european space agency

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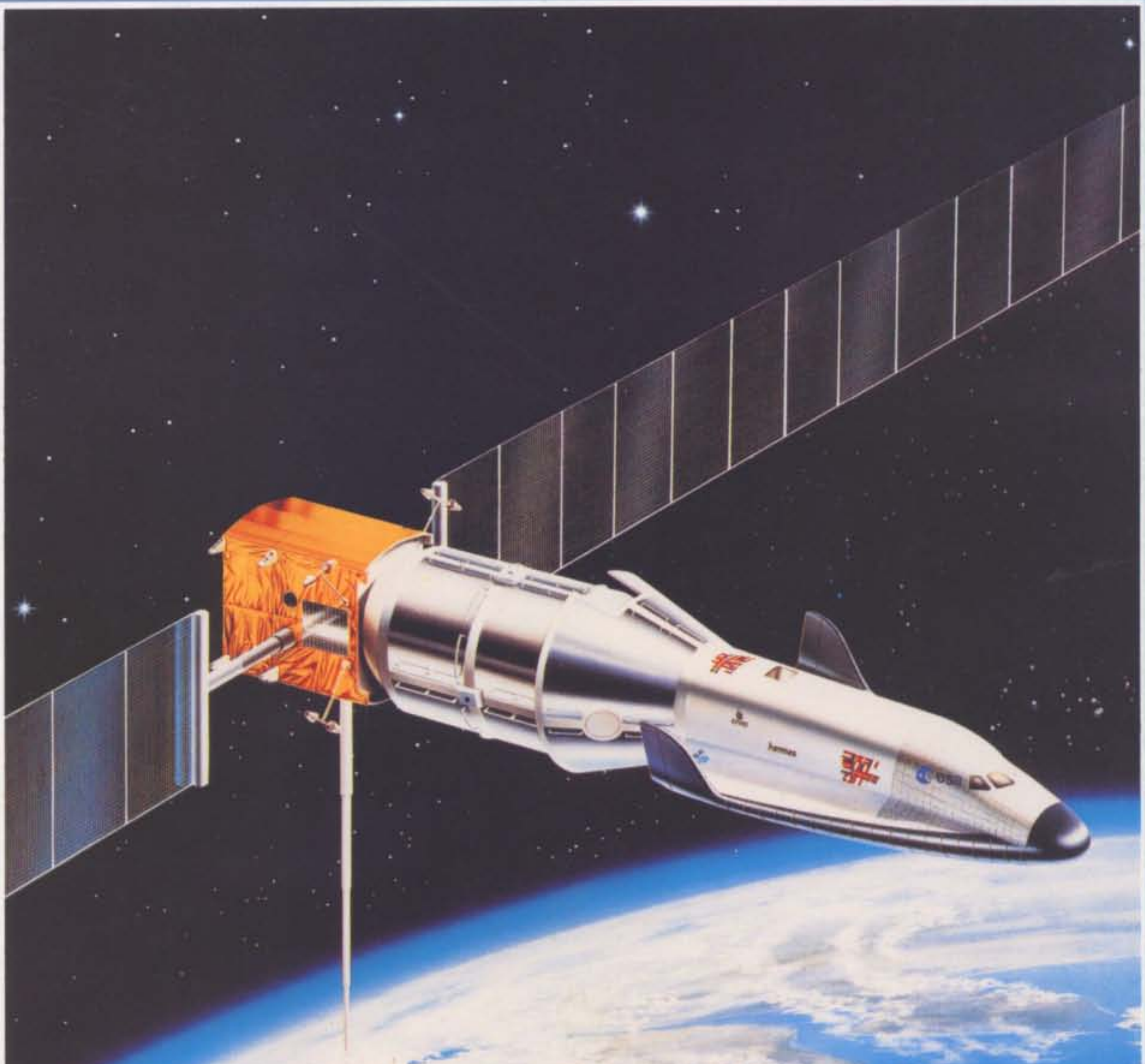

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european space agency

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

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

(a) by elaborating and implementing a long-term European space policy, by recommending space objectives to the Member States, and by concerting the policies of the Member States with respect to other national and international organisations and institutions;
(b) by elaborating and implementing activities and programmes in the space field;
(c) by co-ordinating the European space programme and national programmes, and by integrating the latter progressively and as completely as possible into the European space programme, in particular as regards the development of applications satellites;
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The Agency is directed by a Council composed of representatives of Member States. The Director General is the chief executive of the Agency and its legal representative.

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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 France, l'Irlande, l'Italie, la Norvège, les Pays-Bas, le Royaume-Uni, la Suède et la Suisse. La Finlande est membre associé de l'Agence. Le Canada beneficie d'un statut d'Etat coopérant.

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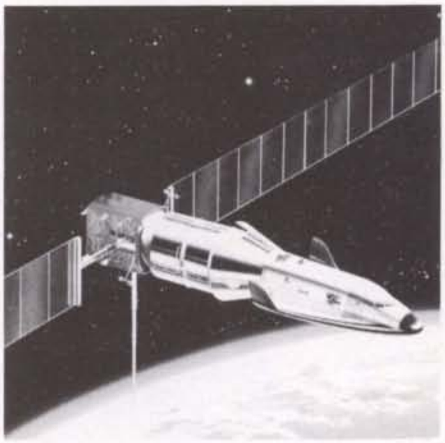
no. 57 february 1989

contents/sommaire



Front cover: The Hermes spaceplane docked with the Columbus Free-Flying Laboratory

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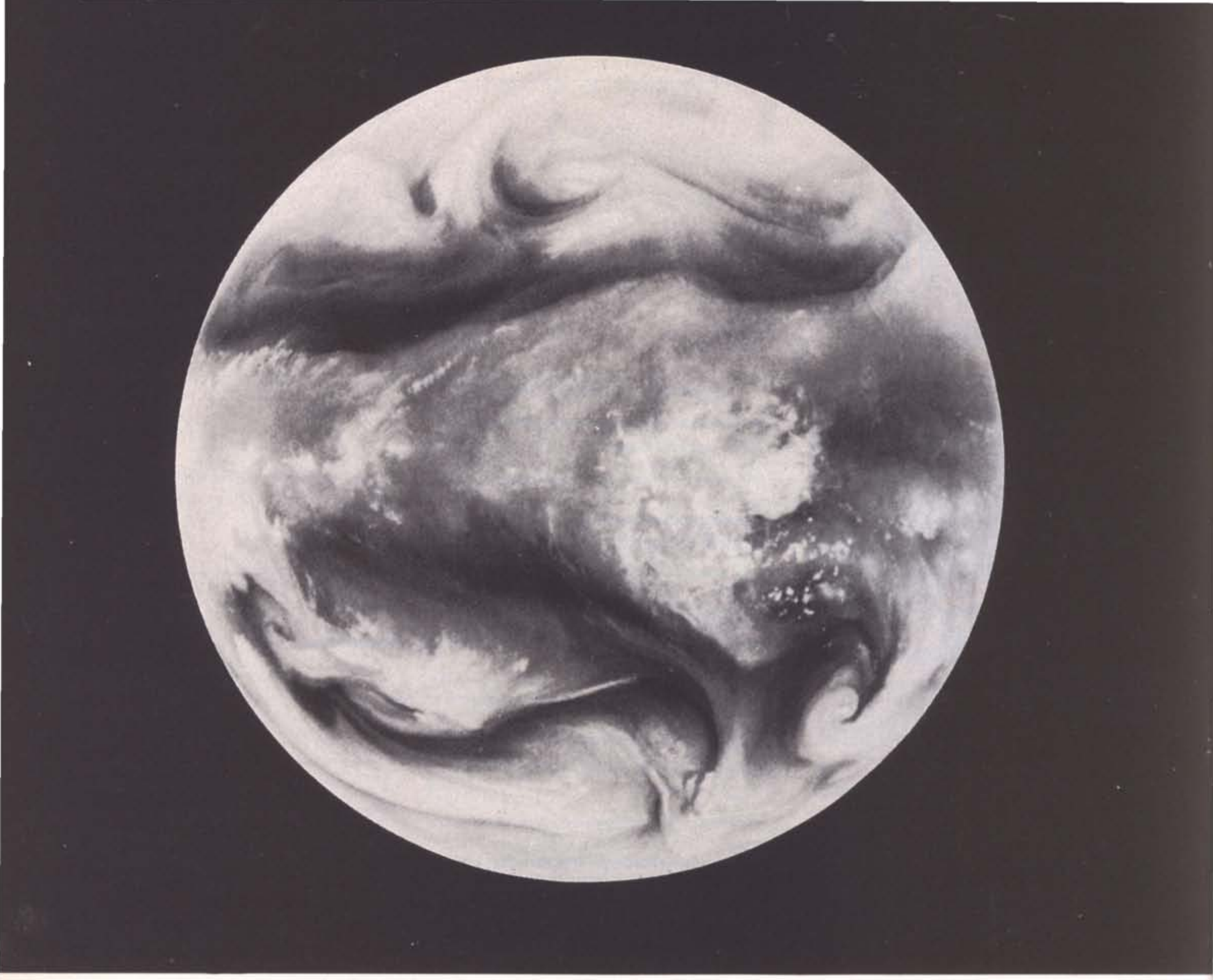


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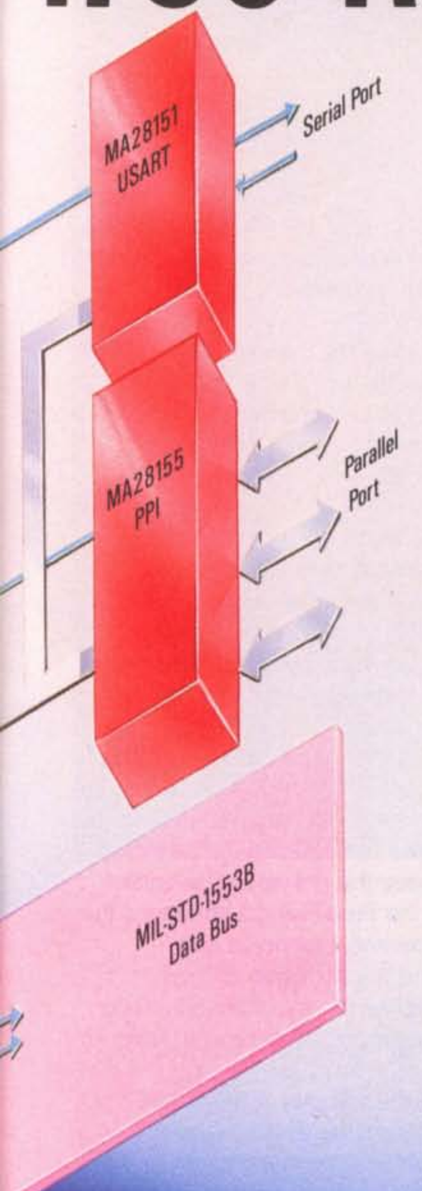

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The Hermes Development Programme

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At the Ministerial Conference in Rome in 1985, it was decided that Europe should gradually acquire autonomy in manned spaceflight. Such autonomy implicitly includes the capability to transport man into space and return him safely to Earth.

During the next Council Meeting at Ministerial Level in November 1987 in the Hague, the proposed Hermes winged-spacecraft solution was endorsed and the first step in its Development Programme was approved.

With the Hermes system, Europe will have an autonomous, manned, in-orbit servicing capability compatible with the other European In-Orbit Infrastructure (IOI) elements, namely the Columbus, Data-Relay Satellite (DRS) and Ariane systems, and with the associated supporting ground infrastructure.

The role of the Hermes system

The current ESA Programme includes the development of the ground and in-orbit elements required to support projects in the fields of science, applications and technology. In many cases, the in-orbit retrieval and replacement of samples and equipment and, due to its experimental nature, the modification of equipment in-orbit, are necessary to achieve a project's objectives. The undertaking of such projects therefore requires an In-Orbit Infrastructure (IOI) that permits manned intervention.

The Agency's planned IOI consists of the Columbus System (the laboratory proper), the manned and unmanned transportation system consisting of the Ariane-5 and Hermes Systems, and the Data-Relay Satellite System (DRSS), which will provide a near-continuous data link between the in-orbit elements and the ground. This IOI will be supported by the associated ground infrastructure necessary to operate the system.

Within the Columbus System, the *Columbus Free-Flying Laboratory* (formerly known as the Man-Tended Free-Flyer, or MTFF) and the *Columbus Attached Laboratory* (formerly known as the Attached Pressurised Module, or APM), attached to the *International Space Station 'Freedom'*, will provide a permanent capability for in-orbit experimentation. Both require manned intervention.

Once in orbit, the Free-Flying Laboratory will be kept operational by means of regular visits from the *Hermes spaceplane*, which will provide the manned in-orbit servicing capability needed.

The Hermes System, composed of the Hermes spaceplane itself, its associated ground segment, the crew and the payload, must be capable of supporting up to four missions per year (with two spaceplanes) for a period of at least 15 years.

The servicing of the Free-Flying Laboratory and the visits to the Space Station dictate the design and performance requirements for the Hermes System. The spaceplane servicing scenario foresees the delivery of scientific equipment to the Free-Flying Laboratory, the retrieval of experiment samples and equipment, and the provision of the necessary supplies for and maintenance of the Laboratory proper, all at regular intervals.

The Hermes crew will play a major role during the missions by deploying and retrieving scientific experiments and undertaking maintenance work. Hermes will provide them with the operational facilities necessary for these tasks, such as a manipulation system, an airlock, and equipment (e.g. space suits) allowing them to conduct both intravehicular and extravehicular activities (IVA and EVA).

The Hermes spaceplane will be launched by an Ariane-5 vehicle from Kourou, French Guiana, will perform its flight mission of nominally 12 days, and will then reenter the Earth's atmosphere, landing either back at the launch site or in Europe (Figs. 1 & 2).

The Hermes System, the Free-Flying Laboratory, Ariane-5, the DRSS system and their associated ground infrastructure must, of course, be developed and operated in a coherent manner (Fig. 3).

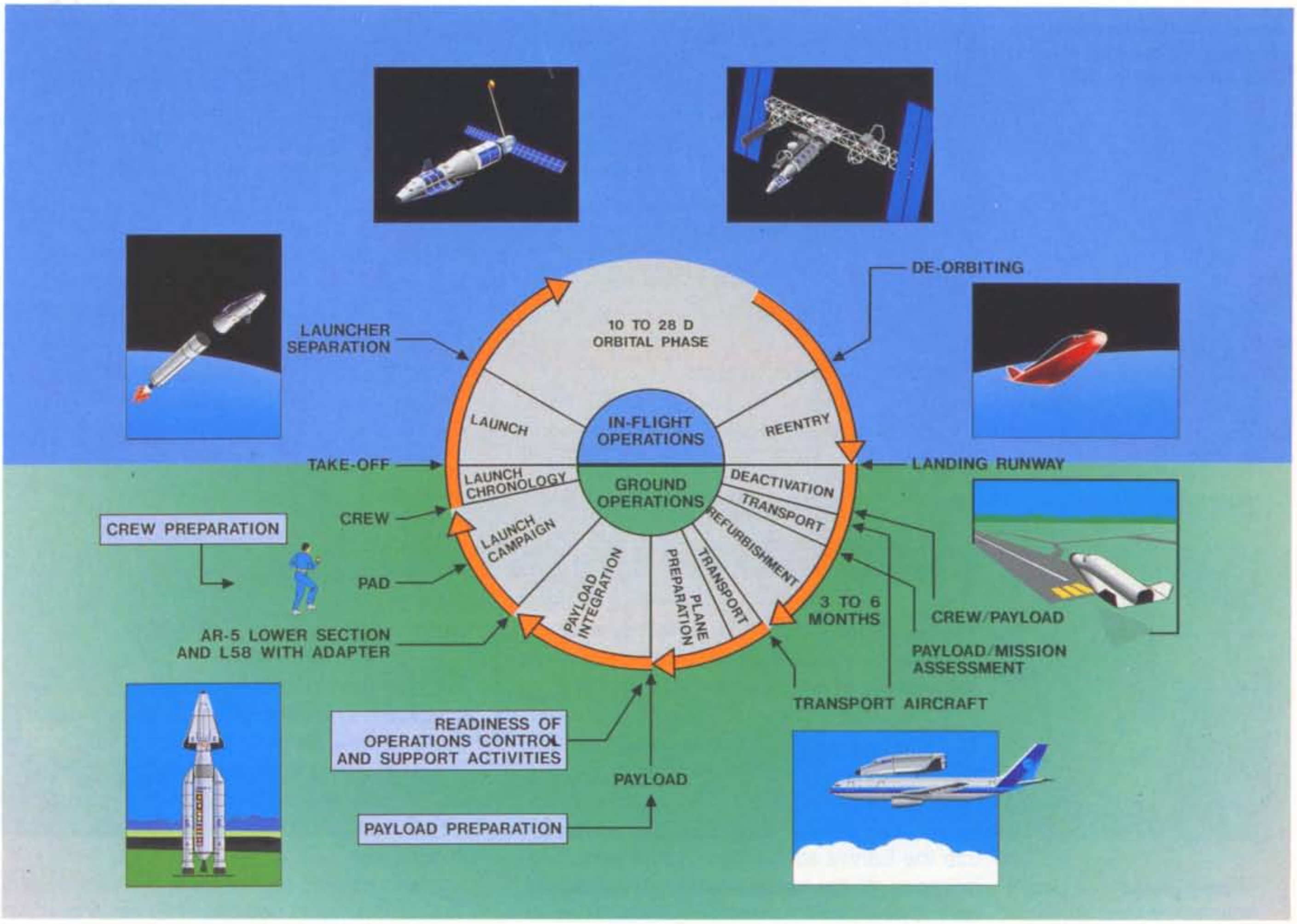

Figure 1 — The Hermes utilisation cycle

- ORBIT - 463 KM CIRCULAR, 28.5 DEG. INCLINATION
- DURATION - 12 DAYS
- CREW - 3 (COMMANDER, PILOT, MISSION ENGINEER)
  - 2 CREW MEMBERS FOR MISSION OPERATIONS
  - CREW SHIFT OF 8 TO 10 (MAX) HOURS

CARGO	MASS (kg)	VOLUME (m^3)
Up to the Free-Flyer	3000	9.0
Retrieved to Earth	1500	3.6

Figure 2 — Summary of Hermes mission requirements

The Hermes System
The overall composition of the *Hermes System* and its various elements are as follows (Fig. 4):

The spaceplane
In carrying out the necessary servicing of the Free-Flying Laboratory, the spaceplane must provide: the stowage volume, mass-carrying capability and onboard resources needed for the Laboratory and its payload; the means for their manipulation and installation; the capability to dock the spaceplane to the Laboratory and to maintain a controlled attitude for the composite; the capability to transfer astronauts and cargo to and from the Laboratory; the ability for crew members to leave the spaceplane and perform servicing activities in space; the necessary communications and data-processing and

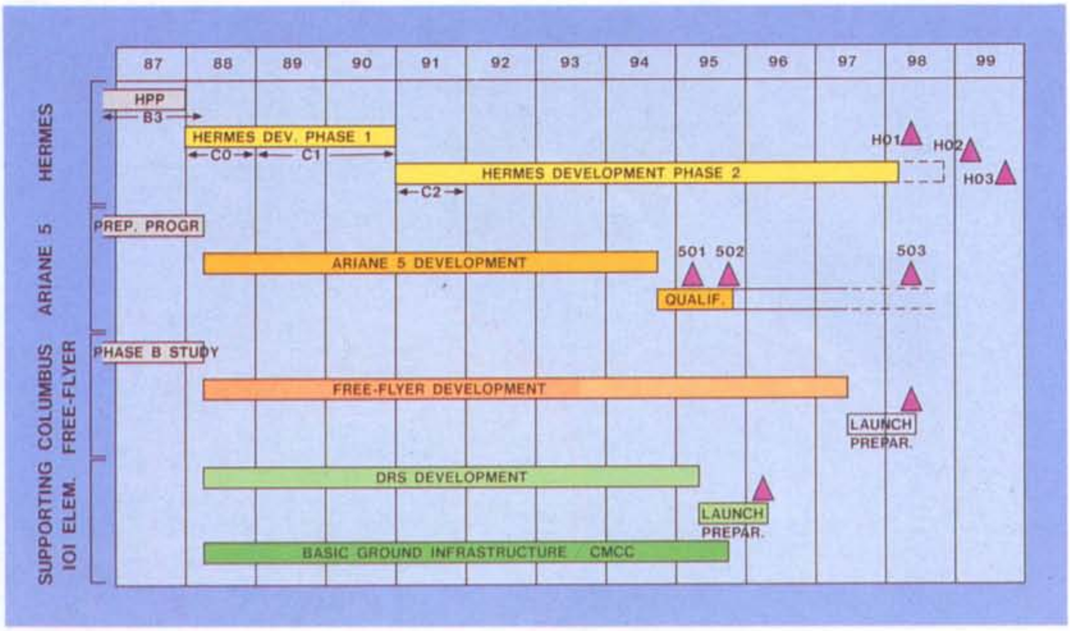

Figure 3 — Development schedule for the ESA In-Orbit Infrastructure (IOI)

transfer capabilities; and the reentry and cross-range capabilities needed to allow the spaceplane to land in Europe.

The spaceplane must also be designed to withstand the extreme thermal and mechanical loads that it will encounter during launch and again during reentry from orbit into the Earth's atmosphere, for at least 30 missions. At the same time, it must require only a minimum of maintenance between missions, in order to keep operating costs as low as possible. A further constraining influence on the spaceplane's design is the maximum lifting capability of Ariane-5.

Last but certainly not least, it must meet manned safety requirements, including a crew rescue system able to cope with a catastrophic launcher failure.

The definition, and subsequent design, of a spaceplane meeting all of these requirements using reliable technologies, whilst still maintaining the basic shape of a winged aircraft-type vehicle, is one of the major tasks for Phase-1 of the Hermes Development Programme.

The configuration selection has been an iterative process, with studies of particular areas and design feasibility assessment being performed in parallel. The configuration retained after these intensive studies is shown in Figure 5.

To limit the critical spaceplane reentry mass, the propulsion used for orbit insertion, along

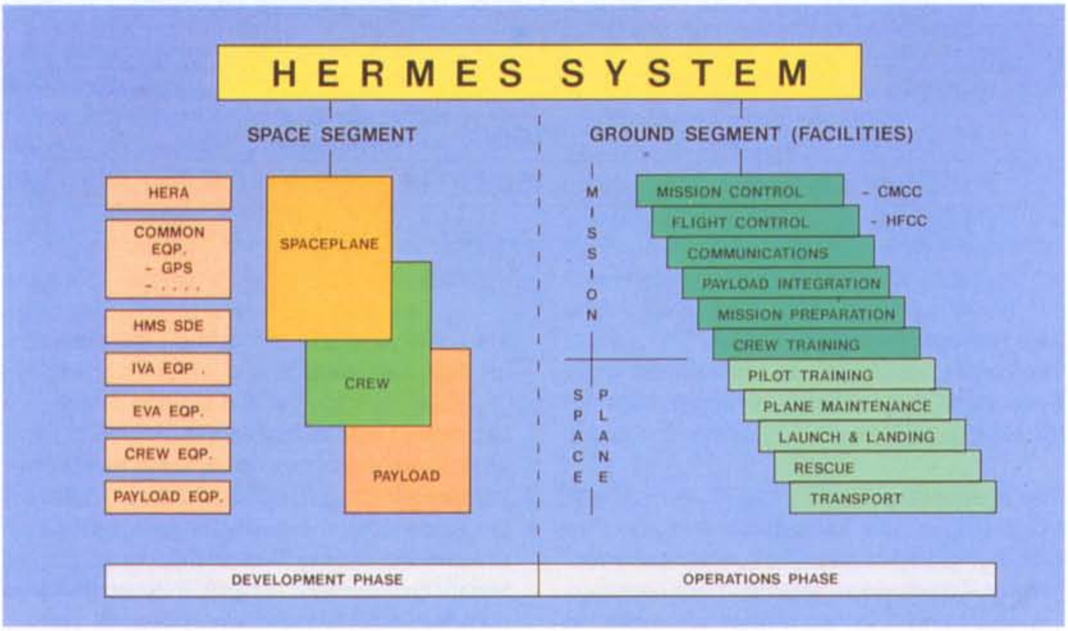

Figure 4 — Composition of the Hermes System

with some payload and subsystem equipment, is located in a so-called 'MRH module' (Module de Resources Hermes). This MRH will be jettisoned from the spaceplane prior to its reentry and will burn up in the Earth's atmosphere.

The crew and crew equipment
The activities to be performed by the Hermes crew during a Free-Flying Laboratory mission are determined both by the scientific objectives of the particular mission and by the repair and maintenance requirements both inside and outside the Laboratory. Both areas are the subject of continuing analyses during Phase-1 of the Hermes Development Programme, and the detailed definition and design of most of the crew equipment — including the HERA, the Hermes Remote Arm — will therefore continue throughout Phase-1, until 1990.

Crew time is a critical spaceplane resource, since the crew's accommodation and life support are primary design drivers. A crew of three is foreseen and analyses have shown that the necessary servicing activities for the Free-Flying Laboratory can best be completed by working in 10 h shifts.

The payload and payload equipment
The spaceplane's design has to meet certain requirements in terms of the accommodation and manipulation of equipment and the resupplying of the scientific payload and the Free-Flying Laboratory. At this point in the programme, a so-called 'reference payload' and initial Free-Flyer servicing requirements are being used as the design baseline.

The basic payload volume, stowage, installation, power, cooling, data-processing and communications needed by the user will be provided by the spaceplane. Additional so-called 'Mission-Dependent Equipment' (MDE), such as the HERA, will be added for particular missions.

The ground segment
The Hermes ground segment consists of those facilities needed to: plan each mission, prepare the crew and the payload, perform the mission, and keep the spaceplane and all ground facilities operational. Its composition and the main purpose of each facility are shown in Figure 6.

Novel areas within the Hermes ground segment compared with previous programmes include:

— The Hermes System's long lifetime of at least 15 years (the objective is to operate the IOI for up to 30 years), the launch, landing and regular ground maintenance of the spaceplane, and its transport between landing and repair locations, require the provision of a variety of new ground facilities meeting both space- and aircraft-type ground-operations needs.

— The operational requirements of other future mission scenarios for the Hermes System, such as rescue missions, autonomous spaceplane missions, and the servicing of other space vehicles, need to be taken into account.

— Manned-mission safety requirements impose specific considerations, e.g. in terms of the provision of redundant control and intervention capabilities, a fail-safe design for ground hardware and software circumventing all human errors that could jeopardise the crew's safety, and the strict control of the configurations of all ground hardware and software and all changes thereto.

All ground facilities used during a mission, although situated at different geographical locations depending on their purpose (control, maintenance, launch, landing, and overall mission control), must interact in complex and often time-critical ways. This calls for the coordinated design and

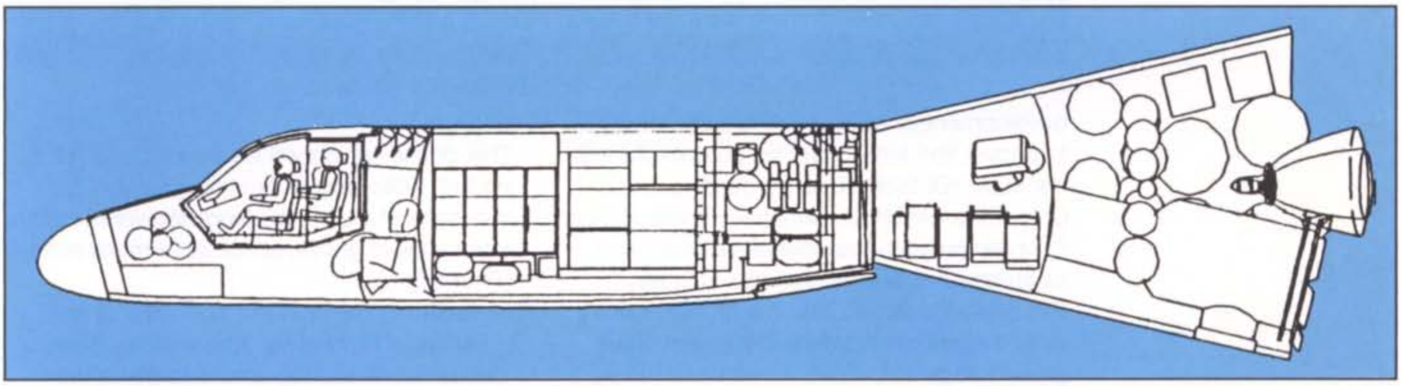

Figure 5 — Configuration of the Hermes spaceplane

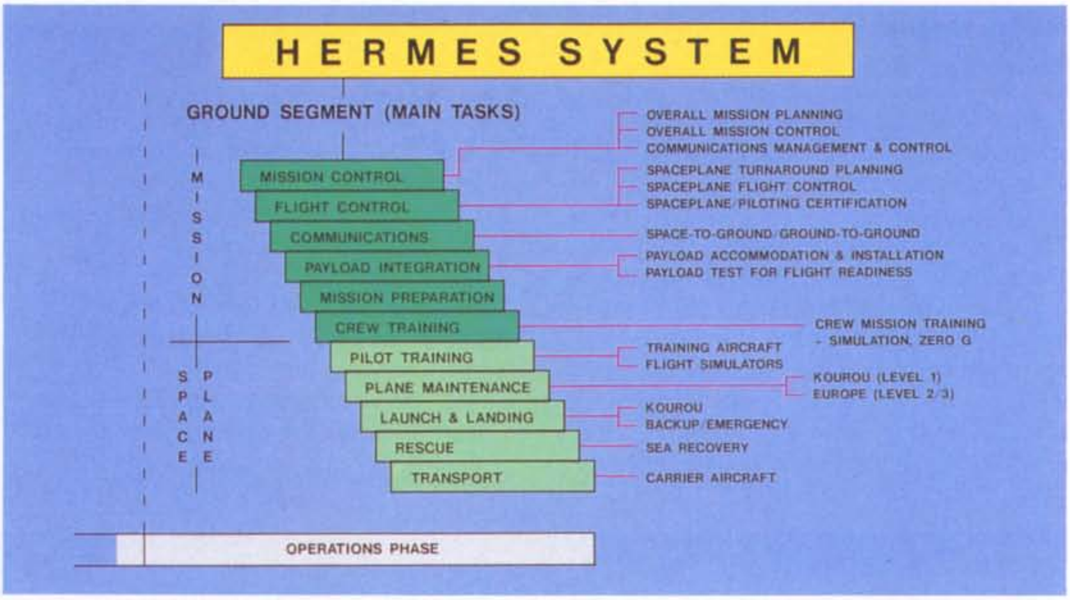

Figure 6 — Overview of ground-segment facilities

development of all Hermes ground facilities. Moreover, the latter must be compatible with the other IOI facilities to be used for the Columbus, DRSS and Ariane-5 Programmes. A single authority has therefore been established at ESA, called the 'Central Design Authority' (CDA), to ensure coherent design and development of the overall IOI ground segment.

The overall concept for the Hermes ground segment has in fact already been defined, and detailed requirements for each of the ground facilities shown in Figure 6 are now being established.

The facilities required for training the crew and preparing them for the mission — including pilot training and neutral-buoyancy simulation — and for the preparation of each payload depend closely on the mission objectives and are therefore subject to further analysis and definition during Phase-1, like the crew and payload equipment mentioned earlier.

The Hermes Development Programme

Overall logic

The relatively long period required to develop some of the new technologies needed, particularly in the areas of aero-thermodynamics, structures, and thermal-protection materials, and their inherent influence on the choice of the final spaceplane configuration, have led to the adoption of a two-phase Development Programme for Hermes (Fig. 7). This Programme was approved by eleven ESA Member States in November 1987, and the implementation of Phase-1 has already been authorised.

Phase-1

This phase, which will be concluded by the end of 1990, has as its main goal the reduction of the risks associated with the remainder of the Development Programme (Phase-2) by:

- reducing the technological risks to an acceptable level by means of a pre-development programme to guide the choice of critical technologies
- advancing and consolidating the definition of the Hermes System and of new types of equipment to allow reliable definition of the content, schedule and cost of Phase-2
- performing the analyses and definition work needed to confirm the choice of configuration and ensure compatibility of those interfaces that have a dimensioning influence on the other IOI programmes
- establishing the industrial and financial structure for Phase-2.

The system-requirements baseline and the coherence of the various elements of the Hermes System will be reviewed in a Preliminary Requirements Review (PRR) early in 1989.

The programme baseline for Phase-2 will be fixed and the requirements frozen to the level of subsystems and critical equipment through a System Requirements Review (SRR) at the end of Phase-1.

Phase-2

This second phase of the Development Programme, culminating in the second flight of a Hermes spaceplane in early 1999, covers the Hermes System's development and qualification for subsequent operational utilisation.

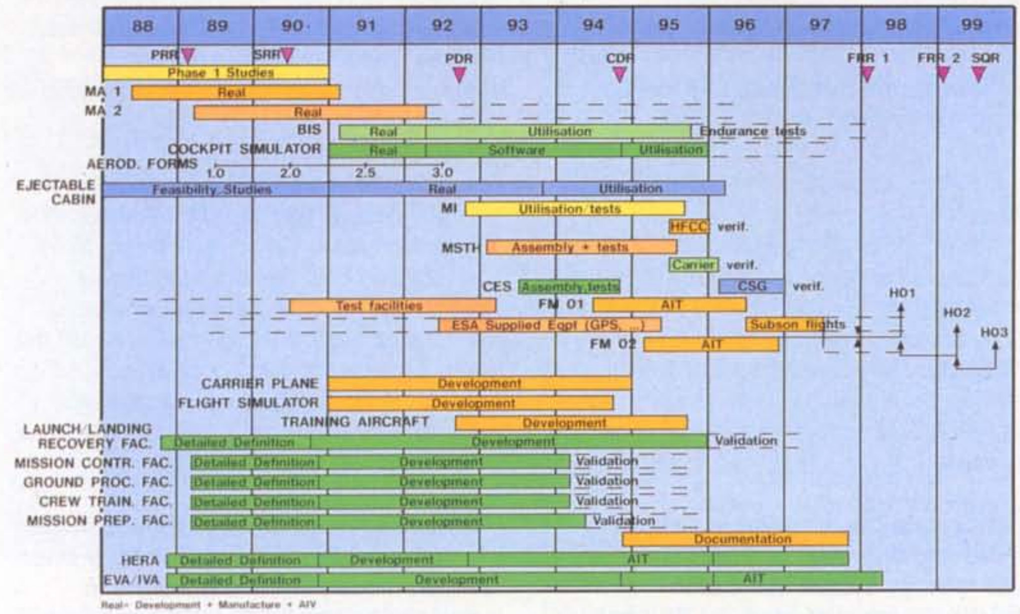

Figure 7 — Overall development schedule for Hermes

It contains four major development increments, each concluded by a Hermes System Review, as shown in Figure 7:

1. During the first increment, the detailed design work will be performed, and breadboards and equipment (engineering models) will be produced. External and internal interfaces will be confirmed during this phase, and the development of the supporting infrastructure will be initiated. This phase will be concluded with the Preliminary Design Review (PDR).

2. During the second increment, the spaceplane's final design will be frozen and the construction of full-scale functional and environmental models will be undertaken.

   Development of the other elements of the Hermes System will continue in parallel, and the first elements of the ground segment will undergo validation.

   The manufacture of flight models of most of the equipment will be released at the end of this phase after a Critical Design Review (CDR).

3. The third increment will consist of full on-ground qualification of the spaceplane, its ground infrastructure, and its interfaces with the other IOI systems. Full-sized spaceplane models produced during the previous phase will be used. Based upon the results achieved, flight hardware and software production will be gradually released, and the two flight models will be integrated.

   In a second step, the full-sized models will be used to verify the integrity of the supporting elements and the ground infrastructure. This phase will include subsonic flights using one of the flight models, and will end with the Flight-Readiness Review (FRR-1) prior to the first orbital (unmanned) flight.

4. The fourth and final increment will serve to complete the qualification of the overall Hermes System for all those performance requirements that cannot be checked during the previous phases. These are:
   — qualification of the spaceplane in terms of its reentry capabilities from Earth orbit
   — qualification of the Hermes System for manned flight to and from orbit
   — operational qualification of the Hermes System within the overall IOI space and ground infrastructure
   — qualification of basic servicing-operations capabilities (servicing of Free-Flyer not yet performed).

   Initial qualification will be achieved by means of two orbital qualification flights. The first (H001) will be unmanned, and the second (H02) will include the crew. After the second flight, the System Qualification Review (SQR) will be held to review the overall qualification status of the Hermes System and the results of the two orbital flights. At the end of the SQR, the Hermes System should be declared ready for operational use.

   Full operational qualification (validation) of the Hermes System will be achieved only after a number of further flights, this number being determined during the Development Programme.

The major qualification areas and tools are summarised in Figure 8.

The objectives of each of the System Reviews mentioned will be to assess the design and performance of the Hermes System step-by-step for conformance with the system requirements laid down by ESA in the Hermes System Requirements Document (HSRD). The HSRD also specifies the method to be applied for achieving qualification and acceptance ('verification') in every case.

The verification status will be regularly reviewed and approved by ESA through a special Hermes System Verification Programme, controlled jointly by ESA and CNES, which will provide documented evidence of qualification and acceptance for operational utilisation. This verification programme must be structured to allow the tracing of all changes affecting qualification that occur in the course of the programme. It will be based on experience gained during the Spacelab Programme, which was also geared to qualification for a manned mission. Because of the large amount of data to be controlled, the use of computerised databases, including verification, configuration and change control, is mandatory. Such a database system will be established during Phase-1.

Figure 9 shows the overall verification logic flow.

The Hermes, Ariane-5, Columbus and ground-segment verification programmes need to be mutually compatible to the extent necessary to ensure complete and coherent verification of all interfaces between these systems. This will be achieved by harmonising the verification concepts and by joint verification management.

Currently, the verification-programme effort is concentrated on definition of the Verification Programme itself, the establishment, review and release of complete and verifiable system requirements, including interfaces with Columbus, the DRSS, Ariane-5 and the Space Station, and on the definition and initiation of the necessary management schemes, implementation plans, procedures and databases.

Full-sized spaceplane development models
It is currently planned to manufacture seven full-sized models of the spaceplane to support its development and qualification within the Hermes System, and of its interfaces with the MTFF, Ariane-5 and the IOI ground segment:
- two full-sized accommodation mock-ups (MA1, MA2)
- a cockpit simulator (SDC)
- an integration test-bed (BIS)
- a static test model (CES)
- an identification or engineering model (MI), and
- a structural- and thermal-test model (MSTH).

These models and their primary roles are as follows:

MA1 and *MA2* are both mock-ups, the first of low fidelity, the second in metal and of high dimensional fidelity. These mock-ups will be used to validate habitability and equipment accommodation (including, later on, that of the payload). They are also to be used to

FLIGHT PHASE	VERIFIABLE ITEMS	QUALIFICATION TOOLS
LAUNCH	STRUCTURAL BEHAVIOUR	· MSTH · CES
IN-ORBIT	SPACEPLANE FUNCTION	· BIS · MI
DATA PROCESSING	SOFTWARE	· TEST BEDS (BVC) · EGSE (BCH) · BIS · MI · SIMULATORS
MANNED OPERATIONS	ORBITAL MANOEUVRES	· SIMULATED RENDEZVOUS & DOCKING · MANNED FLIGHT H02
SERVICING OPERATIONS	EVA, HERA OPERATIONS	· SIMULATORS · FLIGHT H03
REENTRY	AEROTHERMAL BEHAVIOUR	· AERODYNAMIC WIND TUNNELS & CALCULATIONS · GROUND TESTING (PLASMA CHAMBER) · HOO1 UNMANNED INFLIGHT TEST
LANDING	BEHAVIOUR AT LANDING	· PILOT TRAINING WITH SIMULATOR AIRCRAFT · FLIGHT SIMULATOR · DROP-TESTS (appr. 15)
RESCUE	RESCUE EQUIPMENT	· FUNCTIONAL TESTS ON CEM-MODELS
TRANSPORT	CARRIER/SPACEPLANE	· FUNCTIONAL TEST CARRIER WITH MSTH

Figure 8 — Hermes qualification areas and models

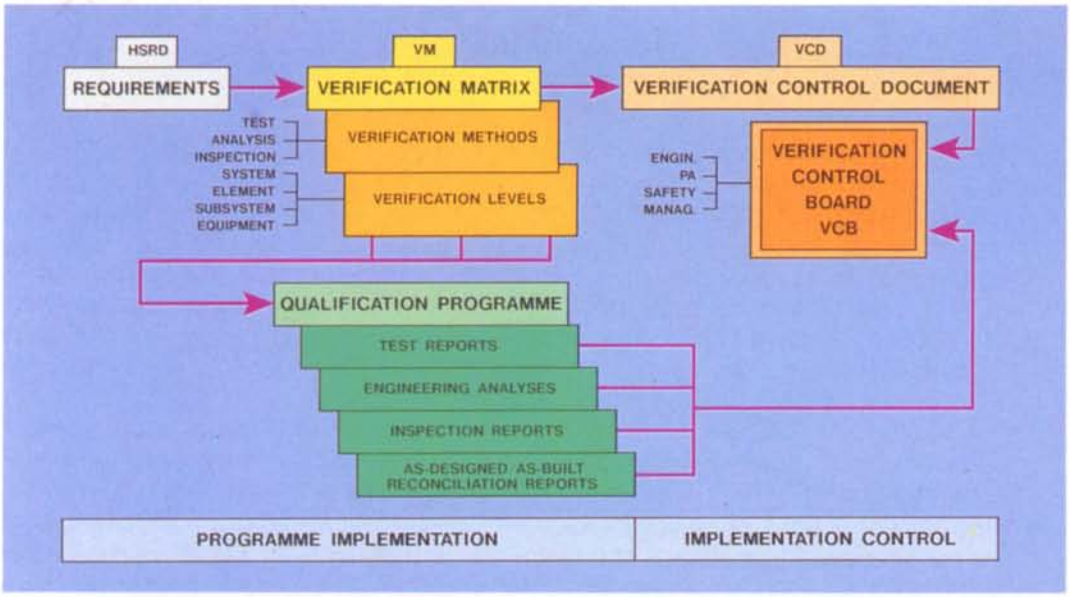

Figure 9 — Hermes System Verification Programme logic

support the definition of the production tools and the further definition of the assembly and integration process.

The *Cockpit Simulator (SDC)* is an essential tool for supporting the development programme's early phase. It will be used mainly to develop the man/machine interfaces.

The *System Integration Model (BIS)*, often called the 'iron bird' in aircraft programmes, is representative of the spaceplane internally, but has no cladding, thereby providing good accessibility for the installation of breadboards and cabling. It will be the main tool for performing development and qualification tests on the electrical, hydraulic and to a lesser extent avionics subsystems. The BIS will also be used for endurance testing.

The *Static Test Model (CES)* will be used to qualify the primary structure under worst-case loading conditions.

The *Identification Model (MI)* is an engineering model that will be functionally fully representative for the flight models, and which will be constantly updated to represent the as-built status. It may also be used to test fly hardware and software.

In addition, it will be used to verify the integration process and utilisation procedures, and to perform functional qualification tests (integrated system tests), including those for electromagnetic compatibility (EMC) and pressurisation, and those environmental and life-support function checks that cannot be conducted satisfactorily on the BIS due to its open structure.

Equipped with operational software, the MI will subsequently be used to verify the interfaces with databanks and with the Hermes Flight-Control Centre (HFCC). During the spaceplane's operational phase, it will serve to qualify engineering changes and validate modified or new operational procedures.

The *Structural and Thermal Test Model (MSTH)* will be used primarily to perform the classical environmental simulation tests (vibration, acoustic, thermal vacuum). After completion of the qualification tests, this model will be used extensively to verify a number of physical interfaces, such as those with the transportation carrier and the launcher system at Kourou in French Guiana.

In addition to these full-sized spaceplane models, a number of test-beds and simulators will be employed. The crew-rescue system in particular will require a number of representative models to verify safety and escape capabilities during the various Hermes flight phases.

Aerodynamic development approach

Two critical flight phases have a dimensioning influence on the spaceplane's design and development, namely those at launch and reentry (Fig. 10):

Launch phase

Hermes will be launched on top of an Ariane-5 vehicle (Fig. 11). Because of the spaceplane's aerodynamic shape, which is necessary for reentry and landing, it will induce strong transverse mechanical forces on the Hermes/Ariane-5 composite, imposing important constraints on its control during the initial aerodynamic flight phase up to an altitude of 50 km.

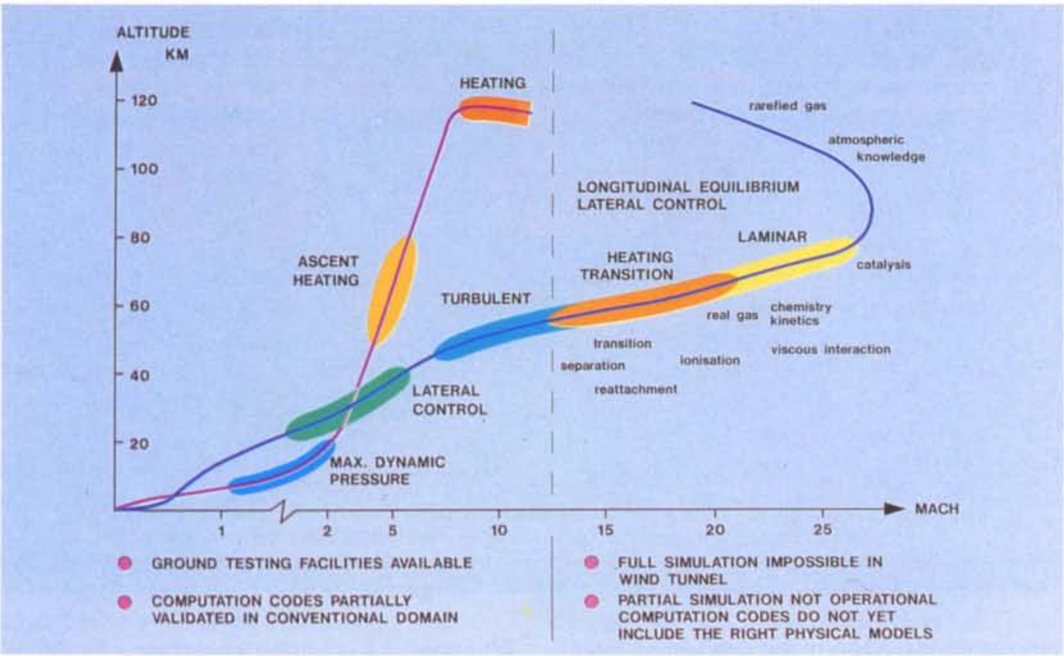

Figure 10 — Hermes aerothermal challenges

Other influences induced by the launcher, such as acoustic noise and vibration, will be minimised by placing the spaceplane on top of the launcher, and thus as far as possible from the motors and booster outlets.

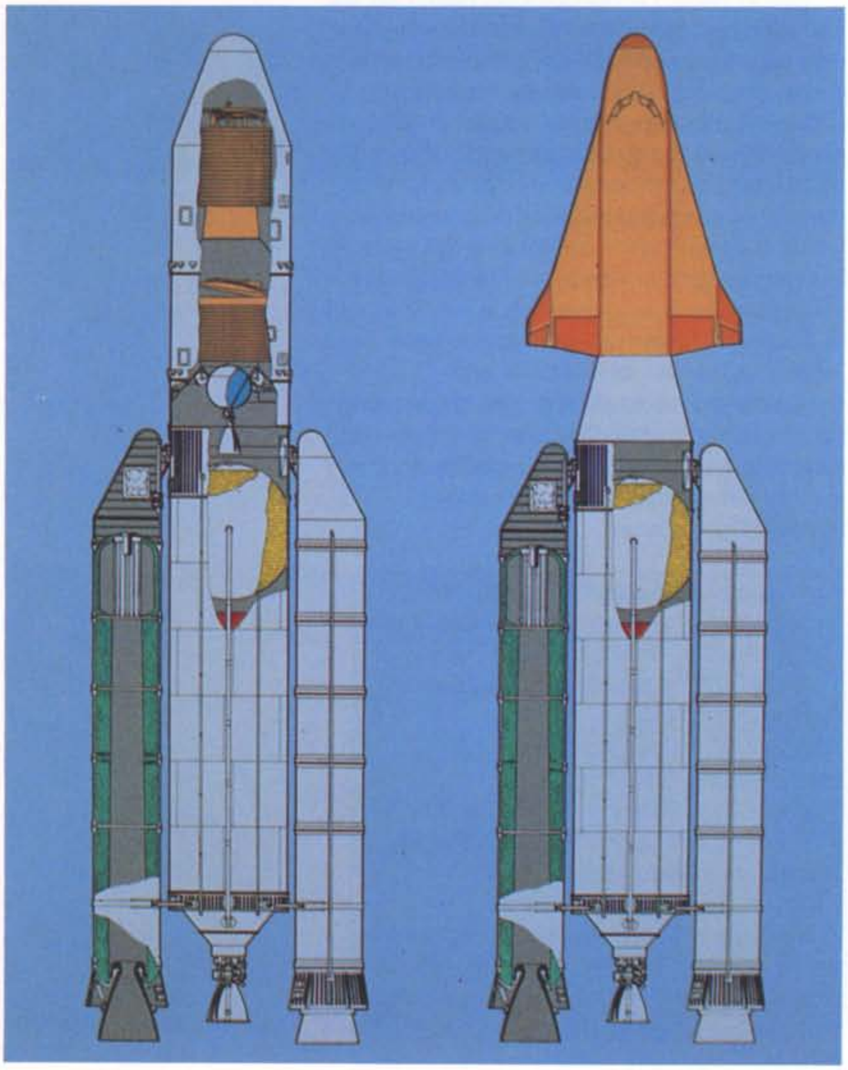

Figure 11 — Ariane-5 in autonomous and Hermes configurations

However, these influences still represent important design drivers.

Reentry from orbit

The spaceplane's reentry from orbit, which involves braking from Mach 25 to some 300 km/h, dictates its aerodynamic design, and has a dimensioning influence on its structure, thermal protection and control, and on its flight-control systems. During the braking process, excessive heating and mechanical loading have to be carefully avoided.

The optimal design criteria for the various speed and altitude (hence air-density) domains of the spaceplane's mission are different and often contradictory. Particularly critical is the transition from the orbital flight phase, with three-axis thruster-controlled attitude control, to the aerodynamic flight phase relying solely on Hermes' aircraft-type control surfaces.

To find the optimum compromise for the Hermes design, research into the behaviour of gases at high temperatures and pressures has to be performed, as well as wind-tunnel tests in various speed, air-density and temperature domains. All must be accompanied by mathematical calculations, requiring large computer facilities. Four iterations are foreseen in the Development Programme, each of which will result in an updating of the spaceplane's shape (called shapes 0, 1, 2, and 3).

Qualification of Hermes' aerodynamic properties will be performed in two steps: the subsonic properties in a series of approx. 15

subsonic tests, in which Hermes will be dropped from a carrier aircraft, and the reentry behaviour during the first unmanned orbital flight.

The choices of materials for thermal protection and structures, the determination of optimum reentry trajectories, the design of the flight control system, of the structure and of the thermal-protection systems, are all closely linked to the results of the aero-thermal development work.

