vibration tests on a structural model of the 8 ton/10m high "Envisat-1/Polar Platform" satellite have recently been performed on the hydraulic shaker "Hydra" in the test centre at ESTEC. It is the first time that a hydraulic shaker of this kind has been used for vibration tests on a satellite system.

Hydra, which has a test platform spanning 5.5 metres, has been developed to perform vibration tests on heavy, as well as geometrically large, elements of spacecraft or launchers. It is capable of testing satellites conventionally, with excitations in the main orthogonal axes, but has additionally been designed for the excitation of transients in 6° of freedom which represents a close simulation of the dynamic inputs to the satellite during its ride on the launcher.

The first tests performed on Hydra were limited to vertical excitations after a preliminary acceptance of the test facility. Full commissioning for all operational modes, including the 6° of freedom transients, is expected during the course of 1997.



# Biorack on the Space Shuttle:

### Another step in ESA's preparation for the International Space Station

When the US Space Shuttle Atlantis lifted off on Sunday, 12 January for the STS-81 mission to the Russian space station Mir, it carried the European Space Agency's Biorack facility on its fifth flight in space and its second of three to Mir.

During this nine-day mission, the Biorack was used to study the effects of radiation and the absence of gravity (i.e. microgravity) on plant, fungus, tissue and cell growth. This research will help to determine the effects of long-duration spaceflight on organisms and prepare for the International Space Station (ISS).

The Biorack integrates several scientific facilities in a single rack, a highly desirable attribute given the limited room available onboard a spaceflight. It offers incubators that permit experiments to be performed in different temperature controlled environments; simulated 1-g that allows investigators to distinguish between effects induced by gravity and microgravity; and a "glovebox" or protected workspace for specimen handling.

Many of the 12 experiments carried out during the flight, prepared by scientists from across Europe and one in the USA, are expected to provide information that can be used to prepare for both life and experimental work on board the ISS. Those experiments include the following:

- Spaceflight conditions, namely cosmic radiation and microgravity, may have an influence on genetic processes in biological material. This is important for all organisms, particularly as flights become longer. Investigators are studying the effects on the DNA of a fungus as a step toward understanding the influence on the genetic processes in general. (Technical University of Munich, D)

- Bacteria can form a film on any surface submerged in or exposed to water, including the water systems for crew life support on board spacecraft. To be able to provide the highest possible water quality on board and limit the crew's risk of infection, and to minimise the deterioration of water systems, experimenters are attempting to determine the effects of spaceflight and microgravity on the formation of such biofilms. (Montana State University, Montana, USA)

- Biological material used in experiments that will be performed on board the ISS will have to be preserved to enable it to endure its transportation to the Station, a journey that will last from several days to a week and will be subjected to adverse conditions, including heavy vibrations, microgravity and radiation. Scientists are looking at different methods of preserving various organisms and whether the basic properties of the specimens are affected. (Institutes in Amsterdam (NL), Zurich (CH), Louvain (B), Banyuls-sur-Mer (F), Milan (I), and Montana (USA)).

Some of the experiments will be pursued further when the Biorack is flown next, in May of this year, on board STS-84. ESA astronaut Jean-François Clervoy will be the payload commander on the mission and will oversee all of the Biorack experiments.

# ESA trades hardware for launch of European laboratory

On 5 March 1997, ESA and NASA signed an agreement in principle under which ESA is to provide additional hardware and services for the International Space Station (ISS) to NASA in exchange for the launch of the European laboratory module on the US Space Shuttle.

The hardware consists of two essential segments of the ISS, the so-called Nodes 2 and 3, and several pieces of advanced technology laboratory equipment (in addition to other elements that it is already contributing). A node is an element used to connect different segments of the ISS. Node 2, for example, will provide the interface between the European and the Japanese laboratory modules.

In return, NASA will launch at no charge, the European laboratory called the Columbus Orbital Facility (COF) on a Space Shuttle flight to the ISS. The COF is presently scheduled to be launched in late 2002/early 2003. Based on an ESA/NASA implementing arrangement which will be established in the near future, ESA will deliver Node 2 to NASA at the end of 1999, for launch in early 2000. Node 3 will follow about two years later.

Under a parallel agreement, ESA will entrust the development of the nodes to the Italian Space Agency (ASI). This will allow Europe to take advantage of the experience gained by Italian industry through the ASI/NASA development of the Mini Pressurised Logistics Module (MPLM) for the ISS.

