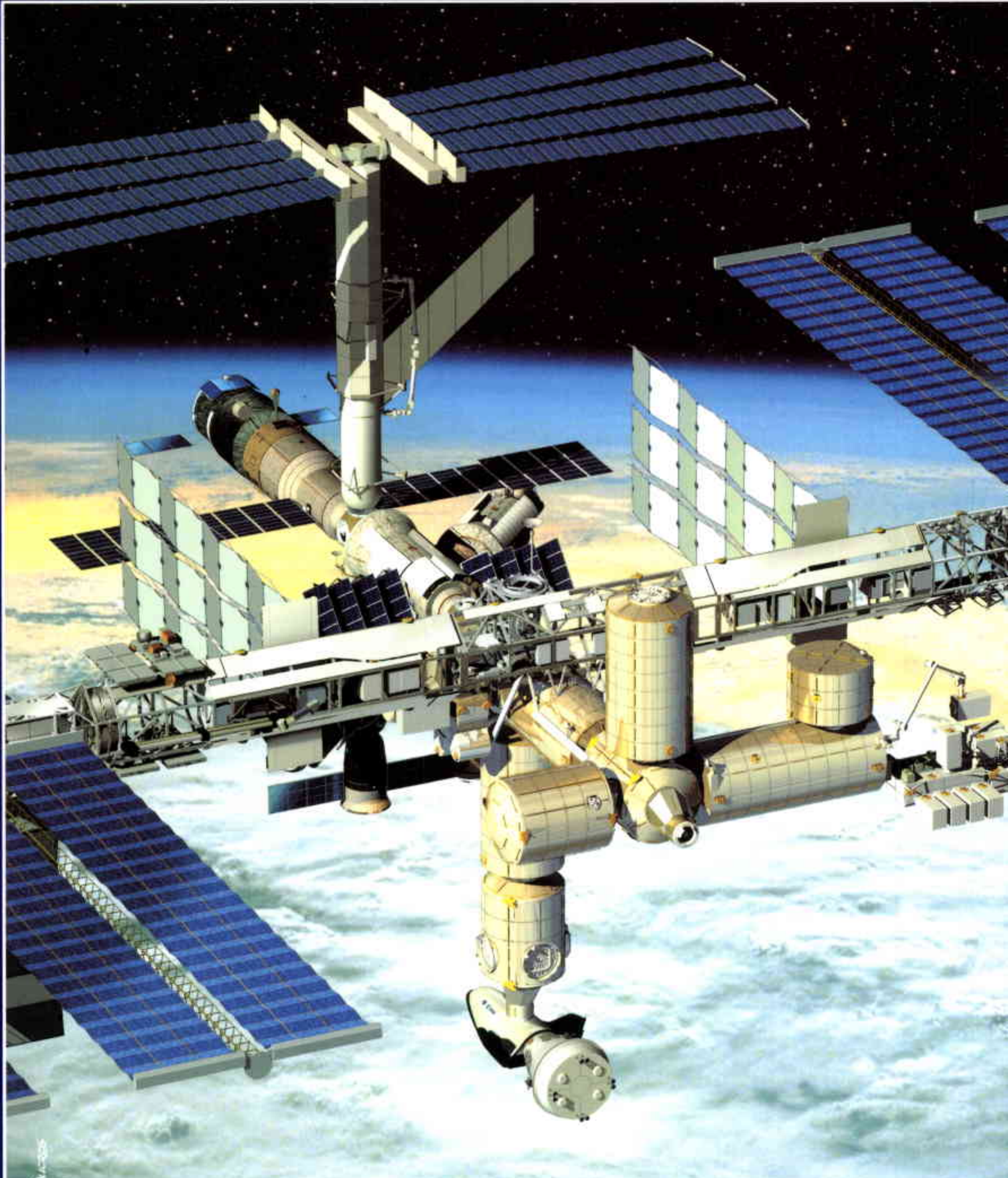
esa bulletin

number 93 - february 1998



European Space Agency
Agence spatiale européenne

european space agency

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

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

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The ESA HEADQUARTERS are in Paris.

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ESRIN, Frascati, Italy.

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agence spatiale européenne

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

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number 93 - february 1998

contents/sommaire

Cover: Artist's impression of the International Space Station, by D. Ducros (see articles on pages 5, 10 and 102)

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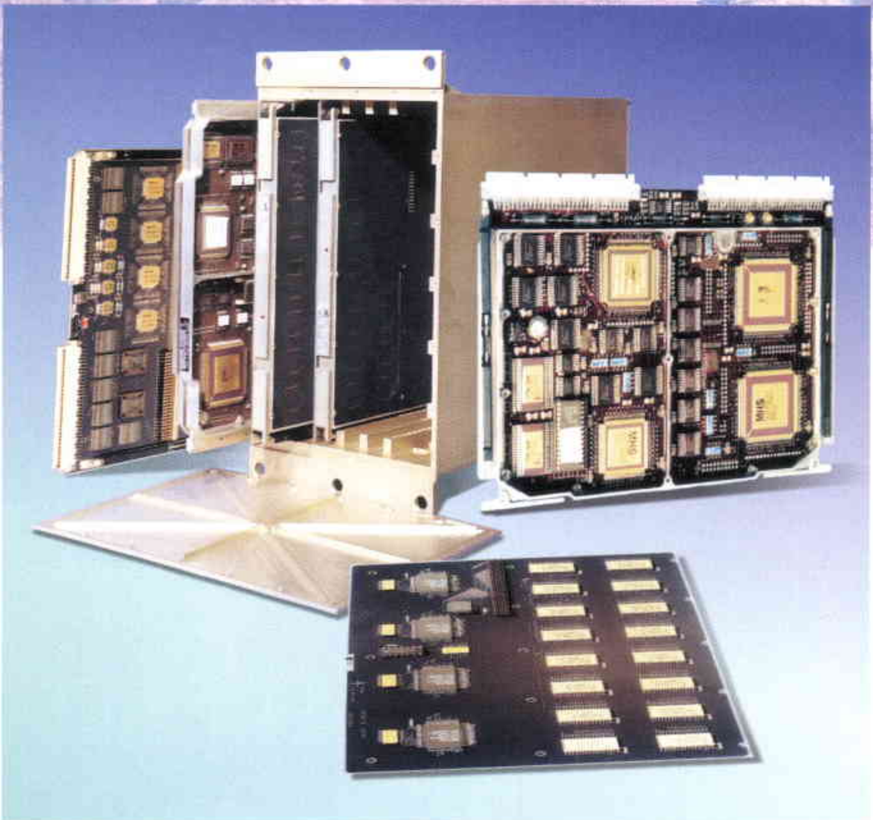

ESA's Data Management System, as part of Russia's Service Module (left, in main artwork), will provide critical control, guidance and navigation functions for the International Space Station. Inset is one of the two DMS Fault Tolerant Computers.

ESA's Data Management System for the Russian Segment of the International Space Station

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In October 1997, two flight units of the Data Management System (DMS-R) for the Service Module of the Russian Segment of the International Space Station were handed over by ESA to the Russian Space Agency (RKA) for use by RSC Energia, the prime contractor for the Service Module and the entire Russian Segment. The Data Management System was developed and manufactured in Europe by an industrial team led by Daimler-Benz Aerospace (DASA) in Bremen, Germany, under a contract placed by ESA's Directorate of Manned Spaceflight and Microgravity in Noordwijk, The Netherlands. The project is governed by a cooperative agreement between ESA and RKA.

This is the first delivery of ESA flight hardware within the International Space Station Programme to another International Partner. It will be launched with the station's third assembly flight, in December 1998.

Role of the Data Management System

The first modules of the International Space Station (ISS) will be the Functional Cargo Block (FGB, built by Russia and financed by NASA), NASA's Node 1 and the Russian Service Module. As the Service Module has to be autonomous from the beginning of its orbital life, it carries its own Data Management System (DMS-R).

Ultimately, the Data Management System will not only control the module itself, but also perform overall control, mission and failure management of the entire Russian Segment, such as:

- system and subsystem control, especially guidance, navigation and control
- mission management and supervisory control by ground and crew
- management of onboard tasks and failure recovery
- time distribution, time tagging and synchronisation
- data acquisition and control for onboard systems and experiments
- exchange of data and commands with the other parts of the station

It will also provide overall guidance and navigation for the entire station.

Overall DMS-R Configuration

The Data Management System architecture of the Russian Segment and its interfaces with the overall International Space Station is shown in Figure 1. Ten MIL-STD buses provide the interconnectivity between the various elements and equipment. The ESA-provided Service Module onboard units are:

- Two Fault Tolerant Computers (Figure 2): a Control Computer and a Terminal Computer.
- Two Control Posts (Figures 3 and 4) for command and control by the crew via the DMS-R, and for commanding experiments and the European Robotic Arm (ERA), which is also being developed by ESA under a cooperative arrangement.

A more detailed block diagram of the Service Module Data Management System is shown in Figure 5. The Control Computer and Terminal Computer have built-in redundancy to provide the required failure tolerance. The Control Posts can be configured to execute different, dedicated tasks or to operate in redundancy mode.

The application software for the onboard computers is being developed by the Russian Service Module contractor, RSC Energia, using an ESA-provided Ground System, which provides the hardware and software environment to support software design, development, simulation, test and validation. It is also being used to integrate hardware and software into the Service Module Flight Model.

Principles and implementation of failure tolerance

The Control Computer and the Terminal Computer feature a fault-masking architecture and are single-failure tolerant.

Figure 1. Data Management System architecture of the station's Russian Segment

Figure 2. DMS-R's two Fault Tolerant Computers (FTCs)

Figure 3. DMS-R Control Post (CP) computer

Figure 4. The two DMS-R Control Posts

Figure 5. DMS-R architecture

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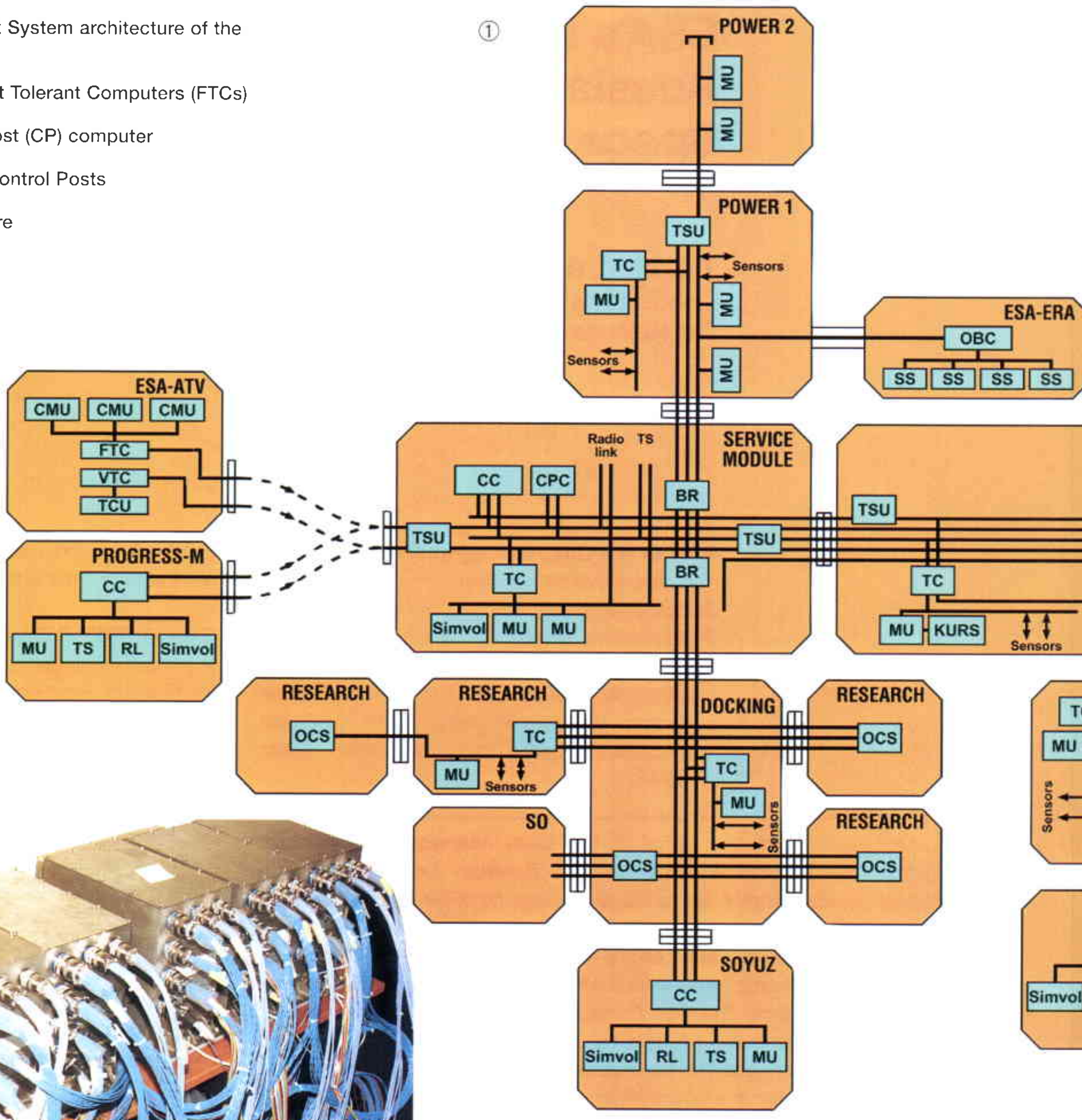

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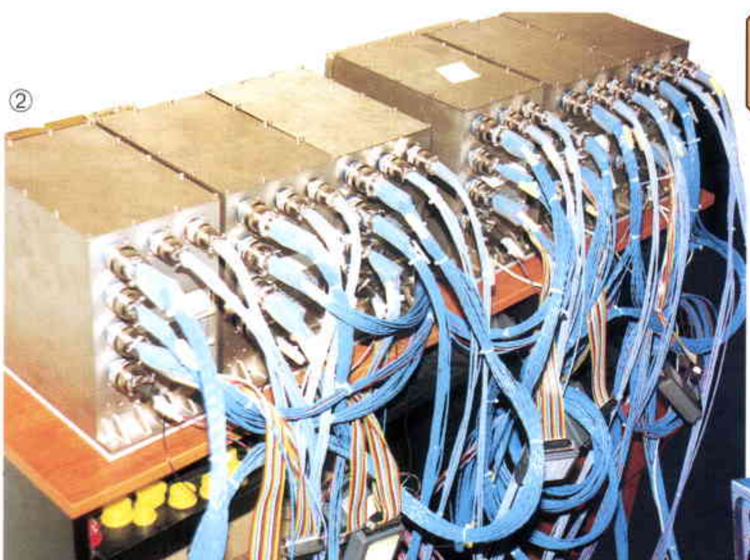

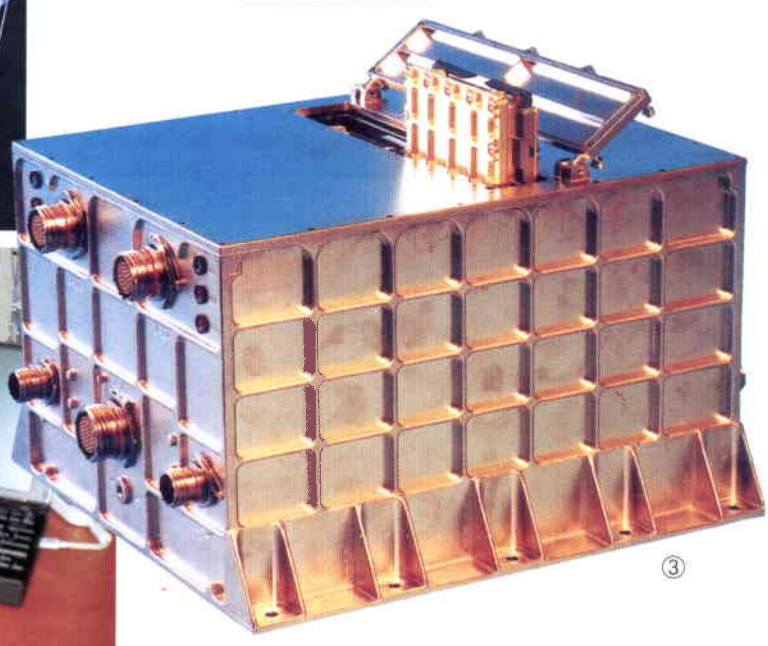

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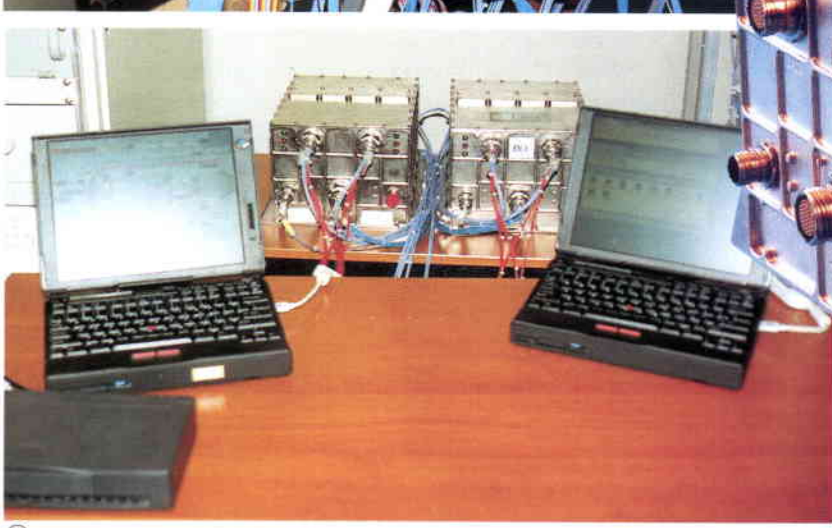

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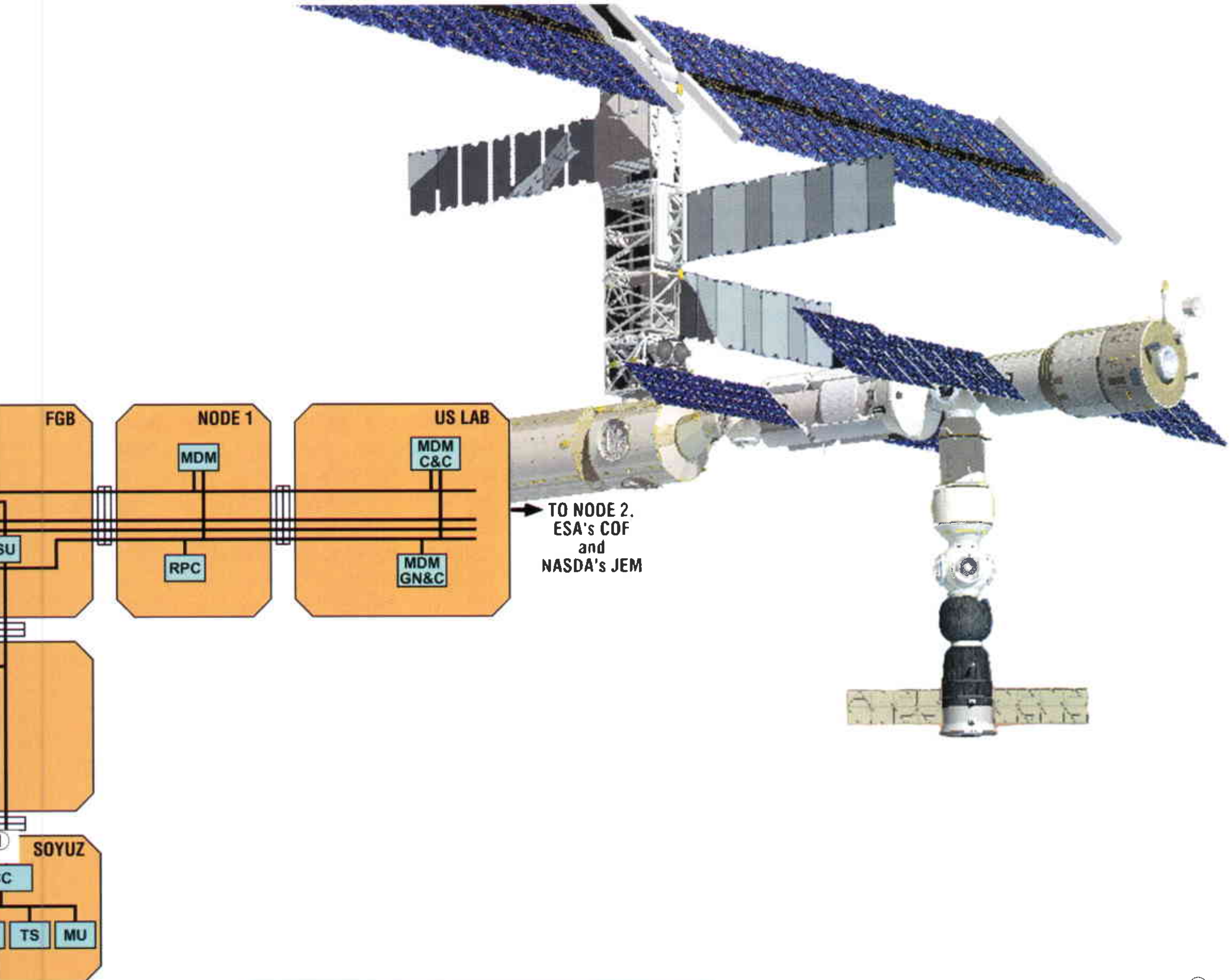

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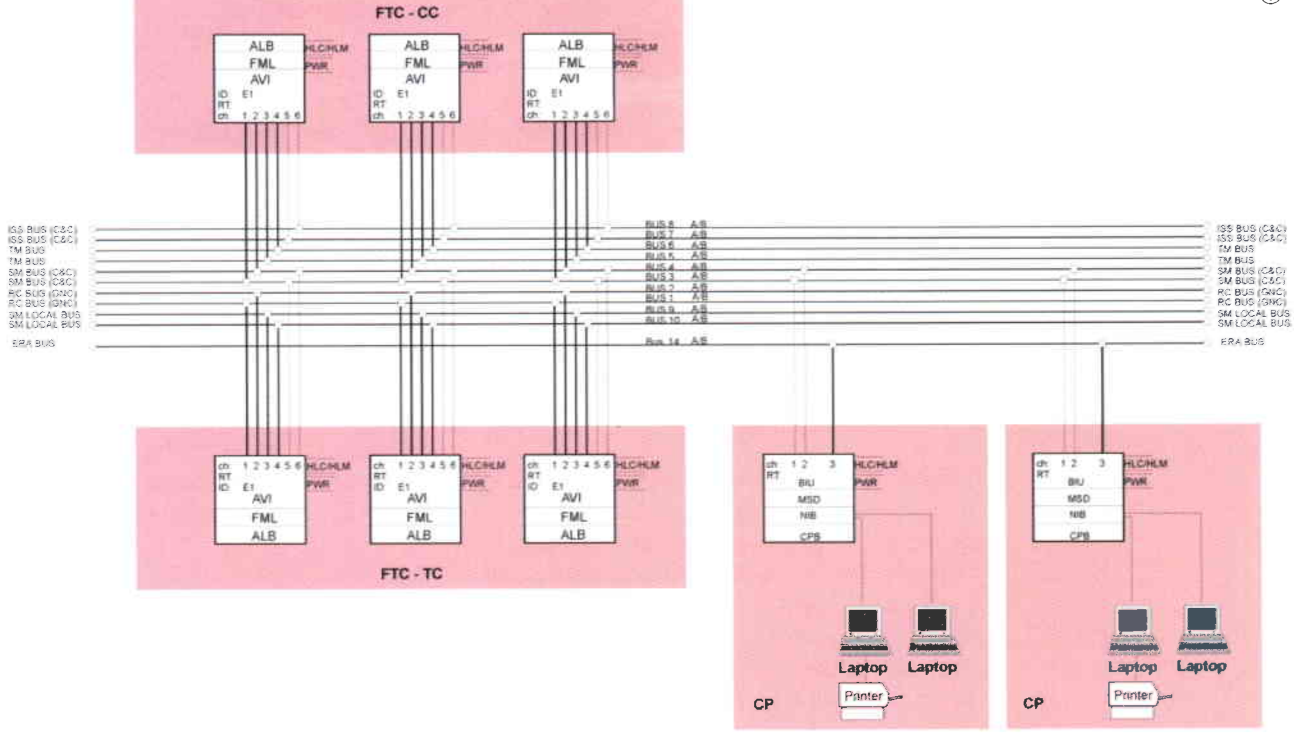

Courtesy: DASA

Fault masking is achieved by majority voting following parallel execution of the application programs in three identical computer units. These units are called Fault Containment Regions. For this voting process, the Fault Containment Regions must receive identical, synchronised input values in order to be able to deliver identical output values.

Because of potential errors in data distribution, some distribution rules have to be considered. These are defined by the 'Byzantine Theory', which specifies the required number of Fault Containment Regions, individual data links and data distribution rounds, depending on the number of failures to be recovered.

As a result, a Byzantine Fault Tolerant Computer system consists of multiple Fault Containment Regions cross-strapped by multiple high-speed point-to-point data links.

In order to survive F simultaneous faults, the system must meet the following requirements (according to Lamport, Shostak and Pease, 'The Byzantine General's Problem'):

- the system must consist of 3F+1 Fault Containment Regions
- the Fault Containment Regions must be interconnected through 2F+1 individual paths
- the inputs must be exchanged F+1 times between the Fault Containment Regions
- the Fault Containment Regions must be synchronised.

For data distribution, electrically-isolated full duplex serial data links are used to avoid error propagation between the Fault Containment Regions. The realisation of an individual data path must be a point-to-point connection. Keeping in mind the data throughput, which is reduced by the required data distribution rounds, these data links must have very high transmission rates.

This DMS-R development is the first time that the Byzantine Theory on failure tolerance has been realised for a space application.

One of the most critical problems in the design of synchronised computer systems is the elimination of deadlock situations, where one software task is waiting for an event or data coming from another software task, which itself is waiting for events or data from the first. In order to avoid such situations, all communication paths in the software have been modelled by an abstraction method in order to reflect all related vectors and variables. The integrity of the design and the absence of any deadlock situation have been verified through many millions of simulation runs. The simulations and design analysis were performed by an independent team at the University of Bremen, Germany.

For the Russian Service Module, the required configuration for the Fault Tolerant Computer consists of three Fault Containment Regions, which provide masking of one deterministic fault.

Associated ground system

The DMS-R onboard equipment is complemented by a set of ground hardware and software for the application software development and verification process, as well as for system integration and check-out. The Ground System is based on the Columbus Ground Software, developed by DASA for ESA's Columbus Orbital Facility, one of Europe's main contributions to the International Space Station. The Columbus Ground Software is a consistent set of software products that forms the basis for a comprehensive set of integrated ground facilities. It is also in use at NASA for the Space Station Mission Build Facility and the System Verification Facility.

The Ground Segment consists of three main facilities:

1. The Software Design and Development Facility
2. The Software Integration and Test Environment
3. The Test Facility with the necessary Electrical Ground Support Equipment and onboard DMS engineering models for system-level software integration. This facility is also connected to the Functional Cargo Block (FGB) ground facility, provided by NASA to support integrated Service Module/FGB/Node/Shuttle interface verification testing.

ESA and Russia: the cooperative experience

A challenging aspect of DMS-R development was working within two contrasting engineering cultures. A number of important differences in approach became evident early on, while some were not fully appreciated at the time.

The old 'Soviet' approach to spacecraft development, like other activities of key importance to the former Soviet Union, was to assign abundant resources within the prime contractor and its various subcontractors, all under the overall responsibility of the General Designer, who had almost absolute power to accomplish the required task.

The development itself was driven mainly by design ideas rather than by detailed functional and interface requirements. It required very close cooperation between individual designers, plus repeated iterations and intermediate breadboarding of individual design elements until the desired overall performance was achieved. This approach meant that functional and interface requirements of the individual design elements could change significantly during the design process, but it offered performance improvements and optimisation during development. Documentation was limited to essential high-level requirements, as all detailed information was open to change anyway.

Although this approach is changing with Russia's political and economic evolution, the old philosophy still very much influences the attitudes not only of individual engineers but also of corporate entities.

In contrast, the Western European approach to development is for the customer to generate a set of System Requirements. These are then used by a prime contractor to elaborate lower-level specifications and interface requirements for subcontractors and, ultimately, to conclude a fixed-price contract. In this scenario, technical changes usually lead to considerable schedule and cost impacts, and are therefore avoided whenever possible.

It is obvious that combining these approaches in a cooperative programme carries the potential for conflicts, so it was no surprise that the DMS-R programme had to surmount such problems. The situation was complicated by the constraint that the requirements for the DMS-R computers were developed with a view to their reuse in ESA's own Columbus Orbital Facility and Automated Transfer Vehicle projects. These requirements were defined in a System Requirements Document (SRD), which established the technical basis for the fixed-price contract with Industry, and in parallel Joint Systems Requirements (JSR), which defined the technical basis of the agreement with the Russian Space Agency.

In practice, the difficulties manifested themselves in the limited emphasis of the Russian partners in following up and reacting to the early DMS-R design and definition activities, including the related reviews. Their interest and involvement started to increase after the Preliminary Design Review, with the consequence that the first requests for changed or new requirements were raised at that time. This continued throughout the implementation and even the verification phases, almost up to the Qualification Review. Similarly, great reluctance was met in freezing the Interface Control Document at a sufficiently early stage.

Considerable analysis and persuasion therefore went into discussing and constraining the Russian changes to items essential for creating a properly functioning integrated system, while limiting schedule and cost impacts to acceptable levels. Eventually, however, it became evident that the most effective approach was to encourage active Russian involvement in matters of common concern long before they would have become interested under the old system. This triggered an early understanding of design characteristics and implications, highlighting unavoidable changes as early as possible. esa

History of European/Russian Cooperation on DMS

The project goes back to 1992, when discussions were initiated between Russia and Europe on potential ESA contributions to the planned Mir-2 station. One candidate was the Data Management System. However, the political climate evolved very rapidly and the International Space Station, built and operated under multi-national cooperation, replaced the separate Freedom and Mir-2 programmes. The European/Russian DMS was also confirmed for the new Space Station scenario and fully endorsed by NASA.

DMS development was formalised in an ESA/RKA Arrangement, signed on 1 March 1996, which defined ESA's DMS obligations and RKA's obligations, in exchange, to design and deliver to ESA the Russian Docking System for ESA's Automated Transfer Vehicle (ATV). The ATV, launched by Ariane-5, will support ISS resupply.

On 10 May 1995, the ESA Council approved the final DMS-R declaration, with a programme participation of approximately 74% from Germany, 13% from France, 8% from Belgium and 5% from The Netherlands. The industrial contract with DASA-RI as prime contractor, and Matra Marconi Space, Alcatel Bell Telecom and RST as direct subcontractors, was signed on 14 December 1995.

Key Milestones during the DMS project implementation phase were:

- System Requirements Review (SRR) December 1994
- Preliminary Design Review (PDR) June1995
- Critical Design Review (CDR) June 1996
- Qualification Review (QR) September 1997
- Flight Acceptance Review (FAR) October/ November 1997

Standard Payload Computer for the International Space Station

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Within the framework of the International Space Station (ISS) utilisation, ESA payloads will be accommodated internally within the Columbus Orbital Facility (COF) and US Lab, and externally attached to the ISS truss. The payloads will cover a wide range of disciplines and technology, but all have one requirement in common: a supporting computer. The computer's two main tasks will be the internal control and monitoring of payload-specific functions, and external communication with the COF and ISS data management systems.

The ESA Manned Spaceflight and Microgravity Directorate, recognising the need to minimise development cost and risk for payload computers, has initiated the development of a Standard Payload Computer (SPLC): a modular payload computer system composed of standard items (Table 1) which can be configured to meet individual payload requirements (Fig. 1). The SPLC is intended for use with all payloads developed under the Directorate's responsibility, and must therefore be flexible enough to suit the data handling needs of simple payloads through to complex facilities. The Directorate has defined a standardisation policy for SPLC usage which is binding on all payload developers, with any exceptions requiring waiver approval from the Director of Manned Spaceflight and Microgravity.

Target environment
To appreciate the goals and applicability of the SPLC, the target environment is first briefly described.

There are two primary locations for ESA payloads on the ISS: in the COF pressurised environment and in vacuum on the external truss. Payloads located within the COF and US Lab will be housed in an International Standard Payload Rack (ISPR). The ISPR, as its name suggests, is built to a common mechanical standard and is present in all modules.

Within the ISPR there are two types of payload: Class 1 payloads require a dedicated rack and are typically discipline-related multi-user facilities such as the Fluid Science Laboratory (FSL) (Fig. 2); Class 2 are payloads able to share the facilities of a single rack. These simpler payloads will be accommodated in a 'European Drawer Rack' (Fig. 3) which further refines the ISPR principle by providing standard accommodation for up to twelve drawers /lockers containing payloads in an ISPR compliant rack.

Payloads on the external truss will be mounted on standard platforms such as the NASA

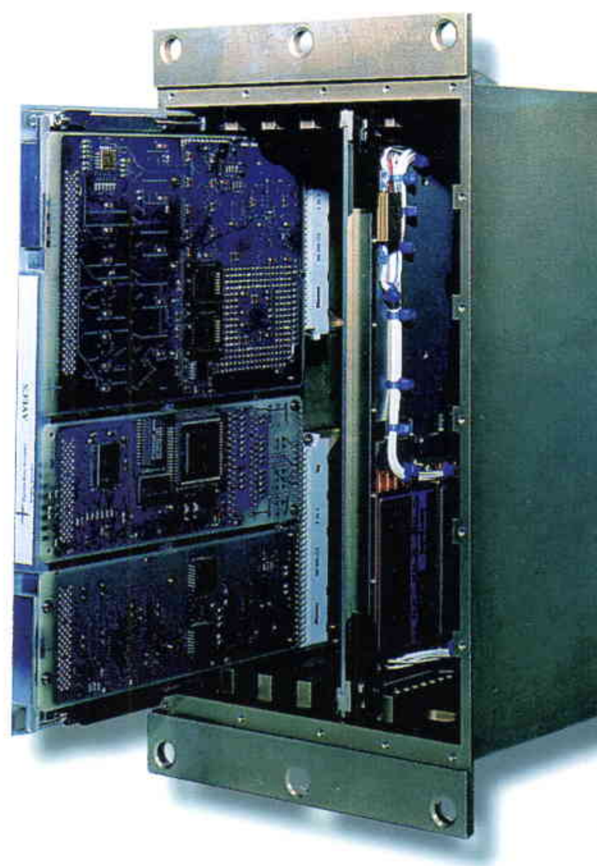


Figure 1. A typical Standard Payload Computer (SPLC) configuration within a five-slot housing

Figure 2. Class 1 payload: Fluid Science Laboratory (FSL)

Figure 3. Class 2 payload: European Drawer Rack

Table 1. SPLC Standard Items List

VME CPU Module	
Power interface	5V / 10W, without mezzanine boards
Data interfaces	master VME bus, a32/D32 mode, 6 serial interfaces, 2 x local mezzanine I/F
CPU	ERC32
Memory	8 MB SRAM, 4 MB EEPROM
Software	basic software package and VxWorks Kernel in Rom
VME Mass Memory Module	
Power interface	5V / < 5W
Host CPU data interfaces	slave VME bus
Memory	disk or DRAM
Storage capacity	50 MB
VME Extension Module	
Power interface	5V / 200 mA (without mezzanine boards)
Host CPU data interfaces	slave VME bus and mezzanine I/O local bus (4x)
MIL 1553B Mezzanine Board	
Power interface	5V / 250 mA 12 V / 300 mA
Host CPU data interfaces	mezzanine I/O local bus
MIL bus	MIL STD 1553B
Ethernet I/F Mezzanine Board	
Power interface	5V / 1W
Host CPU data interfaces	mezzanine I/O local bus
LAN data interface	AUI
Serial I/F Mezzanine Board	
Power interface	5V / 200 mA
Host CPU data interfaces	mezzanine I/O local bus
Data interface	2 asynchronous RS 422 / RS 485
Analogue input I/F Mezzanine Board	
Power interface	5V / < 1W, +/- 12V < 1,2W
Host CPU data interfaces	mezzanine I/O local bus
Performance	12 bit resolution, max. 100 samples/s 8 differential input channels
Digital I/F Mezzanine Board	
Power interface	5V / < 1W
Host CPU data Interfaces	mezzanine I/O local bus
Performance	12 opto-isolated input/ output lines, max. 100 samples/s
SPLC Housing and Power Supply 5-slot version	
Mass	3.4 kg (incl. power supply, backplane, and harness)
Housing size	160mm x 295mm x 260mm
Number of VME slots	5
Construction	coated aluminium
Power supply	120 or 28 V DC input
VME Interface Chips	
FPGA	Master mode
FPGA	Slave mode only
SPLC EGSE	
Development environment	Unix and VxWorks
Test system	PACTS
Hardware platform	VME

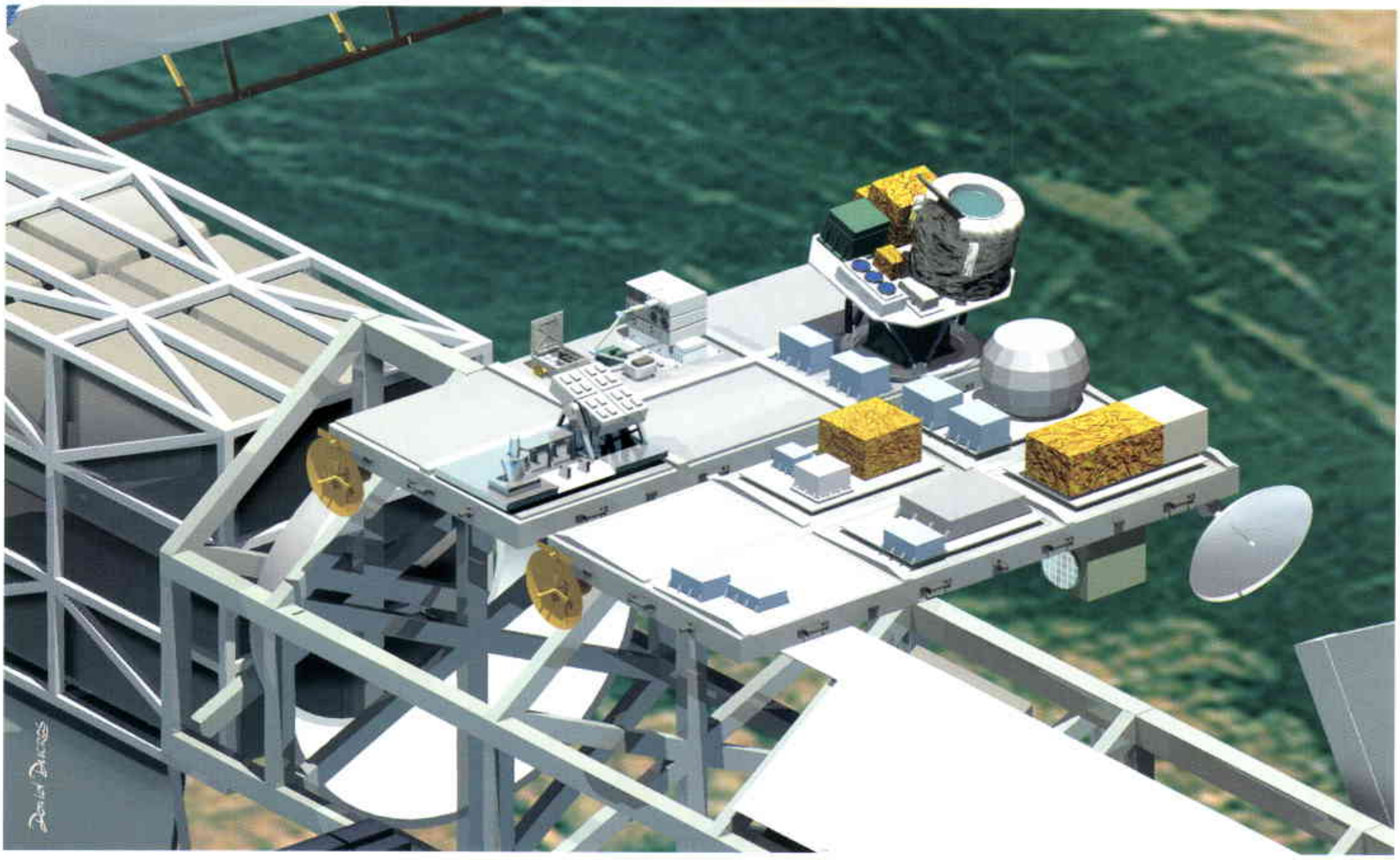
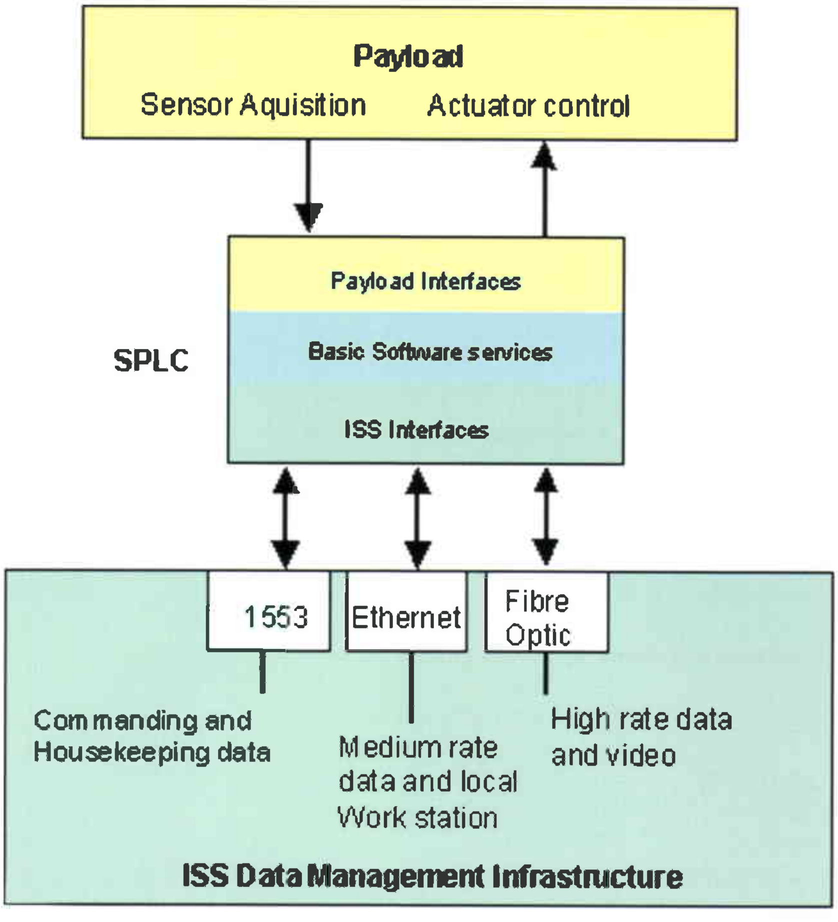


Figure 4. Express Pallet adapter payloads (external on ISS truss)

Figure 5. SPLC with ISS data interfaces



Express Pallet (ExP). The ExP provides a standard physical structure together with the necessary service interfaces for power and data. Multiple payloads may be accommodated on a single pallet depending on physical requirements (Fig. 4).

The role of SPLC is identical in all of the above configurations: it logically resides between the payload and ISS data management system, on the one hand taking care of all external communication and on the other interfacing with the payload. In the case of a Class 1 payload, interfacing is mainly concerned with control and monitoring of payload dedicated electronics. For Class 2 payloads, the SPLC provides the necessary multiplexing to allow the multiple payloads to access a single ISS interface. In both configurations the SPLC may host payload-specific software.

For external payloads, the SPLC provides identical functions, relieving the payload from the complex task of interfacing with the ISS data management system and providing local interfacing to one or more payloads. The main physical difference here is that the SPLC will be subject to the thermal, vacuum and radiation environment of free space.

ISS interfaces

To perform its role of communicating with the ISS data management system, the SPLC must implement the following interfaces (Fig. 5):

- the *MIL 1553 data bus* is the primary interface for command and monitoring of traffic, and is mandatory for all payloads
- the *Medium Rate Data Link (MRDL)* is an Ethernet link typically used for science data with transmission requirements higher than supported by the Mil 1553 bus
- the *High Rate Data Link (HRDL)* is typically used for video applications. This is currently not provided by the SPLC, but may be added in future if required.

In addition to the hardware architecture, the SPLC must implement data transmission protocols specified for each interface, demonstrating its clear advantage. For example, the protocols used over the 1553 bus in the US-LAB are different to those used by the COF. The SPLC allows a payload to be freely moved between the COF and the US-Lab without major rework and re-qualification of the relevant protocols. The SPLC implements both protocols and thus the payload developer is relieved from physical location constraints.

SPLC concept

The strategy of adopting a standardised computer leads to a radical rethink of the payload data handling procurement process. Traditionally, this has been based on proprietary development with repeating costs for qualification, spares, expertise and maintenance for each new payload. Implementations have also tended to be unique with very little opportunity for re-use or utilisation of previous developments. While this may, to some extent, have been justified for short-duration one-off missions, the availability of a standard, long-term space infrastructure calls for a quite different approach.

To support a large number of concurrent payloads, the ISS implementation relies heavily on standardisation particularly in the area of payloads. Physical accommodation, data interfaces, protocols, component quality, operational requirements and maintenance (including spares) must all conform to a common set of standards. The data handling system and associated computer used by each payload must also comply with these common requirements.

For successful exploitation of the SPLC, the design must respond to a number of important criteria. Foremost among these is to ensure that the use of a single standard does not compromise the specific data handling requirements of individual payloads.

The design must also be suitable for a wide range of environments: the COF pressurised module has quite different environmental conditions to those experienced on the external truss, but both are subject to potentially damaging radiation effects.

In response to the above aims, the SPLC is based on the following concepts:

- a one-off development and qualification process
- a modular computer, configurable from a list of space-qualified items according to the payload developer's needs
- an 'open system' which may be augmented by payload developers
- core software providing a suite of common communications services, including a verified protocol implementation required to communicate with the ISS
- standardised ground support equipment and accompanying software development environment
- the use of commercial hardware and software standards and products.

The opportunity therefore exists to provide a single computer suitable for all payloads with only a one-off development and qualification cost. If this is combined with the benefits of multiple procurement, lifetime (10 years) change-out policy for hardware spares and maintenance, as well as long-term software maintenance, there is potential for great savings to be made by all those concerned in the payload development process.

SPLC architecture

A key feature of the SPLC architecture is the strict avoidance of proprietary designs. Wherever possible, the system uses open standards and commercially available products. This was seen as a mandatory requirement for several reasons:

- the core set of functions provided by the SPLC may require the addition of payload-specific electronics, optimally added by the payload developer. This may only be achieved if the SPLC uses well-defined and openly published interface specifications
- using commercial interfaces brings the SPLC into a more competitive procurement arena and improves the possibility for second sourcing
- the use of commercial standards for the flight implementation opens the way for compatible off-the-shelf products to be used for initial development, thus drastically reducing costs
- the tools supporting widely-used commercial standards are generally far superior and better supported than specially written proprietary products.

The resulting SPLC architecture is illustrated below (Fig. 6). It consists of a backplane bus for interconnection of the main electronic boards and a local bus accommodating small mezzanine (piggy-back) boards. The local bus is implemented on two of the main electronic boards (the VME CPU board and the VME extension board) as explained in the next section.

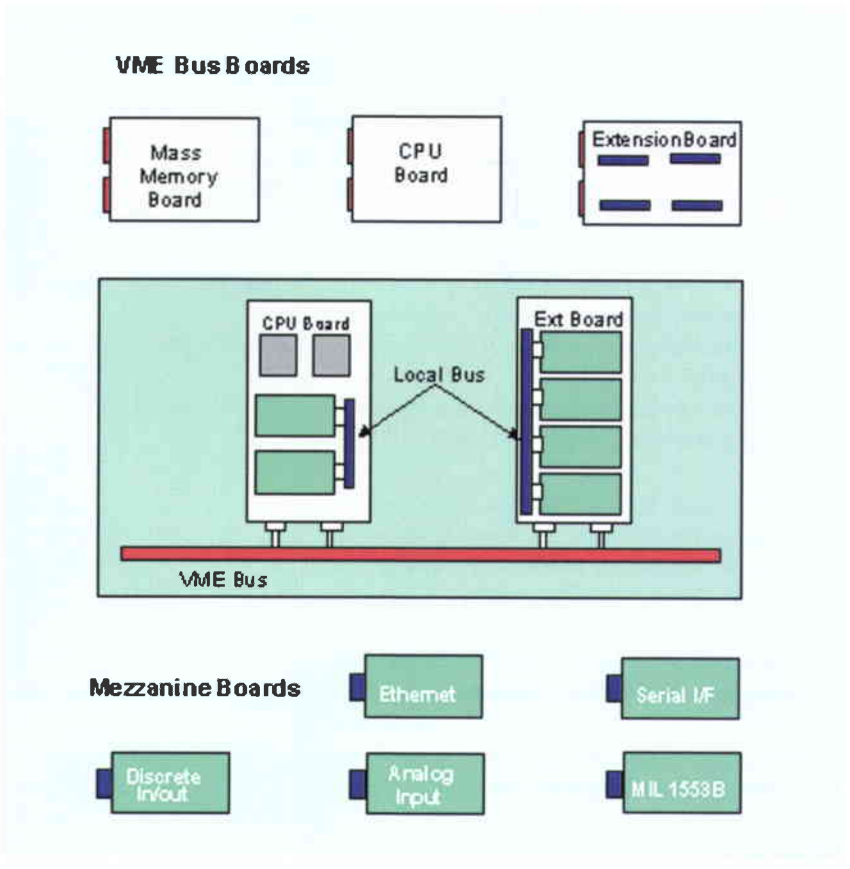
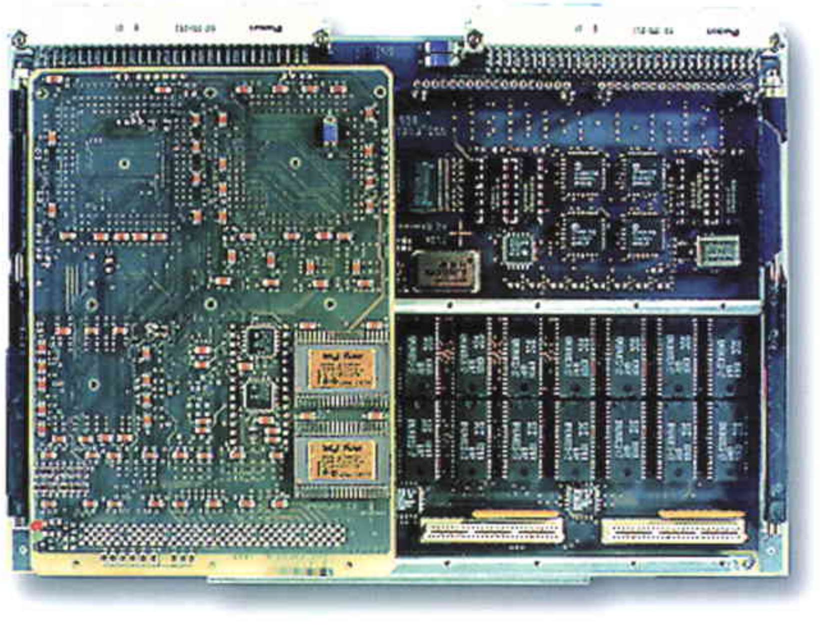


Figure 6. SPLC hardware architecture

Figure 7. VME CPU board



The backplane bus conforms to the industrial standard VERSAModule Europe commonly referred as the VME bus. The VME bus is an open standard allowing boards from different vendors to share the same physical backplane bus. The VME bus standard specifies both electrical and mechanical standards, including board sizes, connectors and bus protocol. VME is widely used in commercial ground applications and has world-wide support from multiple vendors. It is therefore well known to European industry.

The local bus is used to extend the interfacing capability of the SPLC without resorting to a full VME board implementation. The local bus mezzanine boards are dedicated to a specific input/output (I/O), and typically require only a few components to fulfil their function. They are therefore extremely cost-effective to manufacture. Although the local bus has been specifically defined for the SPLC project, the specifications are freely available with no proprietary rights.

The architecture provides maximum flexibility, allowing a variety of VME and mezzanine boards to be freely mixed to meet the requirements of a specific payload.

This type of approach has been used for many years in commercial ground systems, and has been very successful in establishing multi-vendor support for every conceivable interfacing requirement. New requirements are met by the simple addition of a board, with minimum impact on existing systems. Commercial suppliers thus have a stable infrastructure on which to design and deploy their products, and customers gain advantage from a wide choice of supply.

This should be contrasted with previous implementations of payload data handling where suppliers have not had a uniform platform on which to target their products. This has resulted in one-off developments which are expensive, difficult to maintain and often require complete redesigns to meet new requirements.

SPLC core components

Using the open-system concept described above, the SPLC provides a number of pre-developed boards designed to cover the most common payload interfacing requirements.

VME boards

- the *CPU board* (Fig. 7) is based on the ERC32 chip set which is a space-qualified version of the SPARC V7 processor as developed under ESA's Advanced Systems and Technology Programme (ASTP). It

contains the main memory, a 6 Mbyte storage area (RAM), 4 Mbyte EEPROM, the VME bus controller chip as well as six RS422 serial interfaces, one of which is dedicated to a test connector. A small ROM provides for the initial program load and maintenance functions. The CPU board can accommodate two mezzanine boards. This provides an extremely capable single-board computer with sufficient interfacing capability to support many of the simple payloads
- the *mass memory board* is available for storage of experiment data and application software. The board provides in the order of 50 Mbytes of storage using EEPROM which is suitable for use in both vacuum and pressurised environments. The software interface to the mass memory uses typical personal computer standards; several file systems are available, including DOS
- the *extension board* is a VME bus slave board containing up to four I/O mezzanine board slots. For ease of interfacing, the board is memory mapped into the VME memory space.

Mezzanine boards
Five different mezzanine boards are available. All are interchangeable and may be located on the processor and/or the extension board. An example of a mezzanine board is shown in Figure 8.
- a *MIL 1553B board* is used as the main interface to the ISS and optionally as an internal payload interconnection bus. The board contains an embedded microprocessor, relieving the load on the main processor and allowing reprogramming depending on application
- an *Ethernet board* for connection to the medium rate data link and optionally during development. The board is accompanied by a small external transceiver providing the necessary physical interface to the ISS LAN. Both board and transceiver contain latch-up protection circuitry against radiation damage
- a *serial I/F board* provides two serial interfaces for internal payload connections. The interfaces may be configured in bus (RS485) or point-to-point (RS422) mode. Provision is made for payload-specific protocols to be downloaded to the board at run-time, and high-rate data transfer is supported using onboard buffer management
- a *12-channel discrete input/output board* for general-purpose payload interfacing; all lines are isolated using opto-couplers
- an *8-channel analogue input board* for payload data acquisition. This provides 12 bit resolution and a maximum sampling frequency of 100 Hz.

Housing and power supply
The SPLC standard housing is a lightweight 5-slot (Fig. 1) or 8-slot aluminium box with bolted upper cover plate, containing a low-power version of the VME-backplane and a single-board power supply which powers all SPLC boards. The power supply input voltage is baselined at 28 Volts with a 120 Volt input option under consideration. The power supply board needs one slot. Thermal cooling is based on conduction using a base plate. While all the SPLC components are designed for use in vacuum, depending on the individual application, an additional thermal system may be needed for external applications. Payload developers may also choose to provide their own housing.

Developer support
A radiation-tolerant VME interface chip and the mezzanine board specification are available to payload developers who wish to prepare their own payload-specific VME or mezzanine boards.

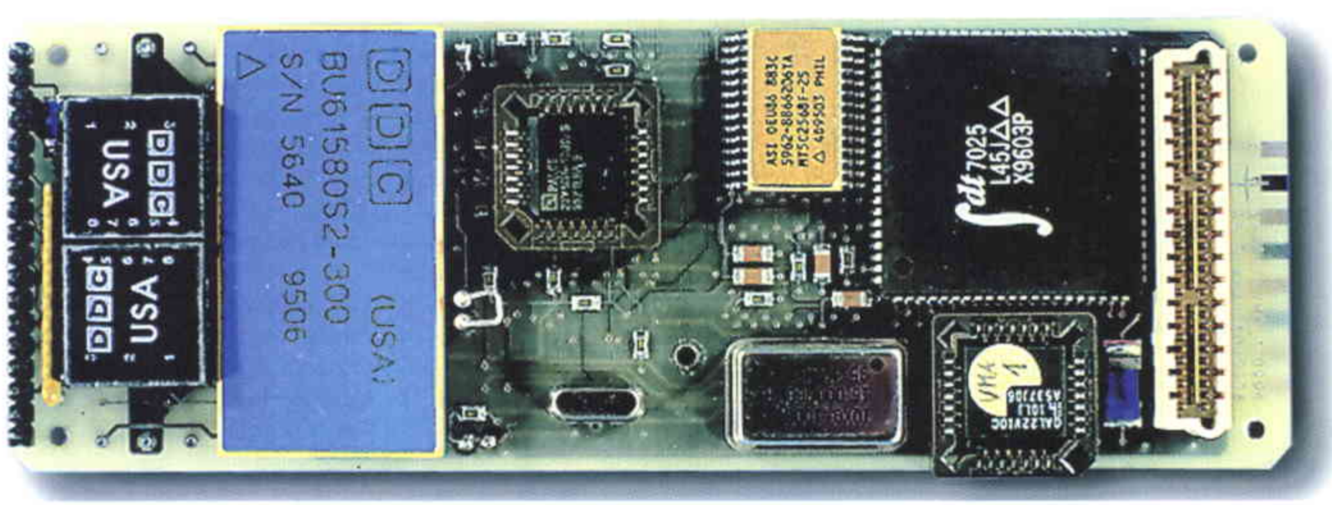


Figure 8. Mezzanine 1553B board

Component quality
While the SPLC is clearly based on commercial standards, it is not possible to directly reuse commercial ground hardware for flight. Aside from the normal component quality issues, the electronic components of the SPLC will be subject to bombardment by ionising particles (e.g. protons and heavy ions) in the space environment of the ISS. These particles can give rise to so-called Single Event Effects (SEE) in sensitive components, typically memories and microprocessors. A SEE can cause two types of failure: a non-destructive, or Single Event Upset (SEU) bit-flip in a register or memory cell, and the more serious Single Event Latch-up (SEL), where a shortcircuit is caused in the device affected.

The SPLC is protected from SEEs in two ways, firstly by selecting flight-qualified components which are inherently SEE immune, and secondly by adding additional protection circuitry. For example, the processor board uses the ERC32 processor (developed by ESA to give a high level of radiation immunity) and the VME interface chip (a specific SPLC development with similar properties). The commercial versions of the Ethernet interface chip are particularly sensitive to latch-up problems but it was not cost-effective to develop a flight device. In this case, the SPLC uses a commercial component with additional latch-up protection circuitry.

All memory on the processor board is protected by Error Detection and Correction Circuitry (EDAC), which is able to detect a radiation-induced bit error and provide the necessary correction before it becomes a problem.

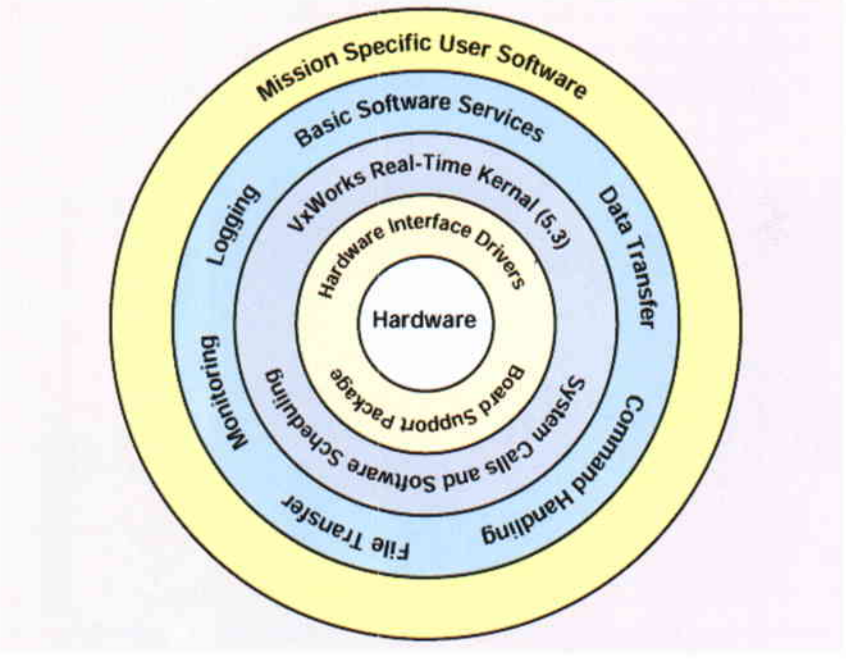


Figure 9. SPLC software

Engineering model components
Lower-cost EM versions of all boards are available for use during payload development. These are identical to their flight counterparts but use commercial-grade components. Recommendations are also available for compatible commercial VME boards which may be independently procured for use in ground or training models, depending on programme requirements.

