esa bulletin

number 47

august 1986

european space agency

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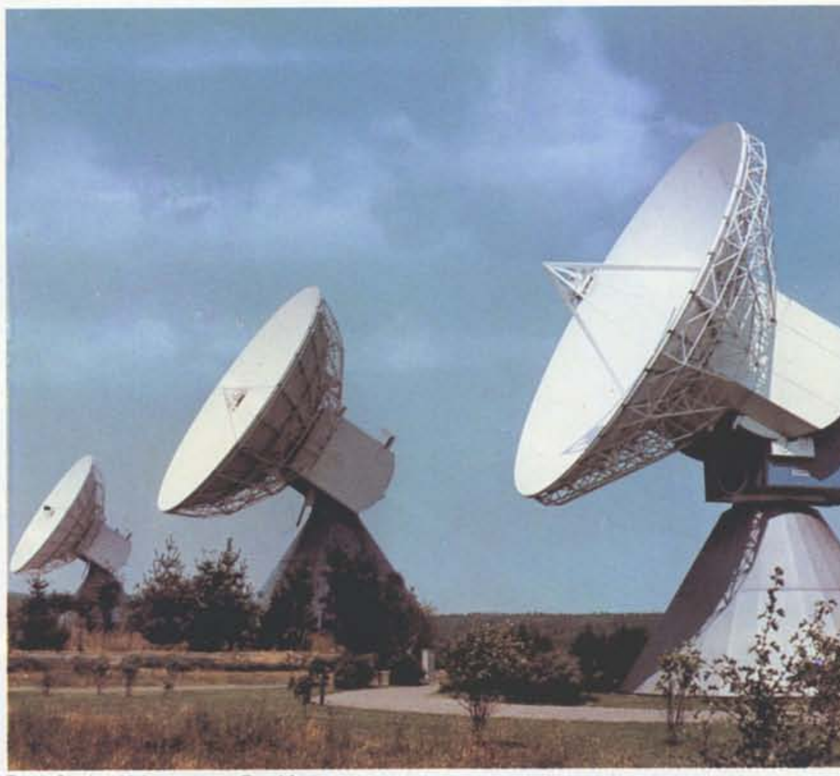
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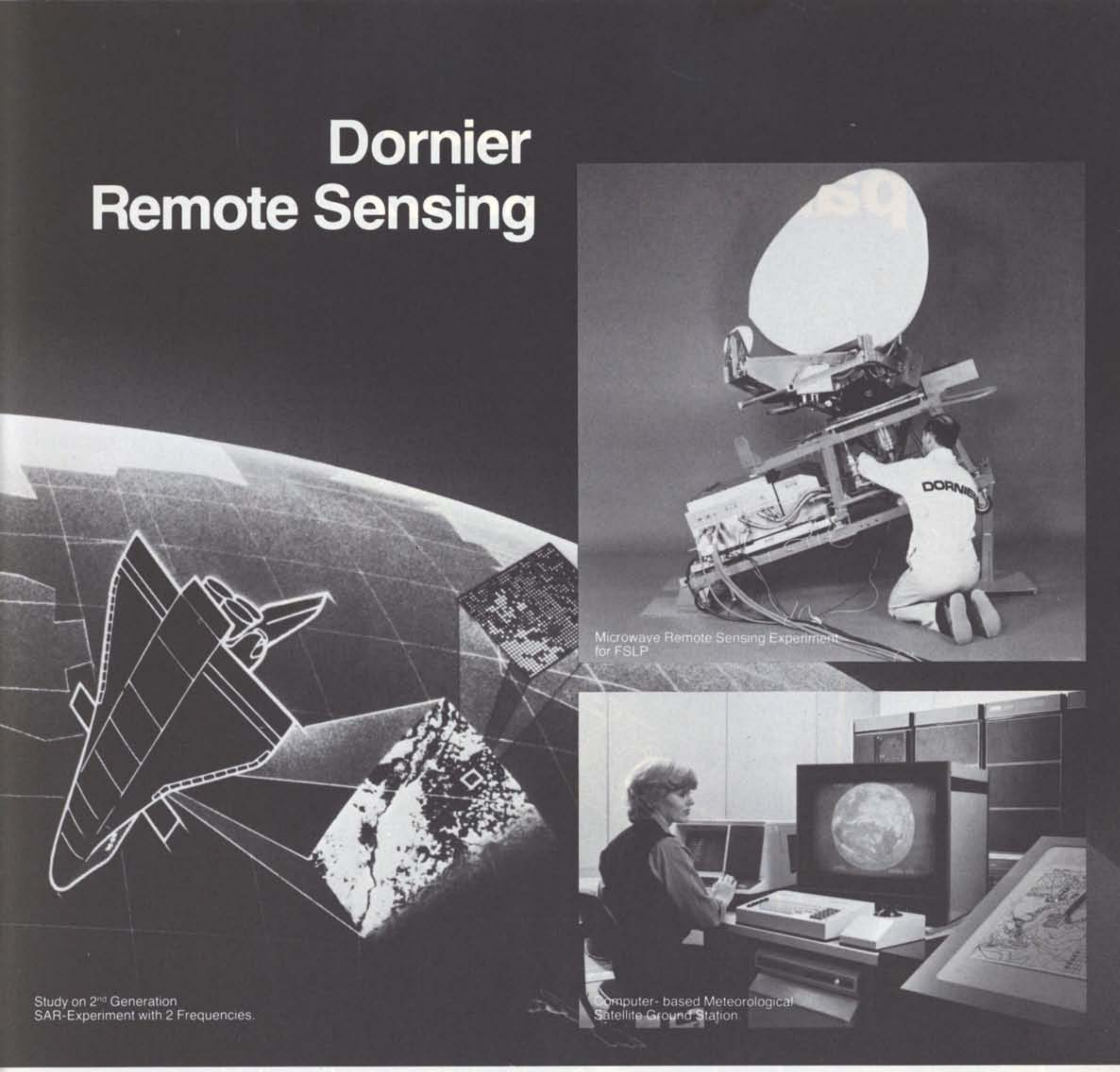

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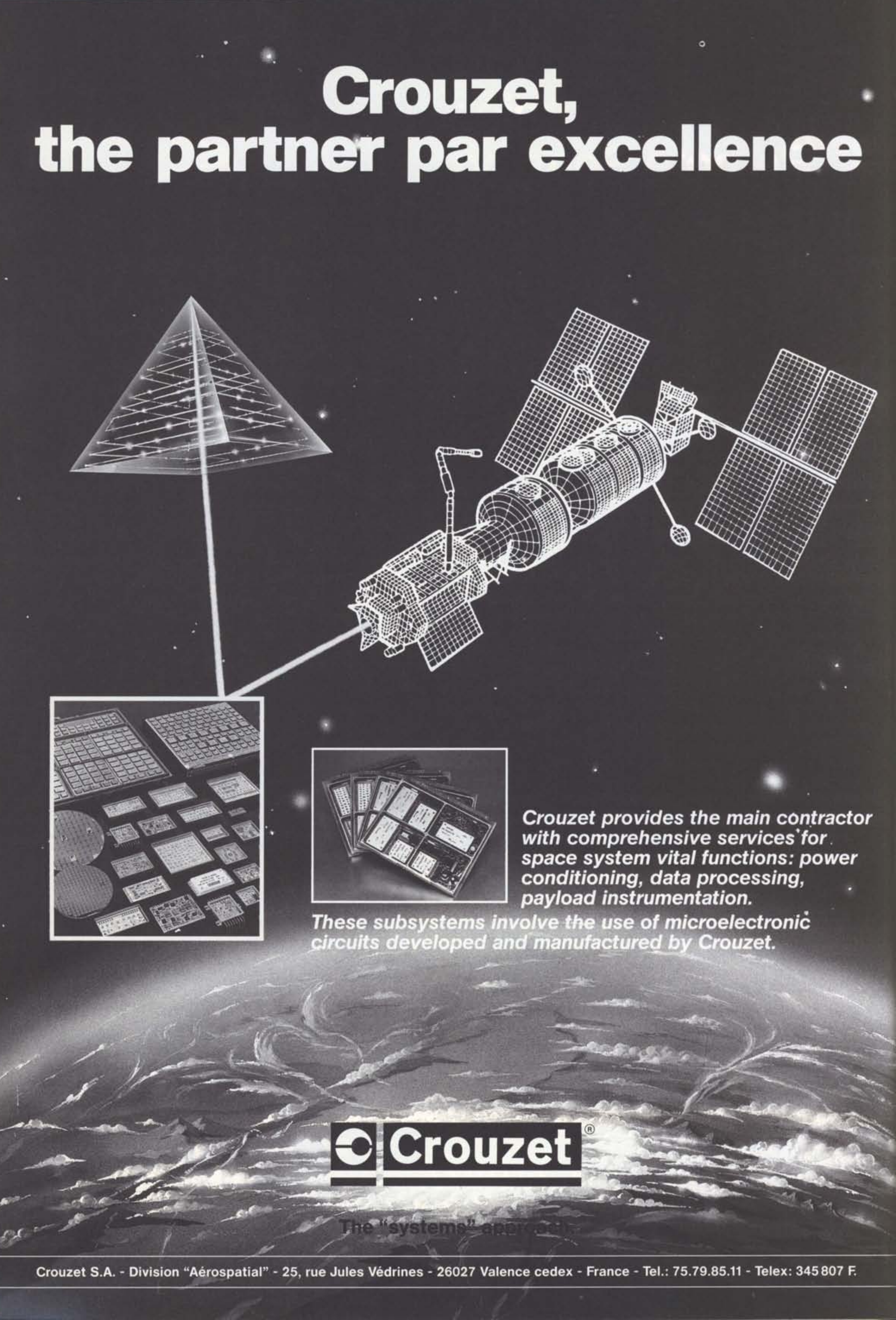
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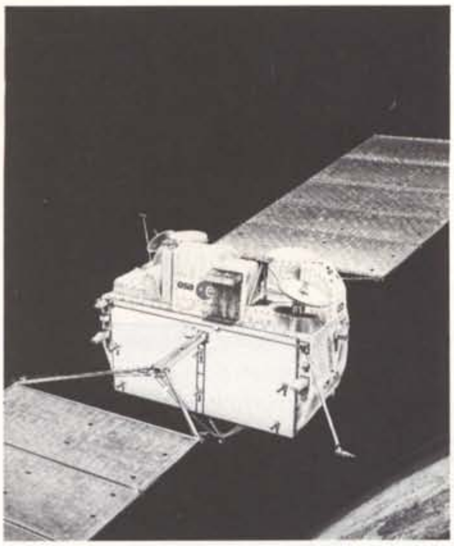