This measure will also significantly reduce the deficit that Italy has accumulated under ESA's policy of fair industrial return, and was welcomed by the Ministers of ESA's Member States at their meeting held in March.

"With this solution, everyone gains", stated Jörg Feustel-Büechl, ESA's Director of Manned Spaceflight and Microgravity, responsible for Europe's Space Station programme. "NASA will get the important equipment that it was seeking, delivered quickly and on time. ESA will get a Shuttle launch for its COF. Italy will see a great improvement in its industrial return situation. And the Space Station will move one step closer to becoming a reality."

# A unique educational experience offered by NSE

At the end of 1996 the Noordwijk Space Expo (NSE) started a unique educational experience in The Netherlands: a 'Remote Sensing Classroom' was inaugurated to support secondary education (remote sensing has now become part of the official geography curriculum in The Netherlands).

The idea behind a "Remote Sensing Classroom" is to obtain detailed information from original satellite images. Students learn how to manipulate Earth observation data like professional scientists. Various themes such as agriculture, climate and weather are covered.

On advanced PC-stations, students are introduced to a programme called "SaMBA" which allows them to work on various remote sensing tasks. Field research is included whenever possible, led by NSE in cooperation with different institutions.


*Noordwijk Space Expo offers students a hands-on classroom experience in the area of remote sensing.*

# ESA's role in space research on comets

ESA has a commanding role in space research on comets. Its Giotto spacecraft was the most daring of the international fleet of spacecraft that visited Halley's Comet in March 1986. Giotto obtained exceptional pictures and other data as it passed within 600 kilometres of the nucleus. Dust from the comet badly damaged the spacecraft, but in a navigational tour de force, Giotto made an even closer approach to Comet Grigg-Skjellerup in July 1992. Now ESA is planning the Rosetta mission that will rendezvous with Comet Wirtanen (see figures 1 & 2) and fly in company with it, making observations far more detailed than the fast flybys of Halley's Comet and Comet Grigg-Skjellerup could achieve.

As for space astronomy, the International Ultraviolet Explorer, in which ESA was a partner, made unrivalled observations of Halley's Comet by ultraviolet light. ESA is also a partner in the Hubble Space Telescope, which saw the historic impacts of Comet Shoemaker-Levy 9 on Jupiter in July 1994, and has recently observed Comet Hyakutake as well as Hale-Bopp (see figure 4). The SOHO spacecraft, built by ESA for a joint ESA-NASA project to examine the Sun, also has a distinctive view of comets. It has observed the hydrogen coronas of comets with its SWAN instrument. SOHO's coronagraph LASCO observed Comet Hyakutake rounding the Sun (when it was invisible to ground-based observers) and has discovered seven new comets very close to the Sun.

ESA's Infrared Space Observatory, ISO provides astronomers with information from comets across a very wide range of infrared wavelengths unobservable from the ground. Besides Comet Hale-Bopp (see figures 3 & 5), ISO has examined Comets Schwassmann-Wachmann 1, Chiron, Kopff, IRAS 1 and Wirtanen. The last of these, Comet Wirtanen, is now making one of its six-yearly visits to the Sun's vicinity.

As comets are relics from the construction of the Solar System, and played a major role in the formation of the planets, they are a link between the Earth and the wider Universe of stars. The carbon

*Figure 1. The ROSETTA mission is a cometary mission which will be launched in the year 2003 by Ariane-5. After a long cruise phase, the satellite will rendez-vous with comet P/Wirtanen and orbit it, while taking scientific measurements. A Surface Science Package (SSP) will be landed on the comet surface to take in-situ measurements. During the cruise phase, the satellite will be given gravity-assist manoeuvres once by Mars and twice by the Earth. The satellite will also take measurements during fly-bys of two asteroids.*