SPLC software
A major part of the development cost for current payloads is software related. The SPLC has targeted this problem by providing a pre-configured software package. The software has been designed with the same basic principle as that of the hardware: to provide a core set of common functions but to be open to adaptation by payload developers if necessary. Commercial products are used wherever possible. The resulting software, is composed of four layers (Fig. 9):

- a *hardware adaptation layer* providing low-level interface drivers and mapping to hardware-specific devices. This layer is hardware independent, allowing the remaining software to be executed on other platforms (e.g. on commercial hardware during initial payload development)
- a *real-time operating system:* the commercial VxWorks kernel has been selected due to its wide use in industry and elsewhere within the ISS
- *basic software* which provides a suite of communication-related services that are generally applicable to all payloads. These are primarily related to formatting and routing data between the various hardware interfaces of the SPLC, but services are also provided for monitoring payload data, file storage and watchdog functions. Of particular importance is the provision of protocols necessary to communicate with the ISS data management system
- *mission-specific software:* in order to adapt the SPLC to the specific requirements of a payload, provision is made for additional payload developer provided software. This may range from simple command handling to complex data processing.

Example payload configurations
The SPLC supports a wide range of payloads and payload configurations (Fig. 10). Payload-specific boards may be incorporated in the SPLC housing or, alternatively, SPLC boards may be incorporated in an existing payload box. The resulting possibilities are extensive, as depicted by the following example.

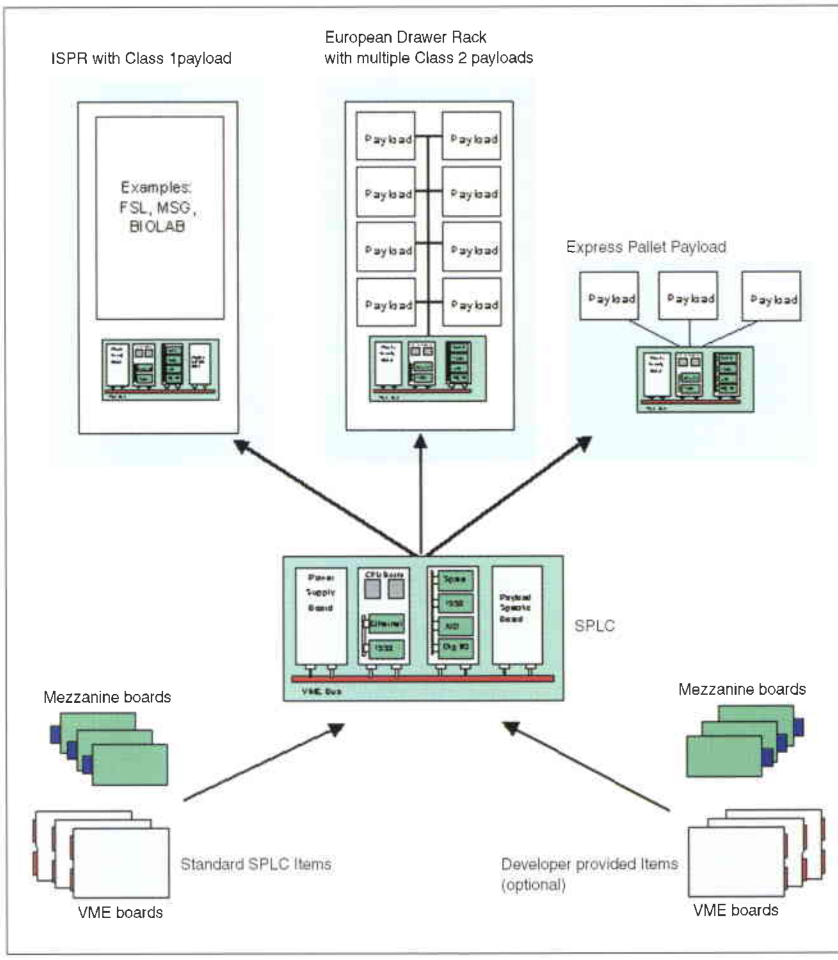


Figure 10. Different payload applications with SPLC

The SPLC is assembled from a core set of qualified boards. Where the SPLC does not provide a board suitable for a particular payload requirement, the payload developers may introduce their own boards. These boards are assembled in a flight configuration, optionally in an SPLC-provided housing or integrated into a developer-provided box. The configured SPLC may then be integrated into its target environment. In the examples shown this may be an ISPR containing a Class 1 payload facility, a European Drawer Rack containing multiple payloads or a stand-alone experiment on an Express Rack Pallet.

Software development environment and ground support equipment

To support software development, checkout, and testing of the payload and SPLC, a combined Software Development Environment (SDE) and Electrical Ground Support Equipment (EGSE) is an integral part of the development. In keeping with the SPLC philosophy, this is based on commercial equipment and reputable public-domain software.

The SDE functionality is implemented using a Unix work station which provides all the necessary tools (VxWorks development environment compilers, debuggers, etc.) to assist the payload developer in the preparation of mission-specific software.

For EGSE, the work station is complemented by a commercial VME crate containing the necessary hardware to connect to all of the SPLC interfaces. Additional VME boards may be added by the payload developer to verify payload-specific interfaces.

To support payload development and testing, the EGSE will incorporate a Payload Computer Test System (PACTS). This software will be pre-configured with a suite of tests for initial SPLC acceptance, and will support payload developer test software for verification of mission-specific application software.

The PACTS software integrates a number of freely available tools to provide a seamless interactive testing environment. This environment is ideal for payload integration staff and scientists whose area of expertise is not computer programming. The tools are mature and widely used in industry.

Test sequences are written in a simple but powerful interpreted language. In addition to procedures, loops and conditional constructs, the language provides object-oriented features such as classes, inheritance, and hiding of private data and functions. This provides a safe, simple and efficient environment for the productive development of large suites of test software. A standard database is used to describe the system configuration under test.

The PACTS provides colour synoptic picture displays, which can be linked to telemetry data by the user. A graphical editor is provided for creating pictures and linking to parameters. During a test session, these pictures are animated by values extracted from the payload telemetry data.

Development history

The SPLC has a long development history. As far back as 1988 ESA recognised that simple and low-cost payload interfacing was a key parameter to the success of payload deployment within the Columbus Programme.

A number of Technology Research Programme (TRP) studies combined under the general heading of Space Data Network (SDN) led to a recommendation for a payload controller based on VME. This resulted in the prototype development of an Adaptable VME Controller for Space (AVECS) and a recommendation for the use of the VME/ERC32/ and VxWorks. In the same time-frame, a VME-based computer was selected for the Data Management System of the ISS Russian service module with direct reuse in the COF.

In 1997, an open competitive Invitation to Tender (ITT) was issued by the Agency for a standard payload computer. The SPLC contract was subsequently awarded to DASA-RI Bremen.

The SPLC project has hence been split into two phases:

- a development phase
- a recurring production phase.

The development phase is scheduled for completion by mid-1998 with the delivery of the qualification- and engineering-model units together with software and the supporting Electrical Ground Support Equipment and Software Development Environment (EGSE/SDE). The production phase will commence immediately afterwards based on an initial order from ESA. Subsequent units will be available at recurring cost according to payload requirements.

SPLC deployment
The deployment of the SPLC will be handled as part of the Standard Payload Outfitting Equipment (SPOE). This is an existing ESA contract providing development and procurement of those items considered common to all ISS payloads.

SPLC units may be ordered by payload developers. The envisaged list of standard items is presented in Table 1. This may range from single VME or mezzanine boards for incorporation into an existing payload design, to a pre-configured SPLC box with embedded software.

As previously mentioned, low-cost engineering versions of all boards are available. These boards may be independently procured.

The SPOE prime contractor will establish a common spares and software maintenance policy. The software maintenance will cover the VxWorks kernel, basic software and test system. Individual hardware and software support may be requested under a separate agreement.

Conclusion and outlook
With the introduction of the SPLC, ESA intends to encourage the development of a standard data handling infrastructure for all European ISS payloads. This infrastructure is founded on proven commercial standards and concepts, allowing many of the advantages enjoyed by commercial ground users to be brought into the arena of space.

The core set of boards and software of the initial development are sufficient to cover the most common payload interfacing requirements, with configurations ranging from a single board computer to a complex arrangement of processors and interfaces. However, the SPLC does not impose any particular configuration; instead it encourages use of a standard platform on which developers may base their implementation and allows the addition of purpose-built boards to support new interfaces, at the same time increasing the stock of available boards.

This arrangement will obviously reduce development and qualification costs as they are incurred only once; further savings are possible due to the bulk component purchasing and the use of a common software and hardware maintenance policy for all payloads. But perhaps the most significant contribution will be that brought by standardisation. Once European industry has embraced this new standard, it will have a much broader base at which to target its products and risky, one-off developments will be kept to a minimum.

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W. Häbel (DASA-RI)
J. Kolinowitz (DASA-RI AVECS Project Manager)

Europe Ready for Ariane-5 Production

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D. Chopin & V. Waughray
Directorate of Launchers, CNES, Evry, France

ESA has shown and continues to show that, despite their differing perceptions and interests, scientists, engineers, industry and governments can overcome national and institutional barriers in the pursuit of a common goal. ESA, in fact, is intended to be not merely an agency dedicated to space, but also an organisation that combines technology and industrial policy at the European level.

Over the last 30 years, Europe has managed to develop a strong capability in all sectors of space activity, and to keep pace with the high-technology developments that the space era has brought in all areas, ranging from space science to space transportation. Cooperation in space research, achieved by combining European scientific and technological potential, is one of Europe's most visible and truly great achievements.

The Ariane family of launchers, which gives Europe autonomous access to space at an affordable cost, is an outstanding example of European success achieved through collaboration.

Production programme re-evaluated

The Ariane family has steadily evolved over time, with mission objectives and the performance of the launchers continuously being modified to meet commercial needs and remain competitive. In turn, the production and launch facilities have also had to be regularly upgraded.

In November 1987, the Ministers of ESA's Member States agreed to finance the Ariane-5 development programme, thereby giving Europe the means to develop the launcher it needs for the next century. As part of that programme, all facets of production have had to be redefined.

The industrial facilities to produce, test and integrate the launcher elements had to be set up very early in the development phase, to be ready for the production of the first ground test and flight demonstration models, and for system validation.

More than 100 companies and 6000 people from 12 European countries have been involved in the development. The industrial organisation established was based on European industry's experience gained through the development of the earlier launchers, Ariane-1 to Ariane-4, and on the principles of ESA's industrial policy. ESA delegated the technical and financial management of the programme to CNES, the French space agency. After completion of three qualification flights, the operation and exploitation of the launch system will be entrusted to Arianespace. As it currently is for Ariane-4, that company will also be responsible for managing and financing the production of Ariane-5 vehicles, marketing launch services world-wide and carrying out launch operations at the Guiana Space Centre in Kourou, French Guiana.

In addition, many launcher elements have to be shipped from Europe to the launch site in Kourou. New containers have been developed to transport elements that are very large or require safe handling from the production facilities, across Europe and the Atlantic Ocean to the recently-upgraded harbour in Kourou. They are moved by road, rail, river or sea to major European harbours, loaded onto seagoing vessels and shipped across the ocean (Fig. 1).

Design criteria

The design of the production facilities was greatly influenced by both the criteria imposed on the development of the launcher and the production design principles adopted.

To minimise risk, several criteria have been applied to the development of the Ariane-5 launcher and the associated ground facilities. They are:

— **Launcher reliability:** With payloads becoming increasingly costly, and potential

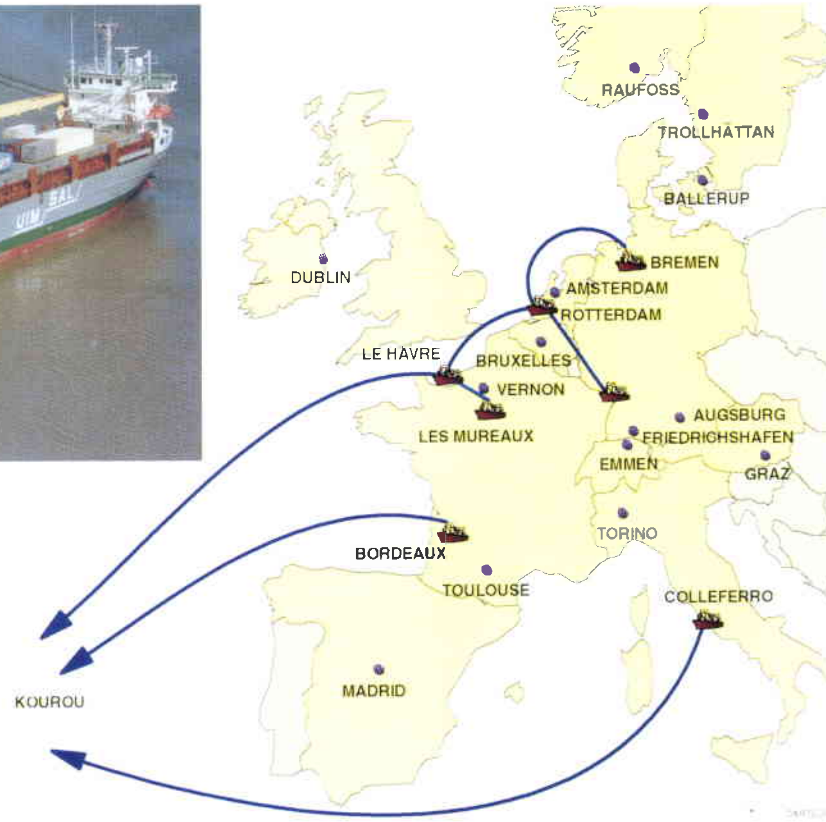


Figure 1. Launcher elements are transported by road, rail, river and sea from their production site to a major European port and then by ship to Kourou. The inset shows a main-stage transport trailer being rolled off from the transatlantic vessel in Kourou harbour

operating losses from a launch failure continuously escalating, commercial users are demanding that the launcher offer the greatest possible reliability. If this reliability is not demonstrated through successful flights, launch insurance premiums will increase.

— Use of proven technologies: In order to meet cost, schedule and reliability requirements during the development programme, only proven technologies must be used.

— European autonomy: Autonomous access to space implies that all aspects of launcher production and operation have to be mastered in Europe. To this end, strict control has to be kept over:
  — the procurement of raw materials, basic components (e.g. special alloys, carbon fibre or electronic components), and propellants
  — the purchase of sophisticated components and even complete subsystems (e.g. rate gyros, computers, and ground equipment)
  — the provision of services, in particular the ground network.

Given the planned production rate of at least eight launchers per year for the next 15 years, several technical and industrial choices had to be made to ensure the following:

— Minimum disruption as a result of any single industrial failure.
— Technologies employed are not likely to become outdated during the given period, or can be modified without a complete redefinition of the basic concepts.
— The recurrent costs are kept as low as possible through the right choice of production and operation techniques, and particular emphasis is placed on reducing maintenance or replacement costs of equipment (design-to-cost approach).

The production and transport processes for each launcher element

The basic approach taken was to produce the Ariane elements in Europe and to integrate them at the Guiana Space Centre (for safety reasons, the booster propellant plant (UPG), the booster integration building (BIP), and the booster test stand (BEAP) were built in French Guiana).

Approximately 30% of Ariane-5 facilities were built in Europe and 70% in French Guiana. Approximately one billion ECU (European Currency Units) have been invested in the ground facilities, representing 20% of the total cost of the Ariane-5 development programme.

Only the Ariane-5 facilities involving major dedicated ESA and/or industry investment are considered here.

Solid propellant stage (EAP)

The EAP is composed of four main subsystems (Fig. 2): the solid propellant motor; the forward skirt; the aft skirt, which supports the whole launcher on the launch platform until lift-off; and the nozzle control system*. Together, the two EAPs provide 90% of the launcher's thrust at lift-off, transmitting it to the core stage via the forward attachment device on the front skirt.

** The EAP manufacturing, integration and test facilities in Kourou were described in ESA Bulletin No. 75 (August 1993).*

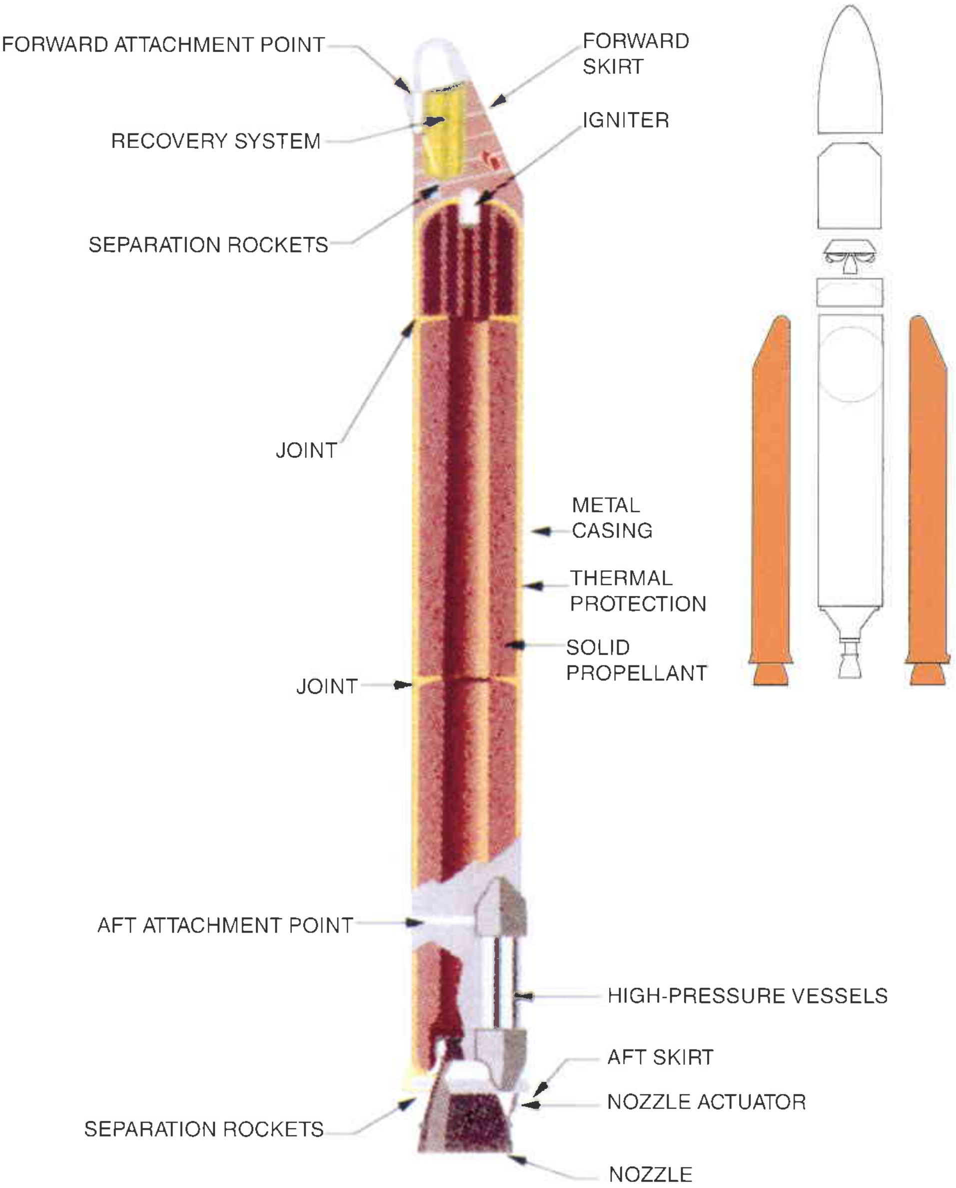


Figure 2. The solid propellant stage (EAP) and its components. The photograph shows a fully integrated solid booster leaving the Booster Integration Building at the Guiana Space Centre

Some Ariane-5 launchers will also carry a special 'recovery kit' with parachutes located inside the front skirts of the EAP. These parachutes will be used to recover the boosters from the sea, after a launch. The boosters will then be analysed at the Guiana Space Centre, and some components will be returned to Europe.

The main propulsion stage is made up of five main components: the front segment S1, the central segment S2, the aft segment S3, the nozzle, and the igniter.

The industrial cycle starts at the MAN-Technologie plant in Augsburg (Germany) with the manufacture and proof-testing of the metal cases of the segments. The S2 and S3 segments are each made up of three cylinders, assembled in Augsburg with 'factory joints' of the clevis-tang type. The S1 segment consists of only one cylinder.

These activities are carried out in two buildings: the case production building and the proof-test building. The most important item of equipment is a counter-roller flow-turning machine. Weighing 500 t, it cold-forms cylinders from a blank of special steel, reducing their wall thickness from 40 mm to 8 mm and increasing their length from approximately 1 m to 3.5 m. A precise heat tempering/quenching treatment then gives these thin-walled sections a breaking strength of 1500 N/mm^2.

A booster consists of seven such sections plus a front dome and an aft dome, which are later joined in a shear pin connection, yielding an overall length of 25 m. The clevis-tang joints withstand a traction force of 50 000 kN during the ignition phase of a launch, and must meet tolerance ranges calibrated in hundredths of a millimetre.

The booster metal cases are shipped from Augsburg (Germany) to Colleferro, near Rome (Italy), where the internal thermal insulation is installed at the dedicated Fiat Avio plant. The insulation is made of rubber (silica and kevlar-filled EPDM) produced by SNECMA/SEP in Bordeaux (France). The metal case degreasing system, the blasting system, the rubber application system, and the autoclave for vulcanisation of the rubber insulation are the main elements of the thermal protection plant.

The thermally-protected front segment S1 is then sent to the propellant plant, also located in Colleferro-Rome, for casting operations. The insulated central and aft segments are shipped directly to the Guiana Propellant Plant (UPG) in Kourou for casting.

The nozzle is manufactured at a dedicated SNECMA/SEP plant in Bordeaux (France) and shipped to Kourou for integration with the EAP. The igniter is cast and assembled at the Fiat Avio plant, and then shipped to Kourou for integration with the EAP.

The forward and aft skirts are manufactured by SABCA near Brussels (Belgium).

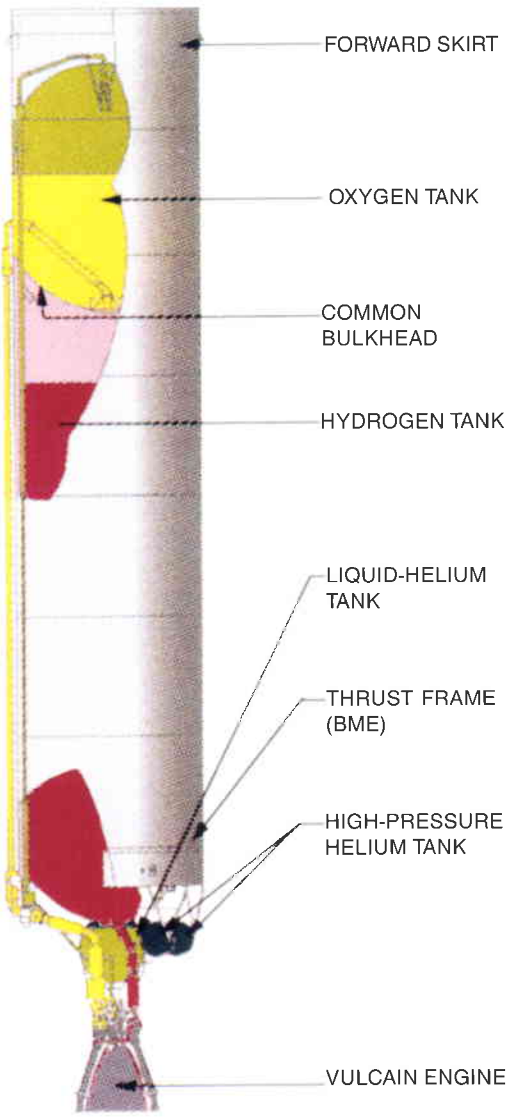
Cryogenic main stage (EPC)

The EPC is composed of five subsystems (Fig. 3): the Vulcain engine and its actuation system, the main tank, the thrust frame, and the forward skirt.

Vulcain engine

The Vulcain engine is made up of four main components: the hydrogen turbopump, the oxygen turbopump, the combustion chamber and the nozzle. The hydrogen turbopump is manufactured by SEP in Vernon (France), the oxygen turbopump by Fiat Avio in Turin (Italy), the combustion chamber by Daimler Benz Aerospace (DASA) in Ottobrunn (Germany), and the nozzle by Volvo Aero Corporation in Trollhättan (Sweden).

The engine is assembled in the SNECMA/SEP cryogenic motor assembly building in Vernon. Firing tests to support the development of the Vulcain engine started in 1990 on two identical,



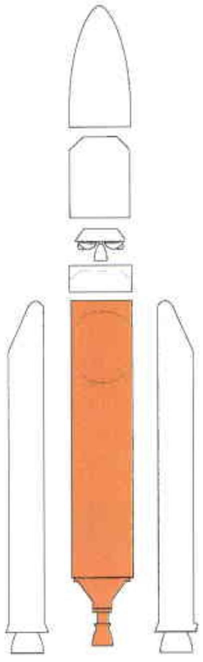
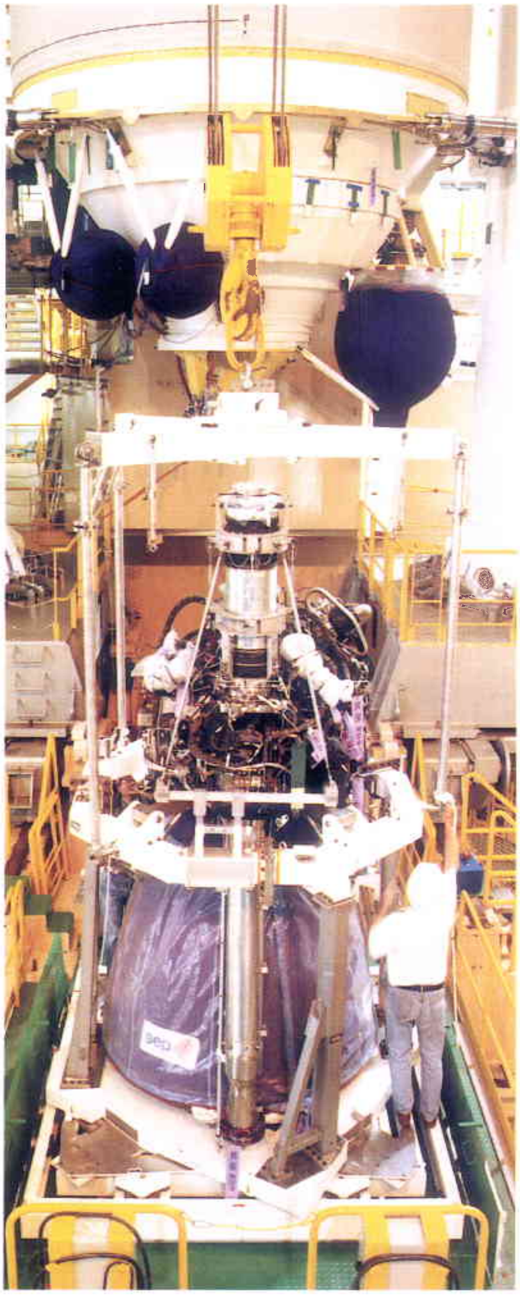


Figure 3. The cryogenic main stage (EPC) and its main components.The photograph shows a fully integrated main stage being brought to vertical position at the Launcher Assembly Building in Kourou



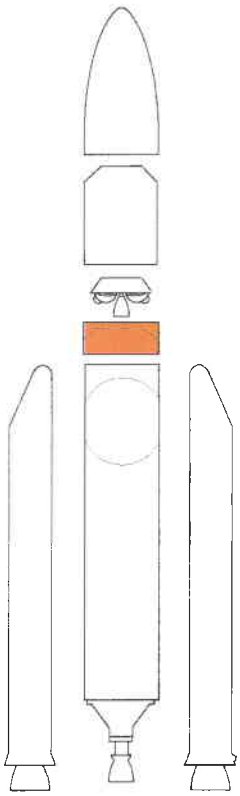


Figure 4. Although the Vulcain engine is integrated into the main stage in Europe, the necessary tooling and procedures are in place in case an engine has to be replaced at the launch site

specially-built test stands, the PF50 stand at SEP in Vernon and the P5 stand at DLR in Lampoldshausen (Germany).

Main tank

The main tank is made of aluminium composite and is divided into two volumes by a common bulkhead. It contains 130 t of liquid oxygen at −180°C and 25 t of liquid hydrogen at −250°C. The metal case is made up of three bulkheads and seven cylinders.

The main tank production cycle starts at DASA/Dornier in Oberpfaffenhofen (Germany) with the manufacture of the three tank bulkheads: the forward bulkhead (oxygen tank), the aft bulkhead (hydrogen tank) and the common bulkhead. Each bulkhead is made up of eight sectors and a Y-ring which provides an interface between the bulkhead and the other EPC components. The most sophisticated pieces of equipment in the facilities are the three welding machines.

The seven cylinders, each one comprising three pre-formed and welded panels, are manufactured at the Cryospace plant in Les Mureaux (France). The cylinders and the bulkheads are then welded together, pressure-tested, insulated, equipped, and finally delivered to Aerospatiale's plant on the same site, for assembling into the EPC stage.

Forward skirt

The forward skirt is made of aluminium and fibre composites. It transmits the thrust generated by the boosters through two fittings to the launcher's central body. These fittings also contain the booster forward jettison mechanisms.

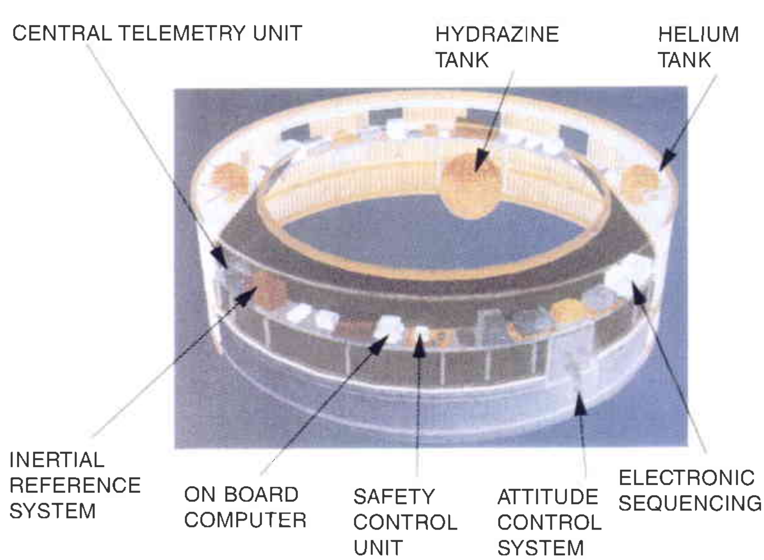


Figure 5. The Vehicle Equipment Bay (VEB). The photograph shows a VEB being mated on top of the main stage in Kourou

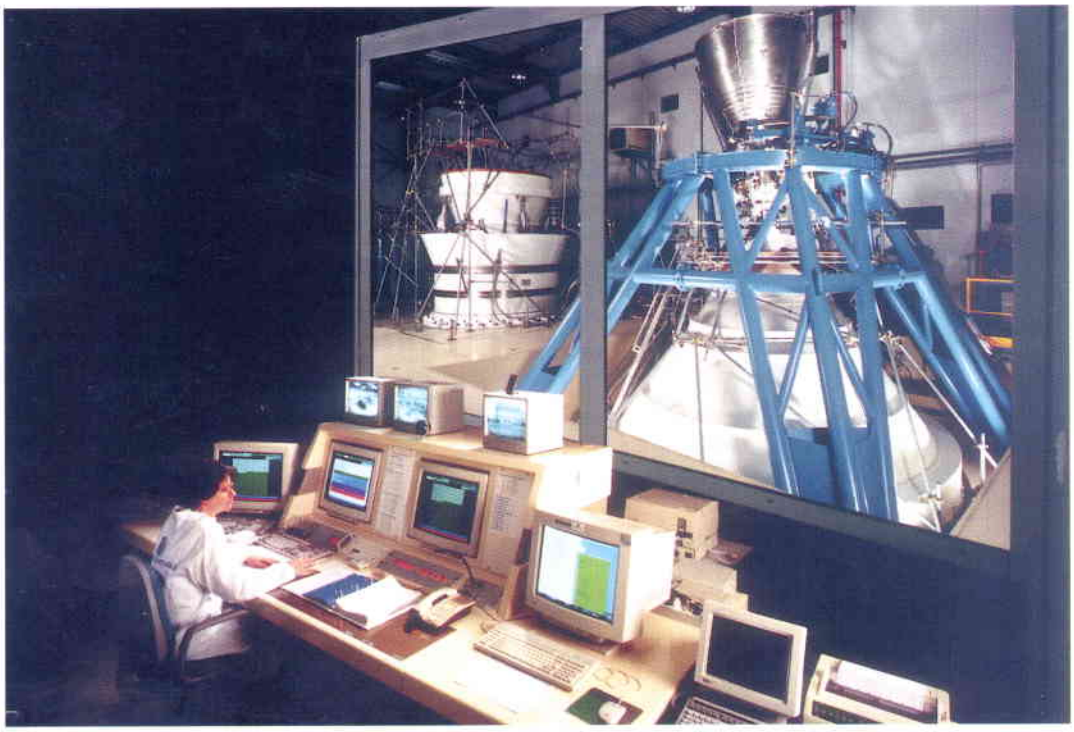
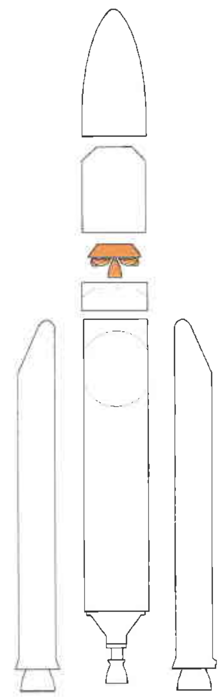


Figure 6. The Functional Simulation Facility at Aerospatiale used to verify the flight-specific software for each launch (Photo courtesy of Gonin/Aerospatiale)



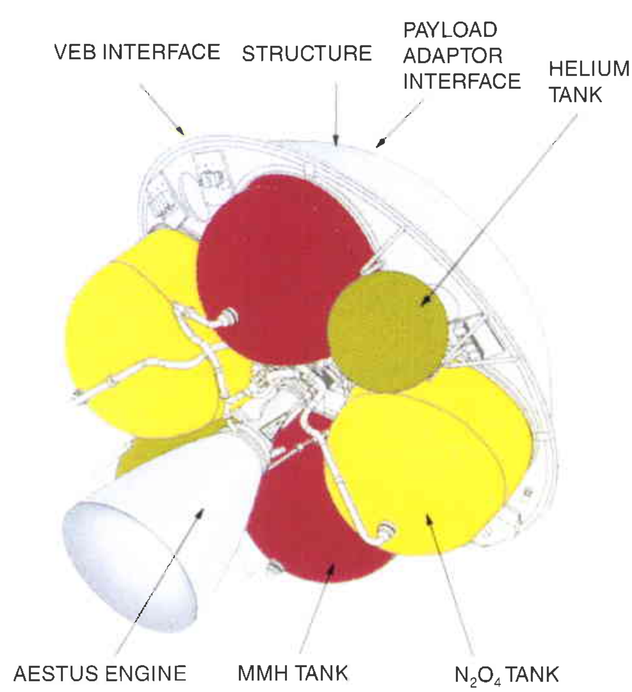
The forward skirt structure is manufactured at MAN-Technologie in Augsburg (Germany). It is then delivered to Aerospatiale in Les Mureaux, where measurement, control, telemetry and pyrotechnic items are installed.

Thrust frame
The thrust frame is assembled at Fokker's Special Products plant in Hoogeveen (The Netherlands) and then shipped to Aerospatiale in Les Mureaux.

The engine thrust actuation unit, the hydraulic system that activates the thrust vector control of the Vulcain engine, was developed and is manufactured at SABCA near Brussels (Belgium).

EPC assembly
All EPC elements and related electrical systems are assembled and then tested using a specific checkout installation in the Aerospatiale assembly building on the banks of the Seine in Les Mureaux. The checkout equipment used during the launcher integration campaign in Kourou is fully compatible with that in Les Mureaux, enabling the same verifica-

Figure 7. The storable propellant stage (EPS). The photograph shows a fully integrated EPS



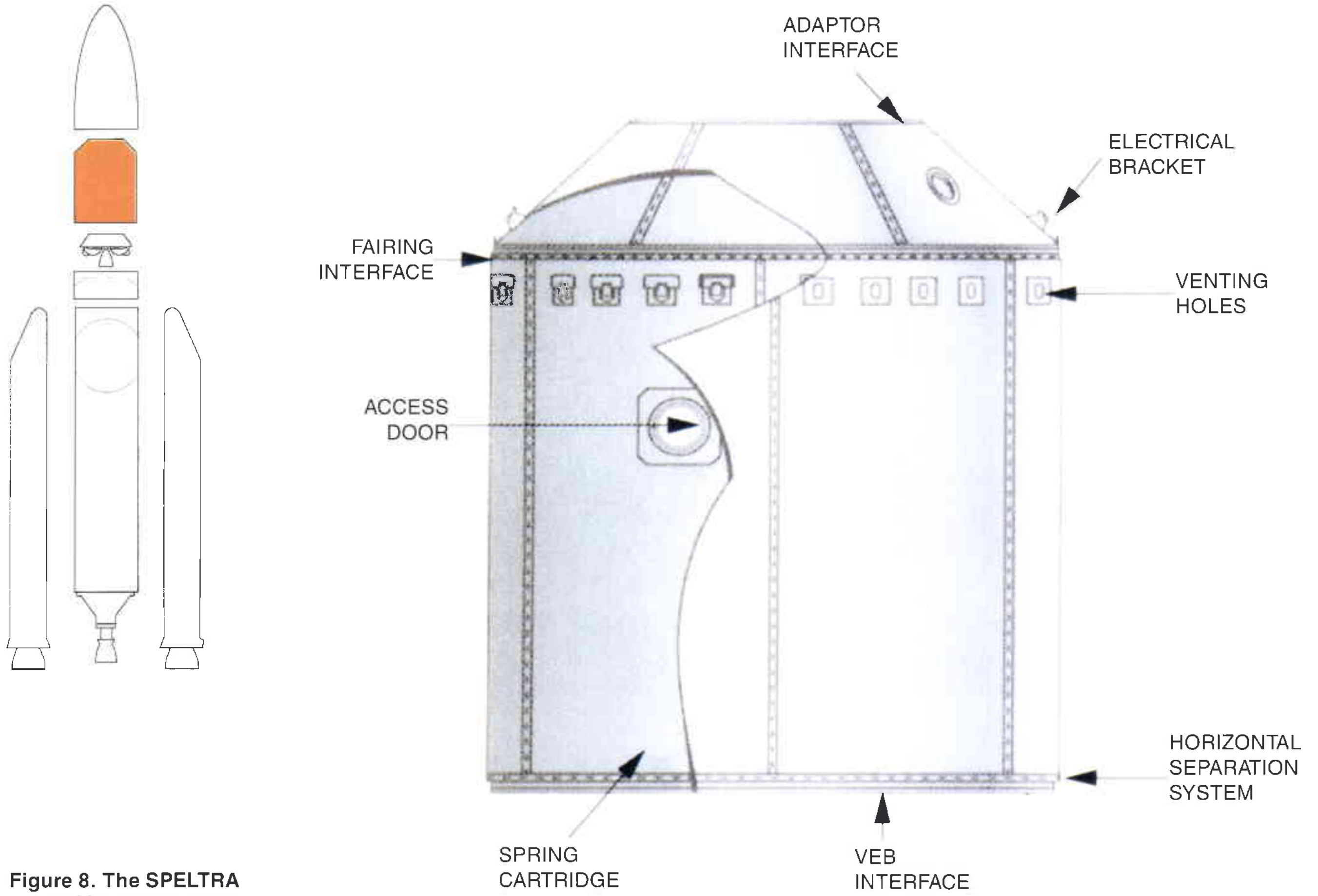


Figure 8. The SPELTRA and its components

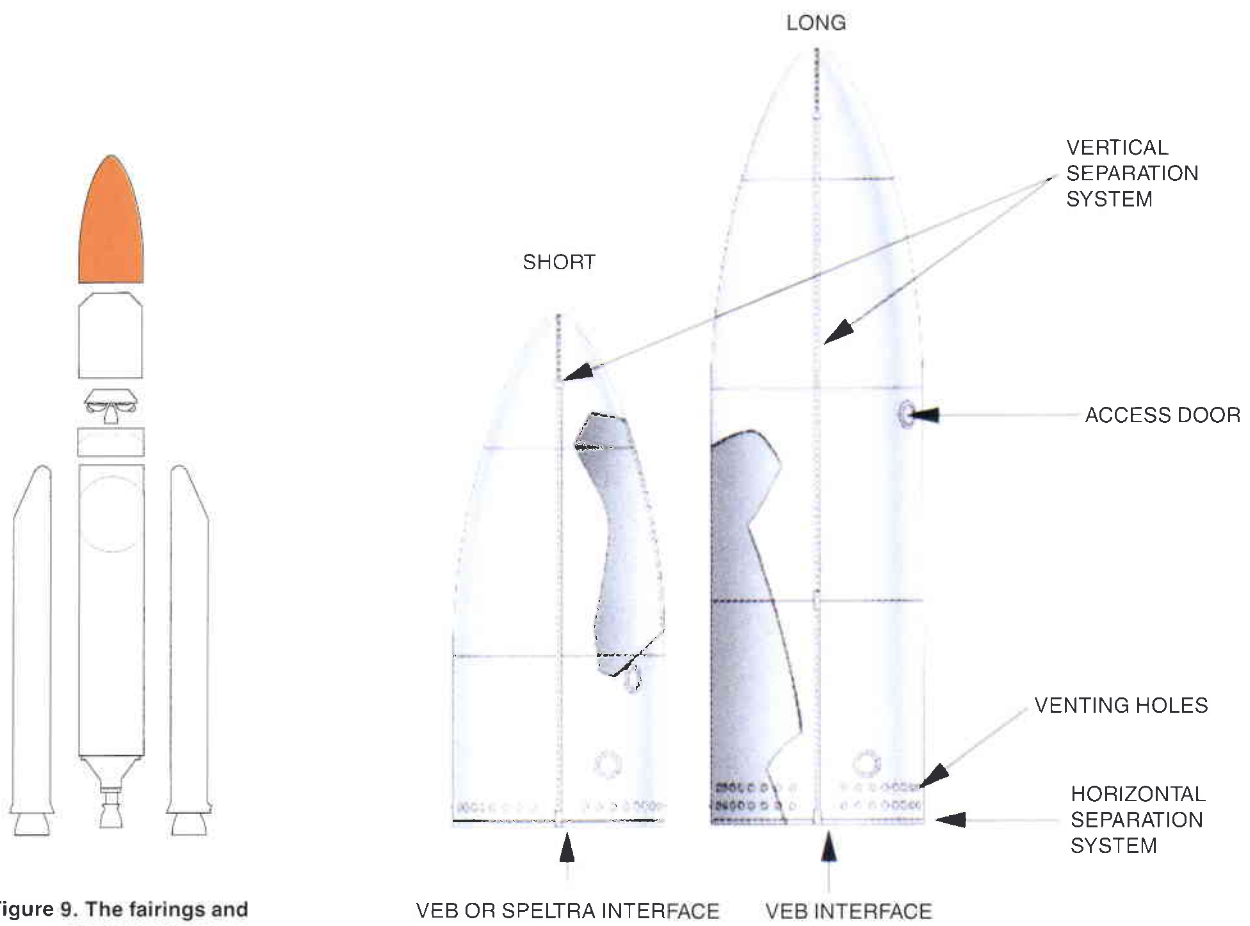


Figure 9. The fairings and their components

Figure 10. The SPELTRA being assembled at Daimler Benz Aerospace in Germany

tions to be run both in Europe and French Guiana.

Once completed, the EPC is placed in a special transport container and shipped to Kourou via the French port of Le Havre (Fig. 1).

Electrical and software system

The Vehicle Equipment Bay (VEB) contains electrical and electronic equipment that performs launcher guidance and control during flight (Fig. 5). It consists of a mechanical structure, including the main structure made up of a cylindrical section and an internal cone, made of aluminium alloy and built by CASA in Madrid (Spain). CASA developed special cylinder and cone assembly tooling for this purpose. The structure is delivered to Matra Marconi Space in Toulouse (France) for integration of the electrical and electronic equipment. Those subsystems include:

- The flight control subsystem including the on-board computer, which is supplied by Saab (Sweden), the electronic sequencing unit from CRISA (Spain), the inertial reference system by Sextant (France), and the switching unit by ETCA (Belgium).
- The electrical power subsystem, including the power distribution unit, which is supplied by Alcatel Kirk (Denmark).
- The telemetry subsystem, including the central processing unit and transmitters, supplied by Intertechnique (France), and the antennae by Saab (Sweden)
- The safety subsystem, including the safety command unit, provided by ETCA (Belgium) and the arming safety unit supplied by Raufoss (Norway).
- The attitude control system, supplied by DASA (Germany). Its main functions are launcher roll-control after booster jettisoning and attitude control of the upper composite during the propulsion phase of the storable propellant stage. It is hydrazine-fuelled and is made up of two tanks and two thruster modules. Specific facilities have been developed for the integration and acceptance of the attitude control system in the VEB: a propellant and pressure loading system; a unit tester; a helium sensor; and measurement and integration tooling.

ETCA (Belgium) has developed a functional checkout system for the VEB, as well as most of the software. Equivalent checkout systems are used at the integration site in Toulouse and at the launcher assembly site in Kourou.

Once integrated, the VEB is taken by road to Les Mureaux, for onward ship transport to Le Havre and Kourou.

Storable propellant stage (EPS)

The EPS is composed of three major subsystems (Fig. 7): the Aestus engine, the mechanical structure and the propellant tanks. The stage was developed by DASA in Bremen (Germany), where stage integration is also performed during the production phase.

The Aestus engine is manufactured by DASA in Ottobrunn (Germany). The engine development tests were carried out at the DLR test stands in Lampoldshausen (Germany).

The mechanical structure was designed as a truncated cone with an upper flange to interface with the VEB. It is manufactured at the CASA plant near Madrid (Spain) and transported to Bremen by road.

Each propellant tank consists of a cylindrical section and two hemispheres made of an aluminium composite. Special equipment has been set up at the Zeppelin plant in Friedrichshafen (Germany) for spin-forging of the cylinders, spin-forming of the hemispheres, heat treatment, and welding of the spheres onto the cylinders.

The assembly, integration and testing of the EPS is carried out on a test stand at the DASA facility in Bremen. This stand is composed of two EPS assembly jigs, and separate electric and pneumatic check-out units. The stand's design affords easy access for integration of stage elements and components since it can handle the hardware in vertical, roll and pitch positions.

The assembled EPS stage is shipped from Bremen to Kourou, via Rotterdam and Le Havre. In Le Havre, it is loaded with other Ariane elements onto a single, custom-built vessel.

External carrying structure for multiple payloads (SPELTRA)

The major structural components of the SPELTRA (Fig. 8) are the carbon-fibre reinforced panels in the cylindrical and conical parts, and the rings. DASA/Dornier in Friedrichschafen (Germany), which is responsible for the development of the SPELTRA, has set up special manufacturing and inspection equipment for the components, and an assembly stand (Fig. 10).

The complete SPELTRA is loaded in the harbour at Kehl on the Rhine and shipped to Kourou via Rotterdam and Le Havre.

Flight adaptors

These are the conical interfaces between launcher and spacecraft. They are made by CASA in Spain using an aluminium honeycomb core reinforced with carbon-fibre layers. Saab (Sweden) provides the clamp-bands for securing the spacecraft during launch, which are released pyrotechnically for spacecraft injection into orbit.

Fairing

The fairing (Fig. 9) is manufactured by Oerlikon Contraves in Zurich (Switzerland).

A vertical integration station in the integration building used for Ariane-4 at the Swiss Federal Aircraft Plant in Emmen has been upgraded for Ariane-5 fairing integration (Fig. 11).

Once completed, each half shell is placed in a custom-made container and transported to the harbour at Basle on the Rhine, and then shipped to Kourou via Rotterdam and Le Havre.

Flight data evaluation

To ensure that optimum launcher performance is maintained, flight data will be evaluated after each launch and, if any anomalies are detected, vehicles in production at that time will be modified.

Although a quick-look evaluation of launcher telemetry is done in real time, it covers only a small proportion of the data. A much more detailed analysis of hundreds of parameters relating to propulsion, guidance, and stage separations for example, is performed after each launch. They are recorded during flight at the Ariane downrange stations. Raw data are then sent, after the flight, through dedicated high-speed links to CNES in Toulouse, where they are decoded, precisely time-stamped and pre-validated.

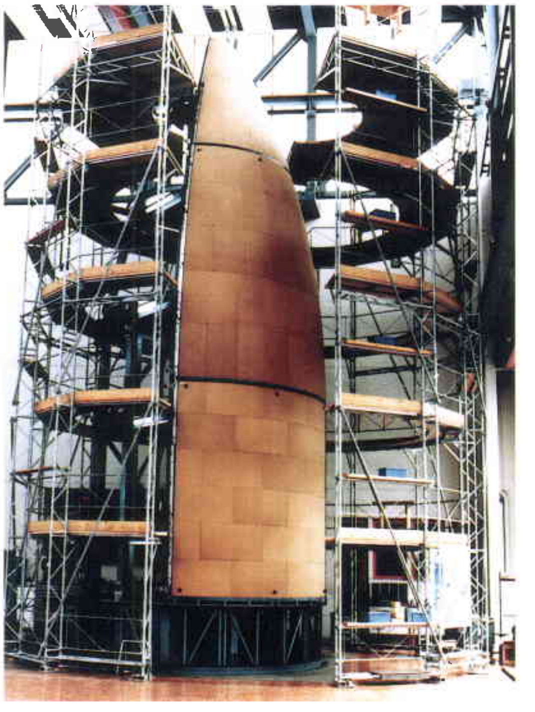


Figure 11. Vertical integration of a fairing

From Toulouse, processed flight data are sent to CNES in Evry and to SEP in Vernon, where the various launcher manufacturers can log in and analyse the data, beginning as soon as four days after launch. Any flight anomalies identified must be fully understood and the production process modified accordingly.

Conclusion

At the current stage of the programme, the industrial facilities are well adapted to production of the new Ariane-5 launcher. One or two need to be upgraded to be compatible with the planned launch rate of eight or more vehicles per year for at least 15 years. Additional installations (buildings, machinery, tooling) are currently being developed, taking into account both the lessons learnt during the development of the launcher and the market expansion that is forecast by Arianespace, the launch operator.

An initial batch of 14 Ariane-5's was ordered by Arianespace from industry in 1995, and a second batch of 20 launchers is to be ordered in 1998 as part of a global commitment for 50 launchers. Once the three qualification flights (501 to 503) have been completed, operational exploitation will start with flight 504.

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ESA's Operational Network for Future Missions - The Introduction of Internet Technologies

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ESOC has implemented and maintains a spacecraft operations support network known as OPSNET, which connects the ESA ground stations and other space-mission-relevant sites with the Operations Control Centre (OCC) in Darmstadt. This article describes the concept and underlying technology of today's OPSNET, as well as the technological changes and augmentations that the present network architecture will undergo in the coming years in order to support Europe's future space missions in an optimal manner. The main drivers for making these functional and technological changes to OPSNET are:

- **the streamlining of organisational responsibilities within ESA**
- **the rapid developments taking place in communications technology and the maintenance limitations of legacy installations**
- **the need to improve interoperability with the operational networks of other agencies**
- **the changing communications requirements in terms of increased bandwidth, data delivery profiles, etc. of ESA projects like XMM, Cluster-II, Integral and Rosetta**
- **the challenge of reducing carrier costs by exploiting the changes in telecommunications tariffs brought about by recent market deregulation.**

OPSNET today

OPSNET was established for the transfer of mission-critical data, voice and message traffic required to support the simultaneous operation of several unmanned spacecraft through one mission-control system and one or more ground stations. As a by-product, it also has to support Spacecraft Validation Tests (SVTs) and Listen-In Tests (LITs) carried out at industrial Assembly, Integration and Test (AIT) sites.

OPSNET therefore connects:

- the central ESTRACK network control facility at ESOC with all of the appropriate ground stations
- active mission-control systems, as dictated by mission planning, with the baseband equipment at the respective ground station
- dedicated flight-dynamics data-processing systems with ranging, antenna-pointing and other mission-control systems at the ground stations
- the mission-control system with the satellite prior to launch when in the various launch-preparation areas at the launch site and eventually on top of the launcher.

In the context of cross-support between ESA and other space agencies, OPSNET resources enable the ground-station network control centres of the various agencies to communicate with one another and to coordinate the transfer of data. If ESA uses other agencies' ground stations, ESA-provided baseband and networking equipment in the form of a Network Data Interface Unit (NDIU) can be installed. This approach allows the other agencies' ground stations to be temporarily integrated into ESTRACK. Other support functions may be made available if a specific mission so demands, the transfer of mission-planning information between a payload operations centre and the respective mission operations centre being just one example.

OPSNET was designed as a Wide-Area Network (WAN). The services that it presently provides are based on Time-Division Multiplexing (TDM) of a combination of circuit and packet switching. Circuit-switched services are primarily exploited for the transfer of digitised voice messages, and very occasionally to transfer NASA NASCOM block or raw spacecraft telemetry (sometimes referred to as asynchronous telemetry). The packet switching is being made available in compliance with International Telecommunication Union (ITU) Recommendation X.25, allowing non-native X.25 subscribers to access the network via packet assemblers/disassemblers.

Figure 1 shows the topology of the present OPSNET X.25 network with the Integrated Switching System (ISS) nodes, the NASA and NASDA Gateways (GTWs), and the attached Network Management Systems (NMS). It is mainly exploited for the transfer of

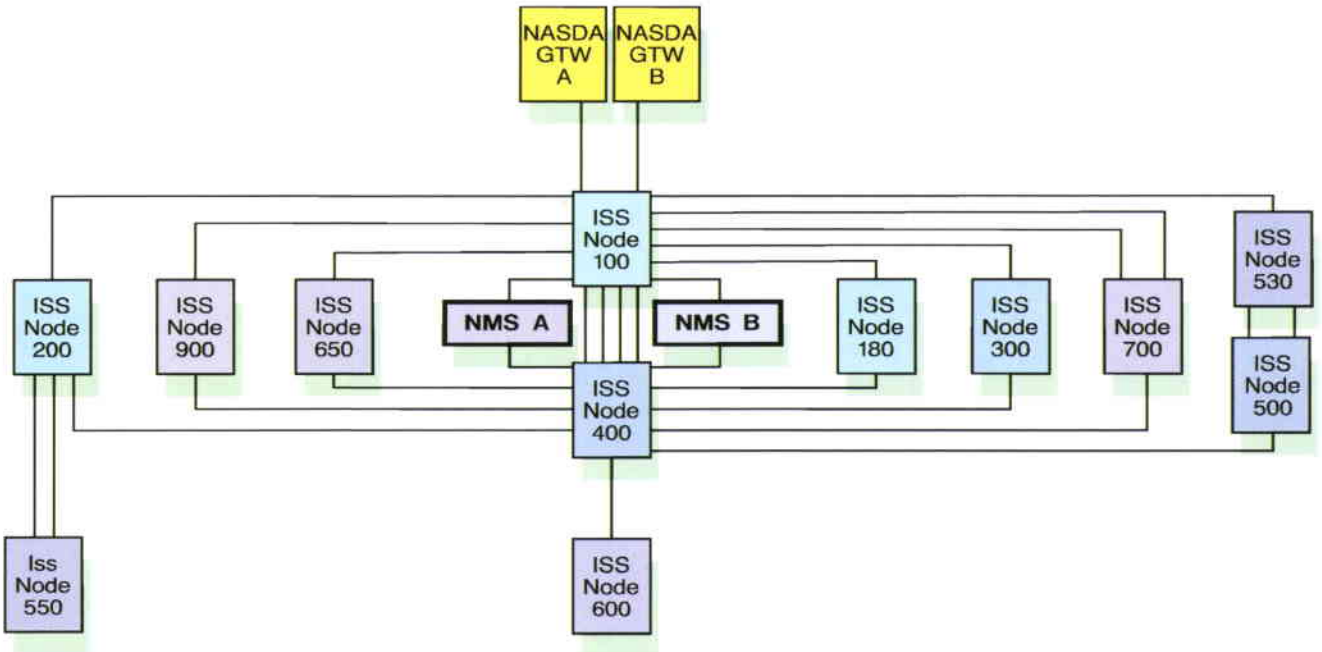


Figure 1. The OPSNET X.25 network topology

telecommand, telemetry, ranging, antenna pointing, station monitoring and control data and operational facsimile messaging between different ground stations, as well as between the ground stations and ESOC itself.

Most of the hardware presently in use for OPSNET is designed for the concurrent operation of X.25 and Frame Relay traffic, although the latter is not yet operationally exploited.

The fact that OPSNET provides mission-critical support means that the network security and network or link availability aspects need to be carefully addressed. The security needs are met by OPSNET being designed as a strictly administered and managed closed private network. Adequate network availability is ensured via the combination of four principles:

- selection of a suitable network topology (a double star within which the switching node at any operational ground station has access to two independent but inter-connected nodes at ESOC)
- operation of two diversely routed leased circuits of adequate bandwidth, or a combination of one leased circuit and one dial-up ISDN channel between ESOC (or a remote mission operations centre) and the appropriate ground station
- configuration of the communications nodes with redundant elements and automatic switch-over functions wherever suitable
- the central OPSNET facility is an integral element of the ESTRACK Network Control Facility (Fig. 2), which is operated around the clock using powerful network management systems (Fig. 3).

Although the present OPSNET meets all of the needs of current missions, it lacks the Internet Protocol (IP) support that allows direct access from the global Internet. ESA is therefore out of step in this respect with NASA and NASDA, which have already adopted IP technology to support their mission-critical communi-cations.

The drivers for migration to IP

Other than the transfer of telemetry, telecommand and ranging applications, the distribution of science telemetry was considered by various missions in the past to be a less critical task and was therefore mapped to other networks, e.g. ESA's administrative network known as ESANET. Today IP is the de-facto standard for inter-networking and thus ideally suited for such applications. With the advent of the World Wide Web (WWW), the market experienced another strong push towards TCP/IP, which relies on the Transmission Control Protocol (TCP) as the transport protocol and IP as the inter-networking protocol. Local Area Network (LAN) interface hardware and TCP protocol software became available free of charge for most computers, whereas X.25 interface cards and protocol software have remained costly add-ons, thereby making them less attractive. The flexibility of IP to use different WAN bearer services like leased lines, ISDN or Frame Relay to connect distributed LANs is another argument for the market penetration of IP technologies. Therefore the combination of connecting hosts to LANs, flexible WAN technologies, and the mature TCP/IP software make the IP protocol suite the most attractive for the future OPSNET.