The Eureca Design Concept

W. Nellessen, Columbus System and Projects Department, ESA Space Station and Platforms Directorate, ESTEC, Noordwijk, The Netherlands

As a first step in its Spacelab Follow-on Programme towards Space Station design and utilisation, at the end of 1984 ESA began development of the European Retrievable Carrier (Eureca). This carrier project will provide the Agency with valuable early experience in the development, utilisation, and operation of unmanned, automated platforms in low Earth orbits.

Scheduled for launch in March 1988, Eureca will be delivered by the Space Shuttle to an orbital altitude of 296 km, will ascend to an operational altitude of about 500 km, and will return to the lower orbit after six to nine months to be retrieved by the Shuttle. A major objective of the first Eureca mission is to perform material-science experiments, but to demonstrate its flexibility the first payload also includes experiments in the fields of solar and astrophysics, as well as technical demonstrations of a European Radio Ionisation Thruster Assembly (RITA)* and direct Inter-Orbit Communication with the Agency's European Space Operations Centre (ESOC) in Damstadt, Germany, via the Olympus satellite.**

* See ESA Bulletin No. 45, pp. 24—33.

** See pp. 29—31, this issue.

Introduction

Well ahead of the first flight of Spacelab in November/December 1983, ESA identified the need for a free-flying carrier system that would allow retrieval by the Shuttle after flight durations beyond the 7 to 10 days envisaged for Spacelab. Early studies of this system, now known as Eureca, were very much influenced by the thought that such a new system should be more economical to build and operate than the 'classical' nonrecoverable satellite system in Low Earth Orbit (LEO). It was also realised that its size should meet European experimenters' needs for the 1988—1993 time frame, and that it should enable Europe to accumulate the technological and operational experience needed to develop and operate larger, autonomous European platform systems in LEO for both commercial and research applications.

The Eureca system is at present in its design and development phase, the first mission being planned for 1988. An attempt will be made here to highlight the principal design and cost considerations for the system's sizing, development, operation and utilisation.

The overall Eureca concept

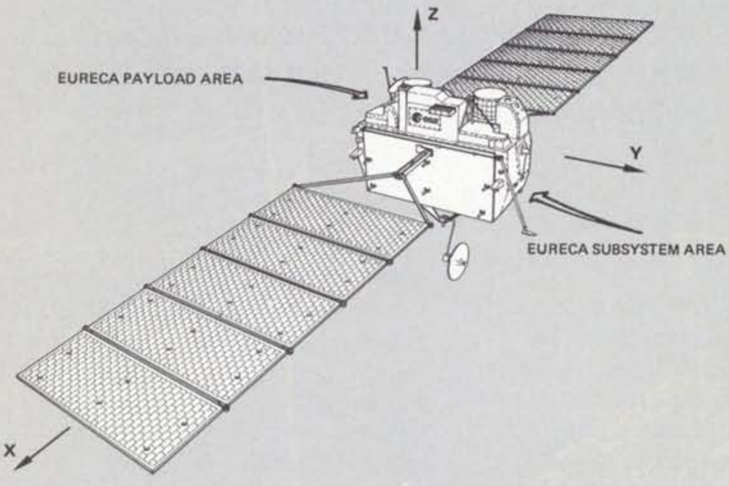
Eureca, shown in flight configuration in Figure 1, is a re-usable platform to be launched and retrieved by the Space Shuttle (STS). After deployment by the Shuttle, it will perform its missions in a free-flying mode for initial durations of six to nine months. After retrieval by the Shuttle and return to its integration centre, Eureca will be refurbished and re-equipped for its next mission. A typical Eureca mission sequence is shown in Figure 2.

The platform's lifetime is envisaged as enabling it to perform five missions in ten years. This resulted from the fact that available financial resources should allow one mission every two years, and that experimenters need sufficient time between reflights to tune their experimental facilities.

Eureca has been devised to be as 'user friendly' as possible. Like Spacelab, it accommodates the users via standardised structural attachments as well as standardised power and data interfaces. Unlike Spacelab, however, the Data Handling Subsystem (DHS) is 'decentralised'. This allows the various users of the DHS to pre-process their data on their own subsystem or experiment facilities before interfacing with the main Eureca DHS. This approach provides greater flexibility to the users, and since less effort is required for integrating the individual user into the system, integration costs and times are reduced. In addition, the DHS interfaces are designed to commercial standards (IEEE 488), so that the users can employ commercially available checkout equipment. This also allows the users to re-use their equipment software at the next higher integration level without the need for re-programming. These measures will help the users to reduce their costs while at the same time providing greater flexibility during the payload-integration process.

Figure 1 — Eureca system capabilities and resources

Figure 2 — Eureca mission scenario



MASS : TOTAL : 4000 kg
AVAILABLE TO PAYLOAD : 1000 kg

VOLUME : AVAILABLE TO PAYLOAD : 8,5 m^3

POWER : AVAILABLE TO PAYLOAD : 1000 W
PEAK. : 1500 W
SOLAR ARRAY OUTPUT : 5000 W

THERMAL CONTROL : LIQUID FREON LOOP (1000 W) AND MULTI LAYER INSULATION

DATA
MANAGEMENT : HIGH SPEED : 256 kbps
LOW SPEED : 2 kbps DOWN LINK (S-BAND)
MEMORY CAPACITY : 128 Mbits
AVERAGE P/L : 1,5 kbps

ATTITUDE POINTING ACCURACY : $\pm 1^{o}$ (3 SIGMA)

MICROGRAVITY : 10^{-5} g < 1 Hz
10^{-3} g > 100 Hz

ORBIT : 525 km ; 28.5^{o}

MISSION DURATION : 6 MONTHS OPERATIONAL + 3 MONTHS DORMANT
DESIGN LIFE : 5 MISSIONS OR 10 YEARS

TURN AROUND TIME :
BASELINE : <1.5 YEARS BETWEEN RETRIEVAL AND NEXT LAUNCH. REDUCTION DOWN TO LESS THAN ONE YEAR UNDER STUDY