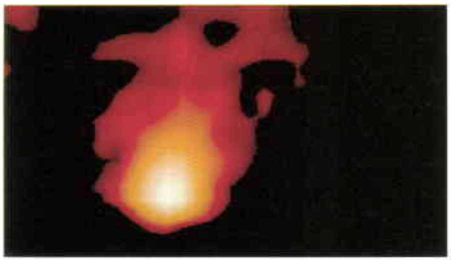
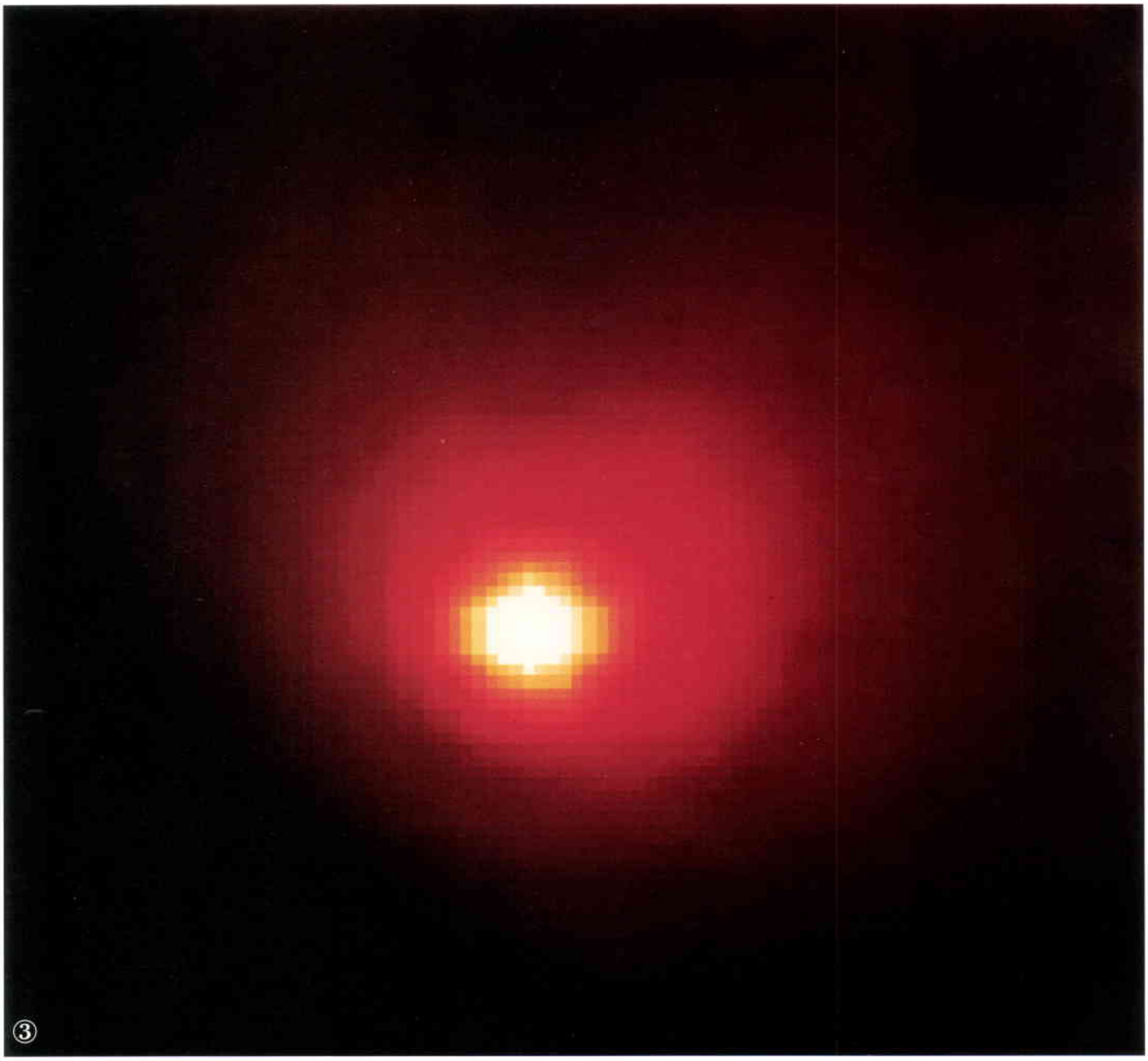


*Figure 2. An ISOCAM infrared image at a wavelength of 11.5 microns, of Comet P/Wirtanen taken on 7 November 1996.*