Figure 12 shows the major Hermes aero-thermal test facilities and their planned availability. Two categories of facilities can be distinguished: wind tunnels for testing the spaceplane's properties in the super- and hypersonic ranges, and plasma chambers supporting the thermal-protection development and verification effort.

Software development approach
All functional interfaces between the Hermes System and Columbus, the DRSS, Ariane-5, and the IOI ground segment will be controlled by computer software onboard the spaceplane and on ground-based computers.

The size and complexity of the software to be handled and controlled in this operational environment by far exceed those of software encountered in previous European space programmes, not to mention the novel interface complexity, safety/reliability, operability and maintainability requirements, and the need for sophisticated rendezvous and docking capabilities.

The primary goals are:
— To exploit the functional commonalities, re-usability and standardisation of software, in order to save on development and maintenance effort and increase software reliability. This requires a suitable breakdown of software into components common to the various users, and the introduction of common standards to be used by all software-development authorities.

A so-called 'Hermes Software Development Environment' (HSDE), compatible with the ESA standards currently under definition for a European Space Software Development Environment (ESSDE), is presently being set up, including a common programming language (Ada). Further standardisation is under investigation for computer and operational interfaces, specific products, development tools, and procedures.

— To use software test-beds and simulators extensively in order to allow hardware and software development and qualification to proceed irrespective of the availability of actual hardware. Standardised onboard software test-beds (Banc de Validation Logiciel, BVL) will be used at several sites for development and partial qualification, which will be completed later via more extended ground testing on the 'iron-bird' (BIS) and the full functional model (MI). The operational system electrical ground-support equipment (Banc de Control Hermes, BCH) is also expected to play an important role during software development and qualification.

— To use early software prototyping (i.e. development of throwaway software 'breadboards' for implementing significant parts of the end products) not only for the assessment of critical areas and

	FACILITY	EXISTING	TO BE MODIFIED	NEW	
AERODYNAMIC	LOW SPEED WIND TUNNELS	AMD-BA VELIZY (F) EMMEN (CH) HERS - CEAT (F)			MACH 0.6 TO 6
	HIGH SPEED WIND TUNNELS	HST/SST - NLR (NL) SIGMA 4 (F)			
	COLD WIND TUNNELS	FFA HYP 500 (S) H2K DFVLR (G)	S4 MODANE (F)		HYPERSONIC
	HOT WIND TUNNELS	CALSPAN (US)	LONGSHOT VKI (B) RW-TH-AACHEN (G)	F4 ONERA (F) HEG - DFVLR (G)	
	RAREFIED GAS WIND TUNNELS	VG1 - DFVLR (G) SR3 - CNRS (F)			
TH. PROT	PLASMA CHAMBERS		P3K (G)	SIROCCO (I) SIMOUN (F)	

Figure 12 — Major aero-thermal test facilities for Hermes

refinement of operational requirements, but also for early interface definition and personnel training in the standardised development environment.

- To employ a software-system development concept based on a mixture of interface-representative software prototypes and deliverable software in order to provide flexibility in development planning and qualification.

- To assess software safety implications, ranging from strict control of development procedures to specific methodologies and diversified implementations of critical functions

- To persue a software system architecture based on so-called 'software replaceble units', optimised for replacement, maintenance, and reverification.

Crew safety
Crew safety will pay a major role in the design and development of the Hermes System, driving such critical factors as: reliability, quality of parts and materials, redundancies in design, allowable stress factors, and operational constraints.

Strict verification and control methods are also imposed by safety considerations, with representatives of an independent safety organisation represented in the various Boards and in reviews. In addition, ESA and CNES have established an independent Safety Advisory Committee (HESAC), in which leading experts from several European countries are participating (see ESA Bulletin No. 54, p. 78).

The meeting of safety requirements is the subject of continual analyses, which include the safety constraints during the launch phase of the Ariane-5/ Hermes composite. These analyses have already shown that this phase constitutes a particular hazard, and a crew escape and rescue capability that will be effective both during launch-pad operations (up to separation of the solid boosters from the launcher) and during the final approach and landing phase is planned. This system will allow the crew to eject from the spaceplane very quickly while it is travelling at speeds up to Mach 5 and at altitudes of up to 50 km.

The development and qualification of the crew escape system constitutes a substantial development programme in its own right, due to the complex interfaces between the plane and the rescue system, the mechanical loads encountered during ejections at high speeds and under high accelerations, the aerodynamic loads during ejections at low altitudes, and the stabilisation of the rescue system needed after ejection. Several different systems are currently under investigation, with an ejectable cabin serving as the reference baseline. The final decision on the system to be flown will be taken in the course of Phase-1.

Conclusion
The Hermes Programme includes a considerable number of elements new to the European space community, in a variety of areas ranging from the specialist management techniques that have to be applied in such a large and complex programme, to new technologies and techniques, to the verification and qualification of a variety of complex interfaces with other space and ground-based systems. Ultimate success will depend on the active participation and cooperation of European industry, particularly in the areas of: management, system design, technological research and development, aircraft and spacecraft design, design and implementation of large software systems, software standardisation, and aircraft and spacecraft verification methods.

The combination of all of these disciplines, with the different backgrounds, methodologies, procedures and standards applied so far by the companies in the many different participating countries, constitutes a tremendous challenge for the European space community. Eleven European countries — Canada is expected to join shortly — and more than 140 industrial companies and national institutes are already involved in the Hermes Programme, working together to meet this challenge.

Planetary Science and Engineering

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1989 will be a year of significant events in terms of planetary exploration. After a gap of more than 10 years — the last launch was on 8 August 1978 — the United States will again launch a spacecraft towards a planet. The Magellan Venus radar mapper is manifested for a Shuttle launch on 28 April 1989. On 25 August 1989, Voyager-2 will be the first spacecraft to fly by Neptune.

Having focussed exclusively on Venus for the past 15 years, the Soviets are now concentrating on Mars. First in a series of missions to this planet will be the Phobos-2 spacecraft, which will be placed in an orbit around Mars on 29 January 1989 and will subsequently encounter the moon Phobos on 8 April 1989.

In 1989, ESA will also be entering the field of planetary exploration, having approved at the end of 1988 its part of the joint NASA/ESA Cassini mission to Saturn and its moon Titan. ESA will provide a probe, called 'Huygens', which will enter the Titan atmosphere.

Last but not least, the Japanese Institute of Space and Astronautical Science (ISAS) will decide on their first planetary mission in May 1989.

Introduction

Planetary exploration began only 26 years ago with the successful Venus flyby of the Mariner-2 spacecraft in December 1962. By August 1989 unmanned space probes will have flown by, orbited or landed on eight of the nine Solar System planets. The Moon, our nearest neighbour, has already been visited by man and samples of lunar material carried back to Earth.

Almost all of today's knowledge about the planets was obtained during these planetary encounters. Colourful close-up photographs of the planetary surfaces and the searches for any forms of extraterrestrial life — so far unsuccessful — have excited scientists and laymen alike. As a byproduct of these visits, images of the Earth have been obtained from far away (Fig. 1), showing its beauty and increasing our awareness of its vulnerability.

The nine planets are notable for their individual, widely varying characteristics, but they also show similarities that allow them to be classified into two groups. The planets of the inner Solar System — Mercury, Venus, Earth and Mars — all have densities of between 3.9 and 5.5 g/cm^3; they are solid objects that may be described as 'rocky' in general constitution. The planets of the outer Solar System — Jupiter, Saturn, Uranus, Neptune and Pluto — all have densities of between 0.7 and 1.7 g/cm^3; they are termed 'gaseous' planets.

With the exception of Mars, the sizes of the planets follow a regular pattern. From Mercury, the innermost planet, they increase towards Jupiter and they decrease from Jupiter to Pluto, the outermost planet. The planets all move around the Sun in the same direction — anti-clockwise if viewed from the ecliptic north or from 'above' (Fig. 2) — in more or less the same plane, and in nearly circular orbits. These are in fact astonishing similarities and they point to a common origin for the planets. How the Solar System formed, with the Sun in the centre and its nine planets, is now an important field of research in its own right.

Formation of the Solar System

Based on radioactive dating of meteorites and lunar samples, there is ample evidence that the solid bodies in the Solar System formed about 4.6 billion years ago. For comparison, it is estimated that the Universe is between 15 and 20 billion years old.

Already in 1644, the French philosopher and scientist R. Descartes proposed that the Sun and the planets had originally formed from a vast nebula of gas. He envisaged the planets as being products of the condensation of

* This article is based on a talk given by Prof. R. Lüst at the Seventh Convocation of Engineering and Technical Sciences, Sydney, Australia, 12—14 October 1988.

Figure 1 — The Earth as seen from Apollo 8, emerging from behind the Moon

'vortices' that developed in the primitive gaseous nebula as it contracted. In 1755, the German philosopher I. Kant adopted Descartes' theory, but suggested in addition that the gaseous nebula had become very hot during the condensation process. In 1976, the French scientist P. Laplace further improved the model by suggesting that the primitive nebula had initially been rotating before contraction began.

Today, Descartes, Kant and Laplace have been proved right: the Solar System is supposed to have originated from the consolidation of an interstellar cloud. In the forties and fifties C.F. von Weizsäcker and his co-workers investigated the behaviour of such a cloud on the basis of hydrodynamic turbulence, taking into account the rotation and gravitation. In the meantime, considerable improvements have been achieved in the theoretical understanding of the formation of the Solar System.

The interstellar cloud finally began to shrink under the influence of its own gravity. As the concentration process progressed, the cloud took on the shape of a flat disc, which rotated faster and faster. In the most central part, the density and the temperature increased more and more and the 'Proto-Sun', containing most of the material, was established, while in the outer part of the disc the various planets were formed.

In the modern versions of the nebular hypothesis, it is assumed that the primordial cloud was composed primarily of hydrogen and helium, but it also contained gases such as ammonia, methane, and water vapour. Interspersed within the vapours of the interstellar cloud were dust grains made up of metals, silicates, and other heavy elements.

The temperature gradient across the disc resulted in the condensation of different materials at different distances from the Sun. The warm regions close to the Sun became rich in high-temperature refractory materials, such as aluminium oxides, metallic iron, and silicate minerals. The highly volatile materials such as water, ammonia and methane remained largely in a vapour state in this part of the nebular disc. The high-temperature materials that condensed in this region of space later formed the inner planets Mercury, Venus, Earth and Mars. The cooler regions of this disc, more distant from the Sun, were of sufficiently low temperature for large amounts of more volatile materials, such as carbonates, water and organic molecules, to be able to condense. These lower-temperature materials eventually formed the cores of the giant planets Jupiter and Saturn, and their moons. The very outermost frigid regions of the disc were so cold that they acquired large concentrations of frozen ammonia and methane. The outer planets Uranus, Neptune and Pluto are largely made up of this frozen material.

In the disc, the newly condensed metallic particles and the globules of water, methane and ammonia must have undergone frequent collisions with each other. Many of these grains stuck to each other and formed larger and larger particles, first centimetre-sized and later kilometre-sized. The asteroids between the orbits of Mars and Jupiter and the comets are believed to be remnants of this early phase in the formation of the Solar System. Collisions later fragmented these asteroid-sized objects into thousands of smaller pieces or resulted in the accumulation of many thousands of the asteroid-sized masses into larger bodies. The largest bodies eventually became the planets.

The newly formed terrestrial planets must have been far more uniform in their internal composition than they are now. The release of gravitational energy, the heat generated by the decay of radioactive elements, and the heat produced by the steady impacts of large asteroid-sized objects, caused the temperatures of the planets to rise rapidly. The heating was sufficiently intense to melt the planets and to drive away any atmospheres that had been initially acquired from the solar nebula. The atmospheres of Venus, the Earth and Mars that we know today are secondary atmospheres, produced by outgassing of planetary material. During the early, molten phase, the dense metallic material sank to the centre of each planet to form a core, leaving the lighter silicate minerals at the surface to form an outer crust. This internal differentiation was probably completed about 4.2 billion years ago.

The newly formed planets were bombarded by frequent collisions with smaller bodies that had not been initially swept up into proto-planetary clusters. In this way, the Solar System was gradually cleared of smaller asteroid-sized masses. The surfaces of most of the solid worlds in the Solar System still bear the scars of these ancient impacts. The most intense period of meteoric bombardment seems to have ended about 4 billion years ago. Since then, most planetary history has occurred within the planets themselves as their radioactively driven heat engines have wound down. On Earth, the chemical evolution led to the origin of life, with the earliest records (single-cell micro-organisms) dating back 3.5 billion years.

Engineering of space probes

Understanding the formation and evolution of our Solar System is one of the main goals of planetary exploration. Until quite recently, we could only study the planets by looking at them from the Earth's surface, using telescopes of ever-increasing power and sophistication. With the advent of deep-space missions, it is now possible to send instrumented probes to explore these planets at close range.

Apart from the exploration of the Moon, all planetary exploration to date has been carried out with unmanned spacecraft, which may be regarded as self-supporting, half-automated, half remotely-controlled robots in space. These spacecraft can be regarded as self-contained systems, with power, telemetry tracking and command, attitude and orbit control and measurement, thermal-control, and data-handling subsystems.

Power is usually derived from arrays of solar cells. In interplanetary space, at a distance of 1 AU from the Sun and with a 90° solar aspect angle, an 1 m^2 array generates about 120 W of power. The power produced by the array decreases with the square of the distance from the Sun. Missions to Jupiter and beyond would therefore require very large solar-cell arrays, which would be very heavy. Consequently, radio-isotope thermo-electric generators are used for missions to the outer planets. The decay of radio isotopes, such as Plutonium 238, generates heat, which is transformed into electrical energy with 10% efficiency by using thermo-electric elements. A radio-isotope device weighing 50 kg can generate 300 W of power.

The telemetry, tracking and command subsystem also includes the antennas. All commands from the ground station to the spacecraft and all the telemetry from the spacecraft to the ground station, consisting of housekeeping and science data, are transmitted via this subsystem. The spacecraft is tracked to determine its position in space and its orbit. The distance from the ground station is determined by measuring very precisely the time taken for a signal to travel to the spacecraft and back. Depending on whether the spacecraft is travelling away from or towards the ground station, the frequency of the received signal is decreased or increased slightly; this, together with orbital calculations, provides a measure of the spacecraft's velocity. A typically

Figure 2 — Sizes and orbits of the nine planets in the Solar System

achievable positional accuracy for a spacecraft several astronomical units away from the Earth would be 100 km.

Tracking is necessary for spacecraft navigation, but it can also be useful for scientific purposes. When a spacecraft passes a planet or a planetary moon, the spacecraft's orbit is deflected. From this deflection, the planet's or the moon's mass, and hence its density, can be determined. For bodies that have no satellites, like Mercury and Venus, this is the only means of determining this fundamental parameter, which is the most important clue to the body's interior structure.

The spacecraft are usually equipped with several antennas, ranging from low- and medium-gain antennas with omni-directional characteristics to high-gain antennas. High-gain antennas have the shape of parabolic dishes, 1 to 2 m in diameter. They are used for the transmission of high data rates (required by imaging instruments) over large distances. Their antenna beams are only a few degrees wide for telecommunications in the S-band (around 2.3 GHz) and less than 1° wide for telecommunications in the X-band (around 8.4 GHz). This makes frequent updating of spacecraft attitude a must.

The attitude and orbit control and measurement subsystem includes an onboard propulsion system and various sensors for determining the spacecraft's attitude, which must be kept stable at all times. This can be achieved either by three-axis stabilisation or by spin stabilisation. Various thrusters on the spacecraft are used in different combinations to change its orbit, its attitude, or its spin rate. Propulsion systems often use mono-propellant hydrazine with nitrogen as pressurant. Most of this propellant is usually used for orbit-correction manoeuvres. The spacecraft's attitude in space and its spin rate are determined by using Earth and Sun sensors and star mappers.

The temperature of a spacecraft has to be controlled within a range of about −20° to +40°C, which is colder than the interplanetary environment close to the Sun and much warmer than far away from it (if the spacecraft carries batteries, the local temperature must not fall below 0°C). This temperature range has to be maintained throughout the spacecraft, which can be a problem with three-axis-stabilised spacecraft, which tend to get much warmer on the sunward side and much colder on the anti-sunward side, and even for spinning spacecraft if their spin axis is not oriented perpendicular to the ecliptic. Passive means of control include designing spacecraft surfaces with different ratios of absorptivity to reflectivity; white-painted parts have a low ratio, and tend to be cold and optical surface reflectors have particularly low ratios. Active means of control include heaters, shutters and louvres.

The data-handling subsystem provides the means for transmitting the housekeeping and payload science data to the ground, and for the ground and on-board control of spacecraft and payload operations. Housekeeping data are transmitted at a low data rate. They contain all the information necessary to monitor the health of the spacecraft sub-systems and the scientific payload, such as temperatures and voltages. Scientific data are transmitted at a high data rate. On-board data storage is required if scientific observations have to be made continuously over a longer period than the ground receiving station is available, or if scientific phenomena have to be observed at a higher temporal or spatial resolution than the capacity of the telemetry link would allow. Up to now, only tape recorders have been used on interplanetary spacecraft; bubble and semiconductor memories are now alternatives.

In interplanetary space, the distances between the spacecraft and the ground stations, and consequently the round-trip signal times, are considerable, requiring a large degree of autonomy in the data-handling subsystem. For example, during the Voyager-2 encounter with Neptune later this year, it will take more than eight hours to send a command to the spacecraft and verify that it has been properly executed.

A spacecraft designed for planetary exploration typically carries a scientific payload weighing about 100 kg and consisting of some ten different instruments. The instruments selected vary from mission to mission and can be broadly divided into remote-sensing and in-situ measuring types. The remote-sensing instruments include cameras, spectrometers for different wavelength ranges, and radar mappers. The in-situ type include gas and dust mass-spectrometers, and particles and fields experiments. The instruments in each of these categories, while similar in overall characteristics and measuring techniques, are all different, being optimised for different missions and reflecting the advances in technology. The same holds for the spacecraft subsystems.

Both the instruments and the subsystems can be considered as building blocks, which are used in different combinations to produce highly specialised spacecraft for planetary exploration.

Some interplanetary spacecraft have carried atmospheric entry probes or balloons to Venus and hard or soft landers to Mars or Venus. These probes or landers can be considered as fully-automated small spacecraft in their own right, with their own power-supply (batteries), telemetry, thermal-control, and data-handling subsystems. Instruments flown on probes and landers include cameras, gas mass-spectrometers, density and temperature sensors, and even small laboratories for making in-situ chemical analyses.

Up to now, all spacecraft for planetary exploration have been launched by rockets. In the future, such spacecraft will also be launched from the Space Shuttle. The most important means of transfer from Earth to another planet is a transfer orbit that requires minimum fuel. For the case of two circular and coplanar orbits (Earth and target planet), the minimum-fuel transfer orbit is an ellipse that forms a tangent to the two circles, called a 'Hohmann transfer' (after W. Hohmann, who discovered this fact in 1925 already).

For a mission to Mars, for example, a Hohmann transfer requires that the Earth be at the perihelion of the ellipse at the time of launch and Mars at its aphelion at the time of arrival (Fig. 3). At the time of launch, Mars will still be far away from the point of encounter, corresponding to the time it takes the spacecraft to travel from the Earth to Mars. This particular relative position between Mars and Earth occurs every 25.5 months, i.e. a 'launch window' for a mission to Mars opens up every 25.5 months.

Launch windows for missions to Venus occur every 19 months, to Jupiter every 13 months, and to Saturn every 12.5 months. Launch windows to the outer planets occur roughly every 12 months, because their orbital periods are so much longer than that of the Earth.

Hohmann transfer orbits have been used for all previous missions to Mars, Venus and Jupiter, but they are not optimal for missions to the outer planets, for which considerable fuel can be saved by using the gravitational pull of one of the major planets. Such a close flyby is called a 'gravity-assist manoeuvre' and works most effectively with Jupiter. Future planetary missions will make more and more use of fuel-saving gravity-assist manoeuvres, even with the smaller planets, at the expense of increased mission duration. The most spectacular exploiter to date of gravity-assist manoeuvres is NASA's International Cometary Explorer (ICE) mission. A series of five lunar gravity-assist manoeuvres (Fig. 4) were used to move the ICE spacecraft from a geocentric to a heliocentric orbit, carrying it first to Comet

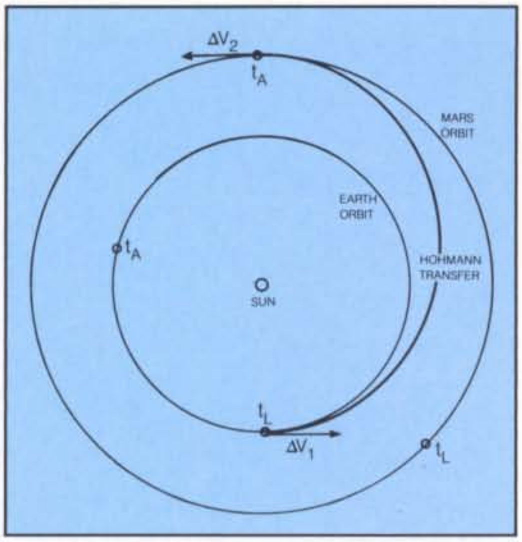


Figure 3 — Hohmann transfer orbit from the Earth to Mars. At the two junction points, impulses delta-V_1 and delta-V_2 are applied in the direction of motion. The relative positions of the Earth and Mars are indicated at the times of launch (t_L) and arrival (t_A)

Table 1 — US planetary missions

Mission	Launch date	Encounter*
Mariner-2	27 August 1962	Venus flyby, 14 December 1962
Mariner-4	28 November 1964	Mars flyby, 14 July 1965
Mariner-5	14 June 1967	Venus flyby, 19 October 1967
Mariner-6	24 February 1969	Mars flyby, 31 July 1969
Mariner-7	27 March 1969	Mars flyby, 5 August 1969
Mariner-9	30 May 1971	Mars orbiter, 13 November 1971
Pioneer-10	3 March 1972	Jupiter flyby, 3 December 1973
Pioneer-11	6 April 1973	Jupiter flyby, 3 December 1974 Saturn flyby, 5 August 1979
Mariner-10	3 November 1973	Venus flyby, 5 February 1974 Mercury flybys, 29 March 1974, 21 September 1974, 16 March 1975
Viking-1	20 August 1975	Mars orbiter, 19 June 1976 Mars soft lander, 20 July 1976
Viking-2	9 September 1975	Mars orbiter, 7 August 1976 Mars soft lander, 3 September 1976
Voyager-1	5 September 1977	Jupiter flyby, 5 March 1979 Saturn flyby, 12 November 1980
Voyager-2	20 August 1977	Jupiter flyby, 9 July 1979 Saturn flyby, 25 August 1981 Uranus flyby, 24 January 1986 Neptune flyby, 25 August 1989
Pioneer Venus-1	20 May 1978	Venus orbiter, 4 December 1978
Pioneer Venus-2	8 August 1978	Four Venus probes, 9 December 1978

* For flybys: date of closest approach
For orbiters: date of arrival in orbit
For entry capsules/landers: date of entry/landing.

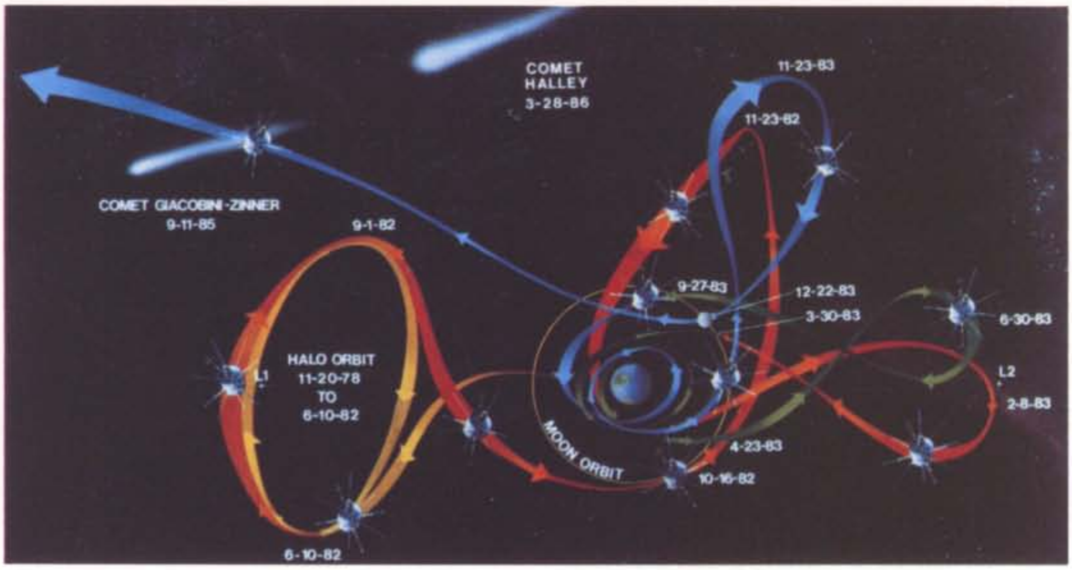


Figure 4 — The extremely complex orbit of the ICE spacecraft, which was changed from geocentric to heliocentric using five lunar gravity-assist manoeuvres

Table 2 — Soviet planetary missions

Mission	Launch date	Encounter*
Venera-2	12 November 1965	Venus flyby, 27 February 1966
Venera-3	16 November 1965	Venus hard lander, 1 March 1966
Venera-4	12 June 1967	Venus atmosphere entry probe, 18 October 1967
Venera-5	5 January 1969	Venus atmosphere entry probe, 16 May 1969
Venera-6	10 January 1969	Venus atmosphere entry probe, 17 May 1969
Venera-7	17 August 1970	Venus lander, 15 December 1970
Mars-2	19 May 1971	Mars orbiter, 27 November 1971 Mars lander, 27 November 1971
Mars-3	28 May 1971	Mars orbiter, 2 December 1971 Mars lander, 2 December 1971
Venera-8	27 March 1972	Venus lander, 22 July 1972
Mars-4	21 July 1973	Mars flyby, 10 February 1974
Mars-5	25 July 1973	Mars orbiter, 2 February 1974
Mars-6	5 August 1973	Mars lander, 12 March 1974
Mars-7	9 August 1973	Mars flyby, 9 March 1974
Venera-9	8 June 1975	Venus orbiter, 22 October 1975 Venus lander, 22 October 1975
Venera-10	14 June 1975	Venus orbiter, 25 October 1975 Venus lander, 25 October 1975
Venera-11	9 September 1978	Venus flyby, 25 December 1978 Venus lander, 25 December 1978
Venera-12	14 September 1978	Venus flyby, 21 December 1978 Venus lander, 21 December 1978
Venera-13	30 October 1981	Venus flyby, 1 March 1982 Venus lander, 1 March 1982
Venera-14	4 November 1981	Venus flyby, 5 March 1982 Venus lander, 5 March 1982
Venera-15	2 June 1983	Venus orbiter, 10 October 1983
Venera-16	7 June 1983	Venus orbiter, 14 October 1983
Vega-1	15 December 1984	Venus flyby, 11 June 1985 Deployment of balloons, 11 June 1985 Descent-probe landing, 11 June 1985 Comet-Halley flyby, 6 March 1986
Vega-2	21 December 1984	Venus flyby, 15 June 1985 Deployment of balloons, 15 June 1985 Descent-probe landing, 15 June 1985 Comet-Halley flyby, 9 March 1986

* For flybys: date of closest approach
For orbiters: date of arrival in orbit
For entry capsules/landers: date of entry/landing.

Giacobini-Zinner and then on to Comet Halley.

The launch-energy requirements, technical complexity, and hence the costs for planetary missions are considerable, and only the USA and the Soviet Union have so far been able to mount a planetary-exploration programme. To increase the scientific return, to add redundancy to the missions, and at the same time to keep the costs down, both nations have adopted the concept of flying several spacecraft of the same type to a given planet: the USA, the Mariner, Pioneer, Viking and Voyager spacecraft; the Soviets the Venera, Mars and Vega spacecraft (Tables 1 and 2).

The Soviets have concentrated their efforts on the exploration of Venus and Mars. They have launched a series of highly successful missions to Venus, including the first Venus orbiter, the first Venus atmosphere entry probe, and the first Venus lander. The Soviet missions to Mars have not proved as successful, but have nevertheless included the first Mars lander.

In the first decade of planetary exploration, the United States also concentrated on missions to Venus and Mars, but has also made successful flybys of Mercury, Jupiter, Saturn and Uranus and, in August 1989, will conduct a Neptune flyby.

Recently, the Japanese and the Europeans joined the Americans and Soviets in the exploration of Solar System bodies, by sending space probes to encounter Comet Halley. This is the first solar system body to have been encountered (almost simultaneously) by six spacecraft from four agencies: Vega-1, Vega-2, Giotto, Suisei, Sakigake and ICE. The desire to coordinate these Halley missions led to the formation of the Inter-Agency Consultative Group for Space Science (IACG), with NASA, Intercosmos, the Japanese ISAS and ESA as members. The IACG still exists and is now coordinating a number of solar-terrestrial science missions being conducted by these four agencies.

Figure 5 — The Y-shaped cloud pattern of Venus, as seen in the ultraviolet by the camera on the Pioneer-Venus Orbiter spacecraft

Milestones in planetary exploration

Mercury

Only one spacecraft has visited Mercury so far, namely Mariner-10. It made three flybys of Mercury in 1974/75 and was able to photograph about 50% of its surface. Mercury is very similar in character to the Moon, its surface being dominated by craters, impact basins and smooth plains and with no significant atmosphere. The surface environment of Mercury is probably the harshest of all planets in the Solar System: 430°C on the day side, −170°C on the night side. Mercury's rotational period is 59 days, which is exactly two-thirds of its orbital period, and consequently one Mercury 'day' lasts 176 terrestrial days.

Venus

In contrast to Mercury, the atmosphere of Venus is very dense, completely shielding the planet's surface from view. At visible wavelengths, the clouds seem to form a uniform blanket over the whole planet. At ultraviolet wavelengths, however, a characteric Y-shaped pattern of clouds becomes visible (Fig. 5), providing evidence for considerable zonal winds at high altitudes. At radar wavelengths, the atmosphere becomes transparent and the surface of Venus can be imaged. Radar images with horizontal resolutions of 10—20 km have been obtained from the Pioneer Venus Orbiter. The best images to date, with resolutions of just a few kilometres, were obtained in 1984 with the synthetic-aperture radars on the Venera-15 and -16 spacecraft (Fig. 6).

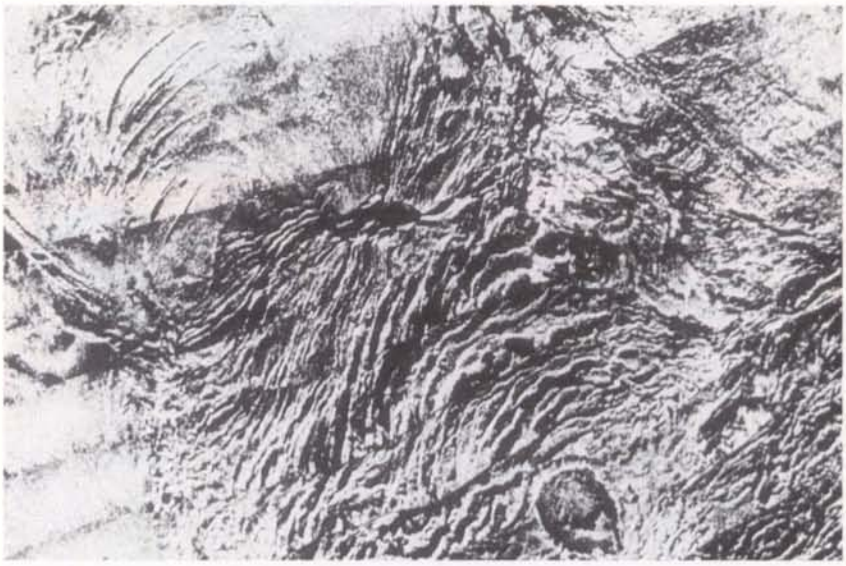


Figure 6 — Detailed image of the surface of Venus, made by the synthetic-aperture radar imagers on the Venera-15 and -16 spacecraft

The first-ever image (Fig. 7) taken from the surface of Venus was captured by the soft-landing spacecraft Venera-9 in 1975. It shows boulders, typically tens of centimetres across, strewn about a rocky landscape.

The temperature on the surface of Venus is incredibly high; about 460°C was recorded by Venera-7 in December 1970. It was the first spacecraft to land on the surface of Venus and survived long enough to make such a measurement.

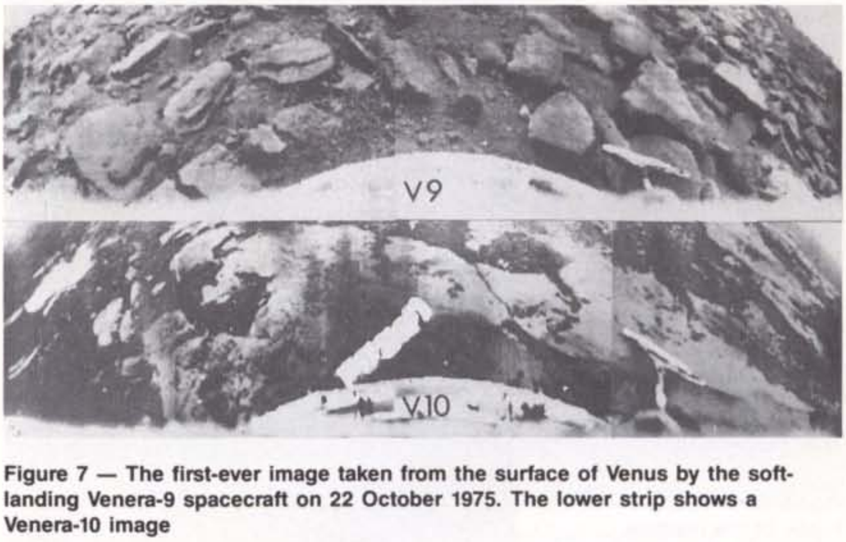


Figure 7 — The first-ever image taken from the surface of Venus by the soft-landing Venera-9 spacecraft on 22 October 1975. The lower strip shows a Venera-10 image

The Moon

Our Moon has been extensively explored by instruments on orbiters, hard and soft landers, and rovers. Man has landed on the Moon six times, between July 1969 and December 1972, and nearly 1000 kg of lunar material has been returned to Earth-based laboratories for detailed analysis. Figure 8 shows astronaut Harrison Schmitt examining a huge rock on the Moon.

Figure 8 — Astronaut Harrison Schmitt examining a large rock on the Moon. Two of the Apollo-17 astronauts explored the lunar surface with the aid of an electrically powered buggy, which can be seen parked to the right of the rock

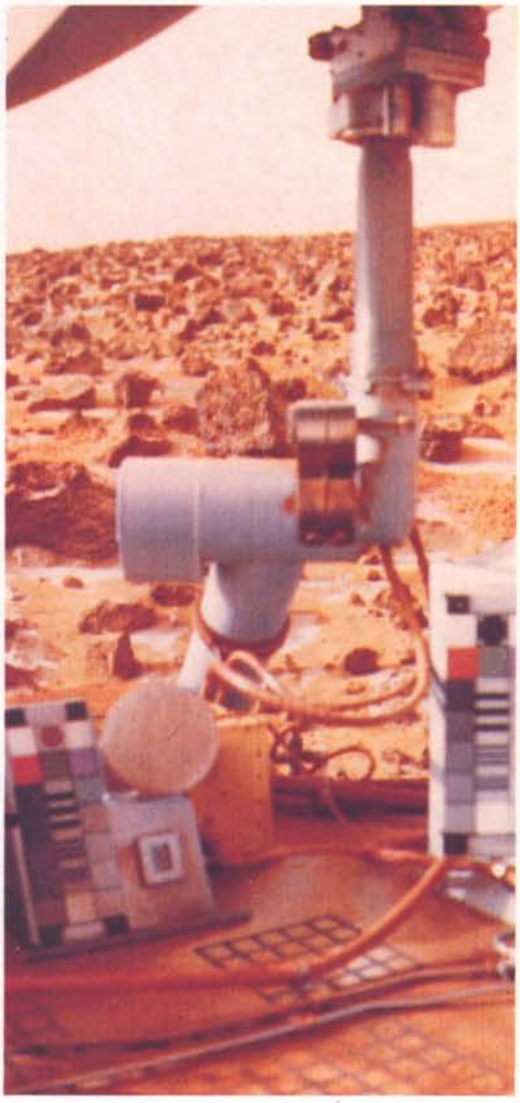


Figure 9 — Frost on the surface of Mars and dust on the surface of the Viking-2 lander are both visible in this picture, taken about one Earth year after the landing

Mars

Like the Venusian atmosphere, Mars' atmosphere is composed mostly of carbon dioxide (CO_2), but it is 10 000 times thinner. Like the Earth's equator, the Martian equator is inclined with respect to the planet's orbital plane, which means that the planet experiences 'seasons' (Fig. 9).

Like the Earth, Mars has two polar caps (Fig. 10), which grow and shrink with the seasons. These caps are composed of water ice, covered by a seasonally variable layer of solid carbon dioxide.

The photographs taken from the Viking Orbiter show a large number of extinct volcanoes in the planet's northern hemisphere, the most prominent being Olympus Mons (Fig. 11). It is 500—600 km across and 25 km high. Judging from the comparative rarity of craters on the slopes of Olympus Mons, it may be only 200 million years old. There is no evidence that any of the Martian volcanoes are still active.

Jupiter

The Voyager-1 and -2 spacecraft approached Jupiter in 1979. Figure 12, taken from a distance of 13 million km, shows Jupiter's southern hemisphere, with the moon Io in the foreground.

The Jovian upper-atmosphere cloud cover exhibits a rich pattern of colours. The highest clouds, 10—30 km below the tropopause, are red; below these are the white clouds, and further down still the brown clouds. The lowest layer of clouds that can be seen is blue in colour and is some 100 km below the tropopause. The substances in the clouds responsible for giving them their characteristic colours are uncertain. Elemental sulphur, phosphorus and even organic molecules

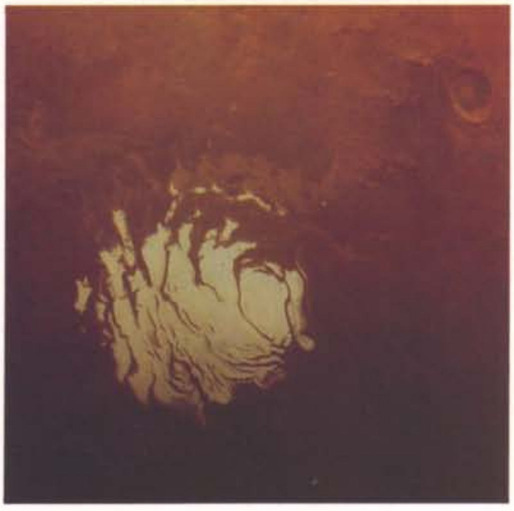


Figure 10 — Viking-2 image of the residual south-polar ice cap of Mars

have been suggested as possibilities. The Jovian atmosphere has violent weather patterns, revealed by the motions of the parallel bands that encircle the entire planet. Between the bands are many turbulent features and vortices, the best known and most prominent being the 'Great Red Spot' at 20°S (Fig. 13).

First observed by R. Hooke in 1664, this massive 50 000 km cloud bank has persisted ever since. The Spot rotates counter-clockwise with a period of about 6 days, and the temperature at its top is substantially colder than that in the surrounding regions. The top of the Great Red Spot is higher than the highest clouds in the surrounding regions. It is probably a gigantic free-wheeling atmospheric disturbance that lies between the counter-flowing north and south boundaries of a zone, more or less analogous to a terrestrial hurricane, but much larger and much longer lasting.

Jupiter's moons
Jupiter has 16 known moons. The four largest — Io, Europa, Ganymede and Callisto — were detected by G. Galilei in 1610, and are referred to as the 'Galilean moons'. The other 12 moons are all much smaller in size — between 10 and 200 km — and may be captured asteroids. The innermost Galilean moon, Io, is one of the most interesting objects in the Solar System. Apart from the Earth, Io is the only body in the Solar System known to have active volcanoes.

Voyager-1 found nine active volcanoes on Io, which are identified by their eruptive plumes; Figure 14 shows the Loki plume, which probably consists of sulphur-dioxide gas and fine dust particles, as an example. Io owes its unique volcanic activity to its location. It is about the same distance from Jupiter as our Moon is from the Earth, but Jupiter is more than 300 times more massive than the Earth, which causes tremendous tides on Io. These tides pull the satellite into an elongated shape, with a several-kilometre-high bulge extending towards Jupiter. This tidal bulge would not contribute to the heating of Io's interior if the moon always kept exactly the same face turned towards the planet, the state towards which it would naturally evolve. However, the gravitational pulls of Europa and Ganymede do not allow Io to settle into an exactly circular orbit. Instead, the Laplace resonance forces Io's orbit to be slightly eccentric, with the result that it twists back and forth with respect to Jupiter on each orbital circuit, while at the same time moving nearer to and then further away from the

Figure 11 — Olympus Mons on Mars

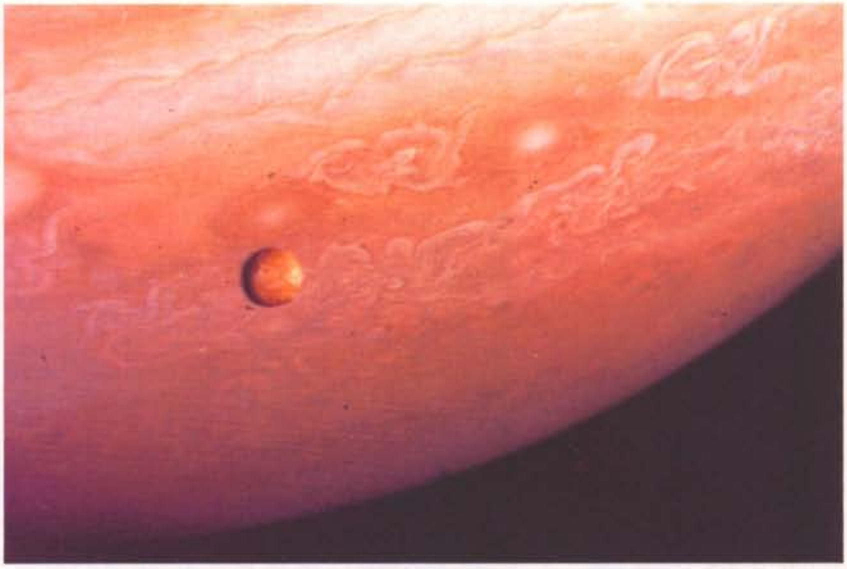


Figure 12 — Southern hemisphere of Jupiter, with the moon Io in the foreground

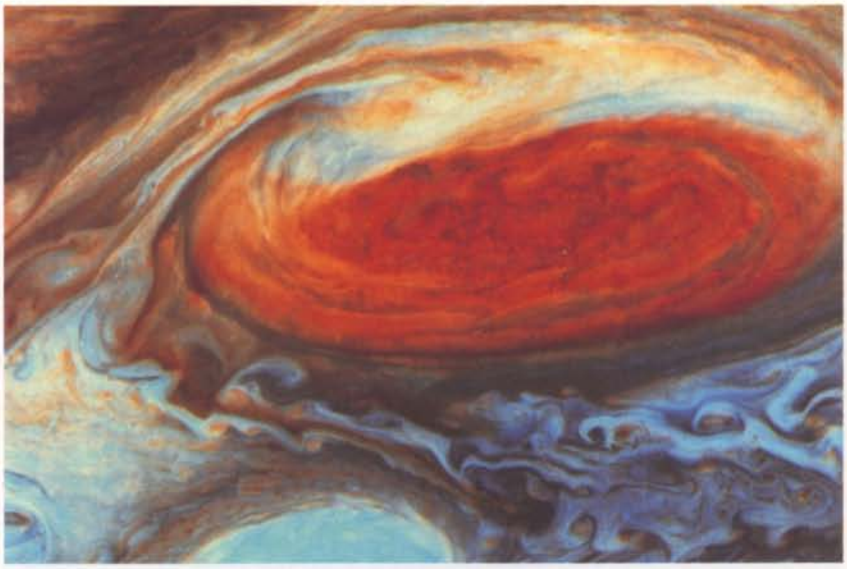


Figure 13 — Jupiter's 'Great Red Spot' and its turbulent surroundings in highly exaggerated colour

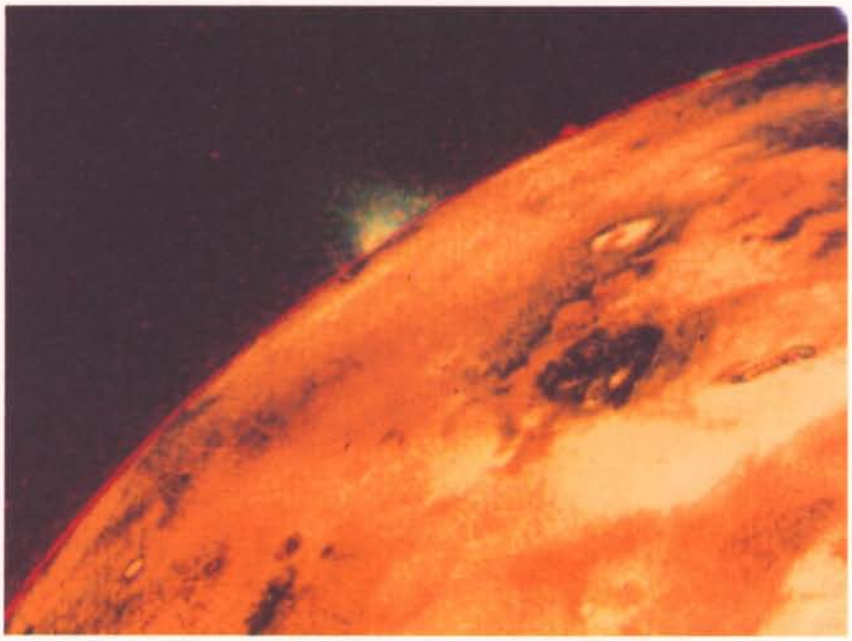


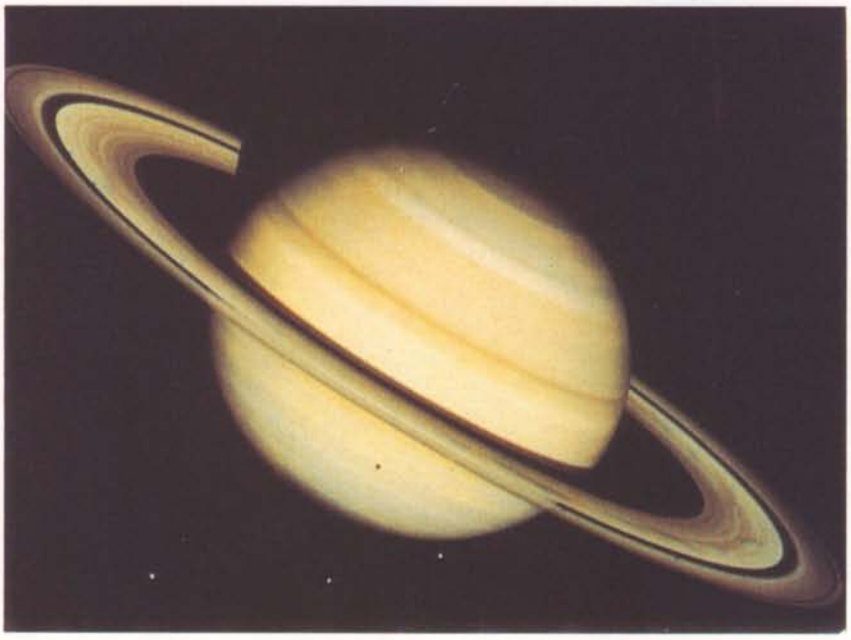
Figure 14 — Eruptive plume of an active volcano on Io. Nine plumes were found on Io; the Loki plume is shown here as an example

planet. The twisting and flexing of the tidal bulge heats Io, melting its interior and providing power to drive its volcanic eruptions.

Saturn

Voyager-1 and -2 approached Saturn in 1980 and 1981. Figure 15 shows Saturn with its ring system and in front the three moons Tethys, Dione and Rhea. The rings were first noticed by Galilei in 1610. Already in the seventeenth century, the Italian astronomer G. Cassini suggested that the rings consisted of a large number of small objects. As we know today, the particles in the rings have sizes ranging from a few metres down to a few microns. On closer inspection, the main rings, labelled A, B, C, D (Fig. 16), are found to consist of thousands of ringlets. The divisions between the rings are probably caused by gravitational interactions with Saturn's moons; in particular, it is thought that Mimas is responsible for the so-called 'Cassini division'.

Figure 15 — Voyager-2 image of Saturn, with its ring system and the three moons Tethys, Dione and Rhea



Saturn's moons

Of Saturn's 17 known moons, nine are rather substantial bodies, with diameters larger than 200 km, Titan being by far the largest. Its diameter is 5150 km, which is 50% larger than that of the Earth's moon. Titan is of particular interest because it is the only moon in the Solar System that has an appreciable atmosphere. Because of the presence of a dense aerosol layer at an altitude of about 200 km, nothing is yet known about Titan's surface (Fig. 19 left).

Voyager-1's measurements in 1980 showed that Titan's atmosphere is surprisingly thick; the surface pressure is 1.5 atm and the surface temperature is −180°C. The dominant component is nitrogen (90%), followed by argon (a few percent) and methane (1%).

Calculations show that the current rate of ultraviolet decomposition of Titan's atmospheric methane is so high all of it should have been destroyed a long time ago. The only possible answer is that there must be an internal source continuously replenishing the methane in Titan's atmosphere. Perhaps that source is a resevoir of liquid or solid methane on the surface that vaporises and replaces the methane in the atmosphere as rapidly as it is destroyed.

Uranus

Voyager-2 encountered Uranus in January 1986. Uranus is rather uniform in appearance because of a thick atmosphere that overlies the levels where clouds form.

One of the Voyager-2 mission's main goals is an encounter with Neptune in 1989. It was this that dictated the Uranus flyby trajectory for a gravity-assist manoeuvre and it so happended that this trajectory took the spacecraft close to Uranus' moon Miranda, which is only 500 km across (Fig. 17). The surface of Miranda shows two types of terrain, one heavily cratered and quite old, the other far less cratered and therefore considerably younger. One explanation is that Miranda was shattered after it differentiated, with different pieces falling back together randomly in a jumbled jigsaw-like manner.

Comets

Since their formation, the nine Solar-System planets and their major moons have evolved quite differently, each developing a characteristic world of its own (Table 3). One class of bodies, however, has evolved very little since the time of Solar-System formation, and these are the comets.

Due to the lack of heating from the Sun and their lack of self-gravitation, these small bodies, orbiting the Sun at large distances, have essentially preserved the chemical and isotopic records of the early Solar System. Sometimes, these bodies, which are only a few kilometres in diameter and too small to be seen from the Earth, approach the Sun where they are heated up. The ices and snows on their surfaces evaporate, taking fine dust particles with them. These two constituents, the gas and the dust, form a transient cometary atmosphere of enormous extent, which is visible from the Earth. About 750 different comets are known today.