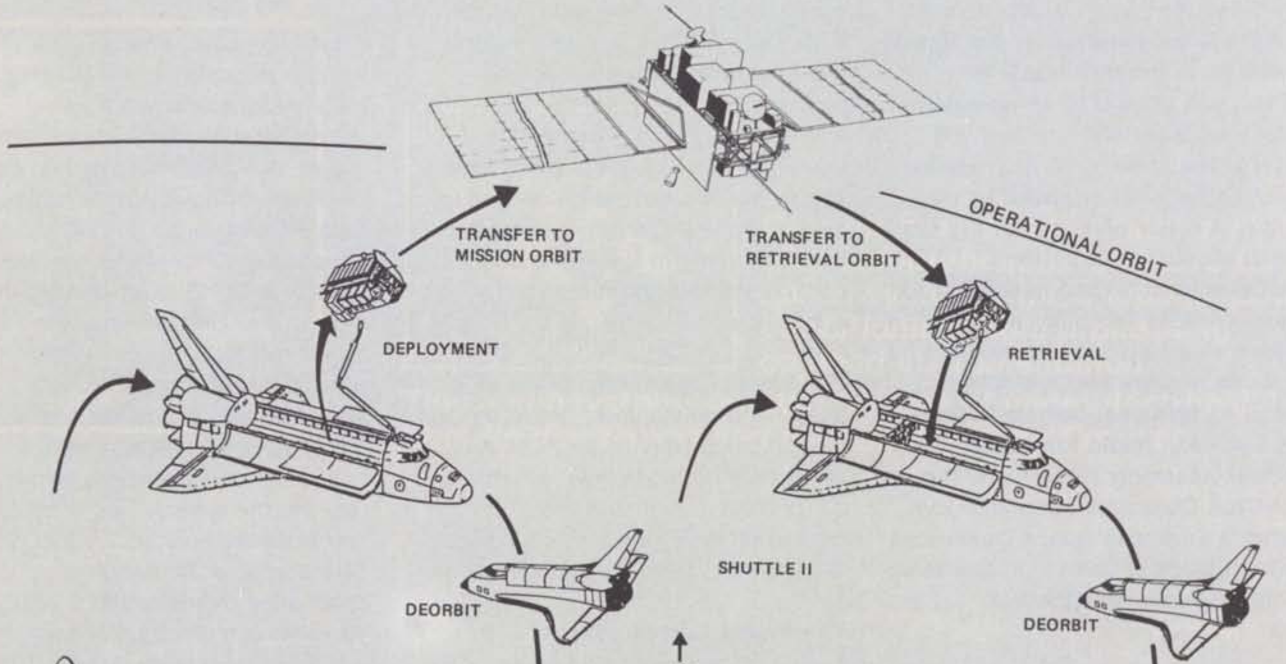


Figure 3 — Eureca payload module layout

For most missions Eureca is intended to be shipped as a fully integrated system, requiring only the minimum of Shuttle-interface and safety checks at the launch site — the so-called 'ship-and-shoot' concept. In flight, the Shuttle will control only the platform deployment and retrieval operations. Free-flight control will be conducted from ESOC via a single ground station. Flight control during times of noncontact with the ground station will be provided by the onboard data-handling subsystem, which is designed for autonomous spacecraft operation for periods of up to 48 h.

An Inter-Orbit Communication (IOC) data-relay package will be flown on an experimental basis on Eureca's first flight. If successful, on subsequent flights it will be used to provide operational data-relay services via a geostationary satellite. This will significantly enhance real-time data coverage, with transmission rates of up to 2 Mbit/s.

The overall configuration of the Eureca platform has been determined primarily by four factors:

(a) maximisation of available payload volume
(b) optimisation of the length-to-mass ratio, to minimise the Shuttle-launch charges
(c) direct attachment in the Shuttle cargo bay via a three-point attachment system
(d) mounting flexibility throughout the length of the Shuttle's cargo bay.

NASA's pricing policy favours relatively short payloads that can be inserted easily anywhere in the cargo bay. This means that, to stay within the load-carrying capability throughout the Shuttle bay, Eureca should not weigh more than about 4000 kg. This, in turn, limits its length to about 2.35 m. As shown in Figure 3, Eureca fulfils these conditions in an ideal manner, whilst still retaining 50 % of its volume available for payload use.

One further point worth mentioning is that for its first mission Eureca has to serve particularly the material- and life-science communities, and residual carrier accelerations during the operating period must therefore not exceed 10^{-5} g. This constraint dictated a cold-gas-assisted

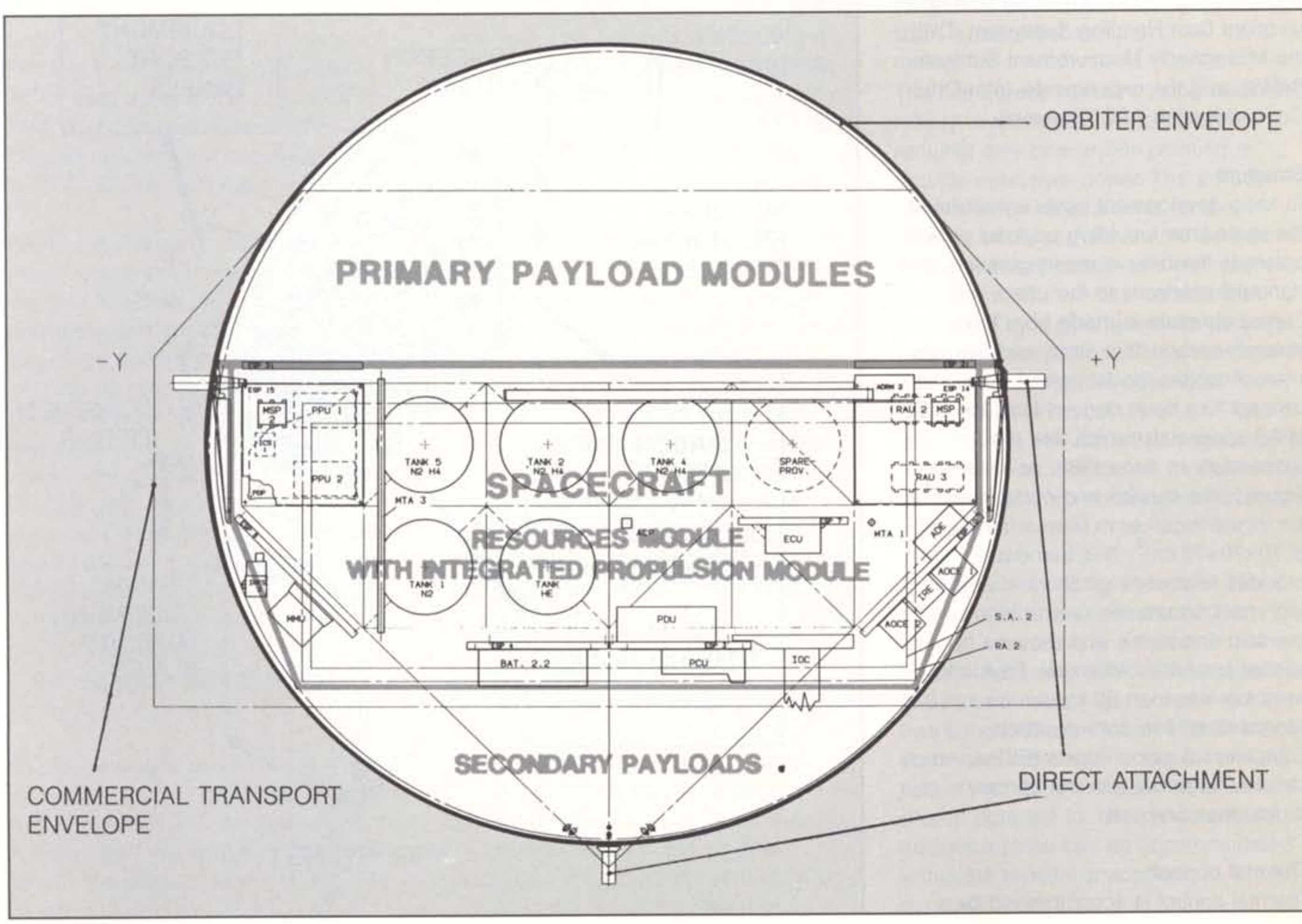
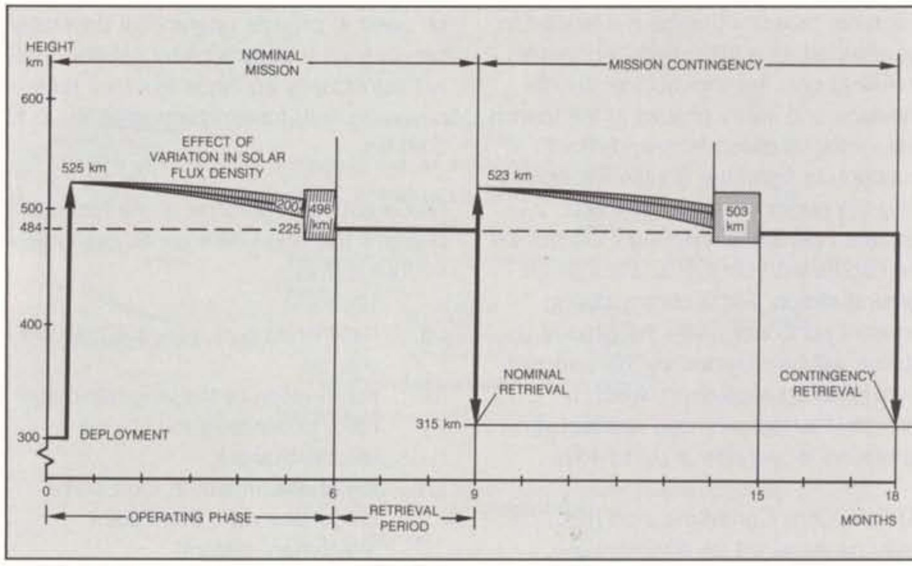