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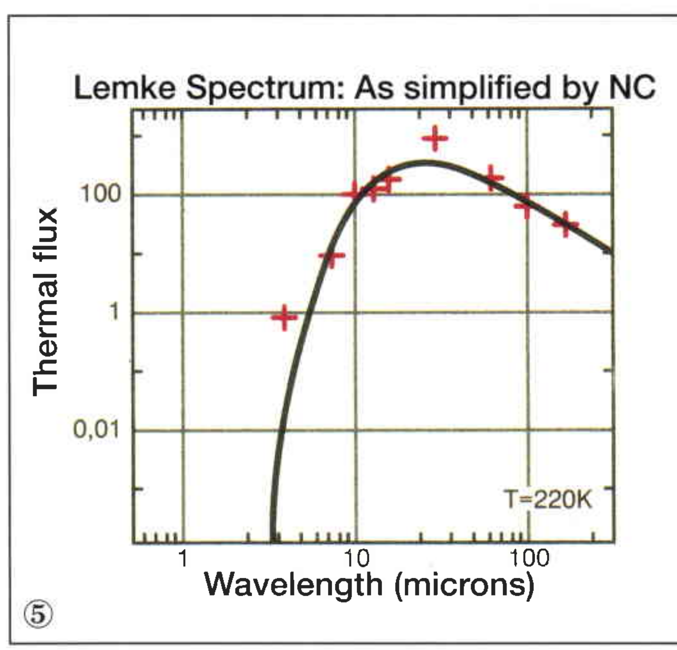
Lemke Spectrum: As simplified by NC
Thermal flux
100
1
0,01
T=220K
1
10
100
Wavelength (microns)

compounds contained in comets probably contributed raw materials for the origin of life on the Earth, and according to one theory the Earth's oceans were made from cometary ice. Growing knowledge of the composition and behaviour of comets is therefore crucial for a fuller understanding of our cosmic origins.

Emphatic confirmation of this long-standing belief of astronomers comes from the detection of the mineral olivine in Comet Hale-Bopp, by ISO. The 28 March issue of the US journal Science carries a report on this result by a European and American team led by Jacques Crovisier of l'Observatoire de Paris-Meudon.

"ISO sees the same materials in Comet Hale-Bopp as in dust clouds around other stars," Crovisier comments. "A key ingredient of both star dust and comet dust is olivine in crystalline form. This is also one of the main constituents of the Earth's interior. Now we can say with real confidence that we stand on a congealed pile of mineral dust, like that contained in the comets swarming around the Sun 4500 million years ago."

Olivine predominates in the mantle below the Earth's thin crust, and crops up at the surface as the olive-coloured gemstone, peridot. Geologists also value minerals rich in olivine, as important sources of chromium, platinum and diamonds.

Ingredients of Comet Hale-Bopp's vapour and dust emit characteristic infrared wavelengths, many of which are clearly observable only in space. The team took advantage of ISO's unparalleled ability to analyse intensities across a wide band, from 2 to 200 microns wavelength, using three of the spacecraft's instruments: the Short-Wavelength Spectrometer SWS, a short-wave spectrometer within the photometer ISOPHOT, and the Long-Wavelength Spectrometer LWS.

ISO's SWS reveals the olivine dust in the great comet in a distinctive cluster of emission peaks (11.3, 16.5, 19.8, 24.0, 27.6 and 33.9 microns). These are characteristic of crystalline forsterite, a form of olivine rich in magnesium. The infrared fingerprint is wholly different from that of the pyroxenes, commonplace silicates of the Earth's crust.

Last year, astronomers using the same instrument on ISO reported strong hints of olivine, in emissions around 33 microns from dust clouds surrounding half a dozen aged and dying stars. This is where Nature makes the olivine from chemical elements released from the old stars. Other SWS users recorded the full cluster of forsterite emissions in a dust cloud surrounding a young star, where planet formation may be in progress. The similarity between the spectra of this star (called HD 100546) and of Comet Hale-Bopp is astonishing. Although the objects are separated by hundreds of light-years, and huge differences of scale, ISO sees the same dominant mineral in both.

Comets carry ices too in their cargoes – principally frozen water, carbon monoxide and carbon dioxide. ISO has shown them to be the principal ices in interstellar space, where they exist on small grains. In Comet Hale-Bopp, ISO detects and measures these materials as they turn into vapour. Crovisier and his colleagues report in Science the rate at which Comet Hale-Bopp sweats off weight in the heat of the Sun.