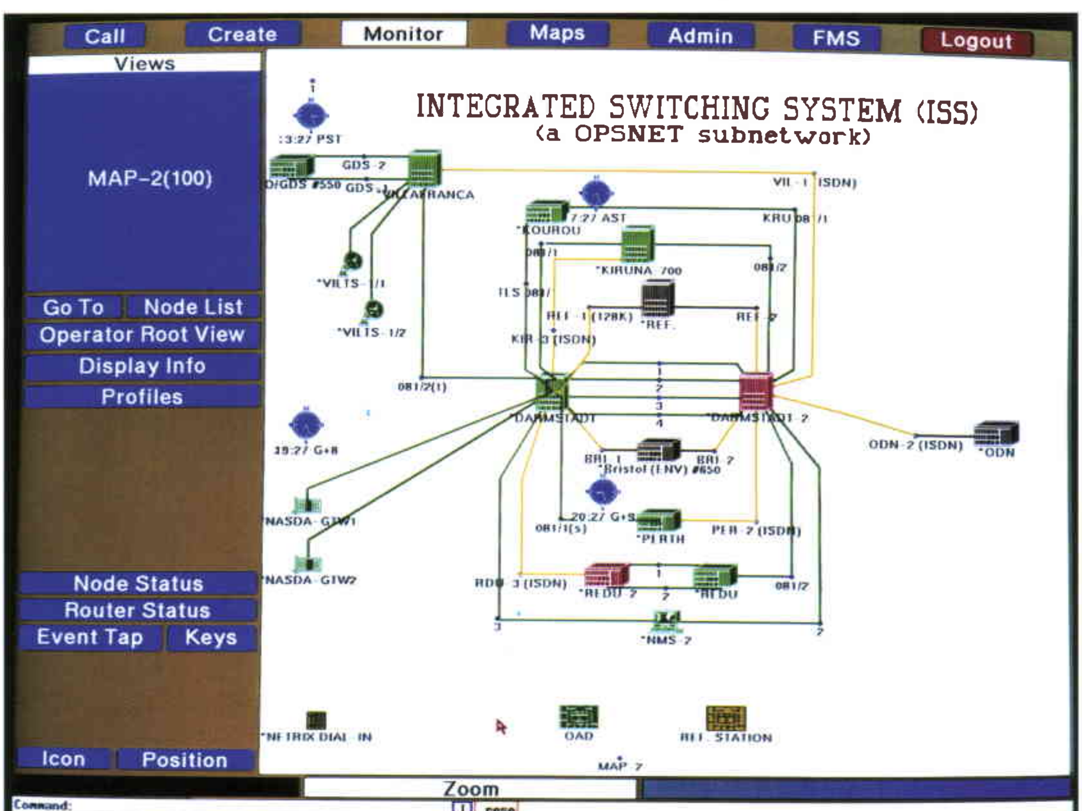


Figure 2. The ESTRACK Network Control Facility

Figure 3. The OPSNET X.25 Network Management Station

Given that ESOC is responsible for the development and operation of the entire ground segments for ESA missions, OPSNET must also be ready to support remote tele-science, scientific data distribution and improved mission planning applications and thereby cater for the complete range of communication requirements of a particular mission.

Other space agencies like NASA and NASDA are already moving their networks towards IP and the traditional approach to inter-agency ground station support will therefore have to change. In the past ESOC has placed ESA equipment at NASA ground stations, which involves high installation costs and a substantial maintenance effort. To overcome this and similar problems, new standards are presently being defined by the Consultative Committee for Space Data Systems (CCSDS) in the field of Space Link Extension Services to allow direct interoperability between ground stations and control centres in a multi-space-agency operating scenario. The goal is that no exchange of equipment should be required for ESA's and NASA's operational networks to provide an end-to-end spacecraft communication and control service.

Migration concept and strategy

The basic IP migration concept is to build-up a core OPSNET Intranet infrastructure (a private network based on IP routers), to which mission-specific elements can then be added. This core implementation involves the following basic components at ESOC:

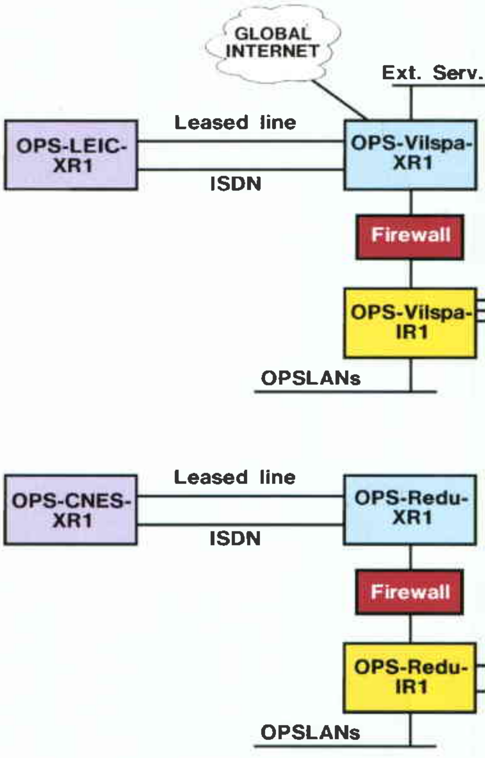
– the OPSNET Intranet point-of-presence (point where users connect to the network), which connects to existing operations LANs, to the existing OPSNET X.25 WAN, and to Internet Service Providers (ISPs) that allow communication via the global Internet, e.g. for World Wide Web (WWW) applications
– network and security management.

In the near future, project-specific points-of-presence will be added at the following stations:

– Redu (Belgium) to serve the Spot-4/Artemis spacecraft
– Villafranca (Spain) to serve the XMM mission
– Kiruna (Sweden) to serve the Envisat platform.

As part of a general upgrading of the ESA S-band stations, the following points-of-presence will also be added:

– Kourou (French Guiana)
– Perth (Western Australia)
– a reference station at ESOC.



The core OPSNET Intranet topology is shown in Figure 4. The internal routers (yellow) connect, via a variety of wide-area communication resources (OPSNET WAN, leased lines, ISDN), the various Operational LANs (OPSLANs) on which the application end systems reside (not shown). At ESOC and Villafranca secure connectivity to the global Internet is provided by security gateways/firewalls. From the external routers (blue), dedicated connectivity can be provided to other points-of-presence that reside outside the security perimeter, but are still part of the OPSNET management domain. External Services LANs which provide the main externally visible applications (e.g. scientific data archive) are accessible from outside, including via the global Internet. The centralised network and security management tasks (green) will be conducted from ESOC.

As any change to a relatively complex network like OPSNET inevitably involves some risk, ESOC has established a reference network for validating proposed new services, for simulating problems like network congestion, and for evaluating the in-service performance of new technological features before implementation.

The communications aspect

The OPSNET Intranet provides a secure and reliable IP-based network service, i.e. all applications residing in the attached end systems at the control centres, ground stations and other remote locations will use IP as the

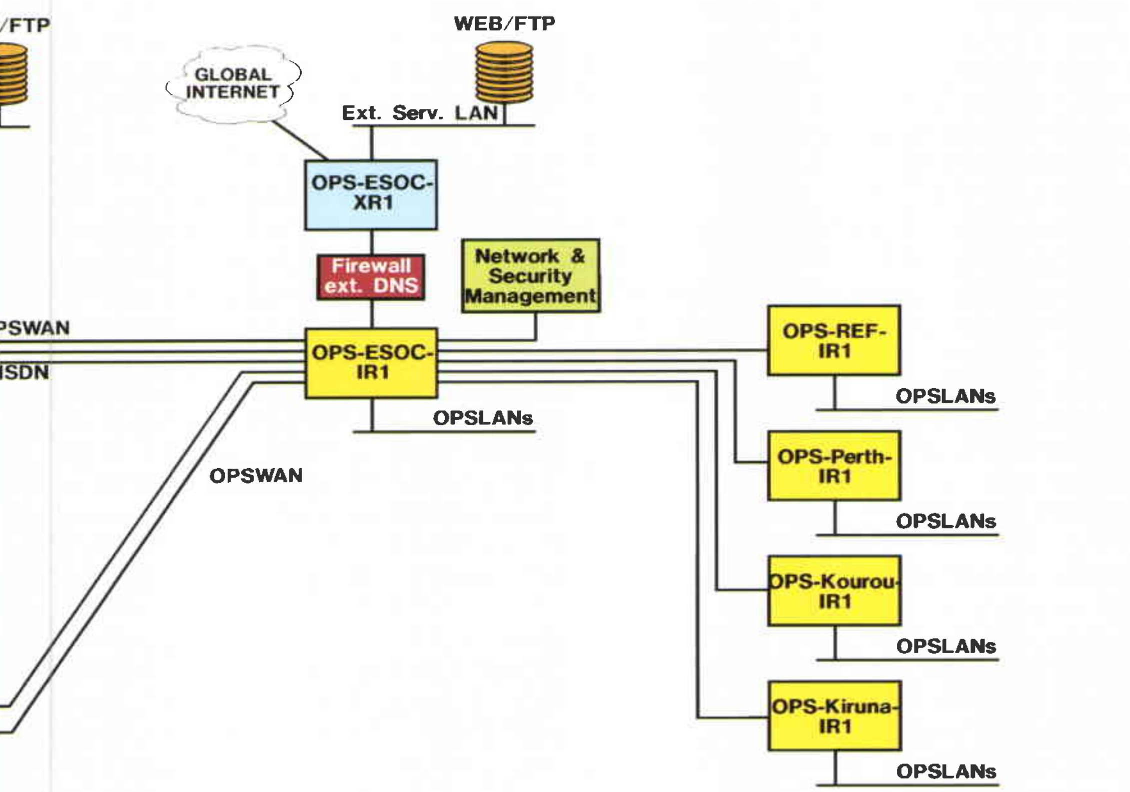


Figure 4. The core OPSNET Intranet topology

inter-networking protocol. The connection-oriented TCP or the connectionless User Datagram Protocol (UDP) will be used as the transport protocol. End systems will be connected via LANs to routers that allow interfacing to a variety of different WAN bearer services.

Initially the OPSNET X.25 service will be maintained as the main bearer service because the existing OPSNET WAN has points-of-presence at all ESA ground stations. This bearer service will be augmented by ISDN on-demand connections, permanent direct terrestrial or satellite-based leased lines, or Frame Relay virtual private network services. This will allow the cost-efficient provision of additional dial-up or permanent bandwidth.

A crucial requirement for any operational communication service is to guarantee throughput and high availability for critical applications. In the past this was achieved by dimensioning the links to meet the individual project needs in a well-specified, fixed operational scenario. By diverse routing of redundant links, an availability of 99.93% is generally achieved. This scheme today does not foresee communication resource reservation or prioritisation on an application basis being enforced by the X.25 network. This leads to inefficient utilisation of the redundant link resources, since the redundant link is barely used during normal (non-failure) operations.

The OPSNET Intranet will initially use IP Version 4, which is the present standard for IP-based networks but which does not allow standard bandwidth reservation. IP Version 6 which is presently being standardised/developed does foresee resource reservation (bandwidth guarantees) and priority allocation in the event of congestion in individual traffic flows. When integrated into the OPSNET Intranet, it will guarantee the most appropriate quality of service for supporting mission operations.

The security aspect

Traditionally OPSNET, providing X.25 connectivity between the individual ground stations and control centres at ESOC, has been a closed network with no outside access. With the establishment of the OPSNET Intranet, serving the entire mission (platform and payload operations), it becomes possible to open the network and to provide payload data transfers from within the OPSNET Intranet to the global Internet, for scientific data distribution for example. It will also allow adequately controlled data transfers between the scientific user community and mission control systems, e.g. for mission planning requests or even payload tele-commanding. As illicit usage of OPSNET internal resources could lead to denial of service for mission-critical applications, strict security measures have to be applied by implementing firewalls at those locations where access to and from the global Internet is possible.

The default security policy will be to disallow all incoming traffic, and to allow only outgoing traffic for file transfer (FTP), remote access via Telnet, and Web access (HTTP). Scientific data will be transferred to and stored on a machine connected to an external-services LAN that is always accessible from outside. Other machines on the External Services LAN could run Web-based applications for mission planning. In this scenario, external users will only be able to access external machines which maintain application associations through the firewall with the internal applications. These schemes will be defined on a project-by-project basis if the default security architecture cannot fulfil the requirements of a particular mission.

Network management

The OPSNET Intranet and the OPSNET WAN network management will be integrated with the ESTRACK Network Control Facility at ESOC. The OPSNET Intranet management will comprise the configuration, monitoring and control of the communication services and the security services (Fig. 5).

The migration phasing

Three major migration phases are foreseen. In Migration Phase 1, projects will be supported by a hybrid combination of X.25 and IP services. This will allow the smooth introduction of the new Intranet without disturbing the operations of existing missions. Based on the new OPSNET Intranet, native TCP/IP applications, e.g. for the Spot-4 mission operations, can readily use the new infrastructure. Science missions like XMM will use X.25 for communication between ground stations and the spacecraft control centre, and IP for communication with all other entities.

In Migration Phase 2, projects will be supported by a pure IP Version 4 network service, i.e. the native X.25 service in the OPSNET WAN bearer network will be phased out. Legacy telemetry, telecommand and ranging equipment that only provides an X.25 interface will continue to be supported via X.25 over TCP/IP, which is a gatewaying function in the router equipment. Telemetry, telecommand, ranging and ground-station monitoring and control applications that are realised on more modern hardware provide both an X.25 and a LAN interface. Since these applications today are based on Open Systems Interconnection (OSI) protocol stacks over X.25, it is possible to reconfigure them to operate over TCP/IP. All legacy applications can thereby be migrated to the new OPSNET Intranet to provide a purely IP service. Even before Migration Phase 3, it will probably be possible to carry voice channels over the Intranet as an IP service connecting the various voice conferencing systems needed for operations coordination.

In Migration Phase 3, projects will be supported by native TCP/IP applications making use of the upcoming standard IP Version 6 resource reservation protocol most applicable for mission operations. Telemetry and telecommand applications will implement standardised space link extension services, thereby allowing easy inter-agency cross-

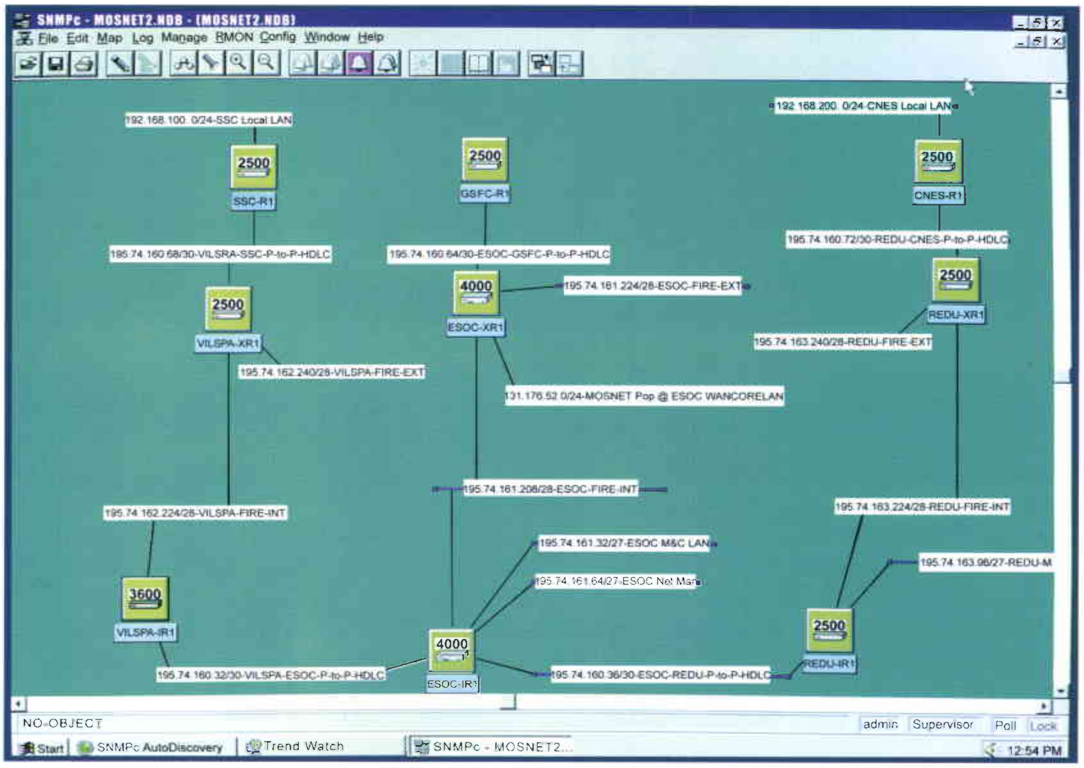


Figure 5. OPSNET Intranet Network Management Station (preliminary)

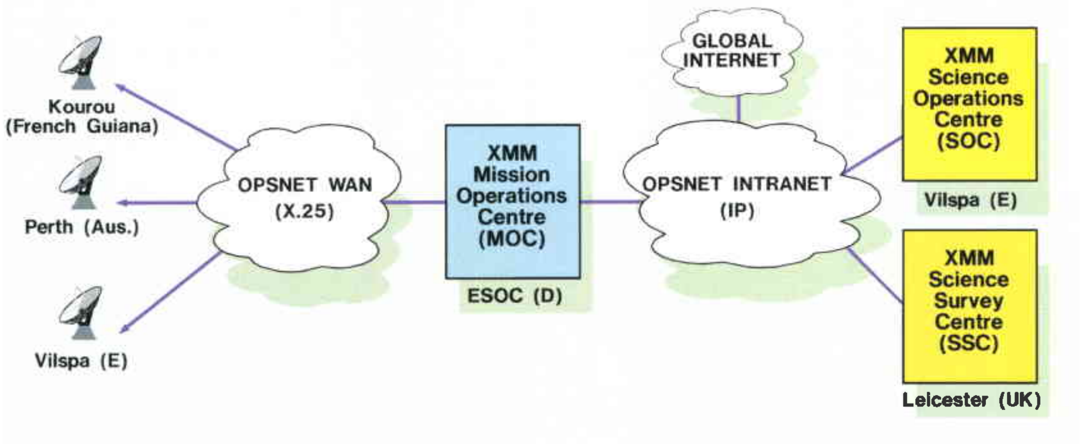


Figure 6. The hybrid X.25 and IP OPSNET communication support structure for the XMM scientific mission

support for spacecraft operations. In fact, a permanent IP-based network infrastructure for spacecraft-operations support is expected to be established between space agencies based on dedicated communication resources. The use of ATM is envisaged for high data rates and bulk data transfers.

Completion of Migration Phase 1 is currently foreseen for the end of March 1998.

The XMM mission example

The OPSNET communication support for XMM is of the typical hybrid nature discussed above for Migration Phase 1 (Fig. 6). Communications between the ground stations involved - Kourou, Perth and Villafranca - and the Mission Operations Centre (MOC) are still based on the X.25 protocol using today's telemetry, telecommand and ranging applications. All other communications between the MOC, the Science Operations Centre (SOC), the Science Survey Centre (SSC) and external users on the global Internet for science data processing and distribution, observation proposal handling and mission planning is based on the Internet Protocol.

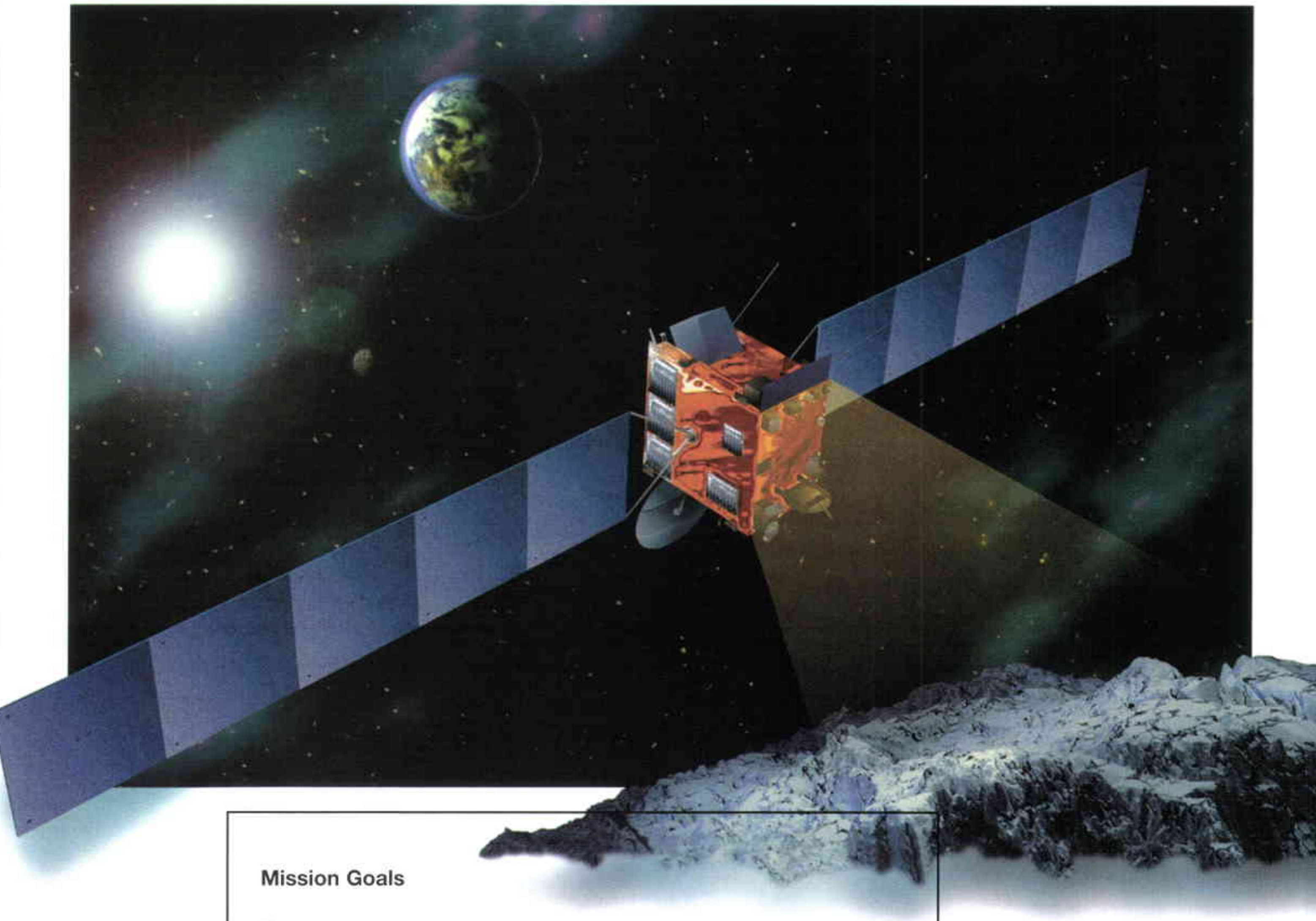
Conclusion

The migration of OPSNET from a network based on circuit-switching and X.25 technology to an IP-based Intranet with Internet scientific data access has just started. Careful synchronisation with current and future programme schedules and project requirements is crucial to ensure that the transition is both smooth and does not impact present project baselines and costs. Every effort is, however, being made to allow existing projects to reap the benefits of enhanced functional network performance as it becomes available. The watchwords of the overall migration process are reliability, safety and security. All of the changes currently foreseen will be rigorously qualified within the offline reference network at ESOC before the new communications hardware, software and service configurations are transferred to the operational environment.

As far as the longer-term future is concerned, such projects as the International Space Station (ISS) and future Earth-observation missions will continue to bring new and ever more demanding communications requirements. Typical examples are the need to support higher data rates (32 Mbps and above) for real-time interactive payload operations for the Columbus Orbital Facility (COF) of the ISS, or for bulk data transfer from the Envisat remote-sensing platform. In order to meet such requirements, the next migration to Asynchronous Transfer Mode (ATM) based services is already being envisaged, as reported in ESA Bulletin No. 92. For OPSNET, the transition to an ATM network or a hybrid infrastructure which includes ATM technology is foreseen technically, but will only be implemented if future missions actually require it. In the meantime, further optimisations and improvements in terms of cost efficiency can be anticipated through, for example, the integration of OPSNET and other mission-dedicated networks, which could result in considerable savings in network management, hardware maintenance and operational staffing once compatible network infrastructures can be established.

Acknowledgement

The authors gratefully acknowledge the constructive interest of the Artemis, XMM, Envisat, Integral, Cluster-II, and Rosetta project and ground-segment managers in the migration of OPSNET to future technologies. Their inputs have been critical in identifying the precise communications support needs for ESA's future missions and in allowing us to devise a reliable, secure and suitably phased migration strategy.



Mission Goals

The prime scientific objective of the mission as defined by the Rosetta Science Team is to study the origin of comets, the relationship between cometary and interstellar material, and its implications with regard to the origin of the Solar System. The measurements to be made in support of this objective are:

- Global characterisation of the nucleus, determination of dynamic properties, surface morphology and composition
- Determination of the chemical, mineralogical and isotopic compositions of volatiles and refractories in a cometary nucleus
- Determination of the physical properties and interrelation of volatiles and refractories in a cometary nucleus
- Study of the development of cometary activity and the processes in the surface layer of the nucleus and the inner coma (dust/gas interaction)
- Global characterisation of asteroids, including the determination of dynamic properties, surface morphology and composition.

The International Rosetta Mission

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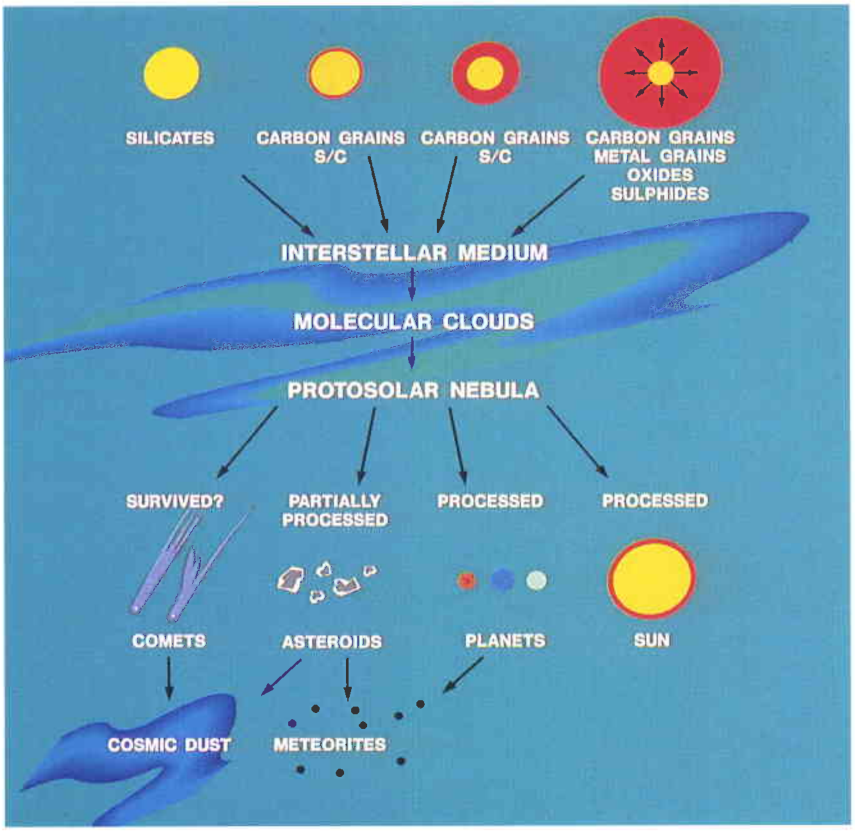
The International Rosetta Mission was approved in November 1993 by ESA's Science Programme Committee as the Planetary Cornerstone Mission in ESA's long-term programme in space science, Horizon 2000. The mission's main goal is a rendezvous with Comet 46P/Wirtanen, but it is also intended to study two asteroids during close flybys on route to the comet. Rosetta will study the nucleus of Comet Wirtanen and its environment in great detail for a period of nearly two years, the near-nucleus phase starting at a heliocentric distance of about 3.25 AU, from the onset of activity through to perihelion, close to 1 AU. On its long journey to the comet, the spacecraft will pass close to the asteroids Mimistrobell and Siwa or Rodari.



Introduction

Direct evidence of the constitution of cometary volatiles is particularly difficult to obtain, as the constituents observable from Earth and even during the flybys of Comet Halley in 1986, result from physico-chemical processes such as sublimation and interactions with solar radiation and the solar wind. What we know today about cometary material from those earlier missions and ground-based observations does, however, demonstrate the low degree of evolution of cometary material and hence its tremendous potential for providing us with unique information about the make up and early evolution of the solar nebula.

The study of cometary material presents a major challenge due to the very characteristics that make it a unique repository of information about the formation of the Solar System, namely its high volatiles and organic-material contents. A fundamental question that the Rosetta mission has to address is, to what extent can the material accessible for analysis be considered representative of the bulk of the material constituting the comet, and of the early nebular condensates that constituted the cometesimal 4.57×10^9 years ago? This representativeness issue has to be addressed by first determining the global characteristics of the nucleus, namely its mass, density and state of rotation, which can provide us with clues as to the relationship between the comet's outer layers and the underlying material.

The dust and gas activity observed around comets, as well as its rapid response to insolation, guarantees the presence of volatiles at or very close to the surface in active areas. Analysing material from these areas will therefore provide information on both the volatiles and the refractory constituents of the nucleus. The selection of an appropriate site for the surface-science investigations should be relatively straightforward, given the mission's extensive remote-sensing observation phase and the advanced instrumentation, covering a broad range of wavelengths, that is to be carried by the Rosetta Orbiter.

The dust-emission processes are induced by very low density gas outflows and should preserve the fragile texture of cometary grains. These grains can be collected at low velocities (a few tens of metres per second) by the spacecraft after short travel times (of the order of minutes), which will minimise alterations induced by any interaction with solar radiation. Similarly, gas analysed in jets or very close to the surface should yield reliable information on the volatile content of the cometary material in each source region.

Comet 46P/Wirtanen

Comet 46P/Wirtanen was discovered on 15 January 1948 at Lick Observatory by Carl A. Wirtanen. Its two subsequent close approaches to Jupiter, in 1972 (0.28 AU) and 1984 (0.46 AU), changed the perihelion of the comet's orbit from 1.63 to 1.06 AU and its period from 6.71 to 5.46 years.

46P/ Wirtanen belongs to a large group of the short-period comets in the Solar System, known as the Jupiter comets. Their orbits with an aphelion around Jupiter's orbit make them observable in principle along their entire orbit. Comet Wirtanen has been observed during all but one (1980) of its apparitions since its discovery. However, only the coordinated observation campaign conducted in 1996/ 1997 in the context of the Rosetta mission has promoted it to being one of the best-monitored (Fig. 1).

Assuming that it has an albedo of 0.04, a radius of about 700 m has been derived for the comet. Given its smallness, the nucleus can be rated as fairly active, producing about 10^{28} water molecules per second.

The spacecraft and its payload

The spacecraft design is driven by the key features of this very complex and challenging mission:

- the fixed and fairly short launch window for Comet 46P/Wirtanen: due to the launch capability required, even with Ariane-5 there are only very few backup scenarios within a reasonable time frame
- the long mission duration of 10.5 years
- the critical gravity assists at Mars and the Earth and the close asteroid flybys, during which both the spacecraft and the payload will be active
- the wide variation of spacecraft-Earth-Sun cycles and distances, which pose strong thermal-design challenges and require large solar arrays (approx. 60 m^2) with novel cells optimised for low-intensity low-temperature operation
- the lengthy operations just a few comet-nucleus radii away from 46P/Wirtanen's surface, in an environment of nucleus-emitted dust and gas that will not be known in great detail during the spacecraft's development.

The long round-trip light times of up to 90 min call for a highly autonomous spacecraft that can also survive the long hibernation periods without any ground contact during the cruise phases.

A preliminary design for the spacecraft is shown in Figure 2, which also gives a good impression of the modular approach used. Striking features are the huge solar arrays and the 2.2 metre diameter High Gain Antenna (HGA), which is steerable in two axes. The payload is mounted on one spacecraft wall, which during the close comet approach phase will be pointed continuously towards the nucleus. All instruments will be body-mounted and the proper attitude will be achieved by rotating the spacecraft with the HGA always Earth-pointing and the solar array pointing towards the Sun.

Scientific payload

Rosetta Orbiter

During its meeting on 21 February 1996, ESA's Science Programme Committee (SPC) endorsed the Rosetta Orbiter payload (Table 1), and originally two Surface Science Packages: Champollion to be provided by NASA-JPL/CNES and Roland to be provided by a European consortium led by MPI and DLR from Germany. Programmatic difficulties subsequently led to NASA's withdrawal from Champollion in September 1996. CNES has since joined the original Roland consortium in an effort to provide a European Lander.

After a one-year 'science verification phase' intended to lead to a clearer definition of interfaces and to identify critical areas where more development work was required, all instruments for the Orbiter's payload were reconfirmed by the SPC in 1997. During this study phase, the investigator teams were required to demonstrate the feasibility of several novel techniques to be applied for the first time with Rosetta flight hardware.

The Orbiter payload will have unprecedented capabilities for studying the composition of both the volatile and refractory material released by the cometary nucleus with very high resolution. The remote-sensing instrument suite will allow characterisation of the nucleus surface in a wide range of wavelengths (UV to mm) with high resolution. The OSIRIS Narrow-

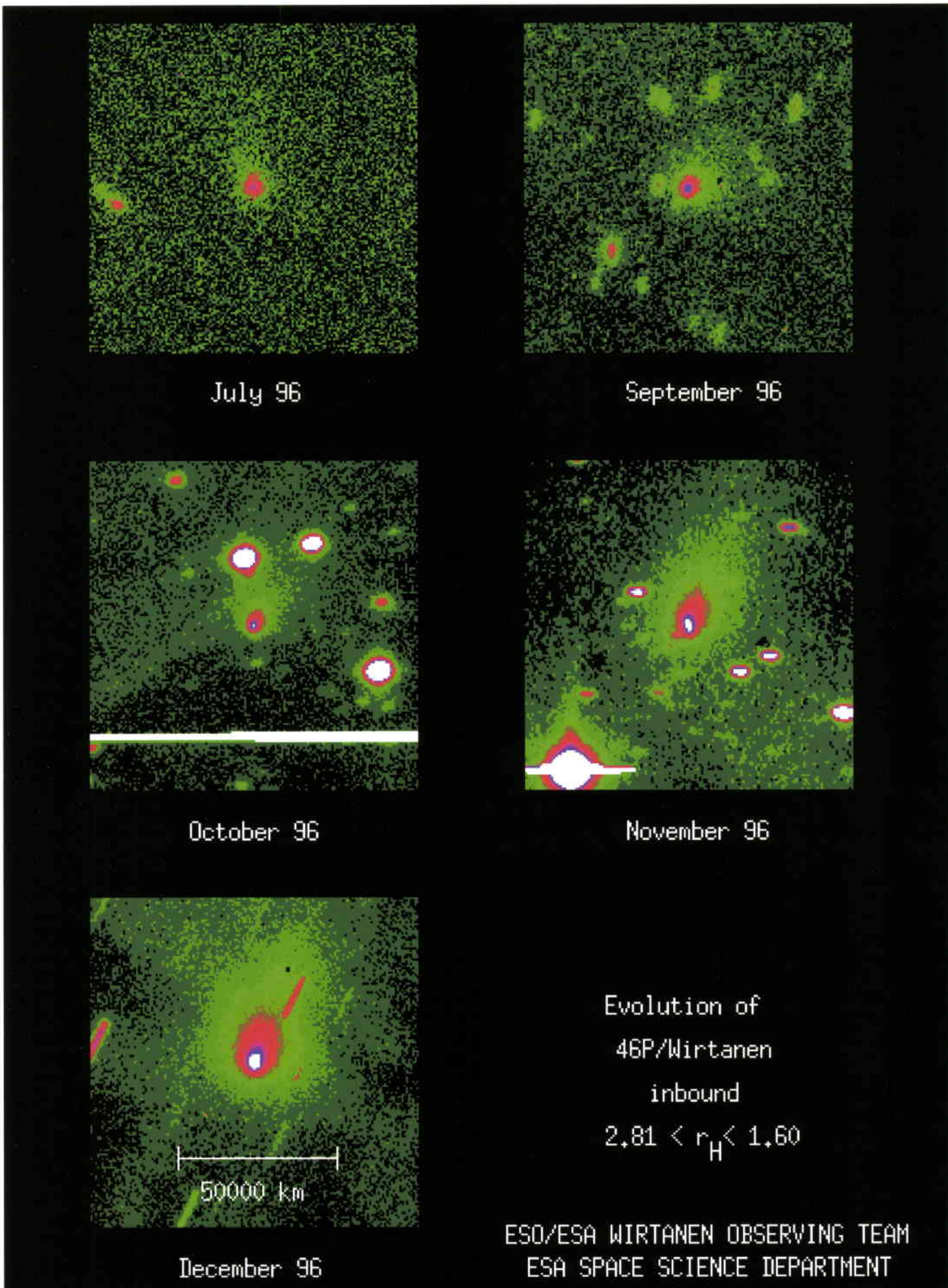


Figure 1. Ground-based observations of Comet 46P/Wirtanen: July – December 1996

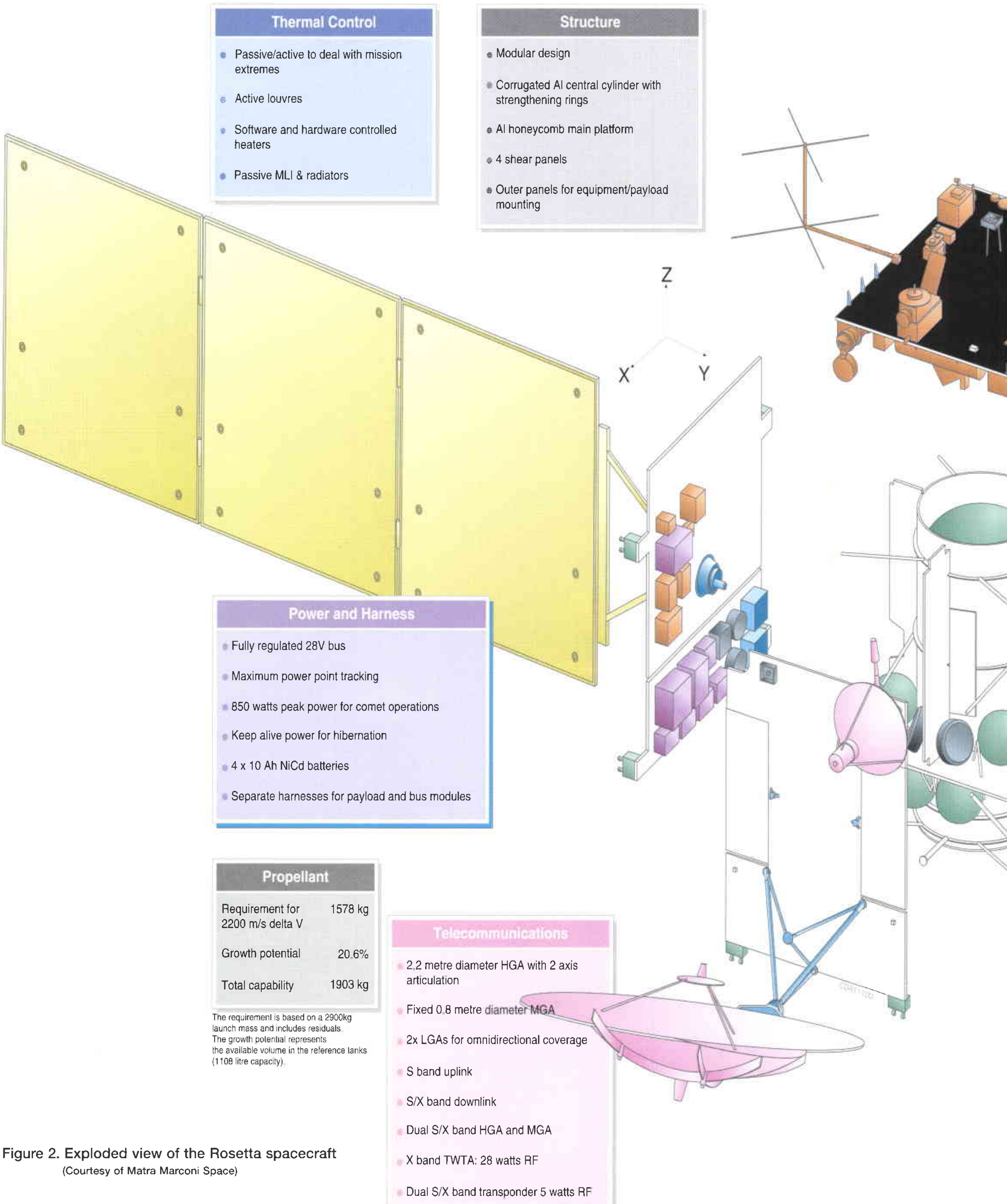


Figure 2. Exploded view of the Rosetta spacecraft
(Courtesy of Matra Marconi Space)

Mass (kg)	
Structure	198.9
Thermal	40.7
Mechanisms	38.6
Solar Array	169.7
Power	90.4
Harness	55.2
Propulsion	171.5
Telecommunications	44.8
Total	**809.8**

All masses include contingencies at equipment level, based on development status

Power Consumption (W)

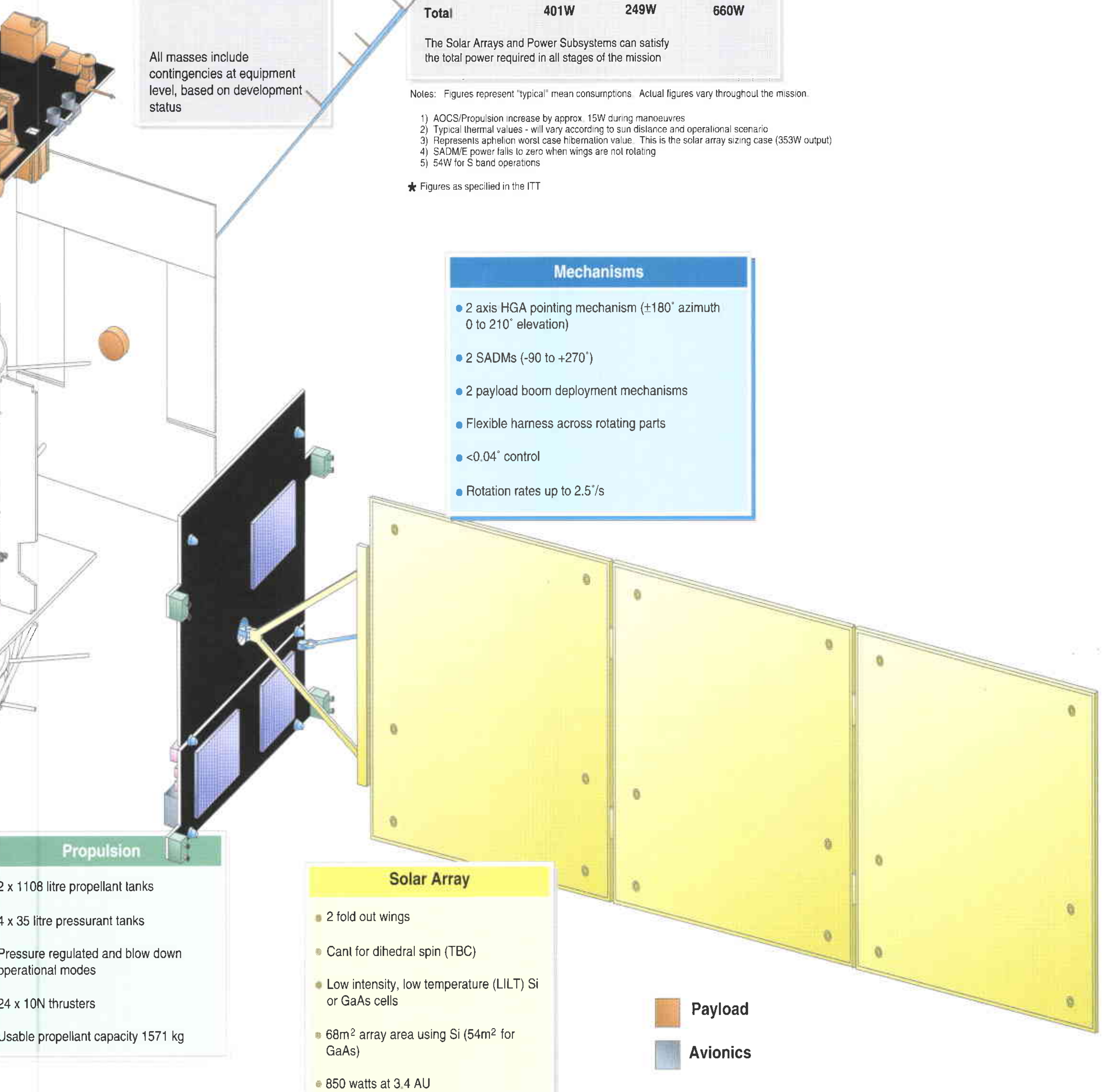
	Active Cruise X Band	Hibernation	Near Comet
Telecommunications	102(5)	8	102
AOCS/Propulsion ★	89(1)	0	134
DMS ★	66	29	66
SADM/E	18(4)	0	18
Power	26	22	30
Thermal	100(2)	190(3)	40(2)
Payload ★	0	0	270
Total	**401W**	**249W**	**660W**

The Solar Arrays and Power Subsystems can satisfy the total power required in all stages of the mission

Notes: Figures represent "typical" mean consumptions. Actual figures vary throughout the mission.

1) AOCS/Propulsion increase by approx. 15W during manoeuvres
2) Typical thermal values - will vary according to sun distance and operational scenario
3) Represents aphelion worst case hibernation value. This is the solar array sizing case (353W output)
4) SADM/E power falls to zero when wings are not rotating
5) 54W for S band operations

★ Figures as specified in the ITT



Mechanisms

- 2 axis HGA pointing mechanism (±180° azimuth 0 to 210° elevation)
- 2 SADMs (-90 to +270°)
- 2 payload boom deployment mechanisms
- Flexible harness across rotating parts
- <0.04° control
- Rotation rates up to 2.5°/s

Propulsion

- 2 x 1108 litre propellant tanks
- 4 x 35 litre pressurant tanks
- Pressure regulated and blow down operational modes
- 24 x 10N thrusters
- Usable propellant capacity 1571 kg

Solar Array

- 2 fold out wings
- Cant for dihedral spin (TBC)
- Low intensity, low temperature (LILT) Si or GaAs cells
- 68m² array area using Si (54m² for GaAs)
- 850 watts at 3.4 AU
  353 watts at 5.2 AU

Table 1. The Rosetta Orbiter payload

Acronym	Objective	Principal Investigator
Remote Sensing		
OSIRIS	Multi-Colour Imaging NAC (Narrow Angle Camera) 2.35°x2.35° WAC (Wide Angle Camera) 12°x12° (250 nm-1000 nm)	H.U. Keller, MPI für Aeronomie, Katlenburg-Lindau, Germany
ALICE	UV-Spectroscopy (70 nm-205 nm)	A. Stern, Southwest Research Institute, Boulder, CO, USA
VIRTIS	VIS and IR Mapping Spectroscopy (0.25 μm-5 μm)	A. Coradini, IAS-CNR, Rome, Italy
MIRO	Microwave Spectroscopy (1.3 mm and 0.5 mm)	S. Gulkis, NASA-JPL, Pasadena, CA, USA
Composition Analysis		
ROSINA	Neutral Gas and Ion Mass Spectroscopy; Double-focusing, 12-200 AMU, M/ΔM~ 3000 Time-of-flight, 12-350 AMU, M/ΔM~ 500 incl. Neutral Dynamics Monitor	H. Balsiger, Univ. of Bern, Switzerland
MODULUS	Isotopic Ratios of Light Elements by Gas Chromatography (D/H; $^{13}C/^{12}C$; $^{18}O/^{16}O$; $^{15}N/^{14}N$)	C. Pillinger, Open University, Milton Keynes, UK
COSIMA	Dust Mass Spectrometer (SIMS, m/Δm ~ 2000)	J. Kissel, MPI für Extraterrestrische Physik, Garching, Germany
MIDAS	Grain Morphology (Atomic Force Microscope, nm Resolution)	W. Riedler, Univ. of Graz, Austria
Nucleus Large-Scale Structure		
CONSERT	Radio Sounding, Nucleus Tomography	W. Kofman, CEPHAG, Grenoble, France
Dust Flux, Dust Mass Distribution		
GIADA	Dust Velocity and Impact Momentum Measurement, Contamination Monitor	E. Bussoletti, Istituto Univ. Navale, Naples, Italy
Comet Plasma Environment, Solar-Wind Interaction		
RPC	Langmuir Probe, Ion and Electron Sensor, Flux-Gate Magnetometer, Ion Composition Analyser, Mutual Impedance Probe	R. Boström, Swedish Institute of Space Physics, Uppsala, Sweden J. Burch, Southwest Research Institute, San Antonio, TX, USA K.-H. Glassmeier, TU Braunschweig, Germany R. Lundin, Swedish Institute for Space Physics, Kiruna, Sweden J.G. Trotignon, LPCE/CNRS, Orleans, France
RSI	Radio-Science Experiment	M. Pätzold, Univ. of Cologne, Germany

Angle Camera, for example, will achieve a resolution of better than 10 cm on the nucleus surface from the closer orbits.

To complement these instruments and to provide for proper monitoring of the comet environment and its interaction with the solar wind, a Dust Flux Analyser and a Plasma Instrument Package have been selected.

Rosetta Lander

The Lander science (Table 2) will focus on in-situ study of the composition and structure of the material that constitute's Comet Wirtanen's nucleus. Measurement goals include the determination of the elemental, molecular, mineralogical, and isotopic compositions of both the cometary surface and subsurface material. The highest priority will be given to the elemental and molecular determinations, as it is believed that some mineralogical and isotopic measurements can be carried out adequately via the Orbiter science investigations. In addition, properties like near-surface strength, density, texture, porosity, ice phases and thermal properties will be derived. Texture characterisation will include microscopic studies of individual grains.

The CONSERT experiment, with hardware on both the Lander and the Orbiter, will attempt to reveal the coarse structure of the nucleus through radio sounding.

Interdisciplinary scientists

Five Interdisciplinary Scientists have been nominated for an initial period of three years to support the mission's implementation:

- *M. Fulchignoni*, DESPA, Observatoire de Paris, France, to develop physico-chemical models of the possible target asteroids in order to provide the Rosetta Project and the Rosetta Science Working Team with a reference data set.
- *P. Weissman*, NASA-JPL, Pasadena, California, USA, to provide thermophysical modelling of the cometary nucleus and of the inner coma of comets.
- *R. Schulz*, MPI für Aeronomie, Katlenburg-Lindau, Germany, now with ESA Space Science Department, to liaise with the astronomical community and to derive a basic characterisation of the target comet from ground-based observations.
- *E. Grün*, MPI für Kernphysik, Heidelberg, Germany and *M. Fulle*, Trieste Astronomical Observatory, Italy, to provide empirical 'engineering models' for the dust environment of the nucleus of the target comet in order to establish a reference data set for the Rosetta Project and the Rosetta Science Teams.

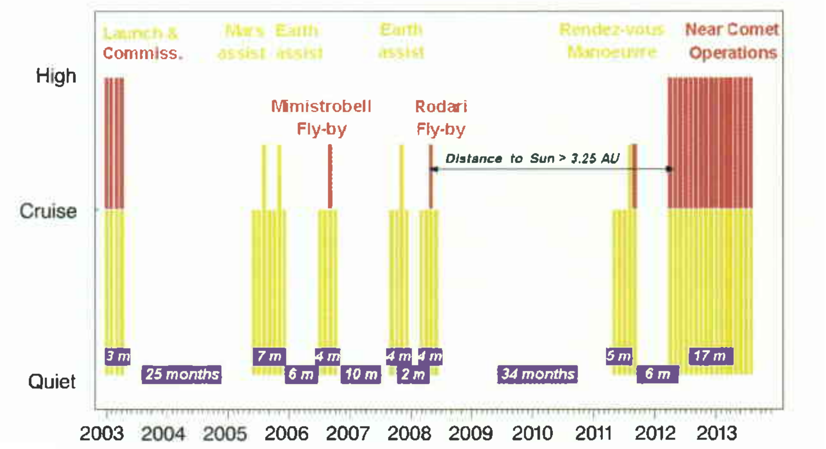


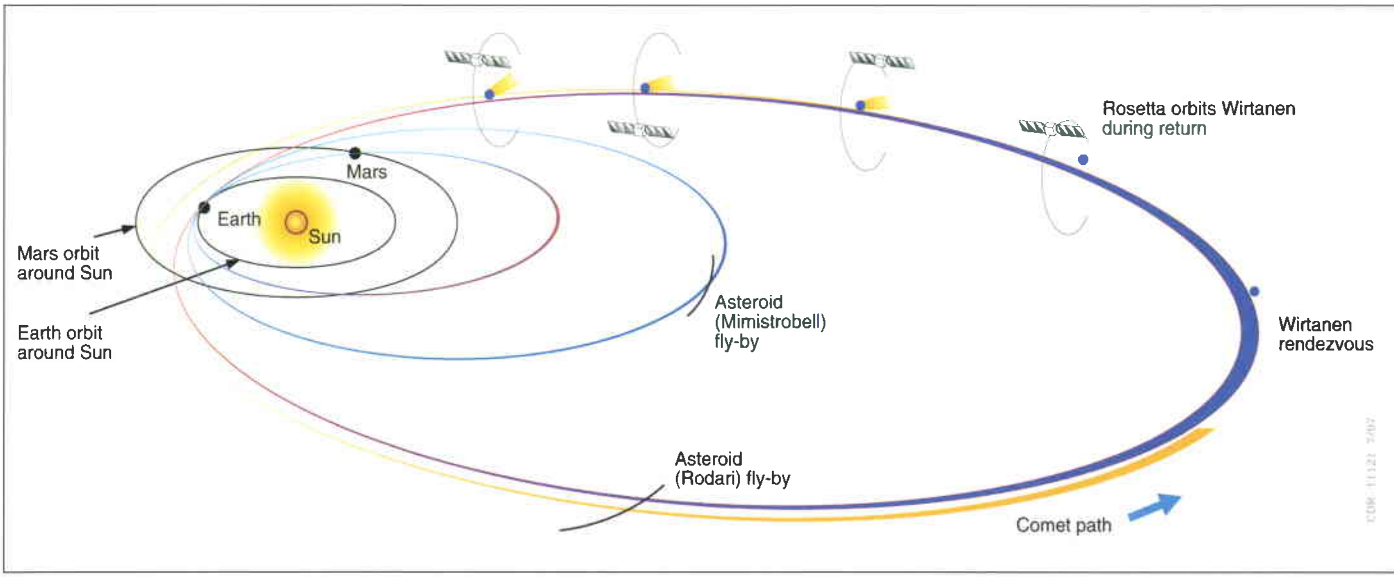
Figure 3. Ground-activity mission profile

Mission overview

Rosetta will by launched in January 2003 by an Ariane-5 vehicle from Kourou, in French Guiana. To gain enough orbital energy for Rosetta to reach its target, one Mars and two Earth gravity assists will be required (Figs. 3,4). The long duration of the mission requires the introduction of extended hibernation periods. The mission can be subdivided into several distinct phases (Table 3).

Table 2. The Lander payload

APXS	Alpha-p-X-ray Spectrometer Sample Acquisition System	R. Rieder, MPI Chemistry, Mainz, Germany ASI, Italy
MODULUS	Evolved Gas Analyser	C. Pillinger, Open University, UK
CIVA ROLIS	Rosetta Lander Imaging System	J.P. Bibring, IAS, Orsay, France S. Mottola, DLR Berlin, Germany
SESAME	Surface Electrical and Acoustic Monitoring Experiment, Dust Impact Monitor	D. Möhlmann, DLR Cologne, Germany H. Laakso, FMI, Finland I. Apathy, KFKI, Hungary
MUPUS	Multi-Purpose Sensor for Surface and Sub-Surface Science	T. Spohn, Univ. of Münster, Germany
ROMAP	RoLand Magnetometer and Plasma Monitor	U. Auster, DLR Berlin, Germany I. Apathy, KFKI, Hungary
CONSERT	Comet Nucleus Sounding	W. Kofman, CEPHAG, Grenoble, France



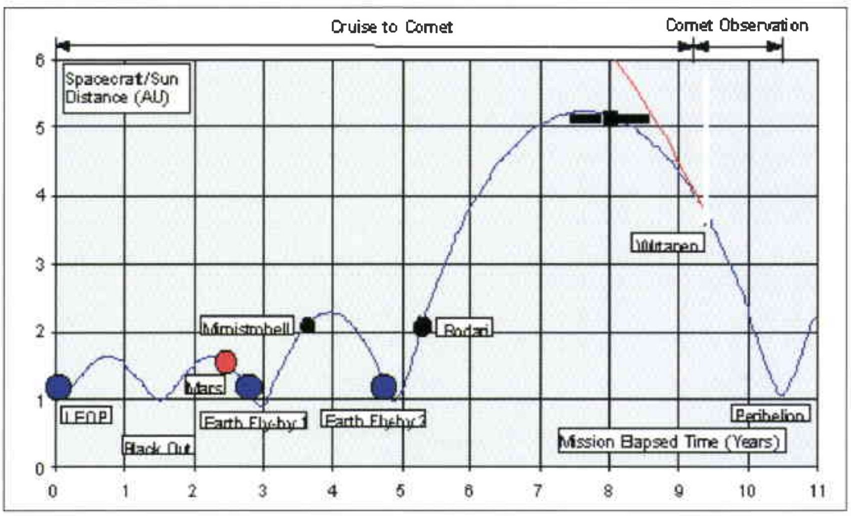


Figure 4a,b. Geometric and temporal schematics of mission phases

Launch (January 2003)
Rosetta will be launched on an Ariane-5. After burnout of the lower composite, the upper stage L9.7 will remain together with the spacecraft in an eccentric coast orbit for about 2 hours (4000 x 200 km), during which the attitude of the composite can be controlled. Before perigee passage, the upper stage will perform a delayed ignition and inject the Rosetta spacecraft onto the required escape hyperbola towards Mars, with an excess velocity of about 3.4 km/s. The spacecraft will be separated from the launcher upper stage in a three-axis-stabilised attitude.

Commissioning Phase (3 months)
Immediately after separation, the spacecraft will autonomously de-tumble, deploy its solar arrays and acquire a coarse three-axis-stabilised Sun-pointing attitude. Ground operations will acquire the downlink in S-band, using the ESA network, and control the spacecraft to a fine-pointing attitude with the High-Gain Antenna (HGA) Earth-pointing using X-band telemetry. Tracking and orbit determination will then be performed and the departure trajectory verified and corrected if necessary. All spacecraft functions required during the cruise to the comet, and in particular the hibernation functions, will be checked out. The scientific payload will then be commissioned, before putting the spacecraft into hibernation mode for the cruise phase to Mars.

Earth-to-Mars Cruise (about 950 days from launch to Mars)
The spacecraft will be put into hibernation mode, during which no ground support is baselined. A long solar conjunction prevents any spacecraft operations being performed from the ground between days 440 and 690. The scientific instruments will be switched off during this cruise.

Mars Gravity Assist (pericentre height about 200 km)
Daily operations will be resumed three months before Rosetta's arrival at Mars. Two orbit-correction manoeuvres are planned at the incoming and outgoing asymptote, which will allow for some science operations during the swingby. During the swingby, there will be an occultation of the Earth by Mars which will last about 37 minutes, causing a communications blackout.

Mars-to-Earth Cruise (about 90 days from Mars to Earth)
The spacecraft will be kept in active cruise mode for this 'short' interplanetary phase.

First Earth Gravity Assist (perigee height about 3400 km)
Operations will be mainly devoted to tracking and orbit determination and maintenance from three months before, until one month after swingby. Orbit-correction manoeuvres are to be executed before and after the swingby itself.

Earth-to-Asteroid Cruise (about 300 days from Earth to Mimistrobell)
The spacecraft will be put into hibernation mode, during which no ground support is baselined.

Mimistrobell Flyby (around day 1330)
Flyby operations will last from three months before, until one month after the flyby. In parallel with the daily tracking, with orbit determination and corrections, the scientific payload will be checked out. The goal is to pass within 600 km of an asteroid, on the sunward side. The relative asteroid ephemeris will be determined with a cross-track accuracy of 20 km by spacecraft optical navigation. The cameras and scientific payload will be pointing in the direction of the asteroid until after the flyby. Scientific data will be recorded onboard in the mass memory and transmitted after the flyby when the Earth link via the HGA is recovered.

After the flyby, the necessary orbit correction will be performed to put the spacecraft on course for the second Earth gravity assist.

Mimistrobell-to-Earth Cruise (about 400 days from asteroid to Earth)
The spacecraft will be put into hibernation mode, during which no ground support is baselined.

Second Earth Gravity Assist (perigee height about 2200 km)
The operations conducted will be the same as for the first Earth swing-by. Before the second Earth gravity assist, however, there is a decision point regarding the further operations up to comet encounter. The nominal mission includes a flyby of a second asteroid and Rodari is the nominal candidate, but Siwa may be selected if there is sufficient propellant available. The exact rendezvous manoeuvre strategy will also be selected based on the available battery power, solar-array degradation and the propellant situation. The nominal rendezvous manoeuvre is to be executed post-aphelion at 4.5 AU to minimise power demands and allow the solar array to be made as small as possible.

Earth to Second Asteroid Cruise (about 160 days)
The spacecraft will be put into hibernation mode as soon as the necessary tracking operations have been completed and an orbit-correction manoeuvre has been performed.