In March 1986, the cameras on the European Giotto and two Soviet Vega spacecraft detected a nucleus approximately 16x8x8 km in the centre of Halley's Comet (Fig. 18). The nucleus is covered by a layer of dust and all the activity emanates from only a few active regions on the sunward side of the nucleus. The measurements made of the elemental and isotopic ratios of the gas and dust have confirmed that cometary material is indeed the most primordial in the Solar System.

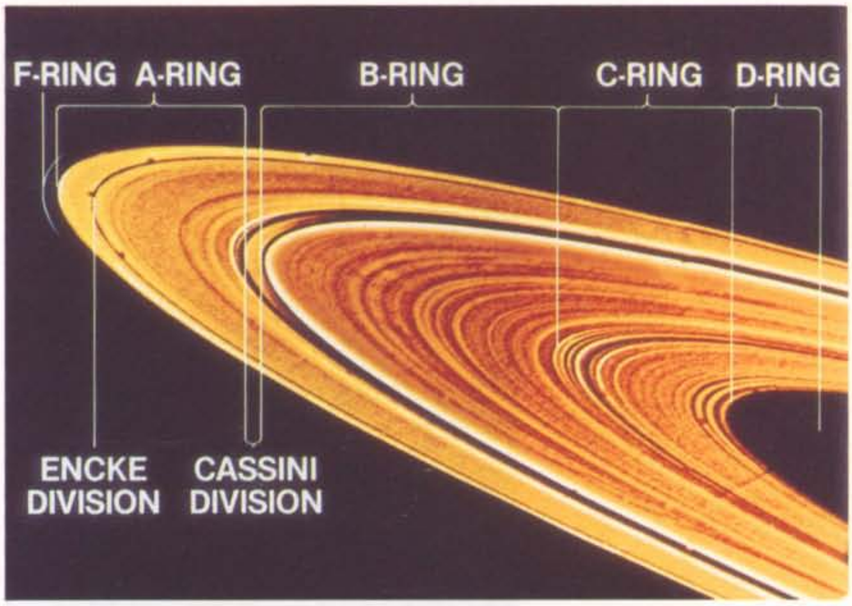


Figure 16 — Details of Saturn's ring system

Figure 17 — Voyager-2 image of Uranus' moon Miranda

Table 3 — Some characteristic parameters of the nine Solar-System planets

	Terrestrial planets				Gaseous outer planets				
	Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune	Pluto
Equatorial radius (km)	2440	6070	6378	3389	71 540	60 330	26 145	25 000	1500-1800
Mean density (g/cm3)	5.43	5.25	5.50	3.93	1.33	0.71	1.24	1.67	0.4-1.0
Number of moons*	—	—	1	0+2	4+12	9+8	5+10	2	1
Magnetic moment (gauss cm3)	~5 × 1022	<1022	8 × 1025	<2.5 × 102 1	1.5 × 1030	4.7 × 1028	4 × 1027	?	?
Surface temperature (°C)	+430 (day) −170 (night)	+460	+20 (day) −15 (night)	−33 (day) −85 (night)	no surface	no surface	no surface	no surface	−230 (day) −270 (night)
Surface pressure (atm)	—	90	1.0	0.008					~0.001
Main atmospheric constituent	—	CO_2 (97%)	N_2 (78%)	CO_2 (95%)	H_2 (81%)	H_2 (89%)	H_2 (74%)	H_2	CH_4
Surface visible from space	yes	no	partially	yes	no	no	no	no	partially?

* Where there is a sum, the first number refers to the major moons and the second to the small moons, which may be captured asteroids.

Figure 18 — Image of the nucleus of Comet Halley obtained by the Giotto Halley Multicolour Camera on 14 March 1986. The Sun is to the left, 27° above the horizontal and 17° behind the image plane

Future planetary exploration

The Solar System is still far from being fully explored and the planetary missions planned for the future promise to be most exciting. In the next 10 to 20 years we will witness the first encounters with asteroids, a more in-depth exploration of Venus, Jupiter, Saturn and its moon Titan, a comet rendezvous, a comet-nucleus sample return and, perhaps most significant of all, a concerted major Mars exploration programme, culminating in the return of Martian samples around the year 2000.

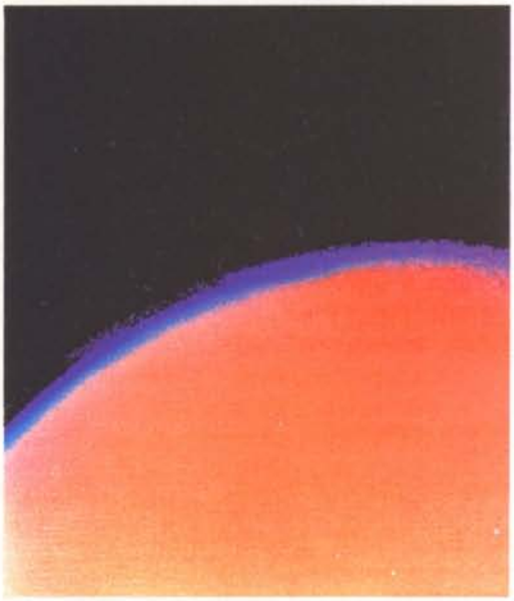
The first encounter with an asteroid will probably occur in the early 1990s. On its way to Jupiter, the Galileo spacecraft will fly by the asteroid Gaspra at a distance of 1000 km in October 1991, and another asteroid in mid-1993. The first dedicated asteroid mission will be the Vesta mission, which is a cooperative project by France (CNES) and the Soviet Union. The two identical Vesta spacecraft, which may be launched in the mid-nineties, will each will fly by four or five small asteroids of different types, and a comet. At one asteroid, each Vesta spacecraft will release penetrators to place instruments on its surface. A Mars gravity-assist manoeuvre will be used to save fuel, and scientific observations will be possible during these close Martian flybys.

A flyby of an asteroid is also planned as part of the US/German cooperative Comet Rendezvous and Asteroid Flyby mission (CRAF). Unlike the fast flybys of Halley's Comet, a cometary rendezvous allows close-up observations to be made over a period of several years, and studies of the varying activity of the nucleus, with high spatial resolution. During the CRAF mission, a penetrator will be shot into the nucleus to measure the chemical composition and physical properties of the crustal and subcrustal material.

It would be most valuable if a sample of cometary material could be returned to Earth-based laboratories for high-precision chemical, mineralogical and isotopic analysis. This is possible during a slow cometary flyby on a free-return trajectory requiring only modest launch energies. A mission of this type had been studied earlier by ESA and is now under study by the Japanese. This Japanese spacecraft, called 'SOCCER' (Sample Of Comet Coma Earth Return), may be launched to a short-period comet in the second half of the 1990s.

The most ambitious cometary mission presently being planned is the NASA/ESA cooperative Comet-Nucleus Sample-Return (CNSR) mission, called 'Rosetta' (the Rosetta stone is an ancient Egyptian tablet bearing inscriptions whose deciphering led to the understanding of hieroglyphics). It is hoped that the analysis of a sample of comet-nucleus material will help us to understand an important part in the early history of our Solar System. The Rosetta mission may not be launched until the year 2000, but it is already being studied as part of ESA's Long-Term Programme for Space Science.

With several exciting missions being devoted to comets and asteroids in the mid- and late



1990s, the detailed exploration of planets is continuing apace. The Magellan mission to Venus is now scheduled for launch in April 1989, having been delayed several years by the tragic 'Challenger' accident. It will be the first US planetary mission since the launch of Pioneer Venus-2 in August 1978. A Venus radar-mapper mission, Magellan will use a synthetic-aperture radar to image about 90% of the Venusian surface to a resolution of better than half a kilometre.

The Galileo mission mentioned earlier is a joint US/German mission, launch of which has also been delayed due to the 'Challenger' accident. It consists of a Jupiter orbiter and a Jupiter atmosphere entry probe. After launch in October 1989, Galileo will undergo three fuel-saving planetary gravity-assist manoeuvres — two at the Earth and one at Venus — before arriving at Jupiter in December 1995. During the 22 months of its primary mission, Galileo will orbit Jupiter ten times and make close passes of its moons Io and Europa.

While Galileo will be the main mission in the next decade devoted to the Jovian System, the Cassini mission could become the main mission devoted to the Saturnian System in the same time frame. A joint NASA/ESA mission, scheduled for launch in 1996 or 1997, Cassini includes both a Saturn Orbiter and a Probe that will enter the atmosphere of Saturn's largest moon Titan (Fig. 19). ESA's Science Programme Committee recently approved the European element of the Casssini mission, which is the procurement of the Titan Probe. This probe is called 'Huygens', after the Dutch astronomer C. Huygens who discovered Titan in 1655.

After more than 20 years of planetary exploration devoted almost exclusively to Venus, the Soviets are now making a concentrated effort to explore Mars. On 7 and 12 July 1988, the Phobos-1 and Phobos-2 spacecraft were launched towards Mars with the primary goal of studying the inner Martian moon Phobos by slowly flying over its surface at an altitude of only 50 m (Fig. 20). During the slow, low-altitude pass over Phobos' surface, laser and ion beams will be emitted to evaporate and ionise surface material, which will subsequently be analysed by mass-spectrometers. During this slow drift phase also, two landers will be released from the Phobos spacecraft: a long-term autonomous station, mainly to perform a celestial mechanics experiment, and a 'hopper'.

The gravitational force on Phobos is two thousand times smaller than that on Earth, allowing the hopper to make 10 m jumps on the moon's surface by activating a spring mechanism. After the series of hops have been damped out, the hopper's scientific instruments can make measurements of Phobos' soil.

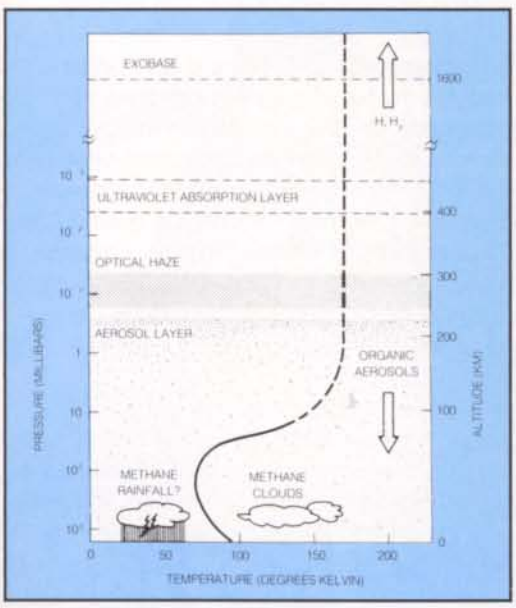
Unfortunately, Phobos-1 was lost in September 1988, but Phobos-2 is still heading for Mars, where it will arrive at the end of January 1989, and will encounter Phobos on 8 April 1989.

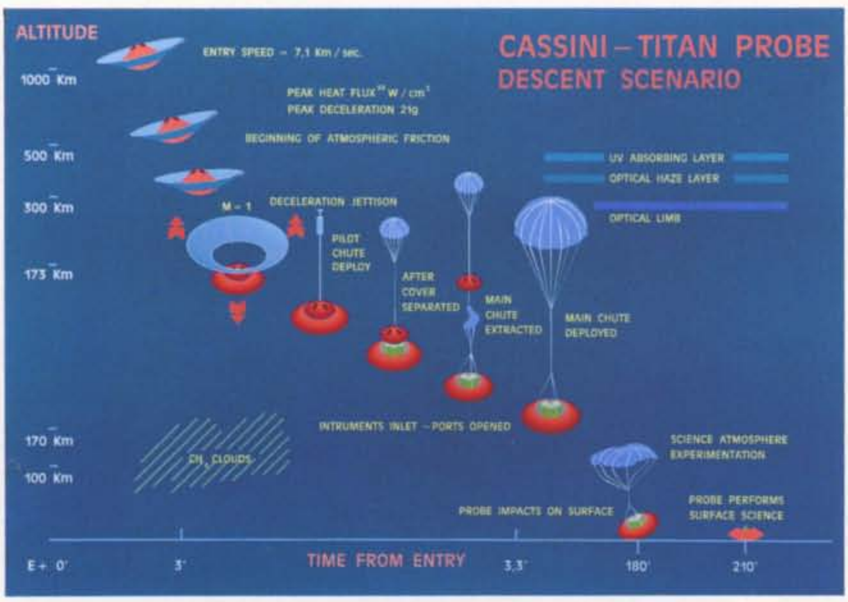
The next two Soviet spacecraft will be launched towards Mars in 1994, to make the most comprehensive study of Mars ever undertaken. Each will consist of an orbiter, a return rocket, a descender carrying a 150 kg rover, a double balloon, a network of 10

Figure 19 — Left: Voyager-1 photograph taken from a distance of 435 000 km showing the thick haze covering Saturn's moon Titan

Centre: Atmospheric profile for Titan

Right: The Titan probe's descent scenario





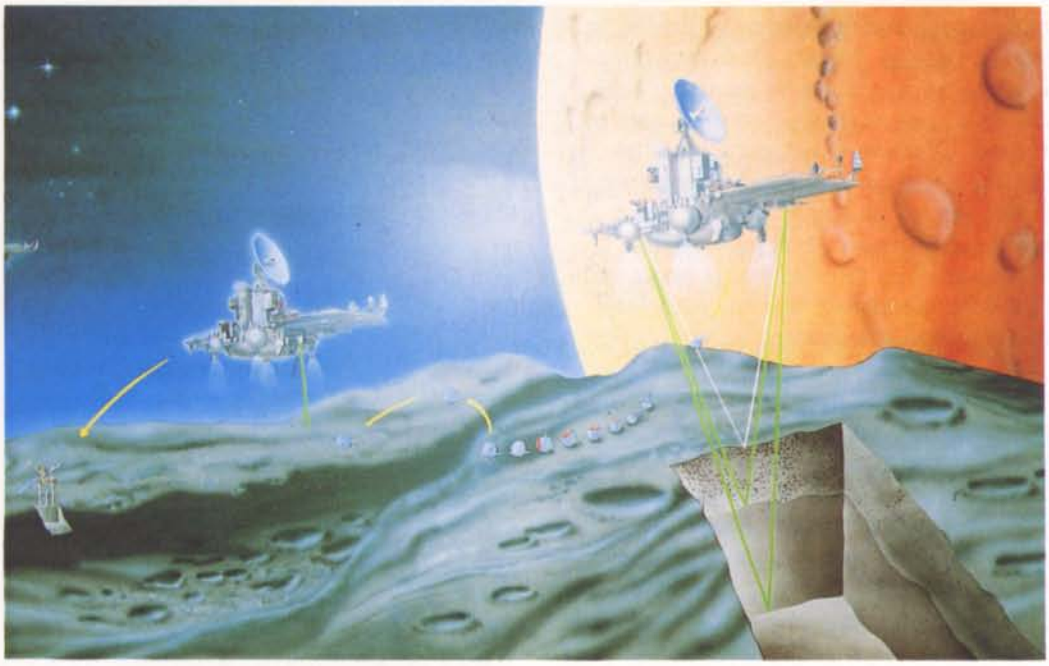


Figure 20 — Artist's impression of the Phobos mission, showing the Phobos spacecraft approaching from the left, delivering the two landers, and emitting a laser and an ion beam while drifting slowly over the moon's surface. Mars is shown in the background

meteo-beacons, several penetrators and a subsatellite. One of the main instruments on the obiter is a camera, which will image about 30% of the Martian surface with a resolution of 1 m. With this high resolution, it is more economical to take the images on film and return the film cartridges to Earth using a small rocket, than to transmit all the data via a data link.

The Mars balloon, supplied by the French, is a double balloon, the upper smaller balloon being filled with helium, the lower larger balloon with Martian air (mostly carbon dioxide). During the day, the lower balloon will be heated by sunlight (like a hot-air balloon), allowing it to float in the Martian atmosphere and be carried along by the Martian winds. During the night, the carbon dioxide will condense and the balloon will sink to the planetary surface. In this way, the instruments on the balloon gondola can be used to study many different sites, over a range of several thousand kilometres.

More detailed investigations will be possible using the instruments on the Mars rover, within its operating range of about 100 km. A global network of meteorological stations will be placed on the Martian surface to study the Martian weather pattern. Penetrators will be released from the orbiter to study the soil down to a depth of 5 m. Finally, it is planned to determine the Martian gravitational field by high-precision tracking of a subsatellite.

Numerous possibilities exist for cooperation between the Soviet Mars mission and the American Mars Observer, scheduled for launch in 1992. The Mars Observer will be equipped with a high-resolution TV camera and other instruments for detailed study of the planet's surface, atmosphere and climate. This cooperation could be the precursor of much more extensive US/USSR cooperation, which would have the goal of returning several kilogrammes of Martian soil to Earth-based laboratories around the year 2000. According to Soviet plans, their proposed mission calls for the launch in 1998 of an orbiter, a large 700—800 kg rover, and a return vehicle. The rover would collect samples and deliver them to the ascent spacecraft, which would then lift the samples to the orbiter. The samples would be returned to the Soviet Space Station for preliminary analysis and testing, prior to being transported back to Earth. Following the return of a Martian sample to laboratories on Earth, the Soviets are planning a manned mission to Mars early in the 21st century.

A manned mission to Mars is also under study by NASA. As a stepping stone, a manned mission to the Martian moon Phobos which could be conducted years earlier is under consideration too.. However, an even higher priority might be given to the establishment of a lunar base, an Antarctic-type permanently manned facility, requiring a series of piloted cargo flights, starting as early as 2005.

All of these programmes are well within reach in the next 26 years. They would be a logical continuation of the past 26 years of planetary exploration, which began in 1962 with the successful Venus flyby of the Mariner-2 spacecraft.

photo: nasa/pat rawlings

Figure 1 — Artist's impression of a Mars base

Life Support on the Moon and Mars

— The Initial Exploitation of Extraterrestrial Resources

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Manned exploration of the solar system in the 21st century will probably lead to the installation of permanently habitable bases on the Moon and Mars (Fig. 1). Maintaining and operating those bases with a minimum of support from Earth will call for optimum regeneration of exploitable products from the consumables used by the bases' inhabitants and systems.

A primary objective within such extraterrestrial settlements will be appropriate exploitation of local resources, in terms of energy sources, soil content, and atmosphere. The bases will also need to achieve self-sufficiency in food production by employing bioregeneration techniques. Extensive waste processing will be needed in striving towards closed hydrogen, carbon and nitrogen cycles.

Introduction

There have been two recent significant indications of a revival of interest in the United States in manned exploration of the Solar System: the publication in August 1987 of Sally K. Ride's Report to NASA's Administrator titled 'Leadership and America's Future in Space', and the holding of the Second Symposium on Lunar Bases and Space Activities of the 21st Century, in Houston, in April 1988. The exploratory missions envisaged include a return to the Moon and the first manned exploration of Mars, with a permanent human presence on celestial bodies beyond Earth orbit as the ultimate goal.

This growth in interest is not limited to the USA, and there are several indications that both the USSR and Japan have begun considering the issues associated with long-term planetary exploration flights and planetary bases. There are political, economic, ethical, societal, legal, managerial and medical, as well as technological, issues involved in this formidable challenge.

The key to success will lie in the furnishing of technologies enabling the 'umbilical links' to Earth to be cut. Self-sufficiency will have to be based not just on indefinite regeneration of consumables, but rather on the evolutionary exploitation of the vast resources provided by the untouched extraterrestrial environments to be inhabited.

Exploration scenarios and conditions

It is possible to formulate several hypotheses for alternative exploration-mission scenarios with which to investigate the technological demands imposed by such missions:

- First manned visit to Mars (crew of 6).
- Expedition to Phobos (crew of 6), and robotic Mars surface exploration.
- Lunar observatory: minimum infrastructure with emphasis on science; several stations, 'aggressive' rovers.
- Highly automated lunar outposts (10—20 people), producing oxygen for propulsion.
- Mars outpost (lunar base as support and test bed).
- Many tens of crew on the Moon, with closed-loop, bioregenerative life support.
- Mars growth stage, initially supported by imported lunar oxygen.
- Evolutionary scenario for economy of interplanetary-propellant usage between low Earth orbit, the Moon, Phobos, and Mars; hundreds of people on the Moon, tens on Mars.

Typical environmental conditions that would be encountered by explorers and settlers on the surfaces of the Moon and of Mars are exemplified in Table 1. Note how 'mild' the Martian environment appears, when compared with the extremely hostile conditions on the Moon.

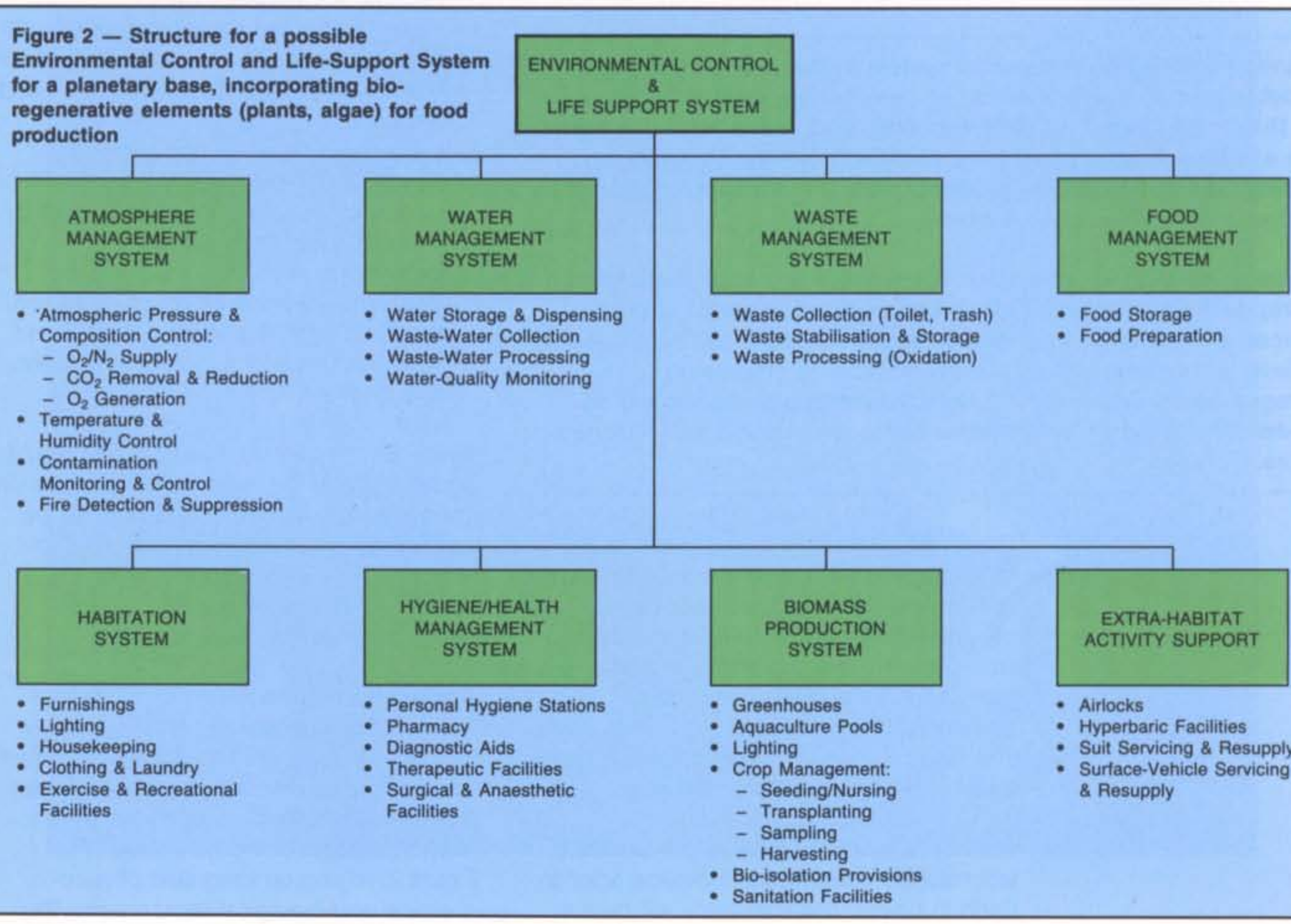
Life-support systems

The practical impossibility of relying upon frequent resupply of consumables from Earth will dictate extensive adoption for planetary bases of closed-loop, regenerative life-support systems of the type shown in Figure 2, relying on integrated physico-chemical and biological components. The

Table 1 — Environmental conditions on the surfaces of the Moon and Mars

	Moon	Mars
Acceleration due to gravity	0.17 g	0.38 g
Diurnal cycle	29 days 12 h 44 min	1 sol = 24 h 37 min
Atmospheric pressure	Hard vacuum	680 to 840 Pa at zero elevation, fluctuating as consequence of the seasonal sublimation of the CO_2 contained in the southern polar cap
Atmospheric composition		CO_2 (95.3%) N_2 (2.7%) Ar (1.6%) O_2 (0.13%) CO (0.07%) H_2O vapour (0.03%)
Typical temperatures	Maximum: 400 K at local noon Minima: 100 K during a 14-day lunar night 150 K during a 4-hour eclipse	Diurnal variation from 190 K to 240 K during summer at mid-latitude (22.5° to 44° N, the Viking landing sites)
Presence of water	Anhydrous	Absent as free liquid, but present as ice in polar caps, in the permafrost extending to lower latitudes, and in hydrous minerals in the soil
Soil mineralogy	Well known; most interesting minerals in large supply are iron-oxide-bearing species (such as ilmenite, $FeTiO_3$) and silicates (such as anorthite, $CaAl_2Si_2O_8$)	Largely speculative. Typical chemical compositions known from Viking sample analyses; in oxides SiO_2 (44% in mass) Fe_2O_3 (19%) Al_2O_3 (6%) MgO (8%) CaO (5%)

Figure 2 — Structure for a possible Environmental Control and Life-Support System for a planetary base, incorporating bio-regenerative elements (plants, algae) for food production



payback time for a bioregenerative system as opposed to an open-loop system based on resupply varies between one year and a decade, depending on the assumptions made. Nevertheless, bioregenerative elements (algae, or higher plants) can be usefully employed in such a life-support system for:

- food production
- air revitalisation (carbon-dioxide removal, oxygen production by photosynthesis)
- waste-water reclamation (uptake of waste water by plant roots and evaporation from leaves).

A life-support system of this sort that uses the symbiotic interactions of humans and other life forms — vegetable, animal, or microbiological — is known as a Controlled Ecological Life-Support System (CELSS). Figures 3 and 4 show schematically the exchanges taking place in such a system between human beings and plants, and their environment. Most of the streams can be 'plugged into each other', like the oxygen (O_2) and carbon-dioxide (CO_2) exchanges between humans and plants.

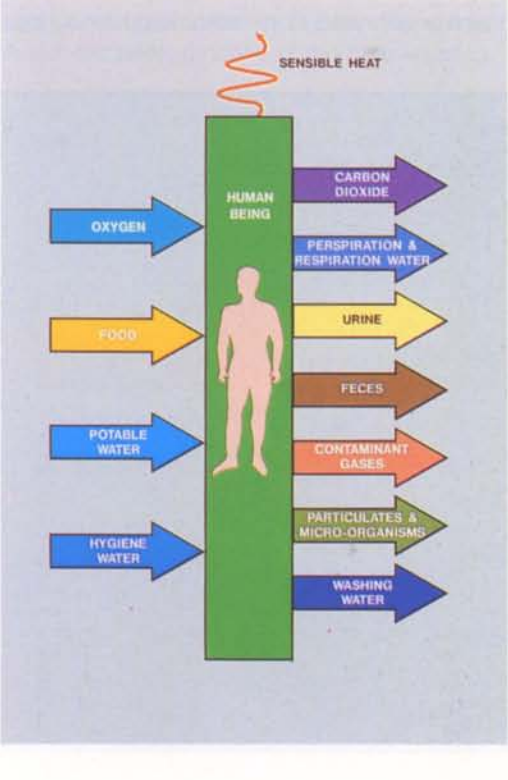
In the terrestrial ecosphere, the stability of bioregenerative processes is guaranteed by huge buffers of gases, water, and biomass (e.g. atmosphere, oceans, forests, animal herds). In a small-scale CELSS, however, the overall ecology needs to be actively controlled or 'engineered', to reduce the sizes of the various reservoirs required and still be able to maintain stability. Rates of activity have to be imposed on each component: increased biomass yields are required from plants, while waste-processing systems have to be improved for faster and more efficient microbiological degradation, supported by physico-chemical processes.

The harshness of the planetary environments means that adequate life support has to be provided by technological means for biological processes like plant and animal growth and reproduction. In addition, crop yields can be dramatically increased compared with those obtained on Earth by deliberately manipulating the environmental parameters.

One possible parameter for improvement is the edible mass yield per unit area of a crop. A minimum growth area of 20 m^2 is likely to be needed for the metabolic support of one person with a highly efficient crop such as wheat. With leafy vegetables such as lettuce, consisting almost entirely of water and cellulose, that figure would increase dramatically. The harvest index, which is the ratio of the edible biomass to the total biomass produced, has to be kept as high as possible, either by genetic engineering, or by screening of cultivars.

Greenhouses in space

Optimum plant growth in a controlled environment calls for:



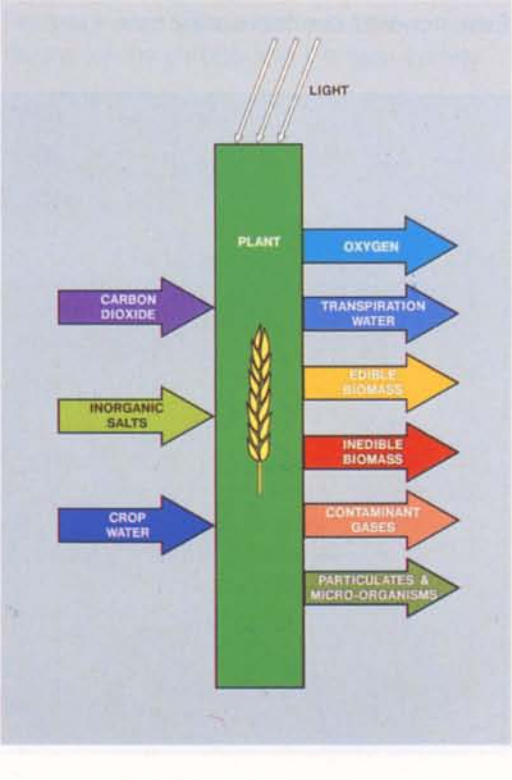


Figure 3 — Synthesis of the mass and energy exchanges occurring between the human body and its environment

Figure 4 — Mass and energy exchanges between a plant and its surrounding environment. Some of the streams (food, oxygen, carbon dioxide and water) can be usefully routed to a human habitat

— Light, in terms of intensity, quality (optimised spectrum), day/night cycling, plant spacing (for optimisation of light distribution on the leaf canopy).
— Nutrient delivery to plant roots, with controlled acidity (pH), chemical concentrations, and supply rates.
— Temperature and humidity control at different levels from those generally required for human habitation.
— Air exchange and ventilation.
— Air composition control; e.g. CO_2 partial pressure may be increased to 150 Pa (versus 32 Pa on Earth) for greater crop yields.

At a planetary base, plants would be grown inside dedicated modules ('greenhouses'), separated and isolable from human habitats. Either conventional soil-type agriculture, or hydroponics/aeroponics techniques could be applied. Hydroponics is based on the supply of nutrients to plant roots via a liquid stream in which the roots are submerged, or the liquid may flow in a permeable-walled pipe (membrane) with which plant roots are kept in contact. Aeroponics also provides the nutrients via a liquid solution, but this solution is sprayed onto the roots, which are freely suspended in air. Nutrient supply rate and composition are easier to control with hydroponics and aeroponics than in soil-based agriculture. The scarcity of water may, however, given the availability of planetary soils with suitable mineral contents, make soil-based agriculture a much cheaper option.

Environmental conditions may have to be individually tailored for particular phases in the relatively long life cycle (30 to 240 d) of a crop, an approach known as 'phasic environmental control'. In this case, separate chambers and nutrient-delivery systems would be necessary for each crop, as well as for batches of the same crop at different levels of maturity. The increased production efficiency would need to outweigh this design constraint. The need for efficient sanitation and bio-isolation of infected crops would also lead to a multi-environment design.

Nitrogen needs to be supplied to plants in some acceptable form for the synthesis of proteins and other biomass components, preferably as nitrates or ammonia. Other macro- or micro-nutrients necessary for healthy plant growth (potassium, sodium, calcium, magnesium, sulphur, etc.) could be recovered from several kinds of waste, but the complex processes and the small masses involved might dictate the importation from Earth of 'pills' of such nutrients.

Provisions will also have to be made for crop management, including seeding, transplanting, sampling, sample analysis, crop harvesting, harvest processing, separation of waste (inedible matter), and treatment of the edible portion for food production. One option would be the extensive use of agri-robotics to handle several of these tasks, to reduce the burden on the very limited manpower available. Some crew involvement needs to be retained for psychological reasons, but the day-to-day management and control of crop health and stability will need to be automated for safety.

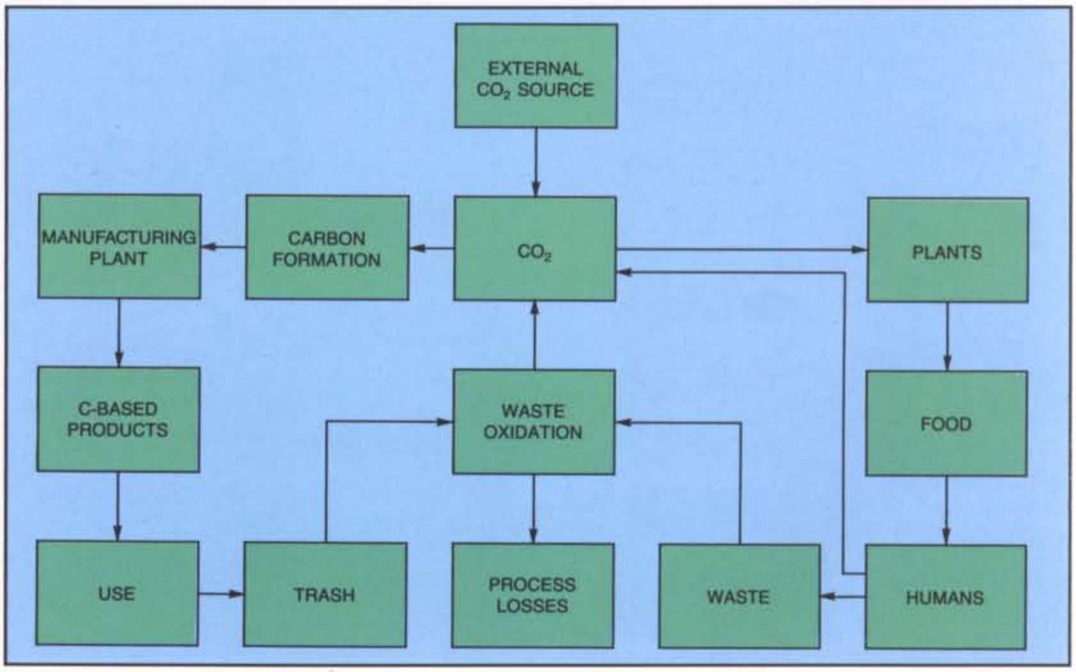


Figure 5 — Possible concept for the utilisation of carbon at a planetary base. It would be present in the human/plants cycle, and in carbon-based chemical products manufactured in-situ

Several problems can be foreseen with a totally vegetable-based diet in terms of the vitamin, fatty-acid, amino-acid, and inorganics contents of edible plant biomass. This is one reason for advocating the inclusion of animals (rabbits, fish, poultry) at an early stage in the building up of a CELSS. Some animals thrive on plant biomass that is inedible for humans (cellulose), while marine animals can be integrated effectively into an algae pool.

Although the benefits of having animals in the system are considerable, the associated problems are also significant. A dedicated environmental control system would be needed for the animals, particularly to avoid the increased risk of contamination.

Waste processing

In a CELSS scenario, a system large enough for adequate food production would yield excess oxygen, and require more CO_2 than generated metabolically by the number of crew supported. Consequently, waste processing is needed for the recovery not only of water, but also the carbon lost in inedible plant matter and human waste. This carbon recovery can be effected as oxidation of organic waste products, yielding CO_2 and additional water.

Simple dry-waste incineration with oxygen or air at high temperature would normally require prior dewatering of the waste and would yield highly contaminated fumes. Unreliable processes such as the handling and pumping of solids would be necessary. A wet oxidation process of the type used in terrestrial sewage-treatment applications allows the use of wet waste as feedstock; it operates at relatively high pressure and temperature (15 MPa, 560 K), but does not achieve 100% oxidation, requiring some post-treatment. Another possibility is a supercritical-water oxidation (SCWO) technique, by which waste is oxidised at very high pressure and temperature (25 MPa, 944 K). This process is highly efficient, with a relatively clean effluent and a very short reaction time.

Electrochemical incineration (i.e. complete oxidation) of biomass such as fecal material and inedible plant waste has also been investigated. The main products from the organic oxidation in this case are CO_2 and hydrogen, which can be reused at various stages in the life-support or power-generation systems. A more novel method would be the use of urine-fed fuel cells, with ammonia and urine organics (plus oxygen) as inputs, and nitrogen, carbon dioxide, water, and electrical power as outputs.

The carbon cycle can be closed relatively easily, thanks to the 'friendliness' of a combustion product like CO_2. A much more complex task is the closure of the nitrogen cycle. Nitrogen products in the waste-processing outlet are generally regarded as contaminants, being unwanted species such as NH_3 or nitrogen oxides. These have to be avoided, either by using an SCWO-like system, or by catalytic processing (platinum or vanadium as catalysts).

Figures 5 and 6 show two potential configurations for the carbon and nitrogen cycles.

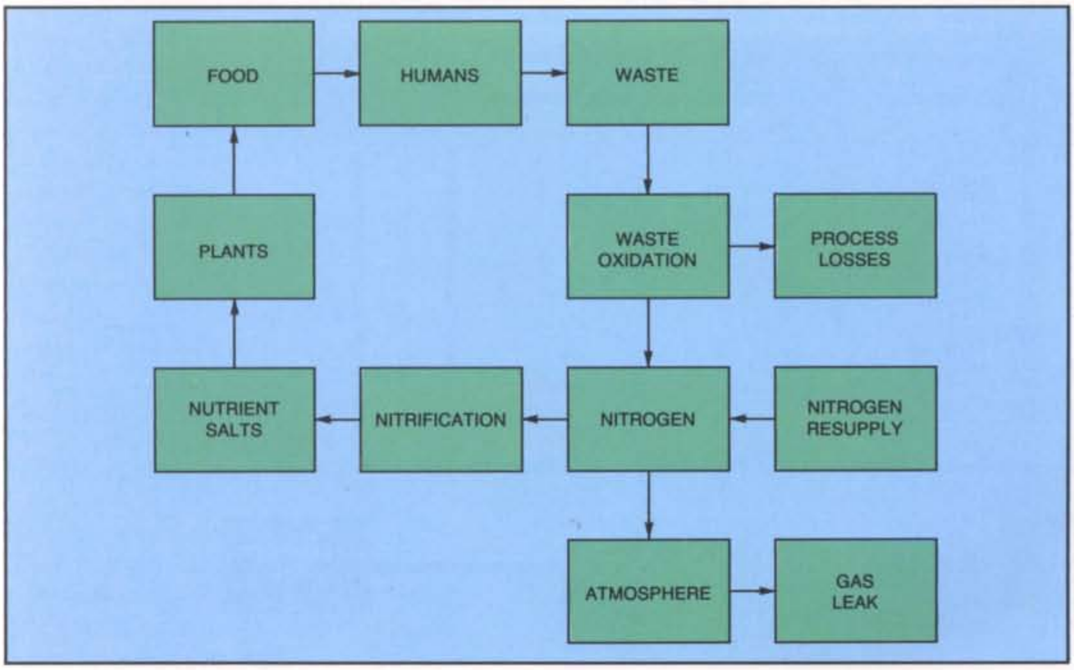


Figure 6 — Nitrogen in a planetary settlement, used essentially as a buffer gas for the living environment's atmosphere, would also participate in the biological cycle between humans and plants. Unlike carbon, nitrogen cannot rely on any major extraterrestrial source of supply

Sulphur compounds are also a constant problem for all waste-treatment processes. Their presence in the incoming feedstock inevitably leads to sulphur dioxide (SO_2) in the outlet product streams. Complex treatments such as liquid scrubbing of combustion fumes would then be needed.

Exploitation of local resources

There are physical limits to the extent of the regenerative processes that are feasible, imposed by:

— loss of water through vacuum venting during the reclamation process
— loss of air and water vapour via atmospheric leakage and in airlock operations
— loss of carbon and nitrogen in oxidation-process residues.

Local planetary resources have therefore to be utilised to make up for losses such as these in the CELSS and thereby minimise the need for resupplying raw materials from Earth. This also increases system reliability and enhances the crew's sense of safety.

Local resources will also be exploited for the manufacture of materials for 'export', an activity that will ultimately be the primary economic reason for a planetary base's existence. In practice, many of the 'local products' will be suitable for both CELSS replenishment and export, thereby establishing a very close link between the life-support system and the local resource processing systems (Fig. 7).

Local resources to be exploited include gravity, sunlight, the soil and the atmosphere.

The partial gravity at a planetary base can be extremely useful for operating gravity-sensitive hardware, such as phase separators or dust/particle collectors. It allows heat transfer by natural convection and it helps the growth of plants in that they can sense the 'up' direction and the collection of hydroponics/aeroponics liquid is easier.

The planetary sunlight is useful for habitat and greenhouse illumination. Glazing or light piping (through a bundle of fibre optics) may be used, with adequate radiation protection (e.g. by metal coating of glazing).

Planetary soil can be used:

— as a source of useful minerals
— as a construction material
— as a plant-growth substrate (e.g. as glass- or rock-wool)

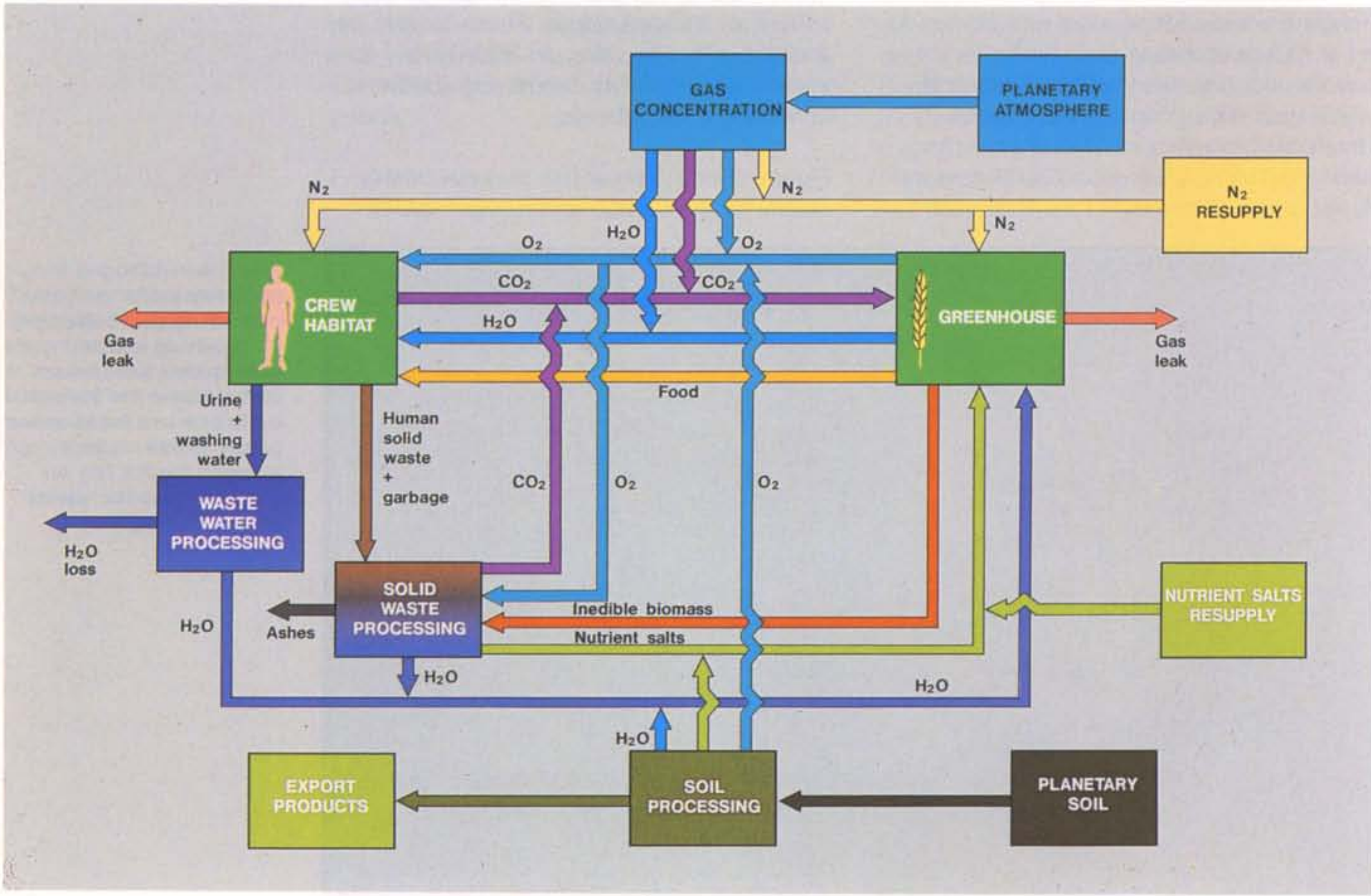


Figure 7 — Complete planetary-base CELSS, for both humans and plants. Local resources, in terms of soil and atmosphere, are fed into the CELSS loop to make up for losses

— as a source of plant nutrient elements (used for hydroponics)
— as a heat sink
— as an adsorbing material in water-filtration systems.

The products of soil mining, aside from the oxygen obtained from the reduction of oxides (as found in lunar ilmenite and anorthite), will mainly be silicon, iron, titanium and aluminium.

'Atmospheric mining' (i.e. concentration of atmospheric water, nitrogen, argon, carbon dioxide) is a very promising option for Mars compared with surface mining, which requires transportation, excavation, in-situ operators, and more logistics in general. Moreover, 'atmospheric mining' can be conducted from a fixed site.

Ideally, whatever processes are chosen should not require expendables, in order to reduce the logistic/resupply risks. Unattended operation, with remote monitoring and control, is also highly desirable.

The concentrated carbon dioxide can be electrolysed (in zirconia cells, at 1200 K) for oxygen production; the carbon-monoxide by-product would undergo a carbonation process. Water extraction is possible only with considerable expenditure of energy (e.g. through phase-change processes), either from soil or from the atmosphere. Carbon, hydrogen and nitrogen, all obtainable from Mars' atmosphere, are not to be found in significant amounts on the Moon, and would therefore have to be imported.

The oxygen and hydrogen products will have a wide range of users, for:
— interplanetary propulsion (LO_2/LH_2)
— hydrogen combustion for heating
— mechanical power (via internal combustion engine, or fuel cell plus electric motor)
— water production (byproduct of H_2 combustion)
— radiation shielding with stored H_2
— cooling with LO_2, LH_2 as heat sinks.

Other foreseeable products include various carbon-based chemical compounds (rubbers, PVC, paints, drugs, etc.), as well as cement, bricks, and fibreglass vessels.

Nitrogen, which is virtually absent on the Moon and also scarce on Mars, is a potentially critical life-support commodity. Efficient methods for recovering nitrogen from planetary-base waste will need to be adopted. On Mars, a nitrogen/argon mixture separated from the local atmosphere could be used for pressurisation. The possibility of avoiding fully-pressurised greenhouses on both the Moon and Mars has been investigated, to reduce the need for gas resupply for leakage compensation and repressurisation. Many plants can indeed accept a very low barometric pressure, provided sufficient partial pressures of carbon dioxide and oxygen, as well as illumination, are maintained.

Conclusion

As we have seen, the developments that will be needed in life-support systems for planetary missions are both numerous and dramatic in nature, not least those associated with:
— improved knowledge of human and plant physiology in extraterrestrial environments (partial gravity, radiation) and controlled-environment agricultural scenarios
— waste processing (down to subsystem level), with the goal of carbon- and nitrogen-cycle closure
— integrated system development and testing, coupling biological and physico-chemical subsystems with adequate control and stability
— improved computer modelling and simulation, including the performance of biological components
— autonomy and artificial intelligence.

Only if these technological challenges are first addressed and mastered can manned bases on the Moon and Mars be regarded as a realistic endeavour.

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ESA's Villafranca Ground Station: 10 Years On and Still Going Strong

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ESA Ground Station, Villafranca del Castillo, Spain

The Villafranca del Castillo Satellite tracking station, often referred to as 'VILSPA', was inaugurated on 12 May 1978 by His Majesty King Juan Carlos of Spain (Fig. 1). Since then the station has supported several international scientific and telecommunications satellite projects and been used by guest observers and experimenters from more than 25 countries.

The VILSPA facilities are therefore now very well known to the astrophysical and telecommunications communities, and the station has gained a reputation as an establishment producing high-quality output and providing professional support.

Background

ESA's VILSPA station is located near the town of Villanueva de la Cañada, in an area called Villafranca del Castillo, approximately 30 km northwest of Madrid. Like the NASA deep-space tracking station in Spain near Cebreros, and the Spanish PTT's satellite communication stations near Buitrago and Guadalajara, VILSPA lies in a natural valley, near the Guadarrama river, and covers an area of some 100 000 m^2.

The original decision to build such a ground station was taken in 1970 in the context of the International Ultraviolet Explorer (IUE) scientific satellite programme, but it was not until 1974 that the ESRO Council decision was made to build this European IUE ground

Figure 1 — King Juan Carlos and Queen Sophia of Spain at VILSPA for the inauguration ceremony on 12 May 1978

station in Villafranca del Castillo. Between 1974 and 1976, the necessary land was acquired and the basic infrastructure was put in place in terms of buildings, power lines, roads, etc., the station's administration being temporarily located in Madrid.

Between 1976 and 1978, three ground systems were in fact established at VILSPA:
- The IUE ground system, consisting of: an S-band antenna; a tracking, telemetry and command (TT&C) station; a computer system; a VHF commanding antenna; a dedicated control centre; an IUE ground observatory; and communications facilities.
- The MAROTS maritime communications satellite's ground system, consisting of: a Ku-band antenna; a TT&C station; and a Payload Test Laboratory. This MAROTS system was subsequently modified to operate at C-band to support the MARECS satellites.
- The OTS Flux Meter and Radiometer were built.

In parallel, the station staff was built up, with a mix of ESA staff, INTA (Spain) contractors, other contractors, and research fellows, and the necessary logistical and administrative support services were put in place.

In 1978-79, VILSPA participated in the first Global Atmospheric Research Programme (GARP). A temporary installation was provided to support the NOAA GOES-1 weather satellite, which was moved to a position over the Indian Ocean for that Programme. A new S-band antenna and two Portacabins, containing a TT&C station and a dedicated computer to process weather images, were installed.

An Exosat ground station, involving an S-band antenna and a TT&C station, was added to the Villafranca facilities in 1982/3.