On 27 September 1996, when the comet was still 444 million kilometres from the Sun, it was shedding water vapour into space at 10 tonnes per second, carbon monoxide at 11 tonnes per second, and carbon dioxide at 5 tonnes per second. Altogether Comet Hale-Bopp's loss of these materials amounted at that time to 2.2 million tonnes per day. Counting molecules rather than mass, the water vapour, carbon monoxide and carbon dioxide were vaporizing in the ratio 10 to 6 to 2.

The temperature at which the water molecules first formed in space, billions of years ago, was about minus 250° C. Crovisier's team arrive at this answer by distinguishing with SWS the infrared signatures of two kinds of water molecules, at 2.6 to 2.9 microns. When water molecules form at ordinary temperatures, the nuclei of both hydrogen atoms spin the same way, in three cases out of four. At very low temperatures of formation, as in interstellar space, contrary directions of spin become commoner. The best match to the ISO spectrum comes from a ratio of 2.45 to 1 for the two molecular types, corresponding to molecule-making at 25 degrees above the absolute zero of temperature.

Publication in Science of this ISO-based report, together with a number of other scientific papers on Comet Hale-Bopp, coincides with the comet's closest approach to the Sun (at 136 million kilometres) due on 1 April.

*Figure 3. Image from ISO's camera ISOCAM. It is one of a series obtained at a wavelength of 15 microns on 1 October 1996. Analysis of the image is still in progress, but the chief feature is the cloud of dust in the comet's head (coma). The bright region is about 100,000 kilometres across, or more than seven times wider than the Earth. At the time, the tail of Comet Hale-Bopp was largely hidden behind the coma because of the relative angles of the comet, the Sun and the Earth.*
*Credit: ISO (ESA), ISOCAM, P. Lamy and the Hale-Bopp team. Image processed by B. Altieri at ESA Villafranca.*

*Figure 4. An image of Hale-Bopp by visible light was obtained by the Hubble Space Telescope, just a week earlier than the ISO image, is shown for comparison. It covers a region of the sky (and the comet) one-fifth as wide as the ISO image. At least five jets of dust are seen emanating from the comet's nucleus, and lit by sunlight.*
*Credit: HST (NASA & ESA), H. Weaver and the WFPC2 team.*

*Figure 5. A spectrum covering a large range of infrared wavelengths from ISO's photometer ISOPHOT. Here the instrument operates as a thermometer, taking the temperature of the Hale-Bopp's dust cloud. The crosses are the measurements by ISOPHOT and the continuous line is the emission expected from an object with a temperature of 220 K, or about -50° C. By this period of observation in October 1996, the dust cloud was much warmer than in March 1996, when the same instrument obtained a temperature reading of -120° C.*
*Credit: ISO(ESA), ISOPHOT, E. Grün and the Hale-Bopp team.*

# ESA and NASDA sign a Memorandum of Understanding on Artemis

On 18 April, Mr Jean-Marie Luton, ESA's Director General and Mr Isao Uchida, President of the National Space Development Agency of Japan, NASDA, have signed a Memorandum of Understanding concerning the launch and utilisation of ESA's telecommunications satellite Artemis (Advanced Relay and Technology Mission Satellite).

This Memorandum of Understanding, an element of wider collaboration between ESA and NASDA, represents one of the most important and advanced space cooperation efforts between the two agencies to date. It stipulates that NASDA will launch the Artemis satellite on a Japanese H-IIA launcher in the year 2000. In exchange ESA will provide NASDA with data relay capacity through Artemis.

ESA's Artemis which will test and operate new telecommunications techniques, has a two-fold mission. It will provide two-way communications via satellite between fixed Earth stations and mobiles (trucks, trains and cars) all over Europe and adjacent regions. In addition, it will allow the reception of data from spacecraft in low Earth orbit and their retransmission to Earth stations and other users, both by using conventional radio waves and, in a revolutionary way, using laser beams. Artemis will provide communication links with, for instance, ESA's future environmental Envisat satellite, the European elements of the International Space Station, NASDA's Optical Inter-Orbit Communications Engineering Test Satellite OICETS, other Japanese Earth Observation satellites and the French Earth observation satellite SPOT 4.