Rodari Flyby (around day 1930)
The operations here will be similar to those for the Mimistrobell flyby, but the flyby distance itself will be greater to be commensurate with the spacecraft angular-rate capabilities because the Mimistrobell flyby occurs at a lower relative velocity.

Table 3. Major mission events

	Nominal Timing
Launch	21 January 2003
Mars gravity assist	26 August 2005
Earth gravity assist #1	26 November 2005
Mimistrobell flyby	15 September 2006
Earth gravity assist #2	26 November 2007
Rodari flyby	4 May 2008
Rendezvous manoeuvre	24 August 2011
Start of near-nucleus operations at 3.25 AU (from Sun)	22 August 2012
Perihelion passage (end of mission)	10 July 2013

Asteroid to Comet Cruise (about 1200 day from asteroid to comet rendezvous manoeuvre)
The whole period - apart from an optional deep-space manoeuvre - will be spent in hibernation mode. Rosetta will be at its furthest from the Sun and from the Earth during this period, i.e. 5.2 AU (aphelion) and 6.2 AU, respectively.

Comet Orbit Matching Manoeuvre (or rendezvous manoeuvre; around day 3140)
This is the major orbit manoeuvre that will ready the spacecraft for the rendezvous, by reducing the spacecraft/comet relative drift rate to about 25 m/s. It will be performed before the comet is detected by Rosetta's onboard cameras, using ground determination of the comet nucleus' orbit based on a dedicated observation campaign.

Near-Comet Drift Phase
The drift phase will be designed such that, when the spacecraft is less than 4.2 AU from the Sun it reaches an appropriate point relative to the comet for the final approach operations to begin, such that cometary debris can be avoided and that good comet illumination conditions are obtained. The final point of the near-comet drift phase will be the Comet Acquisition Point (CAP), where the comet will be observed for the first time by Rosetta's onboard navigation camera or by OSIRIS.

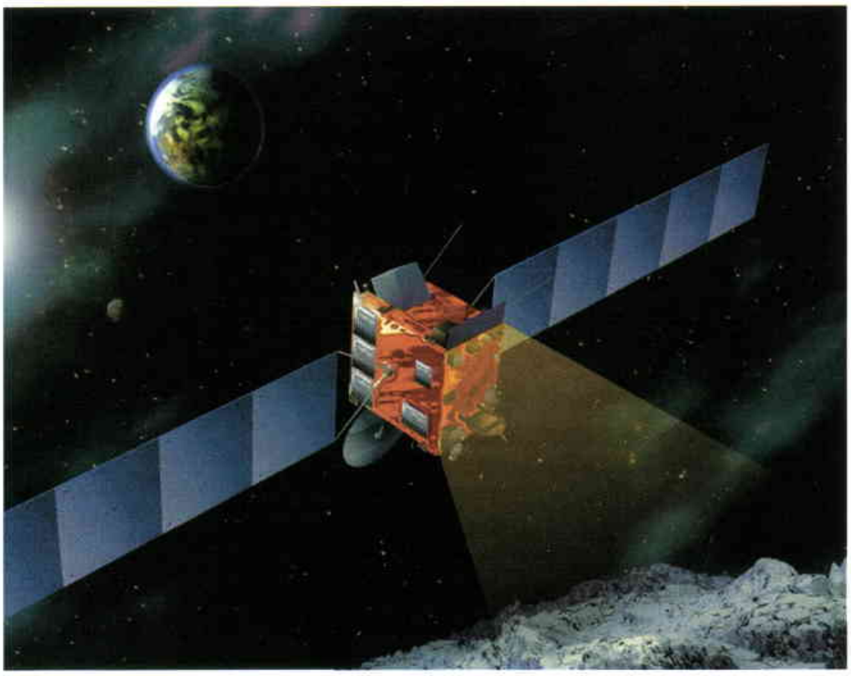
Throughout this phase, the spacecraft will be in active cruise mode.

Far-Approach Trajectory Phase (up to 90 days)
The far-approach operations start at the Comet Acquisition Phase. After detection, knowledge of the comet ephemeris will be drastically improved by the processing of the onboard observations. Image processing on the ground

will derive a coarse estimation of the comet's size, shape and kinematics.

The approach manoeuvre sequence will successively reduce the relative velocity between spacecraft and comet, so that it is just 2 m/s after 90 days. The manoeuvre strategy will be designed to:
- retain an apparent motion of the comet with respect to the star background
- keep the illumination angle (Sun-comet-spacecraft) below 70 deg
- avoid any danger of an impact with the cometary nucleus in the event of manoeuvring difficulties.

The Far-Approach Trajectory ends at the Approach Transition Point (ATP), where a first estimate of the comet's attitude and angular velocity will derived from the analysis of the navigation-camera or OSIRIS images and



'landmarks' will be identified. The ATP is in the Sun direction at about 300 comet nucleus radii from the nucleus. The spacecraft will be in active cruise mode during this phase, with the navigation camera system and some Orbiter payload items switched on.

Close-Approach Trajectory Phase
The close-approach trajectory starts at ATP. Lines-of-sight to landmarks and on-ground radiometric measurements will be used to estimate the spacecraft's relative position and velocity, and the comet's absolute position, attitude, angular velocity, and gravitational constant.

A very good estimate of the comet's kinematics and gravitational constant should be available at the end of this phase, which is the Orbit Insertion Point (OIP). At the OIP the spacecraft will be injected onto a hyperbolic arc to the comet, at a typical distance of 60 comet radii and with a velocity of some cm/s relative to the comet, depending on the comet's size and density.

Transition to Global-Mapping Phase
The transition to global mapping starts at the OIP. Rosetta will follow a hyperbolic arc until it is about 25 comet radii from the target, where a capture manoeuvre will close the orbit. The plane of motion, defined by the spin-axis and Sun directions, will be rotated slightly to avoid solar eclipses and Earth occultations.

Global-Mapping Phase
This preliminary survey of the comet's surface should map at least 80% of the sunlit areas, from polar orbits around the comet at heights of between 5 and 25 nucleus radii. The semi-major axis of the mapping orbit will be chosen as a function of the comet's gravity and spin rate, taking into account the following constraints:
- coverage without gaps
- safety considerations (no impact on nucleus)
- volume of data for real-time transmission
- maximum time to complete surface mapping
- optimum resolution and viewing angle to surface normal, and
- continuous communications to Earth.

The orbital period will usually be greater than the comet's spin period and horizontal swaths will cover the nucleus surface as it is presented. Ideally, all of the Orbiter payload instruments will be operating and the scientific data gathered will be buffered in the onboard memory ready for transmission to the ground station.

During this global-mapping phase, the nucleus' shape, surface properties, kinematics and gravitational characteristics will be derived using optical landmark observations. Based on these mapping and remote-observation data, some five areas (500 m x 500 m) will be selected for close observation.

Close-Observation Phase
Manoeuvre strategies will be designed for sequences of close-observation orbits, flying within 1 nucleus radius of selected surface points. Constraints to be taken into account include:
- uninterrupted communications
- continuous illumination of solar arrays
- safety constraints (no nucleus encounter in case of manoeuvre failure)
- avoidance of debris, dust and gas jets

– adequate illumination of target area, and angle between viewing direction and local surface normal less than 30 degrees.

This phase is expected to last about 30 days and, based on the data collected, it will then be decided to which site the Surface Science Package (SSP) will be delivered. A transition phase to the initial conditions for SSP delivery will then be implemented.

Surface-Science Package Delivery Phase
Surface-Science Package Delivery will take place from an eccentric orbit (pericentre altitude as low as possible, e.g. 1 km) with a pericentre passage near the desired landing site. The time and direction of SSP separation will be chosen such that the package arrives with minimum vertical and horizontal velocities relative to the local (rotating) surface. An ejection mechanism will separate the SSP from the spacecraft with a maximum relative velocity of 1.5 m/s.

Relay-Orbit Phase
After delivery of the SSP, the spacecraft will be injected into the most suitable orbit for receiving the SSP's data and relaying it to Earth. Commanding of the Package may also be required.

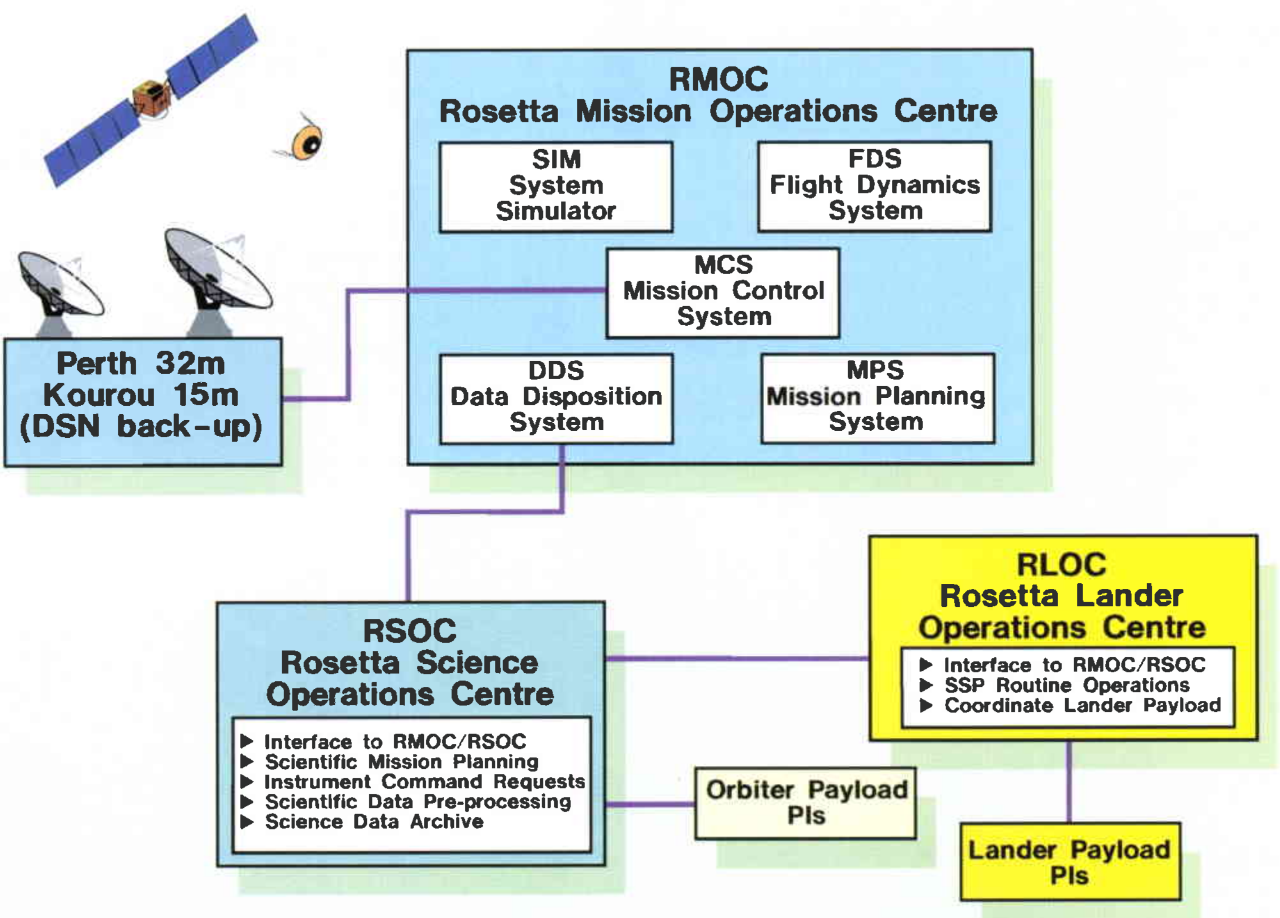
Extended-Monitoring Phase (through perihelion)
After the completion of the SSP-related activities, the spacecraft will spend at least 200 days in orbit in the vicinity of the comet until perihelion passage. The objective of this phase is to monitor the nucleus (active regions), dust and gas jets, and to analyse gas, dust and plasma in the inner coma from the onset of activity until its peak.

The orbital design and mission planning for this phase will depend the scientific results already obtained from of the previous observations and safety considerations associated with the activity pattern of the comet. Extended monitoring of various regions in the vicinity of the nucleus could be performed with successive hyperbolic flyby's following petal-like trajectories.

Run Down (end of mission)
The mission nominally ends at the perihelion pass around day 3800, unless a mission extension is agreed if the spacecraft should survive the cometary environment unscathed!

Mission operations
Throughout its long and demanding mission, Rosetta will be operated and controlled from

Figure 5. The Rosetta ground segment



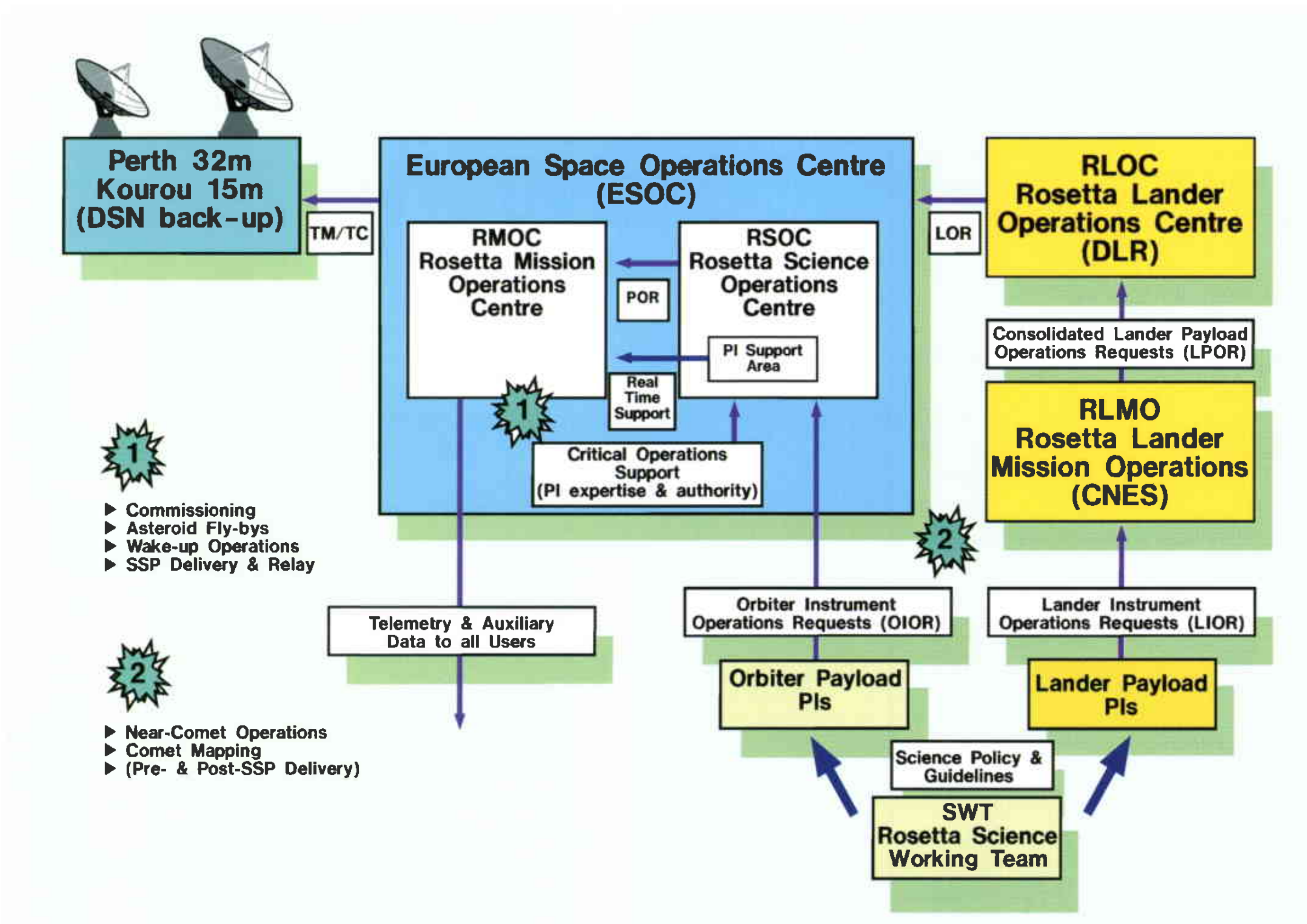


Figure 6. Schematic of Rosetta payload operations

the European Space Operations Centre (ESOC), in Darmstadt, Germany (Fig. 5). The main ground station for the mission will be the new 32-metre Deep-Space Antenna to be built near Perth, in Western Australia. The NASA Deep-Space Network will be used as a back-up during critical mission phases.

During the payload-checkout periods, the asteroid flybys and the near-comet phases of the mission, the Rosetta Science Operations Centre (RSOC) will be co-located with the Mission Operations Centre (RMOC) at ESOC in Darmstadt. A schematic of the mission and science operations facilities is shown in Figure 6.

Conclusion

Rosetta promises to be one of the most exciting planetary missions currently in preparation. It will provide unprecedented access to the original material of the proto-solar nebula and will help us to acquire a real understanding of how comets work.

The recent magnificent displays in our skies of Comets Hyakutake and Hale-Bopp have demonstrated yet again the intriguing mysteries associated with these objects, and fuelled enthusiasm in the scientific community for this novel mission opportunity.

The Project successfully passed its first milestone on 19 December, with the successful completion of the System Requirements Review. The Prime Contractor for Rosetta, selected early in 1977, is DASA-Dornier System of Germany. Responsibilities for the Platform and Avionics have been assigned to Matra Marconi Space UK and Matra Marconi Space France, respectively. Alenia Spazio of Italy is to be responsible for Rosetta's Assembly, Integration and Testing (AIT). esa

Lander Shock-Alleviation Techniques

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Future European space missions have been and are being discussed which involve the landing of scientific payloads on the surfaces of planets or comets in the Solar System, including Mars, Titan, the Moon and smaller remote comets. For all of these missions – Marsnet, Intermarsnet, Ares, Rosetta, Euromoon, etc. – the landing subsystem is a critical element in that a single-point failure could jeopardise the success of the whole mission. Several studies have therefore been performed to investigate potential landing devices and strategies, including the descent, impact, and post-impact stability and operation phases. They have shown that the acceleration peaks transferred to the lander structure during impact can be significantly higher than expected, resulting in major risks to the integrity of the scientific payload. This article reviews work that has been performed in this domain as part of the Agency's Technology Research Programme (TRP).

Introduction

The goal of the recently completed "Lander Shock Alleviation Techniques" TRP study was to identify, analyse, manufacture and test shock-alleviation devices capable of limiting impact loads to well-defined levels. It covered the overall landing subsystem as well as specially adapted support devices for sensitive equipment and payloads. Two types of landers were considered, namely hard- or penetrator-landers, and semi-hard landers, and prototype shock-alleviation components have been manufactured for both types.

Typical shock-alleviation requirements are first reviewed and a brief survey of shock-alleviation technology is presented. Dynamic analysis has been applied to investigate the shock loads on landers and their platforms and the effectiveness of the various shock-alleviation techniques that are available. The results are presented below, together with details of the conceptual design, manufacture and testing of the various prototype devices that have been devised.

Shock-alleviation requirements for space missions

Penetrator-landers

Penetrators of various types have been proposed for several missions to planets and other bodies within our Solar System, including the Moon (Lunar-A mission), a comet (Rosetta mission, although use of a penetrator is now doubtful) and Mars (Marsnet and Intermarsnet missions). In each case, the proposal involves a penetrator impacting with sufficient energy to enter the target surface and subsequently undertaking scientific measurements. Scientific instruments installed on or within these penetrators must survive and operate after being subjected to very high deceleration loads, ranging from 100 to 100 000 g depending on the type of surface being impacted, the type of penetrator and its impact velocity and orientation.

To provide a baseline for investigating shock-alleviation devices suitable for protecting sensitive scientific payloads, four existing designs of penetrator probe - for NASA's Mars Penetrator, the Russian Mars'94 mission, and ESA's Rosetta and Marsnet missions - were first reviewed. Each penetrator was assessed against its own particular mission requirements, in terms of impact velocity, deceleration loads, scientific goals and operational lifetime.

For the Marsnet Penetrator Lander (Fig. 1) which had been studied previously by ESA, the

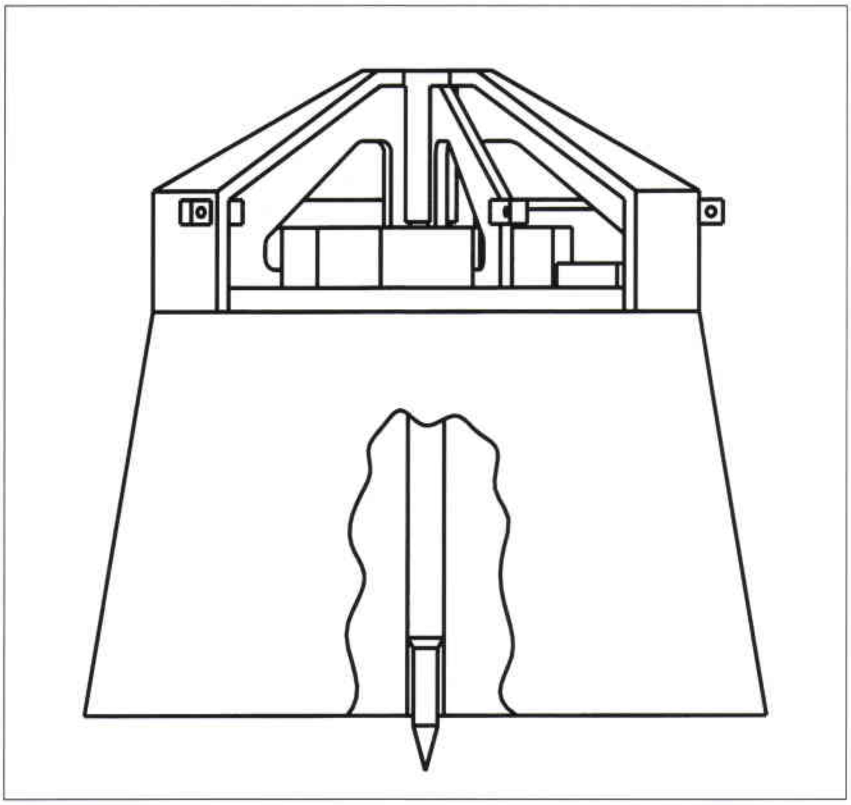


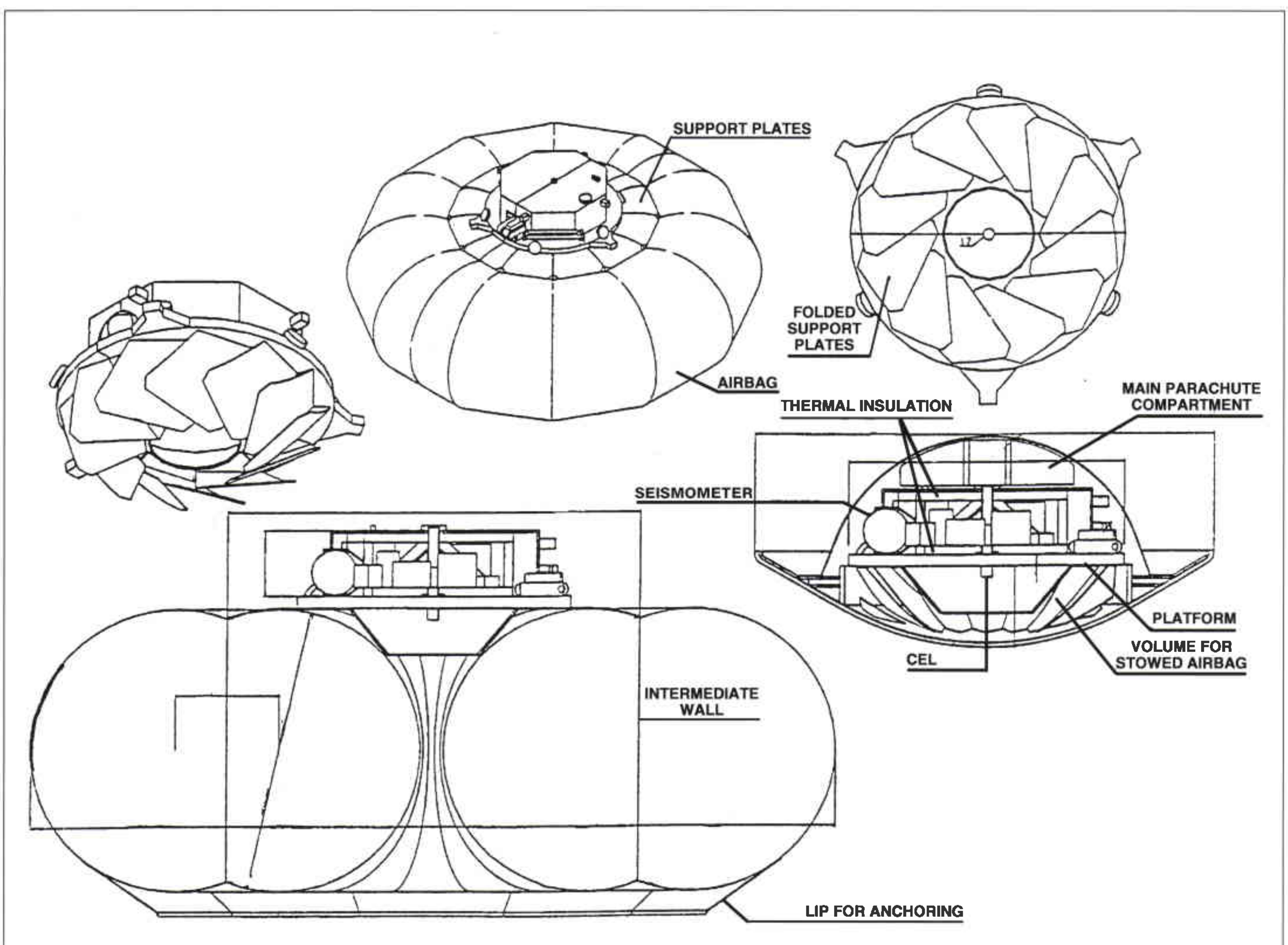
Figure 1. Marsnet penetrator-lander

main performance requirement was to provide a safe and stable platform for the payloads and equipment throughout the impact/penetration process, without exceeding instrument loadings of 700 g. That penetrator is 0.94 m long, with an initial diameter of 0.04 m, expanding to 0.06 m. The diameter of the equipment platform to be shock-protected is 0.90 m. At impact, with a velocity of 70 m/s, the penetrator itself can experience impact loadings of the order of 5700 g, whilst the equipment platform loads are limited to 700 g through the crushing of an aluminium-honeycomb skirt. The time history of shock pulses on the platform approximate to a half-sine pulse with an amplitude of 700 g and a duration of 15 ms. Very sensitive payloads (e.g. cameras) can only withstand about 500 g. It was therefore assumed that the baseline shock-sensitive item would have a mass of 0.6 kg and could be expected to withstand a shock loading of 500 g applied over a period of 15 ms.

Semi-hard landers

Planetary and comet lander missions using low and medium impact velocities - namely Surveyor, Viking, Rosetta and Marsnet - have also been reviewed to establish a set of typical

Figure 2. Marsnet semi-hard lander



requirements. These semi-hard landers do not penetrate the planetary or cometary surface.

The semi-hard lander designed for Marsnet (Fig. 2) has a diameter of 1.2 m and a height of 0.9 m. Its impact velocity is about 25 m/s in the vertical direction, and 0 to 25 m/s in the lateral direction. Overall shock alleviation is performed by an airbag system. The composition of the scientific payloads is similar for all of the soft and semi-hard lander missions, allowing a "typical" payload to be defined, with dimensions of 100x100x100 mm^3 and a mass of 0.7 kg. The maximum allowable deceleration has to be less than 100 g for shock-load inputs composed of long (5 ms) and short (0.5 ms) half-sine pulses with amplitudes of up to 200 g.

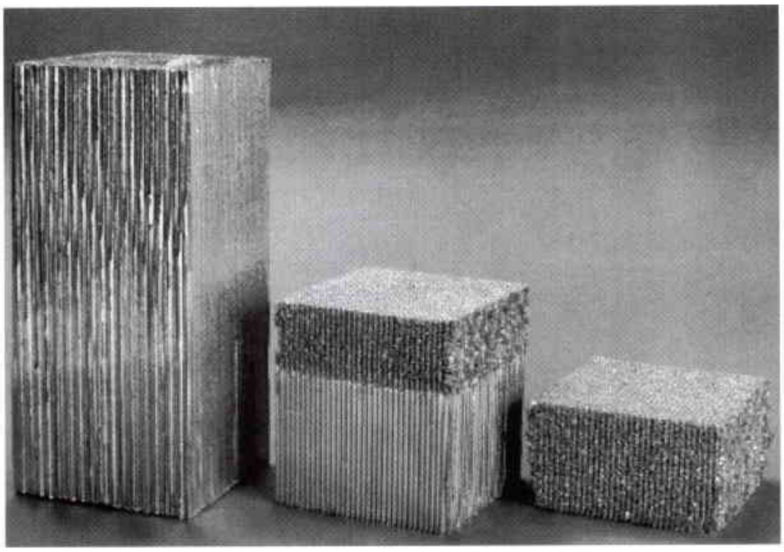
The shock-alleviation device also has to be as small as possible, whilst still maintaining a high functional reliability. There are additional requirements associated with the re-alignment and re-positioning (angular accuracy 1 degree, lateral accuracy 1 mm) of particular payload items such as cameras.

Review of shock-alleviation technology

The types of shock alleviation/absorption techniques that have been reviewed can be divided into devices based on friction and damping, devices based on irreversible deformation, and strategies to reflect shock waves by transmission control.

Among the first type, spring-damper shock isolators and fluid- or gas-filled telescopic dampers have been assessed. Standard metal-wire or elastomer shock isolators meet most of the specifications, but involve excessive elastic displacements because a very low stiffness is required to isolate against low-frequency shock loads. Assuming the use of an airbag landing system for the overall lander, telescopic dampers may be considered for the shock attenuation systems for the individual equipment or payload items mounted on the lander platform. However, the strong temperature dependence (density, pressure and viscosity) of fluid- or gas-based systems makes it difficult to specify critical design parameters such as valve diameters and outlet pressures sufficiently accurately to achieve a safe device. Also, telescopic dampers are usually both bulky and heavy.

Shock-alleviation devices based on irreversible deformation offer the highest specific energy-absorption capability, and crushable aluminium honeycombs and foams, as well as deformable tubes, have been reviewed. When loaded axially, aluminium honeycombs deform permanently in a highly controlled and predictable manner. As shown in Figure 3, as the peak compressive load is overcome, crushing at a constant level is maintained until the material "blocks", forming a solid element. The area under the curve equates to the amount of energy that is dissipated. The manufacturers quote honeycomb crushing strengths only for static crushing and we therefore included dynamic tests in our study.



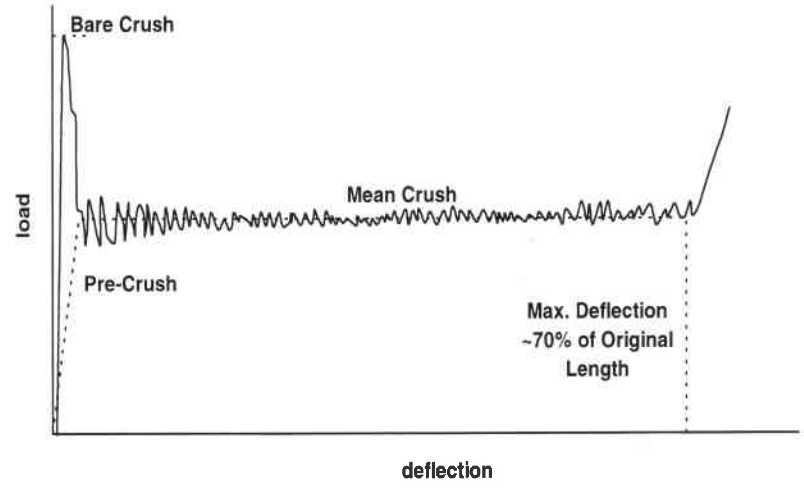


Figure 3. Crushing of aluminium honeycombs

Aluminium honeycombs possess a very low mass density (16-150 kg/m^3) and can be plastically compressed to 80% of their initial length (max. 70% without blocking). Compression strengths range from 0.35 to 17 MPa, and for pre-crushed honeycombs (avoiding the initial peak load) from 0.17 to 7 MPa. The resulting specific energy absorption is up to 30 kJ/kg. The major disadvantage of honeycombs is their dramatic strength decrease when loaded outside the honeycomb cell axis.

Aluminium foams can be produced with various mass densities, depending on the manufacturing process (Fig. 4). The lightest foams (so-called "M-type") are made by injecting gas into molten aluminium-alloy material. They have densities ranging from 70 to 550 kg/m^3 and compression strengths from 0.05 to 8 MPa. Foams made from aluminium powder ("P-type") exhibit better homogeneity, but also have higher densities (300 to 1200 kg/m^3) and compression strengths (2 to 25 MPa). Their specific energy absorption is lower than for honeycombs, and unlike honeycombs structural foams are effectively isotropic, exhibiting the same deformation behaviour regardless of the direction of the applied load.

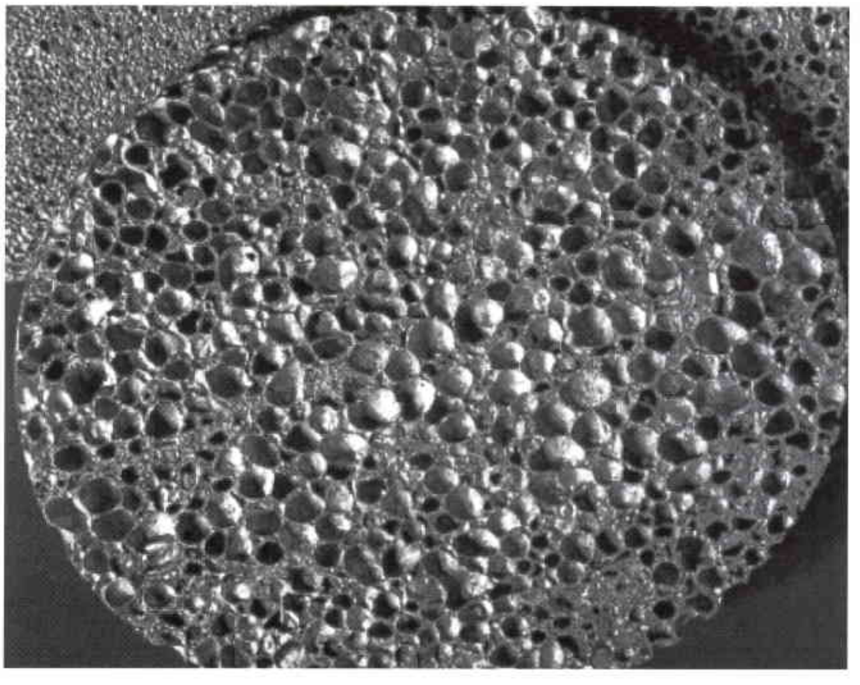


Figure 4. Aluminium foams

Deformable tubes (e.g. fragile or collapsible tubes, or tubes expanded by oversized steel balls) have been used in the aerospace industry for many years, but they too only work effectively in a clearly defined axial direction. Scaling down of the results in the literature for their application to a lander platform appears difficult.

Wave transmission control is only feasible as a means of shock alleviation within the dimensions of penetrator or semi-hard landers for the very high frequency range, whilst the predominant shock loads in the present case are quasi-static with significant contributions up to 1000 Hz.

Of the available shock-alleviation technologies for a penetrator-lander, therefore, the aluminium-honeycomb materials offer the best potential, provided due regard is paid to the need to include some form of guidance system to eliminate any unstable lateral collapsing that could otherwise occur. Tests with aluminium honeycombs and aluminium foams were therefore performed for the semi-hard lander.

Dynamic analysis of shock loads and shock propagation

Penetrator-lander

Finite-element and lumped-mass models have been used to predict the body loads for specific penetrator-lander impact conditions. These models were refined to enable reaction loads to be predicted at various locations, and in particular at the proposed baseline equipment locations on the payload platform. A simplistic model was then validated against the more detailed structural representations, prior to being used for parametric investigations of equipment shock-alleviation devices.

The body loads were computed using the baseline impact conditions defined in Figure 5. The simplified impact model was created using the lumped-mass code ISIM, in which the skirt crush characteristics were based upon static compression tests on a coupon sample (100x100x150 mm^3) of aluminium honeycomb (HEXCEL 1/4-5052-0.0007) and were incorporated into the model as a non-linear general crushing curve, allowing hysteretic loading and unloading conditions to be handled. A vertical impact velocity of 70 m/s was applied to produce the penetrator-lander body response. The results show that at this velocity the skirt has sufficient energy-absorption capacity not to induce blocking, and not to exceed the baseline load limit of 700 g.

The baseline impact envelope was defined as approximating to a half-sine pulse of 700 g amplitude with a duration of 15 ms, which correlates well with the vertical impact response predicted by analysis.

Impact loads on payloads have been predicted using an extended lumped-mass model, including a payload placed on a crushable honeycomb cushion. Even when constraining the length of the shock-alleviation system to within the equipment platform, a load limitation of 500 g is feasible. Further attenuation of the equipment deceleration loadings requires an increase in the stroke distance by extending the attenuation device through the equipment platform and into the volume of the main honeycomb skirt (Fig. 6). The corresponding acceleration profiles show that with the extended protection device, the shock load on the equipment can be limited to 400 g (Fig. 7).

Semi-hard lander

A PATRAN/NASTRAN software package finite-element model of the Marsnet Semi-Hard Lander was used to determine typical shock loads on the lander platform and transform them into standard load cases. Parametric investigations were then carried out with simplistic models. Linear spring-damper isolators can be studied using the shock response spectrum tool within NASTRAN. The nonlinear material behaviour of energy-absorbing media such as aluminium honeycombs or foams is represented by plastic material models in the ABAQUS software package. This finite-element package can also be used for basic shock-wave propagation analysis.

Both vertical and oblique landing cases were analysed, and worst-case loads at various points of the lander platform were identified. The common characteristics of these loading time-histories can be represented by four basic load cases for the semi-hard lander:

Load case 1: Half-sine wave, 0.5 ms duration, 200 g peak
Load case 2: Half-sine wave, 5.0 ms duration, 200 g peak
Load case 3: Single long pulse (load case 1), followed by three short pulses (load case 2)
Load case 4: Similar to load case 3, but short pulses reduced to 120 g peak.

Load cases 3 and 4 were predominantly used in the analysis, whilst the final prototype tests were carried out with load case 2.

Analysis of spring-damper shock isolators using shock response spectra and time-history simulations clearly showed that the effective elastic displacement range is some centimetres, which exceeds the specifications of commercially available elements.

Using ABAQUS, combinations of absorbers, spring and damper elements were investigated using simple lumped-mass models. The irreversible crushing behaviour of honeycombs and foams was modelled using the ABAQUS features for ideal elastic/plastic behaviour. During the conceptual design phase, this approach was extended by introducing isotropic hardening to account for the blocking behaviour of the crushable elements.

Our analysis showed that aluminium honeycombs and foams are promising candidates for energy absorption. Single absorbers used for shock alleviation of a rigid payload are able to guarantee the 100-g acceleration limit with resulting crush strokes of 10 to 20 mm and negligible elastic motion. Structural damping has to be considered as a parallel load path entailing lower absorber crush levels and higher corresponding crush lengths. Series and parallel connections of absorbers with spring-damper elements show worse performances than single absorbers in

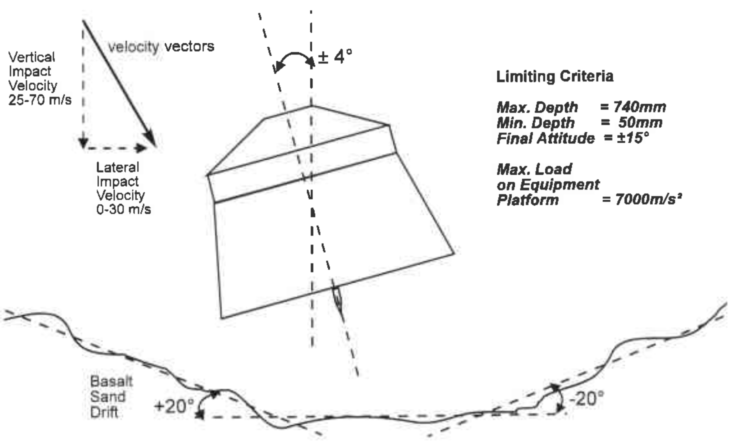


Figure 5. Baseline impact criteria for the penetrator-lander

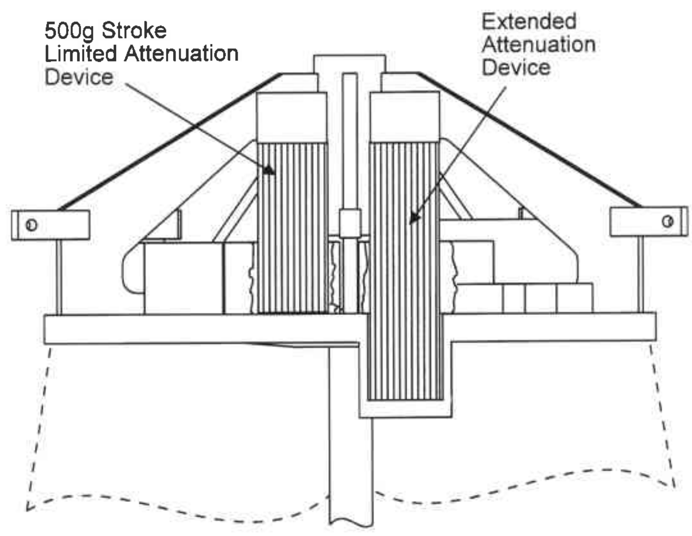


Figure 6. Incorporation of extended attenuation device

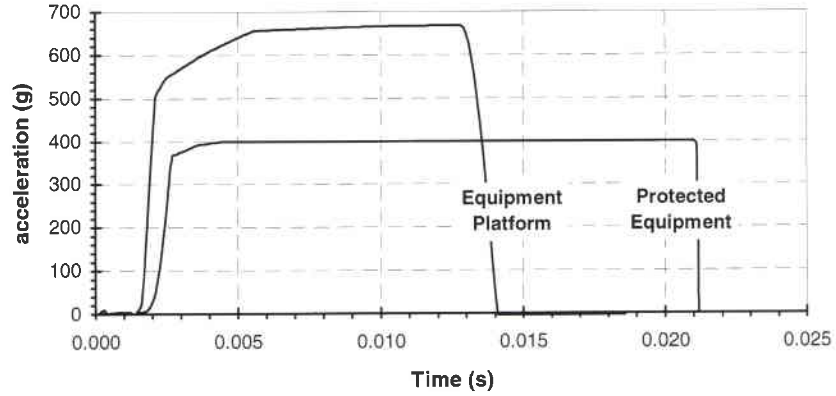


Figure 7. Acceleration profiles of platform and protected equipment

terms of crush stroke and elastic displacement. However, an absorber connected in parallel with a spring-damper element can be used to roughly reposition the payload in its original orientation after the shock load has died down, if elastomer stops are used to restrict the free oscillatory motion.

Experimental investigations of shock-absorbing materials

Static- and dynamic-loading deformation characteristics have been experimentally determined for materials found suitable for the main penetrator-lander impact attenuation device (flared honeycomb skirt) and for a number of payload-equipment energy absorbers (aluminium honeycombs and foams) for both the penetrator and semi-hard landers.

The materials selected for the penetrator lander were HEXCEL aluminium honeycombs 5/32-5052-.0007 (cell size - material grade - wall thickness) for the main skirt and types 3/8-5052-.001, 1/4-5052-.0007, and 3/16-5052-.0007 for equipment protection. The materials selected for equipment protection on the semi-hard lander were HEXCEL aluminium honeycombs 3/8-5052-.0007 (Fig. 8, above) and 1/8-5052-.0007 as well as aluminium foams made by Alcan (Fig. 8, below) and Shinko Wire (Alporas foam).

Static crushing tests were performed on standard test machines and the dynamic crushing tests were carried out using an air-gun facility (Fig. 9). The test conditions and results are summarised in Table 1. The shaded columns indicate the materials selected for application in the prototype devices.

Conceptual design and analysis of shock-alleviation devices

Penetrator-lander

The material tests show that attempts to dynamically crush samples whose heights are considerably greater than their widths lead to undesirable lateral collapsing of the honeycomb stack. An extended attenuation device for load limitation below 400 g (Fig. 6) therefore needs a lateral guiding system for the payload and honeycomb stack.

The proposed shock-alleviation concept foresees installing the equipment to be protected and the honeycomb stack within a tube which offers lateral support (Fig. 10). The guide tube is bolted to the side walls of a solar-array support structure and through the payload platform. The tube is vented to avoid trapped gas being compressed and increasing the reaction loads experienced by the equipment. The venting slots also assist in reducing the overall mass of the device. The ISIM lumped-mass model was used to design the absorber element. A finite-element analysis of the guide-tube structure indicates sufficient safety margins in terms of strength.

Semi-hard lander

The prototype concept has guide rails to

Figure 8. Aluminium honeycombs and foams tested for shock absorption

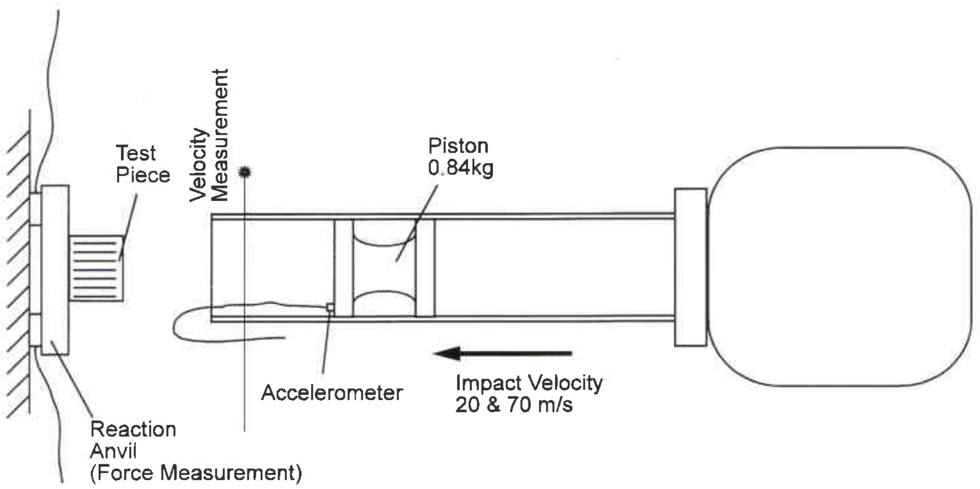


Figure 9. Air-gun facility used for dynamic crushing tests

Table 1. Summary of materials tests

Material	HEXCEL 5/32-5052-.0007	HEXCEL 3/8-5052-.001	HEXCEL 1/4-5052-.0007	HEXCEL 3/16-5052-.0007	HEXCEL 3/8-5052-.0007	HEXCEL 1/8-5052-.0007	Alcan aluminium foam	Shinko Wire / Alporas aluminium foam
Quoted strength [MPa]	0.62	0.32	0.32	0.45	0.17	0.90	0.2	1.0
Mass density [kg/m^3]	41.6	25.6	25.6	32.0	16.0	49.7	77.9	144.9
Static								
Measured strength [MPa]	0.68	0.32	0.38	0.51	0.16	0.94	0.17	0.86
Measured/quoted [%]	+9.6	+0.0	+18.7	+13.3	–5.9	+4.4	–15.0	–14.0
Normalised strength [N/cell]	10.2	28.9	14.2	13.5	15.4	10.4	–	–
Specific energy absorption [kJ/kg]	13.8	9.3	9.8	11.5	10.0	18.9	2.2	5.9
Blocking strain	>0.7	>0.7	>0.7	>0.7	>0.7	>0.7	–	–
Data consistence	good	good	good	good	good	good	good	good
Dynamic								
Impact velocity [m/s]	70	–	70	–	20	20	20	20
Measured strength [MPa]	0.83	–	0.40	–	0.25	1.1	0.19	?
Measured/quoted [%]	+33.8	–	+25.0	–	+47.1	+17.0	+11.8	?
Normalised strength [N/cell]	12.5	–	15.0	–	24.4	12.2	–	?
Specific energy absorption [kJ/kg]	15.1	–	10.5	–	23.6	12.3	2.5	?
Data consistence	good	–	good	–	good	poor	good	poor
General								
Availability	good	good	good	good	good	good	poor	good
Chosen for application	yes	no	yes	no	yes	no	no	no

prevent lateral motion and offers the option of a rough re-positioning and re-alignment of the payload. It was clear from previous analyses that lateral acceleration would not be critical. The main requirements on the concept, known as the Shock Alleviation/Re-Alignment (SA/R) prototype device, are:

1. The device must be able to carry a payload or equipment with dimensions of 100x100x100 mm^3 and a mass of 0.7 kg.
2. The shock loads to be borne by the device are 200 g vertically and 60 g laterally, both applied as 5 ms half sine pulses.
3. In the vertical direction, the 200 g load has to be reduced below 100 g across the whole frequency range. Also laterally, the 100 g limit must not be exceeded.
4. The SA/R device must allow payload re-positioning and re-alignment with 1 mm accuracy in the vertical and lateral directions and with 1deg angular accuracy.

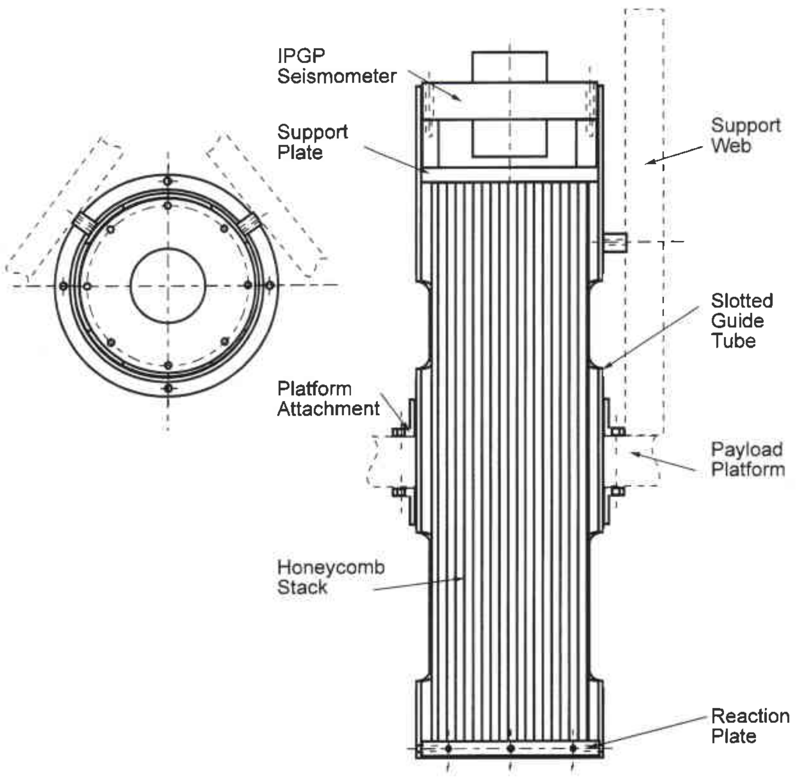


Figure 10. Guide-tube shock alleviation concept

Figure 11. Integrated SA/R prototype device with inclined adaptor

These requirements are reflected in the basic concept for a prototype SA/R device:

1. The payload or equipment is mounted on a support platform with a well-defined interface. The payload plus platform constitute the moving element of the device and their combined mass has to be considered for shock alleviation.

2. The 200 g vertical shock load is reduced to below 100 g by the crushing of an aluminium honeycomb cushion (type HEXCEL 3/8-5052-.0007). Lateral shock loads are carried by a guiding system which has to prevent sticking or canting of the payload platform.

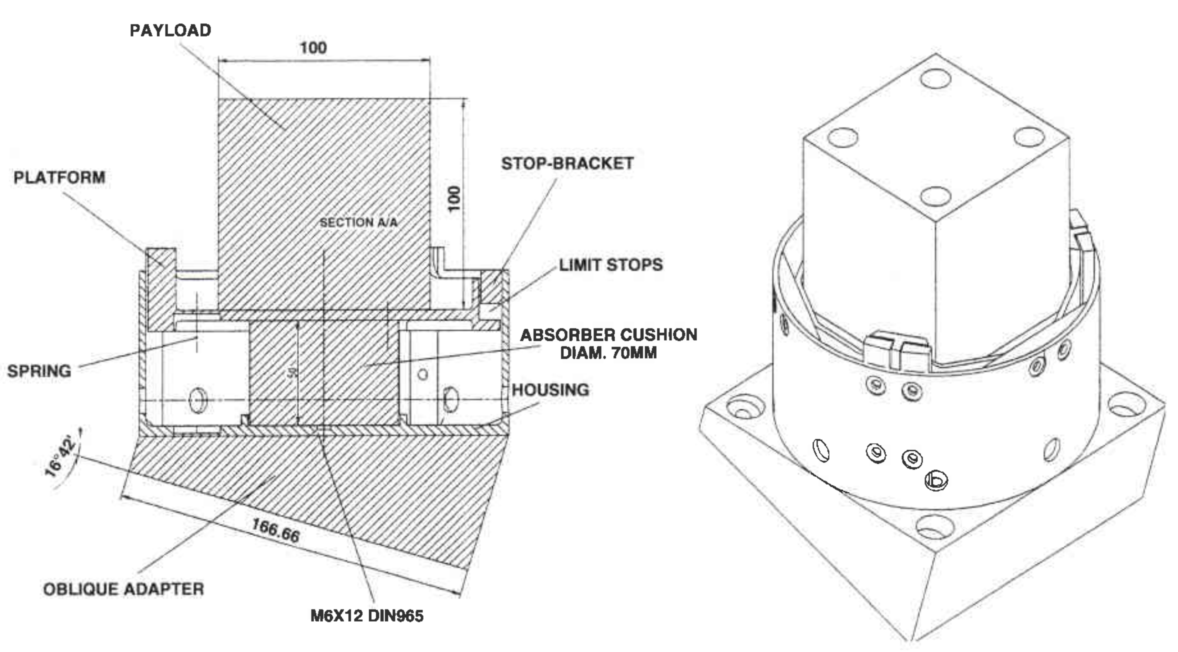
3. Re-alignment of the payload is accomplished with one or more spring elements which take the platform back to its intial position after the shock load has died down. The upward movement of the platform is stopped by elastomer limit stops. The spring elements have to be pre-stressed against the elastomer elements so that the platform comes to rest in a pre-defined position.

Detailed testing and analysis of the main elements (absorber cushion, spring elements, elastomer stops) was conducted in order to complete the SA/R prototype device's design. Performance simulations were carried out with ABAQUS lumped-mass models, including elements for the honeycomb cushion (elastic-plastic with isotropic hardening), springs (non-linear) and elastomer stops (nonlinear spring with linear damper). For the lateral acceleration testing, an inclined adapter was designed. The design drawings of the assembled device are shown in Figure 11.

Testing of prototype devices

Penetrator-lander

The dynamic testing of the penetrator-lander shock-alleviation system was performed with a ballistic air-gun shock-test rig (Fig. 12). A cylindrical aluminium projectile was fired into a



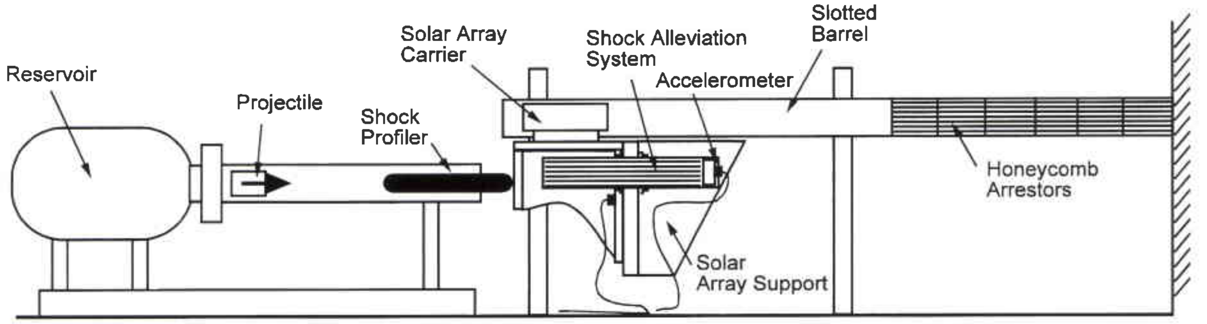


Figure 12. The revised test configuration

polyurethane block (shock profiler) installed on the back of a stationary carrier on which the shock-alleviation device was mounted. During the impact pulse, the kinetic energy of the projectile is transferred via the shock profiler to the carrier, and generates an acceleration profile approximating a half-sine pulse. The carrier and test items are brought to rest using a honeycomb retardation system. An air-gun is used to accelerate the aluminium projectile up to the required impact velocity (typically 80 m/s for the 700 g test). The assembled shock-alleviation device was mounted on the vertical face of the carrier which is attached to a piston located within a slotted guide tube . Additional test items were placed on the baseline mass: three PULNIX CCD cameras, an IPGP seismometer pivot, and a SITe 1024x1024 CCD wafer.

The acceleration measurements verified the functionality of the concept, as the test results summarised in Table 2 confirm. Upon inspecting the degree of deformation of the honeycomb stacks, however, it was found that the test configuration was not performing exactly as predicted. This was found to be because of the reverse ballistic test configuration, where the velocity profile between carrier and baseline mass differs from the actual impact situation on a penetrator-lander. By using a revised lumped-mass model, the crush strokes could be verified analytically.

The models did demonstrate that the deformation characteristics of the honeycomb derived during the initial experimental phase of this study were representative. The predicted baseline mass responses, in terms of amplitude and deformation, correlated very well with those measured during the trial.

Semi-hard lander

The shock tests on the SA/R prototype device were performed in this case on an Avco shock-test machine. The test specimen was mounted on a table, lifted to a pre-specified height and accelerated downwards by air pressure acting on a piston. Various shock-pulse shapes could be realised by choosing appropriate strokes,

Table 2. Summary of inputs and responses

Test No.	Item	Piston Vel.	Carrier Acc.	Duration	Allev. Acc.	Duration	Stroke
WP 3300(1)	PULNiX	49 m/s	270 g	0.016 s	380 g (270g)	0.003 s (0.016 s)	0 mm
WP 3300(2)	PULNiX	81 m/s	700 g	0.012 s	440 g	0.010 s	27 mm
WP 3300(3)	PULNiX	78 m/s	680 g	0.015 s	440 g	0.013 s	26 mm
WP 3300(4)	IPGP	83 m/s	680 g	0.015 s	300 g	0.016 s	70 mm
WP 3300(5)	SITe	79 m/s	620 g	0.015 s	121 g*	-----	180 mm

*calc

air-pressure values, and elastomer impact pads.

The SA/R prototype device was tested in two configurations, namely in a vertical and in an inclined configuration (Fig. 13). Three vertical tests (V1-V3) and two inclined tests (I1, I2) were performed, and the results are summarised in Table 3. The acceleration measurements indicate the proper functioning of the shock-alleviation system, including the 100 g acceleration limit and the rough re-positioning and re-alignment of the payload. However, the crush strokes of the device recorded during the tests were less than half of the analytically predicted values. The kinetic energy measured from the force versus stroke curve during the test was only half that obtained analytically for a half-sine pulse. Simulations using the test acceleration input data correlated well with the experimental results. An additional test with an inclined configuration with 300 g input yielded the kinetic energy specified for the nominal test case.

In the case of the inclined tests, there was a significant dynamic magnification of shock loads, but this was not critical for the 200 g tests. This effect should be further investigated in any future studies/tests.

In general, it was found that simplistic one-dimensional ABAQUS models give reasonably good analytical predictions in the face of significant material data scatter and unknown damping and friction characteristics.

Conclusion

Design specifications for shock-alleviation devices for penetrator-landers and semi-hard landers have been defined on the basis of a review of currently foreseen missions involving lander-type devices. Materials testing and dynamic analyses have helped us to understand the behaviours of shock-absorbing materials such as aluminium foams and honeycombs in such applications. The tests that were subsequently carried out have proved the feasibility of the design concept. The reverse ballistic testing configuration led to smaller crush strokes than predicted for the lander. This could be explained with velocity profiles differing from the actual landing case, and the test results were verified analytically with simplistic lumped-mass models. The predicted baseline mass responses correlated very well with those measured during the trials.