Figure 4 — Eureca baseline mission profile, including contingency

Figure 5 — Eureca primary structure

magnetic attitude-control system with torque levels well below 0.3 Nm. It also makes it necessary to raise Eureca to an orbital altitude of about 500 km to reduce residual decelerations resulting from aerodynamic drag. The higher orbit also helps to minimise consumables' use for altitude maintenance. A typical mission profile for a six-month Eureca mission is shown in Figure 4.

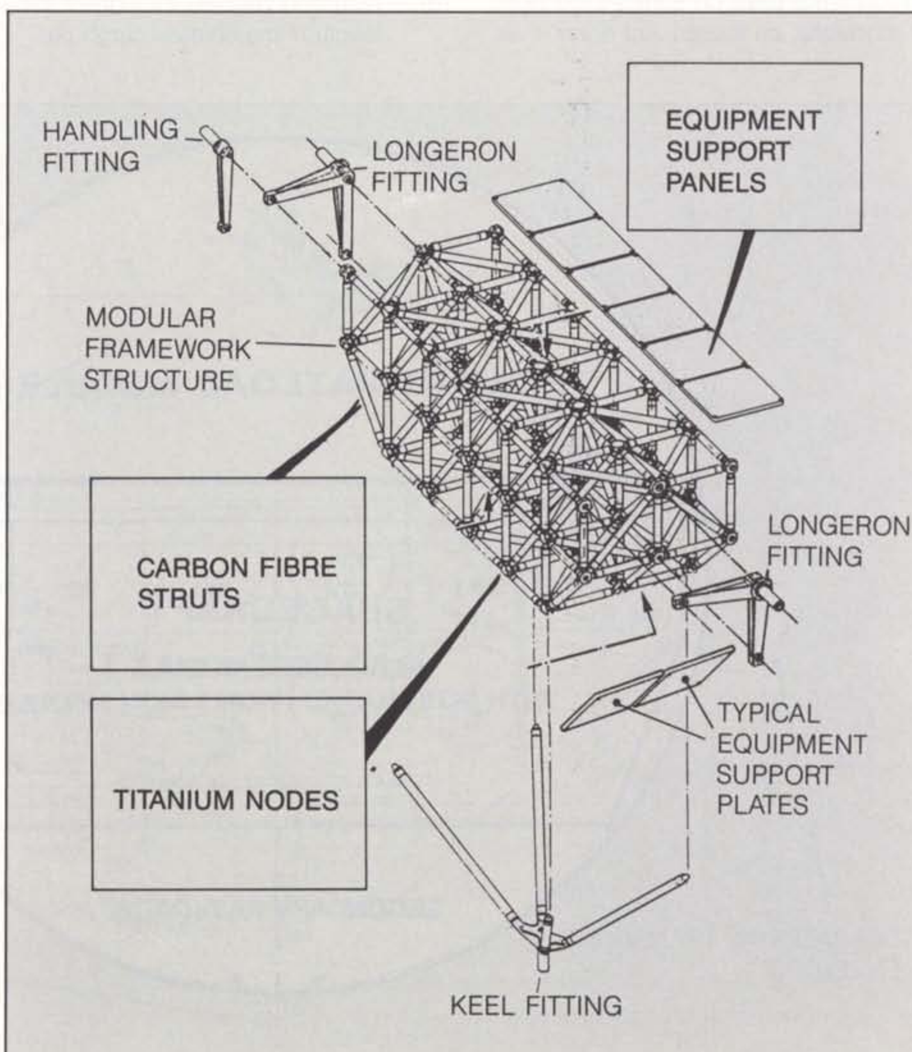


The platform concept

All of Eureca's subsystems are housed within the framework of the structure. They include the Thermal Control Subsystem (TCS), the Electrical Power Subsystem (EPS) including the Solar Array (SA), the Attitude and Orbit Control Subsystem (AOCS) including its Orbital Transfer Assembly (OTA) and Reaction Control Assembly (RCA), the Telemetry and Telecommand (TTC) subsystem, the on-board Data Handling Subsystem (DHS), the Microgravity Measurement Subsystem (MMS), and the experimental Inter-Orbit Communication (IOC) assembly.

Structure

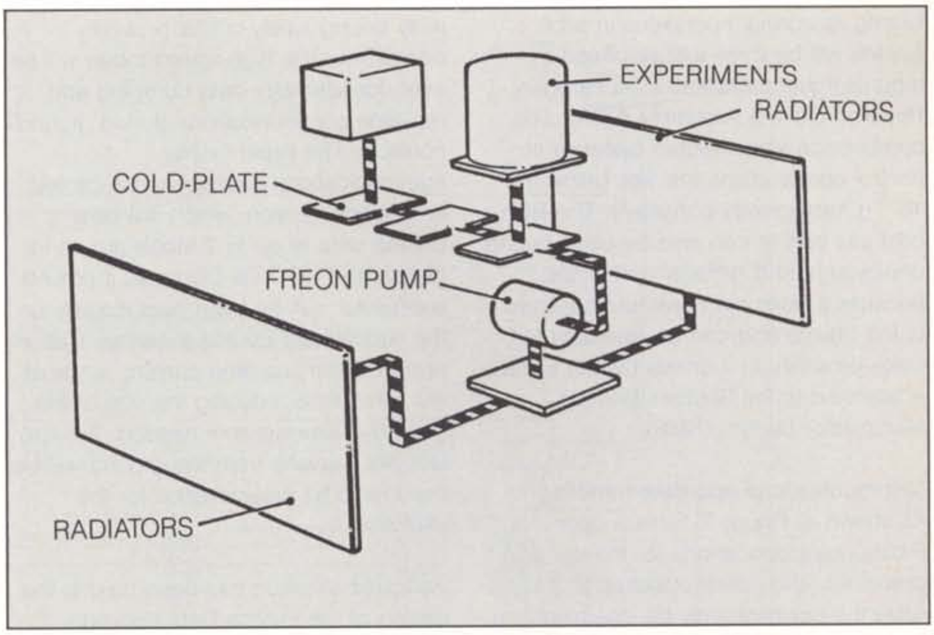
To keep development costs low whilst at the same time providing payload growth potential, flexibility in reconfiguration, and standard interfaces to the users, the Eureca structure is made from high-strength carbon-fibre struts and titanium interconnectors (nodal points). This concept has been derived from the MBB SPAS spacecraft, which flew very successfully in June 1983. As shown in Figure 5, the trusses and nodal points are joined together to form a framework of 70×70×70 cm^3. This framework provides relatively high thermal and alignment accuracies, is simple to maintain and repair, and requires no special jigs for its assembly. Payloads weighing less than 30 kg can be integrated off line onto standard Equipment Support Panels (ESPs), which can be integrated with the primary structure as one unit.



Thermal control

Thermal control is accomplished by a

Figure 6 — Concept of the active thermal control loop



combination of active and passive heat transfer and radiation. Active heat transfer for payload facilities with heat dissipation needs of up to 1 kW, such as the material-science furnaces, is provided by a Spacelab-type liquid-freon cooling loop which dissipates heat to space through two radiator panels. The passive system employs well-proven multilayer insulation blankets in combination with resistance heaters. The entire Eureca system is such that, if the active thermal loop should fail, all essential subsystems will remain functional and the spacecraft can be returned safely to Earth (Fig. 6).