Artemis is being developed for ESA by a European industrial consortium led by Alenia Spazio (Italy). esa

*Mr Jean-Marie Luton, ESA's Director General (left) and Mr Isao Uchida, President of NASDA (right) sign a Memorandum of Understanding representing one of the most important and advanced space cooperation efforts between the two agencies to date.*

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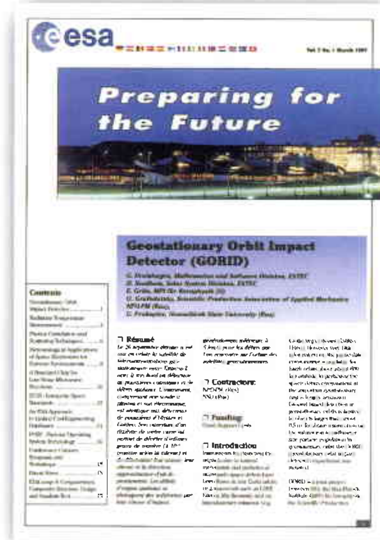


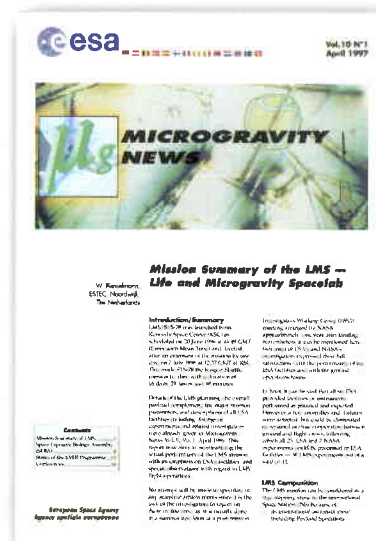


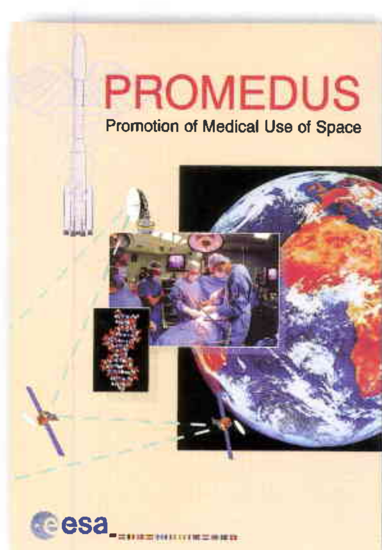


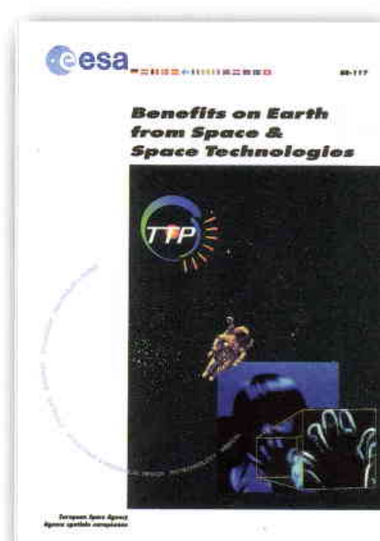

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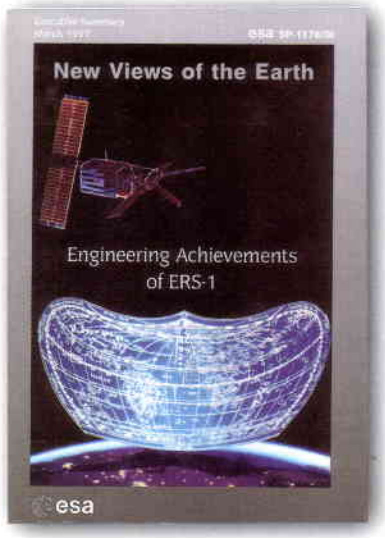


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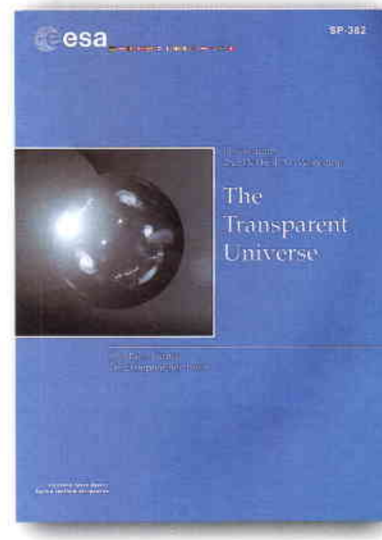


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