In 1988, an S-band transportable station was installed as one of the ESA LEOP* ground-network stations and will probably remain at VILSPA for a year or more.

Mission support

The first mission to be supported by VILSPA, and still the station's most important, is IUE. This joint satellite venture involving NASA, ESA and the UK Science and Engineering Research Council (SERC) provides an astronomical space observatory in geosynchronous orbit and the requisite ground support. Two IUE 'observatories' are available to the scientific community: NASA's IUE Observatory, located at Goddard Space Flight Center, in Greenbelt, Maryland (USA); and the European IUE Observatory at VILSPA provided by ESA.

Figure 2 — Prof. Reimar Lüst (left), ESA's Director General, presenting a model of the IUE satellite to Mr Luis Carlos Croissier, Spanish Minister of Industry and Energy, during the IUE 10 th Anniversary Celebrations at VILSPA on 10 May 1988

VILSPA provides 8 h of real-time support to IUE each day, the remaining 16 h being provided by Goddard. As the satellite's orbital period is 24 h (sideral time), the 8 h support window starts 4 min earlier each day. The real-time nature of the support involves telemetry and command (not tracking, since this is provided by NASA), satellite operations control, and scientific operations. During the remaining 16 h per day, VILSPA carries out image processing and supports other science-related tasks such as databank image retrieval, reprocessing, etc.

The overall mission-support process begins with the approval by the IUE Allocation Committee of the Guest-Observer proposals. All approved proposals enter the scheduling process and each Observer is notified of his/her allocated observing time. The day before the scheduled observation, a VILSPA Resident Astronomer briefs the Guest Observer on the IUE facilities.

Real-time support starts with a test to ensure that the station is ready to accept satellite hand-over from Goddard. The spacecraft controller (shift leader) accepts the hand-over and positions the satellite for VILSPA's next 8 h of scheduled scientific operations. With the information passed on by the Guest Observer to the Resident Astronomer on

*LEOP: Launch and Early Orbit Phase

duty, the telescope operator executes the required manoeuvre, camera-preparation, exposure, and quick-look tasks (Fig. 3). If the Guest Observer is happy with the images obtained, the satellite is prepared for the next observation.

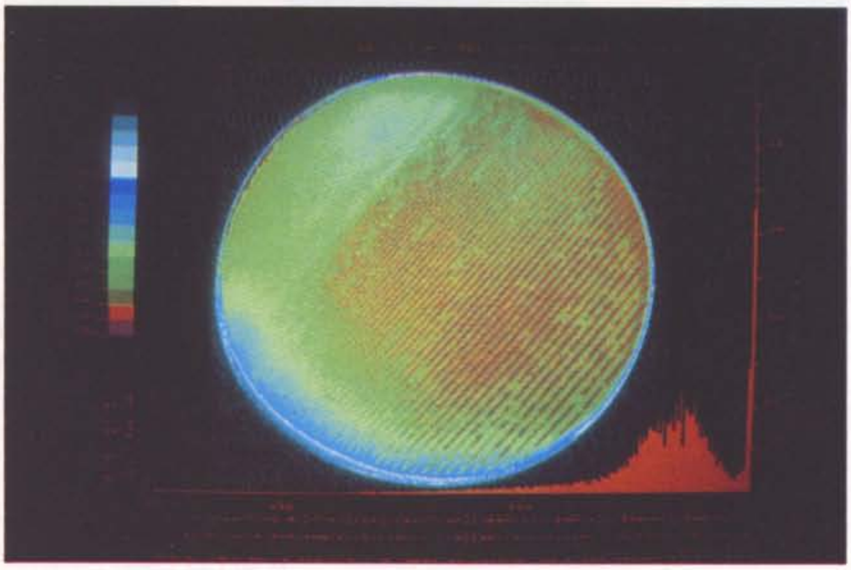


Figure 3 — An IUE high-resolution spectrum

The image processing is carried out by the IUE Ground Computer System (IGCS). Twenty-four hours after making an observation, the Guest Observer has the final products — tapes, plots,and prints (Fig. 4) — in hand.

In addition, the IUE Observatory has a scientific programme of its own, and in collaboration with other astronomical institutes throughout the World. Some of its scientific achievements to date have to be rated as outstanding, such as the work on Supernova 1987A (see ESA Bulletin No. 53).

VILSPA's good computing resources for scientific applications allow local observers, researchers and university students to conduct their own investigations in such a way that they do not interfere with the station's day-to-day operations. Several PhD dissertations have been prepared using the VILSPA IUE databank and computing resources, and it is not uncommon for such theses to be directed by VILSPA IUE Resident Astronomers.

Turning now to the telecommunications domain, MARECS provides high-quality full-duplex communications for voice, data and teleprinter services between ships and coastal stations. Both MARECS satellites are being used operationally by the International Maritime Satellite Organisation (INMARSAT), based in London.

VILSPA has been involved in the MARECS programme since its early stages. MARECS-A was launched in December 1981 and placed initially in a geostationary orbit covering the Atlantic Region. The commissioning and in-orbit acceptance of the MARECS-A payload in January 1982 was performed from VILSPA. MARECS-B2 was launched in 1984 and placed at a geostationary position that allowed it to cover the Pacific Region. The Ibaraki station in Japan was responsible for its support.

In 1986, INMARSAT asked that the two satellites be swapped, MARECS-A being moved to the Pacific Region and MARECS-B2 to the Atlantic Region as prime satellite. Since then, VILSPA has been responsible for the latter's tracking, telemetry and command support on a 24 h/day basis.

VILSPA also provides a daily payload-testing service, and several communications experiments have also been carried out using the station's L- and C-band facilities. The satellite itself is controlled from ESOC in Darmstadt (Germany), while the TT&C back-up is provided by ESA's ground station at Redu (Belgium).

Emergency Position Indication Radio Beacon (EPRIB) experiments proposed by the International Maritime Organization (IMO) have also been performed from VILSPA. They were conducted by six countries (Germany, Japan, Norway, UK, USA, and USSR) forming a subgroup of the CCIR. Phase-4, with a sea-status simulator, was carried out in October 1982, and Phase-5, with the buoys in the North Sea, in February 1983. These tests were declared as being very successful by the maritime world.

Another series of tests were run in 1984 for the 'PROSAT' programme, with the objective of developing small mobile terminals for maritime, land or aeronautical application. The primary goal was to acquire data for the design of the next generation of mobile satellite systems. Phase I was successfully completed in 1984; Phase II is still in progress.

VILSPA is also responsible for the low-data-rate PRODAT system (see article on Terrestrial Mobile Communications in ESA Bulletin No.48). It consists basically of a mobile network on one side and of the public telex and packet-switched data network on the other. The mobile network provides connectivity between the vehicles and the hub station, located at VILSPA, via

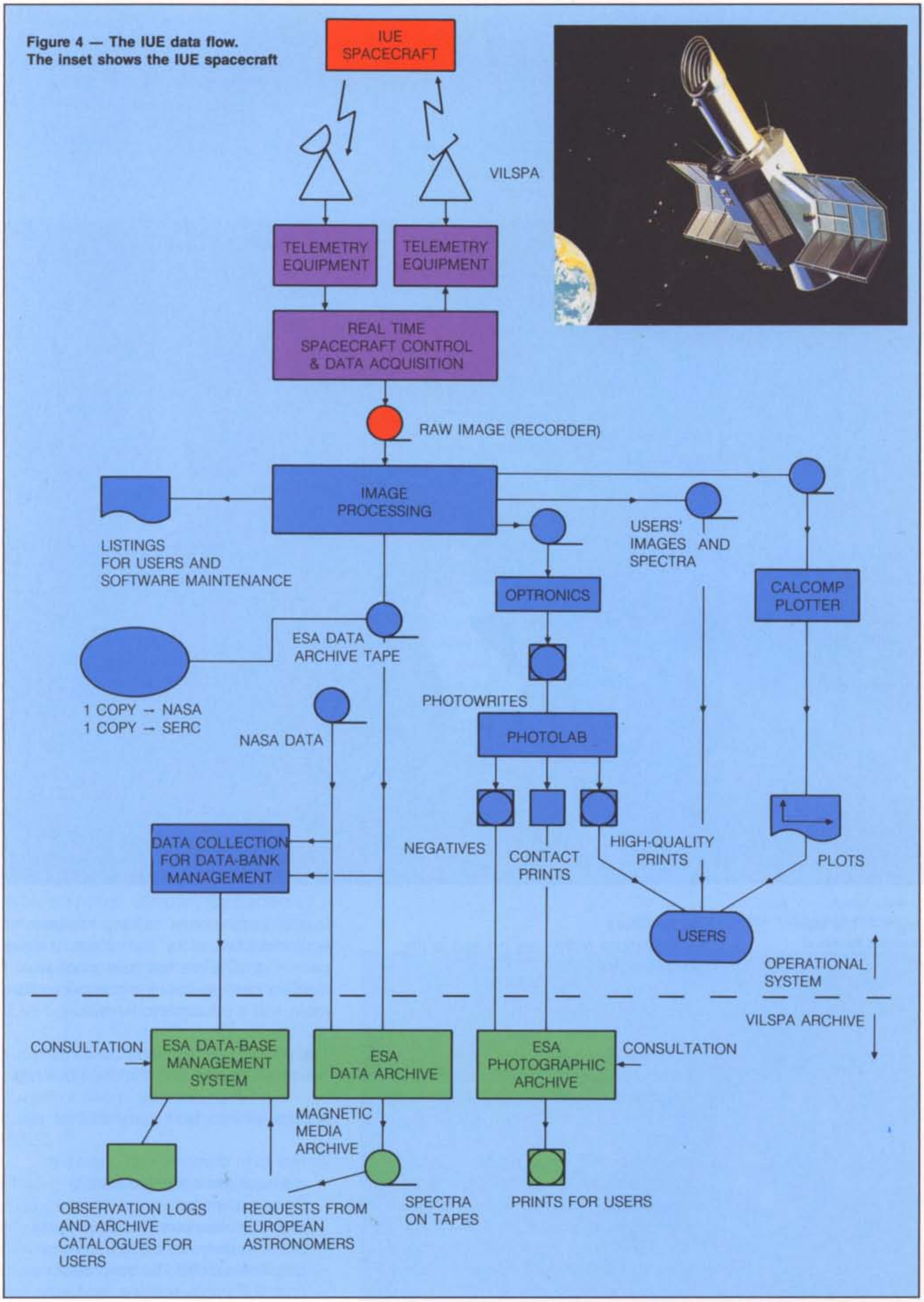


Figure 4 — The IUE data flow. The inset shows the IUE spacecraft

MARECS. The interaction between mobile and terrestrial networks takes place in a store-and-forward mode at the Network Management Centre (NMC) at VILSPA, which acts as a gateway.

At present, VILSPA also supports the Agency's OTS and ECS telecommunications satellites with back-up ranging using a Ku-band fluxmeter/ranging terminal.

— The Payload Test Laboratory (PTL), where all communications tests and experiments are performed.
— The Villafranca Computing Centre houses several computers and terminals for IUE image de-archiving, data processing and editing. The ESALAN interface rack is also located in this room.

photo: picture report

Figure 5 — The Main Equipment Room at VILSPA

Site facilities

The operations rooms are housed in the main building:

— The Main Equipment Room (Fig. 5) contains the telemetry, command and ranging baseband racks, the station computers, the timing system, and the network communications interface with the Operations Control Centre (OCC) at ESOC, in Darmstadt.
— The Computer Room houses a large computer for IUE real-time operations and image processing, as well as the offline equipment for image processing.
— The IUE Control Room and Observatory (Fig. 6), from which the satellite control and scientific operations tasks are carried out.

In addition, the main building houses a test-equipment laboratory, staff offices, a spare-parts and consumables store room, a meeting room, a library, a communications room and a photograhic laboratory.

The power-generation and distribution building is across from the main building.

A large antenna farm dominates the site:

— two 15 m diameter, and one 5.5 m diameter (transportable station) S-band antennas
— one 12 m diameter C-band antenna
— one 4 m diameter L-band antenna
— one 3 m diameter Ku-band antenna
— one VHF uplink antenna, and nine crossed yagi arrays

photo: picture report

Figure 6 — The IUE Ground Observatory at VILSPA

— several other small antennas, including an L-band reference horn, microwave link, radiometer, etc.

A separate building at the station houses a canteen, and four bedrooms for Guest Observers needing overnight accommodation. A small workshop and storage space is also available.

An overall view of the station is shown in Figure 7.

Staffing
There are more than 70 staff working at VILSPA, the majority of whom are employed by INTA, a Spanish company contracted by ESA to undertake station maintenance tasks. These tasks are carried out in accordance with procedures specified by ESOC's Operations Department in conjunction with the ESA Computer Department.

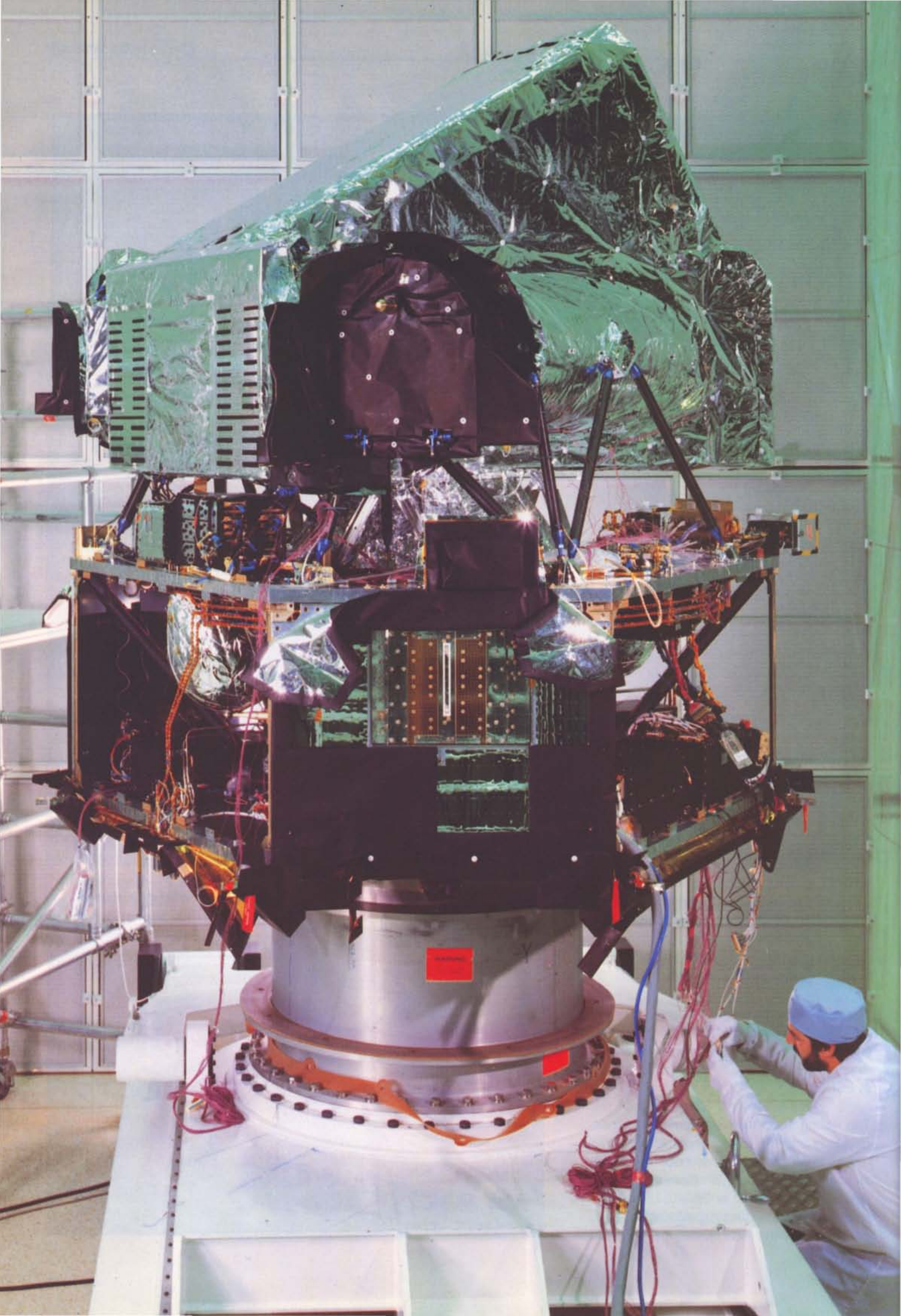
The scientific and operations tasks fall under the responsibility of the IUE Observatory staff, most of whom are supernumerary members of ESA Space Science Department at ESTEC.

The testing of the satellite communications payloads and the experiments with the mobile terminals are carried out under the technical direction of ESA Communications Satellites Department at ESTEC, although routine operations and experiments are performed by the station staff.

The future
VILSPA is one of ESA's S-band network stations for the support of spacecraft in geostationary transfer orbit (GTO). The valuable experience acquired at VILSPA over the last ten years makes the station a worthy contender for the operation of future generations of ESA spacecraft, in both the scientific and telecommunications domains.

Figure 7 — Aerial view of the Villafranca station

photo: altairphoto



Hipparcos — Ready for Launch

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Hipparcos, the first satellite completely devoted to astrometry, is currently waiting for launch. Once in orbit, it will make precise measurements of the positions, parallaxes and proper motions of about 120 000 selected stars brighter than magnitude B=13. Accuracies of the order of 0.002 arcsec are expected for positions and parallaxes, and 0.002 arcsec/year for proper motions. Precise magnitudes will also be obtained for the stars observed.

The telescope on board the satellite will systematically scan the sky throughout the satellite's 2.5 year mission and provide sufficient data to produce an extremely precise stellar catalogue covering the entire celestial sphere. Data collected by the star mapper, which forms part of the satellite's attitude-control system, will also be used in a separate experiment called 'Tycho', to produce a lower precision, but larger, catalogue of approximately 500 000 stars brighter than magnitude B=11. This catalogue will also include two-colour photometric measurements.

Both catalogues are expected to have a profound and lasting impact on many areas of astronomy.

Introduction

The Hipparcos development programme started in 1982. The Agency has overall responsibility for the satellite's design and hardware production, which was contracted out to a European industrial consortium with Matra as Prime Contractor and Aeritalia responsible for procurement of the spacecraft, as well as for the integration and testing of the complete satellite. Some thirty-five European firms and a total of about 1800 individuals have participated, at all levels, in the Hipparcos development programme.

Working closely with ESA, four European scientific consortia have undertaken the scientific tasks necessary for successful completion of the project. The 'Input Catalogue Consortium' has been entrusted with the task of defining the list of stars to be observed by the satellite. The 'Northern Data-Analysis Consortium' and the 'Fundamental Astronomy by Space Techniques' Consortium are responsible for the complete, independent reduction of data collected by the satellite's main instrument and the joint production of the final Hipparcos Catalogue.

The production of the Tycho Catalogue will be the responsibility of the 'Tycho Data-Analysis Consortium', based on the data collected by the star mapper.

The mission objectives and a detailed description of the payload and spacecraft have been presented in ESA Bulletin No. 42 (article by M.Schuyer, May 1985), and in the ESA Brochure 'Ad Astra' (ESA BR-24). The ground segment and the role of the European Space Operations Centre (ESOC), in Darmstadt, which will be responsible for operation and control of the satellite in orbit, have already been described in ESA Bulletin No. 51 (article by J. van der Ha, August 1987). The present article concentrates on the final phases of the development programme, covering the assembly, integration and testing of the engineering and protoflight satellite models, as well as the launch preparations.

Model philosophy

Development of the Hipparcos satellite has been based on the so-called 'protoflight concept', in which only one satellite model, the protoflight model (PFM), is built to flight standard with high-reliability components. This protoflight model combines what in the past used to be the prototype and flight models, resulting in considerable cost savings.

The protoflight model is preceded by a developmental model, the engineering model (EM), which is flight-standard-representative, but is not equipped with high-reliability parts. Qualification and acceptance data are gathered from both models at their respective development levels (unit, subsystem, and system), and full qualification is achieved only at the end of the protoflight model activities.

The assembly, integration and test programme

The assembly, integration and test (AIT) programme for Hipparcos involved the following activities:

- Engineering-model pre-integration, conducted with the EM harness and EM electrical subsystems, mounted on an integration mock-up of the structure. The purpose of this activity was to have an early check on the unit and subsystem mechanical and electrical interfaces.
- EM assembly, integration and testing, conducted with the flight-representative harness, and the EM electrical subsystems, including the payload system, mounted on a flight-representative structure, while the reaction-control assembly was only partially flight-representative.
- PFM assembly, integration and testing, conducted with all flight-representative hardware and software.

The last two of these activities are discussed in more detail below.

Figure 1 — Integration of the beam combiner into the Hipparcos telescope structure at Matra, Toulouse

Assembly, integration and testing of the engineering model

The EM AIT programme started in June 1986 and was completed in August 1987. Its prime objectives were the verification of the electrical design, subsystem-to-subsystem compatibility and satellite-to-ground support equipment compatibility, the validation of the launcher interfaces, and of the procedures and ground-segment equipment for the PFM AIT programme, and the qualification of the satellite's electromagnetic environment.

To achieve these objectives, four major activities were performed:

- payload performance testing
- integrated subsystem testing
- integrated system testing, and
- electromagnetic-compatibility testing.

Payload performance testing

The purpose of the payload performance test on the engineering model was to demonstrate the design's compliance with the specifications and the validity of the measurement methods to be used later in assessing protoflight-model performance.

The payload performance tests included vibration tests, thermal-vacuum/thermal-balance tests, tests to measure the telescope's performance, and a stray-light test to assess the increase in background luminosity when the Earth and the Moon are in the proximity of the telescope's field of view.

The telescope's photometric parameters were calibrated in a dedicated test performed in vacuum at the Institut d'Astrophysique de Liege, in Belgium.

Integrated subsystem testing

The purpose of the integrated subsystem test was to verify the correct functioning of the various subsystems in the satellite environment, which includes the satellite harness and structure, and the other electrical subsystems.

Integrated subsystem tests were performed separately for each of the following subsystems:

- data-handling subsystem, responsible for telecommands, telemetry, on-board data acquisition, distribution and processing, and timing and synchronisation
- electrical power subsystem, responsible for solar-generator output-power regulation, satellite power supply and control during eclipse, battery management, thermal control, and pyrotechnic-device actuation
- telecommunication subsystem, responsible for telecommand reception, telemetry transmission and ranging
- central on-board software subsystem, responsible for on-board data processing and control, including on-board time management, real-time attitude determination, star-file programme management, piloting of the image-

dissector tube, star-mapper processing, payload thermal control, and calibration
- payload subsystem (Fig. 1), which was tested to verify the internal alignment of the focal-plane assembly and the alignment between it and the telescope assembly (Fig. 2)
- attitude and orbit control subsystem, in which both hardware and software were tested in an operating environment as close as possible to that which will prevail under flight conditions.

Integrated system testing
The satellite integrated system test has been performed twice on the fully integrated satellite. One test took place before and the other after the system environmental test programme, to verify that no degradation had occurred after exposing the satellite to realistic space-environment conditions.

In the case of Hipparcos, the most important tests were the so-called 'end-to-end tests', namely:
- the attitude determination and control end-to-end test, to verify that the attitude-control system performs to the required accuracy, and
- the star observation function end-to-end test, to verify the accuracy in piloting the instantaneous field of view of the image dissector tube onto the stars to be observed during their transits of the main grid.

Electromagnetic-compatibility testing
This test was needed to verify the satellite's compatibility with the Ariane environment in electromagnetic terms. The tests performed were:
- verification of electromagnetic compatibility with the launcher and launch site
- verification of immunity to electrostatic discharge, and
- verification of electromagnetic compatibility of the Hipparcos detectors with the magnetic field emitted by the spacecraft.

Assembly, integration and testing of the protoflight model
The AIT programme for the protoflight model of Hipparcos began in May 1987 and was completed in April 1988. In addition to the integrated subsystem tests and integrated system test already performed on the engineering model, the programme also included an extensive calibration of the payload's photometric performance and three major environmental tests, namely:

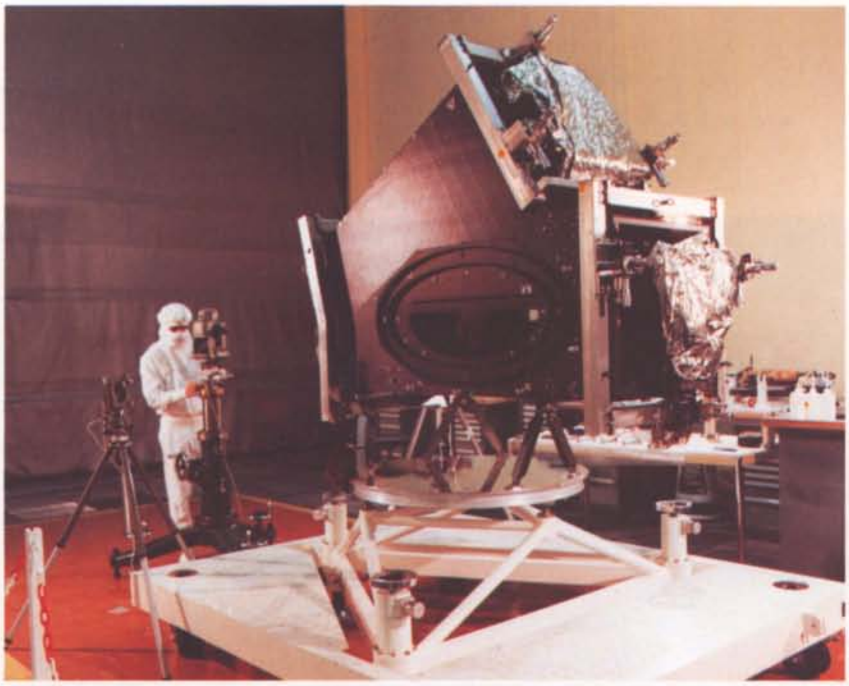

Figure 2 — Alignment testing of the three mirrors of the Hipparcos Schmidt telescope (mirrors mounted to the carbon-fibre structure via three isostatic mounts) in progress at Matra, Toulouse

- a vibration/acoustic test
- a solar-simulation test, and
- a thermal-balance/thermal-vacuum test.

The vibration/acoustic test
This test was needed to verify that the satellite can withstand the acoustic noise and vibration of the launch environment, without suffering structural or electrical degradation. Performed at the Intespace facilities in Toulouse, it confirmed the results obtained from earlier system qualification tests, and provided confidence that the satellite will indeed withstand the dynamic launch environment.

The solar-simulation test
During this test, the satellite was submitted to a realistic space environment similar to the one expected during the mission. The test took place in the new Large Solar Simulator facility at ESTEC, in Noordwijk, and was the first test on a protoflight model to be performed in this facility (Fig. 3).

The test verified the satellite system's functional performance under conditions close to the actual operating conditions, and validated the analytical model used to predict the satellite's behaviour during the mission.

The thermal-balance/thermal-vacuum test
This test was also carried out in the Large Solar Simulator facility at ESTEC, immediately after the solar-simulation test. The protoflight model was subjected to the maximum and minimum temperatures expected in orbit, to verify the satellite's performance in space under such extreme conditions (Fig. 4).

Flight-acceptance review

The Hipparcos launch was originally planned for July 1988. The flight-acceptance review, to confirm that the satellite was flight-worthy and capable of meeting the mission requirements, took place in April 1988, in time to meet that July 1988 launch date. This review marked the completion of the satellite AIT activities and, more generally, of the Hipparcos development programme as a whole.

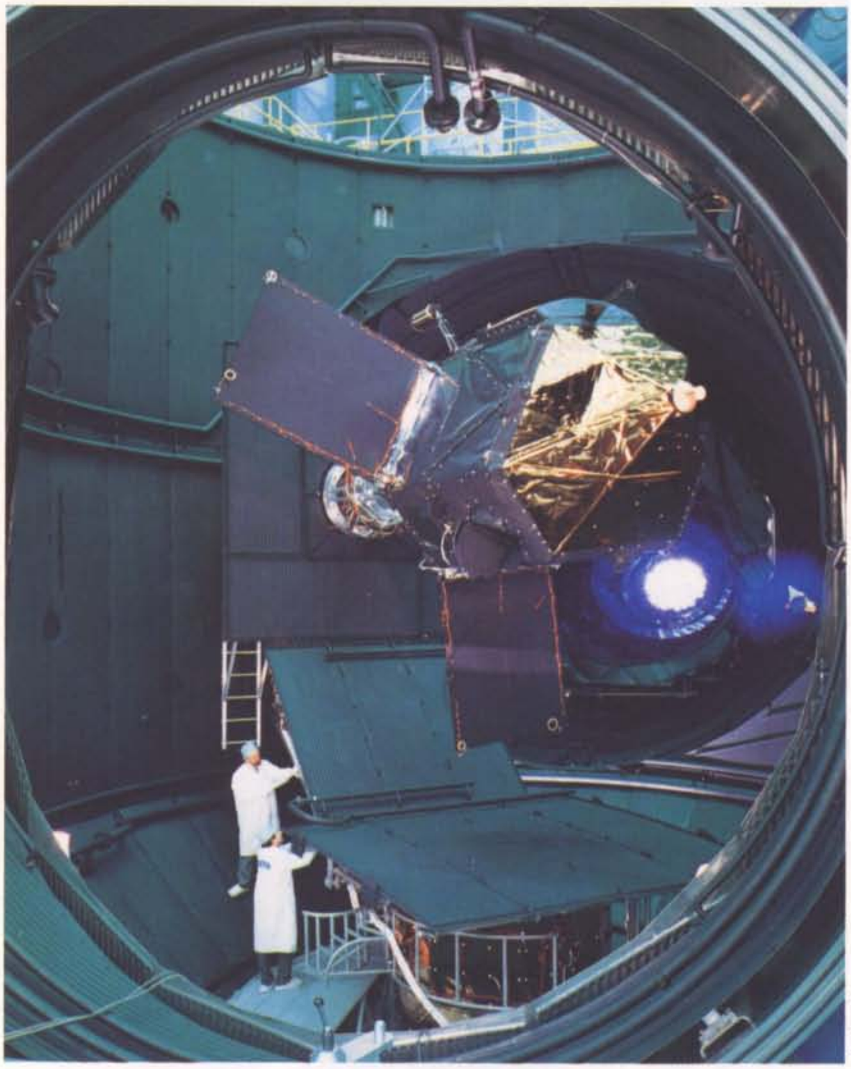

photo: picture report

Figure 3 — Hipparcos mounted on the motion system in the Large Space Simulator at ESTEC. The satellite's solar arrays and telescope baffles were deployed under simulated space conditions during this test

Figure 4 — Hipparcos being rotated about its spin axis in the Large Space Simulator at ESTEC

Due, however, to various delays in the Ariane launch schedule, the Hipparcos launch has had to be postponed to a later date in mid-1989. Since the flight-acceptance review, the satellite has therefore been placed in storage under controlled environmental conditions, waiting to be reactivated and readied for launch.

Launch-range activities and early operations

Hipparcos will be transported to the Ariane launch base in Kourou, French Guiana, about two months before the final launch date. There, it will undergo final preparations and testing, including the final integrated system test. The hydrazine tanks and cold-gas tanks will then be filled and the apogee boost motor integrated into the spacecraft.

After the complete satellite has been balanced and weighed, it will be encapsulated in the Ariane dual-launch structure (SPELDA). The companion satellite that will share the same launch will then be installed on the top of SPELDA, and this composite will be transported to the launch area and mated with the Ariane-4 launch vehicle, ready for the final countdown.

Immediately after launch, several further operations will have to be carried out, such as satellite acquisition by the ground-station network, orbit and attitude reconstitution in the transfer-orbit phase, apogee-boost-motor firing to place the satellite into a near-geostationary orbit, and a drift manoeuvre to move it to its designated position at 12° W above the equator.

Once Hipparcos has reached its final position, payload operations will start, with the spin axis of the satellite pointing towards the Sun. An initial attitude reconstitution will be performed, followed by aquisition of the first star signals by the image dissector tube on the focal plane of the telescope.

For a period of several days, the payload will then undergo the in-orbit calibration necessary to achieve the performance requirements set for the mission. Once this calibration has been successfully completed, the satellite will enter its normal operating mode and begin providing the continuous flow of observational data from which the Hipparcos and Tycho catalogues will be produced.

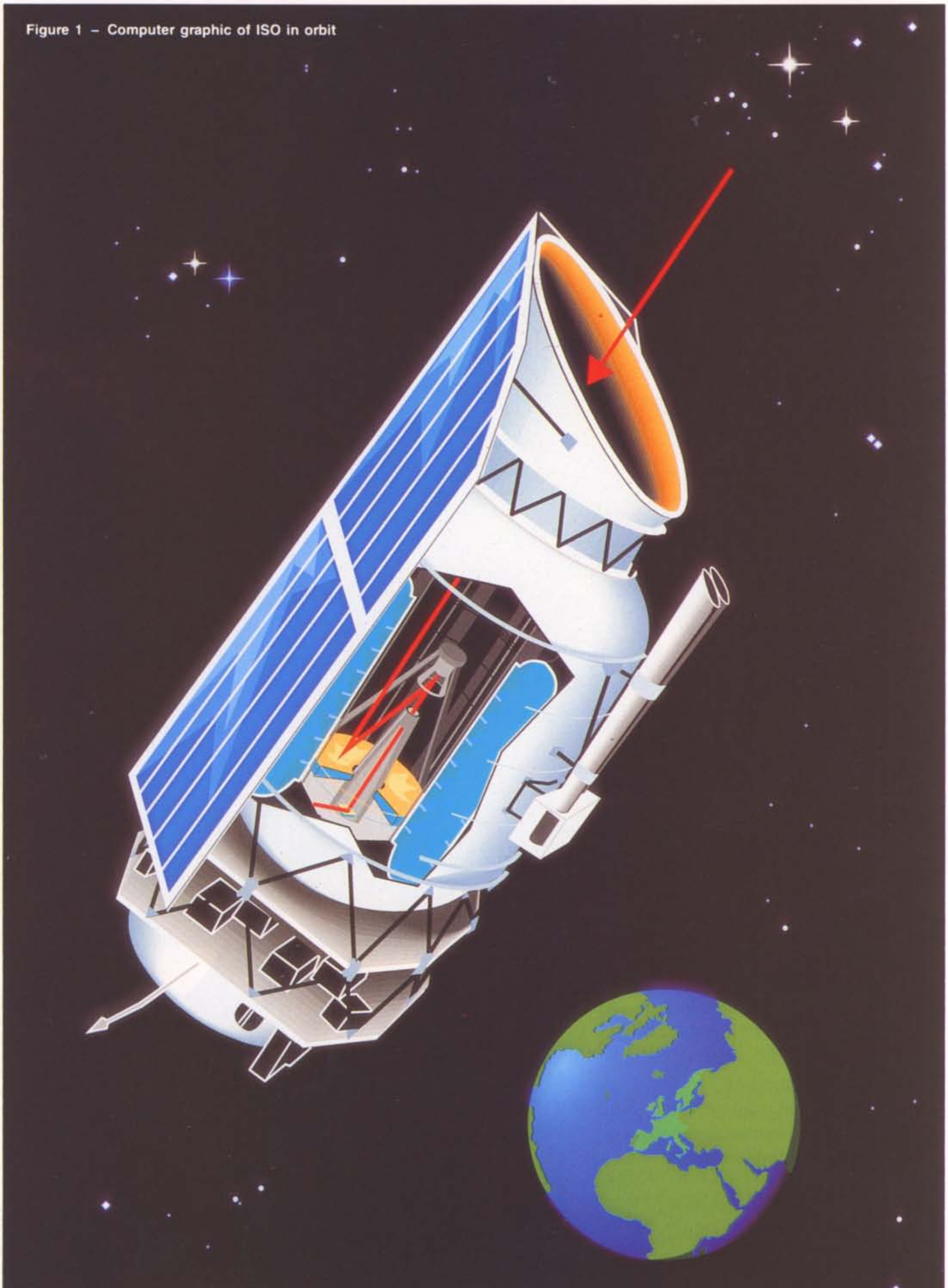

Figure 1 – Computer graphic of ISO in orbit

The Cryogenic System of the ISO Satellite: Achieving Very Low Temperatures for a Large Payload

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There are certain limitations on any terrestrial infrared observatory: the Earth's atmosphere is an absorber of infrared radiation in certain wavelength bands and, since it is relatively warm, it is also an emitter of infrared light, both of which phenomena greatly impair observations made through the atmosphere. While these effects can be reduced to some extent by taking observations from aircraft or balloon-based platforms, they can only be eliminated by placing the telescope and its instruments outside the atmosphere altogether. The resulting thousandfold increase in sensitivity is the reason why infrared astronomy benefits so greatly from operation in space.

The Infrared Space Observatory (ISO), to be launched in 1993, will make detailed astronomical observations of objects and sources, some as cold as 15 K. Since an infrared detection system must be colder than the source it is observing – in order to see it at all – a very significant part of the satellite is the cryogenic system which cools the entire telescope and the scientific instruments to a few degrees above absolute zero.

ISO's major characteristics

Mass at launch	2300 kg
Mass of Helium at launch	310.5 kg
He II tank volume	2240 l
Length overall	5.3 m
Payload Module (PLM) height	4.2 m
PLM diameter	2.0 m
Operational lifetime (Scientific observations)	18 months
Launch date	May 1993
Launcher	Ariane 44P
Orbit parameters	
Perigee altitude	1000 km
Apogee altitude	71381 km
Period	24 hours
Inclination	5.25 deg.

The Agency's Infrared Space Observatory (ISO), shown in Figure 1, will in many senses have a mission complementary to that of the very successful Infrared Astronomical Satellite (IRAS) which flew in 1983. Whereas IRAS provided a nearly complete sky survey in wavelength bands between 8 and 120 μm, ISO will be operated as an observatory and will make accurate pointed observations of up to 10 hours in duration. The major differences in performance between IRAS and ISO are the latter's greatly enhanced sensitivities, improved angular resolution, extended wavelength range (2.5 to 200 μm) and longer operational lifetime (minimum of 18 months observations). The main characteristics of the four scientific instruments are summarised in Table 1.

Why low temperatures are necessary

The ISO instruments are capable of detecting very faint sources in the far infrared portion of the electromagnetic spectrum. All bodies at a finite temperature emit infrared radiation and the spectrum and intensity of this emitted radiation are functions of the temperature of the body; this also applies to the components of the ISO telescope. In order that the instruments are not 'blinded' by this self-emission of the telescope, all parts of the optical subsystem must be kept sufficiently cold. The actual temperature requirements are shown in Table 2.

Satellite design

The ISO satellite consists of two modules. The Payload Module (PLM), the large cylindrical vessel in Figure 1, contains the telescope, the cold parts of the four scientific instruments and the helium subsystem.

The Service Module (SVM) is the rest of the satellite, although the 'dividing line' is not always clear: the sunshield and startrackers

Table 1 — Main characteristics of ISO instruments

Instrument/ Principal Investigator	Main function	Wavelength (μm)	Spectral resolution	Resolution	Outline description
ISOCAM (C. Cesarsky, CEN-Saclay, F)	Camera and polarimetry	2.5—17	Broad-band narrow-band, and circular variable filters	Pixel FOVs of 1.5, 3, 6 and 12 arsec	Two channels each with a 32×32 element detector array
ISOPHOT (D. Lemke, MPI für Astronomie, Heidelberg, D)	Imaging photo-polarimeter	2.5—200	Broad-band and narrow-band filters Near-IR grating spectrometer with $R\sim90$	Variable from diffraction-limited to wide beam	Four subsystems: (i) Multi-band, multi-aperture photo-polarimeter (3—110 μm) (ii) Far-infrared camera (30—200 μm) (iii) Spectrophotometer (2.5—12 μm) (iv) Mapping array (18—28 μm)
SWS (Th. de Graauw, Lab. for Space Research, Groningen, NL)	Short-wavelength spectrometer	2.5—45	1000 across wavelength range and 3×10^4 from 15 to 30 μm	7.5×20 and 12×30 arcsec	Two gratings and two Fabry-Pérot interferometers
LWS (P. Clegg, Queen Mary College, London)	Long-wavelength spectrometer	45—180	200 and 10^4 across wavelength range	1.65 arcmin	Grating and two Fabry-Pérot interferometers

are functionally part of the SVM while being mounted on the PLM. Similarly, the warm electronics units of the instruments are functionally part of the PLM but are carried on the upper platform of the SVM.

The sunshield has two functions. First, as its name suggests, it shields the PLM from illumination by the Sun. Second, it carries on its front face the solar cells necessary for power generation.

An important consideration in the choice of configuration and in the mechanical design of ISO is the necessity to minimise heat inputs to the PLM coming from the SVM, sunshield, startrackers and from the environment. For this reason all of the struts going to the PLM vessel are made from low thermal conductivity materials (mostly glass fibre compounds) and all surfaces looking to the PLM are covered with multi-layer insulation blankets.

A second important consideration is the stability of the aiming of the telescope during an observation. The attitude and orbit control system (AOCS) guides the satellite (primarily) on the basis of data from the star trackers. Clearly, there must be minimal drift between the optical axis of the startracker and that of the telescope, otherwise image quality will be degraded.

Unfortunately, there is plenty of scope for drift induced by transient thermo-elastic effects in the structure between the two optical axes. For this reason, the design of the external thermal control of the PLM has as its goal maintaining stable and uniform temperature gradients in this structure. The

Table 2 — Telescope temperature requirements

Component	Temperature (K)	Temperature stability (Degrees)
Detector cooling interface	$1.7<T<1.9$	±0.05 in 1000 s
Optical subsystem	$2.4<T<3.4$	±0.1 in 1000 s
Primary mirror	<3.2	±0.1 in 1000 s
Secondary mirror	<4	
Lower baffle	<5	
Upper baffle	<7.5	

lifetime is therefore not as long as it could be from purely thermal considerations.

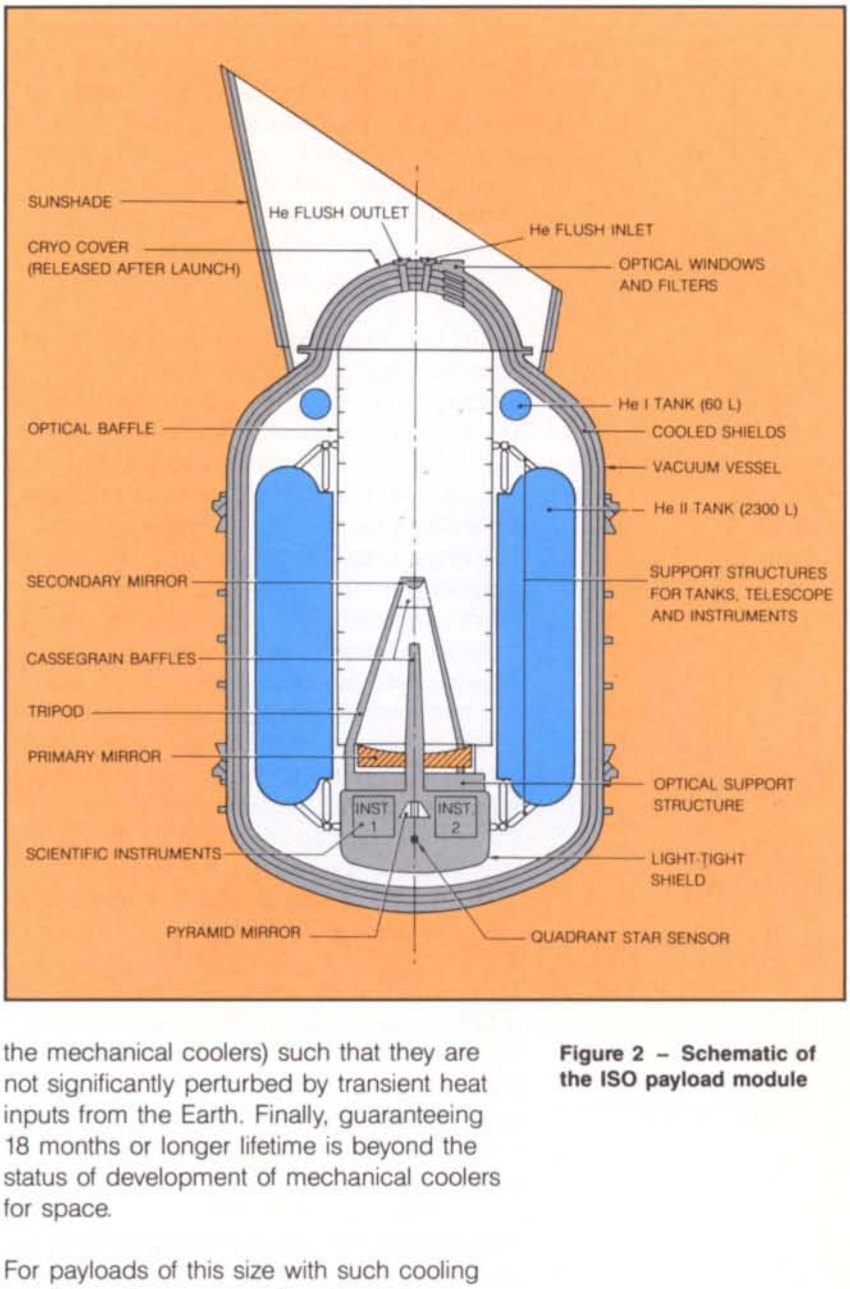

Figure 2 – Schematic of the ISO payload module

Why a cryostat?

A cryostat is a device which maintains a steady, low temperature. In its most common form it consists of an insulated tank of a liquified gas with a low boiling temperature, or a cryogen, whose boiling ensures the low temperature (in the ISO case liquid helium is chosen as the cryogen because of its extremely low boiling point of a few Kelvin).

A stable, low temperature environment must be provided for the ISO telescope and for the four scientific instrument units located in the focal plane (FPUs), but why has a cryostat been chosen for this purpose? Boiling off a stored cryogen is not the only way of providing cooling to payloads. As is evident from the dimensions of ISO, such systems are very large and heavy. Launcher interface problems, testability considerations and general ground handling requirements greatly complicate the design. Furthermore, the lifetime is intrinsically limited by the amount of cryogen stored in the tank(s).

Although alternatives exist (in principle) in the form of closed cycle coolers i.e. 'refrigerators', for a payload (telescope and instruments) as large as that of ISO, there will inevitably be significant heat leaks. Table 3 shows the cooling power delivered by ISO at various temperature stages. No other space-qualified or readily qualifiable hardware exists which could satisfy these requirements. Furthermore, the electrical power consumption of mechanical coolers would be significant. There would be a vibration problem (absent in ISO) and there would be a considerable configuration problem posed by the need to site radiators (used to reject the heat from the mechanical coolers) such that they are not significantly perturbed by transient heat inputs from the Earth. Finally, guaranteeing 18 months or longer lifetime is beyond the status of development of mechanical coolers for space.

For payloads of this size with such cooling requirements, a cryostat is on balance a more straightforward technical solution and will continue to be so for some time.

Table 3 — Average cooling performances

Cooled point	Temperature (K)	Cooling (mW)
Tank and innermost shield	1.8	120
Detectors	1.8	1.5
Optical subsystem	3	20
Baffles	$3<T<7$	100
Vapour-cooled radiation shield (VCS) 1	35	730
VCS 2	65	800
VCS 3	100	900
	Total	2550

The cryostat and its operation

The construction of the cryostat is indicated in Figure 2. The telescope is surrounded by the toroidal, main helium tank and at the lower end by a radiation shield (providing protection from thermal radiation) directly coupled to the tank. The helium bath has to be maintained at a nominal temperature of 1.8 K to satisfy the temperature requirements of certain of the scientific payload's detectors. There is a relationship between the natural boiling point of a liquid and the pressure it experiences – a lower pressure lowers the boiling point (as mountaineers are well aware). Since liquid helium under a pressure of 1 atmosphere boils at 4.2 K, to achieve this equilibrium temperature it is necessary to reduce the pressure on the helium bath, in this case to 17 mbar. This is done simply by pumping on the tank exhaust, cooling the liquid helium by enhanced evaporation (the cooling is given by the latent heat of vaporisation) and then maintaining the low temperature by pumping permanently on the vent line of the cryostat.

Liquid helium at 1.8 K is below the so-called lambda phase transition temperature, or lambda point, of 2.17 K, and is referred to as He II or superfluid helium as opposed to He I or normal liquid helium above this temperature. It is called 'superfluid' because it exhibits a number of remarkable physical properties unique to helium. One of these properties is the thermodynamic fountain effect which permits a simple plug of porous material to function as a phase separator, allowing only gaseous helium into the vent line and retaining the liquid phase in the tank. On the ground this is achieved simply by placing the exit at the highest point of the tank since gravity settles the liquid helium. In microgravity or free-fall conditions the distribution of the liquid in the tank is not known and a special device is required to fulfil this function.

Heat leaks due to electrical harnesses, internal power dissipations of the FPUs and the heat entering the telescope baffle from the environment – the aperture heat load – are removed by actively cooling with the cold helium gas vented from the main helium tank.

After leaving the telescope heat exchangers, at a temperature of about 7 K, the vent gas passes successively through heat exchangers mounted on the three vapour-cooled radiation shields (VCS) before being exhausted to space through a pair of balanced, opposed, 'momentum free' nozzles (see Fig. 3). This balance is important since the thrust from the exhaust gas would otherwise influence the attitude of the satellite.

The functioning of the cryostat throughout almost all of its operational lifetime of 18 months is extremely simple and entirely passive. In fact the vast majority of the 'plumbing' and components in the cryostat are necessary for operations not directly related to the scientific observation phase of the satellite's life. These operations are cool down, filling, superfluid helium production, superfluid helium top-off, achieving 72 hours unserviced operation (autonomy) on the Ariane launcher and coping with the thermal transients in the first few days after launch.

Pre-launch autonomy

During the preparation for launch with the satellite mounted on the Ariane-4 launcher, the cryostat is brought to a 95% full level with He II at 1.6 K, at a pressure in the tank of 8 mbar. This process is completed sometime between 72 and 48 hours before launch. After this time, only electrical access to the satellite is available (through the launcher umbilical lines). Since the helium flow essential to maintain cooling in the VCS is only possible with a pump attached to the vent line, this presents a considerable difficulty – the cryostat cannot tolerate such a period without active cooling.

Various solutions were examined: a vacuum pump mounted on the SVM; an umbilical pump line penetrating the fairing and fitted with valves and automatic disconnects for launch and for fairing jettison.

The solution adopted involves the incorporation into the cryostat of a small auxiliary tank of 60 litres of He I at 4.2 K (1 atmosphere). During the autonomy period, the main tank is closed and helium gas is driven off at the required rate from the auxiliary tank, by controlled electrical heating. This flow substitutes for the normal cooling vent gas flow and in consequence the heat leak to the main tank can be limited to about 0.5 watt. During the 72 hour hold time under this heat load the main bath will warm from 1.6 K to 1.8 K which is the desired launch temperature. Just prior to launch the residual helium in the auxiliary tank is heated out rapidly and the tank is valved off. It has no further function.

Launch and post-launch operations

After the auxiliary tank has been depleted, the cryostat has no further operation, and no helium flow, until well into the Ariane flight. Shortly after the third stage ignition the external valves V1 and V2 are opened allowing the vent line to exhaust to space. Towards the end of the boosted phase of the flight, the shut-off valves V3 and V4 are opened allowing helium to start flowing through the phase separator to the vent line.