Electrical power
The electrical power subsystem generates, stores, conditions and distributes power to all subsystems and payloads. Two deployable and retractable solar arrays with a combined raw power output of about 5000 W, in conjunction with four nickel-cadmium batteries of 40 Ah each, provide the payload with 1000 W of continuous power (24—28 V DC), with peak power capabilities of up to 1500 W for several minutes.

Safety considerations dictate that the power system not be operational during the Shuttle launch and retrieval operations and that critical operations like propulsion operations near the Shuttle be inhibited by proper switching protections. On the other hand, essential functions to guarantee Eureca's survival during its mission must remain powered. Consequently, the fusing concept for the platform is designed such that equipment failures cannot propagate upstream and therefore do not jeopardise the power subsystem. Electromagnetic interference aboard the platform is minimised by employing single-point grounding techniques.

To provide heater power for the thermal conditioning of the hydrazine subsystem, and to maintain very sensitive experiment samples within temperature limits during the Shuttle-attached flight periods, the Shuttle provides 200 W of electrical power to Eureca via a re-connectable umbilical. This power is distributed via a completely separate distribution system from the main Eureca power subsystem, to avoid inadvertent activation of the latter while the platform is in the Shuttle's cargo bay.

Attitude and orbit control
Attitude determination, spacecraft orientation and stabilisation during all flight operations, as well as orbit-control manoeuvres, are performed by a Modular Attitude Control Subsystem (MACS). This subsystem has its own computer and data bus and has been designed for a maximum of autonomy, so that mission requirements will be fulfilled even in the case of severe on-board failures, such as prolonged outage of the on-board data-handling subsystem. In an emergency, the MACS subsystem is capable of switching into a Sun-pointing mode to maintain sufficient power until the ground station can regain control of the spacecraft. The MACS system can be adapted to different mission modes simply by changing the on-board software, which is structured into several independent modules. Additional attitude-control sensors and actuators can be connected directly to the MACS bus without modifying the basic system architecture.

The first Eureca mission, being dedicated mainly to microgravity experiments, requires only coarse Sun-pointing to provide maximum power. The attitude-determination requirements for this mission mode could therefore be satisfied with a relatively simple and cost-effective Earth-sensor/Sun-sensor combination supported by a gyro reference package for eclipse operations. This system makes it possible to keep the spacecraft Sun-pointed with an accuracy of $\pm 1°$ and to determine its attitude with an accuracy of $\pm 0.25°$, which is sufficient for controlling the necessary orbital-change and Shuttle-rendezvous manoeuvres.

To reach its operating altitude of about 500 km and to return to the 300 km retrieval orbit, Eureca uses an Orbital Transfer Assembly (OTA) with a capacity of 620 kg of helium-gas-pressurised hydrazine (sufficient for an in-orbit stay of up to nine months) and two redundant sets of four 20 N thrusters. To provide growth potential for future missons, two additional tanks can be accommodated within the present spacecraft structure.

During its normal operations in orbit, Eureca will be three-axis-stabilised by magnetorquers, assisted by a nitrogen Reaction Control Assembly (RCA). This combination was selected because its control accelerations are well below the 10^{-5} g microgravity constraint. The RCA cold-gas system can also be used during deployment and retrieval operations, because it does not constitute a hazard to the Shuttle and can be operated in close proximity to it or even when Eureca is attached to the Shuttle's Remote Manipulator System (RMS).

Communications and data handling
As shown in Figure 7, Eureca uses S-band communications for the up- and downlinks. The uplink operates at 2 kbit/s, while the downlink may be operated in a low-speed (2 kbit/s) or a high-speed (256 kbit/s) mode. Uplink and low-speed downlink capabilities are compatible with the Shuttle, which will be used for data relay during safety-critical proximity operations. The high-speed mode will be used for telemetry data dumping and real-time communications during ground contacts. The experimental communications package to be carried on the first mission, which will relay Eureca data at up to 2 Mbit/s (Ka-band) directly to ESOC via Olympus, if proved successful, will be used operationally on the subsequent Eureca missions. This will ensure better real-time contact, whilst at the same time reducing the size of the ground-station network needed. Two-way Doppler tracking from the ground will be used for orbit determination for the platform.

Particular attention has been paid to the design of the Eureca Data-Handling Subsystem (DHS). Starting from the premise that future space platforms in LEO will be required to control more complex operations than previous satellites, and taking into account that state-of-the-art technology should be used for retrievable and ground-maintainable spacecraft, the platform's DHS has a hierarchically organised architecture, with decentralised processing and control functions.

Figure 8 shows the organisation of the DHS and its principal interfaces. Potential growth capabilities are also indicated.

The Monitoring and Reconfiguration Unit (MRU) acts as communication front-end processor, provides operator override capabilities, initialises the remainder of the DHS, and supervises the PPU (Powerful Processing Unit), which hosts the system-management function, including the software that controls autonomous spacecraft operations.