The SA/R prototype device for the semi-hard lander was tested on a standard shock-test machine and its performance successfully demonstrated by experiment for both vertical and inclined configurations, including the requisite rough re-positioning and re-alignment of the payload

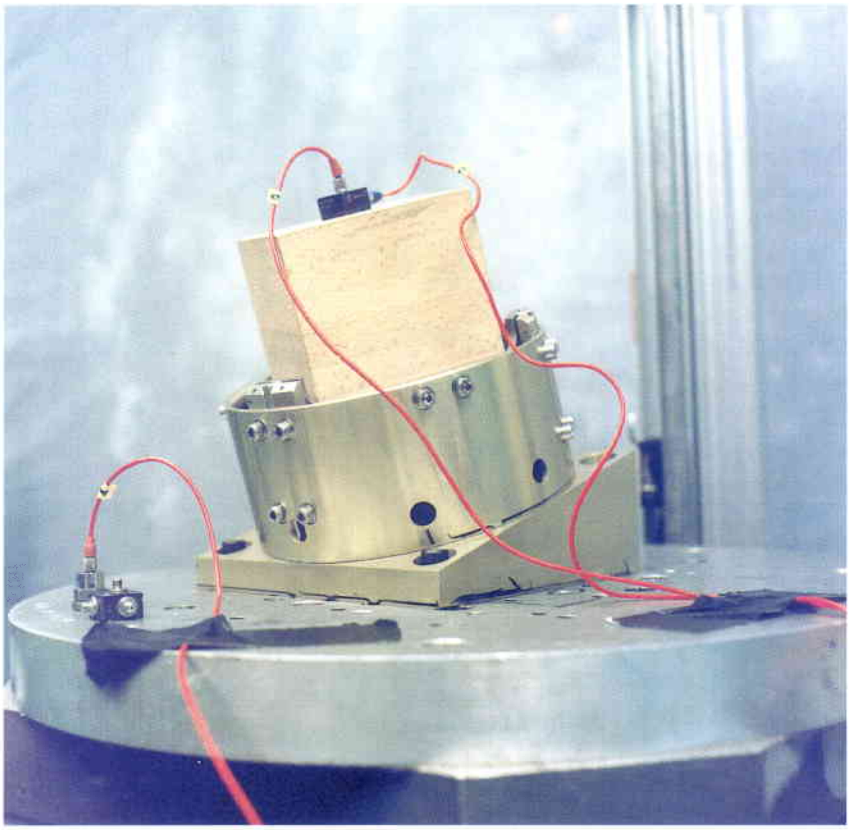


Figure 13. SA/R prototype in test configuration

Table 3. Summary of test results for the SA/R prototype device

Test No.	V1	V2	V3	I1 vertical	I1 lateral	I2 vertical	I2 lateral
Absorber cushion No.	#2	#1	#3	#4		#5	
No. of honeycomb cells	30	30	29	29		29	
max. input acceleration	205.5 g	204 g	205.2 g	185.3 g	55.6 g	291.0 g	87.3 g
max. payload acceleration	68.0 g	84.3 g	71.7 g	75.7 g	92.2 g	90.3 g	146.2 g
max. payload deceleration		–31.4 g	–35.4 g	–27.1 g	–85.7 g	–65.3 g	-140.6 g
crush stroke	9.8 mm	8.6 mm	10.0 mm	7.0 mm		17.2 mm	

ESARAD: From R&D to Industrial Utilisation

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In March 1988 ESA placed a contract for the development of a new thermal radiation analysis tool, to be called ESARAD. The aim of this development was to provide industry with a reference tool for use in European space programmes. Almost ten years later, ESARAD is fully operational and is being used in several ESA projects. Thus, the early R&D activities have come to fruition in the form of a fully industrialised product. This may therefore be a good moment to summarise the efforts devoted to the development and deployment of ESARAD and to review the most relevant issues encountered along the way.

Introduction

The analysis of thermal radiation-driven problems specific to the spacecraft engineering requires the use of specialist tools to characterise the heat flows within the system. Historically, thermal engineers have used tools based in the so-called 'Lumped Parameter Methods' (LPM), which break down the system into a number of control volumes known as thermal nodes and lump the volume properties onto their centroid.

In the mid-eighties, ESA sponsored the development of ESATAN, an LPM-based thermal-analysis package that quickly became established as the standard tool within European projects. However, ESATAN still needed companion software to estimate the radiative exchange factors and absorbed solar, infrared planet and albedo heat fluxes required for solving the nodal heat-balance equations.

Just like ESATAN, the ESARAD project was born with the objective of developing and deploying an industrial-strength product that could replace the multiplicity of old, unreliable and difficult-to-maintain tools that were being used by ESA and industry at the time. It was also expected that the further standardisation of tools would facilitate the communication of models and analysis results between project organisations.

ESARAD was supposed to be a superior tool in several respects:
- in offering a generic but sufficiently rich functionality set
- in providing robust algorithms
- in using state-of-the-art software technology
- in being a software-engineered product, easy to port, maintain and improve.

In March 1988, ESA placed a contract for the development of the software, with GEC Alsthom's Mechanical Engineering Centre (UK) as prime contractor responsible for the pre- and post-processing framework and Matra (F) as subcontractor responsible for the algorithmic kernel.

R&D issues in the ESARAD development

Fulfilling the requirements for ESARAD raised a number of issues that conditioned the eventual success of the project. Not surprisingly, most of the main development was devoted to finding solutions for these technological problems and integrating them into a coherent, usable system.

The first major obstacle was an architectural one. ESARAD was to take advantage of progress in graphical-user-interface (GUI) technology to provide an interactive operating mode. However, there was a strong requirement to support the batch operation featured by most of the older tools and to which many analysts were accustomed. Batch runs were also important to perform the offline analysis required for parametric studies and for large models typical of space projects. The dual operation problem was resolved by introducing a formal computer simulation to drive all ESARAD modules. The GUI modules would produce language statements in response to user actions, and the statements would be interpreted in real time.

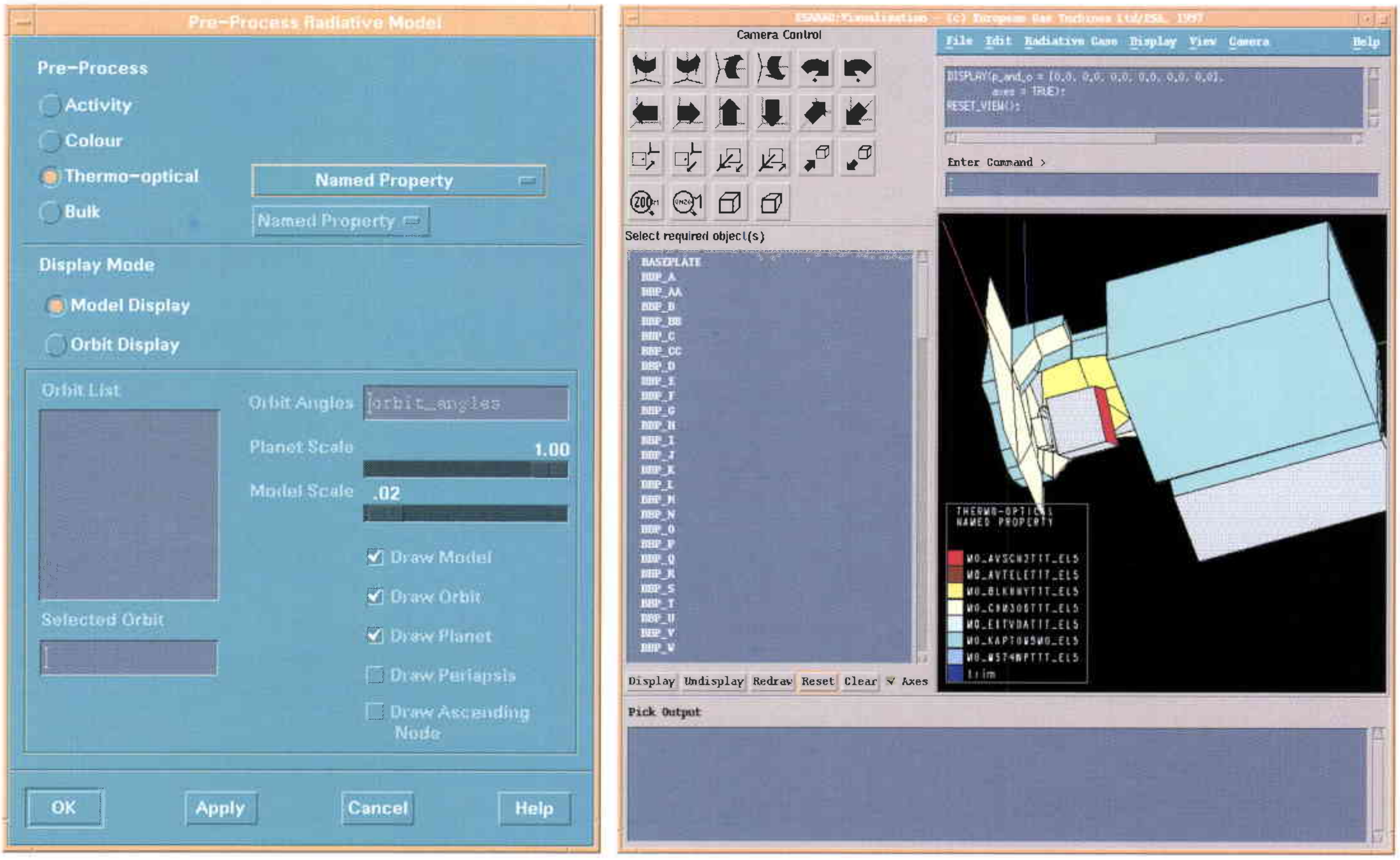


Figure 1. All ESARAD modules can be operated via a Graphical User Interface (GUI). This illustration shows the Visualisation module, which is used to pre- and post-process ESARAD models by means of 3D computer graphics. The display shows how colour can be used to discriminate between the different coatings on the system surfaces

One consequence of using a fully featured language for modelling and simulation purposes is the huge increase in flexibility. Indeed, next to conventional techniques ESARAD can handle more sophisticated approaches like parametric modelling, where dimensional constraints and dependencies between geometric parameters can be specified as part of the model. Changes in some parameter values are then propagated across the system. Users can also define models by means of procedures containing flow control constructs (IF-THEN, FOR-END_FOR, etc.). This is useful in situations where there is a need to describe alternative system configurations in a single model or where a concise description of systems showing symmetries or repetitive structures is required. Furthermore, the language gives users much more control of the analysis than in conventional tools. Runs can be tailored to specific requirements, like making the albedo characteristics of the planet depend of the spacecraft orbital position.

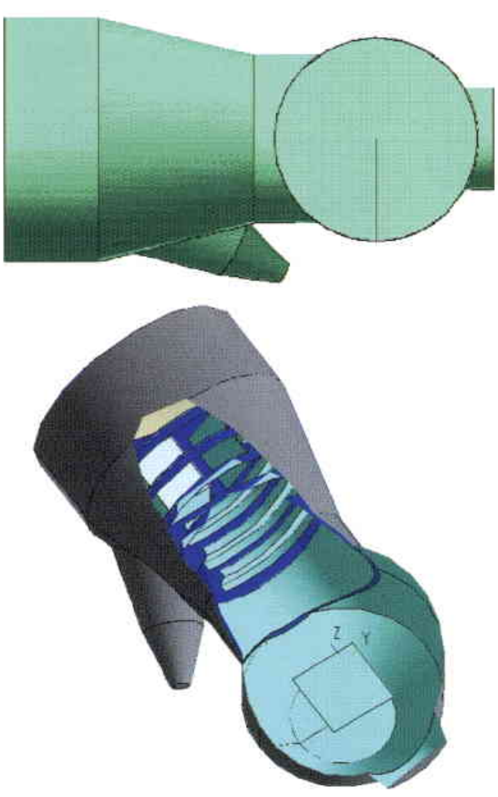
Another important issue was the support for constructive modelling. Typically, thermal radiation-analysis tools are able to handle a limited set of rather basic surface primitives (e.g. plates, discs, cylinders, spheres, etc.). One of the requirements in ESARAD was to extend these modelling capabilities to support the 'cutting' of surfaces by means of boolean subtraction operations. Introducing cutting operations was a real challenge because complex computational geometry algorithms had to be developed to process and analyse cut surfaces. Cutting operations are today one of the most popular and powerful ESARAD features, since they provide a simple and accurate way to model shapes which would otherwise need to be approximated with a multitude of smaller surfaces. Moreover, a concise geometric description reduces the clutter in the model and facilitates its analysis.

Much effort was spent on what was probably the single most critical issue for the success of the software, namely the application of advanced computational techniques for the purpose of radiative calculations. Traditionally, algorithms implementing some variation of the Nusselt projection methods had been used for the calculation of view factors and direct heat fluxes, quantities which depend on the geometrical configuration of the system, but not on its surfaces' thermo-optical properties. Then, so-called 'Matrix Methods' were applied to derive the radiative exchange factors and absorbed heat fluxes required for solving the nodal heat-balance equations in ESATAN. This approach was popular because it was fast, since Matrix Methods process the multi-reflections within the system by taking advantage of the geometrical information built into the pre-computed view factors and/or direct heat fluxes. However, the use of this 'classical' approach may lead to serious

problems because several idealisations are necessary for the method to work. In particular:
- thermal radiation emission and reflection must be diffuse
- faces must be isothermal and have uniform emissivity
- faces must be uniformly irradiated.

The first assumption holds in many cases, but excludes the use of Matrix Methods where specular effects are important. The second and third assumptions depend strongly on the quality of the discretisation and may be violated where proximity and shadowing effects are significant.

Because of these problems, ESARAD calculates view factors and direct heat fluxes by means of Monte Carlo Ray-Tracing (MCRT) methods. Furthermore, MCRT is also offered for the direct calculation of radiative exchange factors and absorbed heat fluxes. In reality, thermal radiation energy is emitted from all surfaces, in all possible directions, and is either absorbed or reflected when it reaches other surfaces. Since it is not possible to account for the infinite number of possible paths that radiation follows, Monte Carlo methods estimate the radiative couplings and heat fluxes by averaging the 'histories' of a random finite sample of energy packets, called 'rays' in this context. The individual history of each ray, namely its emission point, emission direction and ray/face interaction behaviour, is randomly determined. MCRT methods are therefore stochastic in nature.



The MCRT method is a powerful simulation tool that removes many of the limitations of the traditional approach to modelling the thermal radiative behaviour of the system. In particular, faces need not be uniformly irradiated. The only concern when choosing a discretisation is that, in line with the requirements of the lumped-parameter approach, faces should be as isothermal as possible. Curved surfaces like cylinders or spheres do not need to be approximated by planar facets, since ray-tracing can be adapted to work for 'exact' higher-order surfaces. Furthermore, it is possible to describe a great variety of mechanisms for emission, reflection (diffuse, specular, etc.) and transmission of radiation. MCRT methods are also interesting because they admit robust implementations and because it is possible to calculate the error with which estimates are produced. As a matter of fact, ESARAD pioneered the use of statistical methods to control the accuracy of MCRT for thermal-radiation-analysis purposes.

Finally, it is worth discussing the choice of software technologies for the implementation of ESARAD. This was an issue of critical importance to guarantee the cost-effective maintenance and evolution of the tool during a long operational life. The philosophy adopted was to use software standards as much as possible. For example, it was decided that the code should be written in ANSI C, the ESARAD language parsed with the *lex* and *yacc* standard UNIX tools, the data stored in an ORACLE database via SQL, and computer graphics provided through the ISO PHIGS standard. Furthermore, the software had to be well-engineered and therefore ESA's PSS-05 Software Engineering Standards were made applicable throughout the whole development. With hindsight, it can be confirmed that these choices have been very positive. Although some of these standards were not completely mature at the time the development started, clearly it has been possible to keep the maintenance and porting costs low without compromising the functionality and performance of the software.

Key features of ESARAD

ESARAD provides a complete environment for pre-processing, running and post-processing spacecraft thermal radiation analysis.

The starting point is the definition of the so-called 'Geometric Mathematical Model' (GMM). ESARAD has a dedicated Geometry module which allows users to define the geometry, meshing and thermal properties of the system. It is important to note that radiative heat transfer is essentially a surface-to-surface

Figure 2. ESARAD model of the Large Solar Simulator (LSS) test chamber at ESTEC (NL). Cutting operations are used extensively to model the chamber enclosure in a compact and exact way. In general, more traditional modelling techniques require a much larger number of basic surfaces

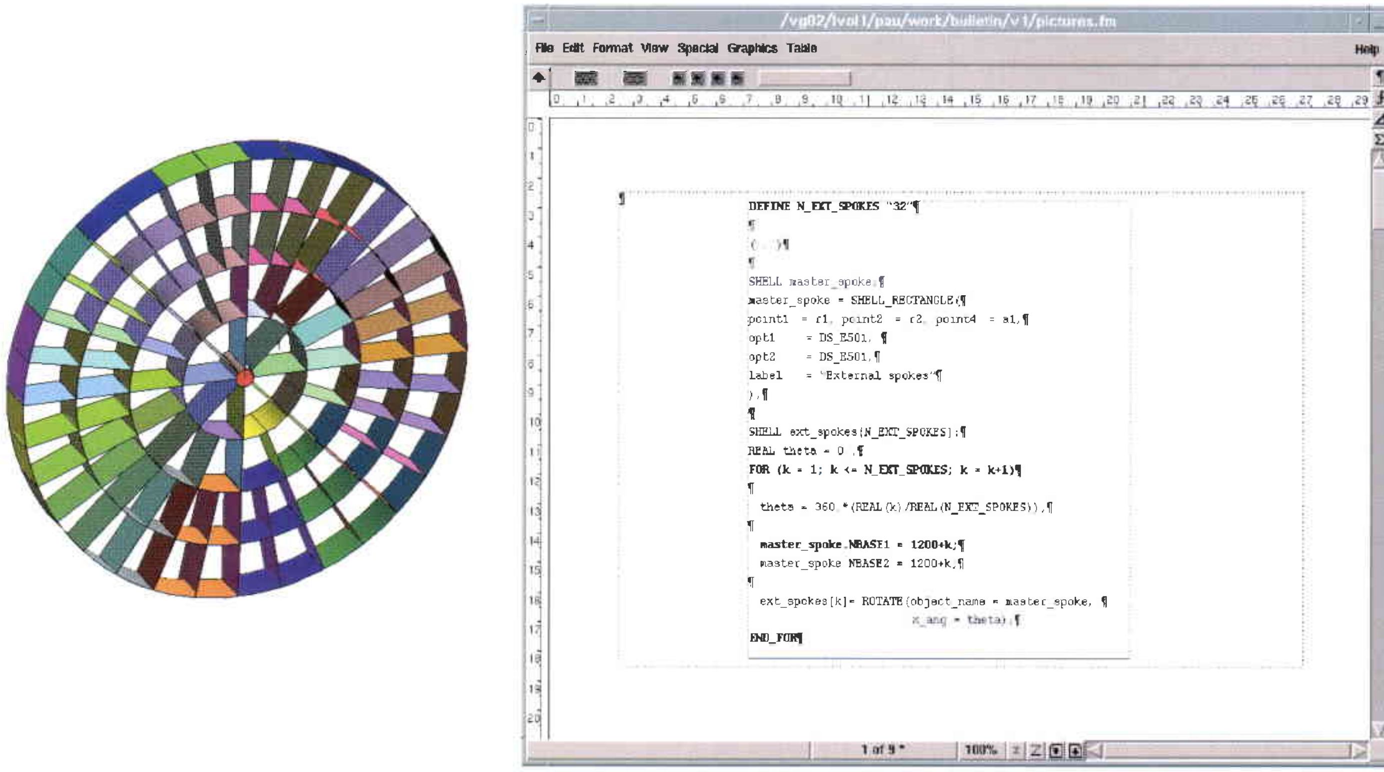


Figure 3. The ESARAD language provides a powerful and flexible means of defining the thermal-radiation model and analysis. This illustration shows the procedural model of a highly symmetrical mirror assembly for a future X-ray astronomy mission. Each thermal node is coloured differently

process. Thus, systems are represented with surface, and not solid, geometry. To enable the calculation of the conductive heat transfer, the surface thickness may be defined as a notional, but not geometric, concept. In order to apply the LPM techniques later on, surfaces are broken down into radiative faces by specifying the mesh resolution along their two characteristic parametric directions. Thermo-optical and bulk property sets are associated to every surface in the system. Finally, the model is assembled by grouping basic surfaces together in the form of a hierarchical GMM, which is very useful for pre- and post-processing purposes. ESARAD also allows the 'black-box' integration of sub-models produced by different companies within a project, a very useful concept borrowed from ESATAN.

ESARAD provides several facilities to assist in checking the correctness of the GMM. For instance, via the Reporting module, users can produce a variety of reports listing all relevant characteristics of the model. Additionally, the 3D computer graphics available in the Visualisation module are a very effective way to inspect the model. Within this module, one can

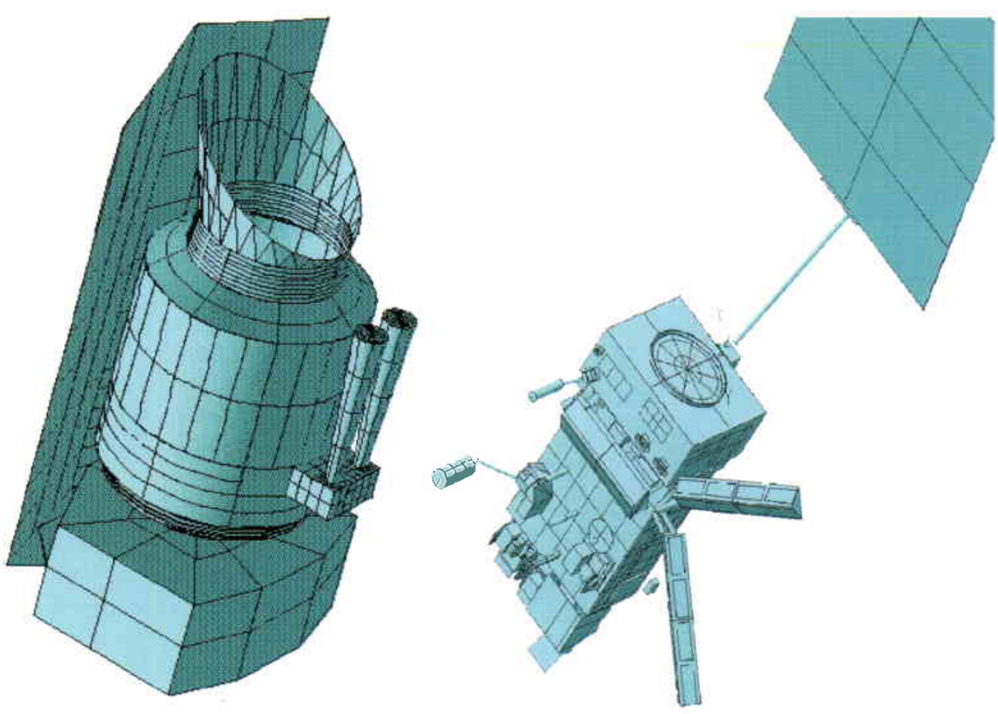


Figure 4. Large models like that of the ISO spacecraft (left) can be hierarchically assembled to facilitate the pre- and post-processing of model parts. The Metop spacecraft's reduced external model (right) is built by integrating the 'black box' submodels of the instruments, Service Module and Payload Module provided by different companies

independently select and display:

- any part of the GMM, ranging from the whole model to individual surfaces
- the values for any attribute associated to the GMM faces, like activity, colour, associated thermal property sets and individual property values (emissivity, absorptivity, diffuse reflectivity, etc.). In the 3D model, GMM faces are coloured according to the mapping of the selected attribute's values to a range of hues. The display can be interpreted by posting a legend next to the model.

In the Visualisation module, users can look at the model from any angle and focus on the relevant parts by using the mouse to control parameters like the view direction, zoom, pan, etc. The type of rendering can be selected to be either wire frame or flat shading. Illuminated shading can also be used to increase the realism of images, which is useful for presentations. To facilitate the production of documentation, users can export the display via graphic formats readily accepted by most word processors and spreadsheets.

In order to predict the thermal behaviour in-orbit, it is essential to characterise the mission which the system being analysed is supposed to perform. This involves specifying:

- the orbital trajectory, which is considered to be Keplerian. ESARAD can handle both interplanetary trajectories around the Sun and planet-centred orbits which can be used to represent terrestrial, lunar and other planetary orbits
- the Sun/planet environment, including the Sun's position, distance and Solar Constant corresponding to the epoch for which the analysis is to be performed, as well as the planet average temperature and albedo coefficient
- the spacecraft attitude, so that the model can be properly oriented in orbit. ESARAD can handle both spinning and three-axis-stabilised spacecraft. Furthermore, users can model spacecraft with parts that move with respect to one another. A common example is spacecraft on which the solar arrays track the Sun whilst the payload must be kept pointed to the Earth. In ESARAD, it is possible to model this sort of behaviour by joining so-called 'bodies', i.e. rigid collections of surfaces, into kinematic GMMs. The bodies' relative movement is characterised by specifying the translational and rotational constraints and degrees of freedom of each joint. Later, users must specify the attitude of each of the bodies to remove all the degrees of freedom and to determine the orientation of the model at the orbital positions for which the calculations will be performed.

Once the mission is defined, users can go back to the Visualisation and Reporting modules to check its correctness, in a way similar to the one described above. Checking the model attitude is essential if the environmental heat fluxes are to be properly calculated.

At this point, it is possible to define and execute the analysis in the ESARAD Kernel module. The concept of cases provides a structured and useful way to organise calculations. Each case embraces, for a particular model, the mission data, the type of calculations to be performed and the parameters driving the calculations themselves (e.g. required accuracy). Cases can always be referenced by name, enabling users to track results back to the source model and mission and thereby improving the configuration control of ESARAD data.

The Reporting and Visualisation modules can

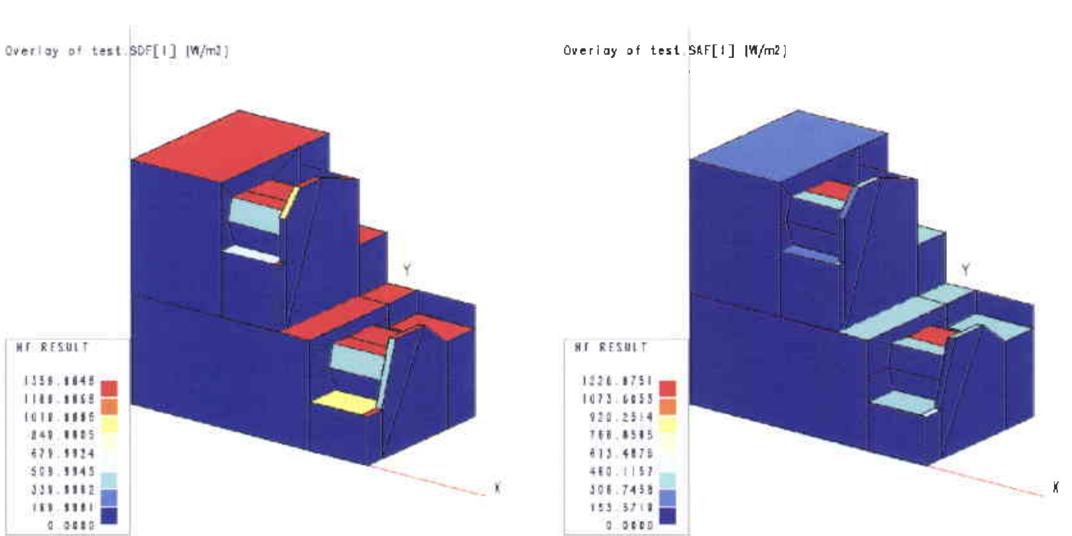


Figure 5. Post-processing of the solar heat fluxes on Metop's Advanced Microwave Temperature Sounder instrument. Differences between the direct and absorbed fluxes are due to the thermo-optical properties of the surfaces and to the existence of multi-reflections

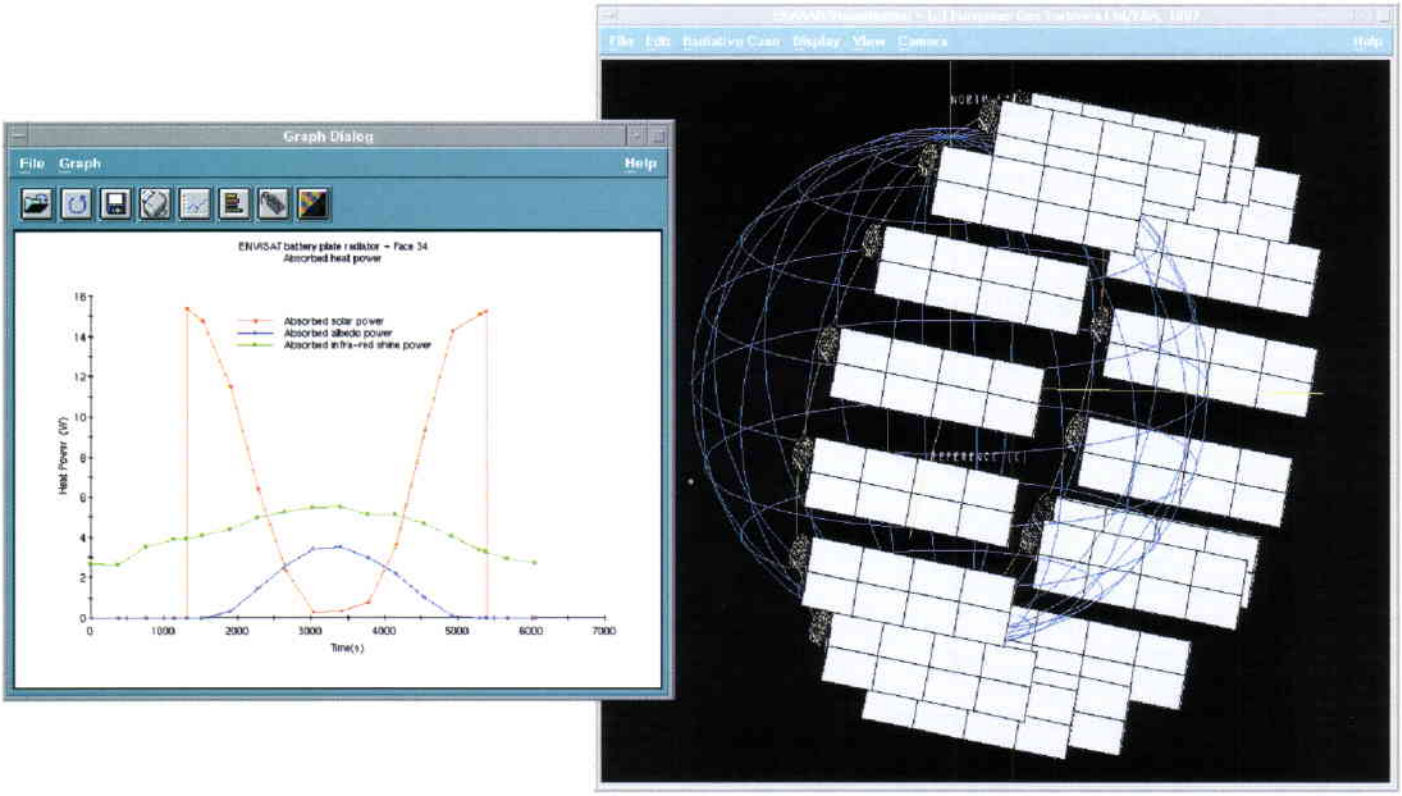


Figure 6. Analysis of the solar-array shading effects for the Envisat mission. Only the Service Module's battery plate radiator (in yellow) is modelled. Note the relative movement between the radiator and the panels along the orbit, due to the permanent Sun-pointing of the arrays. After the calculations, users can query results, produce tabular data and display graphs via the Data Extraction Utility

be used once more, this time to check the calculation results. In particular, it is possible to inspect the radiative couplings, the errors in the coupling calculations and the heat fluxes by displaying colour-coded 3D models. Thus, it becomes straightforward to see which parts of the spacecraft are illuminated, which flux source dominates, whether the calculation accuracy is sufficient for critical faces (e.g. radiators), etc. Furthermore, results can be dumped and post-processed by the Data Extraction Utility (DEU) shared by both ESARAD and ESATAN. Users can query the results of coupling and heat-flux calculations, extract data in tabular form, produce X/Y plots and export tabular data for more sophisticated post-processing in the third-party tools of their choice. In this respect, the DEU generates spreadsheet-ready tabular data files. Users can also include plots into their technical documentation by exporting the DEU graphs into well-accepted graphic formats.

Ultimately, the results of ESARAD calculations need to be given for the thermal nodes making up the Thermal Mathematical Model (TMM) handled by ESATAN. In doing this, several GMM faces are often merged into single thermal nodes. There may be a need for several of these merging schemes, for instance to derive detailed and coarse TMMs from the same GMM. A primary mapping can be defined in the Geometry module by associating thermal node numbers to surfaces. In addition, users can define an arbitrary number of mappings in ESARAD's ESATAN File Formatting module. Users can select mappings by name when pre- and post-processing the model and when generating input files for ESATAN.

ESARAD's validation and deployment

When the ESARAD main development phase was completed in 1992, the challenge was to validate the software for operational use. The most immediate concern was to establish the correctness of the sophisticated algorithms in the Kernel module. In this respect, ESTEC initiated a comprehensive and systematic effort to design and develop a set of reference test cases which could be compared to ESARAD predictions. As a result, a test suite with more than 80 cases has been produced, featuring models for which analytic or verified data are available. The test suite covers virtually all the relevant aspects of the Kernel module and is fully automated.

In parallel with ESTEC's verification of the ESARAD calculations, there was a need to evaluate the suitability of the tool for heavy-duty use in industry. This was accomplished by undertaking several beta-testing campaigns at selected industrial sites. The efforts focused on usability, functionality and performance issues and provided very valuable feedback, most of which has been built into the software ever since. The test suite and the industrial beta-testing continue to be used to check every new ESARAD release.

In mid-1994, the verification efforts had paid off and ESARAD was declared operational. The software was first rolled out to a group of 20 users from the Thermal-Control and Life-Support Division at ESTEC. The deployment required a substantial amount of support activities, including the creation of an on-site user support function in charge of the initial training, the setting up of standardised problem report procedures, the regular presentation of new releases, etc. Progressively, ESARAD has become the only operational thermal-radiation analysis tool at ESTEC, having been used in project-support activities for the SOHO, ISO, Cluster, MORO, Envisat, XMM, Columbus Orbital Facility (COF), Metop, Integral, Rosetta and First/Plank programmes.

The final step in the deployment has been the introduction of ESARAD in industry. Again, this has been a progressive process, with companies initially procuring ESARAD for evaluation purposes and later employing it for full operations. So far more than 30 companies and academic institutions have licensed the software, with ESARAD being used in industry for the Abrixas, COF, DORIS, Metop and Rosetta projects among others. The software is distributed with comprehensive user documentation, including a 'Getting Started Guide', the User Manual (PSS-03-106, an official ESA document) and the Language Reference Manual.

As had previously been done with ESATAN, the distribution and maintenance of ESARAD was entrusted to the prime contractor MEC, an organisation independent from any major space company, in order to ensure high-quality support and equal access to all users. MEC's tasks go beyond the development and maintenance and also cover software installation, user training and support, a 'hot-line' service, the publication of a newsletter and other miscellaneous customer-support activities. These tasks are largely self-funded, with MEC charging yearly maintenance fees to users. ESTEC complements these efforts with the organisation of an annual user meeting, the European Thermal Analysis Software Workshop, which has been held for the last 11 years. This event provides a forum in which users can be brought up to date regarding the software's development and where future requirements can be discussed in an informal but direct way.

Future evolution

ESA's current Technology Research Programme (TRP) continues to support the upgrading of ESARAD for the near future. Leaving aside a number of small-scale improvements, the efforts will be concentrated in two main strategic directions.

Firstly, the functional capabilities of ESARAD will be extended in order to keep pace with the needs of ever more demanding space missions. In particular, new requirements have already been identified for high-power-dissipation spacecraft, typical in telecommunications and Earth observation missions, as well as for lunar, planetary and cometary science missions.

Secondly, there is an important requirement for tighter integration of the analysis process, and therefore of the tools. Indeed, companies need to reduce the overall analysis turnaround time because of competitive pressures. Two aspects of this integration will be addressed:

- integration within the thermal-analysis process, with improved handling and tracking of data from ESARAD to ESATAN to enable the efficient analysis of a wide range of cases
- integration between computer-aided design (CAD) tools, ESARAD and other computer-aided engineering (CAE) tools via ISO STEP protocols, offering the opportunity to derive analysis models directly from the system configuration and to perform multi-disciplinary analysis. This will open the door to the integration of design and engineering applications around a common repository, something widely regarded as one of the key technology enablers for concurrent engineering operations.

Conclusion

Almost ten years of effort have paid off in the form of a powerful, robust and operational ESARAD software suite. It is important to note that R&D activities were necessary, but certainly not sufficient, to guarantee the proper deployment of the tool. In fact, it is essential that projects of this type be driven from the outset by both technological and industrialisation requirements, and that any important decisions take both of these aspects into account. As a result of having followed this approach, today's ESARAD users are benefitting from a well-documented and professionally supported product that is being used in many ESA projects. esa

earthnet *online* — The ESA Earth Observation Multi-Mission User Information Services

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A new information resource – 'earthnet *online*' – is now available to the Earth Observation community on the World Wide Web* (WWW or Web). The online service is provided through release 'A' of the Multi-Mission User Information Services (MUIS) project and offers an integrated and user-oriented service for access to Earth Observation data. MUIS focuses on a more comercially-oriented data presentation in the form of 'products' thereby offering access to a larger user community.

Opening this type of service in a dynamically changing environment like the Web will trigger new and changing user requirements. Therefore, the MUIS project is following an iterative development cycle of two further major releases. Release 'B', currently under implementation, will introduce additional services. It is based on a re-engineered architecture implementing full distribution capability. Release 'C' will achieve full deployment of the distributed services to provide a front-end to an interoperable network of service providers in cooperation with international partners.

Introduction

The ESA-operated **earthnet** *online* service is unrivalled in Europe in terms of the amount of Earth Observation information offered by a single provider. The data covers ESA missions and ESA-managed 'third party' missions including all product metadata as well as an extensive collection of related documentation. The associated service facilities provide systematic online retrieval mechanisms for news and data provided by the Earthnet Programme which is carried out under the responsibility of ESRIN.

Features of earthnet *online*

- catalogue:
  - ERS-1/2, Landsat, NOAA, JERS, Nimbus
  - 10 million inventory records
  - 800 Gbytes of thumbnail and 'quick-look' image data
  - product-specific search criteria
  - multi-mission searching

- product order support:
  - order options and guide descriptions for fifty different product types
  - graphics-supported scene selections
  - persistent order item hotlist

- documentation:
  - ~100 000 Web pages of text and images
  - ERS-1/2 news and information
  - 500 EO-relevant reviewed Web links
  - special SAR interferometry information
  - hosted databases and directories (EarthWatching, EARSeL, CEOS InfoSys, CEOS IDN)

- user interface:
  - geographic maps for catalogue search and presentation of interactive results
  - context-sensitive Help
  - full-text search on all documents
  - support of NASA IMS search protocol
  - planned support of new CEOS PTT-approved catalogue interoperability protocol.

earthnet *online* services

earthnet *online* (Fig. 1) provides information for Earthnet missions via the following electronic services:

- directories and links
  earthnet *online* includes a virtual yellow pages service which draws upon numerous information sources on the Web by gathering pointers, or link references, to locations which may interest users.

- information retrieval
  Extensive documentation material provides a thorough understanding of potential Earthnet data usage. A news feature keeps users up-to-date on missions, programmes and projects.

  Users can download a data catalogue, software for data interpretation and display, and auxiliary data for handling and analysing product data via File Transfer Protocol (FTP).

*http://earthnet.esrin.esa.it

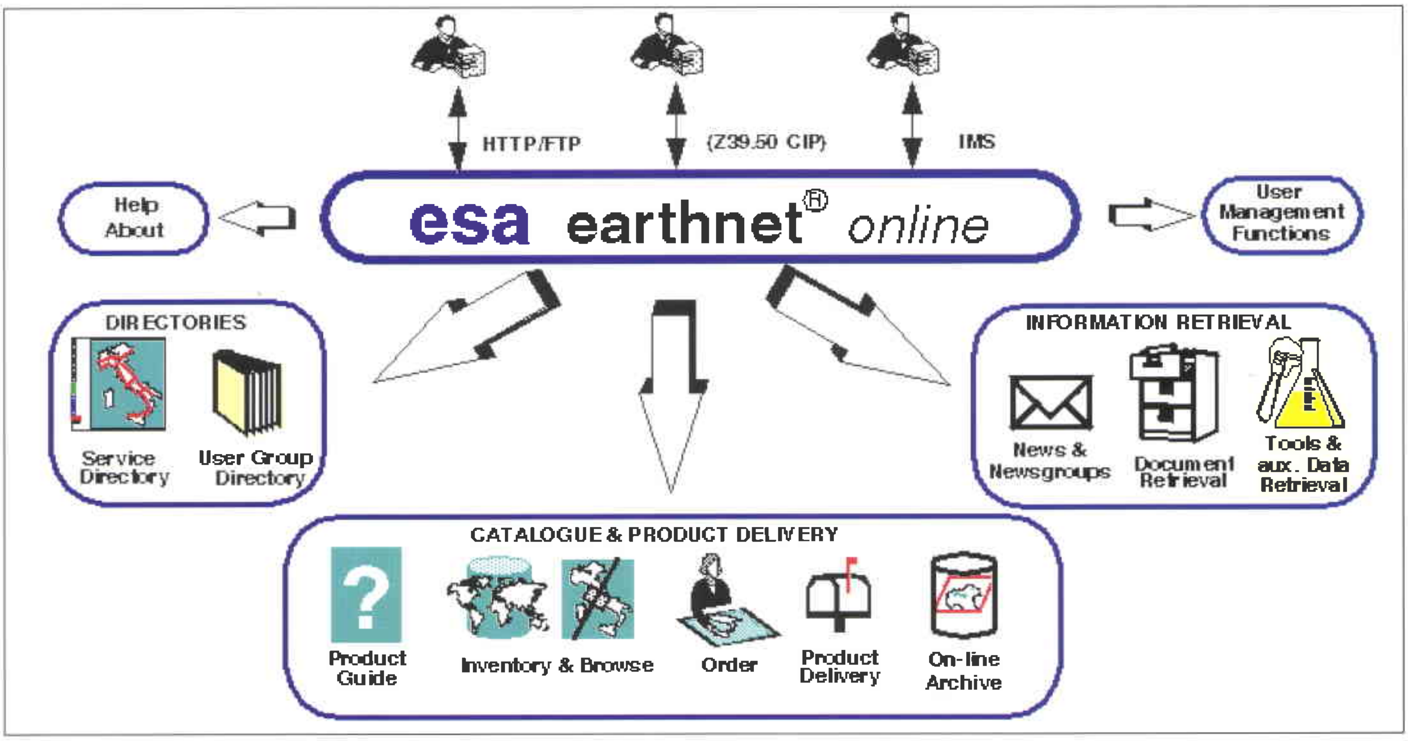

Figure 1. earthnet online services

- catalogue and product delivery
  This is the core service of **earthnet** *online* and covers the following features:
  - product guide
    The product guide includes example images and searchable descriptions of ESA-provided products, classified by application, geophysical parameter, provider, sensor and satellite. It helps to identify the product types which are best suited for a user's requirements.
  - inventory and browse
    The inventory and browse service is the heart of the catalogue. It presents product descriptions in the form of inventory and 'quick-look' data. Users can match their information requirements to the most appropriate available data via a multi-level Web interface. Retrieved product items can be marked for subsequent ordering.
  - support for product ordering
    The ordering facility of **earthnet** *online* is in accordance with the data policies agreed upon by ESA and its commercial partner consortia. The available ESA and commercial product lists and associated order options are offered.
  - online product archive and delivery
    A number of ESA products are regularly provided to authorised users via the FTP facility within **earthnet** *online*. Selective delivery is a mechanism considered for the future; however, bulk data transfer or shipment is likely to remain a task for other Earthnet delivery systems.

Key system requirements
The MUIS project is driven by the following key requirements:

- decentralised
  ESA missions are exploited by distributed national archiving and processing facilities via national providers. MUIS plans a very extensive implementation of the distribution concept for single, specific product, sub-services which can be maintained at different facilities.

- user-oriented
  The MUIS service model is commercially oriented in order to offer users a familiar environment. MUIS focuses on products and their availability, while (whereas) details of satellites, archiving centres and archived tapes will be more transparent to users.

The MUIS user access model is based on the following scenario:

- the user searches and navigates within the product guide using application keywords to identify a product type of interest
- the user identifies available products via an inventory search
- the user verifies product suitability by browsing the images
- the user retrieves the product from the online archive or orders from a provider and retrieves the product from a pick-up point via the product delivery service.

- interoperable
  The final distributed system will be an

interoperable network of federated providers. Access to each of the above services will be provided via transparent routing from the facility to which the user has connected.

- heterogeneous
  Commercial providers can offer their own personalised service. MUIS will support this with a decoupled user interface module which is easily replaceable.

- modular
  A MUIS system shall be reusable for different facilities. Minimum effort will be required to customise locally provided services by 'plugging- in' new or replaceable components.

System baseline architecture

The basic MUIS architecture (Fig. 2) foresees four main architectural blocks:

- user access layer
  Responsible for mapping the MUIS-provided services to different user protocols and interfacing the data server layer.

- data server layer
  The 'core' of the system; ensures that different types of data are accessible via data server- specific functions.

- support layer
  Provides vertically supporting services such as user management, and system monitoring and control

- ECF I/F layer
  Receives data from the individual Mission Ground Segments (ECFs - 'Exploitation Core Facilities') and loads them into the data servers.

User Access Gateway layer

The User Access Gateway (UAG) layer (Fig. 3) is a core architectural element of the MUIS system. It decouples the user service functionality provided via various protocols from the data servers. The UAG contains a user interface gateway module for each supported protocol (HTTP, FTP, IMS, future CIP) which maps all requests into an internal standard protocol (gateway interoperable protocol - GIP). This protocol represents the standard service backbone. It is based on an across-mission standardised parameter/value set described by a CIP-aligned data dictionary. **earthnet** *online* can therefore be easily provided via new protocols with the addition of a specific protocol-GIP gateway.

The data server interface layer contains a translation module for each data server that converts the GIP request into the data server native access mechanism (CORBA, RPC, SQL, etc.). Thus the addition or replacement of a data server is limited to a modification of the specific data server translator module.

A single user request may be split into two different internal service protocol requests (e.g. combined 'Inventory and Browse Search Request') and different requests may be answered by the same data server (e.g. in Figure 2, the browse and product server have been unified). This data server layer internal architecture is hidden within the data server I/F layer.

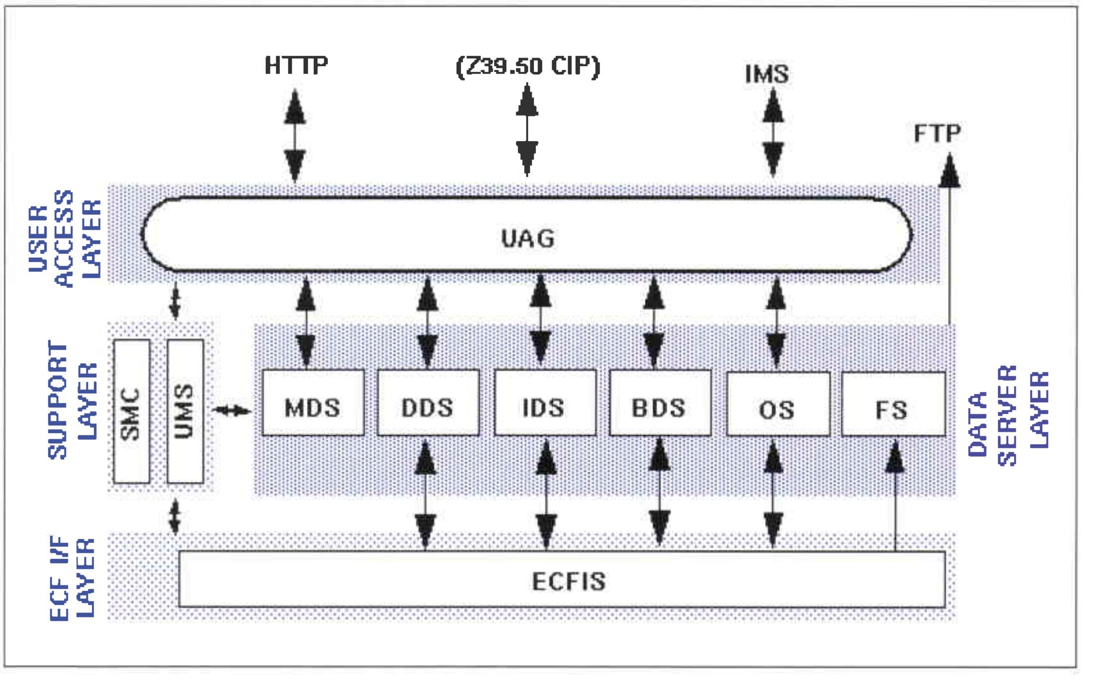

Figure 2. System baseline architecture

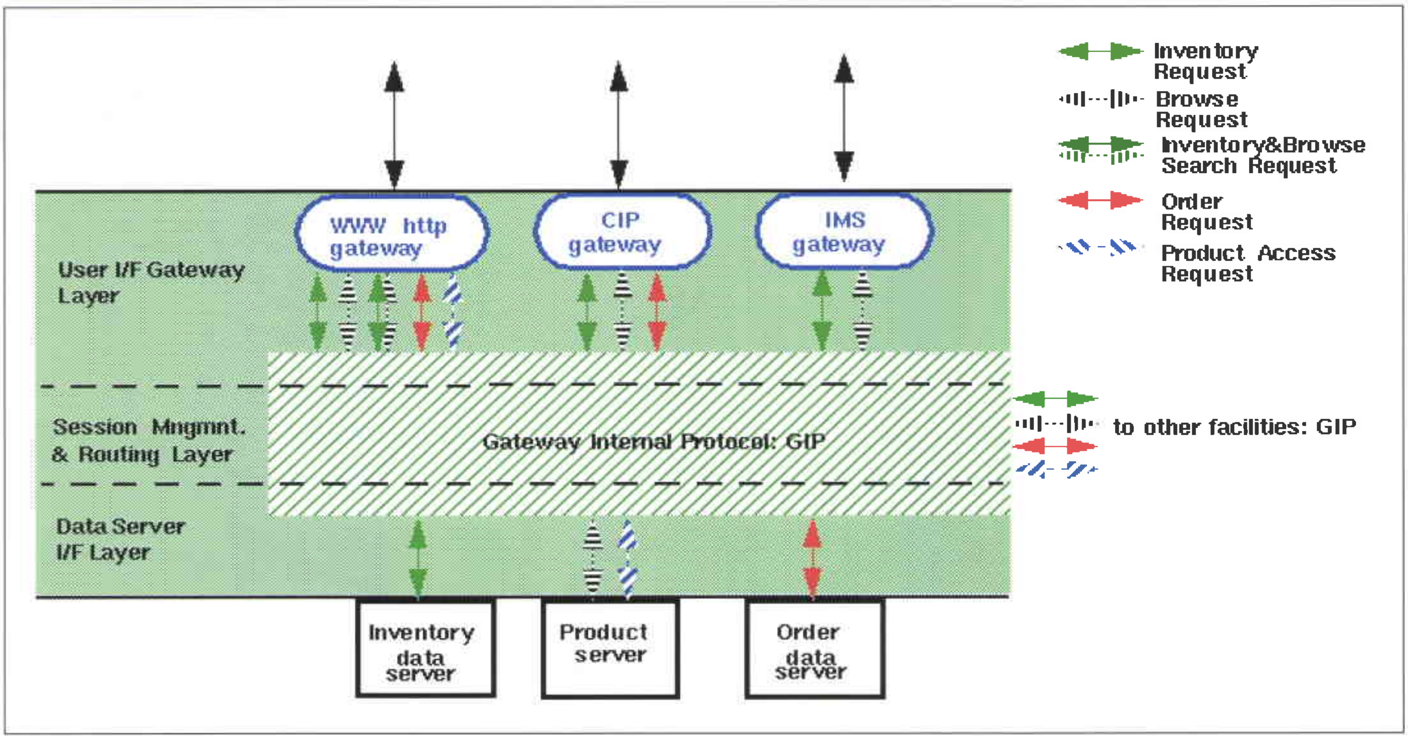

Figure 3. User Access Gateway layer

Lying between the above mentioned layers is the session management and routing layer which is responsible for authentication and authorisation, and managing the user session independently from the protocol. This layer will be extended in the distributed system in order to distribute requests to remote facilities as well.

Data server layer
The backbone of the **earthnet** *online* service is the Inventory Data Server (IDS) which uses an 'objectstore' database. Currently the database holds approximately 10 million product records.

'Quick-looks' are provided through the Browse Data Server, based on a large RAID unit, which can be expanded to hold the envisaged Terabyte of browse data.

The Multi-media Documentation Server (MDS) is implemented on a 'hyperwave' server, currently one of the most advanced and specialised products for hyperlinked documents (CEBIT award '97) and, therefore, specifically suited for Web documentation services.

These main data servers are complemented by the relatively simple order and directory data servers and an FTP accessible file space managed by the file server.

Support layer
This layer comprises user management, and system monitoring and control. In the current centralised system these components could be rather basic, but in the final decentralised architecture they will be distributed with the support layer stretching horizontally over all facilities. In view of this, an expandable agent-manager architecture has been adopted for both subsystems.

ECF I/F layer
This layer currently acts as the interface between the MUIS system and the ESA ERS, Landsat, NOAA, JERS operational ground segments as well as the Nimbus historical archive by loading the received inventory and browse information into the MUIS data servers. It will be extended to include ERS SAR interferometry, and IRS MOS and SeaWiFS missions.

Future outlook
The final, distributed MUIS system (Fig. 4) will implement a network of interoperable providers* who will offer various product types via one of their facilities (e.g. ESRIN, Oberphaffenhofen, Neustrelitz, Maspalomas) on hierarchical data collections (as defined by the CEOS Working Group Information Systems and Services**).

earthnet *online* will remain the focal point of the user service, seamlessly connecting users to the partner providers (and vice-versa). Each provider may opt to reuse the services of another provider enabling accessibility via his own facility. Alternatively, he may chose to hide certain services thereby disabling a link to another provider, (note: no connection from 'Commercial Provider' and 'Partner Organisation' in Figure 4). Browse data of recently acquired images can be made

*Space agencies, partner organisations, commercial providers, national stations, application centres
**Protocol Task Team: "Catalogue Interoperability Protocol (CIP) Specification - Release B"; doc.ref. CEOS/WGISS/PTT/CIP-B. Issue 2.2, March 1997

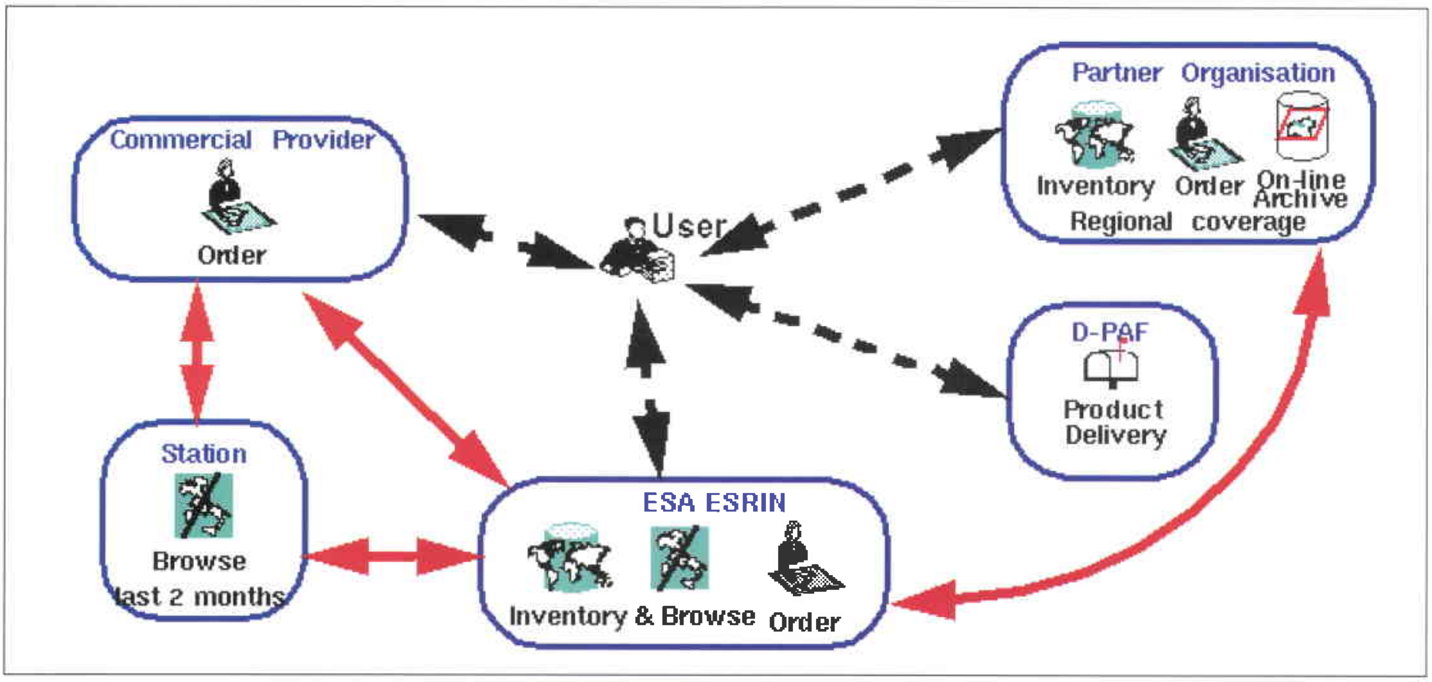

Figure 4. Interoperable ervice network scenario

available directly at stations which are not directly accessible by users, but linked via the interoperable network to other user facilities.

The key components of the distribution concept are the UAG (as already highlighted above), the service directory and user management.

The service directory will be the 'brain' of the interoperable service routing. It holds the overall information on service characteristics and their location in the network and, locally at each facility, it describes the subset of standard service functions and parameters supported by the local data server. The local installation allows each provider to order his preferred overlapping services and hide competitor services.

Interoperable user management is one of the critical issues of the network. The following assumptions are made:
- each provider maintains their user community via a User Management Subsystem (UMS)
- users log in with multiple userIDs when starting a session (one per provider with whom they are registered), thus defining their 'interoperable network visibility'
- providers may mutually agree on granting additional default privileges to all users or specific user groups of other providers
- providers may agree on sharing a user community
- each provider has a main facility where the UMS manager resides. UMS agents are installed at all of the provider's facilities and fed by the UMS manager for user authentication and authorisation. esa

Integrating SAR Data into Geographical Information Systems (GIS)

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Since the 1960s, satellite remote-sensing has increasingly become a primary source of information on our planet. Direct distribution of the resulting data has, however, been mainly limited to a small community of users. Meanwhile, it has become evident that direct access to this data is also desired by a wider range of users – such as urban planners, Earth resource managers and insurance brokers – who have been managing territorial information using Geographical Information Systems (GIS).

In order to fulfil the requirement of moving relevant and current data into these types of systems, data must be extracted from the satellite sensors into a compatible format. In a study performed for ESA, Planetek (I) investigated whether new GIS-oriented products could provide ERS-1 and ERS-2 SAR data to these user communities. The study was focused on two key issues: to identify an end-user product and to specify an appropriate format for product distribution.

Definition of SAR GIS products

Since Geographical Information Systems are not generic, we – the study team – extensively considered and analysed several application domains. In each case, potential GIS products were identified according to two criteria: firstly, their feasibility (ability to satisfy the application requirements) and, secondly, their potential market.

The candidate product types were then ranked according to the following criteria:

Data source
Is the information contained in existing ERS-SAR products, such as the precision image (PRI), sufficient for generating the product, or are other data, such as precise orbit information (PRC), also required?

Product accuracy
In this case, accuracy is defined as its compliance to application requirements rather than final product precision. For each product type, we assessed the accuracy from results already published as well as our practical experience.

Degree of automation
This is a fundamental parameter, since it indicates to what extent an operator must be involved in the processing chain for final product realisation. The degree of automation affects not only the cost of the product, but also the objectivity of the final result (as personal judgement may be involved) and, consequently, product reliability.