At this point due to the acceleration of the Ariane third stage and due also to its location at the top of the tank, the phase separator is 'dry' (i.e. in gaseous helium) on its inlet side. It only becomes wet and commences proper operation when the boost is terminated. This sequence of events guarantees the correct starting of the device which is otherwise difficult to ensure.

After orbital insertion, the cryostat experiences a settling from its initial temperature and helium flow rate corresponding to the warm (300 K) vacuum vessel to its equilibrium condition where the vacuum vessel is predicted to be at approximately 140 K. The helium flow rate drops by a factor of five through this transient phase which will last some 20 days.

With this passive design of phase separator, the correct temperature range of the helium bath cannot be maintained with a single impedance in the vent line. To accommodate the dynamic range in flow rate, the vent line is equipped with two pairs of exhaust nozzles, one of high impedance and the other of low impedance. They initially operate in parallel during the high mass flow rate period: the low impedance nozzles are valved off when the flow rate is low enough.

Cryostat cover

In order to maintain the insulation vacuum while the cryostat is operated in air, the telescope aperture is closed by a cover which is retained in place by a clampband. The cover is fitted with radiation shields which function as (passive) extensions of the VCS in the main cryostat. The thermal connections between them take place via a number of spring-loaded thermal contacts which also serve to eject the cover when the clampband is released. Cover ejection will take place after the initial outgassing of the satellite following launch (for reasons of cleanliness of the telescope), expected to be some 15 days after launch.

The cover has some additional functions at various phases in the satellite's life; it is remarkable how it has increased in complexity from the originally envisaged 'lid'! It is equipped with two optical windows (combined with heat rejection filters) to permit checking of the telescope and instruments inside the cryostat. It has a cooling loop on the innermost shield which may be flushed with liquid helium to provide a cold (and therefore dark in the infrared) background for instrument checkout. It functions as a radiator to cool the vacuum vessel (otherwise insulated with MLI) in the first days of the mission.

Optimising the satellite's 'cryogenic lifetime'

The ISO cryostat design meets all of its performance requirements. Nonetheless it is illustrative of the problems that a space cryostat designer faces and in particular the compromises between the various system performances that one is obliged to make. A good example is what happens when one attempts to optimise the cryogenic lifetime of the satellite.

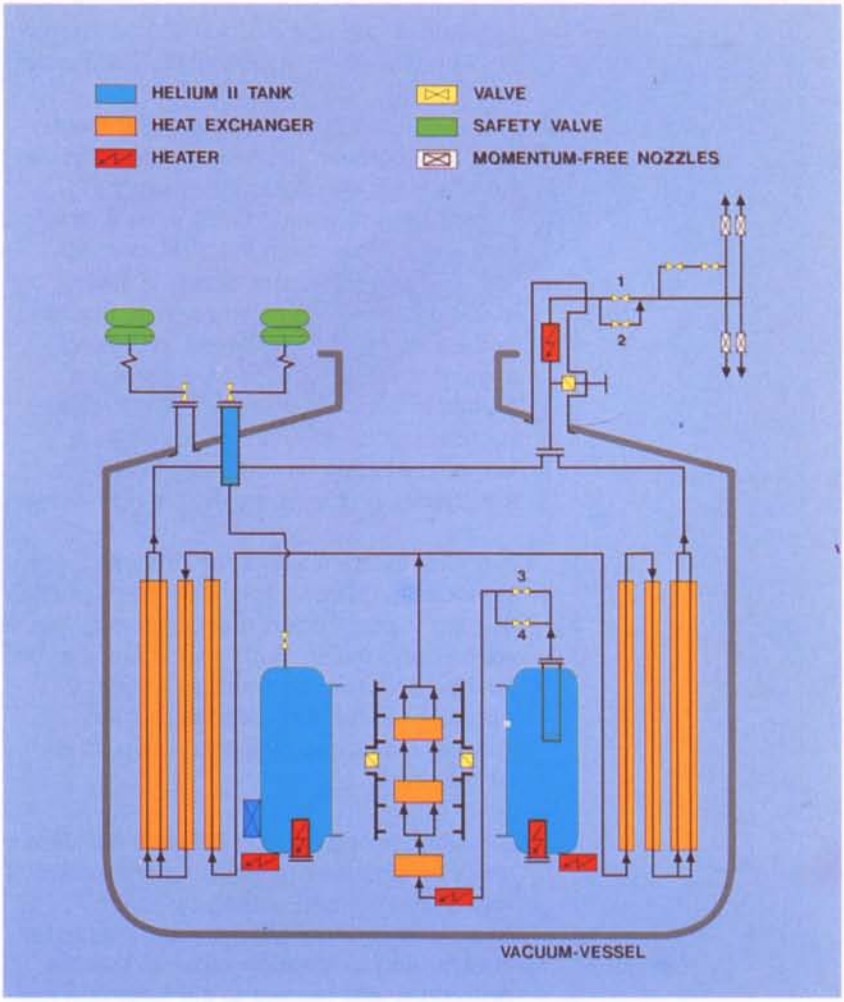

Figure 3 – Operating principle of the ISO cryostat during flight

The lifetime of the cryostat is determined by the equilibrium boil-off rate of the stored helium, itself directly determined by the heat leaks to the helium tank. The use of the cold gas in the VCS intercepts a large part of the heat that leaks through the passive insulation (MLI and vacuum) of the cryostat and greatly increases the lifetime. In principle increasing the number of such VCS increases the theoretical performance: in practice a limit of three of four holds and ISO uses three such shields. (From a point of view of total mass, it becomes cheaper to add helium than shields in order to extend lifetime.)

The mass flow rate – which determines the lifetime – is very sensitive to the temperature of the vacuum vessel. This can be lowered either by reducing the heat leaks to the PLM from the rest of the satellite or by placing radiators on the rear (i.e. non-sunshield) side of the vessel, or by a combination of the two.

The major conducted heat leak is through the struts between the two modules: this can be effectively eliminated by allowing a section of each strut to function as a radiator, diverting the heat from the SVM to space. This brings a significant benefit in lifetime but at the cost of transient temperature gradients in the struts and in the vessel, provoking alignment stability problems. Even more benefit in lifetime (up to a factor of two) can be obtained by allowing the walls of the vessel to function as radiators to space but the stability problems are accordingly worse.

A further problem would result from a significantly reduced mass flow rate, namely that the vapour-cooled telescope would get warmer and the straylight performance in the far infrared would be seriously degraded. Absolute temperature stabilities – very important for some detectors – would also be degraded.

It is worth noting that this full potential lifetime could be exploited by using a combination of vapour cooling and cooling by liquid evaporation and by changing the startracker location and suspension either so that the deflections with respect to the telescope are suppressed or by placing the startrackers inside the cryostat so that they are tied to the telescope axis. Unfortunately for ISO, the first option is too complex and no 'cold' startrackers are available.

Lessons learned for the next generation of space cryostats

ISO will not be the last large, superfluid helium cryostat in space. Although ISO is still some years from launch, many lessons have already been learned from carrying the detailed design forward into the manufacture and testing phase. The ISO programme has benefited greatly from being able to inherit components developed under ESA contract as part of its technology research programme, e.g. the passive phase separator for helium and the electromagnetically operated helium shut-off valve of which there are ten in ISO!

The design, operation and testability of the ISO cryostat would all have been greatly eased if certain components had been available in a sufficiently mature state to be adopted or if certain decisions could have taken with all the wisdom of hindsight. The most important pointers for future missions using superfluid helium are:

i. develop in advance a large bandwidth, flight quality, active phase separator;
ii. for small enough mass flow systems, develop a pump that can be mounted on the satellite for servicing the helium bath during the pre-launch autonomy phase;
iii. for larger mass flow systems, always baseline a dual cryogen system (e.g. with normal liquid helium or liquid nitrogen as the secondary cryogen) to obtain independence on the launcher.

For high accuracy pointing missions, it is highly desirable to investigate the feasibility of developing a startracker or equivalent device that can be located physically on the bore sight of the telescope. This would eliminate the pointing stability problems and permit much longer operational lifetimes through optimisation of the thermal control design.

Conclusions

ISO is the first ESA satellite to make use of cryogenic cooling on a large scale and its cryostat is much larger and offers far higher performance than any other such system that has been or is being constructed. At the time of writing, a detailed design meeting all requirements is complete, the PLM is being integrated and will shortly undergo its first performance tests.

Not only will the ISO mission bring great benefits to infrared astronomy, but the programme demonstrates the maturity of cryogenic cooling technology in Europe and its suitability for a wide range of space-based observations where large-scale cooling is required.

ISO is the first of its kind in Europe – it will not be the last.

Figure 1 — Photographs of the same scene taken from a normal-definition monitor (625 lines) and from a high-definition HDTV monitor (1250 lines) (Courtesy: Philips Research Labs., Eindhoven)

High-Definition Television Broadcasting via Satellite

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ESA has been working for nearly twenty years on the development of direct-broadcasting television satellites, capable of transmitting directly from orbit to small home antennas. The Olympus, TV-Sat and TDF family of satellites are products of the European development effort. TDF-1 has already been launched and is working well, and the others are now nearing readiness for launch and for pre-operational broadcasting demonstrations with improved sound and image qualities. The growing Eutelsat satellite system is providing an increasing number of TV channels to ground networks and the recently launched Astra satellite will soon be available for commercial direct television broadcasting in Europe.

In the meantime, the next generation of television, High-Definition Television (HDTV), has already been under development in the laboratories of broadcasting organisations and electronics manufacturers for several years and will be the next candidate for broadcasting via satellite. Rather than just improving the picture and sound qualities, it will bring the cinema into the home by offering larger screens for wide-angle viewing.

High-Definition Television will offer the same image quality as 35 mm movie film, the improved resolution being achieved by employing more than 1000 lines instead of the current standard of 625 lines, a larger cinemascope-like aspect ratio, and suppression of spurious picture artifacts and noise (Fig. 1). The sound information will also be of higher quality, with stereo reproduction of compact-disc standard, and with several sound channels being provided for different languages.

From a transmission point of view, despite the great progress already made in signal processing and compression, HDTV will require a four- to five-times higher information rate and much larger channel bandwidth than presently used. Moreover, to provide the viewer with the very visible improvement needed to establish a new market, consistently good reception must be assured.

Consistently high quality reception implies robust transmission systems able to provide the requisite error- and impairment-free signal on a continuous basis to the end user in the defined coverage area.

With the present frequency allocations for satellite broadcasting and today's congestion of the electromagnetic spectrum, the transmission bandwidths needed for HDTV can most probably only be found at or above a broadcasting frequency of 20 GHz.

Advanced technologies are required both for the satellite transmitter and the user's ground receiver, because of the high information rates, the need for small, low-cost receiving terminals, and the substantial signal attenuation that occurs in the atmosphere when using these higher, so-called 'millimetre-wave' bands.

Evolution of television standards

Television distribution and broadcasting via satellite already offers today's user access to many more channels and direct reception throughout Europe. The next step will undoubtedly be to improve the quality of television towards cinema-like images.

The initial approach, in Japan in particular, has been radical replacement of the old NTSC standards. The European approach is more one of gradual evolution, with step by step improvements that afford functional compatibility to existing receivers, rather like the initial transition from monochrome to colour television. To provide the best chance of marketing success, this evolution should also follow the availability of European hardware (studio equipment, receivers, recorders, displays, etc.) and software (programmes!).

The upgrading of the existing standards is being based more and more on the availability of digital processing techniques. The D-MAC (Digital + Multiplexed Analogue Component) standards, to be used for the first direct satellite broadcasting, will provide both high-fidelity stereo sound and 625-line images with suppression of many picture anomalies and somewhat improved resolution.

A further step towards HDTV will be possible with the HD-MAC standard at 1250 lines supported by developments from the European Eureka projects. This is probably going to be operational from 1992 onwards, for transmission through existing high-power broadcasting satellites such as TDF, TV-Sat and Olympus.

There is, however, strong motivation for programme producers and broadcasters to bring cinema-like quality sound and pictures into the home as soon as possible. Full HDTV quality will require a further improvement in image resolution, particularly for rapidly moving pictures, and better colour rendition, calling for more processing in the home receiver and higher transmission rates with larger bandwidths, such as are available only via satellite broadcasting.

The HDTV transmission format

The European Broadcasting Union (EBU), the central coordinating body for television transmission in Europe, has already performed studies that have identified several sample systems that can meet the basic HDTV quality requirements in terms of format, picture rate, number of lines, etc. A conclusive report was prepared at the end of 1987 by Study Group 11 of the CCIR on Television Broadcasting Service. The technical features of typical systems summarised in Table 1 are drawn from these reports.

When comparing the various systems, two parameters come into play in even the most basic of transmission analyses, namely bandwidth and overall carrier-to-noise (and interference) ratio. Two other very important parameters for system-dimensioning are coverage area and service availability. The steady technical progress in, and ever-decreasing cost of, digital signal processing is leading to emphasis being put on fully digital systems employing multi-level phase-shift keying modulation, which have very predictable performance in terms of noise- and interference resistance. Systems using analogue frequency modulation require smaller bandwidths but higher carrier-to-noise ratios, and are generally much more sensitive to interference.

Broadcasting performance

The Olympus satellite (Fig. 2), ESA's high-power satellite for television broadcasting to be launched in May 1989, carries two experimental transmission channels: one for Italian coverage, called 'Italian TV1', used here as a reference, and one repointable channel called 'European TV2'. The performance figures for these two channels are summarised in Table 2.

More importantly in the current context, the Olympus platform is able to cope fully with the stringent demands of HDTV broadcasting, because it can provide up to 7 kW of power, and can carry payloads weighing up to 300 kg and needing a large suite of antennas (Fig. 2). Further growth in platform dimensions and performances will certainly take place as larger launchers such as Ariane-5 become available.

The Olympus TV broadcasting payload (TVBS) is designed for the 27 MHz channels allocated by WARC 77 (World Administrative Radio Conference). The key parameter for the satellite payload is the 59.4 dBW effective isotropic radiated power (EIRP) provided by high-power amplifiers (HPAs) capable of delivering some 200 W at end-of-life, and antennas with a gain of 38.5 dB at the edge of the nominal coverage.

Table 1 — Examples of HDTV transmission formats suitable for satellite broadcasting

System	MUSE*	HD-MAC**	HDTV analogue***	HDTV digital****
Lines	1125	1250	1250	1250
Luminance samples/line	1496	1440	1920	1920
Crominance samples/line	374	720	960	960
Transmission bandwidth, MHz	24	27	54	105
Modulation	FM	FM + 2PSK	FM + 4PSK	QPSK
Estimated carrier-to-noise ratio (C/N), dB	17	17	20	14.5

* The MUSE system is being developed, and has been fully tested, in Japan and is compatible with NTSC standards.

** HD-MAC is being developed in Europe and is compatible with MAC packet standards.

*** Digitally assisted analogue system, making optimum use of double channel bandwidth.

**** All-digital example not compatible with MAC packet receivers, retains compatibility at source with 625-line standard.

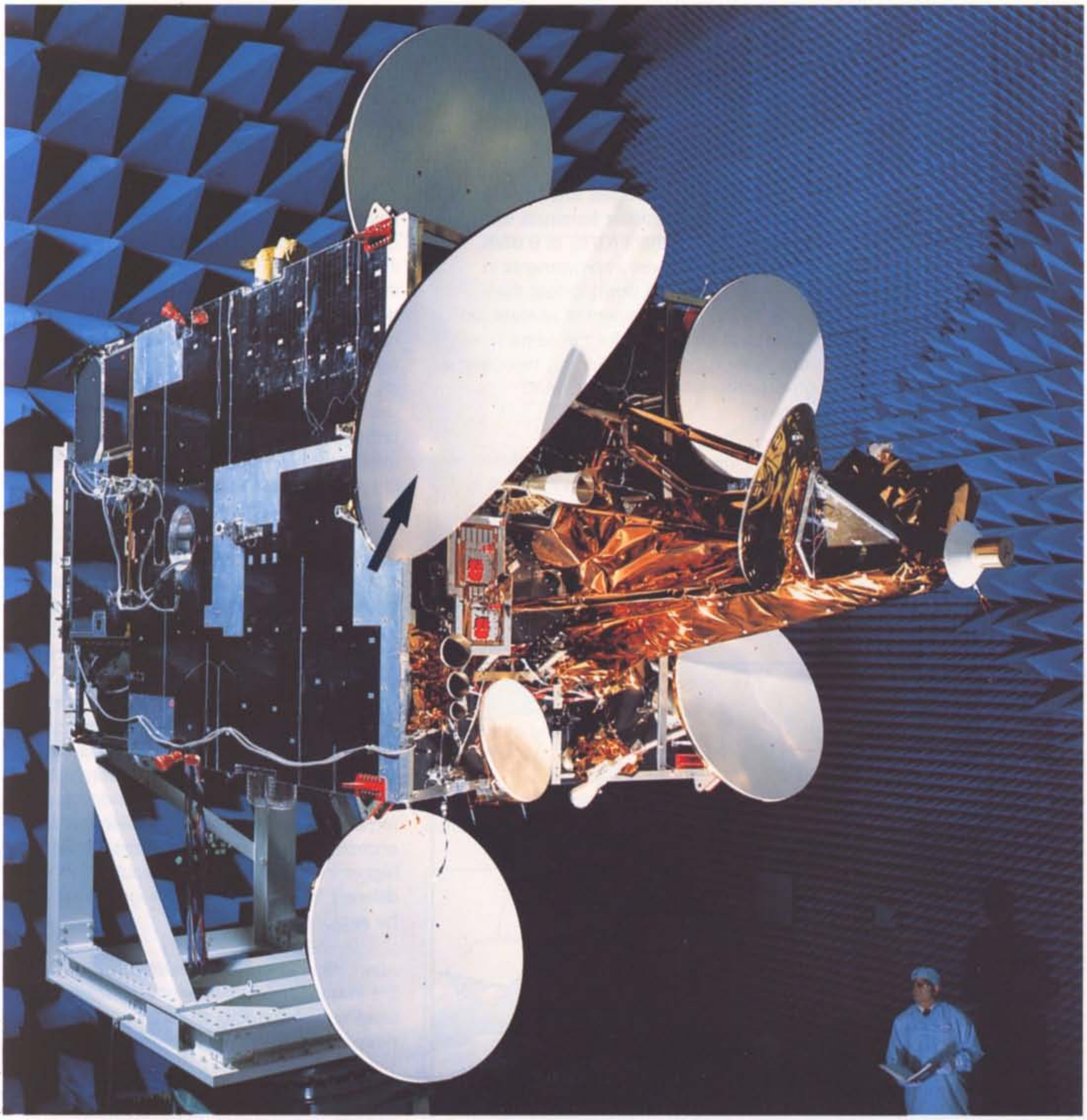


photo: picture report

Figure 2 — Olympus flight-model spacecraft during testing in Canada. The large elliptical dual-reflector antenna (arrowed) will be used to broadcast the Italian TV1 channel

Table 2 — Olympus satellite transmission performance data

	Italian channel TV1		European channel TV2	
	Nominal value	Permissible variation	Nominal value	Permissible variation
Peak radiated power (EIRP; bore-sight axis), dBW	62.4	+0.5 dB typical	62.7	+0.5 dB typical
−3 dB beam width of transmit antenna, deg	2.4×1	negligible	1.5×1.5	negligible
Nominal beam pointing in coordinates, deg	12.3 E 41.3 N	±0.1 stability	repointable	±0.2 stability

For the Italian TV1 channel, Olympus can provide direct broadcasting to very small receiving antennas at the edge of coverage with very high availability (better than 99% during the worst month of the year) and carrier-to-noise ratios of better than 14 dB.

The underlying link budgets are, however, still based on ground receiver terminals with effective figures of merit (G/Ts) of 6 dB/K. Obviously, with present improvements in receiver noise figures down to less than 3 dB, a further improvement of at least 3 dB in G/T could be offered for the same small size of antenna, thereby allowing reception of high-definition television of HD-MAC standard.

Based on the Olympus coverages shown in Figure 3, and taking the Italian footprint in particular, the current goal is to ensure the broadest coverage possible. With HDTV satellite broadcasting, however, where link budgets are more critical, one should not attempt coverage of the marginal reception areas. The provision of consistently good quality HDTV reception with 99% or better service availability is not feasible with today's technology at the coverage margins with a broadcasting satellite of acceptable dimensions and cost. For the time being, it will be more efficient to concentrate the available power in the primary coverage area instead.

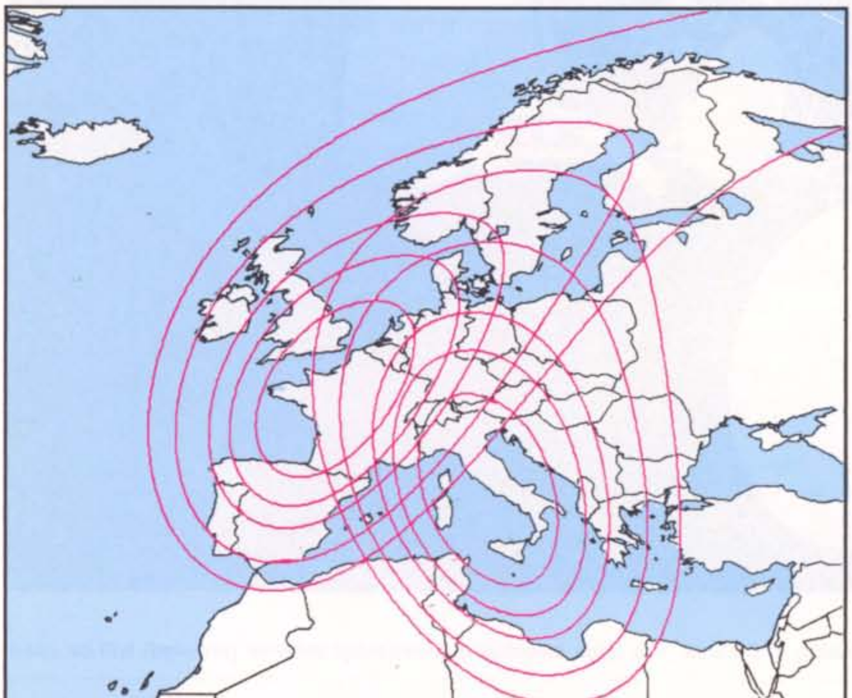


Figure 3 — Sample coverage of the Olympus broadcast mission

The practical feasibility of HDTV broadcasting by satellite has been demonstrated already by experiments performed in several countries (most recently for the Olympic Games using the JBS-2 satellite) with the 'MUSE' system, which is the proposed Japanese standard.

Frequency allocations

None of the systems providing full HDTV quality discussed so far are compatible with the existing WARC 77 frequency planning for the 12 GHz band. The 1977 Plan was designed for analogue FM systems requiring high interference protection. It therefore assigns each country five 27 MHz-wide channels, spaced some 76 MHz apart. The various channels are interleaved with their orthogonally polarised counterparts, which means that by frequency re-use up to 80 channels can be broadcast to different countries from the same orbital position.

As shown in Table 1, for HDTV broadcasting, such analogue systems would require at least double-bandwidth channels 54 MHz wide; the bandwidth needed for the digital channels would be nearly twice this. To retain an adequate number of HDTV channels (three or four) for each country from a single orbital position, quite different planning criteria therefore need to be adopted. These could exploit the reduced protection ratios required by digital modulation and provide more selective geographical coverage, with acceptable satellite-antenna sizes, in the higher frequency bands. Alternatively, different frequency bands altogether should be exploited.

Attenuation and cross-polarisation figures for the frequency bands currently allocated to satellite broadcasting are shown in Table 3 as a function of service availability.

In the 12 GHz band, for a 99% service availability, the typical worst-month attentuation for Europe is 1.5 dB. For 99.9% availability, this increases to 4.5 dB, but low-cost antennas are still usable even for HDTV reception via cable heads.

The next band, from 22.5 to 23 GHz, is allocated to satellite broadcasting in CCIR Regions 2 and 3 (Americas and Asia), but not yet in Europe where it is dedicated to fixed and mobile services, with a window for radio-astronomy at 22.8 GHz. Attenuation rises rapidly in this band to 4.5 dB for 99% of the worst month. This additional 3 dB can be compensated for by doubling the satellite's radiated power (EIRP), and the cross-polarisation at 25 dB is still acceptable

Table 3 — Attenuation and cross-polarisation for different frequency bands

	Frequency, GHz 12		23		42		85	
Percentage of worst month	99	99.9	99	99.9	99	99.9	99	99.9
Attenuation, dB	1.5	4.5	4.5	13.5	11.6	35	19	57
Cross-polarisation, dB	30	20	25	15	24	13	—	—
Sky noise temperature, K	85		200		270			

for frequency reuse. However, the 13.5 dB attenuation at the required 99.9% availability for cable distribution would create problems especially for receiver terminals, which then need to have very large antennas.

In the still higher 42 and 85 GHz frequency bands, atmospheric attenuation increases to well above 10 dB even for 99% of the worst month. It is not easy to envisage technology being available in the next fifteen years or more to provide the satellite transmission powers needed to beam HDTV broadcasts to wide areas at these frequencies.

Consequently, these higher frequency bands cannot be considered as appropriate allocations for broadband HDTV transmission. Adequate bandwidth therefore needs to be allocated in CCIR Region 1, or at least for European coverage, in the 20 GHz frequency range. This was also the view of the 1988 WARC-ORB 2 Conference, which suggested a new planning effort for worldwide allocations in the frequency range up to 23 GHz.

Coverage and service quality

If HDTV broadcasting is to deliver consistently good quality, attention has to be paid to both coverage and service quality. In contrast to the trade-off that has been made for FM satellite television broadcasting, where a higher outage probability in the high-rain-rate areas is compensated for by better quality under clear-sky conditions (Fig. 4), the requirement of a consistently good service and the use of high-compression information techniques being proposed for HDTV transmission will by necessity lead to much quicker changes in quality as a function of signal attenuation, and therefore in service availability also.

For HDTV broadcasting, the primary objective, based on the above discussion, has to be high-quality TV reception with consistent availability throughout the target coverage area for at least 99% of the time. Beyond this, the service threshold will be reached rapidly even for robust digital transmission systems, and the duration of the outage has to be considered.

However, geographically the 1% worst-month outage times correspond to rain attentuation contours that are far from uniform (Fig. 5).

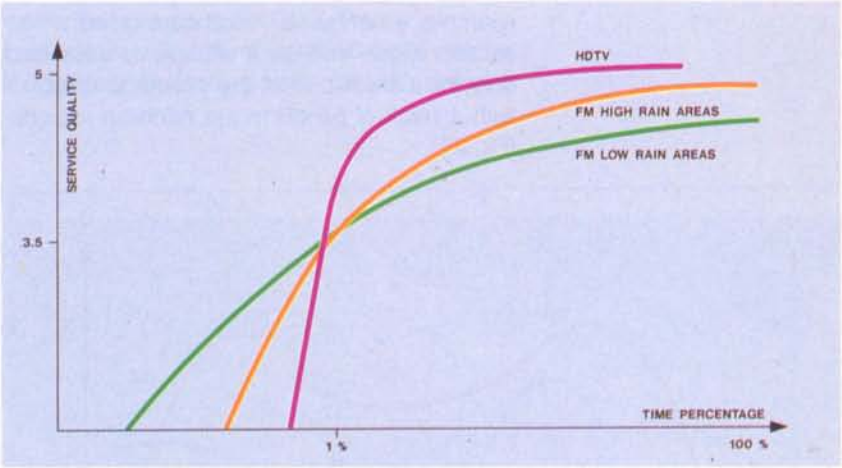
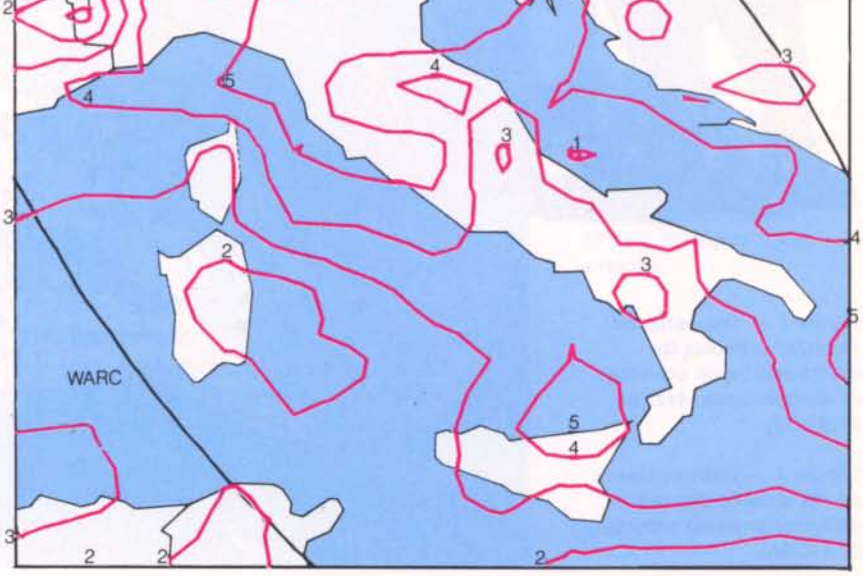


Figure 4 — Trade-off of service quality as a function of service availability

Figure 5 — Total attenuation contours for Italy (contours labelled from 1 to 5 dB)



Only in a few areas in Europe are the average values of 4.5 dB exceeded, with contours of 3 or 4 dB being more typical. Consequently, the satellite system should not be designed based so much on average attenuations across large areas, but more on specific attenuation contours providing the requisite service availability in the particular target broadcast area.

Again taking the Italian coverage as an example, a northwest—southeast cross-section shows that the 4 dB level is exceeded only for a small part of the coverage area, with a peak of 5.5 dB in the northern regions (Fig. 6).

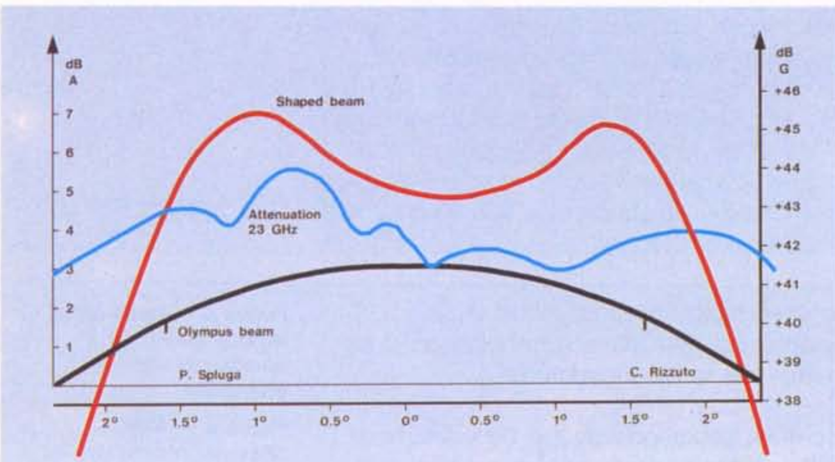


Figure 6 — Cross-sections of antenna patterns and attenuation contours for the Italian coverage

From a simple computation of the minimum elliptical coverage for Italy, and discounting the offshore and non-Italian-speaking areas, the integrated requirement for radiated power to match contoured coverages and propagation attenuation profiles could be considerably less than half the power needed for uniform illumination at peak level. This means that, by accepting to minimise the marginal coverage and matching the propagation margins to actual attenuations, a potential 3 dB improvement can be offered in satellite antenna gain by beam shaping.

Technologies for this beam shaping already exist. One specific method, based on changing the shape of the satellite antennas so that they are no longer simple parabolic reflectors, has been developed and tested by ERA for European coverage (Fig. 7). The measured gain contours achieved using this double-reflector configuration are shown in Figure 8.

More recently, the same approach has been used for the preliminary design of a shaped dual-reflector antenna matching (at 23 GHz) the coverage and attenuation contours for the Italian peninsula and using a larger (3.7 m aperture) deployable reflector developed by Selenia Spazio in the framework of ESA's ASTP-3 programme. The beam shape achieved (Fig. 9) matches the attenuation contours well.

Figure 7 — Dual-shaped reflector antenna for contoured-beam coverage of Europe under test at ERA (UK)

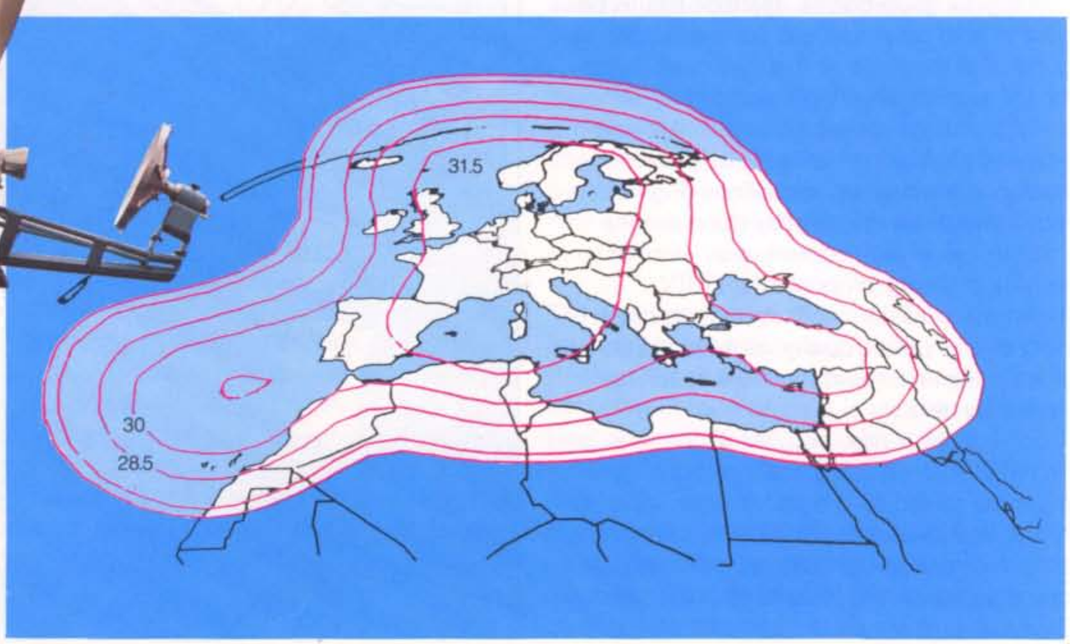


Figure 8 — Gain contours of the dual-contoured reflector antenna (courtesy of TICRA)

In Figure 6, a northwest—southeast cross-section through the shaped-beam pattern is compared with the attenuation curve and the wider beam of the existing 12 GHz Olympus TVBS antenna. The improvement in gain — more than 3 dB in the critical attenuation areas — is clearly evident.

The dual-reflector offset antenna configuration is similar that to be carried by ESA's Olympus satellite for broadcasting its Italian channel (Fig. 2). Olympus has in fact been designed specifically for carrying payloads with multiple antennas, and could therefore be used as a reference for design trade-offs for HDTV payloads.

Critical technologies for HDTV broadcasting

Satellite transmitter

A critical element of the satellite transmitter for broacasting in the 20 GHz band is the High-Power Amplifier (HPA). Long-life satellite Travelling-Wave-Tube Amplifiers (TWTAs) with helix delay lines currently have power limitations at about 100 W for these frequencies. New tube structures and further use of advanced technologies can, however, push the available powers into the 1 kW range. Possible alternatives are TWTAs with coupled cavities or klystrons. Lightweight high-power klystrons are already under development for C-band radar transmitters in the framework of the ESA Technology Research Programme (Fig. 10).

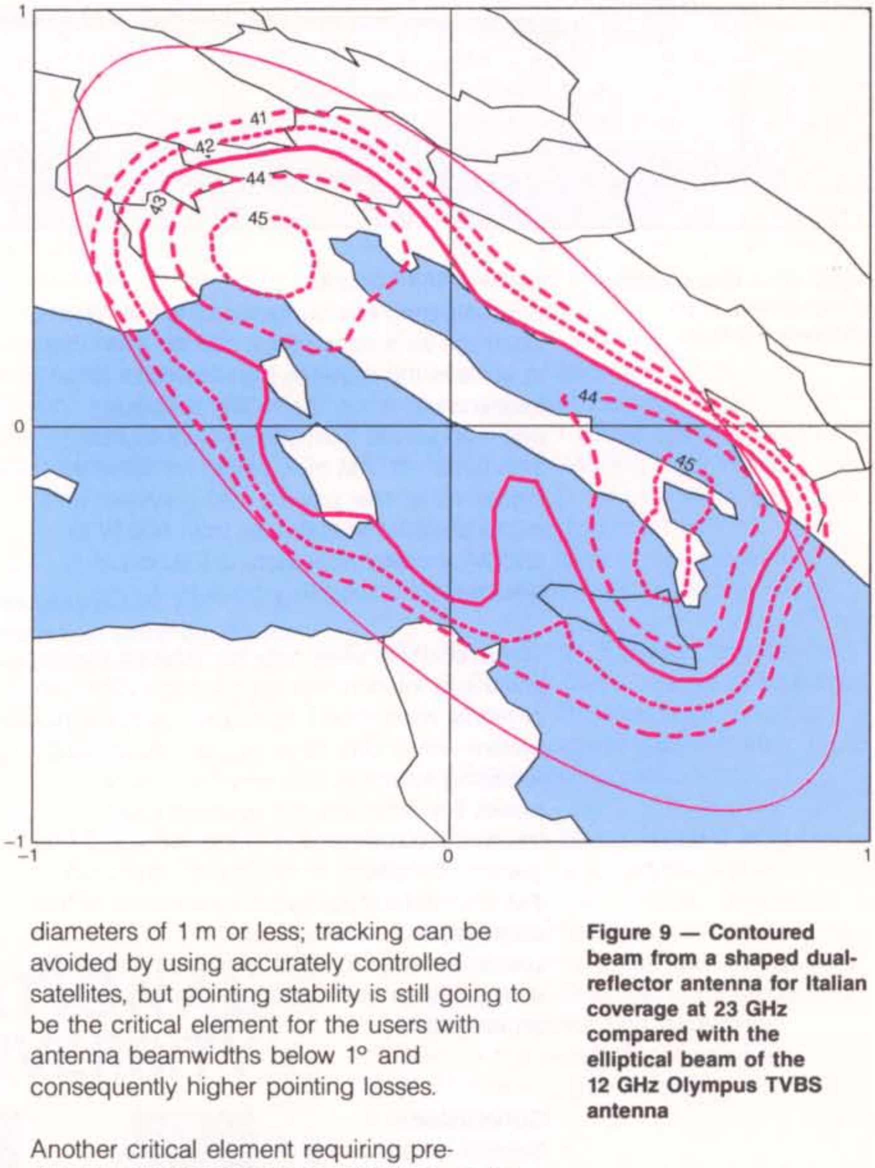
By re-scaling this design to the 20 GHz band, the target goals of 1 kW transmit power and 50% overall power conversion efficiency could be achieved in a reasonable time scale. The klystron can also ensure adequate linearity and bandwidth, and its relatively narrow bandwidth can simplify the output filtering for minimising losses. In fact, the low-loss output filters and the high-power channel multiplexers are critical technologies for these high frequencies and powers.

Fully digital modulation (QPSK) requires a larger bandwidth, but is more resistant to spurious interference than analogue FM modulation and delivers very predictable performance. With a lower and more uniform spectral power density, the satellite transmitter will be simpler to develop. The overall system design for HDTV satellite broadcasting will also be easier to realise and more compatible with other ground and space-communication systems operating in the same frequency ranges and using digital modulation.

Ground receiving terminals

Ground receiver terminals for the 12 GHz band are substantially better today than was foreseen in the original WARC 77 planning, allowing smaller receiver antennas to be used and reception in marginal areas.

The evolution in technology, and the introduction of high-electron-mobility transistors (FETs) in low-noise amplifiers in particular, allows projection of these improved performances up to 23 GHz. Thus, performance figures of up to 16 dB/K can be budgetted for low-cost terminals with antenna



diameters of 1 m or less; tracking can be avoided by using accurately controlled satellites, but pointing stability is still going to be the critical element for the users with antenna beamwidths below 1° and consequently higher pointing losses.

Figure 9 — Contoured beam from a shaped dual-reflector antenna for Italian coverage at 23 GHz compared with the elliptical beam of the 12 GHz Olympus TVBS antenna

Another critical element requiring pre-development for low-cost production will be an integrated high-performance digital demodulator working at around 140 Mbit/s. This should, however, become a classical large-production item for ground telecommunication networks geared to digital transmission.

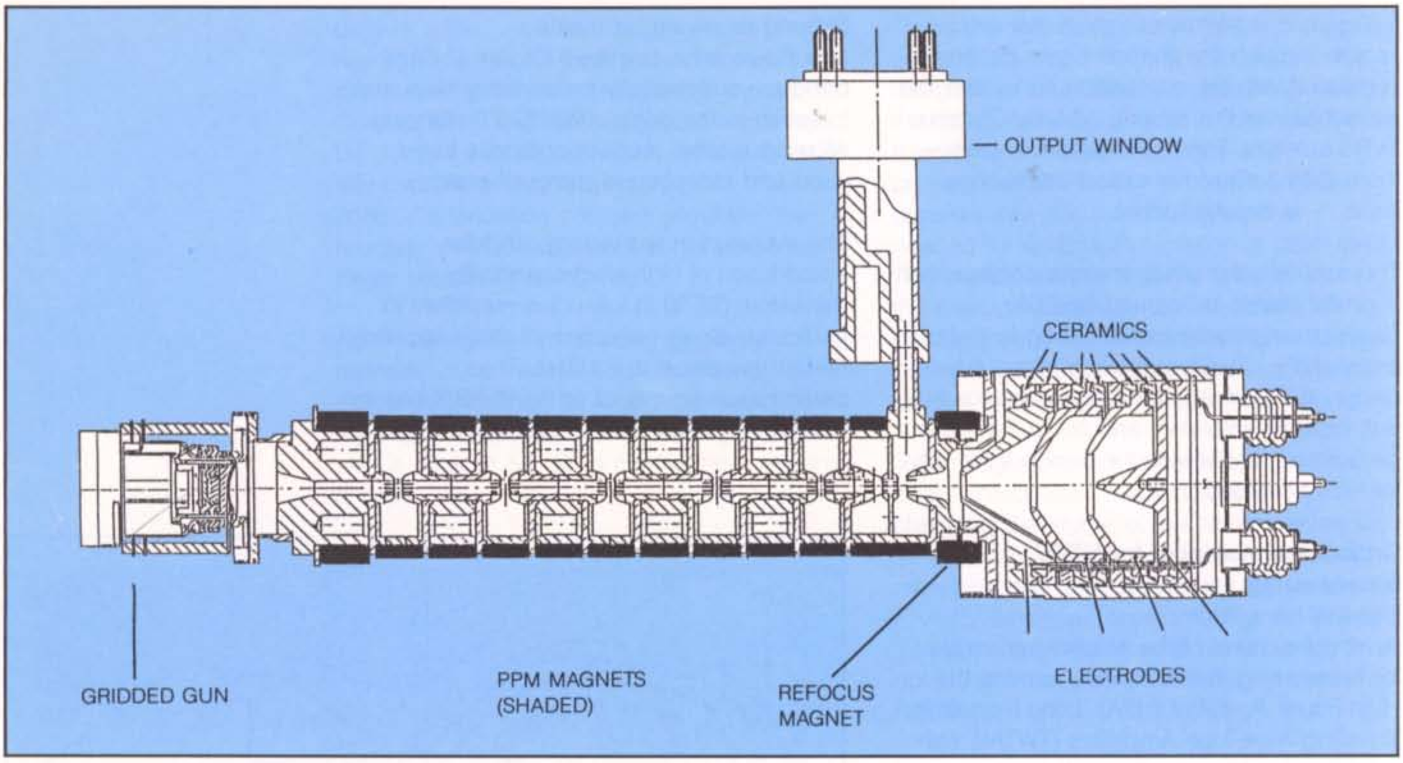


Figure 10 — Cross-section of high-power, high-efficiency klystron

23 GHz link budgets

By comparing link budgets, using the Italian coverage as a reference, it can be seen that, to achieve the requisite signal-to-noise (plus interference) ratios, the HDTV analogue systems derived from HD-MAC or MUSE standards with FM modulation will require higher transmitter powers than a system with digital modulation (increase from 600 W to 800 W), thereby approaching the limit of feasibility for a reliable satellite HPA.

These budgets allow only for reduced up-link noise and interference contributions. The use of highly imbalanced links is well justified in a system with a very large number of low-cost receiving terminals and very high transmit power. Nevertheless, the necessary low interference contribution in the uplink will be particularly difficult to achieve for analogue FM and MUSE-type systems. Because of this sensitivity to interference and the large bandwidth requirements, protected frequency allocations for the feeder up-links will not be an easy task.

Conclusions

Satellite broadcasting of High-Definition Television using the HD-MAC standard in the 12 GHz band is technically feasible with the high-power broadcasting satellites of the TDF/TV-Sat and Olympus families. Operational systems can be implemented within a normal satellite development cycle of four to five years. For full-quality HDTV with broader channels in the 20 GHz bands, some critical technologies still need to be further developed, including the shaped-beam satellite antennas, the 1 kW High-Power Amplifier, the low-loss filtering and transmission chains, and the low-noise ground receiver with an integrated digital demodulator. Development of these technologies is feasible, however, and an HDTV satellite broadcasting system using the 20 GHz band could be operational at the end of the next decade.

Nevertheless, no frequency allocations for HDTV satellite broadcasting are yet available for European use and a frequency-replanning exercise needs to take place. The use of even higher frequency bands for HDTV broadcasting (e.g. 40 GHz or higher) does not seem to be technically feasible.

For satellite broadcasting in either the 12 GHz or 20 GHz bands, existing spacecraft of the Olympus class could accommodate payloads broadcasting three or four high-power HDTV channels, provided the payload design is optimised for high efficiency.

The International Space University

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The International Space University (ISU) was created in 1987 as a non profit-making international graduate education programme for space research and development. Its first session was held in the summer of 1988 at the Massachusetts Institute of Technology (MIT) in Boston, USA. Over a hundred students from all over the World participated in this unique multidisciplinary experience in space education and research.

Introduction

The declared goals of the International Space University (ISU) are to:

- identify, assemble and educate talented students from all nations
- conduct research and design projects of interest to industry while providing students with the critical skills necessary for their future success
- cultivate the leadership abilities of participating students and initiate long-lasting ties among these future heads of industry, government and academia
- enhance and expand international collaboration on space-related projects
- develop a full-year format and permanent campus by 1992, International Space Year.

*Student at the ISU 1988 summer session.

Figure 1 – ISU logo

The ISU Board of Directors and Board of Advisors consist of distinguished business and government leaders, scientists, space experts and academicians from many countries. They include: Prof. Reimar Lüst, ESA's Director General, Academician Roald Z. Sagdeev, Space Research Institute of the Soviet Academy of Sciences, Mr G. O'Neill, President, Space Studies Institute, Princeton, Mr Arthur C. Clarke, Chancellor, University of Moratuwa, and Mr Dean Burch, Director General of Intelsat.

A core faculty of 30 lecturers has been drawn from the top research organisations worldwide – from space agencies (including ESA, NASA and NASDA), from industry and from universities. In addition there are some 70 visiting lecturers from 14 nations, representing the leading researchers and technical experts in their respective fields.

At the 1988 session, ESA was represented by Dr R. Bonnet, ESA's Director of Scientific Programmes, Mr R. Oosterlinck, Head of ESA Personnel Management and Mr I. Pryke, Head of ESA's Washington Office.

To qualify for admission students must be currently enrolled in or admitted to a graduate programme, or have successfully completed a graduate programme no more than five years prior to the start of the ISU summer session. Selection is on grounds of academic excellence and leadership qualities. A high level of motivation and the ability to establish good working relationships are also essential.

A preliminary selection process is carried out by 'National Foundations for the ISU' that have been set up in many countries. Each Foundation proposes a number of students to represent their country, who then go forward to the final selection process. Students are primarily sponsored through scholarship funds provided by government agencies, corporations and foundations and coordinated by the 'National Foundations'. 105 students (82 men and 23 women) from twenty different nations attended the 1988 session. The international nature of the student body is clearly illustrated in Table 1.

All educational activities of the ISU are conducted in English, and all students must be able to demonstrate written and oral proficiency in English. Native English speaking students are required to demonstrate fluency in a second language.

Table 1 – Nationalities of students enrolled in the ISU's 1988 session

United Kingdom	10
France	7
Federal Republic of Germany	5
Italy	3
Switzerland	1
Belgium	1
Canada	10
USA	24
USSR	12
China	8
Japan	5
India	4
Brazil	3
Kenya	3
Australia	2
Saudi Arabia	2
United Arab Emirates	1
Argentina	1
Ecuador	1
Sri Lanka	1
Poland	1

Total: 105

The 1988 summer session

The first session of the ISU, from 20 June to 20 August 1988, began with an initial week of orientation to the MIT facilities and the surroundings (Harvard, Boston etc). This intensive summer programme consisted of over 240 hours of lectures and some 280 hours of design project work, a full year of study compressed into two months.

The programme is designed to provide students with a general understanding of all technical and non-technical areas of importance in the exploration and development of outer space. It was organised around eight space-related fields of study:
- space engineering
- space sciences
- space business and management
- space policy and law
- satellite applications
- space resources and manufacturing
- human performances in space
- space architecture.

Figure 2 – The 'Moon Base' site selection group

The 'Moon Base' design project

Throughout the summer session, the students also participated in a joint design project which allowed the practical application of theoretical course work. All aspects relating to the construction of a base on the Moon for 10 to 15 people by the year 2010 were to be explored. This included the setting up of rules, laws and treaties for the creation of an International Lunar Initiative Organisation (ILIO), the study of the transportation system from the Earth to the Moon and back, all facilities to be implemented on the selected site, ecological systems for self-sufficiency and the human aspects (physiological and psychological).

This International Lunar Initiative focused on solving near-term issues related to organising a major multinational space development venture. Course lecturers coordinated their teaching material directly to the ILIO exercise and provided relevant examples to assist students in the design work.