The Magnetic Bubble Memory (MBM) provides a non-volatile storage capability

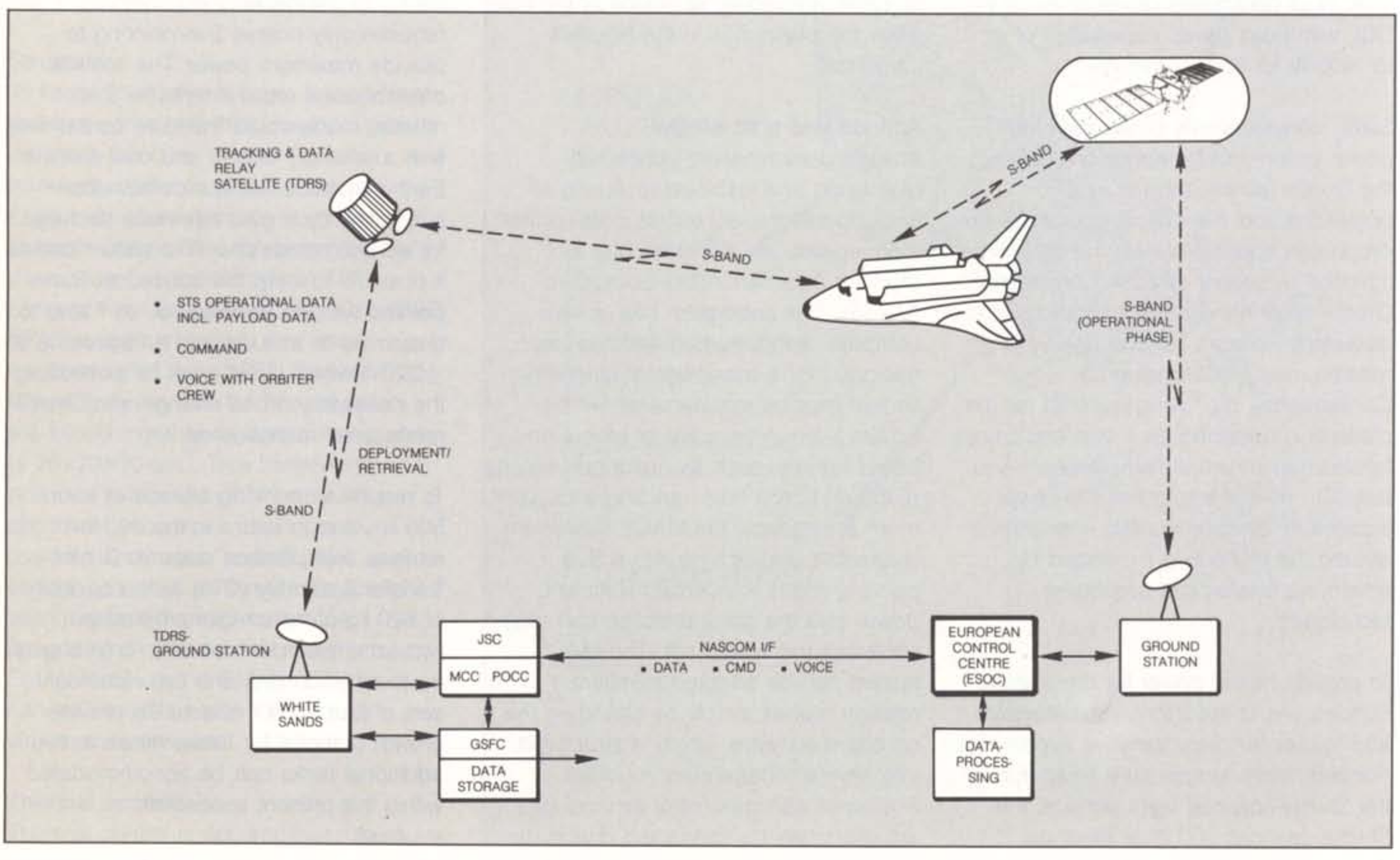
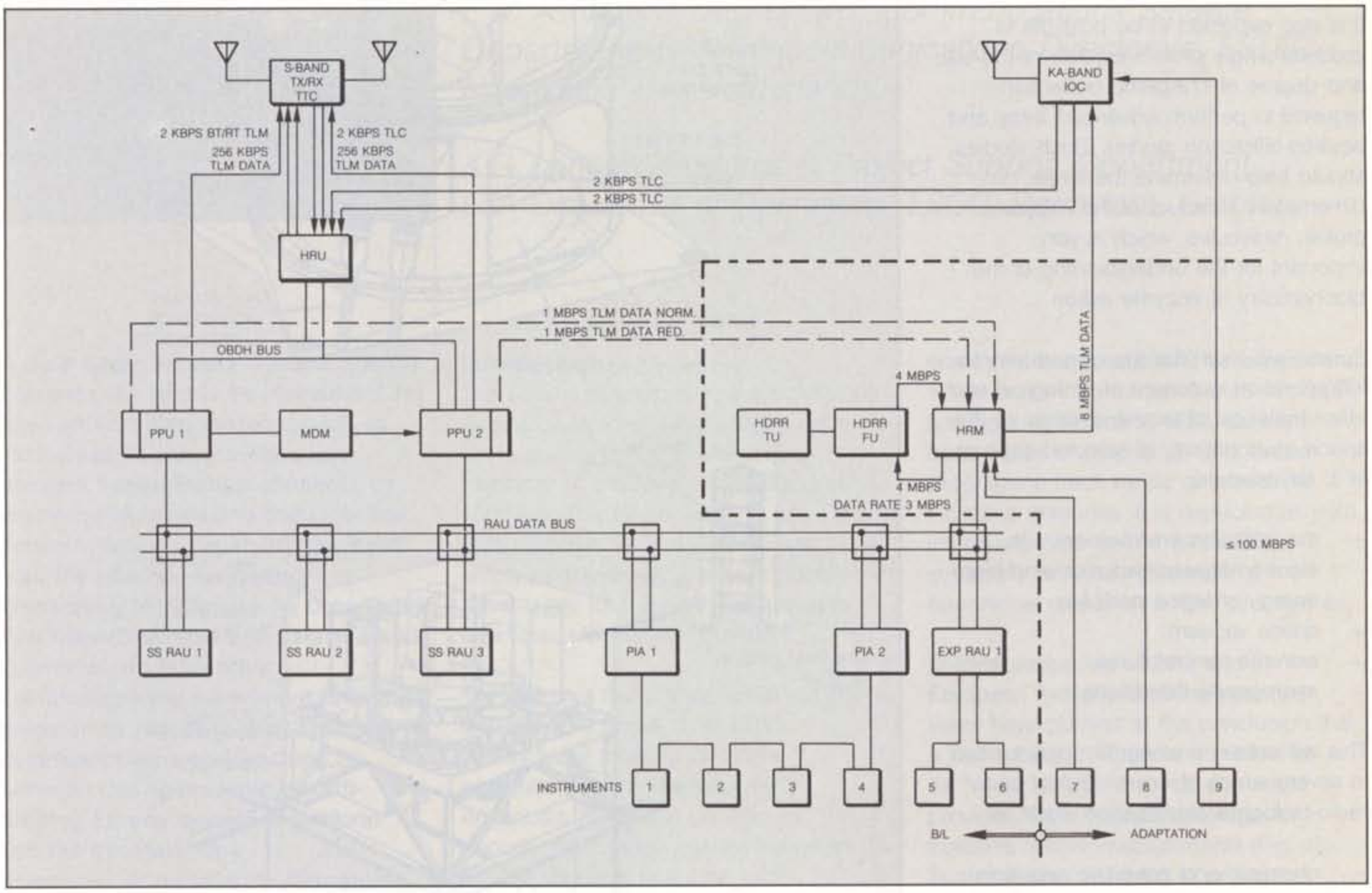


Figure 7 — Eureca communications scenario

Figure 8 — Organisation of Eureca's Data-Handling Subsystem (DHS) and the principal interfaces



for program, telecommand, and telemetry data.

The Remote Acquisition Unit (RAU) bus developed for Spacelab has been selected as the Eureca system bus. As peripherals, RAUs and Payload Interface Adapters (PIAs) also developed for Spacelab will be employed to provide standard interfaces.

The High-Rate Multiplexer (HRM) and High-Digital-Rate Recorders (HDRRs) indicated as growth capabilities can handle data rates of up to 50 and 32 Mbit/s, respectively.

The first mission

The first Eureca mission will be dedicated mainly to research projects that require a controlled microgravity environment. These will occupy about three quarters of the available payload and the remainder will be made up of scientific and technological experiments.

An important feature of the space environment offered by Eureca for investigations involving fluids is the near absence of gravitational accelerations. This has a number of specific advantages, including:
- greatly reduced gravity-driven convection
- negligible sedimentation and buoyancy
- negligible hydrostatic pressure
- possibility of containerless positioning, handling and 'shaping' of liquids.

Even for systems with large thermal and concentration gradients, stable conditions can be achieved within the fluids. This facilitates the study of solidification and processing under largely diffusion-controlled heat- and mass-transfer conditions.

At present, ground-based crystal-growth processes have to be optimised empirically, as existing theories mainly relate to situations that cannot be achieved experimentally. Microgravity experiments can contribute significantly to the bridging of this gap between theory and experiment, thereby facilitating both process optimisation and progress in theoretical understanding.

Such topics as thermodynamic properties at the liquid/vapour or liquid/liquid critical points, molten state, homogeneous nucleation, and glass fining can be investigated. Physical and physico-chemical parameters such as diffusion and segregation coefficients can be determined much more precisely in a microgravity environment.