Need for ancillary data
Remote-sensing data applications can always benefit from the use of ancillary data, but the type and amount of ancillary data needed to guarantee a satisfactory product must be determined. The provision of additional data beyond this requirement could be considered as a means of further improving product accuracy.

Application maturity
This parameter is a tentative assessment of the degree of consolidation of each application, measured by years of study carried out by the scientific community and by the number of application examples. This is not necessarily related to product accuracy and, therefore, it does not infer any quality assessment of the GIS product. Some recently developed

applications may present quite accurate results, but they have not been tested on a wide range of varying situations and the limitations may not yet be clearly understood. On the other hand, other applications, although less accurate, have been fully analysed and validated in terms of reliability. Therefore, from a market point of view, product maturity indicates to what extent the customer is likely to be able to rely on a GIS product. A low level of maturity has been attributed to applications which still have some open issues, whereas the more consolidated applications have been considered as mature.

Cost/benefit ratio with respect to traditional products

For each product type, this criterion accounts for the cost/benefit ratio with respect to the same product obtained by using sources other than SAR data. They include, for instance, field measurements, bathymetric campaigns, aerial photograph interpretation and optical remote-sensing data processing.

Product versatility

This parameter refers to scientific or operational interest and product flexibility. In general, all of the defined applications can be both scientific and operational but, strictly speaking, some products may be identified which appeal only to the scientific community or other very specific users (e.g. public administration or oil exploration industry). A product is marked as flexible if it can be used directly in more than one application. A Digital Elevation Model (DEM) is a typical example of a flexible product, used in civil engineering as well as in hydrogeology.

Figure 1. The ERS spacecraft

Geographical extent

Some products cover only a limited part of the Earth. This may impact applications such as sea ice investigations or studies on desert areas which have geographical limitations.

As a result of the analysis, seven potential products have been selected: flood map, oil spill map, slope map, low-resolution DEM, ice-edge line, coastline map and forest-/non-forest map.

Product format specification

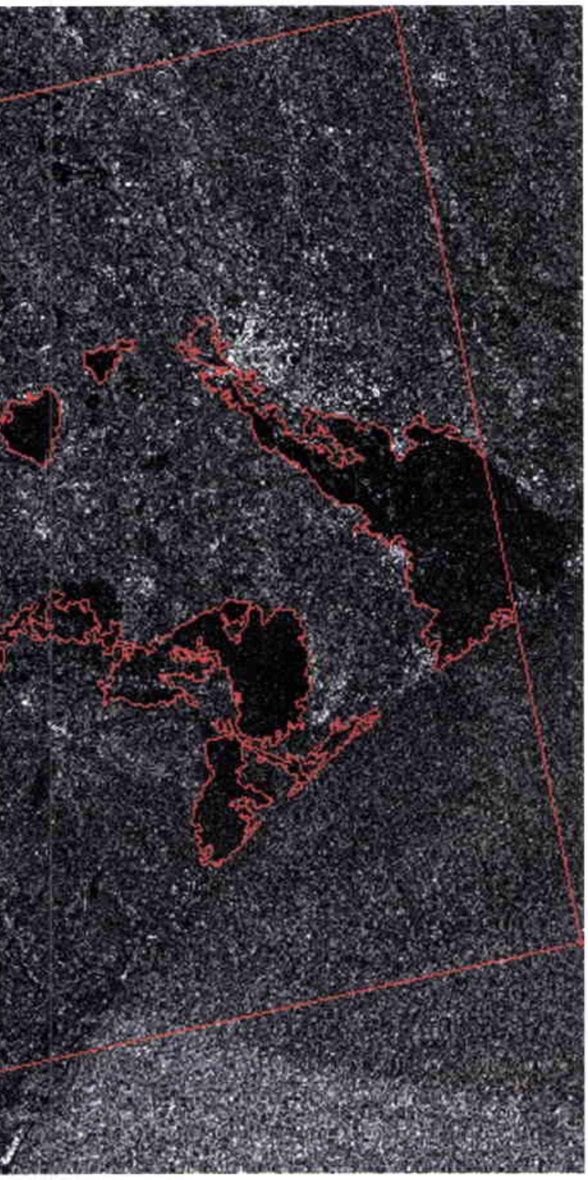
A key factor for the success of any of these new products is their usefulness to the GIS user community. The proposed products must be compatible (be directly readable by) the existing systems. According to our survey, most GIS software packages currently in use are application-specific (related to e.g. hydrology, urban planning) and are primarily based on one or two industry standards. We decided to look for a solution acceptable for most, if not all, of these software packages.

The proposed GIS product format is based on a main file which contains metadata information and pointers to all the relevant geographical data, tabular data and auxiliary files, including the relevant documentation. These secondary files, which may be distributed with the main file or made accessible via a network, form the full product along with the main file. The data file formats chosen are:

- GeoTIFF for raster data
- DXF for vector data
- ASCII, tab separated, for attribute tables.

The list may be expanded, especially for vector data format.

In fact, DXF has several drawbacks in describing GIS data, mainly due to its inability to associate attribute tables with graphical features. These problems can be overcome, but it is worth noting that other formats store GIS data better than DXF. DXF has been chosen for its currently wide distribution.



An example: the flood map

In order to validate the concept proposed in this study, we performed a detailed study of one product.

Due to ESA's focus on disaster management, we selected the flood map. A sample product was prepared for the floods around Béziers in Southern France in January 1996, which was studied elsewhere.

The production followed a preliminary phase of detailed product specification based on application and user requirements. A suitable algorithm was identified using both amplitude SAR images and interferometric coherence images. The result is a vector map of the flooded zones in a format which can be immediately employed by end users. The data is displayed over a raster SAR image of the flooded area (left).

Conclusion

Based on the interest shown by a wide range of user communities, we have proposed high-level GIS-oriented products that we hope will contribute to bringing remote-sensing data to a wider market place than the traditional remote-sensing community. Further work is foreseen to develop additional products such as the oil spill map and the slope map.

Acknowledgements

This study was funded under ESA Contract 12094/I-HE. The interferometric processing was conducted in co-operation with the Physics Department of the University of Bari, Italy. The support of the Italian ERS Production and Archiving Facility operated by the Italian Space Agency (ASI) in Matera, which provided us with a timely supply of high-quality products, was instrumental in achieving the study's goals.

Figure 2. The flooded area around Béziers delineated in red. The outer red square is the SAR scene

Le Partenariat Europe-Russie pour le développement et l'échange de l'expertise professionnelle

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Constatant le poids des notions juridiques et de la terminologie dans la négociation, mais également dans la mise en oeuvre d'accords de coopération internationale dont l'importance va devenir croissante pour tous les acteurs du domaine spatial, qu'ils soient institutionnels ou non, les Directeurs généraux de l'ESA et de la RKA ont proposé, début 1997, la mise en commun de ressources humaines et financières pour un programme d'activités (séminaires, ateliers, tables rondes, etc.) spécifiquement axé sur les besoins prioritaires des acteurs du secteur spatial russe et européen dans les domaines du droit, de la gestion, de l'économie et du financement des projets.

Introduction

Cette initiative a été rendue possible notamment grâce à l'existence d'une clause de coopération en matière juridique qui figure dans l'Accord de coopération spatiale à des fins pacifiques conclu entre l'ESA et le Gouvernement de l'URSS le 25 avril 1990.

Au-delà d'une coopération dont l'ESA et la RKA sont les aiguillons, le Partenariat vise à associer, autour d'une Charte, paraphée le 16 juin 1997 au Salon du Bourget, le plus grand nombre possible d'acteurs russes et européens de ce secteur d'activités. Par ses effets démultiplicateurs dans le domaine des ressources humaines, cette initiative a d'abord pour objet de resserrer les liens entre l'Europe et la Russie, d'établir un climat de meilleure compréhension mutuelle et de favoriser l'émergence progressive d'un 'langage commun pour un bénéfice mutuel', c'est-à-dire d'assurer un environnement propice pour de futures entreprises conjointes.

Ce sont des objectifs ambitieux et de longue haleine compte tenu des singularités culturelles respectives et du poids des usages dans les relations entre partenaires spatiaux de tout premier plan, et qui s'inscrivent des deux côtés comme une nécessité à l'heure où les activités spatiales connaissent de profondes et rapides mutations, en particulier par la croissance exponentielle des applications commerciales dans les domaines des télécommunications, de l'observation de la Terre, ou même des services de lancement, tous défis auxquels ce Partenariat cherche à répondre par une meilleure préparation des hommes.

L'objet de cet article est d'exposer les principaux objectifs poursuivis par la Charte de Partenariat ainsi que les mécanismes retenus pour sa mise en oeuvre. Sont également exposées les premières activités envisagées dans le cadre d'une 'phase-pilote' démarrée à la mi-1997.

Rappelons que ce Partenariat a reçu le soutien de l'Union européenne pour sa phase-pilote 1997, par le biais d'une allocation du programme d'assistance technique à la CEI ('Tacis-Bistro').

La Charte de partenariat

Ce document a été conçu comme un instrument flexible pour permettre de réunir autour d'un ensemble d'objectifs de vaste portée à la fois des institutions (ESA, RKA, agences spatiales nationales, voire des ministères...) et des acteurs du secteur aérospatial (firmes industrielles ou sociétés de services...) ayant leur siège ou principaux établissements dans les Etats membres de l'ESA, de l'Union européenne, ou dans la Fédération de Russie. La Charte est un accord international de type très particulier : elle n'a pas fait l'objet d'une véritable signature par ses initiateurs, non plus que par ses adhérents ultérieurs, mais d'un simple paraphe par les Directeurs généraux de l'ESA et de la RKA, qui se portent en quelque sorte garants de ses objectifs devant l'ensemble de la communauté des Partenaires.

Les Partenaires adhèrent sur simple demande adressée aux Directeurs généraux, qui consultent, avant de prendre leur décision, les représentants des autres Partenaires au sein d'un 'Groupe de pilotage'. Toutefois, cette procédure formelle n'a pas été mise en oeuvre pour les 19 adhérents au Partenariat enregistrés à la date de rédaction de cet article (cf., Tableau 1: Liste des Partenaires à la date du 16 octobre 1997), s'agissant d'entités actives dans le domaine spatial et qui répondaient d'emblée aux principaux critères fixés par l'Article premier de la Charte.

Il est par contre proposé d'y recourir pour examiner la demande d'adhésion à une importante association professionnelle de droit russe, l''Union des Juristes', qui n'a pas de lien avec ce secteur particulier d'activités, mais qui s'intéresse aux objectifs poursuivis par la Charte, et qui peut apporter l'expérience de ses 60 000 membres individuels, avocats ou magistrats dans toutes les spécialités juridiques. Cette association pourrait ainsi se voir reconnaître un statut particulier de type 'Partenaire associé'.

Les Partenaires contribuent au financement des activités du Partenariat sur une base volontaire, et sont également invités à mettre des moyens humains ou matériels à disposition pour limiter au strict minimum les débours et les échanges de fonds. Le Partenariat est doté d'un budget annuel qui prend en compte les apports de différente nature faits par les Partenaires ou par d'autres institutions qui soutiennent ses activités (p. ex. l'Union européenne), et qui sert de cadre de référence à l'éxécution d'un plan annuel d'activités agréé par les Partenaires réunis au sein du 'Groupe de pilotage' qui est l'organe de référence du Partenariat, et dans lequel siègent les représentants des Partenaires. Un compte bancaire spécifique est ouvert par l'ESA au nom du programme de partenariat, et ce compte est géré selon les règles applicables aux dépenses de l'Agence, susceptible des mêmes procédures de vérification.

Exceptionnellement, les Directeurs généraux de l'ESA et de la RKA peuvent décider de convoquer une 'Réunion des Partenaires' pour examiner le bilan et l'avenir du Partenariat.

La Charte ne détermine à dessein aucune durée précise pour le Partenariat, s'agissant d'une entreprise de longue haleine. On peut en déduire que le Partenariat cessera d'exister le jour où ses membres le décideront collectivement, ou bien lorsque leur nombre et leur participation seront devenus insuffisants pour assurer l'éxécution d'un plan annuel d'activités. Cette Charte peut également faire l'objet d'amendements à la majorité des deux tiers des Partenaires représentés et votants au sein de la Réunion des Partenaires.

Tableau 1. Liste des Partenaires

AGENCE SPATIALE EUROPEENNE
AGENCE SPATIALE RUSSE
FOKKER SPACE BV
SABCA
KAYSER THREDE GMBH
ALENIA AEROSPAZIO
DAIMLER BENZ AEROSPACE AG
CNES
AEROSPATIALE
ALCATEL ESPACE
ALCATEL ETCA SA
NORWEGIAN SPACE CENTRE
TECHNOSPACE AERO SA
INTOSPACE GMBH
DORNIER SATELLITENSYSTEME
STARSEM
AUSTRIAN MINISTRY OF SCIENCE AND TRANSPORT
SEP
MATRA MARCONI SPACE

Le Partenariat s'est doté, conformément à la Charte, d'une structure légère destinée à en assurer les aspects opérationnels, à l'animer et à maintenir le lien entre tous les Partenaires. Il s'agit du 'Secrétariat exécutif' composé d'un représentant de l'ESA et d'un représentant de la RKA, qui s'appuient sur un Coordonnateur du Programme pour la gestion des interfaces entre tous les intervenants et la mise en oeuvre des activités. Ce Secrétariat exécutif est localisé à Paris, dans des locaux mis à disposition par l'ESA et par la RKA, et s'est doté d'une appellation destinée à en faciliter l'identification: 'Space, Business & Law Association' (SBLA).

Signature de la Charte de partenariat par MM. Jean-Marie Luton et Yuri Koptev, Directeurs généraux de l'ESA et de la RKA, pendant le Salon du Bourget (Paris, 16 juin 1997).

Aux termes de la Charte, le Partenariat démarre ses activités au 1er janvier 1998. Toutefois, il a été convenu qu'un programme d'activités préliminaires serait lancé dès 1997 dans le cadre d'une 'phase-pilote' destinée à valider les premières hypothèses de travail et les premières orientations. C'est ce programme qui a reçu un soutien financier important de l'Union européenne dans le cadre des fonds 'Tacis-Bistro' qui sont gérés directement par la Mission permanente de l'UE dans la Fédération de Russie.

Les objectifs du Partenariat

L'Article 2 de la Charte tente de définir ces objectifs en huit paragraphes, le neuvième étant libellé en termes généraux: "identifier les besoins en termes d'échanges d'expertise exprimés par les Partenaires, et rechercher les moyens d'y répondre de la façon la plus appropriée". Les principaux objectifs peuvent toutefois être aisément récapitulés:

- Accroître l'expertise dans les domaines-clés qui sont communs à tous les projets spatiaux menés en coopération : droit international, finance, pratiques comptables, assurances et responsabilité, maîtrise d'oeuvre et sous-traitance à l'étranger, gestion de projets internationaux à grande échelle.

- Encourager, entre les personnels respectifs des Partenaires, l'échange de l'expérience professionnelle, des savoirs et des savoir-faire, dans un esprit de confiance mutuelle et pour le bénéfice de tous.

- Favoriser l'émergence progressive d'une bonne compréhension des modes de travail respectifs et des contraintes institutionnelles propres à chaque Partenaire, dans le souci d'une gestion plus efficace de toutes les interfaces de travail mises en oeuvre au cours des différentes étapes des activités de coopération.

- Optimiser l'emploi des ressources humaines et matérielles des Partenaires en leur faisant bénéficier d'un effort spécifiquement adapté à leurs besoins, faisant ainsi l'économie de formations autrement lourdes et coûteuses ou qui ne sont pas, dans certains domaines, dispensées par les filières traditionnelles de formation.

- Stimuler l'intérêt des personnels en améliorant les compétences et les niveaux de performance dans des domaines souvent négligés comme la gestion, le droit et les aspects financiers.

- Encourager le développement de liens personnels directs et des contacts entre les personnels respectifs dans une atmosphère amicale et stimulante, afin de surmonter les barrières culturelles et linguistiques.

Il ressort de ces objectifs que le programme développé par le Partenariat s'adresse avant tout aux personnels déjà formés des Partenaires, et plus particulièrement à ceux qui exercent déjà des responsabilités dans le cadre des coopérations entre la Russie et l'Europe occidentale, ou qui s'y préparent.

Démarrage des activités : la phase-pilote pour 1997

Les semaines qui ont suivi le paraphe de la Charte de Partenariat ont été consacrées à la mise en place de l'infrastructure fonctionnelle nécessaire à un démarrage rapide des trois principales activités prévues au titre de la phase-pilote 1997, à savoir la réalisation, à Moscou:

- de deux séminaires d'une durée de quelques jours chacun sur les thèmes respectifs suivants : 'Environnement juridique des activités spatiales internationales', et 'Gestion des programmes spatiaux internationaux dans les domaines du transport et des télécommunications'

- d'un 'Atelier-Exécutif' pour les dirigeants du secteur spatial russe et occidental ayant pour thème principal 'Les aspects concrets de la coopération et des affaires spatiales internationales'.

Ce programme a fait l'objet d'une présentation aux Partenaires au cours d'une première réunion informelle du Groupe de pilotage tenue au Centre technique de l'Agence (ESTEC) à Noordwijk, Pays-Bas, le 16 septembre 1997. Cette réunion, qui fut suivie d'une table ronde avec les personnels de l'Agence concernés par la coopération avec la Russie, a permis de vérifier que les objectifs du Partenariat répondaient bien à une demande, qui peut être qualifiée de très soutenue, tant du côté des Partenaires que de celui des personnels, une constatation qui s'est également vérifiée du côté russe au cours de présentations faites à Moscou dans les semaines suivantes. La plupart des interventions ont ainsi souligné le besoin d'une amélioration dans la préparation, sur tous les plans, des personnes amenées à conduire, ou à participer à, des coopérations spatiales dans le contexte euro-russe.

La réalisation de ce premier programme d'activités s'appuiera sur les moyens mis à disposition par les Partenaires, en particulier sous la forme d'intervenants ou d'animateurs pour des séminaires, et bénéficiera de l'expérience développée par l'Université Internationale de l'Espace (ISU, Strasbourg) dans le domaine des formations pluriculturelles et multidisciplinaires spécifiquement adaptées aux besoins du secteur spatial.

Activités envisagées pour le Plan annuel 1998

Les Partenaires se verront proposer, avant la fin 1997, un programme d'activités pour 1998 comprenant la réalisation de plusieurs séminaires, d'un ou deux 'Ateliers-Exécutifs' pour les niveaux dirigeants des organismes adhérents, ainsi que des 'Ateliers-Experts' permettant des présentations sur des sujets techniques dans des domaines d'excellence. Les thèmes de ces activités seront retenus sur la base des résultats d'une étude et d'une analyse détaillées des besoins des Partenaires, en cours de réalisation.

Conclusions

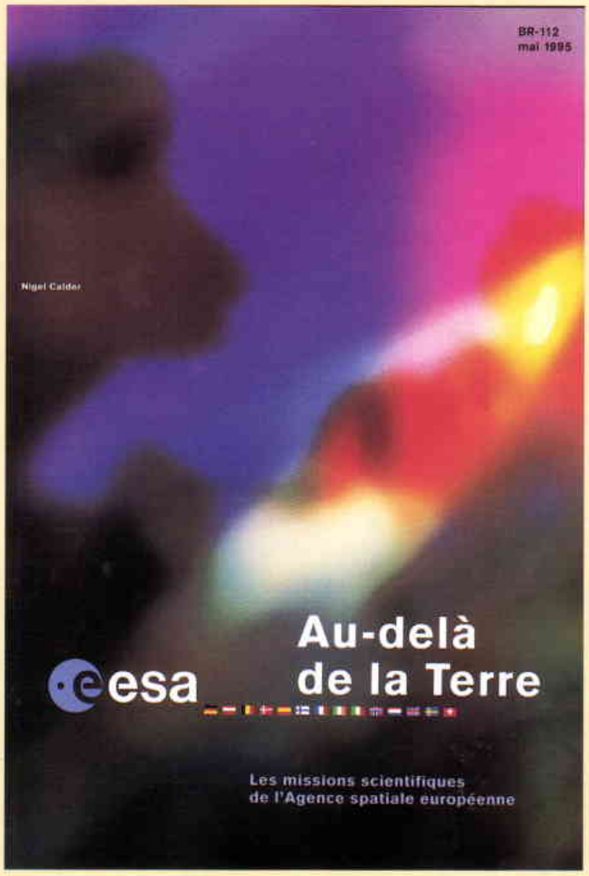
L'initiative de ce Partenariat a été prise par les Directeurs généraux de l'ESA et de la RKA après que se soit écoulée une première période (1991-1996) de coopération intensive entre les deux agences, et entre l'Europe spatiale et la Russie d'une façon plus générale. Cette période a été marquée à la fois par la disparition de l'URSS, la naissance de l'Agence spatiale russe (1992), et par l'accès de la Russie à la scène spatiale internationale (Station spatiale internationale et marché mondial des services de lancement).

Des deux côtés, pour des raisons différentes, sont menés de façon parallèle de très considérables efforts de restructuration du tissu industriel, et qui ont conduit à l'apparition d'entreprises conjointes pour exploiter de manière plus rationnelle et plus économique des moyens développés dans d'autres contextes ou avec d'autres finalités. Des deux côtés, l'enjeu est identique face au développement très rapide de nouveaux segments de marché dans le secteur des applications civiles (télécommunications, navigation, gestion des ressources naturelles) qui appellent à un rôle de plus en plus important des marchés, des investisseurs et des utilisateurs, et à une diminution relative du rôle des commandes étatiques.

Dans ce contexte, la coopération internationale revêt un autre caractère, prend un autre sens: elle devient un élément essentiel de la pérennité de pans entiers de l'industrie spatiale, elle joue un rôle moteur dans le maintien de hauts niveaux de compétence et dans la recherche de la compétitivité sur des marchés qui s'étendent à l'échelle de la planète.

Le présupposé de cette initiative de Partenariat est que le succès de toute entreprise de coopération internationale passe par une préparation et une formation adéquates des personnes chargées de la préparer et de la mettre en oeuvre, et que l'élaboration progressive de concepts communs, l'émergence d'une 'langue commune' sur les éléments incontournables de toute entreprise spatiale internationale (comme la définition des responsabilités respectives, les assurances et garanties financières, les schèmes contractuels, etc.), au-delà des différences proprement linguistiques ou culturelles, bénéficieront à tous les acteurs de ce secteur, en Russie comme en Europe occidentale.

Enfin, si l'initiative de ce Partenariat revient aux deux agences spatiales, il convient de souligner qu'il a été conçu pour répondre avant tout aux besoins de leurs partenaires industriels respectifs, et que c'est à eux qu'il revient maintenant de lui donner l'élan nécessaire à son épanouissement rapide.



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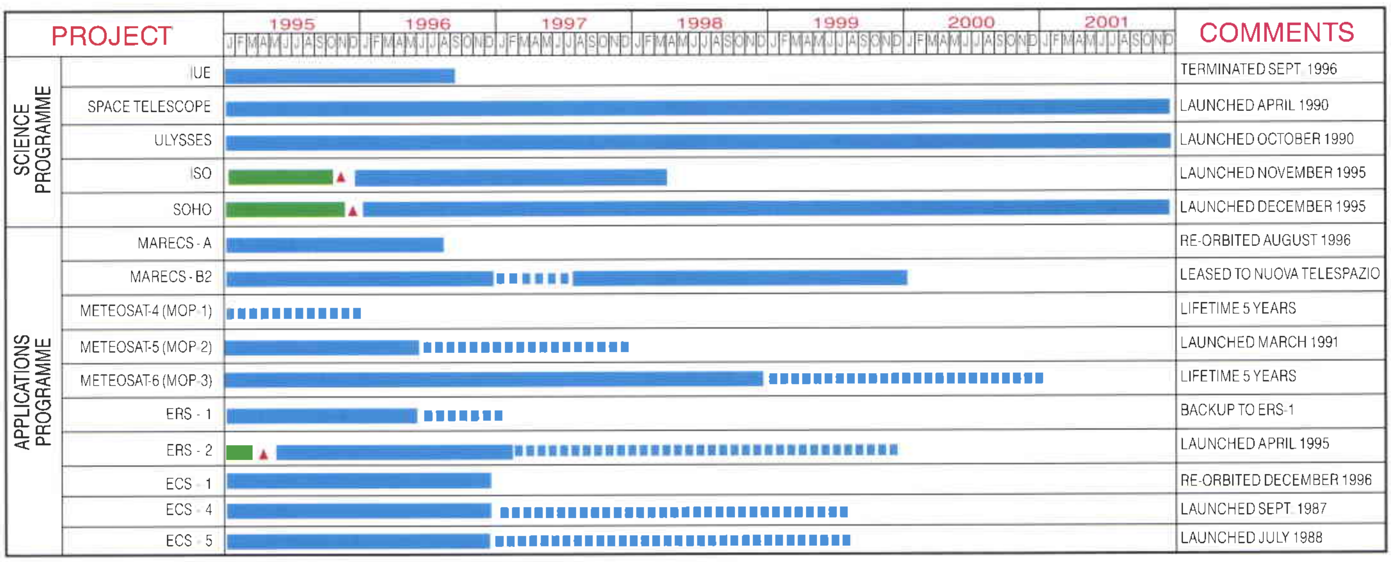
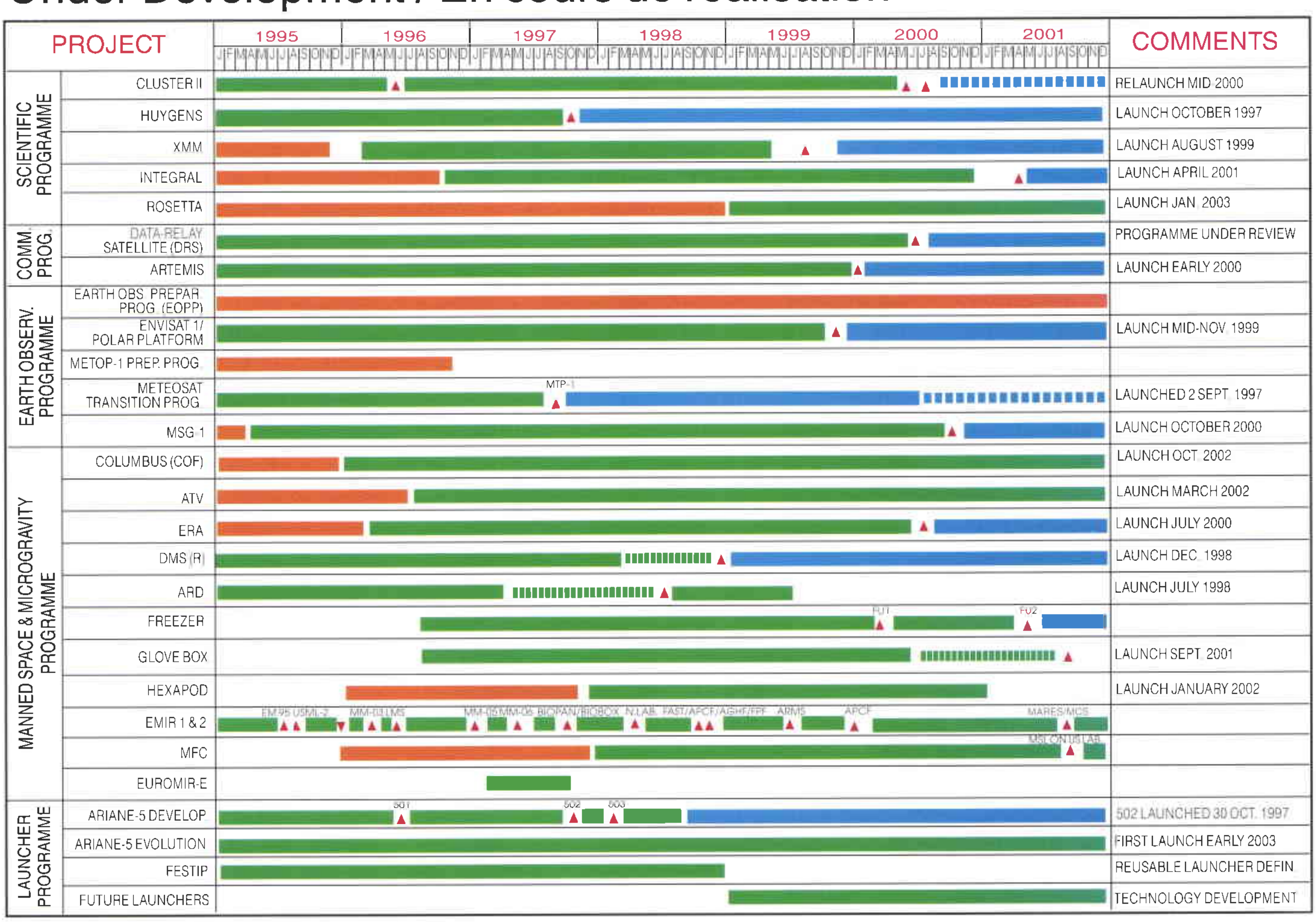
Programmes under Development and Operations
Programmes en cours de réalisation et d'exploitation

(status end December 1997)

In Orbit / En orbite



Under Development / En cours de réalisation



DEFINITION PHASE — MAIN DEVELOPMENT PHASE — ▲ LAUNCH/READY FOR LAUNCH

OPERATIONS — ADDITIONAL LIFE POSSIBLE — ▼ RETRIEVAL — STORAGE

ISO

L'exploitation d'ISO se poursuit sans problèmes, tous les systèmes du satellite et du secteur sol restant en excellent état de fonctionnement. Le 11 décembre, une troisième manoeuvre de maintien à poste a été exécutée avec un écart maximum de 0,27 % par rapport aux prévisions et il a été procédé à une troisième mesure directe du niveau d'hélium liquide restant dans le réservoir. Les résultats se révèlent cohérents au regard des mesures précédentes, laissant entendre que la mission se poursuivra jusqu'au maximum de sa durée d'exploitation prévisionnelle, à savoir jusqu'au 10 avril 1998 ± deux semaines et demie.

Pendant une grande partie du mois de septembre et début octobre, le satellite s'est trouvé dans une configuration orbitale telle qu'il a dû traverser des phases d'éclipse dont certaines ont duré jusqu'à 166' 30", alors que les scientifiques les avaient évaluées à environ 80'. Début septembre, par ailleurs, il est apparu inévitable de commettre quelques entorses mineures aux contraintes de direction de pointage liées à la Terre, cela plusieurs minutes par jour au moment du passage au périgée. Des mesures spéciales ont donc été prises pendant cette période, consistant notamment à limiter les directions de pointage et à utiliser un nombre restreint d'instruments. ISO a vaillamment surmonté ces difficultés puisque sa batterie et son système de pointage ont fonctionné au-delà de toute attente et que les entorses inévitables aux contraintes de pointage n'ont pas eu l'impact escompté.

Certaines pouponnières d'étoiles parmi les plus proches et les mieux étudiées de notre Galaxie s'étendent dans les constellations d'Orion et du Taureau. Si la mission n'avait pas été prolongée, ISO n'aurait pu observer le ciel dans cette direction puisque le télescope, maintenu à basse température, doit toujours rester à l'abri du rayonnement infrarouge intense de la Terre et du Soleil. La première occasion de pointage vers ces régions s'est présentée en août-septembre et, malgré les contraintes opérationnelles précitées, de nombreuses observations scientifiques ont pu être réalisées. A la faveur de la prolongation de sa mission, le satellite aura, au printemps prochain, une deuxième occasion de scruter ces régions passionnantes.

L'Union astronomique internationale (IAU) tient son assemblée générale tous les trois ans. Lors de sa dernière session, au cours de l'été 1997, elle a consacré toute une journée à la présentation et à la discussion des résultats d'ISO, dont certains montrent que ce satellite n'a pas d'équivalent pour explorer et analyser bon nombre des phénomènes auxquels nous devons notre existence. Les chercheurs ont présenté par exemple des clichés exceptionnels de la nébuleuse Trifide (voir figure ci-jointe), région dans laquelle se trouve une nouvelle génération d'étoiles massives en cours de formation. En lumière visible, on observe un grand nuage de gaz éclairé par de jeunes étoiles chaudes. Des nuages de poussières sombres partagent la nébuleuse en trois lobes, d'où son nom. L'image d'ISO fait apparaître un changement d'aspect remarquable : les nuages sombres deviennent lumineux et les régions lumineuses obscures. En pénétrant dans les poussières, ISO a décelé, à l'intérieur des nuages sombres, des régions denses contenant de nouvelles étoiles en voie de formation.

Cluster-II

Les négociations contractuelles avec le maître d'oeuvre, Dornier, ont été menées à bien. Les activités d'approvisionnement de tous les équipements du satellite et des charges utiles ont démarré conformément au calendrier, qui prévoit le lancement des quatre satellites Cluster à la mi-2000. Pour la plupart des équipements, il s'agit de fabriquer une deuxième fois les éléments de Cluster-I, à l'exception des amplificateurs haute puissance et des enregistreurs à semi-conducteurs.

Alors que les amplificateurs haute puissance de la mission initiale avaient été livrés par la NASA, ceux de Cluster-II seront approvisionnés en Europe. En ce qui concerne les enregistreurs à semi-conducteurs, il a été jugé souhaitable de procéder à une modification de conception puisqu'on ne dispose plus des composants d'origine et que des travaux de développement technologique ont eu lieu dans l'intervalle. Il faudra également apporter quelques modifications mineures (raccourcissement des mâts radiaux servant de support à certaines expériences) pour pouvoir loger Cluster-II dans la coiffe du lanceur Soyouz.

En ce qui concerne le financement partiel de la charge utile, des contrats ont été signés entre le maître d'oeuvre et les agences assurant le financement au niveau national et des instituts spécifiques.

Contract signature for Cluster-II at Dornier (D) on 14 January 1998, by R.M. Bonnet (left), ESA's Director of Science and K. Ensslin, President of Dornier Satellitensysteme GmbH

Signature du contrat Cluster-II le 14 janvier 1998 par MM. R.M. Bonnet, Directeur des programmes scientifiques de l'ESA (à gauche) et K. Ensslin, président de Dornier Satellitensystème GmbH

ISO

Operations of ISO continue to go very smoothly, with all satellite and ground-segment systems continuing to perform excellently. On 11 December, a third station-keeping manoeuvre was successfully carried out with performance matching plans to within 0.27%. On the same day, the third direct measurement of the amount of liquid helium remaining on-board was made. The results were consistent with the earlier measurements, with indications that the lifetime will be at the upper end of the predicted range of 10 April 1998 ± 2.5 weeks.

During much of September and early October, ISO's orbital geometry in the extended mission was such that it underwent eclipses with durations of up to 166.5 min, compared with the design value of some 80 min. Additionally, during early September, marginal violations of the Earth constraint on the pointing direction could not be avoided for some minutes each day as ISO went through perigee. Special operational measures were therefore put in place for this period, including restrictions on pointing directions and on the number of instruments that could be used. ISO successfully came through this difficult period with better-than-expected battery and pointing performance and less-than-expected impacts from the unavoidable violation of the pointing constraints.

Some of the closest and best-studied star factories in our Galaxy sprawl across the Orion and Taurus constellations. Without the extension of its life, ISO could never have looked safely in that direction in the sky as the cold telescope must always remain averted from the intense infrared glow of both the Earth and the Sun. The first chance to look at these areas came in August-September and, despite the necessary operational restrictions described above, many scientific observations were performed. With its lifetime currently predicted to last until April 1998, ISO will even have a second chance to observe these exciting regions in the Spring.

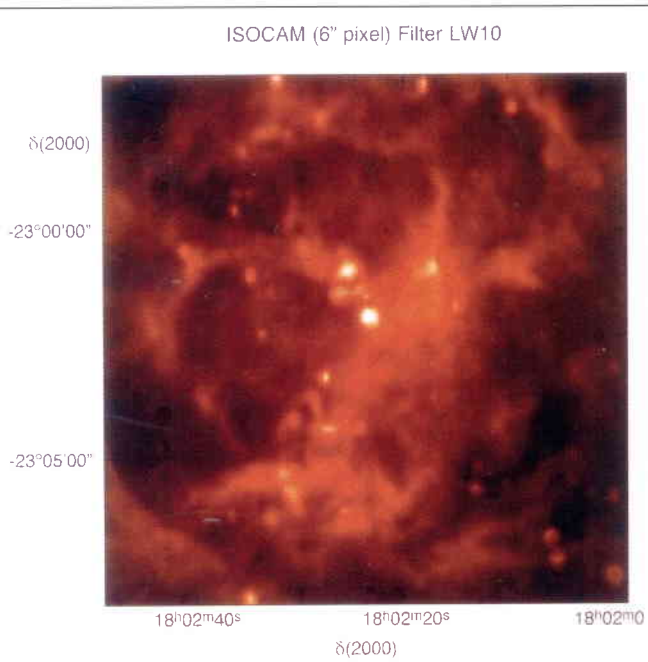
The International Astronomical Union (IAU) holds a General Assembly once every three years. At last Summer's meeting a full day was devoted to the presentation and discussion of ISO results. Some of these results dealt with ISO's unmatched ability to explore and analyse many of the universal processes that made our existence possible. Taking just one example, impressive ISO data were presented of the Trifid Nebula (see below), a region in which a new generation of massive stars are forming. Seen by visible light, hot young stars light up a large cloud of gas. It is criss-crossed by dark dust clouds which divide the bright nebula and give it its name. The ISO image shows a remarkable change in appearance. The dark clouds become luminous and the bright regions are dark. By penetrating the dust, ISO reveals dense regions inside the obscuring clouds where new stars are forming.

Cluster-II

The contract with the Prime Contractor Dornier has been successfully negotiated and agreed by both parties. The procurement of all spacecraft and payload equipment has been initiated, consistent with the delivery of four Cluster spacecraft for launch in mid-2000. For most equipment, this involves a rebuilding of the Cluster-I units, the exceptions being the high-power amplifiers and the solid-state recorders.

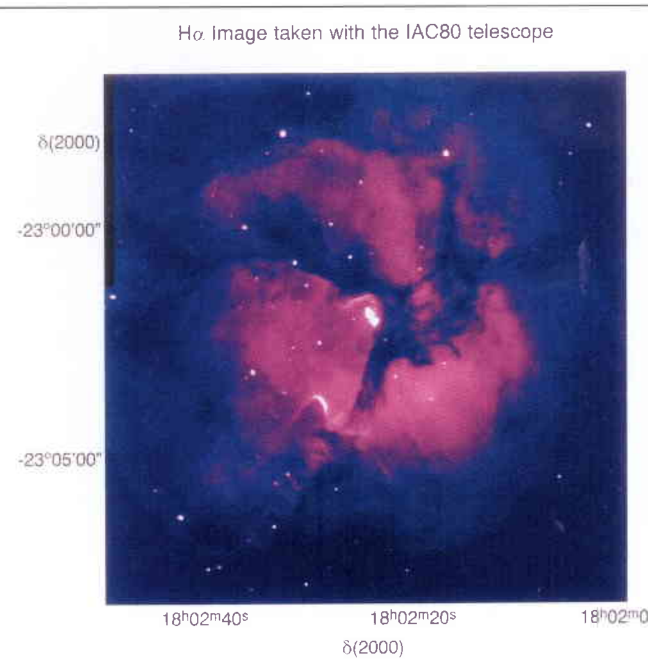
The high-power amplifiers for the original mission were delivered by NASA, but those for Cluster-II will now be procured in Europe. For the solid-state recorders, the non-availability of the original components and the technological developments that have taken place in the meantime have made a new design appropriate. Minor modifications to shorten the experiment-carrying radial booms are also required to allow the Cluster-II spacecraft to fit inside the Soyuz launch vehicle's fairing.

The partial funding of the payload has also been successfully initiated, with contracts signed between the Prime



ISOCAM infrared image at 8-15 microns

Credit: ESA/ISO, ISOCAM and J. Cernicharo et al.



IAC8O visible-light image (H-alpha)

Credit: IAC, Observatorio del Teide, Tenerife

L'étude de faisabilité ayant établi qu'un lancement par une fusée Soyouz ne présenterait pas de problème majeur, l'Agence a signé avec Starsem un premier contrat portant sur une analyse préliminaire de la mission, qui aura pour objet d'étudier en détail les trajectoires de lancement ainsi que les efforts mécaniques et thermiques correspondants.

Pour ce qui est du secteur sol, une étude est en cours sur les conséquences de l'utilisation d'une seule station sol (Villafranca) au lieu des deux prévues à l'origine (Odenwald et Redu). Le Centre commun d'opérations scientifiques (JSOC) examine les modifications à apporter aux logiciels pour traiter les données scientifiques.

XMM

La revue critique de conception au niveau système s'est tenue en septembre et octobre. Elle a pris fin le 30 octobre, date à laquelle les membres de la commission de revue ont confirmé à l'unanimité que le concept du véhicule spatial était mûr et que l'intégration du modèle de vol pouvait commencer.

L'intégration du modèle d'identification du véhicule spatial est terminée et une série d'essais a été menée à bien chez Dornier (D). Le satellite est actuellement soumis à des essais système après intégration. Les derniers essais à réaliser sur ce modèle, à savoir les essais de compatibilité électromagnétique, s'achèveront fin avril.

La campagne d'essais d'ambiance conduite sur le modèle structurel et thermique (STM) se poursuit à l'ESTEC (Noordwijk, NL). Les équipes de Dornier (D) et Comet ont réussi à respecter leurs calendriers respectifs et les résultats d'essai obtenus jusqu'ici justifient la confiance qu'inspire le concept système dans son ensemble.

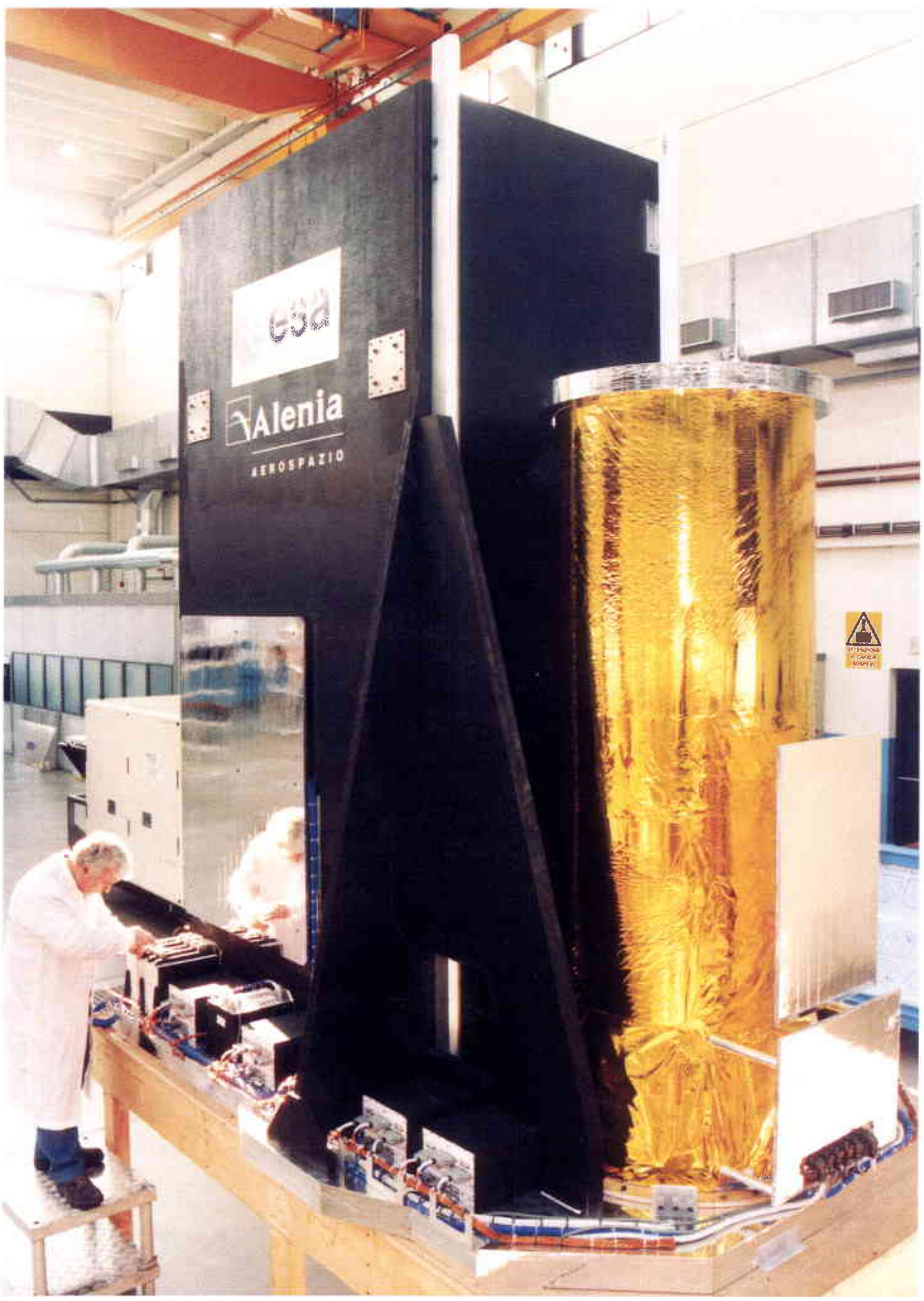
La livraison des équipements de vol est en cours, ce qui permettra de procéder à leur intégration au modèle de vol du satellite à partir du début de 1998, conformément à ce qui était prévu.

Les essais du troisième module de vol des miroirs ont confirmé que ses caractéristiques techniques sont sensiblement meilleures que ne l'exigeaient les spécifications. Media Lario (I) travaille maintenant sur le modèle de réserve qui sera livré début avril 1998. Au Centre spatial de Liège (B), les modules de miroirs sont essayés avec les baffles de protection contre le rayonnement X parasite. Les premiers résultats confirment que les baffles empêchent efficacement les rayons X qui ne sont pas dans l'axe de pénétrer dans le système de miroirs, sans réduire les performances dans l'axe de visée.

A l'issue d'une courte période d'étalonnage des installations fin novembre, le troisième module de vol des miroirs est maintenant soumis à des essais à l'Institut Max Planck (D), en association avec un modèle de vol de l'ensemble à réseau de diffraction (RGA).

La livraison du modèle de vol des expériences, initialement prévue pour le début du mois de janvier 1998, a été reprogrammée sur la période mars-juillet de manière à ce que les essais d'étalonnage nécessaires puissent être conduits à Orsay (F). Cette modification a pu être inscrite dans le calendrier d'intégration global sans qu'elle ait de répercussions sur la date de livraison du véhicule spatial.

Les travaux de développement du secteur sol ont progressé conformément à ce qui était programmé au titre de la phase de conception détaillée.



Full-scale mock-up of the Integral payload

Maquette grandeur nature de la charge utile d'Intégral

Contractor and the national funding agencies and specific institutes.

After completion of a feasibility study that demonstrated that there are no major problems involved in launching with the Soyuz vehicle, the Agency has signed an initial contract with Starsem for the preliminary mission analysis. This study will examine the launch trajectories and resulting mechanical and thermal loads in full detail.

For the ground segment, the implications of using only one ground station (Villafranca) instead of the original two (Odenwald and Redu) are being addressed. The Joint Science Operations Centre is studying software updates for processing the scientific data.

XMM

The system-level Critical Design Review was held in September and October. It was concluded on 30 October, when the Review Board members unanimously confirmed that the spacecraft design is mature and that integration of the flight satellite could commence.

Integration of the engineering model of the spacecraft is complete and a series of tests have been successfully conducted at Dornier (D). The satellite is currently undergoing integrated system testing. By the end of April, the final tests on this model, namely the electromagnetic compatibility tests, will have been completed.

The environmental test campaign at ESTEC in Noordwijk (NL) on the Structural and Thermal Model (STM) is continuing. The Dornier (D) and Comet teams have succeeded in maintaining their respective schedules and the test results obtained to date have reinforced confidence in the overall system design.

Flight equipment is currently being delivered in time for the integration of the flight satellite to start early in 1998, as foreseen.

The tests on the third flight mirror module confirmed a performance significantly better than specified. Media Lario (I) is now working on the spare model, which will be delivered at the beginning of April 1998. At Centre Spatial de Liège (B), the mirror modules are being tested together with the X-ray baffles. Initial results confirm that the baffles are effective in their task of preventing off-axis X-rays from entering the mirror system, without reducing the on-axis performance.

After a short facility calibration period in late November, the third flight mirror module is now being tested at Max-Planck Institute (D), together with a flight model of the Reflection Grating Assembly (RGA).

Delivery of the flight-model experiments, originally foreseen for early January 1998, has been rescheduled for the March-July period to allow the necessary calibration tests to be conducted at Orsay (F). This planning modification can be accommodated into the overall integration schedule without impacting on the spacecraft delivery date.

The ground-segment development work has progressed according to plan with the detailed design phase.

Following the successful launch of Ariane-502, the detailed flight parameters are being evaluated by CNES in order to confirm the specified interface and performance parameters. The project has formally confirmed to Arianespace that the scheduled launch date remains 2 August 1999.

Integral

The main event recently was the signature of the Arrangement between ESA and the Russian Space Agency (RSA) concerning cooperation on Integral, whereby RSA will provide a Proton launcher in exchange for a share of the scientific data. The signature formalises the launcher baseline to which the project had been working for the past several years and opens clearer channels of communication for further interface work with the Proton launch authorities.

The spacecraft development work is progressing nominally. Some ground-support equipment and parts of the Structural and Thermal Model (STM) are being delivered by the subcontractors, in preparation for the STM test campaign planned for April. Payload-instrument development is also progressing, despite there being manpower shortages at some institutes. All teams should, nevertheless, be ready with the models of their instruments to support the STM campaign.

The entire ground segment, which will command the satellite in orbit and analyse the scientific data back on the ground, has been reviewed. The Review Board's report recommended clarification of the ground-segment management structure in order to define better the contribution of the instrument teams to the Integral Science Data Centre (ISDC) and to review further ground-station scenarios in order to guarantee full ground coverage for the mission.

Rosetta

The Phase-B has continued with the official kick-offs of activities by the platform major subcontractor, Matra Marconi Space UK, and the avionics major subcontractor, Matra Marconi Space France. The offer received from the remaining subcontractor for Assembly, Integration and Verification (AIV) is still in progress.

The preparation of the Invitations to Tender (ITTs) and Requests for Quotation (RFQs) for equipment suppliers has been progressing in parallel.

The spacecraft design is currently being refined, with attention focussing at this early stage on its thermal and mass aspects. The qualification of the low-intensity, low-temperature solar cells is in process. Definition of the instrument designs is also in process.

Definition of the ground segment is proceeding on schedule, with attention currently focussed on release of the Rosetta Mission Implementation Plan and on the development of the 32 m deep-space antenna to be located in Perth, Western Australia.

Artemis

Flight-model integration is continuing with nearly all payload equipment now integrated onto the flight spacecraft panels. The Silex optical data-relay terminal has also been delivered to Alenia Aerospace in Rome. Final integration of

A l'issue du lancement Ariane-502, le CNES a procédé à une évaluation détaillée des paramètres du vol afin de valider les paramètres de fonctionnement et d'interface spécifiés. Les responsables du projet ont officiellement confirmé à Arianespace que la date de lancement reste fixée au 2 août 1999.

Intégral

Le principal événement marquant de ces derniers temps a été la signature par l'ESA et l'Agence spatiale russe (RKA) d'un arrangement relatif à la coopération au projet Intégral, au titre duquel la RKA assurera le lancement d'Integral au moyen d'un Proton en contrepartie de données scientifiques. La signature de cet arrangement rend officiel le lanceur de référence sur la base duquel les responsables du projet ont travaillé ces sept dernières années et précise les voies de communication avec les autorités de lancement du Proton pour ce qui est de la poursuite des travaux sur les interfaces.

Les travaux de développement du véhicule spatial se poursuivent de façon nominale. Les sous-traitants livrent actuellement certains équipements de soutien sol et certaines parties du modèle structurel et thermique (STM), en préparation de la campagne d'essai du STM prévue pour avril 1998. La réalisation des instruments de la charge utile progresse elle aussi en dépit de la pénurie de main d'œuvre à laquelle certains instituts doivent faire face. Toutes les équipes devraient cependant avoir terminé le modèle de leur instrument à temps pour la campagne d'essai du STM.

La totalité du secteur sol qui assurera la commande et le contrôle du satellite en orbite et l'analyse des données scientifiques transmises au sol a fait l'objet d'une revue. Dans son rapport, la commission de revue a recommandé que la structure de gestion du secteur sol soit précisée afin de mieux définir les obligations des équipes responsables des instruments vis-à-vis du centre des données scientifiques d'Intégral (ISDC) et d'examiner de plus près les scénarios relatifs aux stations sol de manière à ce que la mission bénéficie d'une couverture au sol complète.

Rosetta

La phase B s'est poursuivie avec le démarrage officiel des activités du principal sous-traitant de la plate-forme, Matra Marconi Space UK, et du principal sous-traitant de l'avionique, Matra Marconi Space France. L'offre reçue du sous-traitant restant qui prendra en charge les activités d'assemblage, d'intégration et de vérification (AIV) n'est pas encore finalisée.

La préparation des appels d'offres (ITT) et des demandes de prix (RFQ) à envoyer aux équipementiers progresse en parallèle.

On affine la conception du véhicule spatial en s'attachant surtout, à ce stade préliminaire, aux aspects thermiques et de masse. La qualification des photopiles faible intensité basse température est en cours de même que la définition des concepts d'instrument.

La définition du secteur sol progresse conformément au calendrier, l'attention se portant pour le moment sur la publication du plan de mise en œuvre de la mission Rosetta et sur les activités de développement de l'antenne espace lointain de 32 m qui doit être installée à Perth, en Australie occidentale.

Artémis

L'intégration du modèle de vol se poursuit : pratiquement tous les équipements de la charge utile sont maintenant intégrés aux panneaux du modèle de vol du satellite. Le terminal de relais de données optique Silex a également été livré à Alenia Aerospace à Rome. Pour procéder à l'intégration définitive du satellite, on attend la livraison des derniers éléments sur lesquels on procède actuellement à des essais au niveau sous-système.

Les activités de développement du secteur sol pour les opérations battent leur plein et l'intégration de la station principale de télémesure, télécommande et poursuite doit commencer sous peu.

Terminal en orbite terrestre basse (LEO) Silex

Le programme d'essai du terminal LEO Silex a été mené à bien sur la plate-forme Spot-4 qui sera expédiée sur le site de lancement en janvier; le lancement lui-même est fixé à mars 1998.

EOPP

Stratégie future

Plusieurs réunions du groupe de travail sur la stratégie d'observation de la Terre et du groupe de travail industriel ad hoc se sont tenues depuis la fin du mois d'août. Ces réunions, ainsi que l'atelier industriel qui s'est déroulé les 23/24 octobre, ont débouché sur des recommandations claires en ce qui concerne la future stratégie d'observation de la Terre. Cette stratégie doit maintenant être examinée dans le cadre d'une série de réunions bilatérales avec chacune des délégations de l'ESA et avec le Conseil directeur du programme d'observation de la Terre avant d'être communiquée au groupe de travail du Conseil chargé de préparer la conférence ministérielle de 1998.

Parallèlement, un appel à propositions préliminaires dans le domaine de la surveillance de la Terre a été préparé pour envoi à l'industrie et il a été demandé à la Commission européenne ainsi qu'à Eumetsat de définir leurs besoins.

Programmes futurs

Les douze Etats participants ayant donné leur accord, comme il a déjà été dit dans le numéro précédent du Bulletin de l'ESA, pour que certaines activités de l'Extension 2 soient engagées à titre exceptionnel, ils ont approuvé en octobre la Déclaration de programme et le plan de travail révisés, ce qui s'est traduit par la diffusion d'appels d'offres pour quatre études de phase A relatives à des missions d'exploration de la Terre ainsi que par le démarrage d'un certain nombre d'activités de soutien.

Campagnes

Les résultats définitifs de l'atelier POLRAD ont été publiés récemment et les plans relatifs à l'expérience CLARE 1998 (Expérience de radar et lidar de nébulosité) ont été présentés à la communauté des utilisateurs à l'occasion d'un atelier qui s'est tenu du 12 au 14 novembre.

Plate-forme polaire/Envisat

Système Envisat-1

La résolution de la plupart des questions soulevées lors de la revue critique de conception au niveau du système de la mission Envisat (EMS-CDR) a bien avancé.

the spacecraft is awaiting delivery of the last items from subsystem testing.

Development of the operations ground segment is in full swing, with integration of the prime telemetry, tracking and command (TTC) station due to commence shortly.

Silex Low Earth Orbit (LEO) terminal
The Silex LEO terminal has completed its test programme on the Spot-4 platform, which will be shipped to the launch site in January for a March 1998 launch.

EOPP

Future strategy
Various meetings of the Earth-Observation Strategy Task Force and the Industrial Ad-Hoc Working Group have taken place since the end of August. These meetings, together with the outcome of the Industrial Workshop held on 23/24 October, have resulted in clear recommendations for the draft future Earth-Observation Strategy. This strategy is now to be discussed in a series of bilateral meetings with individual ESA Delegations and with the Earth-Observation Programme Board before being forwarded to the Council Working Group preparing for the 1998 Ministerial Meeting.

In parallel, a Call for Outline Earth-Watch Proposals has been prepared for sending to industry and the European Commission and Eumetsat have been requested to identify their requirements.

Future programmes
Following agreement, already reported in the previous issue of ESA Bulletin, to exceptionally initiate some Extension 2 activities, the twelve Participating States reviewed and agreed the revised Programme Declaration and Work Plan in October. This has resulted in the release of Invitations to Tender for four Earth-Explorer Phase-A studies, as well as the initiation of a number of supporting activities.

Campaigns
The final POLRAD Workshop results have recently been published (ESA WPP-135), and the plans for the Cloud Lidar and Radar Experiment, CLARE 1998, have been presented to the User Community, at a Workshop on 12-14 November.

Polar Platform/Envisat

Envisat-1 system
Resolution of most of the issues raised at the Envisat Mission System Critical Design Review (EMS-CDR) has progressed well. The Data Policy document, elaborated by the Data Policy Task Force, is still awaiting the approval of the Earth Observation Programme Board. The Announcement of Opportunity (AO) for scientific data exploitation and pilot projects is awaiting the approval of the Programme participants prior to its release. The High-Level Operations Plan (HLOP) is well advanced, and discussions with DOSTAG are focussing on the ASAR operation strategy.

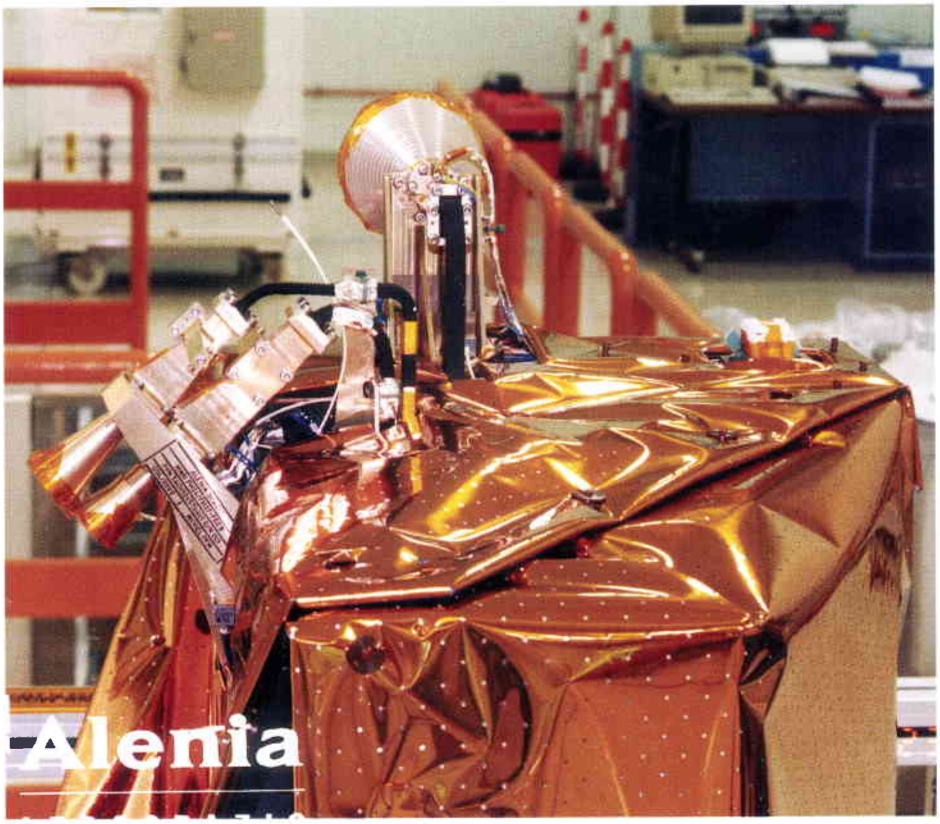
Polar Platform (PPF)
The Polar Platform engineering-model (EM) activities have continued with the execution of several functional tests involving the instruments and the PPF payload support functions. Future activities involve the integration of the ASAR EM and satellite-level tests (integrated system tests and EMC).