After preliminary discussions the participants decided to divide the project into sections, with teams dedicated to each. Care was taken to ensure that the groups included 'specialists' with the relevant expertise or interest. The 'environmental impact' sub-group, for example, included students specialising in architecture, space sciences, policy and law, who were able to address such questions as: What would be the impact of repeated launches from the lunar

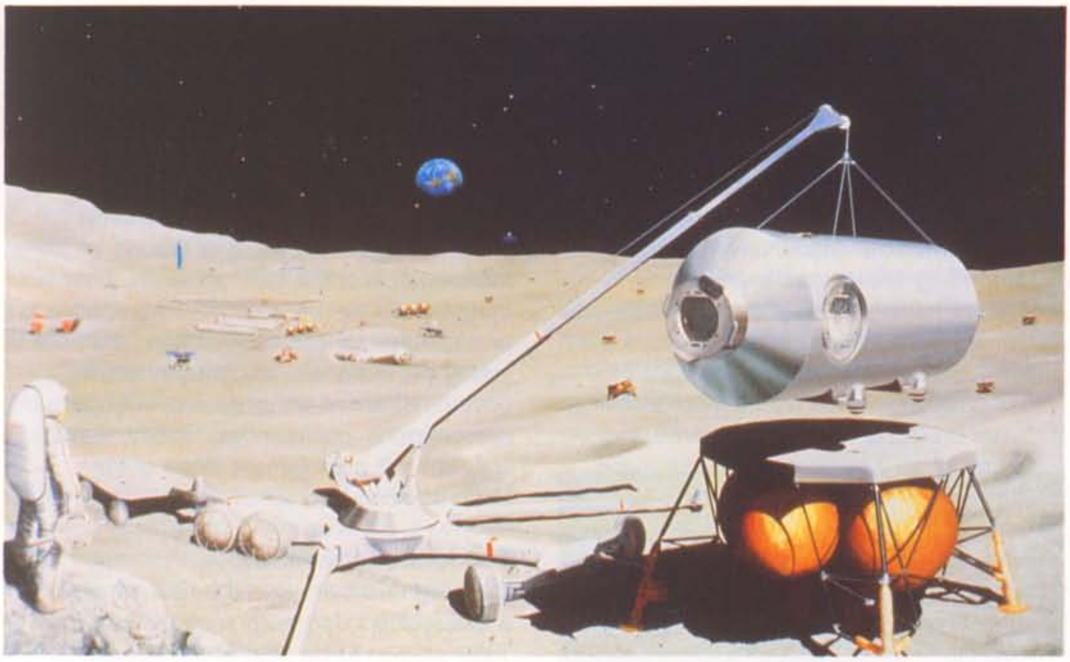


Figure 3 – 'Lunar base' design concept (courtesy of NASA/Pat Rawlings)

surface? Would they create dust orbiting around the Moon which would disturb astronomical observations?

After four weeks a mid-term review was held, at which each group gave a status report. This allowed the exchange of ideas and problems, particularly in areas where there was some overlap. The review was valuable, both in terms of the increase in interaction between the groups, and in giving direction to the second and final phase.

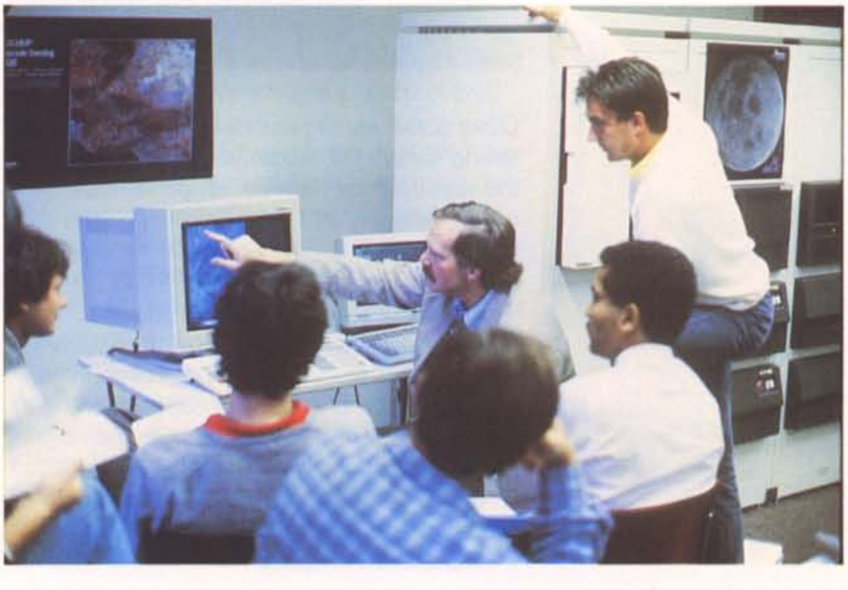
Amongst other engineering tools, students were given the opportunity to work with computer databases containing digitised maps of the Moon made during the Apollo missions. It was possible, for instance, to visualise concentrations of elements at different locations on the surface of the Moon (mainly around the Moon's equator). It was then easy to overlay information on elevation, concentration and distances to make final decisions concerning the location of the lunar base (Figs. 3 and 4).

Special activities

The ISU also offered a programme of extracurricular lectures, seminars and visits during the summer session, including:

- a satellite tele-education lecture given by Richard O'Neill to approximately one hundred American universities
- lectures by Edwin E. Aldrin (the second man to walk on the Moon) on human behaviour in the constraining environment of spacecraft and on new space transportation systems
- lectures by Charlie Walker, payload specialist on the Space Shuttle, who performed protein purification experiments, by Rhea Sheddon and Byron Lichtenberg, both life scientists and payload specialists for the Spacelab missions, and by B. Pogue, who spent three months on board Skylab
- conferences dedicated to special topics such as space debris, space art, international and private business initiatives, philosophy and space
- a visit to the Harvard Observatory, where scientists are working on a radio-telescope dedicated to the Search for Extra-Terrestrial Intelligence (SETI) and on two optical telescopes for observation of the stars
- a visit to the National Air and Space Museum, Washington
- a visit to Intelsat's Headquarters in Washington.

Figure 4 – ISU students using computer databases derived from the Apollo missions to site a lunar base



'Hands-on' sessions also gave the students the opportunity to participate more actively in various projects, for example:
- a session of robot manipulation by remote control, which simulated the delay in the transmission of information from the Earth to the Moon to provide an understanding of the problems encountered by scientists performing telescience experiments
- a 'lunar mining' contest during which teams had to build robots that could drag as much sand as possible over a designated distance (some innovative 'lunar bulldozer' designs have resulted)
- testing of an American-designed space suit (Fig. 5)
- testing of a spinning bed that simulates gravity, a candidate for the Space Station 'Freedom'.

Figure 5 – Lecture on an American space suit design given by Prof. L. Kuznetz (left), University of California

Other activities, organised by or with the strong support of students, served to cement the relationships between students from widely differing ethnic backgrounds, and included:

- intercultural hours at which students presented their country and their culture
- a 24-hour festival of science-fiction films
- preparation of a letter of support for the Space Station Freedom sent to the American Congress
- the writing of a 'philosophical preamble' on the students' views concerning the exploitation of space
- evening discussions and presentations on the impact of religion on all space developments.

The ISU European Alumni Association
The European students who participated in the first ISU session in 1988 felt it was important to make people in Europe aware of the existence of this new university. They therefore decided to create an association to promote the benefits of the ISU to the public, young professionals, students, industries, governments and universities through presentations, conferences, reports, etc. Its activities will complement those of the National Foundations.

The future of the ISU
Over the next five years the ISU will move to a different location each summer, with the 1989 session to be held at the Université Louis Pasteur, in Strasbourg, France. ISU's Board of Directors selected the Université Louis Pasteur from numerous potential locations, based on an evaluation of academic facilities, student housing and other considerations. According to Prof. Reimar Lüst, ESA's Director General, the decision to host the ISU in Strasbourg is a very important one: 'Reports on the 1988 session have shown that it has been very successful and demonstrate that the ISU could develop an important international educational collaboration. The decision to come to Europe will make it a truly international endeavour.'

The 1989 session will start on 30 June and run until 31 August. A total of 120 graduate-level students from more than 20 countries are expected to attend.

Tele-education programmes are foreseen for the 1989 session using one of the four payloads of ESA's Telecommunication Satellite Olympus, scheduled for launch at the end of May 1989. It will be possible for a lecturer

Further information on the ISU may be obtained from:

European Alumni Association for the ISU
Tel. Int: (31)1719.83926
or
International Space University
636 Beacon Street
Suite 201-202
Boston, USA
Tel. Int: 1 (617)247-1987

located anywhere in Europe to address the ISU students in Strasbourg via a video link. Broadcasting of ISU courses to universities or interested institutions should also be possible via Olympus.

At the end of its first five years the University will move to a permanent campus, the location of which remains to be determined. For the first year of a two-year programme students will attend a foundation course on campus; the second year will be spent at a university appropriate to the student's specialist subject.

In the long term, students may even be able to spend a research period aboard a space station (Mir or Freedom), perhaps the first step towards a permanent in-orbit campus ? (Fig. 6).

Conclusion
Quoting Senator John Glenn, the first American in space: 'An International Space University dedicated to the study of space is the next logical step towards expanding human potential at the frontiers of space... Our future in space belongs to our young people, and the International Space University must be designed to meet their challenge to us to provide the education, the resources, and the support they need to realise the dreams of all of us as we reach for the stars.'

The young professionals who attend the ISU lectures given by space specialists gain both theoretical and technical knowledge. They have the opportunity to meet more than one hundred peers who have the same high level of interest in space development, and form a network of friends and colleagues from all over the World. The European students at the 1988 session found it particularly valuable to interact with students from parts of the World where 'space' is perceived in a totally different way. As some students wrote in their final reports, 'The ISU '88 proved to be a personally rewarding experience; educationally, socially and in terms of my future career development. The experience gained will have a strong positive influence in all my future endeavours'. 'Not only did we receive extremely intense exposure to space-related problems, we also learned to work together as an international team. This ISU 88 will form the beginning of the development of an international network that will eventually aid greatly in the exploration of space'.

There are also clear benefits for an organisation (space agency, university or industrial firm) from sending both students and lecturers to the ISU or from providing sponsorship, and not just in terms of expertise gained and new ideas for projects and systems designs. By hosting the ISU, the Host Campus confirms its willingness to participate and contribute to the new era of space technology, thus increasing its international standing in the field. Perhaps more importantly, the ISU improves understanding between nations. One group of students wrote in the 'philosophical

Figure 6 – A permanent in-orbit campus for the ISU?

preamble': 'Human intelligence will help us as we go, and with it we may assure the survival of ourselves and other lifeforms. Step by step, from artificial satellites to space stations to Moon bases, and beyond, we are progressing towards a stage where we shall establish new worlds in space which may serve as future refuges for life ... The international community can be regarded as a family, with each member having a role to play, and sharing efforts, rewards, and responsibility for the other members. On 'Spaceship Earth', every person and every nation can make a contribution to space exploration'.

Acknowledgment
The author would like to thank all the European students who provided material for this article through reports produced on the ISU '88.

Le prochain vol spatial franco-soviétique — Des robots et des hommes

(Reproduction d'un article paru dans Le Monde daté du 20-21 novembre 1988)

Hubert Curien
Ministre français de la Recherche et de la Technologie

Dans une semaine, le cosmonaute français Jean-Loup Chrétien doit rejoindre la station spatiale soviétique Mir pour un séjour de près d'un mois. Cette mission pose à nouveau la question de l'utilité des vols habités.

M. Hubert Curien, ministre de la recherche et de la technologie, présidait le CNES en 1980, quand il fut envisagé de renoncer à l'envoi d'hommes dans l'espace et de s'en remettre à des robots.

Il explique pourquoi l'homme est indispensable pour certaines missions actuelles, mais aussi pourquoi, avec de nouvelles missions, sa présence pourrait devenir une nécessité permanente.

Très bientôt, Jean-Loup Chrétien sera lancé dans l'espace pour la deuxième fois, en compagnie de cosmonautes soviétiques. Patrick Baudry a navigué naguère à bord de la navette spatiale américaine. Ces évènements ne passent pas inaperçus: sont-ils aussi utiles que spectaculaires? J'ai eu le devoir et le plaisir de négocier assidûment avec les responsables des programmes spatiaux en Union soviétique tout autant qu'aux Etats-Unis d'Amérique ces excursions spatiales françaises et d'apporter ainsi la preuve d'une conviction que je me suis attaché à fonder sur un faisceau d'arguments tout autant scientifiques et techniques que politiques. Le temps n'est plus aux enthousiasmes spatiaux inconditionnels. Il faut raisonner, comparer, compter ses écus. L'homme dans l'espace est-il plus efficace ou moins onéreux que le robot?

La réponse n'est pas si simple, car les tâches qui peuvent être confiées aux cosmonautes sont en fait de natures fort diverses: travailler dans une station-laboratoire, réparer des satellites déficients, observer la terre ou les astres, ou encore assembler en orbite de grandes structures.

Un laboratoire habité dans l'espace? L'homme y sera quasi irremplaçable aussi longtemps qu'il s'agira de mettre au point un processus nouveau par essais successifs et intelligemment corrigés, mais dès que pourra commencer une production plus routinière, le robot sera sans doute un opérateur sûr et plus économique.

Une 'station-service' pour la réparation des satellites? Malheureusement, les satellites les plus usuels sont situés sur des orbites équatoriales très hautes ou polaires, c'est-à-dire très exposées à des radiations mal supportées par des êtres vivants: les stations-service ne peuvent donc pas être placées à demeure sur les très grandes autoroutes spatiales.

Des observatoires dans l'espace? Pour réaliser un pointage fin vers l'objet visé, il faut assurer à la plateforme une parfaite stabilité que le moindre geste de ses habitants éventuels risque de troubler. Assembler de grandes structures en orbite? Là, des hommes peuvent oeuvrer avec un talent que les robots sont encore certainement très loin de pouvoir imiter.

Chercheurs ou charpentiers plutôt que réparateurs ou laborantins, tel est le type d'embauche maintenant affiché pour l'espace. Une embauche qui n'est cependant susceptible d'intéresser que des candidats temporaires et il y a sans doute plus d'avenir en orbite pour des visiteurs que pour des colons. Sauf sur la Lune, ce qui est plutôt pour après-demain.

S'il est volontairement incisif, mon propos n'est nullement désabusé. Il ne me conduit en aucune manière à la conclusion que nous serions mieux inspirés, nous Français, nous Européens, en laissant aux Etats-Unis et à l'URSS l'exclusivité des sports spatiaux individuels ou en équipe. Imaginons, en effet, que l'Europe ait décidé de rester en dehors des programmes qui impliquent la présence de l'homme dans l'espace. Elle aurait aussitôt acquis la réputation peu enviable d'un continent de seconde classe qui renonce à s'attaquer aux domaines techniques les plus difficiles.

Nous aurions bien pu affirmer que nous agissions par pure sagesse: qui nous aurait crus? Pensez-vous que les Japonais aient l'intention de faire l'économie de l'homme dans l'espace? Ils viennent de signer un accord avec la NASA pour participer à la construction et à l'exploitation de la station spatiale américaine.

Et croyez-vous que, dans le futur, si l'évolution des techniques faisait que la présence de l'homme dans l'espace se révélait essentielle pour telle ou telle activité économique ou militaire à présent encore mal perçue, nos deux grands partenaires nous feraient le royal cadeau du savoir-faire qu'ils auraient acquis sans nous? Quelques incidents durement vécus nous en font sérieusement douter.

Le ciel sans angélisme
Lorsque, en 1975, Français et Allemands ont voulu mettre en orbite leurs satellites de télécommunication Symphonie*, alors que la fusée Ariane n'était pas encore prête, ils ont dû accepter les conditions des détenteurs du monopole commercial des lanceurs: les Américains ont placé nos Symphonie en position parfaite, à la stricte condition que nous renoncions à faire avec ces satellites la moindre concurrence aux leurs. Voilà qui nous a confortés, à l'époque, dans notre volonté de construire notre propre fusée! Le commerce est le commerce et il n'y a pas plus d'angélisme dans le ciel qu'ailleurs.

L'Europe qui s'unit doit définir son autonomie, non pas dans l'isolement, mais dans l'équilibre avec les autres grandes puissances économiques mondiales. Pour le choix et le suivi de nos grands programmes spatiaux, nous disposons d'une institution qui a fait ses preuves: l'Agence spatiale européenne. C'est à travers elle que nous nous engageons dans la réalisation de l'avion spatial Hermès et dans la participation à la future station orbitale américaine.

Les vols de Jean-Loup Chrétien et celui de Patrick Baudry ont été cependant décidés par des conventions bilatérales de la France avec l'URSS, d'une part, et les USA, d'autre part. Les Français seraient-ils, dans l'espace, des Européens frondeurs? Notre engagement spatial européen est en réalité très sincère et factuel: la France tient le premier rang des cotisants à l'Agence spatiale européenne. Mais notre foi européenne ne saurait nous conduire à nous imputer à péché toute coopération bilatérale, France-USA ou France-URSS. Ces actions servent aussi d'aiguillon et de ferment aux programmes multilatéraux qui sont de beaucoup les plus nombreux.

Et parlons maintenant un peu d'argent. Les activités spatiales coûtent au total, par an, cent francs à chaque Français et cent dollars à chaque Américain, à peu près. Nos amis d'outre-Atlantique en font-ils trop? Nous pouvons en tout cas, quant à nous, en faire significativement plus sans passer, dans les comparaisons internationales, pour des dépensiers inconsidérés.

Le bon sens et la saine gestion de notre potentiel innovatif doivent cependant nous conduire à faire en sorte que l'accroissement de nos dépenses spatiales, et notamment celles des vols habités, ne se fasse d'aucune manière au détriment des efforts si nécessaires dans les autres domaines de la recherche et de la technologie. C'est le conseil donné, avec quelque solennité, par l'Académie des sciences dans un récent rapport. Un conseil sage que nous étions tout prêts à suivre: le projet de budget de la recherche pour 1989 en apporte la confirmation.

Lorsque, dans quelques jours, la télévision nous montrera Jean-Loup Chrétien sortant de la station Mir pour évoluer en scaphandre dans l'espace, je suis sûr que tous nos compatriotes se sentiront concernés.

Vouloir être là où il se passe quelque chose est une pulsion à laquelle il est souvent imprudent de résister.

* Le programme franco-allemand Symphonie visait à démontrer la compétitivité des industries des deux pays dans le domaine des télécommunications spatiales et de la retransmission d'émissions de télévision. Deux satellites furent construits à cet effet et le premier lancé le 19 décembre 1974

The Forthcoming Franco-Soviet Space Flight — Of Robots and Men

(Translation of an article in Le Monde, dated 20-21 November 1988)

Hubert Curien
French Minister of Research and Technology

One week from now the French cosmonaut Jean-Loup Chrétien will be joining the Soviet space station 'Mir' for a stay of almost a month. This mission raises once again the question of the usefulness of crewed space flight.

Hubert Curien, France's Minister of Research and Technology, was Chairman of the French national space agency CNES in 1980, when the idea was mooted of giving up sending men into space in favour of reliance on robots.

In this article he explains why a human presence in orbit is essential for certain current missions, and why, with the advent of new missions, it could become a permanent necessity.

Very soon now Jean-Loup Chrétien will be launched into space for the second time, in the company of Soviet cosmonauts. Not so long ago, Patrick Baudry flew on the American Space Shuttle. Such events do not go unnoticed, but are they as useful as they are spectacular?

It was my responsibility and pleasure to negotiate these French excursions into space with those in charge of the Soviet and American space programmes, thereby demonstrating a personal conviction based on a set of arguments that are political as well as scientific and technical.

The era of unconditional enthusiasm for space ventures is past. Now is a time for reasoning, comparing and counting one's money. Are human beings in space more efficient or less costly than robots?

The answer is not so simple, since the tasks that can be entrusted to cosmonauts are actually of very different kinds: working in a laboratory station, repairing defective satellites, observing the Earth or the stars, or assembling large structures in orbit.

A crewed laboratory in space? Human beings will be virtually irreplaceable as long as it is necessary to perfect a new process by successive tests that require intelligent correction. But as soon as production of a more routine nature can begin, the robot will doubtless be a more reliable and more economical operator.

A 'service station' for satellite repairs? Unfortunately the most common satellites are situated in very high equatorial orbits or in polar orbits, where they are very exposed to radiation highly dangerous to living beings. Service stations cannot therefore be located on the great space highways.

Space observatories? In order to achieve fine pointing at the target, the platform has to be absolutely stable, and the slightest movement of any human crew member would be likely to disturb it. Assembly of large structures in orbit? This is an area in which human beings can work with skills that robots are still certainly very far from being able to imitate.

Researchers and carpenters, rather than repair mechanics or laboratory workers, are the kind of jobs now on offer in space – jobs that are however likely to be open only to the most highly qualified candidates! Moreover, the jobs are of a rather temporary nature, and there is no doubt more of a future in space for visitors than for colonists. Except on the Moon, which is not on the immediate agenda.

While I have deliberately not minced my words, I do not wish to convey disillusionment. I do not conclude in any way that we in France and in Europe would be better advised to leave individual or team space sports to the United States and Soviet Union. Imagine for a moment that Europe had decided to remain outside programmes involving a human presence in space. It would have immediately acquired the unenviable reputation of a second-class continent that was not prepared to tackle the most difficult technical areas.

Of course we could have explained that we were motivated strictly by reason. But who would have believed us? Do the Japanese intend to do without a human presence in space? They have just signed an agreement with NASA on participation in the construction and exploitation of the American Space Station.

And are we to believe that, in the future, if the often non-linear evolution of technology makes a human presence in space essential for a given economic or military activity that we can hardly glimpse at the present time, our two major partners would make us a present of the know-how they had acquired without us? Several incidents that have caused us considerable difficulties give serious reason to doubt it.

Business is business
When, in 1975, France and Germany wanted to put their 'Symphonie' communication satellites* into orbit, and the Ariane launcher was not yet ready, they had to accept the terms imposed by those who held the commercial launcher monopoly. The Americans put our Symphonie satellites exactly where we wanted them, on the strict condition that we undertook not to use them in any way to compete with their own satellites. That was what confirmed us, at the time, in our resolve to build our own rocket! Business is business, in space as everywhere else.

Europe, in striving towards unity, must define its autonomy not in isolation, but in balance with the other major World economic powers. For the choice and supervision of our major space programmes we have an institution that has proved its worth – the European Space Agency. It is through the Agency that we are engaging in the development of the Hermes spaceplane and in participation in the future American Space Station.

The flights of Jean-Loup Chrétien and Patrick Baudry were, however, decided under bilateral agreements between France and the Soviet Union in the one case, and the United States in the other. Are we French lacking in European commitment where space is

Prof. H. Curien

concerned? Actually, our commitment to the European space endeavour is very sincere and very concrete. France is the foremost contributor to the European Space Agency. But our faith in Europe does not mean that we consider any form of bilateral Franco-American or Franco-Soviet cooperation as beyond the pale. Such cooperation also serves as a stimulus and catalyst for the far more numerous multilateral programmes.

And what about the money side of things? The total annual cost of space activities is more or less one hundred francs for each French citizen and one hundred dollars for each American. Are our friends on the other side of the Atlantic doing too much? In our case, we cannot do much more without appearing, in terms of international comparisons, to be reckless spendthrifts.

Common sense and sound management of our innovatory potential must, however, lead us to ensure that the increase in our space expenditure, particularly on crewed flight, does not take place to the detriment of the efforts that are so sorely needed in other fields of research and technology. That was the advice given, with some solemnity, by the Academy of Sciences in a recent report. Wise advice indeed, which we were quite prepared to take, as witnessed by the draft research budget for 1989.

When, in a few days' time, our television screens show us Jean-Loup Chrétien emerging from the Mir station in his spacesuit, I am sure every French citizen will feel personally involved.

The wish to be where the action is, is an impulse that it is often unwise to resist.

* The Franco-German 'Symphonie' programme was designed to demonstrate the competitiveness of French and German firms in the space telecommunications field and in the retransmission of television programmes. Two satellites were built for this purpose, the first of which was launched on 19 December 1974.

ESA's Redu Station Celebrates Twenty Years of Operations

On 8 November 1988, ESA's Director General, Prof. Reimar Lüst, welcomed Vice-Prime Minister Schiltz of the Belgian Government, Ambassadors from six Member States, senior representatives of five others, the Director General of Eutelsat, and honoured guests to the celebrations at ESA's Belgian ground station (Fig. 1). In reminding the audience of the many satellites controlled and monitored by Redu since it was first declared operational on 1 January 1968, especially the ECS series of European communications satellites, Professor Lüst spoke of Redu's future role with Olympus, and beyond to the era of the Data-Relay Satellites.

His theme of looking to the future was echoed in the presentations by Mr Kurt Heftman, ESA's Director of Operations, Mr Giorgio Salvatori, ESA's Director of Telecommunications Programmes and Mr René Collette, Head of the Agency's Communications Satellites Department.

The Director General of Eutelsat, Mr Andre Caruso, whose organisation leases the ECS satellites, paid tribute to the Redu team, and spoke of the warm relationship that exists between ESA and Eutelsat at both management and technical level, a bond of common interest which he saw continuing and growing.

In his address, Vice-Prime Minister Schiltz spoke of Belgium's long interest in, and support for the European Space Agency. He sees a challenging but fruitful era ahead with Europe taking its rightful place as a major space power. He had the confidence to forecast another celebratory gathering in Redu in 20 years' time.

The speeches of Minister Schiltz and Prof. Lüst are reproduced here.

photos: picture report

Address by Prof. Reimar Lüst, Director General, ESA

Ministers, your Excellencies, fellow guests and colleagues,

There is a saying in almost all languages that what goes up must come down. We are gathered here today to celebrate an extension of that saying, which we might reword: 'What goes up into space has a great deal to send down!'

It is true that popular interest in space is centred around the launches, and there is less glamour in the months and years of work that follow to keep the satellites in their correct orbits and to reap the harvest of data that satellites produce. But we know that without the care and attention to detail that goes into the network of tracking and receiving stations, the rest of our work would be in vain.

The story of Redu goes back beyond the twenty years we celebrate today. When the European Space Research Organisation (ESRO) was created, the Belgian Government offered to host a ground station, and a number of sites were offered. A trip to those sites was organised, and the intrepid travellers set out into a then little- known area of Belgium. All good stories have a twist in their tail, and this is no exception: Redu was not on the original list. One can imagine the slightly discouraged searchers coming over the brow of the hill and seeing one of nature's lovely surprises: a natural bowl shaped like a dish antenna. When its location, free from the problems of highly concentrated industrial complexes, was taken into account, the searchers knew their task was over.

At that time ESRO was only concerned with scientific satellites, but the final fulfilment for Redu lay in its potential as a ground station for communications satellites. The story of the European Communication Satellites (ECS) is a story of success, not only for the technical excellence of the satellites themselves, but for the concept of joint European responsibility.

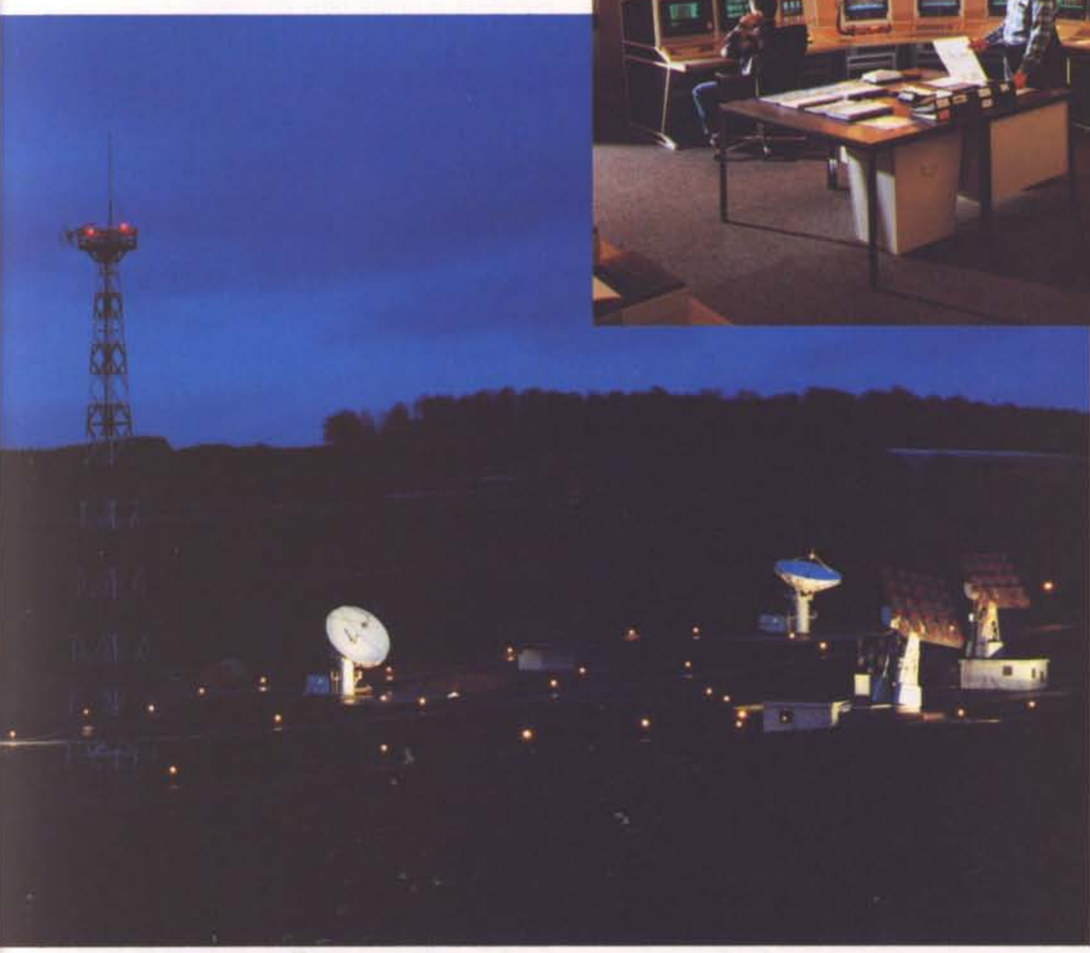


Figure 1 – General view of ESA's Redu Station
Inset: The ECS Control Centre at Redu

Eutelsat was created by the PTTs of our Member States to represent them in the operational role of the communications satellite system. It is to Eutelsat that the ECS satellites are formally handed over when they are commissioned ready for operational service. But as we heard from the Head of the Redu Station earlier, ESA is responsible for keeping the satellites functioning correctly through the ECS Control Centre here in Redu.

This concept was a pilot scheme which has since led to somewhat similar arrangements in several ESA activities adapted to specific needs; the arrangement with Inmarsat for use of our Marecs satellites, the setting-up of Arianespace to market Europe's launch vehicles, and recently the advent of Eumetsat which represents the European meteorological offices on similar lines to Eutelsat and the PTTs.

Figure 2 – Prof. Reimar Lüst, Director General of ESA

In celebrating 20 years of activity in Redu, we must be careful not to suggest that this is an end in itself. It is important that we look ahead and see what our future programmes have to offer to this quiet corner of Belgium. I stress the quiet corner and the excellent relationship between the ESA station and its host village. European Governments face strong environmental lobbies, and it is pleasing to report that the ESA station does not generate local hostility nor offer any damaging pollution or disturbance to the local flora and fauna. Indeed, it is there for all to see on the approaches to Redu – the proud claim that this is the village of space and books. As a token of that dual distinction, the invitations and programmes for today's celebrations were printed locally on handmade local paper.

For the future then, Redu will continue with the ECS missions for some years to come. Next year it will have even more exacting tasks in the communications disciplines when Olympus, the most advanced telecommunications satellite to serve Europe, will be commissioned.

Beyond that are even more adventurous ideas in the same fields. If one could look into a crystal ball and see ahead to the 40-year celebrations, it is possible that our successors will be making full use of teleconferencing facilities, not needing to travel half way around the world to hold a face-to-face discussion. Redu might well be the centre of such a facility.

For myself, I believe that useful though such facilities will be, they can never replace the human touch of such gatherings as today's.

In the midst of such technical achievements as are represented by Redu, we must not forget the human endeavours at the heart of all our successes. It is that human success which we celebrate today, and I thank you all for joining me in saying 'Well done Redu – our toast is to the next 20 years!'

Address by Vice Prime Minister Schiltz of Belgium

Ladies and Gentlemen, Director General,

I think that there is little need to remind you that Belgium has always had, and continues to have, a keen interest in space research and technology. For almost a quarter of a century now we have been supporting Europe in space, regardless of the different Ministers and Governments that have come and gone.

We clearly demonstrated this support at the Ministerial Conference in The Hague for the Agency's three major programmes: Ariane-5, Hermes and Columbus. But our support is not limited to these three major programmes: utilisation programmes such as microgravity, Earth observation and telecommunications are certainly just as important.

Indeed, ESA's telecommunications programmes have enabled Europeans to use their own satellites to relay their television programmes and to ensure their telephone

Figure 3 – Vice Prime Minister Schiltz of Belgium

and data transfer networks around our continent. They have also prepared our industries for their presence in the commercial market for satellites and terminals.

Belgium has participated in the development of the ECS, Marecs and Olympus satellites. This participation has allowed our companies to achieve commercial successes abroad. I am thinking here of the international markets of Eutelsat, Intelsat and Inmarsat, as well as foreign domestic markets such as those for Telecom-2, Skynet, TV-Sat and TDF, the latter dating from the satellites launched by Ariane.

ESA's telecommunications satellite programmes have also led to the Redu station being entrusted with the monitoring of the four ECS satellites in orbit and also the testing of the Olympus satellite. And this is only a beginning.

Belgium is not only involved in the development of satellites as such, but also and above all in their utilisation. In this context, our companies have developed terminals to receive documents transmitted by satellite. We have seen one of these in operation today in Redu. The same terminal is normally used by my administration to receive ESA documents via satellite.

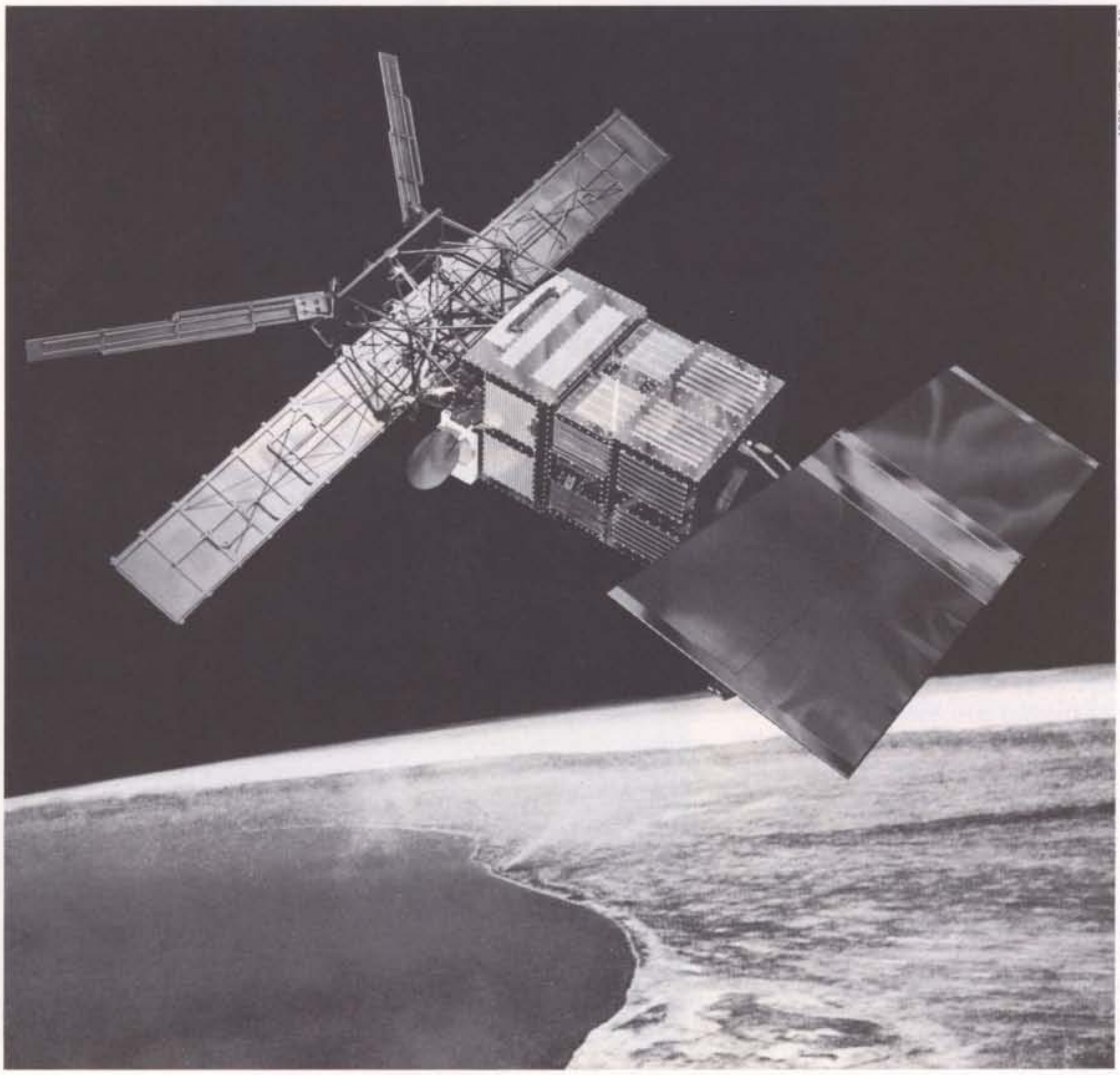
In the utilisation field, Belgium is also proud to be prime contractor for the development of terminals that will be used by FAO in Africa to combat the famine and natural catastrophes that ravage that continent.

The terminals market will soon receive a substantial boost from the deregulation that is shortly to occur in Europe. This fact, together with the development work on terminals being carried out by ESA, will make it possible for small firms that do not yet have any experience in the space field to gain access to it. For me this is very important, because it will lead to broader foundations for space activities within our country's industrial policy.

To conclude, I would like to say that ESA has taken up the challenge of European autonomy in the domain of manned flights. It must now also take up the challenge offered by the new generation of telecommunication satellites, especially the Sat-2 and DRS satellites. These projects will allow the Redu Station to ensure its future and its identity as a monitoring station for European telecommunications satellites. I would like to thank ESA's Director General in this connection for the promises that he made to us at the Ministerial Conference in The Hague.

I shall probably not have the pleasure of coming here to celebrate Redu's 30th Anniversary in 10 years' time, but I am sure that my successor will find it an even larger and more futuristic station than it is already.

Dornier – Milestones in Space.



From the beginning of space research in Europe Dornier has participated in all important national and ESRO/ ESA-projects for space exploration.

Dornier, for instance was prime contractor for the satellite projects AEROS A/B, ISEE-B, Ulysses/ISPM, and the complex space systems FOC and IPS.

Dornier moreover designed major subsystems for the projects HELIOS, GEOS, GIOTTO, Spacelab and ARIANE. At present Dornier is prime contractor for the development of ROSAT (German X-ray satellite) and ERS-1 (ESA European Remote Sensing Satellite) together with national and international partners.

As a modern and successful aircraft enterprise Dornier has accepted the challenge of space technology. Dornier will also make an all-out effort to contribute all their expertise to the current large-scale European projects: ARIANE 5, HERMES, COLUMBUS.

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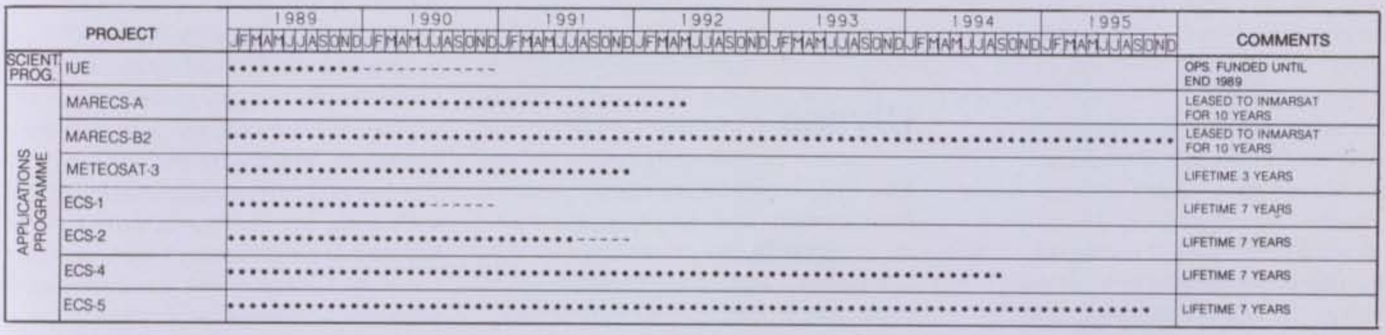
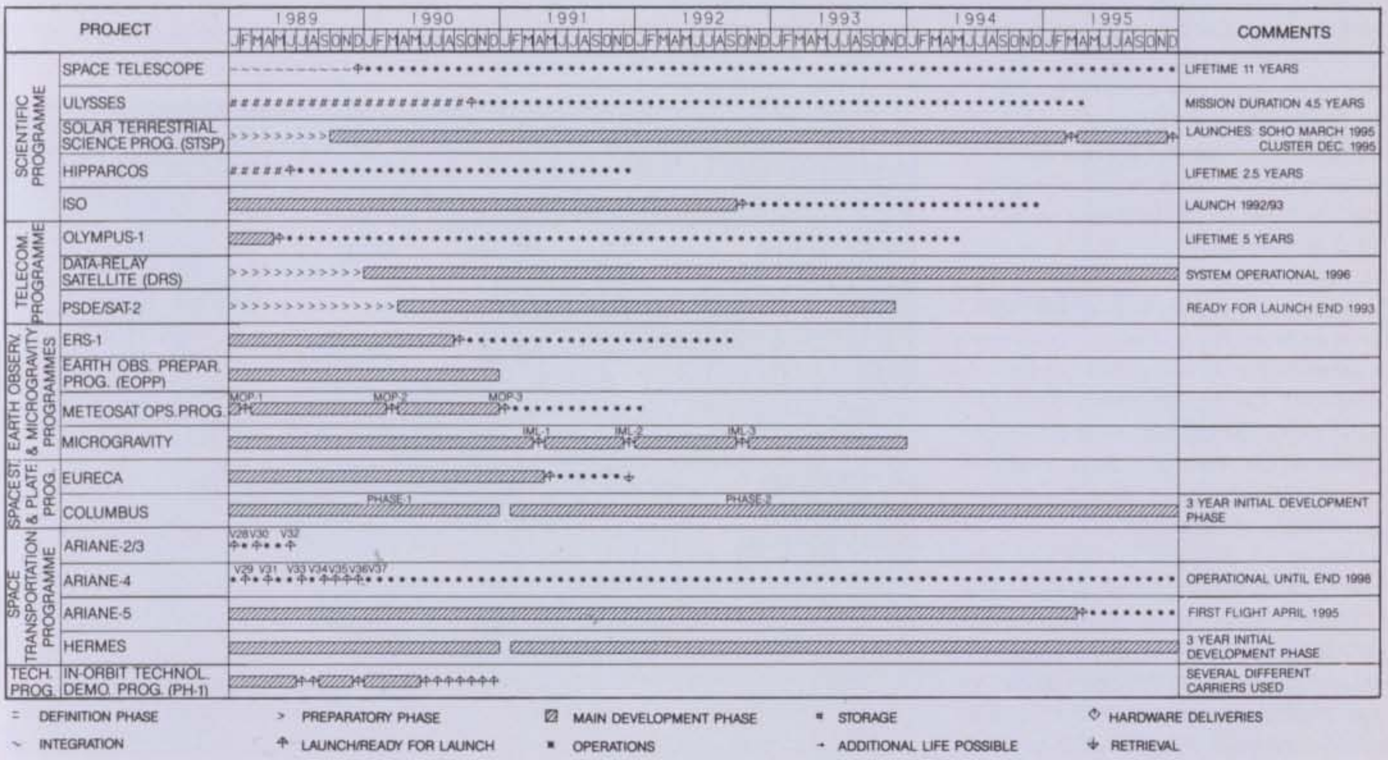


Under Development / En cours de réalisation



IUE

Le véhicule spatial IUE continue d'assurer en totalité le programme scientifique approuvé. Les deux gyroscopes opérationnels ne présentent pas de signes de dégradation. Un système de commande d'orientation opérationnel à un gyroscope unique est prêt pour l'éventualité d'une défaillance de gyroscope et l'étude d'un système sans gyroscope a été lancée. La courbe de températures du véhicule spatial dévie légèrement par rapport aux prévisions, mais ce n'est pas préoccupant.

Le SPC ayant approuvé la prolongation des activités d'IUE jusqu'à la fin de 1989, l'appel de propositions pour la 12ème année d'observation a été lancé avec une date limite fixée au 15 décembre 1988 pour la réception des offres.

Des archives IUE à faible dispersion uniforme (ULDA) sont désormais disponibles dans 12 pays. Au cours des cinq mois écoulés depuis la mise en place du système, 130 utilisateurs appartenant à 58 instituts y ont eu recours. La version 2.0 des ULDA, contenant tous les spectres à faible résolution jusqu'au 1er janvier 1987, sera disponible à partir du début de 1989. Des archives complètes d'IUE seront mises en place à la fin de 1989.

Résultats scientifiques

Contrairement aux prévisions théoriques, l'écho lumineux de SN 1987A a été détecté par IUE dans l'ultraviolet. On pense obtenir sous peu confirmation définitive de ce résultat lorsque de nouvelles observations auront été faites pour confirmer le déplacement radial prévu de l'écho UV.

De nouvelles observations ont été faites sur le système Pluton-Charon, confirmant l'augmentation de son albedo dans l'ultraviolet. Cet accroissement s'est révélé moins rapide que ne le prévoyait la diffusion de Rayleigh. Les résultats concordent avec la présence de glace non chargée et contaminée.

Pour la première fois, un objet extérieur au système solaire a été détecté dans la gamme 320–500 Å. Un objet quasi stellaire à Z = 2,74 a été observé sur toute la plage de mesures allant jusqu'à la limite inférieure d'IUE à 1200 Å.

Télescope spatial

Les modifications des panneaux du réseau solaire destinées à en augmenter la puissance et à les protéger de l'oxgène atomique ont été menées à bonne fin. Les panneaux font actuellement l'objet d'essais de recette et doivent être livrés aux Etats-Unis en mars 1989.

La date du lancement du Télescope spatial est désormais fixée au mois de décembre 1989, ce qui laisse suffisamment de temps pour y adapter les panneaux avant son expédition pour le lancement au Kennedy Space Center.

La chambre à objets faibles (FOC) montée dans le Télescope spatial fait toujours l'objet de vérifications mensuelles.

Ulysse

Le STS ayant enregistré deux lancements réussis, les pronostics d'un lancement d'Ulysse en octobre 1990 apparaissent aujourd'hui beaucoup mieux fondés. Malgré les modifications apportées récemment au manifeste des lancements de la Navette, Ulysse, tout comme les autres missions planétaires, a conservé la fenêtre de lancement qui lui avait été précédement assignée. Ces derniers mois ont vu l'évaluation technique d'un éventuel lanceur de remplacement en cas de report important du lancement de la Navette.

En Europe, la principale activité a consisté à remplacer les puces de mémoire TTC-244 suspectes dans certaines parties des sous-systèmes de télécomunications et de traitement des données à bord. Il s'est agi d'un travail extrêmement complexe car il a exigé l'enlèvement d'un revêtement conformé opaque couvrant l'ensemble des plaquettes de circuits imprimés. Il a fallu déterminer à l'aide de clichés radiographiques les emplacements à dénuder. Ces travaux ont été pour la plupart menés à bonne fin et rien ne permet de prévoir que la tâche ne soit pas terminée à temps.

Les derniers mois ont également été marqués par la mise en place des équipes et la préparation des matériels nécessaires à la nouvelle certification du véhicule spatial qui doit débuter fin janvier 1989. Il a fallu pour cela constituer à l'ESTEC, à l'ESOC et dans l'industrie des équipes presque entièrement nouvelles car la plupart des spécialistes avaient été dispersés dans d'autres projets lorsque le lancement de 1986 a été annulé. Les équipes, maintenant en place pour la plupart, sont en cours d'entraînement. Les principaux éléments du matériel de vérification ont été préparés et le véhicule spatial de

Qualification Model of Ulysses on exhibition at the National Air and Space Museum in Washington

Modèle de qualification d'Ulysse, exposé au Musée national de l'Aéronautique et de l'Espace à Washington

IUE

The IUE spacecraft continues to support the approved science programme fully. The two operational gyroscopes show no signs of degradation. An operational 1-gyro attitude control system is ready in case of a future gyro failure. Work on a zero-gyro system has started. Although the temperature evolution of the spacecraft appears to deviate slightly from predictions, this gives no cause for concern.

Following the Science Programme Committee's approval of the extension of IUE operations through 1989, the call for proposals for the l2th year of observing time has been issued, with a deadline for proposals of 15 December 1988.

The IUE Uniform Low Dispersion Archive (ULDA) has now been installed in 12 countries. In the five months since installation, 130 users from 58 institutes have registered. Delivery of ULDA version 2.0, containing all low resolution spectra up to 1 January 1987, is planned for early 1989. Production of the final IUE archive is scheduled to start in late 1989.

Scientific results

The light echo of SN 1987A was detected in the ultraviolet by IUE contrary to theoretical predictions. Final confirmation of this result is expected to be obtained shortly when new observations will be made to confirm the radial motion expected from the UV echo.

New observations were made of the Pluto-Charon system, confirming the rise in the ultraviolet albedo. The slope was found to be less steep than expected for Rayleigh scattering. The results are consistent with the presence of a neutrally contaminated frost.

For the first time an object outside the Solar System was detected in the 320-500 Å range. A quasi-stellar object at Z = 2.74 was observed all the way down to the IUE limit at 1200 Å.

Space Telescope

The modifications to the solar array wings to increase the power output and to provide atomic oxygen protection have been completed. The wings are now undergoing acceptance testing and are scheduled to be delivered to the USA in March.

The launch of Space Telescope (ST) is now scheduled for December 1989 which will allow sufficient time to fit the wings to the ST prior to its shipment to Kennedy Space Center (KSC) for launch.

The Faint Object Camera which is installed in the ST continues to be checked out each month.

Ulysses

Following two successful Shuttle launches the prognosis for the Ulysses launch in October 1990 is promising. Despite the modifications recently introduced into the Shuttle launch manifest, Ulysses, in common with the other so-called 'planetary' missions, has retained its previously assigned launch window. During recent months there has been a technical evaluation of a possible back-up launcher in case of major Shuttle delays.

Within Europe the main activity has been the replacement of the suspect memory chips in parts of the on-board data handling and telecommunications subsystems. This was an extremely complex operation involving the chipping away of an opaque conformal coating covering the complete printed circuit boards. The locations to remove the coating had to be determined with the aid of X-ray photographs. The majority of this work has now been successfully accomplished and no major problems are anticipated in completing the task in time.

Other major tasks have included the preparation of manpower and equipment for the start of the spacecraft recertification, scheduled to start in late January 1989. This has involved assembling virtually complete new teams in ESTEC, ESOC and in industry since most of the personnel were dispersed to other projects when the 1986 launch was cancelled. Most of the teams are now in place and undergoing training. The major checkout equipment items have been prepared and the qualification spacecraft to be used in the early stages of the recertification is being returned from Washington DC where it has been on exhibition at the US National Air and Space Museum.

Preparations on the launcher side continue to be satisfactory, despite some small delays in the PAM-S. Work-around solutions have been found by the contractor concerned and the whole team, ESA, industry, NASA and the experimenters are looking forward to a successful launch in 1990.

STSP

The current round of meetings with the selected experimenters has been completed and the first draft of the individual Experiment Interface Document (EID) has been issued. The current level of definition of the selected experiments is variable, leading to a lack of uniformity. This will be corrected during the next round of meetings and a further issue of the EID is planned for early 1989 to provide a firm baseline for the evaluation of the industrial tenders and the subsequent negotiations.

The Invitation to Tender (ITT) was issued as planned at the beginning of October 1988. Proposals from industry are requested by 15 February 1989.

The ESA/NASA Memorandum of Understanding (MOU) has been modified and agreed with NASA following the request of the ESA Council at its June meeting. The MOU was resubmitted to Council for approval at its December meeting.