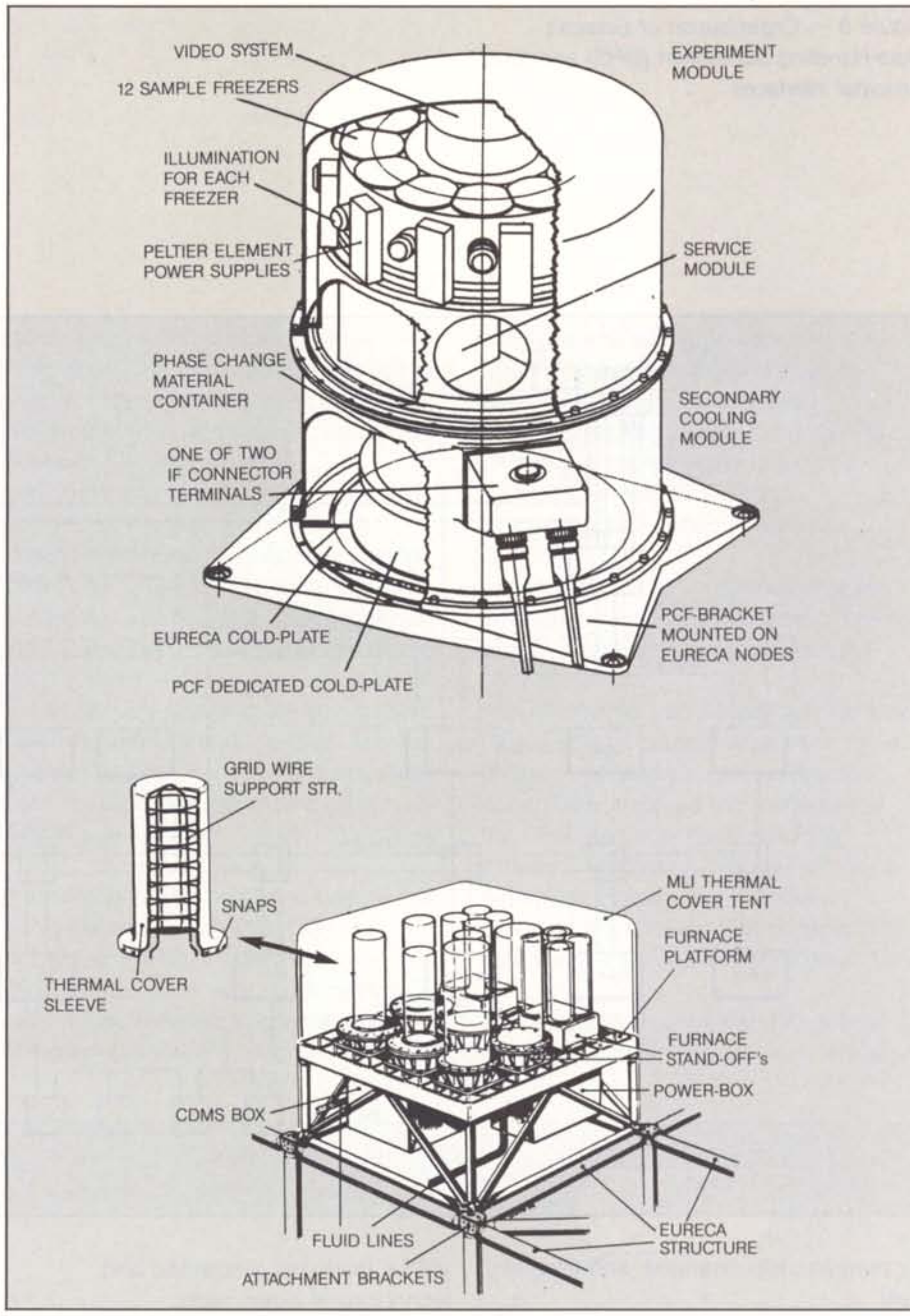


Figure 9 — Eureca multi-user facilities for microgravity research

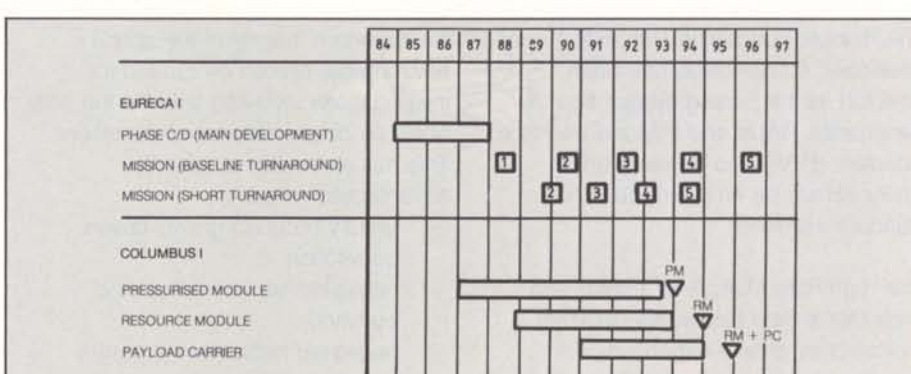


Figure 10 — Tentative flight schedule for Eureca vis-a-vis the Columbus platform

It is also expected to be possible to produce single protein crystals of the size and degree of crystalline perfection required to perform advanced X-ray and neutron-diffraction studies. Such studies should help determine the three-dimensional structure of the enzyme protein molecules, which is very important for the understanding of the biochemistry of enzyme action.

Eureca will also offer the opportunity for long-duration exposure of biological and other materials of terrestrial origin to the space environment, or selected aspects of it; for example:

- the radiation environment with electromagnetic radiation and high-energy charged particles
- space vacuum
- extreme temperatures
- microgravity conditions.

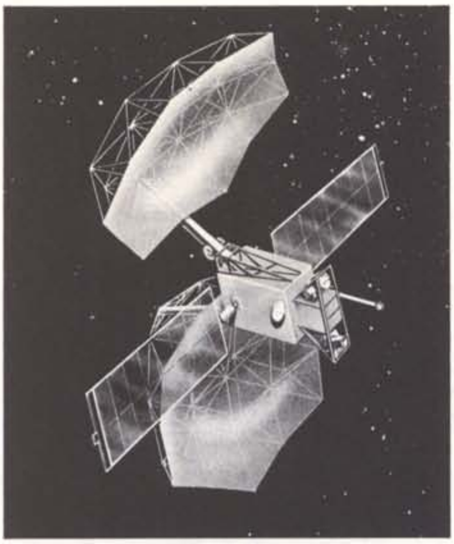
This will enhance research opportunities in several areas of exo-biological and radio-biological significance, such as:

- chemical and pre-biotic evolution under exposure to solar radiation
- formation and stability of organic molecules in cosmic matter
- biological mechanisms of resistance to environmental extremes
- interplanetary transfer of life
- effects of cosmic-ray particles on biological matter
- consequences of the combined actions of cosmic radiation and microgravity.

Figure 9 shows two of the major microgravity research facilities planned for the first missions which are currently under development as part of the ESA-funded Eureca Programme.

Future missions

Work is currently in progress to assess the platform's substantial adaptability to other types of missions. First studies demonstrating the flexibility of the Eureca concept have prompted the astronomy and solar-physics science communities to define a more refined model payload for detailed accommodation studies on Eureca. In addition, two more missions are planned in the field of microgravity research. Figure 10 shows the current tentative flight schedule for the first Eureca mission based on these early accommodation studies.



The ESA Data-Relay Satellite Programme

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A Data-Relay Satellite System (DRSS) improves the return on investment for low-earth-orbiting systems such as earth-observation satellites and manned Space-Station elements by dramatically increasing the real-time communications capability per orbit with the ground. An Agency Preparatory Programme on Data-Relay Satellites (DRS) has been started and, in parallel, an inter-orbit communications experiment is being prepared to test data-relay-type communications and tracking between the Agency's low-earth-orbiting Eureca re-usable platform and the geostationary communications satellite Olympus. The development schedule being assumed for DRS foresees commissioning of the operational system in the mid-1990s.

Introduction

The DRS is positioned in a synchronous geostationary orbit which allows up to 70 % coverage of the total orbital trajectory of a satellite at an altitude of 1000 km. The NASA Tracking and Data Relay Satellite System (TDRSS) has amply demonstrated the operational advantages for low-earth-orbit satellite and Space-Shuttle management.

The use of a Data-Relay Satellite (DRS) will allow the efficiency of ESA's conventional tracking and data-acquisition network to be greatly enhanced. It will also provide an important insurance against bulk data-storage medium failure on earth-observation satellites, as well as enabling very quick data processing where quasi-temporal effects are being observed and need reacting to.

An internal DRS effort has been started by ESA with the objective of preparing a systems performance specification and the requisite Invitation-to-Tender documentation for major industrial study contracts planned to be sent out to industry in 1986, as part of the Data-Relay Satellite Preparatory Programme (DRPP). Use is being made of data from a number of smaller external studies performed in industry, as well as ESA-generated mission requirements obtained from discussions with potential users.

In parallel, an inter-orbit communications experiment is being prepared to test data-relay communications and tracking between ESA's low-earth-orbiting Eureca re-usable platform and its Olympus communications satellite. This experiment, which is planned to commence with the first flight of Eureca in 1988, uses the frequencies of 18 and 28 GHz and a programme track mode of one of the Olympus antennas. It is expected to yield interesting data for the future DRS, especially with the refinement of operational search-and-track procedures.

Studies performed in ESA and in European Industry over the past two years have pointed to the conclusion that a two-satellite DRS system, orbited at 44 °W and 61 °E, respectively, would provide very adequate coverage for Europe's mission requirements (Fig. 1). Such satellites will have to provide reliable service over a ten-year period, including the eclipse periods.