The flight-model (FM) Payload Module structure has been refurbished and integration of the FM harness is in progress at Matra Marconi Space in Bristol (UK).

The FM Payload Equipment Bay integration has been completed, with the exception of the tape recorders, delivery of which has been delayed by several problems. Following the recommendation of the EMS-CDR Board, a Solid-State Recorder (SSR) is under development to replace one of the four tape recorders. This SSR will be provided by DASA/DSS (D) following selection through an industrial competition. Other EMS-CDR issues have been progressed satis-factorily, except the compatibility of the Service Module with the Ariane-5 generated shock loading, which remains a concern. The Ariane-502 in-flight results will be exploited in a forthcoming analysis.

Flight model of Envisat's MWR instrument

Modèle de vol de l'instrument MWR d'Envisat



Le document relatif à la politique des données, élaboré par le groupe de travail ad hoc, n'a pas encore été approuvé par le Conseil directeur du programme d'observation de la Terre. L'appel à propositions (AO) de projets pilotes et d'exploitation des données scientifiques doit être approuvé par les participants au programme avant de pouvoir être diffusé. L'élaboration du plan d'exploitation de haut niveau (HLOP) en est à un stade avancé et les débats avec le DOSTAG sont axés sur la stratégie d'exploitation de l'ASAR.

Plate-forme polaire (PPF)

Les activités portant sur le modèle d'identification (EM) de la plate-forme polaire ont continué avec l'exécution de plusieurs essais fonctionnels faisant intervenir les instruments et les fonctions de soutien de la charge utile de la PPF. Au nombre des activités à venir figurent l'intégration du modèle d'identification de l'ASAR ainsi que des essais au niveau du satellite (essais du système intégré et essais de compatibilité électromagnétique).

Le modèle de vol (FM) de la structure du module de charge utile a été remis à hauteur et l'intégration du modèle de vol du faisceau de câbles est en cours chez Matra Marconi Space Bristol (R-U).

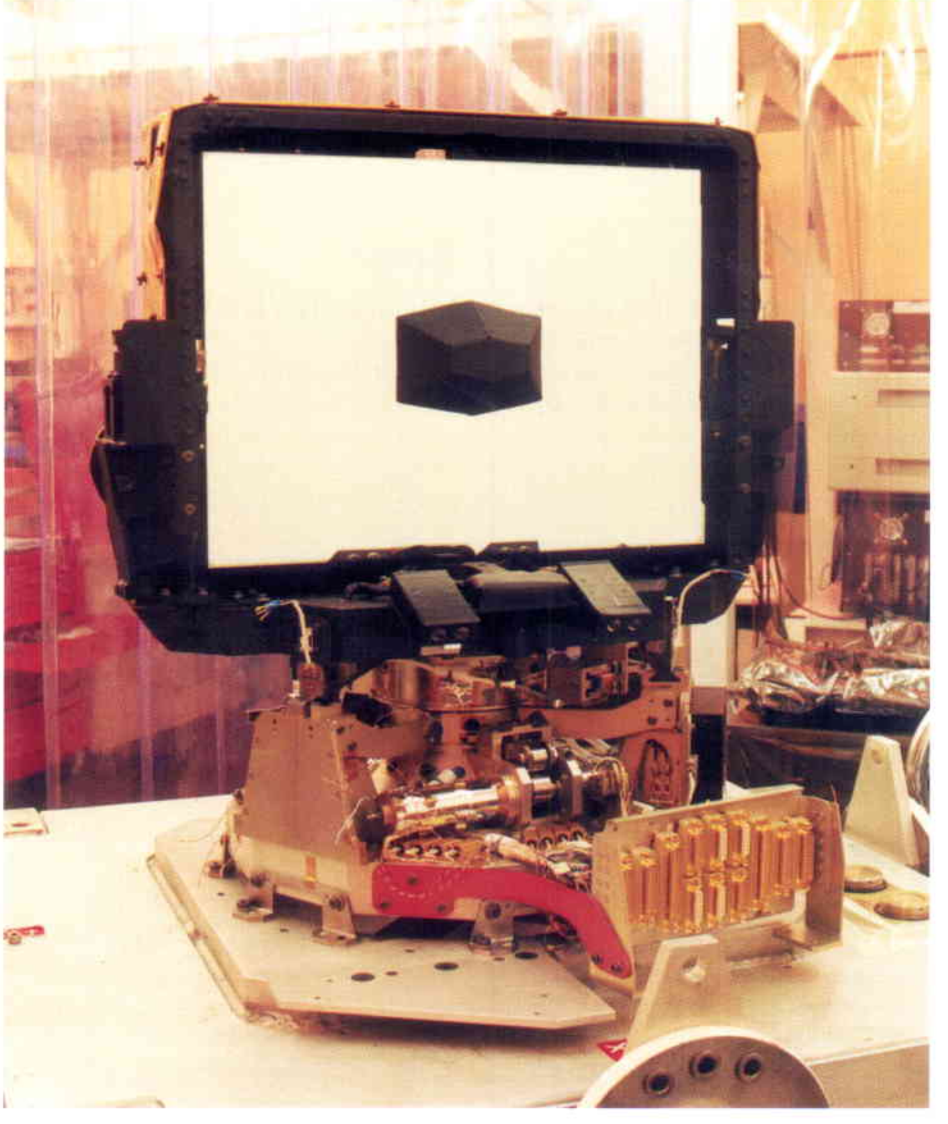
L'intégration du modèle de vol de la case à équipements de la charge utile est terminée, exception faite des enregistreurs sur bande dont la livraison a été retardée en raison de différents problèmes. Conformément aux recommandations de la commission de l'EMS-CDR, on est en train de mettre au point un enregistreur état solide (SSR) qui remplacera l'un des quatre enregistreurs sur bande. Ce SSR sera fourni par la DASA/DSS (D) qui a été retenue dans le cadre d'une procédure concurrentielle. La résolution des autres problèmes mis en lumière lors de l'EMS-CDR a progressé de façon satisfaisante, hormis en ce qui concerne la compatibilité du module de servitudes avec les contraintes induites par le choc de séparation du lanceur Ariane-5, qui demeure une question préoccupante. Les résultats du vol Ariane-502 seront exploités dans le cadre d'une analyse à venir.

Charge utile Envisat-1

Le programme du modèle d'identification des instruments est maintenant presque terminé et les résultats d'ensemble des essais ont confirmé la validité des concepts d'instrument. A l'issue de la revue critique de conception système de la mission Envisat (EMS-CDR), l'équipe de projet et l'industrie ont procédé à une réévaluation détaillée des caractéristiques prévisionnelles de fonctionnement en vol des instruments. Il en ressort que les caractéristiques attendues se situeraient tout à fait dans les limites des spécifications. Les résultats de l'EMS-CDR ont été présentés dans le détail au DOSTAG.

Des modifications relativement mineures ont récemment été apportées d'une part au concept de l'instrument MERIS afin de corriger les images parasites et d'autre part au concept de l'électronique de l'interféromètre du MIPAS afin de compenser le comportement non linéaire marqué du matériel du séparateur de faisceau que l'on a récemment décelé dans la plage inférieure de la gamme des températures de fonctionnement de l'instrument (1800 K). Un filtre additionnel a également été introduit dans les modules d'émission et de réception de l'antenne de l'ASAR afin d'éliminer le problème des interférences RF de l'instrument RA-2 (problème décelé pendant l'EMS-CDR). Ces modifications conceptuelles sont maintenant validées et l'on procède sans délais à leur mise en oeuvre dans le matériel de vol des instruments.

L'assemblage et l'essai des modèles de vol des instruments avancent de façon satisfaisante dans l'ensemble. Outre le MWR déjà livré, les autres modèles de vol des instruments doivent être livrés de façon échelonnée au premier trimestre 1998.



Flight model of the Steering Front Assembly for Envisat's GOMOS instrument

Modèle de vol de l'ensemble avant de l'instrument GOMOS d'Envisat

Envisat-1 payload
The instrument engineering-model programme is now nearly completed and the overall test results have confirmed the validity of the instruments' designs. Following the Envisat Mission System Critical Design Review (EMS-CDR), a detailed reassessment of the predicted instrument in-flight performance has been carried out by the Project Team and Industry. It has shown that the expected performances are well within specification. An extensive presentation on the EMS-CDR results has been given to the Earth-Observation DOSTAG.

Relatively minor design changes recently had to be introduced into the MERIS instrument to correct for ghost images, and into the MIPAS interferometer electronics to compensate for strong nonlinear behaviour of the beam-splitter material, which has recently been discovered to occur in the instrument's lower operating temperature range (1800 K). An additional filter has also been introduced into the transmit and receive modules of the ASAR antenna to eliminate an RF interference problem from the RA-2 instrument (a problem identified during the EMS-CDR). These design changes have now been validated and their implementation in the instruments' FM hardware is proceeding without delay.

The assembly and testing of the flight-model instruments is progressing well overall. With the MWR already delivered, the planned staggered delivery of the other FM instruments is expected to begin in the first quarter of 1998.

Envisat-1 ground segment
For the Flight Operations Segment (FOS), the flight control software and satellite simulator software versions integrated at ESOC in Darmstadt (D) are ready to support the first compatibility test with the Service Module of the Polar Platform planned for early 1998.

Integration of the Payload Data Segment (PDS) facilities onto the Reference Platform is progressing well. A data chain representative of an ESA Payload Data Handling Station (PD-HS) is being assembled with a complete ASAR processor. All other instrument processing facilities are under development, with the MIPAS level-1b processor due for factory acceptance testing before the end of 1997.

As far as the Processing and Archiving Centre (PAC) activities are concerned, the French PAC (F-PAC) development effort is still the only one that has been formally kicked-off. Detailed discussions with the other PACs are still in progress, and several of them will hopefully be ready for development kick-off shortly. Good progress has been achieved in terms of the use of generic elements developed within the framework of the PDS contract.

Meteosat Transition Programme (MTP)

Following its successful launch in September, Meteosat-7 has now been fully commissioned in orbit by Eumetsat and shown to be capable of totally satisfying the operational mission. Carrying sufficient fuel for five years, the spacecraft should be capable of operating beyond 2002.

The integration of Meteosat-7 was started in the early Summer of 1996 and completed with the environmental acceptance tests in early 1997. The Flight-Readiness Review was held on 10 July 1997 and the launch campaign started immediately thereafter. It was a classical recurrent spacecraft programme, but special difficulties were introduced by the advance of technology in the ten-year period between the building of Meteosats-4, 5 and 6 and that of Meteosat-7. Industry is to be congratulated for the fact that the images produced during the MTP commissioning tests were more than equal to any produced by the earlier spacecraft. It is expected that the MTP spacecraft will enter into commercial service in the Spring.

Nearly 20 years after the launch of the first European Meteosat spacecraft, Meteosat-7 is the last spacecraft of this 'first generation' design. Beyond 2002, the European weather services will receive data from the Meteosat Second Generation spacecraft, currently being developed under ESA contract, which will provide many more channels and more frequent images.

Metop

The offer for the main development phase for Metop-1, -2 and -3 was received in early September. Evaluation was completed by mid-October and a fixed-price deal, which settled all outstanding issues revealed by the Tender Evaluation Board, was achieved before the end of that month. This was a very significant achievement and enabled a Contract Proposal to be prepared in time for the necessary legal processes within both ESA and Eumetsat.

Programmatically, major progress has been made on the ESA side, with the approval of the Contract Proposal and more than 90% of the expected subscription now having been received. Only one subscription is now outstanding. The ESA programme can be considered conditionally approved, depending on the Eumetsat commitment and the remaining subscription. A special Council Meeting is foreseen in January 1998, at which it is hoped the final programmatic commitment can be obtained.

Integration of the MTP (Meteosat-7) flight model into the lower fairing on the Ariane launcher (V99)

Intégration du modèle de vol du satellite MTP (Météosat-7) à la partie inférieure de la coiffe du lanceur Ariane (V99)

Secteur sol d'Envisat-1

En ce qui concerne le secteur des opérations en vol (FOS), les versions intégrées à l'ESOC (Darmstadt, D) du logiciel de commande et contrôle en vol et du logiciel du simulateur du satellite sont prêtes pour le premier essai de compatibilité avec le module de servitudes de la plate-forme polaire prévu début 1998.

L'intégration des installations du système des données de charge utile (PDS) à la plate-forme de référence se déroule de façon satisfaisante. Une chaîne de données représentative d'une station de traitement des données de charge utile (PD-HS) de l'Agence est en cours d'assemblage avec un processeur ASAR complet. Toutes les autres installations de traitement des instruments sont en cours de réalisation et le processeur de niveau 1b de MIPAS doit être soumis aux essais de recette à sa sortie d'usine d'ici fin 1997.

En ce qui concerne les activités des centres de traitement et d'archivage (PAC), les travaux de développement du PAC français (F-PAC) sont toujours les seuls à avoir officiellement démarré. Des discussions détaillées avec les autres PAC continuent et il faut espérer que les travaux de réalisation de plusieurs d'entre eux pourront commencer sous peu. Des progrès satisfaisants ont été faits en termes d'utilisation des éléments génériques mis au point dans le cadre du contrat relatif au PDS.

Programme Météosat de transition (MTP)

Eumetsat a mené à bien la phase de mise en service en orbite de Météosat-7, lancé avec succès en septembre. Le satellite a démontré qu'il était à même de satisfaire pleinement aux impératifs de la mission opérationnelle. Possédant une réserve d'ergols suffisante pour cinq ans, il devrait être en mesure de fonctionner jusqu'au delà de 2002.

L'intégration de Météosat-7 a commencé au début de l'été 1996 et s'est terminée par les essais de recette en conditions ambiantes début 1997. La revue d'aptitude au vol s'est tenue le 10 juillet 1997 et la campagne de lancement a commencé immédiatement après. Il s'agissait certes d'un programme classique portant sur une série de satellites mais qui comportait des difficultés particulières en raison des progrès technologiques accomplis sur la période de dix ans qui a séparé la construction des satellites Météosat-4, 5 et 6 et celle du satellite Météosat-7. Il y a lieu de féliciter l'industrie car la qualité des images produites pendant les essais de mise en service du satellite MTP est au moins égale sinon supérieure à celle des images fournies par les satellites antérieurs. Le satellite MTP devrait entrer en service commercial au printemps 1998.

Près de 20 ans après le lancement du premier satellite météorologique européen, Météosat-7 est le dernier satellite du concept de 'première génération'. Au-delà de 2002, les services météorologiques européens recevront leurs données de satellites Météosat de deuxième génération, dont le développement est en cours au titre d'un contrat ESA, et qui comporteront de nombreux autres canaux et fourniront des images plus fréquentes.

Métop

L'offre relative à la phase principale de développement de Métop-1, 2 et 3 a été reçue début septembre. L'évaluation s'est achevée à la mi-octobre et un arrangement à prix forfaitaire réglant toutes les questions mises en lumière par la commission d'évaluation des offres a été conclu avant la fin de ce même mois. Ce résultat vraiment significatif a permis de préparer une proposition de contrat à temps pour que les procédures juridiques indispensables puissent être menées à bien tant au sein de l'Agence que chez Eumetsat.

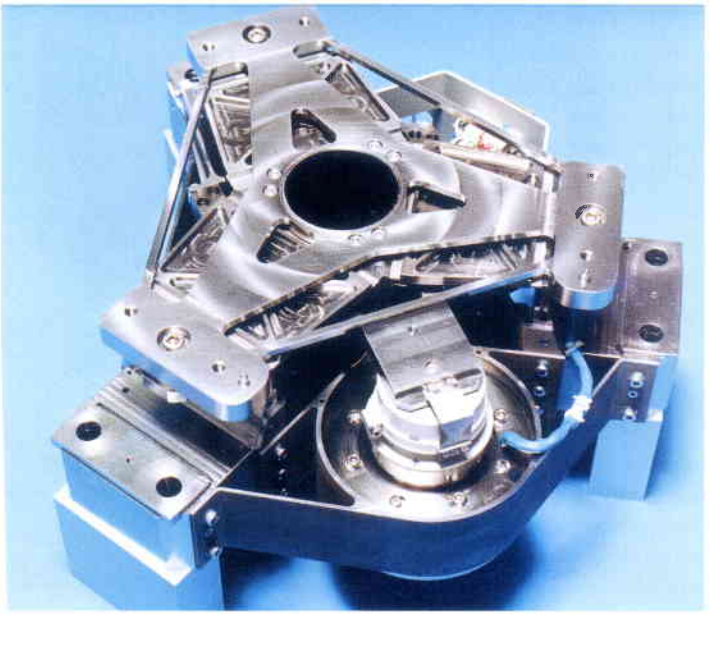
Le fait que la proposition de contrat ait été approuvée et que plus de 90% des souscriptions attendues aient désormais été reçues représente pour l'Agence une avancée programmatique majeure. Il ne reste qu'une seule souscription en suspens. Le programme de l'ESA peut être considéré comme approuvé sous réserve de la souscription manquante et de l'engagement d'Eumetsat. Il est prévu de tenir en janvier 1998 une session spéciale du Conseil au cours de laquelle on espère pouvoir parvenir à un engagement programmatique définitif.

Météosat de deuxième génération (MSG)

La revue de conception préliminaire (PDR) de l'unité de balayage du SEVIRI (imageur visible et infrarouge amélioré non dégyré) n'est pas terminée et le calendrier de cet instrument demeure sur le chemin critique.

La structure primaire du satellite destinée au modèle structurel et thermique (STM) a été livrée au maître d'œuvre, Aérospatiale (Cannes, F) chez qui les différents sous-systèmes et équipements seront intégrés.

Au niveau des équipements, les diverses revues critiques de conception en cours devraient à terme permettre d'autoriser le



Refocussing mechanism for the MSG spacecraft

Mécanisme de recentrage du satellite MSG

Meteosat Second Generation (MSG)

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

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

At equipment level, various critical design reviews are in progress which should ultimately release the flight hardware manufacturing. Some STM items are being used for equipment qualification, such as the Refocussing Mechanism shown in the accompanying photograph.

ERS

The ERS-2 satellite has continued to support the mission, providing both high-quality data and very good availability.

Some symptoms of equipment ageing have been detected in the AMI instrument that could degrade the data quality in the future. An investigation is in progress to devise operational measures that could slow the ageing process and maintain the current high data quality for as long as possible.

Close monitoring of the spacecraft's gyroscopes has shown that their performances are stable, and that the satellite's pointing is within specification.

ERS-1 is being maintained as an operational backup and periodic check-outs show that all of its essential performance levels are being maintained.

International Space Station Programme

ISS overall assembly sequence
Through the intensive reassessment of the launch sequence conducted by NASA and the International Partners, all problems related to the International Space Station Assembly Sequence have been resolved. This has resulted in an October 2002 launch date for the Columbus Orbital Facility (COF), fully meeting ESA's objective of a launch before the end of 2002.

The Russian Service Module, containing the ESA-furnished Data Management System (DMS-R), will be launched in December 1998 and the Russian Science and Power Platform, including the European Robotic Arm (ERA), will be launched in July 2000.

The launch date for Node 3 appears in the updated Assembly Sequence for the first time and is set for July 2002, which is just seven months after the "earliest delivery date" shown in the COF Launch Barter Agreements.

The NASA Habitation Module is still included in the Assembly Sequence, but the launch date has been delayed to December 2003.

Columbus Orbital Facility (COF)
The COF System Preliminary Design Review (PDR) started on schedule in October. The review has gone well to date, and the provisional conclusions are that the concerns identified are quite normal for this stage of the programme, and are properly covered by agreed actions. The major concern relates to the fire-suppression scenario, where there are some areas within the module which do not enable fires to be put out with the ISS standard portable fire extinguisher. Design modifications will be required to resolve this. In parallel, NASA has conducted an independent Safety Review Phase 1, the initial conclusions of which are also encouraging.

The implementation of COF Attachment Points for external payload accommodation has been proposed by ESA to fulfil the user's requirements for external utilisation. Discussions are in progress with Delegations on the possibility of funding this additional COF capability.

COF launch barter
The ESA/NASA COF Launch Barter Arrangement was signed on 8 October and the ESA/ASI Arrangement on the Node 2/Node 3 project was signed on 12 December.

The initial system configuration and primary structure design activities related to Nodes 2 and 3 have been completed. The RFQs for the European item procurements have been released and the initial selection of subcontractors has been made, with the exception of the ECLSS components which await the final definition of the items available from NASA free of charge. Activities related to RFQs to US suppliers for Node 3 items and possible alternative European suppliers for some items are underway.

With regard to the Software Deliveries, DMS-R items and associated Sustaining Engineering for NASA, the engineering-support personnel have started work at Houston. The first hardware deliveries, namely those of the Fault-Tolerant Computer (FCR) development models, have been made to NASA.

MPLM Environmental Control and Life Support Subsystem (ECLSS)
All Engineering Models and Ground Support Equipment have been delivered to the Prime Contractor. All subsystem-level qualification test reports have been approved by the Agency. The Prime Contractor is proceeding with the generation of the MPLM System Qualification Review. Equipment qualification and acceptance testing is underway and Equipment Qualification Reviews have started in November and will proceed through January 1998. Delivery of the first set of flight hardware took place in December.

Automated Transfer Vehicle (ATV)
The Phase-C/D proposal was received late in October and complemented by the detailed prices a month later. The proposal for the Production Phase-E was also received at the end of October.

During the proposal evaluation some significant deficiencies became apparent and the ATV contract proposal is not now expected to be submitted to the Agency's Industrial Policy Committee (IPC) before June 1998.

Agreements in Principle have been reached with RSA on urgent work to be undertaken by RSC-Energia, in particular for the definition and verification of interfaces and the elaboration of an acceptable demonstration-flight scenario.

démarrage de la fabrication du matériel de vol. Certains éléments du STM sont utilisés pour la qualification des équipements, tel le mécanisme de recentrage du MSG qui apparaît sur la photographie jointe.

ERS

Le satellite ERS-2 continue de remplir sa mission: il fournit des données de haute qualité et sa disponibilité est très élevée.

Des symptômes de vieillissement ont été décelés au niveau des équipements de l'AMI, ce qui peut laisser présager une dégradation de la qualité des données à l'avenir. Une étude est en cours pour trouver des moyens opérationnels de ralentir le processus de vieillissement et de maintenir la haute qualité actuelle des données aussi longtemps que possible.

L'étroite surveillance des gyroscopes du véhicule spatial montre que leurs caractéristiques de fonctionnement sont stables et que les caractéristiques de pointage du satellite sont conformes aux spécifications.

ERS-1 reste en situation de réserve opérationnelle et les vérifications périodiques accomplies montrent que ses caractéristiques de fonctionnement demeurent satisfaisantes pour l'essentiel.

Station spatiale internationale (ISS)

Séquence d'assemblage de l'ISS

Grâce au réexamen approfondi de la séquence de lancement auquel ont procédé la NASA et les partenaires internationaux, tous les problèmes liés à la séquence d'assemblage de la Station spatiale internationale ont été résolus. En conséquence, la date de lancement de l'Elément orbital Columbus (COF) a été fixée à octobre 2002, ce qui correspond parfaitement à l'objectif de l'ESA, qui est d'obtenir un lancement avant fin 2002. Le module de service russe comprenant le système de gestion de données (DMS-R) fourni par l'ESA sera lancé en décembre 1998 et la plate-forme russe 'Science et énergie', sur laquelle sera installé le bras télémanipulateur européen (ERA), en juillet 2000.

La date de lancement de l'Elément de jonction 3 apparaît pour la première fois dans la séquence d'assemblage actualisée et est fixée à juillet 2002, soit sept mois seulement après la date de livraison la plus proche figurant dans les accords de compensation pour le lancement du COF.

Le module d'habitation de la NASA figure toujours dans la séquence d'assemblage, mais son lancement a été reporté à décembre 2003.

Elément orbital Columbus (COF)

La revue préliminaire de conception du COF au niveau système (PDR) a démarré comme prévu en octobre. Cette revue a bien progressé jusqu'ici et il apparaît, en première analyse, que les préoccupations qui se sont fait jour sont tout à fait normales au stade actuel du programme et devraient trouver une réponse adéquate avec les mesures qui ont été décidées. La principale préoccupation porte sur le scénario de lutte anti-incendie, selon lequel il existe certaines zones à l'intérieur du module dans lesquelles un incendie ne peut être combattu avec l'extincteur portable standard de l'ISS. Des modifications de conception seront nécessaires pour résoudre ce problème. Parallèlement, la NASA a conduit la phase 1 d'une revue de sécurité indépendante, dont les premières conclusions sont encourageantes.

L'ESA a proposé d'équiper le COF de points de fixation pour charges utiles externes afin de répondre aux besoins des utilisateurs en matière d'expériences dans le milieu spatial. Des discussions sont en cours avec les délégations quant à la possibilité de financer cette capacité additionnelle du COF.

Compensation du lancement du COF

L'arrangement de compensation ESA/NASA du lancement du COF a été signé le 8 octobre et l'arrangement ESA/ASI relatif au projet d'éléments de jonction 2 et 3 l'a été le 12 décembre.

Les activités liées à la configuration initiale du système et à la conception de la structure primaire en ce qui concerne les éléments de jonction 2 et 3 ont été menées à bien. Les demandes de prix concernant les approvisionnements en équipements européens ont été envoyées et la liste initiale des sous-traitants a été arrêtée, sauf en ce qui concerne les composants de l'ECLSS, pour lesquels on attend la définition finale des éléments qui seront disponibles gratuitement auprès de la NASA. On procède actuellement à la préparation des demandes de prix qui doivent être envoyées aux fournisseurs américains pour les composants de l'élément de jonction 3 et, pour certains d'entre eux, à d'éventuels fournisseurs européens.

Pour ce qui est des fournitures de logiciels, des composants du DMSR et du soutien technique continu à apporter à la NASA pour cet équipement, le personnel d'assistance technique a commencé ses travaux à Houston. Les premiers matériels ont été livrés à la NASA: il s'agit des modèles de développement d'ordinateur à tolérance de panne (FCR).

Sous-système de régulation d'ambiance et de soutien vie du MPLM (ECLSS)

L'ensemble des modèles d'identification et des équipements de soutien sol ont été livrés au maître d'oeuvre. Tous les rapports d'essais de qualification au niveau sous-systèmes ont été approuvés par l'Agence. Le maître d'oeuvre prépare actuellement la revue de qualification système du MPLM. Les essais de qualification et de recette des équipements sont en cours et les revues de qualification au niveau des équipements, qui ont commencé en novembre, dureront jusqu'en janvier 1998. La livraison des premiers matériels de vol a eu lieu en décembre 1997.

Véhicule de transfert automatique (ATV)

La proposition de phase C/D a été reçue fin octobre 1997, les prix détaillés ayant été communiqués un mois plus tard. La proposition relative à la phase de production (phase E) a également été reçue fin octobre.

L'évaluation des propositions a révélé certaines anomalies significatives et l'Exécutif estime maintenant que la proposition de contrat relative à l'ATV ne pourra être soumise au Comité de la politique industrielle de l'Agence (IPC) avant juin 1998.

Des accords de principe ont été conclus avec la RKA sur les travaux urgents qui doivent être entrepris par RKK Energia, notamment en ce qui concerne la définition et la vérification des interfaces et l'élaboration d'un scénario de vols de démonstration acceptable.

ATV Rendezvous and Pre-development (ARP) activities
Flight Demonstration no. 3 on Shuttle flight STS-86 (25 September-4 October) was successfully performed for both RVS and GPS during the approach and docking to Mir. The flight data are under evaluation.

Crew Transport Vehicle (CTV)
The Manned Space Programme Board, meeting in December, fully endorsed a proposal presented by the Executive for a reduced-cost programme for an applied re-entry technology programme. The proposal covers the continuation of the X-38 ESA/NASA cooperative activities until completion of this programme in mid-2000, and includes activities for the detailed design and development of the orbital flight vehicles of the X-38 programme, in areas of particular European technological interest.

It is the intention to implement the proposed cooperative activities within the framework of the existing dedicated arrangements (Exchange of Letters) between ESA and NASA on the X-38 cooperation.

Atmospheric Reentry Demonstrator (ARD)
Following the successful Ariane-502 launch, it is planned to reactivate ARD activities as soon as the launch preparation schedule is known. Given the encouraging results of flight 502, flight 503 is currently expected to take place in late Spring 1998.

Operations and Ground Segment
Following a Multilateral Operations Technical Interchange Meeting (TIM) in mid-1997, a series of multilateral teleconferences were conducted to update the 10 volumes of the Station Programme Implementation Plan (SPIP), with the intention of baselining these documents at the occasion of the next Multilateral Operations and Utilisation Control Board (MO&UCB) scheduled for 8-10 December 1997 in Houston.

The definition study of the COF/ATV Operations Control Functions and Facilities successfully passed its Implementation Review in September and the Final Review was successfully completed at the end of November.

The definition study of the COF/ATV Operations Support Functions and Facilities is experiencing some delay. The Implementation Review is now tentatively planned for January 1998, with completion of the study not now expected before end-March 1998.

The study related to the Implementation Definition of the associated Ground Communications Infrastructure successfully passed its Implementation Baseline Review, and the Final Review was conducted in mid-November.

Utilisation
The Announcement of Opportunities for External Payloads has, as a first intermediate output, led to the occupancy of six Express Pallet Adapters with top-quality experiments to be flown in the framework of the Early Space Station Opportunity. Supporting studies of different payload groupings have been carried out, concentrating on mechanical, geometrical, interface and resource assessments. Payloads for Physical and Life Sciences, Earth Observation, Space Science and Technology are envisaged.

For projects that are envisaged in later phases of the programme, studies are ongoing for Space Science (Large X-Ray Facility) and for Earth Observation (Wind Lidar Facility). A feasibility study for the assembly of a large X-Ray Facility at the Space Station has been approved by ESA's Science Programme and Industrial Policy Committees (SPC and IPC). The release of the Invitation to Tender (ITT) was foreseen for December. Likewise an ITT for the Phase-A of the Wind Lidar Facility is in preparation, for which IPC and Earth-Observation Programme Board (PB-EO) approval has also been obtained.

EUROMIR-E mission status
Due to the damage to the Russian Spectr module in which the EUROMIR equipment is located, an agreement has been reached with the Russian side terminating EUROMIR-E activities and replacing them with an experiment mounted externally on the Russian Segment of the ISS (mounted on the Service Module during a Russian EVA).

Astronaut activities
An analysis has been made of the future assignments for ESA Astronauts presently training in the USA vis-a-vis a number of missions of interest to ESA. It has shown that the present ESA Astronaut Corps will not be able to meet all of the requirements of the upcoming missions. In particular, it will be unable to provide sufficient astronauts for the International Space Station operations after the COF launch, particularly as only experienced astronauts will be eligible for this phase. Recruitment of a number of new astronaut candidates has therefore been initiated, at the same time incorporating as many national astronauts as possible into the

The Automated Transfer Vehicle (ATV)

Le véhicule de transfert automatique (ATV)

Activités de prédéveloppement du rendez-vous de l'ATV (ARP)
Le troisième vol de démonstration réalisé dans le cadre de la mission STS-86 de la Navette (25 septembre - 4 octobre) a été un succès quant au fonctionnement du RVS et du GPS au cours des phases d'approche et d'amarrage à Mir. Les données de vol sont en cours d'évaluation.

Véhicule de transport d'équipage (CTV)
A sa réunion de décembre 1997, le Conseil directeur des programmes spatiaux habités a approuvé sans réserve une proposition de programme à coût réduit présenté par l'Exécutif portant sur l'application de la technologie de rentrée atmosphérique. Cette proposition couvre la poursuite des activités menées en coopération entre l'ESA et la NASA sur le projet X-38 jusqu'à l'achèvement de ce programme à la mi-2000 et inclut des activités de conception détaillée et de développement des véhicules d'essai de vol orbital du programme X-38 dans des domaines présentant un intérêt technologique particulier pour l'Europe.

Pour la mise en oeuvre des activités proposées, il est envisagé d'agir dans le cadre des arrangements spécifiques (échange de lettres) existant entre l'ESA et la NASA pour la coopération au projet X-38.

Démonstrateur de rentrée atmosphérique (ARD)
Après le succès du lancement Ariane 502, il est prévu de reprendre les activités ARD dès que le calendrier de préparation du prochain lancement sera connu. Compte tenu des résultats encourageants du vol 502, le vol 503 pourrait avoir lieu à la fin du printemps 1998.

Activités opérationnelles et secteur sol
A la suite d'une réunion d'échange technique (TIM) sur les opérations à la mi-1997, une série de téléconférences multilatérales ont été conduites pour mettre à jour les dix volumes du plan de mise en oeuvre du programme de Station spatiale (SPIP), l'objectif étant d'officialiser ces documents à l'occasion de la prochaine réunion de la Commission multilatérale de contrôle des opérations et de l'utilisation (MO&UCB), qui doit se tenir du 8 au 10 décembre 1997 à Houston.

L'étude de définition des installations et fonctions de contrôle des opérations du COF/ATV a passé le cap de la revue du plan de mise en oeuvre en septembre et la revue finale a été menée à bien fin novembre.

L'étude de définition des installations et fonctions de soutien des opérations du COF/ATV connaît quelque retard. La revue du plan de mise en oeuvre est maintenant programmée en janvier 1998, l'étude ne devant pas s'achever avant fin mars 1998.

L'étude liée à la définition de la mise en oeuvre de l'infrastructure de communication au sol associée a passé le cap de la revue du plan de mise en oeuvre et la revue finale a été conduite à la mi-novembre.

Utilisation
L'avis d'offre de participation aux charges utiles externes a conduit, dans un premier temps, à réserver six adaptateurs de palettes express à des expériences jugées prioritaires, qui doivent être embarquées dans le cadre des occasions de vol initiales à bord de la Station spatiale. L'Exécutif a procédé à des études de soutien portant sur différents lots de charges utiles en axant son évaluation sur les caractéristiques mécaniques, l'encombrement, les interfaces et les ressources. Les charges utiles considérés portent sur la physique et les sciences de la vie, l'observation de la Terre, la science spatiale et la technologie.

Pour ce qui est des projets envisagés à un stade ultérieur du programme, des études sont en cours dans les domaines de la science spatiale (grande installation dans le rayonnement X) et de l'observation de la Terre (lidar vent). Une étude de faisabilité portant sur l'assemblage sur la Station spatiale d'une grande installation travaillant dans le rayonnement X a été approuvée par les comités de l'ESA chargés du programme scientifique et de la politique industrielle (SPC et IPC). L'envoi de l'appel d'offres (ITT) est prévu en décembre. De même, l'Exécutif prépare un appel d'offres pour la phase A du lidar vent, qui a également reçu l'approbation de l'IPC et du Conseil directeur du programme d'observation de la Terre (PB-EO).

Situation de la mission EUROMIR-E
Du fait des dégâts subis par le module russe Spectre qui abrite les équipements EUROMIR, un accord a été conclu avec la partie russe pour mettre fin aux activités EUROMIR-E et pour les remplacer par une expérience montée à l'extérieur de la composante russe de l'ISS (module de service) lors d'une sortie dans l'espace des Russes.

Activités des astronautes
Une analyse a été conduite sur les affectations futures des astronautes de l'ESA qui s'entraînent actuellement aux Etats-Unis au regard d'un certain nombre de missions présentant un intérêt pour l'Agence. Il s'est avéré que le corps des astronautes ESA actuel ne sera pas en mesure de répondre à tous les besoins des missions à venir. En particulier, il ne pourra pas fournir un nombre suffisant d'astronautes pour l'exploitation de la Station spatiale internationale après le lancement du COF, surtout si l'on considère que seuls les astronautes expérimentés pourront être retenus pour cette phase. L'Exécutif a donc engagé le recrutement d'un certain nombre de nouveaux candidats astronautes, tout en intégrant le plus grand nombre possible d'astronautes nationaux dans le corps des astronautes européens. Dans ce contexte, les critères médicaux et la procédure de sélection sont en cours de réexamen et l'Exécutif prépare un programme de formation de base qui doit démarrer au second trimestre 1998 au Centre des astronautes européens (EAC) près de Cologne, Allemagne.

Livraisons à court terme
Système de gestion de données pour le module de service russe (DMS-R)
La revue de qualification du DMS-R s'est achevée de manière concluante fin septembre et la revue de recette des premières unités de vol d'ordinateurs à tolérance de panne (FTC) a eu lieu début octobre. Les deux premiers FTC ont été livrés respectivement à la RKA/RKK Energia les 11 et 27 octobre. Il convient de mentionner que ces premiers matériels de vol pour le DMS-R, totalement conformes aux spécifications techniques, ont été livrés dans les délais et dans les limites de leur enveloppe financière. La livraison des autres unités de vol a eu lieu en décembre.

La définition du soutien technique à long terme que l'industrie européenne doit fournir aux contractants du module de service russe pour le DMS-R a été

European Astronaut Corps. In the context of this new recruitment effort, both the medical criteria and the selection procedure itself are being reviewed, and a Basic Training Programme is being prepared, which is scheduled to start in the second quarter of 1998 at the European Astronauts Centre (EAC) near Cologne, in Germany

Early deliveries

DMS-R Data Management System for the Russian Service Module
The DMS-R Qualification Review was successfully concluded at the end of September, with the flight-unit Acceptance Review for the first flight-unit Fault-Tolerant Computer (FTC) deliveries in early October. The first two FTCs were delivered to RSA/RSC-Energia on 11 and 27 October, respectively. It is worth mentioning that this first DMS-R flight hardware, fully compliant with the technical specifications, was delivered on schedule and within its financial envelope. The remaining flight units were delivered in December.

The technical definition of the DMS-R long-term engineering support to be provided by European industry to the Russian Service Module contractor has been discussed and agreed with RSC-Energia. This definition will be used as an input to the planned barter negotiations between ESA and RSA, due to be finalised in early 1998.

In the meantime, an interim agreement has been endorsed by ESA and RSA to initiate urgent DMS-R work in Europe in exchange for urgent work to be performed by RSC-Energia for the integration of the Automated Transfer Vehicle (ATV) with the Russian Segment.

European Robotic Arm (ERA)
A revised date of July 1999 for the delivery of the ERA flight model to Russia has been agreed with RSA. This date is one year before the scheduled launch of ERA on the Science and Power Platform (SPP), thereby allowing sufficient time for integration of the ERA on the SPP in Russia and the subsequent processing of the SPP at the NASA launch site.

A revised industrial schedule, compatible with the new launch date, has been derived by the Prime Contractor and a significant effort is underway to bring subcontractor work in-line with the revised schedule.

The Electrical Interface Model has been shipped, this being the first substantial ERA delivery to Russia. It will allow RSC-Energia to verify the electrical interface between ERA and the Russian Segment.

The next major deliveries - the Geometric Model (GEO) and the Weightless Environmental Model (WET) - remain scheduled for December 1997/January 1998. They are to include the changes required by the new launch configuration.

Laboratory Support Equipment (LSE)
The Preliminary Design Reviews (PDRs) for the Early Deliveries, the MELFI and the Material Science Glovebox (MSG), were successfully completed in October and preparations for their Critical Design Reviews (CDR) are in progress. The initial Phase-C/D proposal for the Hexapod was unacceptable both technically and financially and the subsequent updated proposal has been received and is currently being evaluated.

The Phase-B final presentation for the Coarse Pointing Device (CPD) took place at the end of October and negotiations on the start of Phase-C/D are ongoing. The ITT for the European Drawer Rack (EDR) has been prepared and is ready for release. The procurement proposal for the Technology Exposure Facilities (TEF) has been submitted to the Adjudication Committee.

Development of the Standard Payload Outfitting Equipment (SPOE) for SPLC, RPDA and AAA is in progress.

Microgravity

EMIR-1 and EMIR-2
The launch of the Russian Foton-11 recoverable capsule, carrying the ESA microgravity payloads Biobox-3 and Biopan-2 and three Autonomous Experiments, took place successfully on 9 October. The Biobox carried experiments to measure the effects of microgravity on skin and bone cell development. The three Autonomous Experiments were designed to investigate the impact of the same effects on the biological clocks of beetles, algae and fruit flies. The Biopan was dedicated to experiments in the fields of exobiology, radiobiology and material science, to study the effects of microgravity, cosmic and ultraviolet radiation, vacuum and extreme temperatures. The investigators included scientists from Belgium, France, Germany, The Netherlands, Spain and Russia.

Foton-11 landed in Kazakhstan on 23 October. The ESA payload was retrieved and transported to ESTEC, where the experiments were handed-over to the respective scientists. Eleven of the 12 ESA experiments on board had worked nominally but, due to an electrical fault, one experiment in Biobox had not been activated .

Preparations for the three sounding-rocket flights Maser Technology, Mini-Texus-5 and Maser-8 continue, with launches foreseen in the first quarter of 1998.

The ESA-developed experiments for Neurolab (EDEN) have been installed in the Neurolab Spacelab. Final testing is proceeding and the launch is planned for April 1998. This will be the last flight of a Spacelab module and will bring the Spacelab Utilisation era to a close after approximately 15 years of activities. NASA has introduced "gap filler missions" to cover the period between the end of the Spacelab missions and the operation of the International Space Station. For the first of these missions, STS-95, scheduled late in 1998, ESA's Micro-gravity Programme will participate with a significant payload contribution which includes experiments relating to metallurgy and crystal growth (Advanced Gradient Heating Facility (AGHF) and Morphological Transitions in a Model Substance (MOMO)), crystal growth of proteins (Advanced Protein Crystallisation Facility (APCF)), microgravity effects on cells (Biobox), and adsorption and surface-tension studies (Facility for Adsorption and Surface Tension (FAST)).

Studies on a number of instruments for the early utilisation of the International Space Station have been completed and some equipment development has started. These instruments include an Advanced Respiratory Monitoring System (ARMS), a Muscle Atrophy Research and *examinée et arrêtée sur le plan technique avec RKK Energia. Elle servira de base de négociation pour l'accord de compensation prévu entre l'ESA et la RKA, qui doit normalement être finalisé début 1998.*

Dans l'intervalle, un accord intérimaire a été approuvé par l'ESA et la RKA afin de lancer des activités urgentes sur le DMS-R en Europe en échange des tâches également urgentes que doit exécuter RKK Energia pour intégrer le véhicule de transfert automatique (ATV) sur la composante russe.

Bras télémanipulateur européen (ERA)
Il a été convenu avec la RKA que la date de livraison du modèle de vol de l'ERA à la Russie était désormais fixée à juillet 1999, soit un an avant le lancement prévu de l'ERA sur la plate-forme 'Science et énergie' (SPP), ce qui laissera suffisamment de temps pour l'intégration de l'ERA sur la SPP en Russie et pour les interventions ultérieures sur la SPP au site de lancement de la NASA.

Un calendrier révisé des activités industrielles, compatible avec la nouvelle date de lancement, a été établi par le maître d'oeuvre et d'importants efforts sont en cours pour faire coïncider les travaux des sous-traitants avec ce nouveau calendrier.

Le modèle d'interface électrique a été expédié et constitue la première fourniture importante à la Russie dans le cadre de l'ERA. Il permettra à RKK Energia de vérifier les interfaces électriques entre l'ERA et la composante russe.

Les prochaines livraisons importantes, qui seront le modèle géométrique (GEO) et le modèle d'ambiance en impesanteur (WET), restent prévues pour décembre 1997/janvier 1998. Elles devront inclure les modifications qu'impose la nouvelle configuration de lancement.

Equipements de soutien de laboratoire (LSE)
Les revues préliminaires de conception (PDR) des éléments à livrer à court terme que sont le MELFI et la boîte à gants de recherche en microgravité ont été conduites avec succès en octobre et les préparatifs des revues critiques de conception (CDR) de ces éléments sont en cours. La proposition initiale de phase C/D relative à l'Hexapod ayant été jugée inacceptable sur les plans technique et financier, une nouvelle proposition actualisée a été reçue et est en cours d'évaluation.

La présentation finale de la phase B du dispositif de prépointage (CPD) s'est déroulée fin octobre et des négociations ont lieu actuellement au sujet du lancement de la phase C/D. L'appel d'offres pour le bâti à tiroirs européen (EDR) est maintenant prêt à être lancé. La proposition d'approvisionnement relative aux installations d'exposition au milieu spatial pour recherches technologiques (TEF) a été soumise au Comité d'adjudication.

Les équipements complémentaires des charges utiles standard (SPOE) sont en cours de développement pour le SPLC, le RPDA et l'AAA.

Microgravité

EMIR-1 et EMIR-2
La capsule récupérable russe Photon-11 a été lancée le 9 octobre avec à son bord les charges utiles de recherche en microgravité Biobox-3 et Biopan-2 et trois expériences autonomes de l'ESA. Biobox emporte des expériences visant à mesurer les effets de la microgravité sur le développement des cellules de la peau et des os. Les trois expériences autonomes sont conçues pour étudier les incidences de la microgravité sur les horloges biologiques de coléoptères, d'algues et de mouches des fruits. Biopan emporte des expériences dans les domaines de l'exobiologie, de la radiobiologie et des sciences des matériaux et vise à étudier les effets de la microgravité, du rayonnement cosmique et ultraviolet, du vide et des températures extrêmes. Les chercheurs proviennent de Belgique, de France, d'Allemagne, des Pays-Bas, d'Espagne et de Russie.

Photon-11 a atterri au Kazakhstan le 23 octobre. La charge utile de l'ESA a été récupérée et transportée à l'ESTEC, où les expériences ont été remises à chaque responsable. Sur les douze expériences de l'ESA, onze se sont déroulées normalement et une (sur Biobox) n'a pas pu être réalisée en raison d'une défaillance électrique.

Les préparatifs des trois fusées-sondes Maser Technology, Mini-Texus-5 et Maser-8 se poursuivent, les vols étant prévus au premier trimestre 1998.

Les expériences réalisées par l'ESA pour Neurolab (EDEN) ont été installées dans le Neurolab du Spacelab. Les derniers essais sont en cours et le lancement est prévu en avril 1998. Ce sera le dernier vol d'un module du Spacelab, dont l'utilisation s'achève après une quinzaine d'années d'activités. La NASA a mis en place une série de missions qui feront la jonction entre la fin des missions Spacelab et la mise en service de la Station spatiale internationale. Le programme de recherche en microgravité de l'ESA participera à la première de ces missions, STS-95, prévue fin 1998, et contribuera de manière significative à la charge utile avec des expériences de métallurgie et de croissance des cristaux dans un four à gradient (AGHF) et de transition morphologique sur des substances modèles (MOMO), des expériences de croissance des cristaux de protéines (APCF), des expériences sur les effets de la microgravité sur les cellules (Biobox) et des études sur l'adsorption et la tension de surface (FAST).

Les études d'un certain nombre d'instruments conçus pour la phase d'utilisation initiale de la Station spatiale internationale sont terminées et la mise au point de certains équipements a commencé. Parmi ces instruments figurent un système de surveillance respiratoire de pointe (ARMS), un système de recherche et d'exercice en atrophie musculaire (MARES), le dynamomètre à poignée et à pince (HGD/PFD), le système d'exposition d'échantillons biologiques au milieu spatial (SEBA), l'installation de diagnostic pour la cristallisation des protéines (PCDF) et le système de culture modulaire (MCS).

Installations de recherche en microgravité pour Columbus (MFC)
L'ESA a reçu fin septembre 1997 la proposition industrielle de phase C/D relative à Biolab, les négociations ont été menées à bien et le contrat a été signé à l'ESTEC le 5 décembre.

Le contrat de phase B du Laboratoire de sciences des fluides a été conclu et la demande de prix relative à la phase C/D envoyée fin décembre. Le contrat de phase C/D sera lancé en avril 1998.

L'ESA est parvenue à un accord préliminaire d'embarquement du

Exercise System (MARES), the Hand-Grip and Pinch-Force Dynamometers (HGD/PFD), the Space Exposure Biological Assembly (SEBA), the Protein Crystallisation Diagnostics Facility (PCDF) and the Modular Cultivation System (MCS).

Microgravity Facilities for Columbus (MFC)

The Biolab Phase-C/D industrial proposal was received at the end of September and, following successful negotiations, the contract was signed at ESTEC on 5 December.

The Fluid Science Laboratory's Phase-B has been concluded and the Request for Quotation (RFQ) for its Phase-C/D was issued at the end of December. The Phase-C/D contract will be initiated in April 1998.

A preliminary agreement has been reached to fly the Material Science Laboratory (MSL) in the US Lab, with a planned launch date of September 2001. The industrial Phase-B for MSL, scheduled for completion in March 1998, is progressing, with the breadboarding tests nearly complete. The Phase-C/D is planned to start by mid-1998.

Two parallel Phase-A studies for the European Physiology Modules (EPM) facility, each lasting eight months, were initiated in November.

Ariane-5

The Ariane-502 launcher preparation campaign continued at the Guiana Space Centre in parallel with the numerous qualification activities in Europe, culminating in the successful launch on 30 October, as reported in the previous issue of ESA Bulletin.

A major milestone had been achieved in early September with the launcher countdown rehearsal, involving the filling of the main stage with liquid hydrogen and liquid oxygen on the launch pad and performing actual countdowns up to H0 minus 3 seconds. Integration of the upper stage (the Maqsat H&B and Teamsat payloads, Speltra structure and fairing) then followed in the Final Assembly Building, leading to the filling of the upper stage and the attitude-control system during the second half of October.

Qualification work was still continuing in parallel in Europe in several areas, including:
- combined rupture tests on the mechanical structure of the vehicle's upper part
- main-stage control loop
- validation of the last modifications on the flight programme.

The first phase of flight-data analysis (level zero) after the successful 30 October launch showed that:

- the two solid boosters behaved highly symmetrically throughout their flight, and propulsion of the Vulcain and Aestus engines was also nominal
- the navigation, guidance and control system was stable at all times, and demonstrated its ruggedness and its reactive capability, with no anomalies identified in any part of the flight programme
- the analysis does, however, show some non-conformances, which can be traced back to a single source, namely a higher than expected roll torque in the Vulcain engine; the flight programme correctly diagnosed and counteracted this torque using the vehicle's attitude-control system; this roll movement induced a slightly early shutdown of the Vulcain engine, and a loss in orbital velocity of 210 m/s.

A group of experts is currently investigating the cause of this roll torque.

On 25 November, ESA handed the ELA-3 Ariane-5 launch complex at the Guiana Space Centre over to Arianespace for operational exploitation, following the qualification of the facilities during the first two Ariane-5 launch campaigns. This facility represents an investment of over 800 million ECU and is by far the largest installation built by ESA as part of the Ariane-5 Development Programme. CNES was responsible for its design, construction and operation during cryogenic main stage testing and the first two qualification flights, in its capacity as prime contractor for the development of the Ariane-5 launcher and launch facilities.

Preparations for the hand-over of ELA-3 management responsibility to Arianespace had been under way for some years, with the progressive integration of Arianespace engineers and technicians into the CNES teams, to ensure that personnel training was properly completed following the first two Ariane-5 qualification flights.

Future launchers

Continuation of FESTIP, the Future European Space Transportation Investigation Programme, was approved in September, and the associated programme of work has therefore been resumed.

In-Orbit Technology Demonstration Programme

STOF (Slosh Test Orbital Facility)

Industry is continuing to work on post-Critical Design Review (CDR) issues, before Phase-D can start. ESA expects to conclude the CDR early next year. A study has been started to assess how the ESA-developed Advanced Crew Terminal can be used to gather and store experiment data from Sloshsat experiments. NASA experts are currently studying any implications for Shuttle operations. Hardware is currently being manufactured and critical components like the Marmon clamp band and pyrotechnic separation bolts have been ordered. ESA and Verhaert are currently working on an update to the Fracture Control Plan, which is required to conclude the CDR.

TPX-II (Two-Phase Flow Experiment II)

A problem occurred during assembly and component acceptance testing, with a failure of the capillary wick of the evaporator. Recovery actions involving a local redesign were immediately started and have already shown good results. Due, however, to the already very tight schedule, caused mainly by the different interpretations of Shuttle safety requirements and the additional design and analysis activities incurred, NASA has been informed that the planned early-January delivery date cannot be met. A new launch date has not yet been identified, but the current planning foresees having the TPX-II experiment ready for delivery to NASA by May/June 1998. esa

Laboratoire de sciences des matériaux (MSL) à bord du laboratoire américain, le lancement étant prévu en septembre 2001.

Les travaux industriels de phase B relatifs au MSL, qui devraient s'achever en mars 1998, progressent et les essais du montage table sont presque terminés. La phase C/D devrait commencer d'ici la mi-1998.

Deux études parallèles de phase A ont été lancées en novembre au sujet des modules de physiologie européens (EPM) et devraient durer chacune huit mois.

Ariane-5

La campagne de préparation du vol Ariane-502 s'est poursuivie au Centre spatial guyanais parallèlement aux nombreuses activités de qualification menées en Europe et le vol a eu lieu avec succès le 30 octobre (voir numéro précédent du Bulletin).

Une étape essentielle avait été franchie début septembre lors de la répétition de la chronologie de lancement: l'étage principal avait été rempli d'hydrogène et d'oxygène liquides sur le pas de tir et l'on avait procédé à des simulations en conditions réelles des chronologies jusqu'à H0-3s. L'étage supérieur (charges utiles Maqsat H&B et Teamsat, structure Speltra, coiffe) a ensuite été intégré dans le Bâtiment d'assemblage final. Le remplissage de l'étage supérieur et du système de contrôle d'attitude a eu lieu pendant la deuxième quinzaine d'octobre.

Les travaux de qualification se sont poursuivis parallèlement en Europe dans divers domaines, notamment:

- *essais à rupture combinés, au niveau de la structure mécanique de la partie supérieure du lanceur,*
- *circuit de pilotage de l'étage principal,*
- *validation des dernières modifications apportées au programme de vol.*

La première phase d'analyse des données de vol (niveau zéro), après la réussite du vol du 30 octobre, a montré ce qui suit:

- *Les deux moteurs à propergol solide ont fourni une poussée très symétrique du début à la fin de leur vol et les moteurs Vulcain et Aestus ont fourni une propulsion nominale.*
- *Le système de navigation, guidage et pilotage a fait la preuve de sa stabilité, de sa robustesse et de ses capacités de réaction, et aucune anomalie n'a été décelée sur l'ensemble du programme de vol.*
- *L'analyse fait toutefois apparaître quelques anomalies toutes attribuées à la même origine : l'apparition sur le moteur Vulcain d'un couple de roulis supérieur aux prévisions. Le programme de vol a correctement assuré le diagnostic et la correction de ce couple par l'intermédiaire du système de contrôle d'attitude du lanceur. Ce mouvement de roulis a entraîné l'arrêt légèrement prématuré du moteur Vulcain et une perte de vitesse de 210 m/s lors de la satellisation.*

Un groupe d'experts étudie la cause de ce roulis.

Le 25 novembre, l'ESA a remis à Arianespace l'ensemble de lancement ELA-3 conçu pour Ariane-5, et dont la qualification a été réalisée lors des deux premières campagnes de lancements d'Ariane-5, pour qu'Arianespace en assure désormais l'exploitation opérationnelle. Ce complexe, qui représente un investissement de plus de 800 millions d'ECU, est de loin la plus grande installation réalisée par l'ESA dans le cadre du programme de développement Ariane-5. Le CNES a assuré sa conception, sa construction et son exploitation au cours des essais de l'étage principal cryotechnique et des deux premiers vols de qualification, en sa qualité de maître d'œuvre chargé du développement d'Ariane-5 et des moyens de lancement associés.

Le transfert des responsabilités de gestion de l'ELA-3 à Arianespace était préparé depuis quelques années, avec l'intégration progressive des ingénieurs et des techniciens d'Arianespace dans les équipes du CNES, de manière à assurer la formation adéquate du personnel à l'issue des deux premiers vols de qualification d'Ariane-5.

Futurs lanceurs

La poursuite du FESTIP, le programme européen de recherche appliquée sur les futurs systèmes de transport spatial, a été approuvée en septembre et le programme de travail a repris.

Programme de démonstration technologique en orbite

STOF (Installation orbitale d'essais de ballottement)

L'industrie poursuit les travaux sur les questions soulevées par la revue critique de conception (CDR), avant de pouvoir engager les travaux de phase D. L'ESA espère clore la CDR au début de l'année prochaine. Une étude a été lancée pour déterminer comment utiliser le terminal de pointe pour l'équipage mis au point par l'ESA pour recueillir et stocker les données d'expériences de Sloshsat. Les experts de la NASA étudient actuellement toutes incidences éventuelles sur les activités de la Navette. Le matériel est en fabrication et les composants critiques, comme la bride de serrage Marmon et les boulons de séparation pyrotechnique, ont été commandés. L'ESA et Verhaert travaillent à une mise à jour du plan de contrôle de fracture, nécessaire pour pouvoir clore la CDR.

TPX-II (Expérience d'écoulement diphasique II)

Un problème est survenu lors de l'assemblage et des essais de recette des composants, à savoir une défaillance au niveau de la mèche capillaire de l'évaporateur. Les mesures prises immédiatement, qui incluent une revue partielle de la conception, donnent déjà de bons résultats. Le calendrier étant toutefois très serré, en raison des problèmes d'interprétation des impératifs de sécurité de la Navette et des travaux de conception et d'analyse supplémentaires occasionnés à ce sujet, la NASA a été informée que la date de livraison prévue début janvier ne pourrait pas être respectée. Une nouvelle date de lancement n'a pas encore été fixée à ce jour. La TPX-II devrait pouvoir être livrée à la NASA d'ici mai ou juin 1998. esa

The Hipparcos and Tycho Catalogues

The Mission Products

The principal parts of the Hipparcos Catalogue are provided in both printed and machine-readable form. Tycho Catalogue results are provided in machine-readable form only. The printed volumes include a description of the Hipparcos and Tycho Catalogues and associated annexes, a description of the satellite operational phase, a description of the corresponding data analysis tasks, and the final data.

Machine-readable versions of the catalogues are provided in two forms: the definitive mission products are released as a set of ASCII files on a series of CD-ROMs, which contain all of the printed catalogue information as well as some additional data. Auxiliary files containing results from intermediate stages of the data processing, of relevance for the more-specialised user, are also included.

A distinct single CD-ROM product, Celestia 2000, contains the principal astrometric and photometric data, in compressed form, along with specific interrogation software developed for specific platforms.

The Hipparcos Mission

The Hipparcos space astrometry mission was accepted within the European Space Agency's scientific programme in 1980. The Hipparcos satellite was designed and constructed under ESA responsibility by a European industrial consortium led by Matra Marconi Space (France) and Alenia Spazio (Italy), and launched by Ariane-4 on 8 August 1989. High-quality scientific data were acquired between November 1989 and March 1993. The scientific aspects of the mission were undertaken by nationally-funded scientific institutes. All of the scientific goals motivating the mission's adoption in 1980 were surpassed, in terms of astrometric accuracy, photometry, and numbers of stars.