Hipparcos

The actions and investigations arising from the Flight Acceptance Review were examined during September at a specifically convened actions closure meeting. The meeting found that the general technical status was satisfactory with the majority of concerns cleared; some hardware changes are being implemented to overcome the problems encountered in the areas of components and baffle deployment. The outstanding issues are to be closed during the satellite reactivation programme.

qualification à utiliser dans les premières étapes de cette nouvelle certification a été réexpédié de Washington DC où il avait été exposé au Musée national de l'Aéronautique et de l'Espace des Etats-Unis.

Du côté du lanceur, les préparatifs continuent d'être satisfaisants malgré certains retards enregistrés avec le PAM-S. Le contractant a mis au point des solutions de rattrapage et toute l'équipe, ESA, Industrie et NASA ainsi que les expérimentateurs se préparent à affronter une lourde tâche en 1989 dans la perspective d'un lancement en 1990.

STSP

La série de réunions en cours avec les expérimentateurs retenus s'est achevée et le premier projet de document d'interface des expériences (EID) a été établi. Les expériences choisies en étant à des stades de définition différents, le niveau de détail de la définition des interfaces pèche par manque d'uniformité. Cet état de chose sera corrigé au cours de la prochaine série de réunions et une nouvelle version de l'EID doit être préparée pour le début de 1989 afin de constituer une base de référence solide pour l'évaluation des offres industrielles et les négociations ultérieures.

L'appel d'offres a été lancé comme prévu début octobre 1988; les réponses ont été demandées à l'industrie pour le 15 février 1989.

Le mémorandum d' accord (MOU) ESA/NASA a été modifié et arrêté en commun à la suite de la demande formulée par le Conseil à sa session de juin. Il a été soumis à nouveau au Conseil pour approbation à sa session de décembre.

Hipparcos

Les mesures à prendre et les recherches à mener à la suite de la revue d'aptitude au vol ont été examinées courant septembre lors d'une réunion convoquée spécialement pour constater la conclusion des points en suspens. La réunion a trouvé satisfaisant l'état technique général, les points préoccupants étant réglés en majorité; certaines modifications sont apportées au matériel afin de remédier aux problèmes rencontrés dans le domaine des composants et de l'ouverture des écrans. Les questions encore en suspens doivent être résolues au cours du programme de réactivation du satellite.

La période de stockage du satellite a pris fin courant novembre. Les équipements électriques de soutien au sol ont été intégralement vérifiés, ce qui a permis de passer à l'intégration et à l'essai de la charge utile et de la plate-forme. Fin novembre, la charge utile a été entièrement réintégrée avant d'être soumise à un essai système intégré qui fait partie du programme de vérification de la charge utile avant son montage sur la plate-forme.

Le principal incident enregistré au cours de cette période a été le nouveau report de la période de lancement du satellite à juin 1989, les probabilités quant à la date du lancement proprement dite renvoyant celui-ci à la fin du mois. Ce report a été annoncé par Arianespace mais il n'a pas été publié à ce jour de révision du manifeste. Les activités de réactivation et le calendrier général ont été réaménagés dans la mesure du possible pour prendre en compte ce dernier report.

ISO

La phase de conception détaillée et de réalisation (phase C/D) du satellite se déroule dans de bonnes conditions. Les travaux sont exécutés sous couvert d'une autorisation préliminaire d'engagement de travaux pendant que les conditions d'un contrat définitif de phase C/D sont à l'étude. Le montage de l'organisation industrielle, dirigée par l'Aérospatiale (France), s'est achevé avec le choix des sous-traitants responsables de l'unité cryo-électronique, du décodeur de traitement des données et de l'équipement central de vérification. Ces sous-traitants s'étaient tous mis au travail dès le mois de septembre.

L'avancement des activités de conception détaillée est satisfaisant. Les principaux problèmes de conception tiennent au fait que la marge de puissance électrique est trop faible, que la régulation thermique du module de service est trop complexe et que les roues à réaction (de la commande d'orientation) risquent de ne pas survivre aux charges en vibration communiquées par le lanceur. On est également préoccupé par le sous-système de commande d'orientation et par son logiciel, celui-ci étant fondé sur un nouveau langage (ADA). Des mesures particulières sont à l'étude afin de résoudre ces problèmes dans les prochains mois.

D'importantes activités sont en cours sur le matériel parallèlement aux activités de conception détaillée. La plus délicate a été le polissage du miroir primaire du télescope qui a pris près de quatre mois de plus que prévu. Le miroir en est aux étapes suivantes de fabrication (montures mécaniques, revêtement réfléchissant) en préparation des premiers essais à froid dans l'installation refroidie à l'hélium liquide de l'Institut d'Astrophysique de Liège (IAL).

En plus des activités ci-dessus concernant le matériel, tous les composants cryotechniques critiques du module de charge utile ISO (cryostat) en sont aux essais de qualification. Le montage sur table du sous-système d'alimentation a été lancé tandis que la fabrication d'articles longs à réaliser et destinés à la structure du module de service et au sous-système de commande à réaction a été autorisée.

Le calendrier d'ensemble du programme est en cours de révision afin de rattraper le retard dû au polissage du miroir primaire. Plusieurs essais et activités de nature à réduire les délais ont été mis en évidence. Les travaux visant à restructurer le calendrier du programme devraient être terminés en décembre 1988.

Instruments scientifiques

Les travaux de conception détaillée et de réalisation des quatre instruments scientifiques progressent de façon satisfaisante. Les maquettes inertes pour essais des instruments scientifiques (essais thermiques, d'alignement et de simulation de masse avec le télescope du satellite) en sont aux essais de recette finale, conformément au calendrier.

The satellite storage period came to an end during November. The electrical ground support equipment was fully checked out, permitting the integration and testing of the payload and spacecraft modules to proceed. At the end of November, the payload had been fully reintegrated and had undergone a payload integrated system test, the latter forming part of the payload verification programme prior to payload integration with the spacecraft.

The major incident of the period was the further delay of the satellite launch to June 1989. This delay was announced by Arianespace but, to date, a revision of the launch manifest has not been published. The reactivation activities and schedule have been readjusted as far as possible to take account of this.

ISO

The detailed design and development phase (Phase C/D) of the satellite is proceeding well. Work is being carried out under a preliminary authorisation to proceed whilst the terms and conditions of a definitive Phase C/D contract are discussed. The build-up of the satellite industrial organisation, led by Aerospatiale (France), has been completed with the selection of sub-contractors for the cryo-electronics unit, the data handling decoder and the central check-out equipment. These recently selected sub-contractors had all commenced work by September 1988.

The detailed design activities are proceeding satisfactorily. The main design problems are that the electrical power margin is too small, that the service module thermal control is too complex and that the reaction wheels (for attitude control) may not survive the vibration loads given by the launcher. A further concern lies in the attitude control sub-system and its software which is based on a new language (ADA). Special actions are underway to solve these problems in the next few months.

Considerable hardware activities are underway in parallel with the detailed design activities. The most difficult has been the polishing of the telescope primary mirror which has taken nearly four months longer than foreseen. The mirror is now undergoing the next manufacturing steps (e.g. mechanical attachments, reflective coating) in preparation for the first cold tests in the liquid helium cooled facility at the Institut d'Astrophysique de Liège (IAL).

In addition to the above hardware activities, all critical cryogenic components of the ISO payload module (cryostat) are in qualification testing. Breadboarding of the power subsystem has started and manufacture of long lead items for the service module structure and the reaction control subsystem has been authorised.

The total programme schedule is being reviewed with the aim of recovering the time lost in polishing the primary mirror. Several tests and operations have been identified to improve the schedule. A restructured schedule should be completed in December 1988.

Scientific instruments

The detailed design and development activities for the four scientific instruments are proceeding satisfactorily. The test dummies of the instruments (for alignment, thermal and mass simulation testing with the telescope) are in final acceptance testing and are on schedule.

The most serious problem that has again emerged recently concerned ISOPHOT 'S', the grating spectrometer part of ISOPHOT. The co-investigator for the full programme is facing funding difficulties. The schedule implications at this late stage are so serious that other means of providing the grating spectrometer are being investigated by the Principal Investigator. Two Principal Investigators (LWS and SWS) have confirmed that they will be able to supply a full set of flight spare units. Discussions are continuing with the three other Principal Investigators who still have funding problems.

Ground segment

Progress in the definition of the ground segment has been good. A global concept has been defined and the principles have been agreed with the Principal Investigators for scientific (observatory) operations and with ESOC for the satellite control operations.

Both Australia and the USA (NASA) are submitting proposals for provision of a second ground station for ISO. Japan is likely to join forces with NASA in its proposal. The proposals will be evaluated by ESA as soon as all details are received and then the matter will be put to the Science Programme Committee.

Ariane

Negotiations with Arianespace on the launch services contract are reaching the final stages with only a few significant issues remaining to be resolved.

Olympus

After completion of the thermal vacuum testing of Olympus-1 in August at the David Florida Laboratories in Ottawa, a late problem was discovered with the high-power TWTAs in the TV broadcast payload which required resetting of the parameters in the TWT power supplies to reduce the output power. Since this necessitated removal and replacement of a number of equipment items, it was decided to perform a repeat but abbreviated thermal vacuum test of the spacecraft in order to ensure that all systems are performing satisfactorily. The spacecraft is expected to be back in the chamber before Christmas and testing will start in January 1989.

During November a system validation test was successfully performed by ESOC. The various spacecraft subsystems were exercised using telecommand and telemetry links which were relayed to and from the David Florida Laboratories using leased data lines.

Meetings involving representatives of the Prime Contractor (BAe), ESOC, the Redu ground station and ESTEC have been held in order to define in detail the test procedures for the in-orbit performance checks on the spacecraft immediately after launch. This complex phase of the mission will be performed from Redu and transportable earth stations will be positioned at geometrically strategic locations within the European coverage zone in order to facilitate antenna performance measurements. A period of 90 days after launch has been allocated for this commissioning and test phase.

Following commissioning, the Utilisation Programme will commence. Collaboration between the Olympus

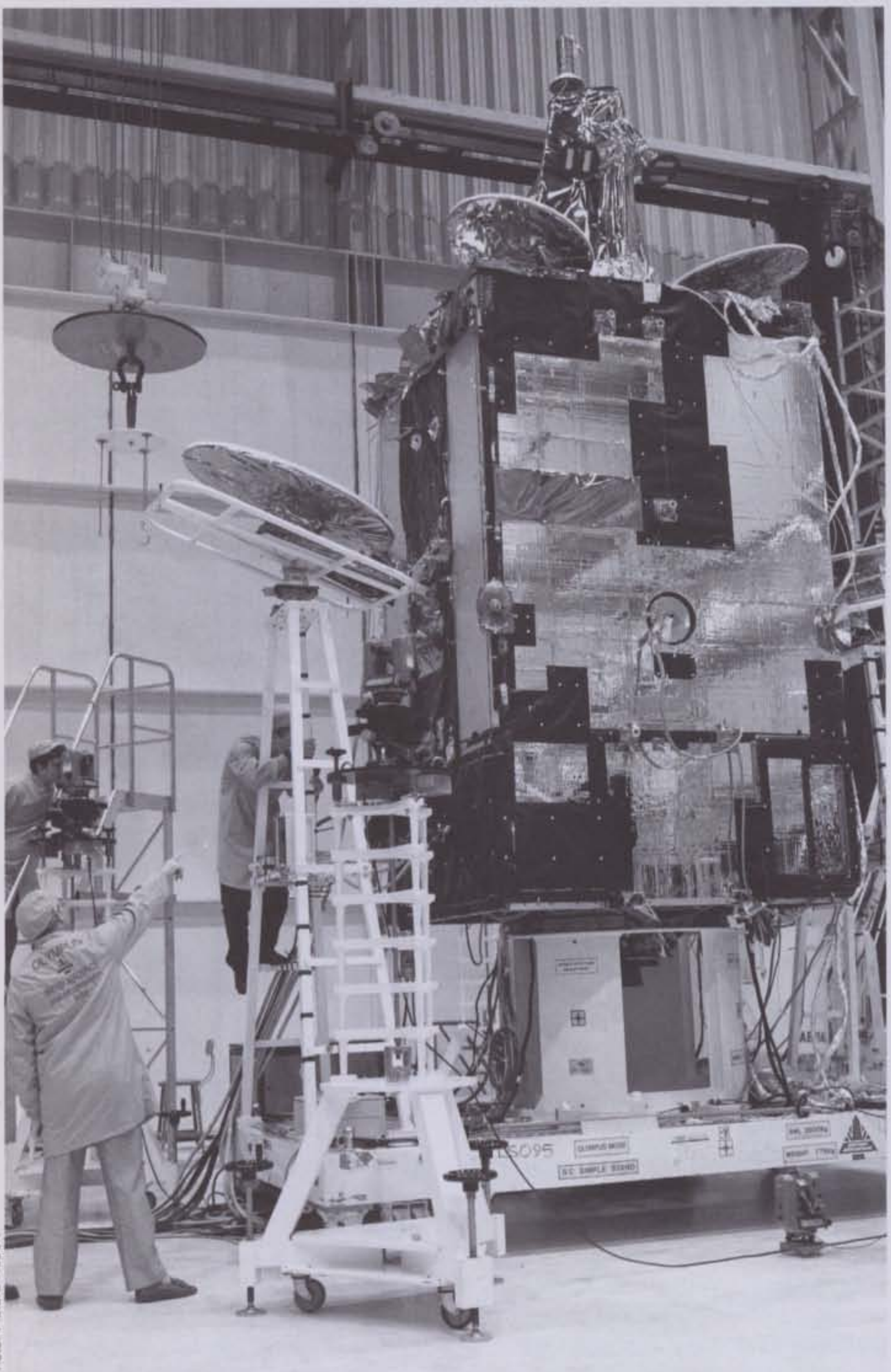


Photo: Picture Report

Olympus under test at the David Florida Laboratories in Ottawa

Olympus aux essais aux Laboratoire David Florida à Ottawa

Le problème le plus grave qui a refait surface récemment intéresse l'ISOPHOT 'S', spectromètre à grille faisant partie d'ISOPHOT. Le chercheur responsable de ce programme rencontre de multiples difficultés de financement. Les incidences sur le calendrier à un stade aussi tardif sont si graves que le chercheur principal examine d'autres moyens d'obtenir le spectromètre à grille. Deux chercheurs principaux (LWS et SWS) ont confirmé qu'ils étaient en mesure de fournir un ensemble complet d'unités de vol. Des discussions se poursuivent avec les trois autres chercheurs principaux qui continuent d'avoir des problèmes de financement.

Secteur sol

Des progrès sensibles ont été faits dans la définition du secteur sol. Un concept d'ensemble a été défini tandis que les principes étaient arrêtés en commun avec les chercheurs principaux pour la conduite des activités scientifiques (observatoire) et avec l'ESOC pour les opérations de contrôle du satellite.

L'Australie et les Etats-Unis (NASA) soumettent des propositions en vue de fournir une deuxième station sol pour ISO. Il est vraisemblable que le Japon unira ses forces à celles de la NASA dans cette proposition. Les propositions seront évaluées par l'ESA dès que tous les détails auront été reçus (en novembre), à la suite de quoi la question sera soumise au SPC.

Ariane

Les négociations avec Arianespace au sujet du contrat de lancement en sont au stade final, seules quelques questions de peu d'importance restant à résoudre.

Olympus

Après des essais thermiques sous vide du véhicule spatial Olympus en août dernier, au laboratoire David Florida d'Ottawa, les ATOP à haute puissance de la charge utile de télévision directe ont posé un problème de dernière minute nécessitant un nouveau réglage des paramètres des alimentations en énergie des TOP en vue de réduire la puissance de sortie. Cette opération ayant demandé le démontage et le remplacement d'un certain nombre d'équipements, il a été décidé de refaire des essais thermiques sous vide abrégés du véhicule spatial pour vérifier le bon fonctionnement de tous les systèmes. Le véhicule spatial devrait être de retour dans la chambre avant Noël pour des essais qui démarreront en janvier 1989.

En novembre, l'ESOC a procédé avec succès à un essai de validation système. Au cours de cet essai, les différents sous-systèmes du véhicule spatial ont été actionnés au moyen de liaisons de télécommande et de télémesure relayées par des lignes louées de transmission de données entre l'ESOC et le laboratoire David Florida.

Des réunions ont été organisées avec des représentants du maître d'oeuvre (BAe), de l'ESOC, de Redu et de l'ESTEC pour la définition détaillée des essais et des procédures connexes destinés à vérifier le fonctionnement du

Payload Utilisation Secretariat (OPUS), located at ESTEC, and the experimenters who will be using the various payloads is accelerating. Loan agreements are being discussed with a number of experimenters who wish to make use of the earth stations procured for the Olympus programme.

On the ESTEC site, work is proceeding on a utilisation programme operations and maintenance centre for the transportable stations. One of the stations (TDS-5) will be used in the United Kingdom to provide an uplink for the broadcast payload.

A series of meetings was held with Arianespace and Centre spatial Guyannais (CSG) personnel in October, as a result of which a detailed integrated plan has been agreed for the Olympus launch campaign. Arianespace have announced the date of 29 May 1989 for the launch of Olympus on V-32, and the spacecraft will therefore be delivered to CSG on 3 April 1989.

ERS

The flight-model platform assembly, integration and test are nearing completion and delivery is foreseen by the end of December 1988 with a final review in early 1989.

Progress on the Active Microwave Instrument engineering model has continued to be affected by additional difficulties. However, the major problems now appear to have been solved and Functional baseline testing will commence shortly. Delivery for payload integration and performance testing is expected by the end of December 1988.

As a result of the above delays, the engineering model payload test programme will be extended to the end of June 1989.

Delivery of the flight model Active Microwave Instrument is expected in June 1989.

The Flight Acceptance Review is foreseen for May 1990 ready for launch in September 1990.

Work on the ground segment facilities and the launch operations planning are proceeding according to plan.

Earthnet

The satellite missions handled by Earthnet (Landsat, MOS-1, Tiros and Spot) have continued to be performed satisfactorily.

ERS-I
Contracts for the fast delivery processing chains for Gatineau, Maspalomas, and Fucino stations have been awarded and work is in progress.

The Commission of European Communities is expected to award development contracts for the fast delivery data distribution system in the first half of 1989.

Phase C/D contracts for the French and German processing and archiving facilities are proceeding satisfactorily and those for the United Kingdom and Italy are under negotiation.

Activities related to the precise tracking of ERS-1 by the laser station network are progressing.

EOPP

Solid Earth Programme 'Aristoteles'
The technological pre-development study continues. The second phase on the gradio-accelerometers was concluded with a successful review and one laboratory model is now available. The third and last phase of this study has started and will be devoted mainly to testing of the laboratory model on a tilt table and a specially designed pendulum test bench.

The Gradiometer Data Analysis Study on the reduction of the gradiometer measurements is in progress and will provide simulations of, and the relevant software for, predictions of gradiometer data reduction in an Earth-bound reference frame.

Additional study activities planned to start early next year will include:
- extension of the baseline gravity mission by a three-year Precise Positioning Mission
- possible addition of a magnetometer
- possible addition of Global Positioning System (GPS)
- updated microwave tracking system
- possible use of an Ariane-5 qualification flight.

Potential participants' meetings on the optional Aristoles programme are planned to start early in 1989.

Meteosat Second Generation
Following the rejection of the recommendations of the pre-Phase A satellite configuration studies by Eumetsat delegate bodies and after further discussions within the Eumetsat technical committees, ESA has been requested to perform studies of the following instruments:
- an enhanced imager with sounding-type capabilities. This includes options with and without a high-resolution visible channel
- a separate high-resolution visible imager
- an infrared sounder optimised for use over Europe without a microwave sounder
- a high spectral resolution infrared sounder.

The above studies are scheduled to take place between May 1989 and March 1990.

Phase A is planned to start by end 1990, with launch of the first Meteosat second generation satellite not earlier than 1998.

Polar Platform
The preparation of the request for quotation for the Phase A studies of the first polar-orbiting mission is in progress and will be released in February 1989.

The core facility instruments to be studied will be:

- radar altimeter
- active microwave instrument with enhanced performance
- synthetic aperture radar
- medium-resolution imaging spectrometer atmospheric lidar
- multifrequency imaging microwave radiometer scatterometer.

It is planned to place two competitive studies for each instrument except the proposed second advanced microwave instrument. Proposals are expected to be received in March 1989. A wide range of *satellite en orbite immédiatement après son lancement. Redu sera la station de contrôle de cette phase complexe de la mission; des stations terriennes transportables seront mises en place en des points stratégiques de la zone de couverture européenne de façon à faciliter la mesure des caractéristiques de fonctionnement des antennes. Pour cette phase de mise en service et d'essais, une période de 90 jours après le lancement a été prévue.*

Après la mise en service officielle commencera le programme d'utilisation. La collaboration entre l'OPUS (Secrétariat pour l'utilisation des charges utiles d'Olympus), situé à l'ESTEC, et les expérimentateurs qui utiliseront les différentes charges utiles s'accélère. Des discussions sont en cours pour la mise au point d'accords de prêt avec un certain nombre d'expérimentateurs souhaitant utiliser les stations terriennes approvisionnées pour le programme Olympus.

Sur le site de l'ESTEC, les travaux avancent en vue de la mise sur pied d'un centre d'exploitation et de maintenance des stations transportables du programme d'utilisation. L'une de ces stations (TDS 5) sera mise en oeuvre au Royaume-Uni pour la fourniture d'une liaison montante destinée à la charge utile de radiodiffusion.

A la suite d'une série de réunions tenues en octobre avec Arianespace et le personnel du CSG, un plan intégré détaillé a été arrêté pour la campagne de lancement d'Olympus. Arianespace ayant annoncé que le lancement d'Olympus aurait lieu le 29 mai 1989 sur V-32, le véhicule spatial devra arriver au CSG le 3 avril 1989.

TDS-5 transportable ground station for the Olympus programme

Station terrienne transportable TDS-5 destinée au programme Olympus

ERS

L'assemblage, l'intégration et les essais du modèle de vol de la plate-forme seront bientôt achevés et la livraison prévue pour fin décembre 1988 sera suivie d'une revue finale début 1989.

L'avancement des travaux relatifs au modèle d'identification du détecteur actif à hyperfréquences se heurte à de nouvelles difficultés. Les principaux problèmes semblent toutefois aujourd'hui résolus et les essais fonctionnels de référence vont commencer sous peu. La livraison de ce modèle pour intégration de la charge utile et essais de fonctionnement est attendue pour la fin décembre 1988.

Par suite de ces retards, le programme d'essais du modèle d'identification de la charge utile sera prolongé jusqu'à fin juin 1989.

La livraison du modèle de vol du détecteur actif à hyperfréquences est escomptée pour juin 1989.

La revue d'aptitude au vol est prévue pour mai 1990, avec lancement en septembre de la même année.

Les travaux portant sur les installations du secteur sol et la planification des opérations de lancement avancent conformément aux plans.

Earthnet

Les missions remplies par les satellites dont Earthnet a la charge (Landsat, MOS-1, Tiros et SPOT) se sont poursuivies de façon satisfaisante.

Secteur sol d'ERS-1
Les contrats des chaînes de traitement de données à livraison rapide des stations de Gatineau, Maspalomas et Fucino ont été attribués; les travaux sont en cours.

La Commission des Communautés européennes devrait attribuer les contrats de réalisation du système de distribution des données à livraison rapide au cours du premier semestre 1989.

Les contrats de phase C/D des installations de traitement et d'archivage de France et d'Allemagne progressent de façon satisfaisante et ceux du Royaume-Uni et de l'Italie sont en cours de négociation.

Les activités relatives à la poursuite précise d'ERS-1 au moyen du réseau de stations laser avancent.

EOPP

Programme d'étude du solide terrestre Aristoteles
L'étude de prédéveloppement technologique se poursuit. La deuxième phase relative aux accéléromètres GRADIO s'est achevée sur une revue satisfaisante et l'on dispose maintenant d'un modèle de laboratoire. La troisième et dernière phase de cette étude a démarré; elle sera principalement consacrée aux essais du modèle de laboratoire sur une plate-forme de

Satellite Météosat opérationnel MOP-1

The Meteosat Operational Programme's MOP-1 satellite

instrument and technology studies are being performed in support of this and subsequent polar-orbiting missions.

Meteosat

Pre-operational programme
Meteosat P2 has been used as the primary satellite for operational meteorological activities since the completion of its in-orbit commissioning in August 1988 and has now been renamed Meteosat 3. Apart from some non-critical anomalies the satellite is functioning nominally.

Meteosat F2 will be kept on stand-by until the successful launch and commissioning of the first satellite of the operational programme, MOP-1, in the first half of 1989.

LASSO
The LASSO experiment for international clock synchronisation carried aboard Meteosat P2 has successfully overcome some initial difficulties.

Firings from the CERGA ground-based laser station towards Meteosat P2 have been persistently prevented by bad weather conditions. Echoes have been received on relatively few nights during the first two months. The extraction of true on-board datation signals from the telemetry for these nights has proved difficult and the correct operation of the on-board subsystem was delayed.

At present, the system is performing satisfactorily and it is hoped to extend operations to include other laser stations.

Operational programme
The MOP-l satellite has successfully completed its qualification results review and will be shipped from Cannes to Kourou on 5 January. Launch is currently scheduled for 24 February 1989.

Manufacture of flight hardware and integration of both subsequent models, MOP-2 and MOP-3, is progressing satisfactorily in Aerospatiale.

Microgravity

Extended Phase-2
Work is continuing in Industry on the various elements of the Extended Phase 2 programme.

Biorack
The Acceptance Data Packages of the experiments in Biorack for the IML-l mission are undergoing the final review cycle with the investigators; at the same time the flight crew procedures are being finalised. For familiarisation and training purposes a video recording has been prepared for each experiment presenting the experiment objectives, the experiment hardware and operations.

A progress meeting with the NASA IML-l mission management was held on 24 and 25 October 1988. The Biorack verification plan, the critical structures verification plan, the operation and integration/assembly plan, the payload operations control centre requirements document, the stowage configuration, timeline, crew procedures and training plans were reviewed. The nominal and non-nominal crew procedures are being updated to reflect the latest mid-deck stowage configuration.

Advanced Gradient Heating Facility
The breadboard model of the furnace of the AGHF and its associated ground support equipment, as developed during the AGHF Phase-B, has been demonstrated by the contractor. The technical performance of the hardware was excellent.

Fluid Physics Facilities
The critical design review (CDR) for the Critical Point Facility is nearing completion and that for the Advanced Fluid Physics Module is in progress. Two problems have been identified concerning mass and the power available.

Anthrorack
Critical design reviews have been held at sub-system level and the system level CDR is underway.

Sounding rockets
Two successful sounding-rocket flights, Texas-19 and -20, were launched from Kiruna on 28 November and 2 December respectively. Both flights included ESA experiment modules, the results from which are currently under investigation.

Parabolic flights
The Agency will in future be using the CNES Caravelle for Microgravity parabolic flight experiments rather than the NASA KC 135 plane. A demonstration flight of the Caravelle is planned for January 1989 and the first ESA campaign flight is scheduled for mid-February 1989.

Eureca

Assembly of the Eureca flight structure and propulsion subsystem has been completed by SNIA/BPD in Italy. Having passed its high pressure and leakage tests, this assembly will be shipped to MBB/ERNO by mid-December 1988.

The five panels of the first solar array wing have passed their acceptance tests and are now being assembled, together with the Eureca radiator, for further acoustic testing at IABG. The second wing will be assembled in the first quarter of 1989.

In parallel to the above activities, six of the 15 flight payload instruments have undergone extensive interface testing in the Eureca payload test facilities. The remaining instruments will be tested in *tangage et un banc d'essai pendulaire spécialement conçu à cet effet.*

L'étude sur l'analyse des données gradiométriques, concernant la première étape du traitement des mesures du gradiomètre, est en cours; elle comprendra des simulations, avec la fourniture du logiciel connexe, en préparation du traitement des données gradiométriques dans un repère terrestre.

Il est prévu de mettre en route au début de l'an prochain des études additionnelles portant sur de nombreuses options importantes pour le programme:
- *prolongement de la mission 'gravité' de référence par une mission de localisation précise de trois ans*
- *addition possible d'un magnétomètre*
- *addition possible d'un équipement GPS (système mondial de localisation)*
- *système de poursuite à hyperfréquences amélioré*
- *utilisation possible d'un vol de qualification d'Ariane 5.*

Le démarrage des réunions de participants potentiels au programme facultatif Aristoteles est prévu pour début 1989.

Météosat de deuxième génération
A la suite du rejet par les organes délibérants d'Eumetsat des recommandations relatives aux études de préphase A sur la configuration des satellites et après discussion avec les comités techniques d'Eumetsat, il a été demandé à l'ESA d'effectuer les études d'instruments suivantes:
- *Etude d'un imageur amélioré disposant de capacités du type sondeur, comprenant des options avec et sans canal visible à haute résolution dans le visible*
- *Etude d'un imageur séparé à haute résolution dans le visible*
- *Etude d'un sondeur infrarouge optimisé pour son utilisation au-dessus de l'Europe sans sondeur à hyperfréquences*
- *Etude d'un sondeur infrarouge à haute résolution spectrale.*

La période prévue pour ces études va de mai 1989 à mars 1990.

La date de démarrage de la phase A est prévue pour fin 1990, conduisant au lancement du premier satellite Météosat de deuxième génération en 1998 au plus tôt.

Plate-forme polaire
La consultation relative aux études de phase A de la première mission en orbite polaire est en cours de préparation; elle sera lancée en février 1989.

Les instruments de l'installation du noyau à étudier sont les suivants:
- *Altimètre radar*
- *Détecteur actif à hyperfréquences à caractéristiques améliorées*
- *Radar à synthèse d'ouverture*
- *Spectromètre imageur à moyenne résolution*
- *Lidar atmosphérique*
- *Radiomètre imageur à multi-hyperfréquences*
- *Diffusiomètre*

Deux études concurrentielles sont prévues pour chaque instrument, sauf en ce qui concerne le deuxième instrument à hyperfréquences de conception avancée proposé. Les offres devraient parvenir en mars 1989.

Un large éventail d'études d'instruments et d'études technologiques sont en cours, pour cette mission sur orbite polaire et les suivantes.

Météosat

Programme préopérationnel
Météosat P2, aujourd'hui devenu Météosat 3, assure les activités météorologiques opérationnelles à titre principal depuis sa mise en service officielle en orbite, en août 1988. A l'exception de quelques anomalies de caractère non critique, le satellite fonctionne conformément aux prévisions.

Météosat F2 sera maintenu en réserve jusqu'au lancement et à la mise en service de MOP-1, premier satellite du programme opérationnel, au premier semestre de 1989.

Expérience LASSO
L'expérience LASSO de synchronisation internationale d'horloges à bord de Météosat P2 a surmonté avec succès quelques difficultés initiales.

Les essais de tir laser en direction de Météosat P2 à partir de la station sol du CERGA ont constamment été gênés par de mauvaises conditions météorologiques. Des échos ont pu être reçus sur un nombre relativement limité de nuits au cours des deux premiers mois. Les signaux de datation vraie à bord se sont révélés difficiles à extraire des données de télémesure de ces nuits et le fonctionnement correct du sous-système embarqué s'en est trouvé retardé.

A l'heure actuelle, le système fonctionne de façon satisfaisante et l'on espère pouvoir étendre les opérations à d'autres stations laser.

Programme opérationnel
Le satellite MOP-1 a subi avec succès la revue d'aptitude au vol et quittera Cannes pour Kourou le 5 janvier. Son lancement est actuellement prévu pour le 24 février 1989.

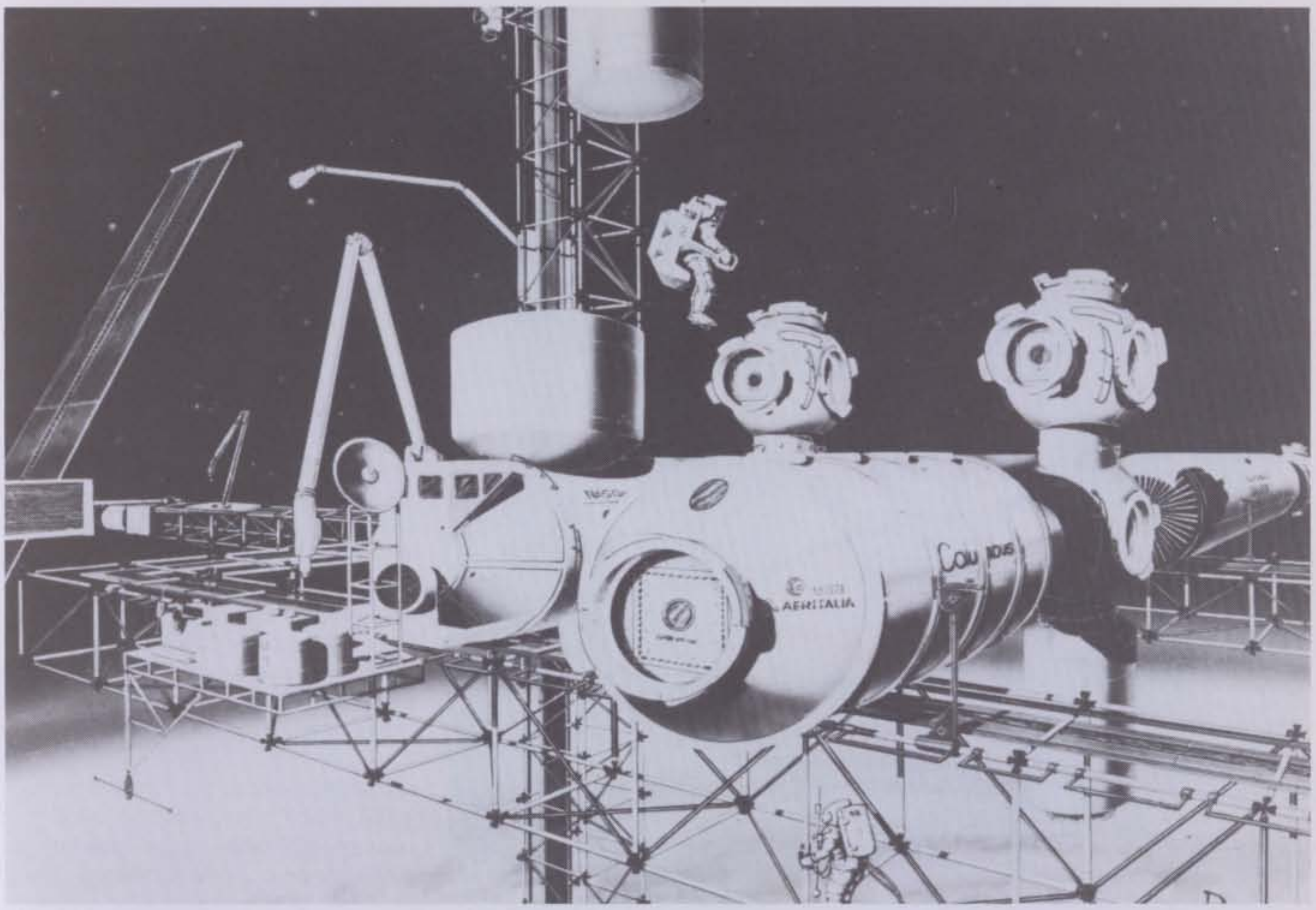
La fabrication des matériels de vol et l'intégration des deux modèles suivants, MOP-2 et MOP-3, progressent de façon satisfaisante à l'Aérospatiale.

Microgravité

Extension de la Phase 2
Les travaux se poursuivent dans l'industrie sur les différents éléments de ce programme; un éclairage particulier peut être apporté aux points suivants:

Biorack
Les dossiers de recette des expériences Biorack pour la mission IML-I en sont au stade final de révision avec les chercheurs tandis que la dernière touche est donnée aux procédures concernant l'équipage de vol. Un enregistrement vidéo a été préparé pour chacune des expériences à des fins d'entraînement: il présente les objectifs, le matériel utilisé et le mode de fonctionnement de chaque expérience.

Une réunion d'avancement s'est tenue les 24 et 25 octobre avec l'équipe de gestion NASA de la mission IML-I. Elle a permis de passer en revue le plan de vérification du Biorack, le plan de vérification des structures critiques, le plan d'intégration, d'assemblage et de mise en oeuvre, le document sur les impératifs du Centre de contrôle de l'exploitation de la charge utile, la configuration des moyens de rangement et de stockage, les séquences opératoires, les plans de formation et les procédures des équipages. Pour ces derniers, des procédures normales et



Le laboratoire raccordé Columbus et la Station spatiale 'Freedom'

The Columbus Attached Laboratory and Space Station 'Freedom'

the first six months of 1989, after which final integration of the payload will commence.

The current NASA STS flight manifest indicates a launch in May 1991 and retrieval in December 1991.

Space Station Freedom/Columbus

At the end of September 1988 an Intergovernmental Agreement on the International Space Station was signed by representatives of nine ESA Member States with the United States, Canada and Japan. This was followed by a Memorandum of Understanding (MOU) with NASA entitled 'Cooperation in the Detailed Design, Development, Operation and Utilisation of a Permanently Manned Civil Space Station', which was signed by ESA and Canada.

ESA released the planned Phase C/D Request for Quotation (RFQ) update in September followed by a formal Phase C/D RFQ clarification with the Prime Contractor. The Prime Contractor's RFQs to the Columbus industrial consortium were formally released mid-November with a target submittal date for the integrated proposal to ESA set for end May 1989.

Two key Phase C-Zero technical milestones were achieved during November when industry baselined an updated Columbus Free-Flying Laboratory (formerly MTFF) configuration and a major change to the Columbus Attached Laboratory (formerly APM) primary structure design and internal architecture in order to meet the Agency's common Phase C-Zero/Phase C/D RFQ system requirements,

The Phase C-Zero mid-term review for the two parallel Columbus Polar Platform studies was also successfully completed together with the mid-term review of the Platform's first mission analysis study.

The final selection of the Platform concept to be implemented for Phase C/D will be made by the ESA Council in March 1989, after which the selected concept will form an integral part of the Space Segment Phase C/D industrial proposal.

ESA completed its evaluation of the CNES-proposed Hermes spaceplane configuration options during September and at a joint meeting with CNES it was agreed to baseline the 5MX-C* configuration for the Hermes Phase Cl. Of primary importance to the Columbus programme is that this configuration can accommodate a Freedom/Free Flyer compatible docking port assembly. Subsequent to the baselining of the new Hermes spaceplane configuration, a joint ESA/CNES/industry review of the Hermes systems requirements document has been successfully completed.

ESA has continued to participate in numerous Space Station Freedom working groups throughout the reporting period to further clarify and develop Columbus/Freedom interface requirements and architectures. A complete update of the Level 2 joint

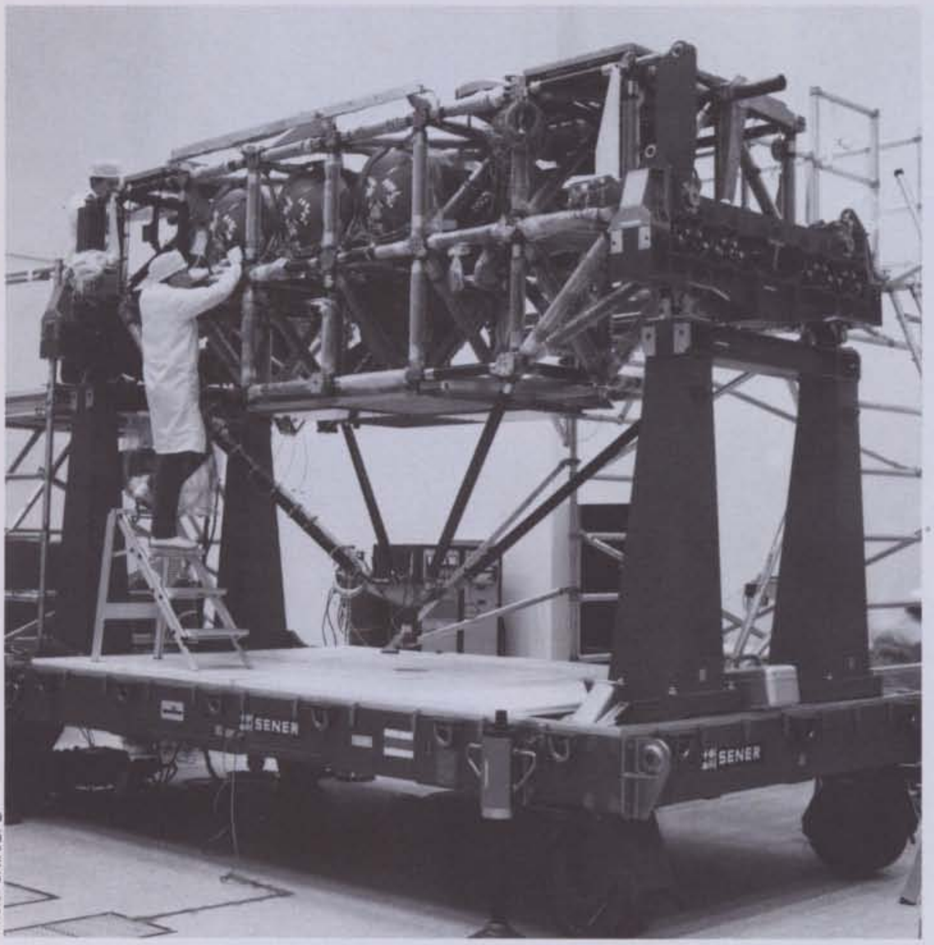


Photo: SNIA/BPD

Assembly of the Eureca flight structure and propulsion system at SNIA/BPD

Assemblage de la structure et du système de propulsion de vol d'Eureca chez SNIA/BPD

exceptionnelles sont en cours d'actualisation en fonction de la dernière configuration des aménagements des quartiers de la Navette.

Four à gradient de technologie avancée (AGHF)
Le contractant a fait la démonstration du montage sur table d l'AGHF et des équipements associés de soutien au sol tels qu'ils ont été réalisés au cours de la phase B. L'aspect matériel et les caractéristiques techniques de l'installation ont été jugés excellents.

Installation de physique de fluides
La revue de conception critique (CDR) touche à sa fin pour l'installation au point critique tandis que celle du module de physique des fluides amélioré progresse. Deux problèmes ont été mis en évidence en ce qui concerne la masse et l'énergie disponible.

Anthrorack
Des revues de conception critiques (CDR) ont été conduites au niveau des sous-systèmes et la CDR au niveau système est en cours.

Fusées-sondes
Au cours de la période à l'examen, deux fusées-sondes ont été tirées avec succès pour les missions Texus-19 et 20, lancées de Kiruna le 28 novembre et le 2 décembre respectivement. Les deux vols emportaient des modules d'expériences de l'ESA dont les résultats sont actuellement à l'étude.

Vols paraboliques
L'Agence utilisera, à l'avenir, pour les expériences de microgravité en vol parabolique, la Caravelle du CNES à la place du KC 135 de la NASA. Un vol de démonstration de la Caravelle est prévu en janvier 1989 et la première campagne de vols de l'ESA est programmée pour la mi-février.

Eureca

L'assemblage de la structure et du sous-système de propulsion de vol d'Eureca a été mené à bien par SNIA/BPD en Italie. Ses essais haute pression/étanchéité ayant donné toute satisfaction, cet ensemble va être envoyé chez MBB/ERNO vers la mi-décembre.

Après des essais de recette réussis, les cinq panneaux de la première aile du générateur solaire sont en cours d'assemblage, avec le radiateur d'Eureca pour des essais acoustiques complémentaires chez IABG. La deuxième aile sera assemblée au premier trimestre 1989.

Parallèlement à ces activités, six des quinze instruments du modèle de vol de la charge utile ont subi des essais d'interface approfondis dans les installations d'essai de la charge utile Eureca. Les instruments restants seront soumis aux essais durant le premier semestre 1989. L'intégration finale de la charge utile démarrera ensuite.

Le manifeste actuel des vols STS de la NASA prévoit le lancement d'Eureca pour mai 1991 et sa récupération en décembre de la même année.

Station Spatiale Freedom/ Columbus

Fin septembre, les représentants de neuf Etats membres de l'ESA ont signé avec les Etats-Unis, le Canada et le Japon un accord intergouvernemental sur la Station spatiale internationale, auquel a fait suite un Mémorandum d'accord (MOU) avec la NASA relatif à la 'Coopération en matière de conception détaillée, de développement, d'exploitation et d'utilisation de la Station spatiale civile habitée en permanence', qui a été signé par l'ESA et le Canada.

L'ESA a publié, le 1er septembre, la mise à jour prévue de la demande de prix de phase C/D, qui a été suivie d'une clarification officielle de cette dernière avec le maître d'oeuvre. Les demandes de prix du maître d'oeuvre au consortium industriel Columbus ont été officiellement publiées à la mi-novembre. La proposition devrait être soumise à l'ESA fin mai.

Deux étapes techniques-clés de la phase C-zéro ont été franchies en novembre lorsque l'industrie a inscrit dans la base

Space Station Elements Renamed

The President of the United States has named the Space Station *'Freedom'*.

On the European side, the abbreviations APM (Attached Pressurised Module), MTFF (Man-Tended Free Flyer) and PPF (Polar Platform) will no longer be used when referring to the Columbus elements of the Space Station Freedom. In future:

the *APM* will be known as the *Columbus Attached Laboratory*

the MTFF will be known as the *Columbus Free Flying Laboratory*, and

the *PPF* will be called the *Columbus Polar Platform*.

requirements documentation has also been initiated following completion of the Freedom Level 2 and Level 3 Preliminary Requirements Reviews (PRRs). Completion of this activity is targeted for December 1988.

Utilisation activities have concentrated on supporting a Multilateral Utilisation Study conducted by the four Space Station Freedom partners to arrive at a jointly agreed outfitting of Freedom's three pressurised laboratory modules and to achieve the commonality for payload interfaces postulated in the MOU. An essential input for the study is the Columbus payload data base of which part 1 (pressurised payloads) has been completed by DFVLR-CUPG.

Activities in the Columbus mockup at ESTEC continue with emphasis on the development of a module control station and a general purpose workbench. The telescience testbed is nearing completion and will be transferred to ESTEC in March 1989 for first experiments.

TDP

Common support subsystems
Payload Control Unit
The software development system will be delivered to the Agency by mid-December, which is compatible with the requirements of the first customer (Attitude Sensor Package experiment) for the Payload Control Unit.

Experiments
Gallium Arsenide Solar Array (GaAs): the engineering solar array panel has been manufactured. The flight unit model and two patches of ultra-thin cells are now foreseen to be delivered in January 1989 due to a shift of the UOSAT-E launch. The Invitation to Tender (ITT) for Phase-2 will focus on a solar array panel of 4 x 4 cm cells and will be issued by the beginning of 1989.

For reasons of safety and the complexity of the experiment a contract covering only Phase B began in October 1988. It will be completed in February. The output of this phase will be a complete experiment definition including subsystems specifications and an estimate for Phase C/D.

The *Heat Pipe Radiator and In-Space Aluminium Coat experiment* is presently under review. The ITT for the *Inflatable Space Rigidised Antenna* is pending final launch agreement.

The *Transputer and Single Event Upset* engineering model and testing equipment has been manufactured and integrated.

The *Liquid Gauging Technoloqy experiment* ITT has not yet been released since the experiment is presently under review.

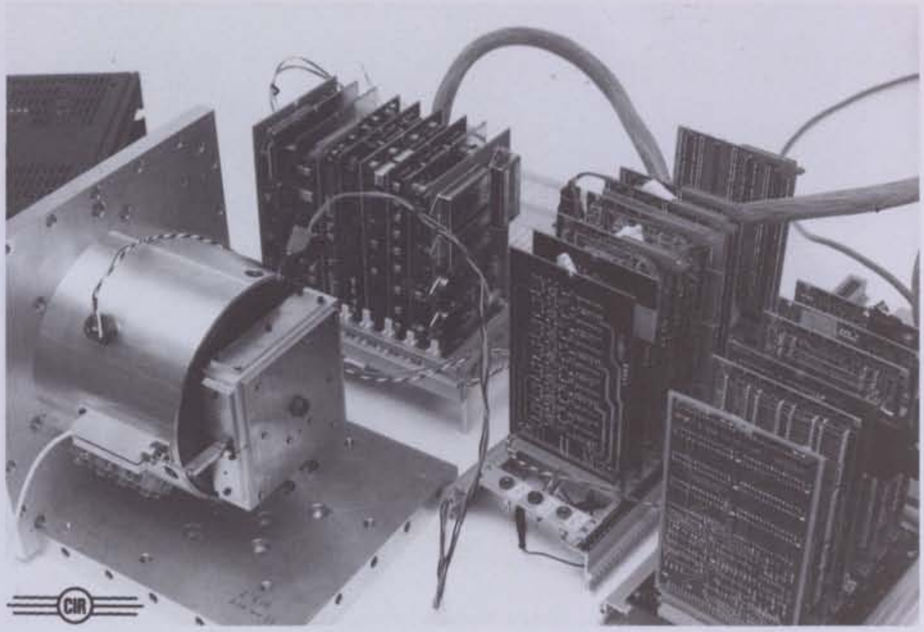
ESA/NASA cooperative experiments
International cooperation with NASA's Office of Aeronautics and Space Technology is progressing well with the exchange of letters for a joint phase B of the *In-flight Contamination Experiment (IFCE)*; this was completed in October. Work on the NASA Phase B is in progress, with a mid-term review foreseen for mid-December in USA. The ESA Phase B activities are also in progress. The proposal for the work on Quartz Microbalance Sensor adaptation for atomic oxygen detection is under preparation. The parallel ESA/NASA Phase B activities should be completed in March 1989.

For the *Solar Array Module Plasma Interaction (SAMPIE)* a technical meeting took place in NASA/LERC at the end of September 1988. A joint ESA/NASA technical experiment proposal was discussed and agreed. A draft of an exchange of letters for a joint phase B has been prepared. A proposal for the study of the SAMPIE experiment is currently being evaluated. This study is part of the preparatory activities for the next TDP phase.

Flight opportunities
For the Hitchhiker-G experiments (Attitude Sensor Package, Collapsible Tube Mast with IFCE) manifesting and pricing policy are still under discussion. Discussions on a launch agreement have been initiated.

Concerning the Get-Away Special (GAS) experiments, the final safety review for the Solid State Microaccelerometer (G-2I) is now planned for January 1989.

Integration of the UOSAT-E experiments (Transputer and Single Event Upset and Gallium Arsenide Solar Panel with two solar cell patches) is scheduled for March 1989. The launch is foreseen as piggy-back to the Ariane 4/SPOT-2 satellite (together with five other micro-satellites, one UOSAT-D, four AMSAT) in June 1989.



de référence une configuration actualisée du MTFF et un important remaniement de la conception de la structure primaire de l'APM et de son architecture interne destiné à répondre aux impératifs système de l'Agence pour la demande de proposition commune de phase C-zéro/phase C/D.

L'examen à mi-parcours de la phase C-zéro concernant les deux études parallèles de plates-formes polaires a également été mené à bien ainsi que la revue à mi-parcours de l'étude portant sur l'analyse de la première mission de plate-forme polaire. Lorsque le choix final du concept de plate-forme polaire à mettre en oeuvre pour la phase C/D aura été arrêté par le Conseil de l'ESA en mars 1989, le concept retenu deviendra partie intégrante de la proposition industrielle de phase C/D du secteur spatial.