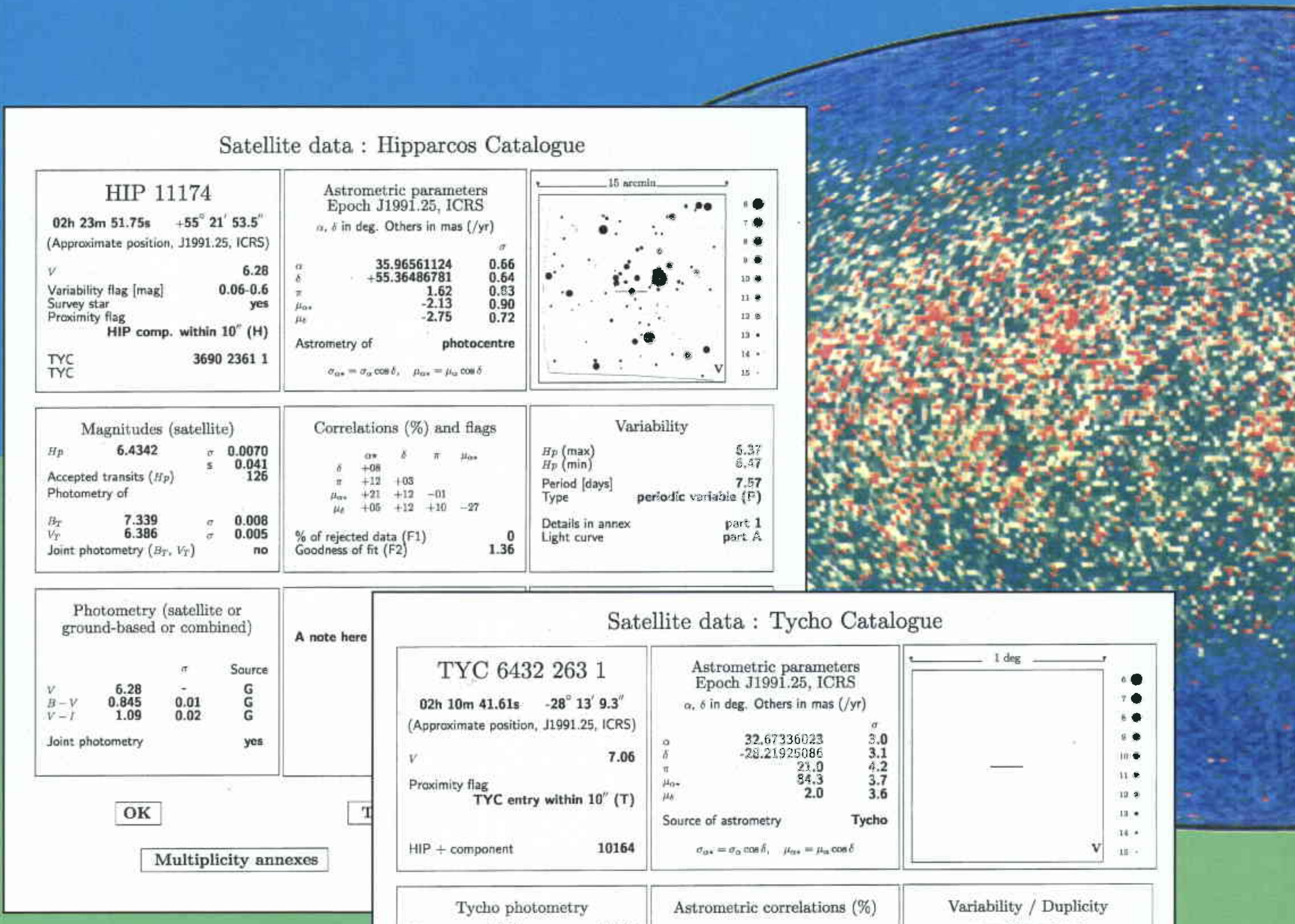
The global data analysis tasks, proceeding from nearly 1000 Gbit of satellite data to the final catalogues, were undertaken by three scientific consortia: the NDAC and FAST Consortia, together responsible for the production of the Hipparcos Catalogue; and the Tycho Consortium, responsible for the production of the Tycho Catalogue. A fourth scientific consortium, the INCA Consortium, was responsible for the construction of the Hipparcos observing programme. The production of the Hipparcos and Tycho Catalogues marks the formal end of the involvement in the mission by ESA and the four scientific consortia.

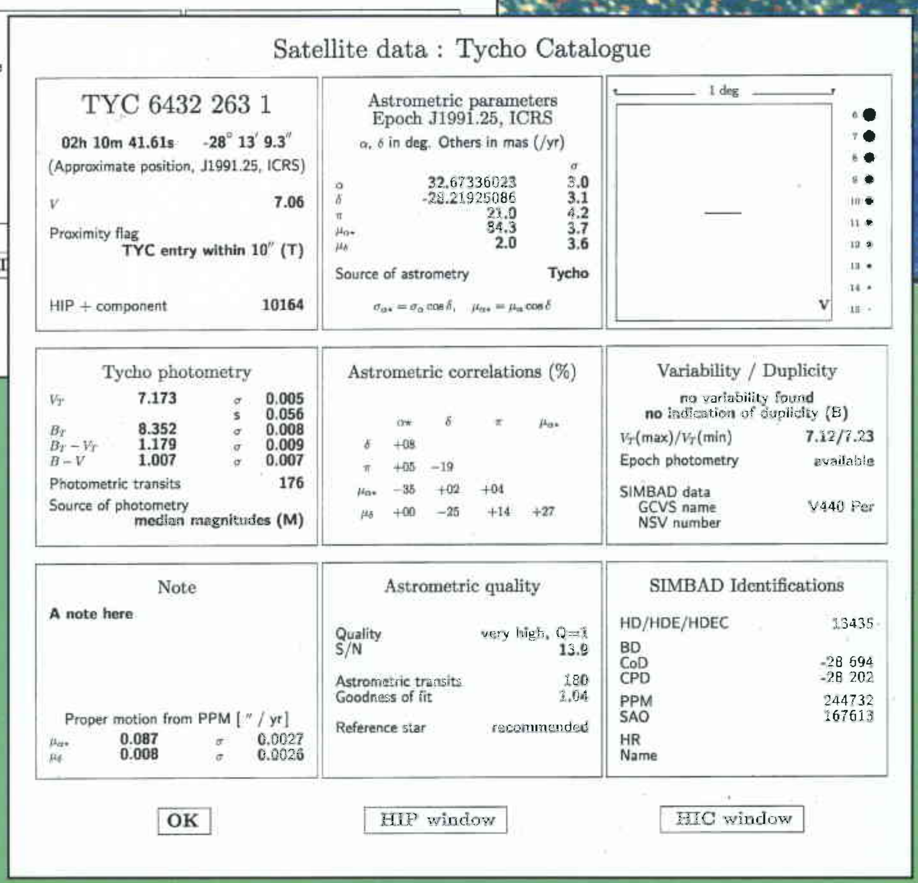
The Hipparcos and Tycho Catalogues

The final products of the European Space Agency's Hipparcos mission are two major stellar catalogues, the Hipparcos Catalogue and the Tycho Catalogue.

Each catalogue includes a large quantity of very high quality astrometric and photometric data. The astrometric data in the Hipparcos Catalogue is of unprecedented accuracy: positions at the catalogue epoch (J1991.25), annual proper motions, and trigonometric parallaxes, have a median accuracy of approximately 1 milliarcsec. The Hipparcos Catalogue includes annexes featuring variability and double/multiple star data for many thousands of stars discovered or measured by the satellite. The Hipparcos and Tycho Catalogues will remain the definitive astrometric stellar catalogues for many years.

Celestia 2000





Celestia 2000

Celestia 2000 is a CD-ROM package containing the Hipparcos and Tycho catalogues, plus related annexes, in compressed binary format, along with dedicated software permitting interrogation, sample construction and information display.

It has been designed and constructed with both the professional and amateur astronomer in mind.

The package is designed for IBM PC and compatibles running under Windows 3.1, Windows 95, or Windows NT.

Order Form

Final results from the ESA Hipparcos space astrometry mission are available in three formats:

— A 16–volume hard-bound printed catalogue, containing descriptions of the data reduction techniques, along with the Hipparcos Catalogue and related annexes, plus an ASCII version of the Hipparcos and Tycho Catalogues and annexes in a set of 6 CD-ROMs.

—A subset of the above consisting of Volume 1 (Introduction and Guide to the Data) and the ASCII CD-ROM set.

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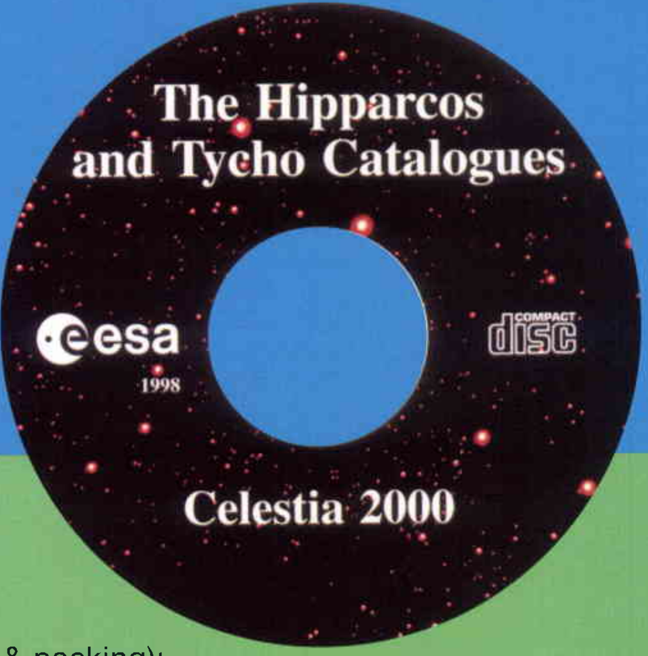

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In Brief

Ariane Launches a Further Seven Satellites

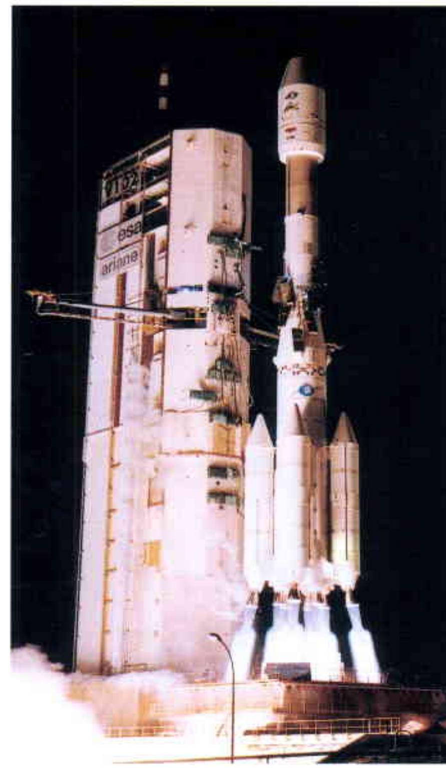
Ariane-4 launchers have successfully placed another seven satellites into geostationary transfer orbit.

Ariane V102 (44L version launcher) lifted off on 12 November 1997 (10:38 CET) carrying SIRUS-2 (Sweden) and CAKRAWARTA-1 (Indonesia).

Ariane V103 (44P version launcher) lifted off on 2 December 1997 (11:52 CET) carrying JCSAT-5 (Japan) and Equator-S (Germany).

Ariane V104 (42L version launcher) lifted off on 22 December 1997 (01:17 CET) carrying Intelsat 804.

Ariane V105 (44LP version launcher) lifted off on 4 February 1998 (00:29 CET) carrying Brasilsat B3 and Inmarsat 3F5.



International Space Station Nodes 'Made in Europe'

Mr Antonio Rodotà, ESA's Director General, and Mr Sergio de Julio, President of the Italian Space Agency (ASI) signed an Arrangement, on 12 December 1997 in Rome, concerning the management, execution and funding of the Nodes 2 and 3 for the International Space Station (ISS).

Under this Arrangement, ESA will entrust ASI with the development and manufacturing of the two Nodes, for which Alenia Aerospazio (I) is the prime contractor.

Mr Antonio Rodotà, ESA's Director General (left) and Mr Sergio de Julio, President of the Italian Space Agency (ASI) during the signing of the Arrangement concerning Nodes 2 and 3 for the International Space Station (ISS)

The Nodes constitute the interconnecting elements between various laboratory and habitation modules of the ISS. They also provide for crew and experiment support. Node 1 has already been developed and manufactured by US industry under NASA contract. Nodes 2 and 3 will be 'made in Europe' using European know-how and technology.

According to a Barter Agreement between ESA and NASA, signed on 8 October 1997 in Turin, ESA will provide the two Nodes, as well as additional high-technology laboratory equipment and services to NASA, while the US Space Shuttle will ferry the European Columbus laboratory module to the Space Station on a launch presently planned for October 2002. The launch of Node 2, the first European-built Node of the Station, is currently planned for April 2001.

The Arrangement between ESA and ASI allows Europe to take full advantage of the experience gained by Italian industry through the development of the Mini-Pressurised Logistics Module (MPLM) and the synergy between the MPLM, Nodes 2 and 3, and the European Columbus laboratory module. The MPLM, the two Nodes, and the Columbus laboratory all make use of the same structural concept.

Partners Sign International Space Station Agreements

Ministers, ambassadors and senior government officials of 11 ESA Member States* met with their counterparts from the United States, Russia, Japan and Canada in Washington D.C. on 29 January to sign agreements on the International Space Station.

A representative of each of the 15 countries participating in the Space Station signed the 1998 Intergovernmental Agreement on Space Station Cooperation which establishes the framework for cooperation among the partners for the design, development, operation and utilisation of the Space Station. It defines the rights and obligations of each of the countries and their jurisdiction and control with respect to their elements of the Space Station.

Antonio Rodotà, Director General of ESA, the European cooperating agency in the programme, together with Daniel Goldin, Administrator of NASA, the United States' cooperating agency, have also signed a Memorandum of Understanding. This accord supplements the Intergovernmental Agreement and defines the roles and responsibilities of each agency in the design, development, operation and utilisation of the Station for its planned 10-year operational lifetime.

ESA's Director General, Antonio Rodotà, addressing the participants in the Intergovernmental Agreement on Space Station Cooperation signing ceremony in Washington D.C. on 29 January 1998

The International Space Station will be the first international, permanently occupied outpost in space. It will serve as a versatile research institute that will orbit the Earth for at least 10 years and as an innovative centre for testing new technologies under space's unique conditions.The first element of the Space Station is currently scheduled to be launched in June of this year.

For more information on the International Space Station, you can visit:
http://www.estec.esa.int/spaceflight

*Belgium, Denmark, France, Germany, Italy, The Netherlands, Norway, Spain, Sweden, Switzerland, and the United Kingdom. esa

At the signing of separate bilateral Memoranda of Understanding with NASA are (left to right): Yuri Koptev, RKA; Antonio Rodotà, ESA; Daniel Goldin, NASA; William Evans, CSA; Isao Uchida, NASDA

ESA Astronaut Pedro Duque to Fly on Space Shuttle Mission

On 21 November 1997, ESA's Director General, Antonio Rodotà, and Spain's Minister of Industry and Energy, Josep Pique, announced that ESA astronaut Pedro Duque has been assigned to the Space Shuttle mission (STS-95) currently scheduled for October 1998. NASA Administrator Daniel Goldin confirmed the appointment during his recent talks with Mr Rodotà at ESA Headquarters in Paris.

Pedro Duque, 34 years of age, will be making his first spaceflight, thus becoming the first Spanish national to go into space. Duque, an aeronautical engineer, was an astronaut candidate proposed to ESA by the Spanish Ministry of Industry and Energy's Centre for the Development of Industrial Technology (CDTI) following a national selection in 1990/91. He was then recruited for the ESA astronaut corps in 1992.

Announcement on 21 November in Madrid of Pedro Duque's selection for STS-95: (left to right) Pedro Duque; Antonio Rodotà, ESA's Director General; Josep Pique, Spain's Minister of Industry and Energy; and Pedro Ferraras, Vice Minister of Industry and Energy

In August 1993, he began training at Star City, Russia, for the joint ESA-Russian Euromir 94 mission. During that 30 day flight (October/November 1994), he coordinated the interface between fellow ESA astronaut Ulf Merbold onboard the Russian space station Mir and the scientific investigators and project management on the ground.

In May 1995, NASA selected Duque as an alternate Payload Specialist astronaut for the Space Shuttle's STS-78/ Life and Microgravity Spacelab (LMS) mission. During that flight (June-July 1996), he acted as the interface between the crew onboard the Shuttle and the researchers on the ground. He will be a Mission Specialist on STS-95.

Duque, who is based at the European Astronaut Centre in Cologne, Germany, is currently in NASA's Mission Specialist Class at the Johnson Space Center in Houston, Texas.

The 10-day mission will be dedicated to research in near-weightlessness. ESA plans to have a significant payload on board this mission: five facilities for scientific investigations. Two of those facilities, one for materials science experiments and another used to grow protein crystals, were previously on board the STS-78/LMS flight for which Duque trained. ESA's three other research facilities will be used to investigate the effects of near-weightlessness on cell cultures, the solidification process in metals, and adsorption and surface tension phenomena.

ESA/Russia Cooperation Strengthened

Further steps towards closer cooperation between ESA and Russia were taken during the visit of ESA's Director General, Mr A. Rodotà to the Russian Space Agency (RKA) on 18-19 November 1997. Discussions centred around satellite navigation and the International Space Station. Two important agreements were also formalised.

On the morning of 18 November, Mr Rodotà and Mr G.E. Mamedov, Vice-Minister for Foreign Affairs of the Russian Federation, signed an additional customs clearance agreement providing for a larger band of special exemptions.

Signature of this agreement will immediately benefit the transfer of equipment already underway in the course of cooperation on the European Robotic Arm and the DMS-R (Data Management System for Russia) computers, the flight models of which were recently delivered to RSC Energia. These computers are to become the data-processing core of the Russian segment of the International Space Station: the service module where the crew will work and sleep during the Station assembly phase. This ESA project is being handled by the Agency's Directorate for Manned Spaceflight and Microgravity, working with teams from RKA.

The agreement will also facilitate the loan of equipment for research and experimental purposes and remove some significant obstacles to cooperation.

On the same day, Mr Rodotà and his Russian counterpart, Mr Yuri Koptev signed an agreement for a Russian Proton launcher to lift ESA's Integral satellite into space in 2001. This agreement assures a place for Russian astronomers in Integral's science team supervising the instrumental and astronomical aspects of the mission, and ends five years of study and negotiation which began when scientists and engineers were first defining Integral.

Hipparcos Pinpoints an Amazing Gamma-ray Clock

The position in the sky of the "silent" neutron star Geminga is now known to within about 10 millionths of a degree (0.04 arc-second) thanks to results from ESA's Hipparcos star-fixing satellite, according to a recent paper by Patrizia Caraveo (Milan) and colleagues.

Geminga is a unique object: a highly compressed, spinning neutron star which does not emit radio beeps like the well-known pulsars. Yet it is a powerful source of pulsating gamma-rays and X-rays. Geminga is probably the prototype of millions of radio-silent neutron stars in the Milky Way Galaxy.

Geminga rotates like a lighthouse, flashing a beam of gamma-rays and X-rays towards the Earth 252 times a minute. The first detection of pulsations in Geminga's emissions came from the German-US-UK Rosat X-ray satellite in 1992. NASA's Compton gamma-ray observatory detected the same pulses in gamma-rays and observed them for several years up to 1996. Re-examination of the gamma-ray counts for Geminga from NASA's SAS-2 satellite (1972-73) and ESA's COS-B satellite (1975-82) led to the detection of the same pulses retrospectively. Astronomers then had the tantalising prospect of reconstructing, from sporadic periods of observations, every tick of Geminga's clock over a period of 24 years, 1972-1996.

Positioning Geminga accurately enough was the remaining hurdle. The gamma-ray clock seems to run fast or slow depending on the Earth's motion in orbit. Each year at the end of March, the Earth and any attendant gamma-ray satellites are travelling towards Geminga in the constellation Gemini at about 30 kilometre per second. Geminga's timekeeping speeds up by 9 seconds a day. Six months later, on the other side of the Sun, the Earth is receding at the same speed, and Geminga's pulses seem slower by the same amount. To correct for this seasonal effect required the more exact position of Geminga provided by Hipparcos data.

Motions in Earth orbit of the SAS-2, COS-B and Compton spacecraft at the times of the intermittent gamma-ray observations also had to be taken into account. The outcome is a coherent 24.2-year reconstruction of more than 3 billion rotations of Geminga.

Created by the collapse of the core of an exploding star about 300 000 years ago, Geminga has no renewable source of energy. Nevertheless, it is more luminous in its gamma-rays and X-rays than the Sun is by visible light. Interaction between the spinning neutron star and a surrounding magnetosphere of ionized gas powers the emissions by extracting energy from the rotation and slowing the star down. The new timings suggest that Geminga is like a watch that loses less than one microsecond a year. However, the rate of slowdown is increasing faster than expected by comparison with other young pulsars.

Another puzzle concerns a slight rhythmic change in the pulse-rate of Geminga, in a cycle of 5 years, seen most clearly in the recent Compton observations. While this could be a fluke due to errors in the rather sparse data, a physical explanation could be the presence of a planet with about twice the mass of the Earth orbiting around the neutron star every 5 years, and causing it to wobble.

Michael Perryman, ESA's project scientist for the Hipparcos mission, sees the multiplicity of instruments and wavelengths used in the Geminga study as an illustration of the overarching role of Hipparcos*:

"The results from Hipparcos provide a framework for every branch of astronomy and bring new precision to all of them," Perryman comments."Hipparcos never saw Geminga, because it is far too faint. Yet when used to calibrate other observations in visible light, the Hipparcos and Tycho Catalogues** give a position for Geminga far more accurate than could ever be expected from the X-ray and gamma-ray observations alone. Similarly Hipparcos relates the entire Universe seen by radio and infrared telescopes to the local frame of bright stars."

The story will broaden into a hunt for other silent neutron stars like Geminga, using ESA's super-sensitive X-ray astronomy satellite XMM, due to be launched in 1999. Two years later XMM will be followed into orbit by Integral, ESA's successor to COS-B as a gamma-ray astronomy satellite of vastly enhanced performance.

Giovanni Bignami, Director for Science at the Agenzia Spatiale Italiana (ASI) in Rome, named Geminga in 1976 and has hunted it, along with his colleagues in Milan, for more than 20 years. (In the Milanese argot, 'ghèminga' means 'it's not there' and referred to Geminga's invisibility at radio wavelengths.)

"Geminga is a shining example of how multinational collaboration in astronomy pays off," Bignami says. "We in Europe have done very well out of ESA in space astronomy, and also in our collaborations in ground observatories. We have world-class facilities that none of our home countries could offer us on their own. While governments ponder ESA's future role in science they should sense the surge of excitement throughout Europe, as astronomers beat all expectations in using the superb opportunities that come from ESA membership."

* More information on Hipparcos can be found on the Web at
http://astro.estec.esa.nl/Hipparcos

** The Hipparcos and Tycho Catalogues (ESA SP-1200) are available from:
ESA Publications Division
fax +31 (0)71 565-5433 or
e-mail: fdezwaan@estec.esa.nl

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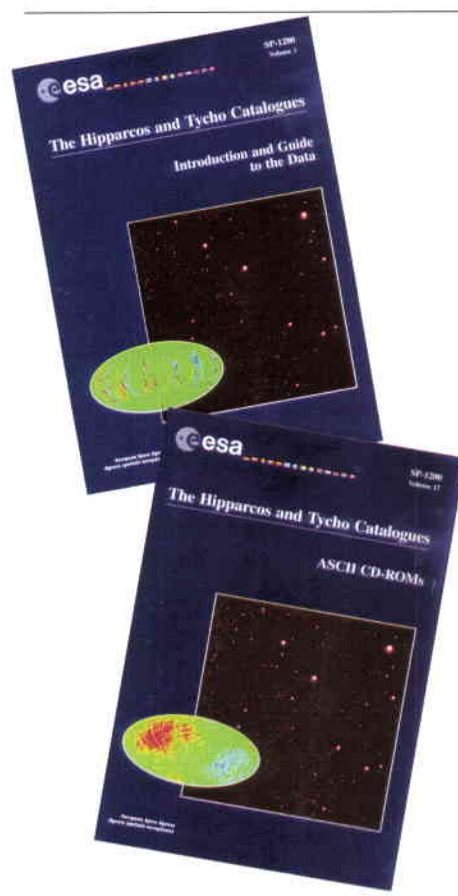


ESOC Rescues NASDA Mission

ESA and the National Space Development Agency of Japan (NASDA) have a long history of cooperation in the field of ESA ground station support to Japanese missions. ETS 7 (Engineering Test Satellite 7) is the latest Japanese mission supported by the ESA network following its launch from the Tanegashima Space Centre by an H-II rocket on 27 November 1997.

The ETS 7 mission is aimed at preparing Japan for its role in the International Space Station. It will provide experience of the supply of goods and fuel to in-orbit spacecraft, and the assembly of structures in space. It also includes rendez-vous and docking technology and space robotics, which are especially relevant to unmanned missions.

ETS 7 comprises two satellites which were attached to each other during the Launch and Early Orbit Phase (LEOP) operations and separated after the commissioning phase for rendez-vous and docking experiments.

On 29 November, ETS 7 lost attitude and the solar panels were no longer oriented towards the Sun, preventing the batteries from being recharged. This would have meant the loss of the satellite within 6 hours.

At 24:00 GMT, NASDA called ESOC requesting emergency support from ESA's ground stations at Kourou (French Guiana) and Perth (Western Australia). At 01:50, the Kourou station was ready to support the upcoming pass. Earth-spacecraft contact was reestablished and shortly after the first acquisition of the spacecraft telemetry, NASDA could send the required commands to ETS 7 to acquire the correct attitude. At 04:39 GMT, the Japanese agency confirmed that the spacecraft was restabilised.

This particularly successful operation will be followed by an agreement between ESA and NASDA for the continuation of routine phase support of ETS 7 by the same two ESA stations into Spring 1998.

Telemedicine: from Sarajevo to Tirana

The partners involved in the first European pilot project for telemedicine via satellite met on 17 November 1997 at the Celio Military Polyclinic in Rome to take stock of the first results of a joint effort which has put hospitals in Italy and Bosnia in close contact with each other thanks to space applications.

In September 1996, with ESA's help, an innovative telemedicine network was activated to provide medical care services from two Italian hospitals (San Raffaele Hospital in Milan and the Celio Military Polyclinic in Rome) to the Italian Field Hospital involved in the peacekeeping mission in Sarajevo. Further support was given to the health care structure of the University Clinical Centre of Sarajevo.

The initiative, dubbed SHARED (Satellite Health Access for Remote Environment Demonstrator), exploited dedicated ground stations and satellite links to conduct medical consultations, online surgery mentoring and medical training between the three hospitals.

After a year of successful operation, the network, which uses ground terminals and satellite capacity provided by ESA, is now being extended to include the Hospital 'IDI' in Tirana, Albania.

Session of ophthalmic surgeon-training between Milan and Sarajevo

Based on an enhanced version of the DICE multi-point video conferencing system developed by European industry for ESA, the telemedicine satellite network combines video conferencing with real-time exchange between multimedia computers and medical peripherals of images such as X-rays, scans, pathology samples, etc. An additional feature is provided by an ISDN multi-point conference unit acting as a bridge between the satellite network and other hospitals connected to the terrestrial ISDN network.

The links between the hospitals are supported by up to four digital carriers of 384 kbit/s using capacity leased by ESA on the Eutelsat II-F4 satellite.

"We are very proud of having contributed to such a humanitarian project that helps bring space within closer reach of human beings in their everyday life" said ESA's Director General, Antonio Rodotà, at the presentation.

The SHARED project stems from cooperation between ESA (provider of the communication infrastructure), the Italian Space Agency (which funded the pilot projects, through ESA's ARTES programme), the Italian Ministry of Defence (responsible for system operations) and TelBios (a consortium involving the San Raffaele Hospital and Alenia Aerospazio which proposed and coordinated the project).

ESA and NASA Exchange Views on Future Cooperation

ESA's Director General, Antonio Rodotà and NASA's Administrator, Daniel Goldin, met at ESA Headquarters in Paris on 11 November 1997 to take stock of their ongoing collaborative ventures, to exchange views on the future of their respective agencies and to discuss further cooperation.

During their discussions, Mr Rodotà and Mr Goldin confirmed their commitment to closer relations aimed at enhancing the already strong cooperation between the two agencies.

The Director General outlined the strategic evolution underway which, in partnership with all of the Agency's Member States, will reinforce the development of space applications such as telecommunications, satellite navigation, Earth observation and Earth sciences. To this end, ESA will make every effort to bring together, in a coherent and balanced way, all the potential of its Member States in terms of knowledge, expertise and resources so that Europe can become a stronger player in the applications field and an even stronger partner in international cooperation.

Further discussions included potential international cooperation on the exploration of Mars and the need for coordination of the various missions envisaged, in order to avoid duplication of effort. ESA has introduced the Mars Express mission into its recently restructured long-term science programme. This mission consists of an orbiter carrying a scientific payload and up to four mini-lander modules. The management plan for the mission was approved in November 1997 by ESA's Science Programme Committee. The mission itself is expected to be approved in November 1988 for launch in May/June 2003. A number of ESA Member States and NASA have expressed interest in supplying the landers and other elements of the mission.

Regarding the International Space Station (ISS), for which ESA/NASA cooperation is already well established, both Directors agreed it was vital to bring all partners together to establish ground rules on Station utilisation. They evaluated the joint efforts needed to make all potential users fully aware of the availability of the unique habitat for microgravity experiments, science, Earth observation and technology development.

ESA is a key partner in the ISS programme. Its major contributions consist of the Columbus Orbital Facility (COF), a multi-purpose scientific and technological laboratory module permanently attached to the core of the Space Station, and the Automated Transfer Vehicle (ATF), a cargo vessel to be launched by Ariane-5 for re-supply missions. ESA will also be present in 16 of the 47 assembly flights needed to build the station over the period 1998-2003 with equipment contributing to this international endeavour. esa

Industrial Briefing

'Call for Outline Mission Proposals for Earth Watch Partnership'

The high interest of European industry in the new manner of working with ESA to serve Earth Observation user markets was reflected by the more than 100 representatives of European industry attending an ESA Industrial Briefing at ESTEC on 18 December 1997. The participants covered the range from small and medium size enterprises — particularly the Earth Observation data value-adding industry — to large aerospace companies.

The major objectives of the meeting were two-fold: firstly to inform industry about ESA's Earth Observation strategy and of the planning for the future ESA E.O. programme, and secondly, to answer questions concerning the 'Call for Outline Mission Proposals for Earth Watch Partnership'. This Call, issued by ESA in early December 1997, is the first major step by the Agency towards market- and applications-oriented Earth Observation missions to be undertaken in a partnership between industry, ESA and other entities such as the European Commission. The responses by industry, invited for February 1998, will not only contribute to the preparation of major decisions concerning the future ESA E.O. programme, but will also form the basis for concrete Earth Watch missions to be implemented in the near future. esa

More than 100 representatives of European industry attended the ESA Industrial Briefing at ESTEC (NL)

Mercure Satellite Helps UNEP Link the World

On behalf of ESA's Director General and six of ESA's Member States, René Collette, ESA Director of Applications, formally handed over the Mercure satellite communications network to Prof. Reuben Olembo, Deputy Executive Director of the United Nations Environment Programme (UNEP) on 5 November 1997 in Geneva.

The ceremony took place in the presence of nearly 100 participants including delegates from the six contributing ESA Member States – Austria, Belgium, Norway, Spain, Switzerland, United Kingdom – as well as many UNO representatives and ambassadors from countries all over the world.

The satellite-based telecommunications network was donated to UNEP to help the United Nations' environmental effort fulfil its leadership role by providing the specialised agency with a global communications capability for the transfer and exchange of up-to-date, easily accessible environmental databases and archives of its many partners such as the Global Resource Information Database (GRID) and the Infoterra Global Environmental Information Exchange Network.

With its headquarters in Nairobi (Kenya) and offices scattered around the world, often in remote locations, UNEP can now depend on a reliable space-based system which will particularly benefit those countries that do not have sufficient telecommunications resources. UNEPnet (Internet) can now be accessed through the global Internet via the Mercure system which will support a new communication culture both within UNEP and to its many external partners. The Mercure network will cut costs since it also supports the transfer of facsimile, e-mail and video transmission.

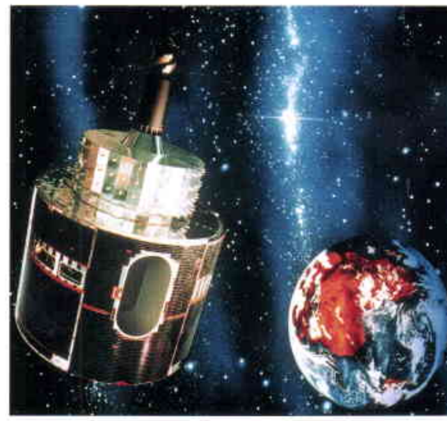
To cope with the implementation of the Mercure network, an international industrial team was set up by the six participating ESA Member States. As a follow-up to the United Nations Conference on Environment and Development held in Rio de Janeiro in 1992, the European Space Agency was asked to manage the participating countries' contributions (11.75 MUC at 1992 economic conditions) and to coordinate efforts between UNEP, the industrial team and the network operator, the Swiss Telecom PTT.

The traffic hubs of the Mercure network are at the UNEP Headquarters and at the UNEP Regional Office for Europe in Geneva. The UNEP Regional Offices and UNEP-GRID centres in the western and eastern hemispheres will be served by Intelsat satellites located over the Atlantic Ocean and the Indian Ocean, respectively.

Mercure satellite dishes and facilities have been installed in 16 countries (Kenya, Bolivia, Cuba, Khazakstan, Nepal, Bahrain, Mozambique, China, Thailand, Russian Federation, Costa Rica, Niger, Vietnam, Austria, Norway, Switzerland). Eleven other countries have already voiced their interest in hosting a station.

More information on the Mercure project is available at:
http://www.estec.esa.nl/mercure.

Mercure Governing Board meeting in Geneva



20 Years of Meteosat Achievement

On 24 Novermber 1997, a gathering took place of many of the scientists, engineers and managers (right) who took Meteosat from an idea – conceived through long European debates and development phases – into operation.

With the seventh Meteosat now in orbit, they were able to look back on almost three decades of hard work and achievement:

- Meteosat-1 launched in November 1977
- Meteosat-2 in June 1981
- Meteosat 3 in June 1988
- Meteosat 4 in March 1989
- Meteosat-5 in March 1991
- Meteosat 6 in November 1993
- Meteosat 7 in September 1997

Since the launch of the first Meteosat, 20 years of imagery and derived meteorological data have helped to significantly improve weather forecasting. Direct benefits have been derived in the areas of air and marine transportation, as well as the construction, energy, retail, agriculture and leisure industries. Lives have also been saved through warning and early evacuation of populations threatened by hurricanes or other severe weather events.

ESA, which developed the Meteosat programme, and EUMETSAT, which now operates it, jointly hosted the event to commemorate more than 20 years of European achievement and cooperation. A ceremony was held at EUMETSAT Headquarters, followed by a visit to ESA's Operations Centre, ESOC in Darmstadt, Germany.

Many of Meteosat's scientists, engineers and managers gathered to commemorate more than 20 years of European achievement and cooperation

Departure of René Collette

René Collette, Director of Application Programmes, will be leaving the Agency at the end of March 1998, after 34 years of outstanding service.

Dr. Collette joined ESRO in November 1964 as a Principal Engineer in the former Large Astronomical Satellite Division. In June 1969 he was appointed to the post of Head of the Systems Studies Division and in 1970 to the post of Telecommunications Project Manager.

With the establishment of ESA, he became the Head of the Communications Systems Department. In this function, he was responsible for the development of the Orbital Test Satellite (OTS), Europe's first experimental telecommunications satellite; for the deployment of the European Communication Satellite series leased to EUTELSAT; and for the MARECS satellites leased to INMARSAT. He also supervised the development of the Olympus satellite.

At its December 1989 meeting, the ESA Council appointed Dr. Collette to the post of Director of Telecommunications Programmes. During this time Artemis, with its novel optical communications capabilities, was developed, including a cooperative venture with Japan, and GNSS 1 and GNSS 2 were promoted in the field of navigation.

In April 1997, Dr. Collette was entrusted with managing the new Directorate of Applications. He concentrated his most recent efforts on the consolidation of the METOP Programme.

René Collette has made a great and lasting contribution to ESA. He has always demonstrated a profound dedication to Europe and the Agency, its objectives and its Staff. His expertise and international experience have been recognised by his peers in all of the sectors for which he was responsible.

ESA 2000

The travelling 'ESA 2000' space science exhibition is coming to the end of its six months' tour of Berlin, Germany. The popular attraction has sparked public interest in the domains of science and culture.

The exhibition was first opened on 13 August 1997 at the Förster-Sternwarte by Dr F. Jansen, ESA consultant for the exhibition and astrophysicist at the Astrophysical Institute of Potsdam (D). His opening speech centred on ESA's space science satellites of the past, present and future. The exhibition was one of the main highlights during the institute's 50^{th} anniversary celebration which peaked on 22 October with visits by Ms I. Stahmer, Berlin Senator for Schools, Youth and Sport, and well-known figures from the areas of science, culture and politics.

On 5 November the exhibition opened at the most popular astronomical institution in Germany, the Archenhold-Sternwarte. The 101 year old Sternwarte welcomed Prof J. Ortner, Chairman of the Austrian Space Agency, to give the opening speech entitled, 'The Space Science Programme of ESA'. Additionally, the brochure 'ESA 2000' (BR-118) which contains many panel photos of Huygens, SOHO, ISO, HST and Ulysses and their results, was introduced to the public.

The Berlin-based exhibition will close following the 'Lange Nacht der Museen in Berlin' (Long night of Berlin museums) on 14 February. During the event, the city of Berlin provides shuttles for visitors to travel between all of its famous museums for the entire night. The Archenhold-Sternwarte, as part of ESA 2000 will host an astronaut food shop and provide telescopes for viewing the night skies.

During its stay in Berlin, ESA 2000 will have attracted approximately 40 000 visitors of all age groups. esa

Top right: The Archenhold-Sternwarte in Berlin, host of the ESA 2000 exhibition since November 1997.

Centre: Celebrating the success of ESA 2000 are (left to right): Prof. J. Ortner, Chairman of the Austrian Space Agency; F. Jansen, of the Astrophysical Institute of Potsdam; Prof. D.B. Hermann, Director of the Archenhold-Sternwarte and the Zeiss-Großplanetarium

Right: Part of the ESA 2000 exhibition

(Photos courtesy of M. Arndt)

ESA Hands Over Ariane-5 Launch Complex

On 25 November 1997 in Kourou, French Guiana, Mr Fredrik Engström, ESA Director of Launchers, Mr Michel Courtois, Deputy Director-General of CNES and Mr Jean-Marie Luton, Chairman of Arianespace, signed a document formally handing over Ariane launch complex ELA-3 from ESA to Arianespace. (see photo insert)

Representing an investment of some 800 million ECU, ELA-3 is by far the largest installation built by ESA under the Ariane-5 development programme. CNES was responsible for its design, construction and operation during cryogenic main stage testing and the first two qualification flights, in its capacity as prime contractor for the development of the Ariane-5 launcher and launch facilities. Arianespace will now take over responsibility for ELA-3 operations including launcher integration and launch operations, final payload preparation, management and maintenance of facilities, insurance, safety, and quality control, in addition to the similar responsibilities it has discharged since 1986 for the ELA-2 complex dedicated to Ariane-4.

Preparations for the hand-over of ELA-3 management responsibility to Arianespace had been under way for some years, with the progressive integration of Arianespace engineers and technicians into the CNES teams to ensure that personnel training was properly completed following execution of the first two Ariane-5 qualification flights. Particular attention has been paid to the industrial set-up in order to secure a coherent and optimised structure meeting ELA-2 and ELA-3 operations and maintenance requirements. To that end, Arianespace is contracting the same European companies which have hitherto been working under CNES contracts. Twelve firms (from Belgium, France, Germany, Italy and Spain) provide some 250 specialists under operations and maintenance contracts for the fluids and mechanical systems, computerised checkout systems, power supply and air conditioning.

Arianespace also draws on the Guiana Space Centre's support services for Ariane-5 launch campaigns, on the same basis as for Ariane-4 launches. These support activities, managed by CNES on behalf of ESA with European contractors, include coordination of overall launch range operations, ground and inflight safety, tracking and telemetry stations, meteorology, telecommunications, operations and maintenance for payload preparation facilities and logistical facilities.

More information on the Ariane-5 ground facilities can be found at
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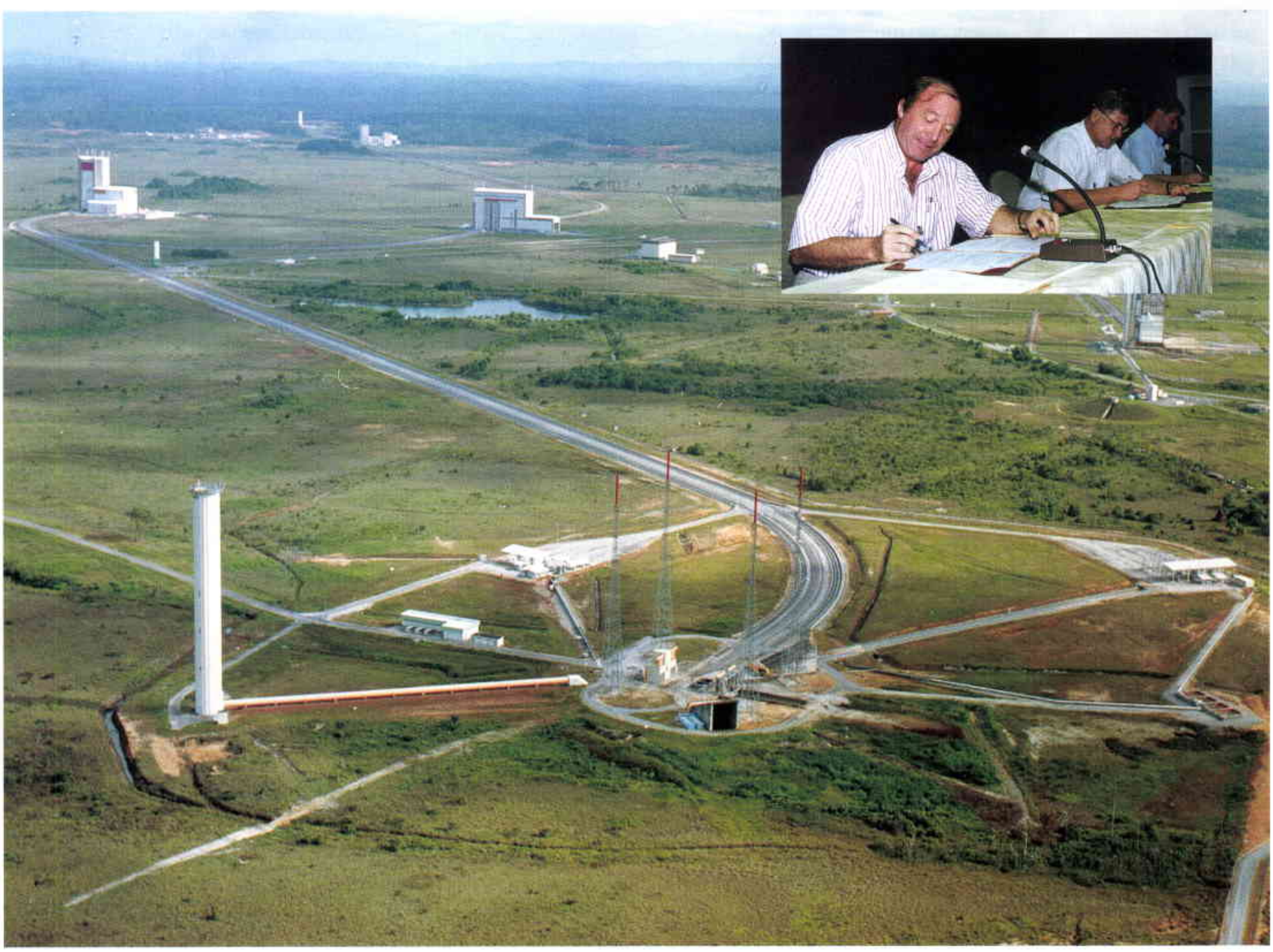

Photo insert (left to right) M. Courtois, Deputy Director-General of CNES; F. Engström, ESA Director of Launchers; J-M. Luton, Chairman of Arianespace

Ultraviolet Astrophysics Beyond the IUE Final Archive

Sevilla, Spain: 11-14 November 1997

This conference, which was co-sponsored by ESA, NASA, PPARC, SEA and EAS, marked the completion of the International Ultraviolet Explorer Project (IUE) and its Archive production phase. The conference brought together, for the last time, the broad astrophysical community which has, over a period of 18 years (1978-1996), used the IUE spacecraft efficiently and productively (3435 refereed publications, based on data obtained with IUE, have appeared in the professional literature). The conference was attended by 170 participants from 16 countries, who discussed and highlighted the many ways in which the results obtained with IUE have completely revised our ideas on e.g. comets, stellar evolution, galactic haloes, the power sources possibly associated with massive black holes in the nuclei of active galaxies, and many other areas of astrophysics. Two other important aspects were also addressed extensively during the conference:

- The first was the formal presentation, by the Project, of the IUE Final Archive (IUEFA) together with the INES system developed by ESA. It combines a more advanced extraction of the 110 000 spectra of IUE, for convenient direct application of the IUE data to scientific analysis, with a completely redesigned access system. The INES system, with its modernised and distributed data retrieval, is based on the active participation of the National Hosts (currently 28) to allow world-wide access to the IUE data. It is expected to assure the long term availability of the invaluable IUE archival data in an economic way.

- The second issue, which was extensively discussed in an open forum, was the limited number of opportunities foreseen in the programmes of the major space agencies for continued capabilities of the type which had been supplied by IUE. This is not only important for the clarification of the new astrophysical problems raised by the IUE observations, since at least some of these can be expected to be addressed through new observations with the existing ultraviolet capabilities of the Hubble Space Telescope. It is also very important to provide flexible access to the ultraviolet domain, at sufficient sensitivity that observing capabilities will be available to support, in the future, the serendipitous science which is an essential part of observational astrophysics, especially in a Universe where many dynamic phenomena show important multi-wavelength characteristics.

The Mayor of Sevilla, Mrs. Soledad Becerril Bustamante (centre), together with the IUE Project Scientists, Willem Wamsteker (ESA, right) and Yoji Kondo (NASA, left) during the official presentation of the Organising Committee in the City Hall

These concerns were addressed in the context of a World Space Observatory, since it was realised that the needs for such a facility extend well beyond the defined programmes of the major space agencies, and the scientific requirements to support such capabilities are possibly more efficiently addressed in a broader forum than provided by the individual agencies. To assure that this important issue would be addressed in the future, a working group was formed from the participants, to analyse and present the scientific justification in more detail, with all its multi-disciplinary implications, and to identify new ways of ensuring that the UV domain will not be an area where astronomers are unable to make essential observations.

The Proceedings of the conference will be published as ESA SP-413 (February, 1998).

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Director General Visits Bavaria

On 8 December 1997, ESA's Director General, Mr A. Rodotà visited the Bavarian Government as well as the top management of MAN Technologie. He also attended a reception given by Mr Edmund Stoiber, Head of the Bavarian Government, in the Kaisersaal of the Munich Residenz, where the ESA Council at Ministerial Level took place in November 1991. The following day he met with Mr Otto Wiesheu, Minister of State for Economy, Transport and Technology and with Mr Rudolf Rupprecht, Chairman of the Board of MAN to discuss space-related activities.

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Mr Antonio Rodotà (left) with Mr Edmund Stoiber (right) Head of the Bavarian Government and Mr Horst Rauck (centre) of MAN Technologie

Huygens, Alive and Well

Tests carried out on 23 October 1997 by ESA's Space Operations Centre (ESOC) confirmed that ESA's Huygens probe is in excellent condition, following its launch on 15 October aboard NASA's Cassini spacecraft. The dual Cassini-Huygens mission is now en route for Saturn, by way of Venus. In 2004, Huygens will plunge into the atmosphere of Saturn's enigmatic moon Titan.

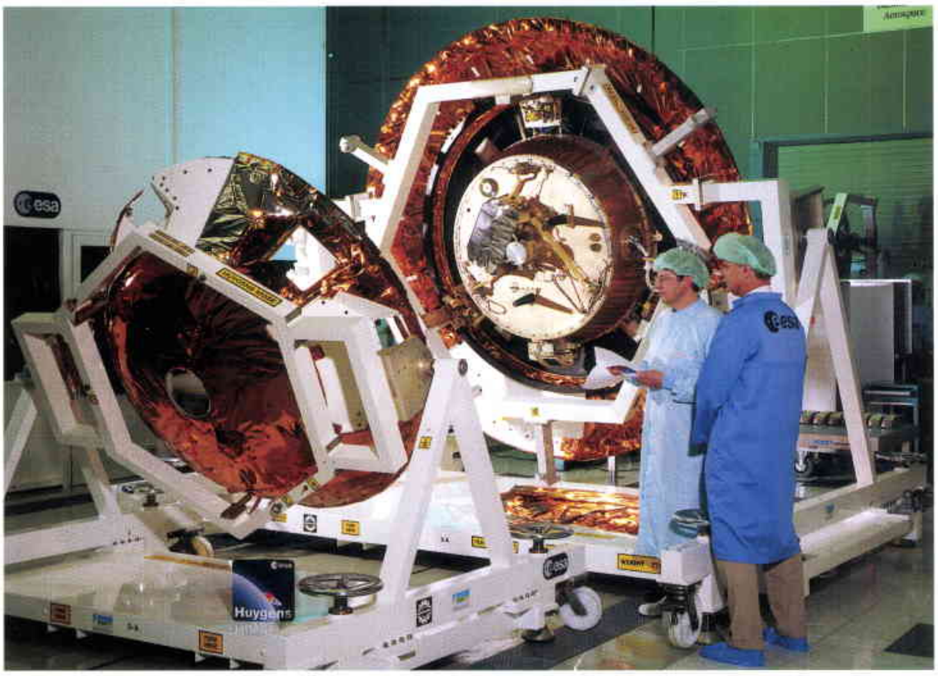
ESOC established connection with the Huygens probe at 10:09 CET using NASA's link to Cassini. Thanks to ESOC's new flight operations system, engineers and scientists responsible for the mission were quickly able to check that Huygens is alive and well in all respects.

ESA's project management team and representatives of the contractors who built Huygens were able to report that the engineering system and subsystems are all performing nominally.

The Principal Investigators from Europe and the USA in charge of the six instruments on Huygens were also present for the experiment functionality test:

- HASI to analyse Titan's atmosphere and weather
- DWE to measure wind speeds during the descent
- GCMS to analyse chemical compounds on Titan
- ACP to break down aerosols for chemical analysis
- DISR to produce images and spectra of Titan
- SSP to determine the nature of Titan's surface.

"Six experiments, six green lights", reported Jean-Pierre Lebreton, ESA's Huygens Project Scientist. esa



RENDEZVOUS WITH THE NEW MILLENNIUM

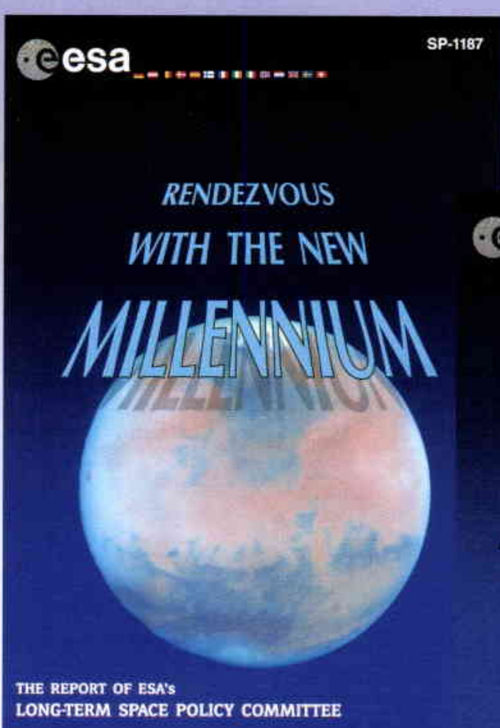
The Report of
ESA's Long-Term Space Policy Committee

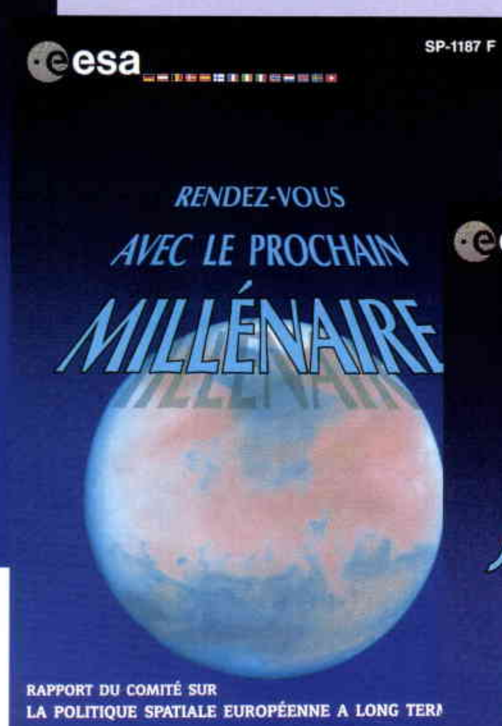
With 30 years of space activities behind us, we can now look forward to the next millennium on far more solid ground than the early pioneers ... At present, most space activities go from study phase to launch in about 10 years. The near-future is therefore already accounted for, and the major options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

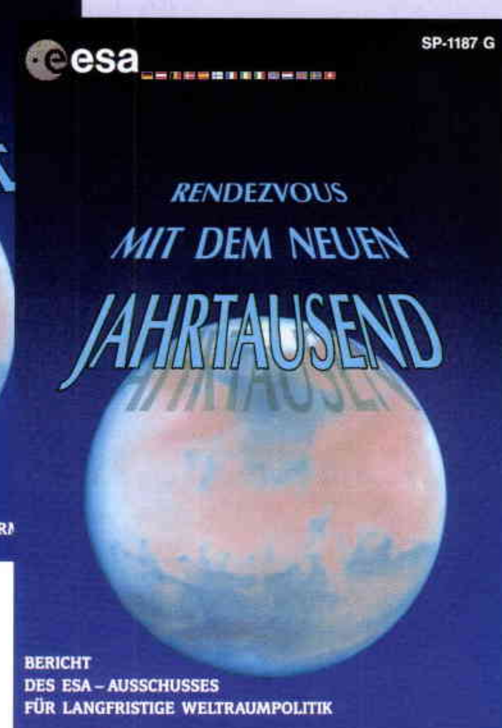
To identify a strategic vision for European space activities in the next century — one that will respond both to the challenges and threats facing humanity in the future — the ESA Council created a Long-Term Space Policy Committee (LSPC) in June 1993. The Commitee's task was to prepare a report on European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

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

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







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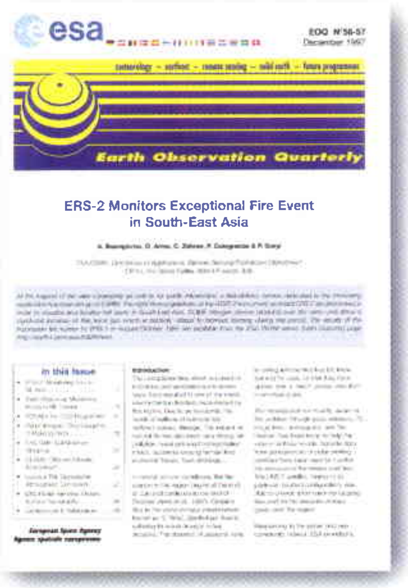

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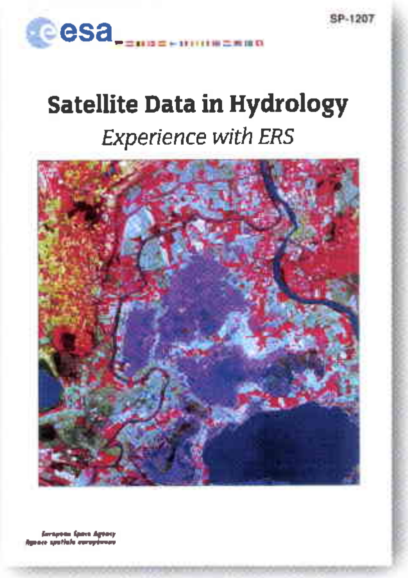

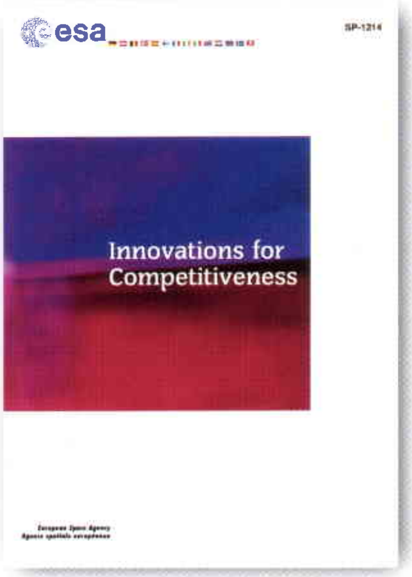

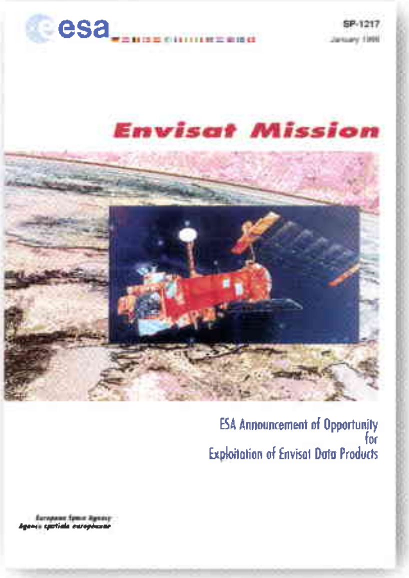

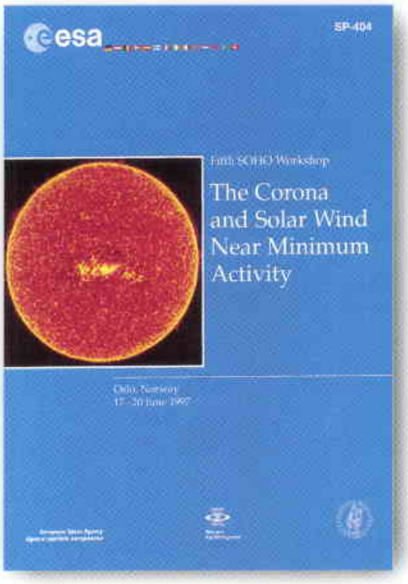

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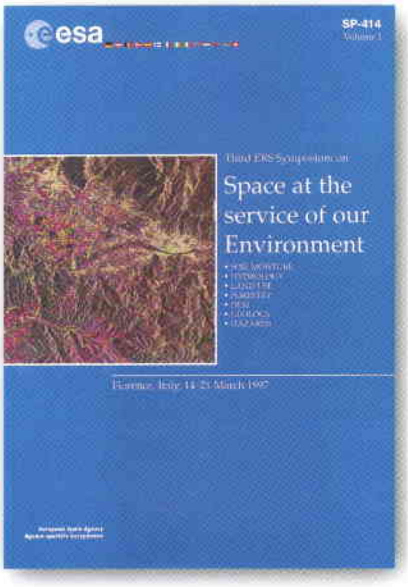

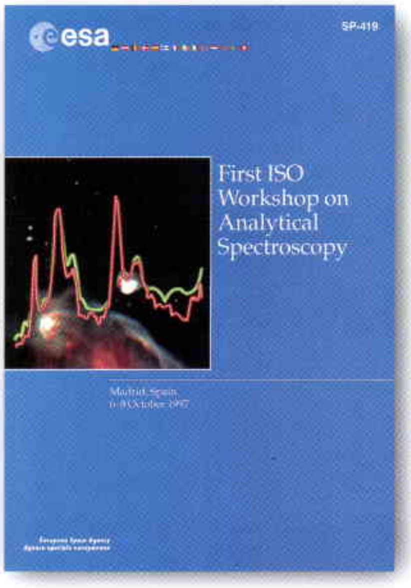

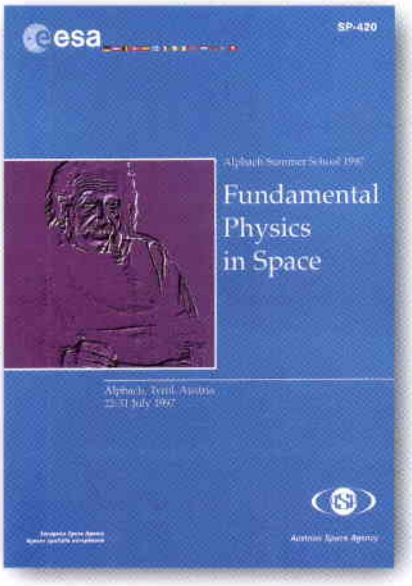

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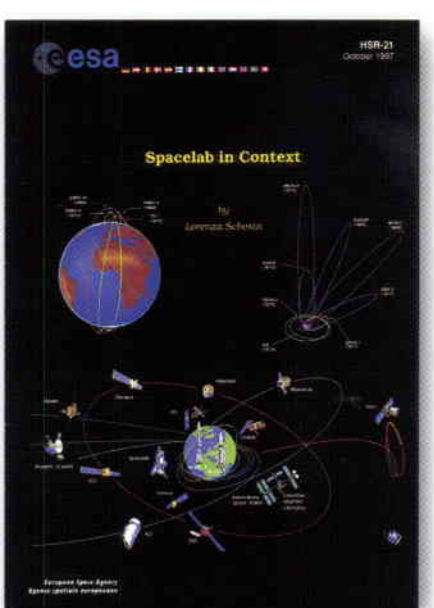

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