L'ESA a terminé en septembre l'évaluation des options proposées par le CNES pour la configuration de l'avion spatial Hermès et il a été convenu lors d'une réunion avec le CNES de prendre la configuration 5MX-C comme base de référence pour la phase C1 d'Hermès. Le point primordial pour le programme Columbus est que cette configuration permet l'installation d'un dispositif d'amarrage compatible avec la Station spatiale et le MTFF. Après l'adoption de la nouvelle configuration de l'avion spatial Hermès conme base de référence, l'ESA, le CNES et l'industrie ont revu ensemble le document sur les impératifs système d'Hermès (HSRD).*

L'ESA a continué de participer tout au long de la période considérée à de nombreux groupes de travail de la NASA sur la Station spatiale en vue d'expliciter et de développer plus avant les impératifs et les architectures d'interface Columbus/Station spatiale. Une mise à jour complète de la documentation sur les impératifs communs de niveau 2 a également été entreprise à la suite des revues sur les impératifs préliminaires (PRR) de niveau 2 et de niveau 3 de la Station spatiale. On espère mener à bien cette activité d'ici à décembre 1988.

Dans le domaine de l'utilisation, les activités ont été centrées sur le soutien d'une étude d'utilisation multilatérale effectuée par les quatre partenaires de la Station spatiale en vue d'aboutir à la définition d'un équipement agréé par tous, pour les trois modules laboratoires pressurisés de la Station spatiale Freedom, et de réaliser la banalisation des interfaces de charge utile postulée dans le MOU. La base de données sur les charges utiles de Columbus, dont la première partie (charges utiles pressurisées) a été mise sur pied par le DFVLR-CUPG, constitue un élément essentiel de cette étude.

Les activités se sont poursuivies sur la maquette de Columbus à l'ESTEC, l'accent ayant porté sur la mise au point d'un poste de commande de module et d'un poste de travail à usage général. Le banc d'essai de téléscience, qui est proche de son achèvement, sera transféré à l'ESTEC en mars 1989 en vue des premières expériences.

TDP

Sous-systèmes de soutien communs
Unité de commande de la charge utile
Le système de réalisation du logiciel de cette unité sera livré à l'Agence à la mi-décembre, date compatible avec les besoins de la première expérience 'Ensemble de détection de l'orientation'.

Expériences
Générateur solaire à l'arséniure de gallium (GaAs)
La fabrication d'un modèle d'identification du panneau complet est terminée. Par suite d'un report du lancement UOSAT-E, il est prévu désormais de livrer le modèle de vol et deux panneaux de piles ultrafines courant janvier 1989. L'appel d'offres relatif à la phase 2, qui portera principalement sur un panneau de générateur solaire comportant des piles de 4 x 4 cm, sera lancé au début de l'année.

Solid-State Microaccelerometer Experiment breadboard

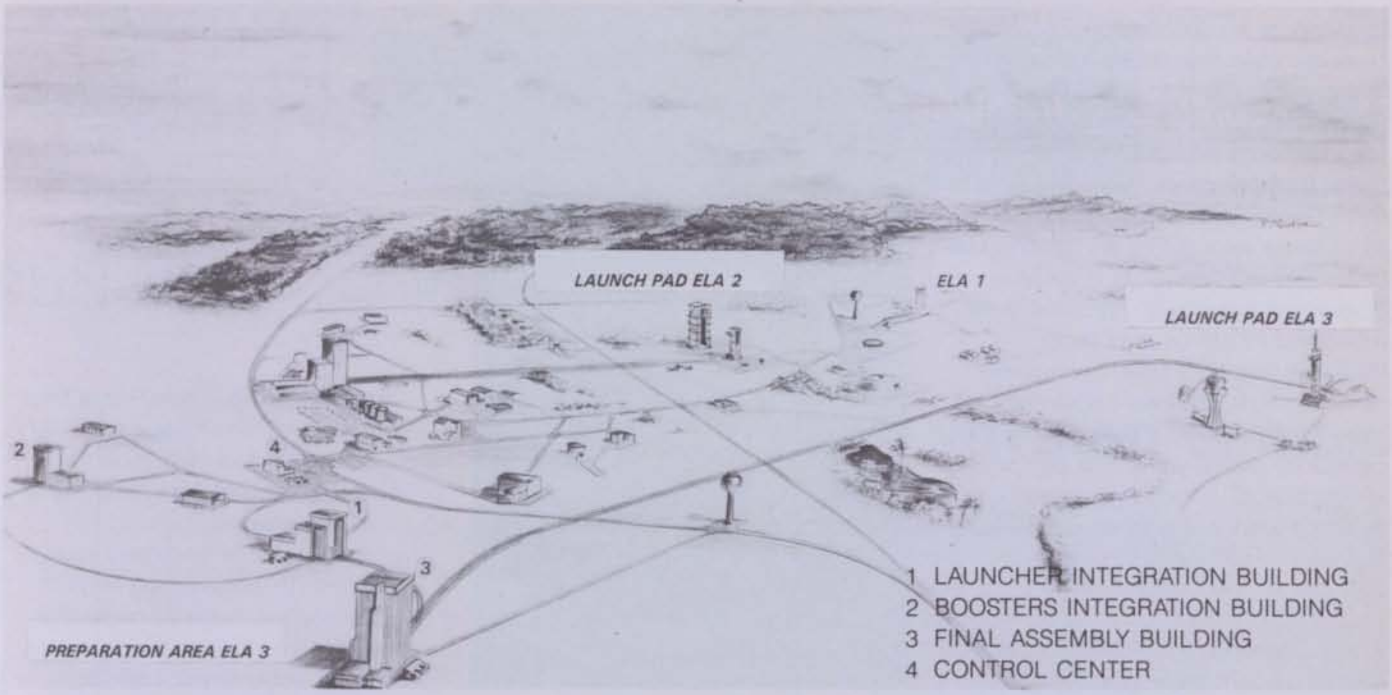
Maquette sur table de l'expérience microaccéléromètre à l'état solide

Compte tenu de la complexité de l'expérience et des problèmes de sécurité, un contrat couvrant la seule phase B a débuté en octobre 1988 et se terminera en février 1989. Cette phase doit déboucher sur une définition complète de l'expérience, avec spécification des sous-systèmes, et sur une estimation pour la phase C/D.

L'expérience de radiateur à caloducs et d'aluminage dans l'espace est actuellement à l'examen. L'ITT relatif à l'antenne gonflable et rigidifiable dans l'espace *est suspendu dans l'attente d'un accord définitif sur le lancement.*

Pour l'expérience transordinateur et perturbations sous l'effet de particules élémentaires, *le modèle d'identification et le matériel d'essai ont été fabriqués et intégrés.*

L'ITT de l'expérience de technologie de jaugeage des liquides n'a pas encore été lancé, cette expérience faisant actuellement l'objet d'un nouvel examen.



Vue d'ensemble de la base de lancement d'Ariane

Overview of the Ariane launch pads

TDP next phase preparation
In the framework of the preparatory activities for the next TDP phase, the Announcement of Opportunity to solicit small experiments will be released by the end of 1988 to industry, research centres and universities.

The majority of proposals for preparatory studies to define complex experiments are now under evaluation. A workshop to foster an exchange of ideas on the flight experiments and to seek advice before preparing the final programme content will be organised in the second half of 1989.

Ariane

Site work on the major building project for new ground facilities at Kourou was officially inaugurated on 14 November 1988 (see page 101 of this issue). These are needed for Ariane-5, the new European launcher whose first flight is scheduled for April 1995.

The Ariane-5 ground facilities will include:

- The Ariane-5 launch complex, ELA-3, which includes:
  - a preparation zone with an integration hall (BIP) for the P230 boosters, a launcher integration building (BIL) and a final assembly building (BAF). The latter will be used for final checkout of the launcher and integration of the payload;
  - an Ariane-5 launch zone, linked to the first by a double-track crawlerway for moving the launch table, launcher and umbilical mast.
- A teststand (BEAB) for the P230 solid booster. This highly spectacular stand will allow the booster to be tested in the vertical position; it has a dry flame-chute 50 m deep, built in granite. The first booster test is planned for 1991.
- A propellant-grain production plant (UPG) which, from 1990 onwards, will allow loading of the two main segments of the Ariane-5 solid booster (each segment carries 100 tonnes of grain) in Kourou. The third, front segment carries 23 t, and can be shipped to Guiana after being loaded with propellant in Italy by BPD.

The following figures give an idea of the extent of the work being done in Guiana as part of ESA's Ariane-5 programme:

- The construction site covers 600 hectares
- The earthworks involve moving 3 million cubic metres
- Concrete: 150 000 t to be poured, with 5000 t of metal reinforcement
- Road system: 40 km. Crawlerway: 2 × 7 km
- Installed electric power: 20 MW
- Girderwork: 20 000 t (three times that in the Eiffel Tower).

Expériences en coopération ESA/NSA
La coopération internationale avec le Bureau de technologie aéronautique et spatiale de la NASA a bien progressé avec l'échange de lettres relatif à une phase B commune de l'expérience de contamination en vol (IFCE); cette procédure s'est achevée en octobre. Les travaux sur la phase B de la NASA progressent également, avec une revue à mi-parcours prévue pour la mi-décembre aux Etats-Unis. Les activités de phase B de l'ESA sont également en route. La proposition d'adaptation d'un capteur de microbalance à quartz pour la détection de l'oxygène atomique est en préparation. Les activités parallèles ESA/NASA de phase B devraient s'achever en mars 1989.

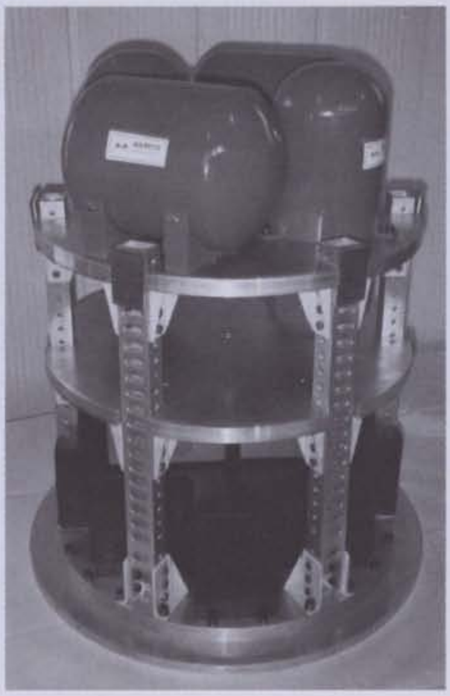
Pour l'expérience d'interactions entre le module de générateur solaire et le plasma (SAMPIE), une réunion technique s'est tenue fin septembre au LERC de la NASA. Une proposition d'expériences techniques communes ESA/NASA a été examinée et approuvée. Un projet d'échange de lettres relatif à une phase B commune a été préparé. Une proposition d'étude de l'expérience SAMPIE a été reçue et est en cours d'évaluation. Cette étude fait partie des activités préparatoires de la prochaine phase du TDP.

La possibilité de nouvelles expériences communes ESA/NASA est à l'étude.

Occasions de vols
Pour les expériences faisant appel au porteur Hitchhiker-G (ensemble de détection d'orientation, mât à tube enroulable avec l'IFCE) les dates de lancement et les prix sont toujours en suspens. Des négociations ont été lancées au sujet d'un contrat de lancement.

Pour les expériences GAS, la revue finale de sécurité concernant le microaccéléromètre état solide (G-2I) est désormais fixée à janvier 1989.

L'intégration des expériences UOSAT-E (transordinateur et perturbations sous l'effet de particules élémentaires, et générateur solaire à l'asénuire de gallium avec deux lots de photopiles ultrafines) est prévue pour mars 1989 et le lancement, en tandem avec le satellite SPOT-2 sur Ariane 4 en même temps que cinq autres microsatellites, un UOSAT-D et quatre AMSAT, pour juin 1989.



The Liquid-Gauging Technology Experiment mock-up

Maquette sur table de l'expérience de technologie de jaugeage des liquides

Préparation de la prochaine tranche du TDP
En préparation de la prochaine tranche du TDP, un avis d'offres de participation portant sur des petites expériences sera diffusé fin 1988 parmi les industriels, les centres de recherche et les universités.

Les propositions d'études préparatoires destinées à définir des expériences complexes sont pour la majorité en cours d'évaluation. Un atelier destiné à encourager les échanges d'idées sur les expériences de vol et à rechercher des avis avant d'établir le contenu final du programme sera organisé au cours du second semestre 1989.

Ariane

Le 14 novembre 1988, le chantier d'un important projet de construction à Kourou a été inauguré. Il s'agit des nouvelles installations au sol d'Ariane-5, le futur lanceur européen dont le premier vol est programmé pour avril 1995.

Les installations au sol d'Ariane-5 comprendront :

- *Le complexe de lancement Ariane-5 (ELA-3) qui se compose:*
  - *d'une zone de préparation avec un hall d'intégration (BIP) pour les propulseurs P230, d'un bâtiment d'intégration lanceur (BIL) et d'un bâtiment d'assemblage final (BAF) qui servira à la vérification finale du lanceur et à l'intégration de la charge utile;*
  - *d'une zone de lancement Ariane-5 reliée à la précédente par une double voie ferrée permettant de transporter la table de lancement, le lanceur et le mât ombilical.*
- *Un banc d'essai (BEAB) pour les propulseurs à poudre P230. Sur ce banc d'essai très impressionnant, les propulseurs seront essayés en position verticale; il comprendra un carneau de type sec en granit, de 50 m de profondeur. Le premier essai de propulseur doit avoir lieu en 1991.*
- *Une usine de production de blocs de poudre (UPG). Dès 1990, cette usine assurera le chargement des deux segments principaux du propulseur à poudre d'Ariane-5. Chacun d'eux contient 100 tonnes de poudre. Le segment frontal en contient 23 tonnes et pourra être expédié en Guyane après remplissage en Italie par la firme BPD.*

Les chiffres qui suivent donnent une idée de l'importance des travaux entrepris en Guyane dans le cadre du programme Ariane-5 de l'ESA:

- *Le chantier s'étend sur 600 hectares.*
- *Les travaux de terrassement porteront sur 3 millions de mètres cubes de terre.*
- *150 000 t de béton seront coulées et armées de 5000 t de métal.*
- *Réseau routier: 40 km; voies ferrées : 2×7 km.*
- *Puissance électrique installée: 20 MW*
- *Ouvrages métalliques: 20 000 t (3 fois plus que pour la Tour Eiffel).*

In Brief

ESA Council Approves 5% Increase in the Scientific Programme Budget

The ESA Council has approved the Agency's level of resources for its mandatory activities, the scientific programme and the general budget. This completes the decision cycle started in November 1987 at the Ministerial Meeting in The Hague, when the Agency's Long-Term Plan was approved in principle.

The Agency's scientific budget will now increase by an average of 5% annually up to 1992, enabling the planned scientific programme 'Horizon 2000' to go ahead.

Prof. Roger Bonnet, ESA's Director of Scientific Programmes, commented after the decision that: 'The Council's unanimous decision was one of extreme importance to the Scientific Programme. It shows a great will to go forward together. We have several important projects in this coming period, both those which are already underway and those which will be initiated shortly'.

Cassini to Explore Saturn's Moon Titan

ESA's Science Programme Committee (SPC), at its meeting in Paris on 24 – 25 November 1988, selected the planetary Cassini/Titan Probe mission as the Agency's next scientific project.

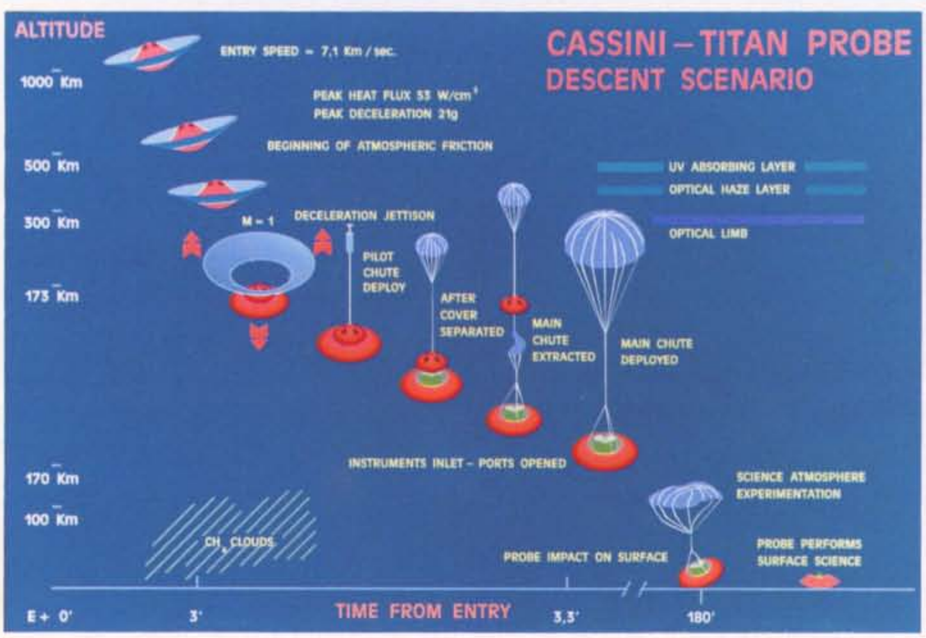
The Cassini/Titan Probe project was in competition with four other missions (see ESA Bulletin no. 55, pp. 10 – 40): Vesta, a multiple asteroid and comet fly-by mission involving ESA, CNES and the Soviet Interkosmos; Lyman, an ESA/NASA ultraviolet space observatory; Quasat, a radio Very Long Baseline Interferometer (VLBI) satellite involving ESA, NASA, Australia and Canada; and GRASP, a high-precision gamma-ray telescope, an ESA-only mission.

The Cassini mission, named after the 17th Century French-Italian astronomer who discovered several of Saturn's moons and ring features (the so-called 'Cassini division') is a cooperative international mission to be undertaken jointly with NASA. The specific target of the mission is Saturn's moon Titan, the largest moon in our Solar System and the only one known to have a thick, organic-rich, nitrogen atmosphere. The surface pressure is 1.5 bar and the temperature is 94 K (– 179°C). Scientists believe that the chemical processes in the Titan atmosphere may resemble those at work on the primitive Earth before life began.

The SPC's decision is the culmination of a six-year study, which started in early 1983 after the initial proposal was received from a European team led by Dr Daniel Gautier from the Observatoire de Paris, Meudon, France, and Dr Wing Ip of the Max-Planck-Institut für Aeronomie, Katlenburg-Lindau, Germany, who suggested that this mission be undertaken jointly with NASA.

Cassini is scheduled to be launched by NASA in April 1996. En route to Saturn, the spacecraft will fly-by the asteroid 66 Maja in 1997 and Jupiter in late 1999, arriving in the Saturn system in October 2002.

Once the NASA-built orbiter arrives at Saturn it will target and release the ESA-built probe called Huygens, after the Dutch astronomer and physicist who discovered Titan and the Saturnian rings in 1656, into Titan's atmosphere. A large conical decelerator will slow the probe



The Titan Probe descent scenario

down to subsonic speed (266 m/s) at an altitude of 180 km. A parachute system will then be deployed to allow a slow, two-to-three hour descent to the surface of Titan, which scientists speculate may be covered by ethane/methane lakes or oceans. The 5 m/s low-velocity impact may be soft enough to allow analysis of a surface sample before the probe dies. During the probe's descent, the orbiter will be used as a radio relay station to transmit its data back to Earth.

Building of ELA-3 Begins

On Monday 14 November 1988, in the presence of the heads of the regional administration and the local political and civil authorities, ESA and CNES inaugurated construction work on ELA-3, the third Ariane launch complex and the associated Ariane-5 ground facilities in Guiana.

This third launch complex is being built to meet the requirements of Europe's Ariane-5 launcher and is scheduled to be operational for the launcher's first test flight in 1995. ELA-3, which has a design lifetime of 20 years, assuming eight to ten launches per year, will consist of the following main facilities:
- the booster integration building, where the solid propellant booster stages will be assembled and checked out;
- the launcher integration building, where assembly and checkout operations will be carried out on Ariane-5's central body and its solid propellant boosters;
- the final assembly building, where the assembly and checkout operations will be carried out on the vehicle equipment bay, the upper stage, the payloads and the fairing;
- the launch zone, where the launchers will be filled with propellant and final checks carried out;
- the No. 3 launch centre, from which operations will be controlled until the launch.

ELA-3's design is such that preparations can proceed on two separate launchers in parallel. From 1993 onwards, ELA-3 will also be used as a test site for Ariane-5's cryogenic main stage.

MOP-1: en route to Kourou

The first satellite of the Meteosat Operational Programme, MOP-1, was shipped on 5 January from the prime contractor Aerospatiale, Cannes, to the Kourou launch site in French Guiana.

MOP-1 is to be launched on 28 February with another passenger, JC-Sat, on Ariane flight V29.

After launch and in-orbit checkout, MOP-1, positioned at 0° in geostationary orbit, will become the prime provider of meteorological satellite data covering Europe. In this role, it will replace Meteosat-3, which will continue to perform the LASSO laser-ranging experiment while acting as back-up for MOP-1.

Contributions to the Ariane-4 Development Programme

Several recent articles and publications have mentioned different contribution schemes for the Ariane-4 Development Programme. The definitive breakdown of contributions is as follows:

Belgium	4.05
Denmark	0.17
France	62.60
Germany	16.28
Ireland	0.07
Italy	5.87
Netherlands	1.76
Spain	1.77
Sweden	1.15
Switzerland	1.55*
United Kingdom	4.64

* An additional contribution from Switzerland leading to 3.81% was covered by the Ariane-3 programme.

Ariane Goes from Strength to Strength

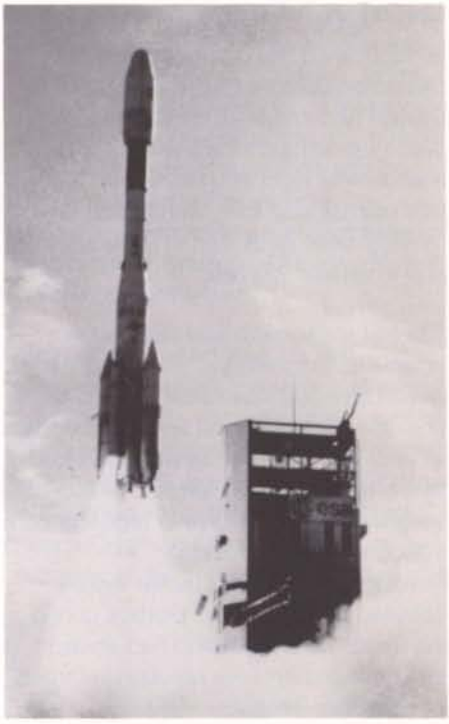
Ariane V28, carrying the telecommunications satellite Intelsat V(F15), was successfully launched from the ELA-1 launch pad in French Guiana on 26 January at 22:21 hours local (Kourou) time. After a propulsion phase of 18 min 11 s, the satellite was injected into Geostationary Transfer Orbit. 34 min after launch Intelsat V(F15) was acquired by the Zamengoe ground station in the Cameroons. The apogee boost motor was fired on Sunday 29 January, transferring the satellite to near-geosynchronous orbit.

Less than two months earlier, on 9/10 December, the first operational flight of Ariane-4 (V27) under the auspices of Arianespace, was launched, completing a total of seven successful Ariane launch campaigns in 1988.

Aboard V27 were the British telecommunications satellite Skynet 4B, the modular platform of which was derived ESA's well-proven OTS/ECS platform; and Astro 1A, built for the international Société Européenne des Satellites (SES) in Luxembourg by GE Astrospace (USA). Astra 1A will be used for direct broadcasting of commercial television throughout Europe.

The dual launch was made possible by use of the SPELDA (Structure porteuse externe pour lancement double Ariane), with Astra 1A inside the SPELDA and Skynet 4B on top, within the nose fairing.

By 16 December both satellites had completed the critical manoeuvres, apogee booster motor firing and solar panel deployment, and are now on station and performing nominally.



ESA Payload Specialist Selected for IML-1 Mission

NASA announced on 11 January that ESA's Dr Ulf Merbold and Dr Roger K. Crouch of NASA have been selected as candidate payload specialists for material science experiments on the International Microgravity Laboratory (IML-1) mission aboard the Shuttle Columbia in April 1991. NASA also announced that it has extended an invitation to nominate two candidate payload specialists for the life sciences experiments on IML-1 to the Government of Canada.

Dr Ulf Merbold flew as ESA's Payload Specialist on the Spacelab-1 mission in November/December 1983. Prior to joining the Agency in 1977, he was a solid-state physicist at the Max Planck Institute for Metals Research, where his main fields of research were crystal lattice defects and low temperature physics.

After the initial training period, NASA will designate, in consultation with ESA, a prime and a backup payload specialist for the materials sciences portion of the IML-1 mission and will also designate, in consultation with the Canadian Ministry,

ESA payload specialist Ulf Merbold

a prime and a backup payload specialist for the life sciences portion.

IML-1 will be the first of a series of microgravity investigations using the Spacelab module. It will focus on materials and life sciences, two disciplines needing access to a laboratory in reduced gravity. The IML series are designed to fly at 17 to 25 month intervals, enabling investigators to analyse the results of the flight experiments and use that knowledge to design additional experiments.

The investigations will use five life sciences experiment facilities, designed to be used and flown again – Biorack, Protein Crystal Growth Facility, Gravitational Plant Physiology Facility, Microgravity Vestibular Investigations and Space Physiology Experiments; and three materials facilities – the Fluid Experiment System, Vapour Crystal Growth System, Mercury-Iodide Crystal Growth System and the Critical Point Facility. These reusable facilities have been built by American, European, Canadian and Japanese investigators and organisations for reflight aboard the Spacelab system.

ESA is providing two major facilities for the IML-1 mission: the enhanced version of the original Biorack that was successfully on Spacelab D-1 in 1985, and the newly developed Critical Point Facility for thermodynamic studies under microgravity.

In addition to the experiments that require the reusable facilities, three other life science and three other materials science experiments with unique hardware will be carried aboard IML-1.

ESA Life-Sciences Experiments on the Soviet Satellite Biokosmos

In September/October 1987 two small, self-contained ESA experiments were carried on-board a Soviet Biokosmos satellite (Biokosmos-8) for the first time. Just 14 months after agreement on the mission was reached between Interkosmos and ESA, the results have recently been published in various Soviet and European journals.

The first experiment was devoted to dosimetric mapping (i.e. a survey of quantitative and qualitative aspects of cosmic radiation) inside and outside the satellite; the second was designed to study the potential synergistic effects of weightlessness and cosmic radiation on insect embryos in the early developmental stages. Earlier results obtained using the ESA Biorack during the Spacelab D-1 mission had shown that development was seriously retarded due to these effects.

The Biokosmos programme offers unique experimental conditions to biologists: high-inclination orbits, the use of fairly simple experiment hardware, the high frequency of missions (one every two years) and unconventional sample recovery. ESA not only obtained excellent scientific results, but also acquired some refreshing project experience in preparing experimental hardware for flight at short notice and under unusual conditions.

ESA has just signed a similar agreement to fly another five experiments using equipment derived from Biorack on the next mission, Biokosmos-9, scheduled for July 1989. For the first time, the experiments have been selected on the basis of an Announcement of Opportunity issued by ESA to the European life-sciences community calling for proposals to work in collaboration with Soviet scientists on Soviet spacecraft.

Heinz Oser, ESA, Paris

American Presidential Award for IUE

In a White House ceremony in Washington on 10 November 1988, the President of the United States, Mr Ronald Reagan, presented ESA with the American Presidential Award for Design Excellence for the International Ultraviolet Explorer (IUE) spacecraft.

An astronomical satellite that studies ultraviolet radiation, IUE is a cooperative venture between NASA, ESA and the UK Science and Engineering Research Council. Since its launch in 1978 IUE has been, and continues to be, one of the most productive astronomical tools ever built.

Within the framework of the Presidential Award, Manfred G. Grensemann and Ferdinando Macchetto, ESA IUE Project Managers 1974 – 1976 and 1976 – 1978 respectively, received Federal Design Achievement Awards. Alain Pierre Fournier-Sicre, industrial and integration/test engineer for the IUE solar array, received the same honour. Mr Grensemann and Mr Fournier-Sicre were presented with their awards by ESA's Director General, Prof. Reimar Lüst, at the Agency's Science Programme Committee meeting on 25 November 1988.

Presentation of the Federal Design Achievement Award to Mr M.G. Grensemann, ESA IUE Project Manager 1974 – 1976

ESA Establishes European Centre for Space Law

In October 1988 the Agency presented its concept for a European Centre for research into space law to a meeting attended by some 70 academics, barristers, company lawyers, national representatives and students. The broad lines of the proposal and a draft Charter were endorsed, and a General Meeting is planned for the spring of 1989.

Operating under the auspices of ESA, the Centre is intended to provide a forum for all those with an interest in space law. It will support, build on and raise the status of existing work in the field, stimulate research, and promote, in a multidisciplinary framework, the study of existing problems. Once established, the Centre will be able to work in cooperation with various bodies engaged in similar activities.

The first step will be for ESA to develop a computerised information system around a legal database to which all participants will have access. Further information may be obtained from:

Mr G. Lafferranderie
European Space Agency
8 – 10 rue Mario Nikis
F-75738 Paris cedex 15
France

ESA's Tele-invoicing System – ETIS

Telematic links for the transmission of invoices between ESTEC's Finance Division and Industry have been established using the ESA Telematic Invoicing System (ETIS). This pan-European system, which will have a profound effect on the administration and control of payments, is compatible with the ESA Financial System (EFSY) and project/management control systems such as the Management and Technical Information System (MATIS), developed for the Columbus Programme. Expansion to cover all ESA establishments is foreseen once the initial trial period in ESTEC is complete.

A trial of tele-banking for international payments will begin shortly, the last link in a fully electronic invoicing/payment system.

ETIS is described in detail in a brochure (ESA BR-53) available from ESA Publications Division. Further information can also be obtained by contacting:

C.W. Pridgeon
Head of Finance
ESTEC, P.O. Box 299
2200 AG Noordwijk
The Netherlands

Essay Competition 'Astronomy from space'

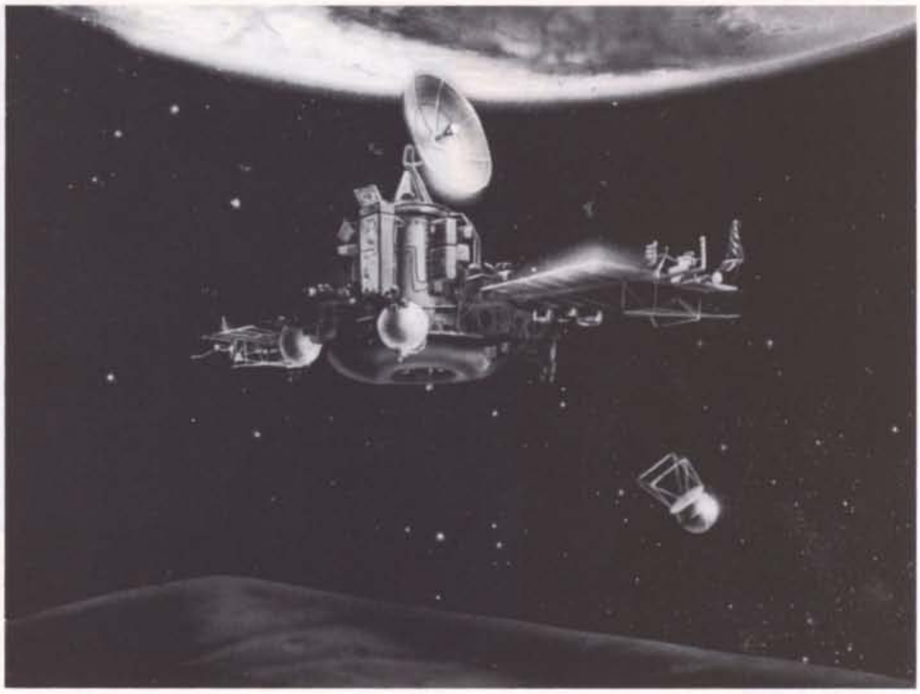
In this, ESA's Silver Jubilee year, two important astronomical satellites, the Hubble Space Telescope (HST) and Hipparcos, will be launched. As part of the Silver Jubilee celebrations the Agency's Scientific Directorate has organised an essay competition open to European students aged between 16 and 21 years on the theme 'Astronomy from Space'.

Prizes will be awarded to the best essay from each Member State participating in the Agency's Scientific Programme, as judged by a specially created board in each participating State (Belgium, Denmark, Federal Republic of Germany, France, Ireland, Italy, The Netherlands, Spain, Sweden, Switzerland, the United Kingdom, Austria, Norway and Finland). The winners will be announced during the official celebrations due to take place in Paris in April. Each winner will receive a set of scientific publications and be invited to visit the Space Telescope European Coordinating Facility located at the European Southern Observatory in Garching near Munich.

ESA will also select three to five outstanding essays, the writers of which will be invited to visit either the Space Telescope Science Institute in Baltimore and the HST Scientific Operations Center in Greenbelt, Maryland, or the Kourou Space Centre in French Guiana on the occasion of the Hipparcos launch.

Phobos II Closest Approach to Mars

Phobos II, the Soviet probe orbiting the planet Mars with a period of three days and six hours, reached the point of closest approach for the first time on 1 February at 18 h 39 min GMT at an altitude of 864 km above the Martian surface. The scientific data stored on the spacecraft recorder during the approach and around the first periapsis (passing one of the two points in an astronomical orbit that lie closest to the centre of gravitational attraction) was transmitted to Earth on 2 February.



The Phobos probe

Part of the Phobos payload is the Plasma Wave System (PWS) built by the Space Science Department of ESA*, which is yielding a wealth of new and exciting information about wave activity and plasma density in the Martian environment. Electron plasma oscillations have been observed in the solar wind during the approach. Phobos II crossed the bow shock (a shock wave marking the boundary where the flow of ionised particles from the solar wind first meets Mars' ionosphere) several times. The spacecraft crossed the shadow of Mars in 1 h, 48 min and the PWS sensors recorded a temperature of less than −30°C but continued to perform perfectly.

In the first week of April, the probe will rendezvous with one of the two Martian moons, its namesake Phobos.

* The PWS instrument has been developed by the Space Science Department of ESA with the collaboration of the Laboratoire de Physique et Chimie de L'Environnement (CNRS, France), the Institute of Geophysics and Planetary Physics, UCLA, USA, the Space Research Institute of the USSR Academy of Sciences IKI, and the Space Electronics Laboratory of the Aviation Institute, Poland.

ESA at Technospace 88

The Technospace international conference and exhibition, which took place in Bordeaux, in southwest France, from 5–9 December 1988, was a major forum for all those involved in providing and using space technology and services.

Space transportation systems meeting international needs for the next twenty years were an important theme of Technospace, where participants were able to debate the requirements for transport to space stations. ESA exhibited one of the European elements of the Space Station Freedom, the Columbus Free-Flying Laboratory (1/4 scale model), as well as the Hermes spaceplane and the Ariane-4 and Ariane-5 launchers (1/10 scale models). There was also a full scale model of Hermes on display, which proved to be one of the highlights of the exhibition.

Remote sensing will play an important part in our gaining a better understanding of our planet in the next decade. In this context, ESA exhibited a 1/5 model of the first European remote-sensing satellite ERS-1, which will be launched in 1990 to monitor ocean, ice and land resources.

On the science side, a full-scale model of the Hipparcos astrometry satellite, to be launched in June 1989, was on view.

Prof. R. Lüst, Director General of ESA and President of Technospace '88, being interviewed by Business Channel

Address by Prof. Reimar Lüst, at the Inauguration of Technospace '88

Ladies and Gentlemen,
I am greatly honoured and pleased to be able to welcome you on behalf of Technospace and the European Space Agency to the second Technospace exhibition here in the city of Bordeaux. This event brings together representatives from space agencies, industrial firms as well as the actual users of space not only from Europe but from the whole World. I wish to express my thanks to Minister Quilés and Mr Chaban-Delmas for their strong support which is demonstrated by their presence today.

Space activities can contribute in an important way to our economic growth and our standard of living. Space has already become indispensable for weather forecasting, radio and TV communications, navigation and the rapidly developing field of Earth observation. And we are now entering an era in which such activities will exert an even greater influence on our living conditions and quality of life.

While in other areas the political will in Europe was still not strong enough to overcome certain difficulties, in space research we are fortunate that there has been a great willingness on the part of governments to see Europe play a major role. Jean Monnet, had he been able to witness it, would have been proud of it.

At their meeting in The Hague little more than a year ago, the Ministers responsible for space matters in Europe reaffirmed their determination that in order to be able to respond to the new prospects space offers for science and applications, Europe should have a Long-Term Space Programme which could give industry the confidence to deploy the necessary skills and the essential infrastructure to carry out plans taking us into the next century. The main objectives of the plan are:

1. to expand Europe's autonomous capability in space;
2. to sustain and enhance Europe's competitiveness in all sectors of space;
3. to strengthen Europe's position as a competent partner for international cooperation and in particular with the United States through a significant participation in the International Space Station.

I should like to say a few words on the last point since one of the goals of Technospace is to stimulate international cooperation.

We can begin 'at home' as it were, in Europe. ESA is itself a proud testimony to the concept of cooperation and out of that cooperation between 13 European States have come rewarding results: 14 scientific satellites and 10 application satellites have been developed and successfully launched. We also have Spacelab and Ariane which is so successful in the launcher market, as the prime example of our achievements.

Close cooperation between Europe and the United States has been demonstrated by quite a number of cooperative projects, with particular success in space science. The continuation of our collaboration with NASA but also with other space agencies is embodied in our Long-Term Space Plan, the main example being 'Columbus' which is based on collaboration with the United States, Canada and Japan.

Beyond Europe we are increasingly faced with issues such as the global warming effect, commonly known as the 'greenhouse effect', the depletion of the ozone layer, the air pollution in towns, water pollution in rivers, lakes and coastal waters, and the loss of a large portion of the World's forests in developing countries. A broader international initiative is needed, firstly to understand the critical issues better, and secondly to initiate corrective actions. In spite of the fact that we live in a world of conflicting or at least divergent political and economic interests, I do believe that many of these problems can be solved only, or certainly more easily, when there is an appropriate international endeavour. ESA's role in coordinating the European contribution to global Earth observation and monitoring is to build upon the sound foundation it has already laid to provide the space-based technology that will be needed.

Finally let me make a few remarks on ESA's role vis-à-vis European industry. One very important motivation for the whole ESA programme is to advance European technology and to encourage European industry. European industry needs to be fully competitive to meet the challenges of the World market.

Those with experience of space activities know that space can be considered an important technological driving force which demands exceptional standards of quality control, improved production processes and expert project management. Space technology calls for a wide range of technological innovations that can be applied elsewhere, such as in advanced avionics, information technology, robotics and new materials. This demand can foster the flexibility and innovation required to promote economic modernisation. The ambitious projects undertaken jointly by European States provide, I believe, a strong stimulus for technological advancement in Europe.

It is essential for the success of the new programmes that all the various efforts made in different parts of our countries are combined in such a way as to make them more efficient to maintain the role of Europe in the World. This type of gathering will certainly contribute to this goal.

I hope that this Exhibition will give all participants a chance to become better acquainted, to exchange views and ideas, and to set up dialogues that will continue long after we have left Bordeaux. This forum will have been a success if we go away with confidence in each other and better equipped for the tasks with which we are confronted.

The Olympus Propagation Experiment

The Olympus Propagation Experiment (OPEX) group was established as a cooperative venture involving a large number of interested organisations in order to coordinate the effective use of experimental data obtained from the Olympus propagation payload (see ESA Bulletin 54, p 34–38).

OPEX is coordinated by the Propagation Section of the Electromagnetics Division in ESTEC. The list of organisations currently involved is given in Table 1. The principal aim of the group is to ensure that standard approaches are used throughout the process of producing propagation statistics, i.e. through the two distinct stages of data preprocessing and data analysis. Experimental results will then be directly comparable and exchangeable without uncertainties regarding equipment quality and data analysis procedures.

To make such standardisation feasible the Agency placed a contract for the 'Study of software and procedures for standardised processing of propagation data'. The prime contractor, Siemens Austria in Vienna, and subcontractor Institute of Applied Systems Technology (IAS) in Graz, have now completed user-requirement and software-requirement documents for the ground-station-dependent data preprocessing phase. At the same time subcontractor CSR Ltd. of Ilkley, England has completed equivalent documents for the site-independent data analysis part. All of these documents were produced after intensive consultation with the Agency and representatives of the OPEX group. The study will be completed at the end of the year when the software architectural design document is produced.

A follow-up contract, beginning early next year, for the production of the standard software is now under consideration. The software will be available to all members of the OPEX group.

The next meeting of the OPEX group will take place on 10 and 11 April 1989 in Vienna, preceding the 'Olympus Utilisation Conference'.

O. Turney, ESTEC, Noordwijk

Table 1 – Organisations involved in the OPEX group

Technical University Graz	Graz, Austria
Austrian Solar and Space Agency	Vienna, Austria
Bell Telephone Manufacturing Co.	Antwerp, Belgium
Newtech	Antwerp, Belgium
EBU Technical Centre	Brussels, Belgium
UCL/Lab. de Telecomm.	Louvain-la-Neuve, Belgium
CRC/Radio Prop. Lab.	Ottawa, Canada
FTZ	Darmstadt, Germany
Dornier System	Friedrichshafen, Germany
Inst. für Rundfunktechnik	Munich, Germany
DFVLR	Oberpfaffenhofen, Germany
P&T/Radio Comms. Office	Copenhagen, Denmark
Elektronikcentralen	Copenhagen, Denmark
TUD/Electromagnetics Institute	Copenhagen, Denmark
UF Data Analysis	Graesred, Denmark
ETSI Telecomunicacion	Barcelona, Spain
ETSI Telecomunicacion	Madrid, Spain
INTA Depto. Avionica	Madrid, Spain
CNET	Paris, France
IRAM	Grenoble, France
EUTELSAT	Paris, France
March Microwave	Braintree, UK
University of Bradford	Bradford, UK
Signal Processors Ltd	Cambridge, UK
Rutherford Appleton Lab.	Didcot, UK
University of Essex	Colchester, UK
CSR Ltd	Ilkley, UK
BTRL	Martlesham, UK
Portsmouth Polytechnic	Portsmouth, UK
BAe	Stevenage, UK
Coventry Polytechnic	Coventry, UK
University of Surrey	Guildford, UK
University of Leeds	Leeds, UK
British Telecom International	London, UK
Department of Trade and Industry	London, UK
BBC Research	Tadworth, UK
IBA	Winchester, UK
University College Cork	Cork, Eire
Telecom Eireann	Dublin, Eire
University College Dublin	Dublin, Eire
Politecnico di Milano	Milan, Italy
CNR/PSN	Rome, Italy
Fond. Ugo Bordoni	Rome, Italy
Selenia Spazio	Rome, Italy
Telespazio	Rome, Italy
CSELT	Turin, Italy
Telecomm. Research Est.	Kjeller, Norway
ELAB	Trondheim, Norway
NIVR	Delft, The Netherlands
Technical Univ. Delft	Delft, The Netherlands
Technical Univ. Eindhoven	Eindhoven, The Netherlands
APT	Huizen, The Netherlands
Dr. Neher-Lab. PTT	Leidschendam, The Netherlands
Universidade Aveiro	Aveiro, Portugal
Swedish Telecom. Radio	Farsta, Sweden
Helsinki University of Technology	Espoo, Finland
Finnish PTT	Helsinki, Finland
Swiss PTT	Berne, Switzerland
Virginia Tech	Blacksburg, USA
NASA/JPL	Pasadena, USA
NASA HQ	Washington DC, USA

Publications

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

ESA Journal

The following papers have been published in ESA Journal Vol. 12, No. 3:

APOLLO – A SATELLITE-BASED INFORMATION DISTRIBUTION SYSTEM
CASAS J M ET AL

APPLICATION OF EXPERT SYSTEM TECHNIQUES TO THE CASSINI TITAN PROBE
CIARLO A & SCHILLING K

MODELLING THE MECHANICAL PROPERTIES AND DYNAMICS OF THE TETHERS FOR THE TSS-1 AND TSS-2 MISSIONS
ANGRILLI F ET AL

MEASUREMENT OF THERMAL CONDUCTIVITY AND THERMAL CONTACT RESISTANCE IN COMPOSITE MATERIALS FOR SPACE APPLICATIONS
MARCHETTI M ET AL

A PRECIPITATION INDEX FROM THE ESOC CLIMATOLOGICAL DATA SET
KERRACHE M & SCHMETZ J

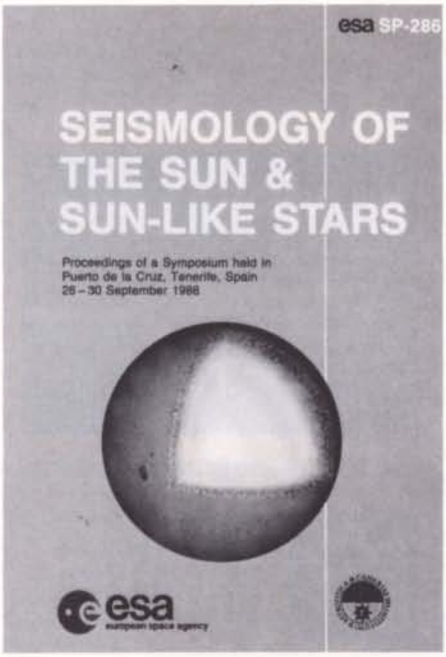
CLASSIFICATION OF IUE SPECTRA: A RULE-BASED APPROACH
RAMPAZZO R ET AL

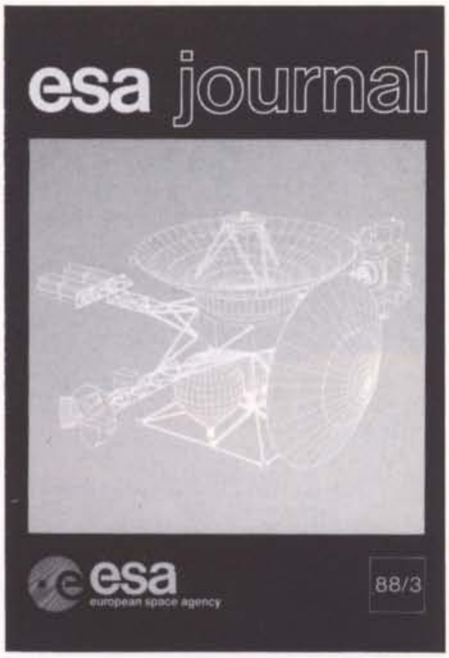
STRUCTURAL RELIABILITY IN AEROSPACE DESIGN
PATKI A V

Special Publications

ESA SP-277 // 637 PAGES
EUROPE IN SPACE – THE MANNED SPACE SYSTEM, PROC INTERNATIONAL SYMPOSIUM HELD IN STRASBOURG, FRANCE, 22 – 29 APRIL 1988 (OCT 1988)
DAVID V & LONGDON N (EDS)

ESA SP-286 // 691 PAGES
SEISMOLOGY OF THE SUN AND SUN-LIKE STARS, PROC SYMPOSIUM HELD IN TENERIFE, SPAIN, 26 – 30 SEPTEMBER 1988 (DEC 1988)
ROLFE E J (ED)





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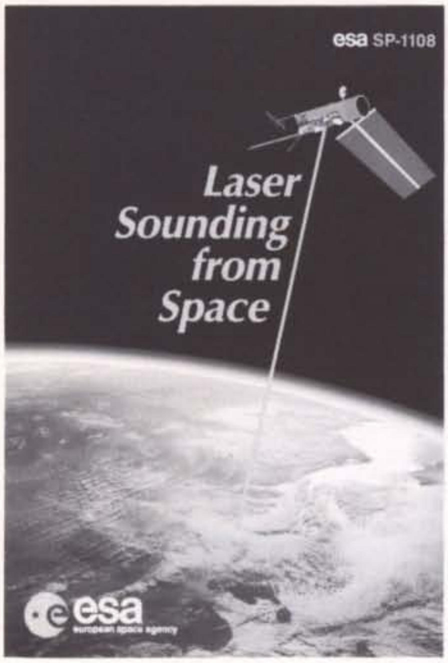

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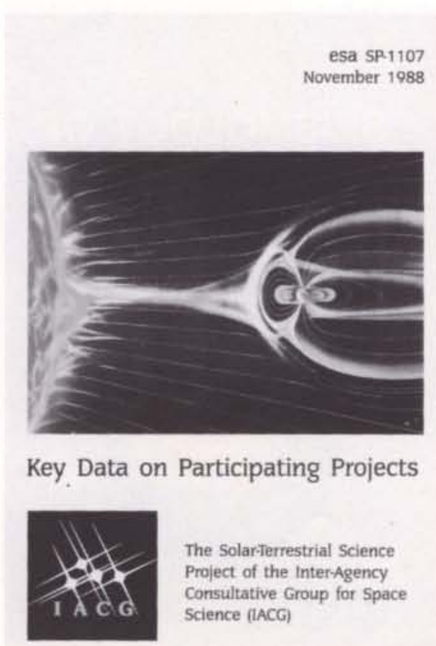

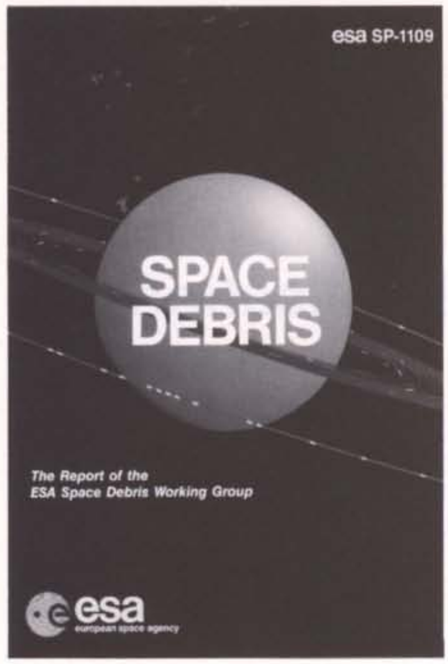

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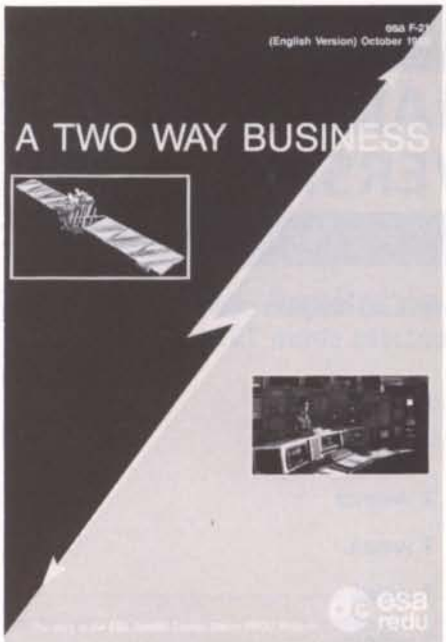

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