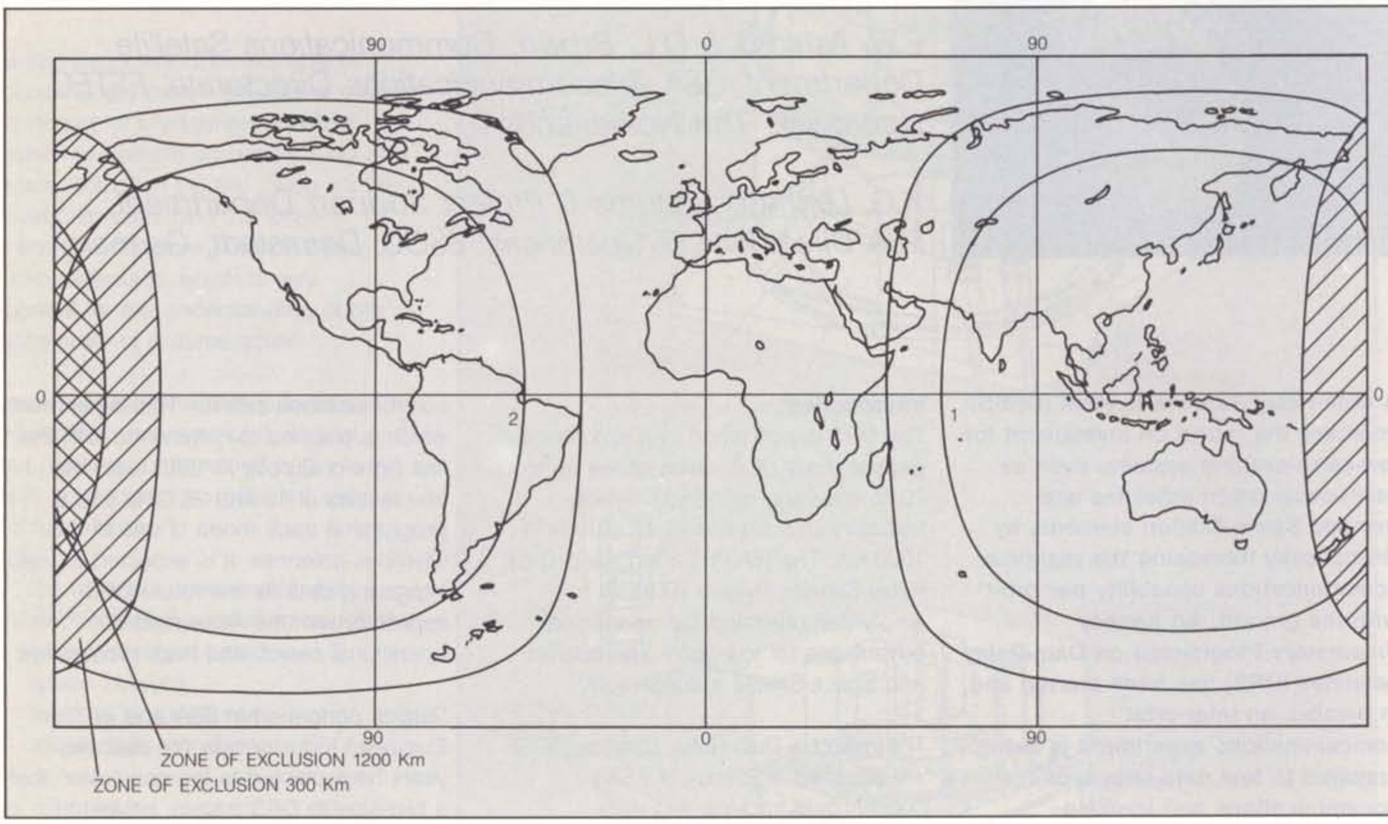
The development schedule being assumed for DRS at present foresees a first launch for the operational system in the third quarter of 1994, leading to the beginning of operations, per se, in the first half of 1995. This assumption will however, be re-assessed and possibly modified on the basis of studies within the DRPP, in concert with the development schedule for potential user programmes.

Decisions will be taken on a specific configuration for the DRS space segment after the planned industrial studies, on the basis of analyses and trade-off studies made during the DRPP.

Potential customers for a DRSS system

Generally speaking, all activities going on

Figure 1 — Schematic of typical Data-Relay Satellite (DRS) coverages for satellites at 44 °W and 61 °E



in space which need some sort of connection with the ground, either for data acquisition, commanding or tracking, can benefit from a DRS. Missions that produce very large amounts of data and need very long coverage arcs benefit particularly.

Within the programmes foreseen in Europe for the next 15 years, prime candidates as DRS users include:

— the European elements of the Columbus programme participating in the NASA Space-Station project, including polar-platform and infrastructure capabilities such as rendezvous and docking (several hundred Mbit/s)

— the remote-sensing programmes, in particular the advanced land-observation mission, with very high data rates (several hundred Mbit/s)

— Ariane-5 and Hermes operations, including data acquisition and tracking.

Mission-specific benefits

There are three principal reasons why a mission may wish to utilise the DRS's services:

— acceptable time delay between data acquisition and operational use is very short

— data quantity is too high for on-board storage

— coverage gaps would exist with conventional ground-station networks.

Operational benefits

Since a spacecraft can, via the relay, be in very frequent or near-continuous contact with the ground, on-board logic can be much simpler and hence more reliable. The spacecraft needs less autonomy or capability to survive in the event of extended periods of no contact with the Control Centre, and it also needs a less sophisticated on-board processor and memory. Scheduling can be done more safely and in a more flexible manner from the ground, where more resources and expertise exist. Also, on-board mass data storage may not be required (except for the case of a single DRS and the need to acquire low-speed oceanic data from the other side of the globe).

The operation of remote-sensing missions, including scheduling of the requisite observation passes, orbit adjustment, attitude and housekeeping data monitoring and control can be made considerably simpler and safer, since much longer and more frequent periods of contact with the spacecraft are possible. Consequently, even near-real-time changes in the observation schedule can be arranged, e.g. in case of an exceptional need for observation of a rapidly varying phenomenon. Due to the more frequent monitoring possibilities, spacecraft status and health can be better supervised and unacceptable trends in behaviour can be more quickly resolved. Remedial operations can be started faster, resulting in an overall increase in the useful mission time.

Due to the fact that housekeeping and payload data can be transmitted to one central place, consistent data quality and optimum sensor settings and calibration can be ensured. This applies equally to the raw, preprocessed, and final data, because identical procedures can be applied.

The problems of data distribution to the final users can also be eased, and the long delays often inherent in data transport from remote overseas acquisition stations can be avoided.

Economic benefits
Due to the extended coverage provided by a DRS system, it will not be necessary to expand, operate and maintain a large network of ground stations. If one aimed to cover the globe completely, including land masses and oceans, for a data-gathering satellite at an altitude of about 800 km one would need a theoretical network of 41 stations with partially overlapping coverage, or a theoretical network of 22 stations (e.g. 8 stations at the equator, 2 x 6 at approximately 45 ° latitude and 2 stations at the polar caps) to cover 84 % of the Earth's surface. Clearly, the cost of operating and maintaining such a network is very high, the actual figures varying in the range of several million dollars per year per station, depending on the type of hardware implemented, the manpower involved, the degree of processing foreseen and the geographical location.

Since in the conventional approach data are recorded at a particular ground station, transportation costs (and delays) to the central archive and distribution facility are also involved. Obviously, these costs can also be reduced with a DRS system, but probably more important is the availability of global data within a very short time at a central location with adequate infrastructure and efficient communication channels.

Since at least preprocessing and the first stages of further processing could be done in a central facility or at a smaller number of powerful installations, considerable overall savings could also accrue due to more efficient use of hardware, software and human resources.

To compare the cost of the European DRS with other available services, such as the TDRS system, one must also consider the high charges that would accrue for use of a single access service. For example, for continuous support of a high-data-rate mission such as Columbus, one would be faced with a charge of 128 $ per minute for delivery of data to the White Sands Facility in the USA. Including data transmission to Europe in near-real-time, a minimum yearly cost of ca. 65 M$ for TDRS use plus 10 M$ for data transmission would result.

The objectives of the DRS programme

The basic objective of the overall DRS programme is to provide a cost-effective infrastructure, in space and on the ground, to support future European space programmes, which will provide users with the following near-continuous services:

— transfer of data to and from low-earth-orbiting spacecraft and launchers for users and ground controllers

— communications between low-earth-orbiting spacecraft and their ground control stations

— provision of telemetry and telecommand links between ground controllers and spacecraft in orbit

— the ability to carry out ranging operations for orbit and position determination for spacecraft in orbit and, possibly, launchers during ascent.

The particular objectives, within the context of these overall objectives, of the DRPP are to:

— establish and define in detail, the configuration of the necessary DRS space and ground segments to provide cost-effective data relay, information transmission, telemetry, telecommand and ranging services to foreseen European space programmes, including, in particular, Columbus, Ariane-5, Hermes and advanced earth-observation satellites

— investigate the feasibility, and determine the costs versus benefits, of incorporating the European DRS system into a possible global data-relay satellite system, in cooperation with other national bodies

— study, during the course of the programme, technology elements that require development activities, and initiate these to ensure their timely availability in support of the overall programme

— obtain, by the end of the programme, a detailed technical baseline for the space and ground segments that will need to be developed, implemented and operated in subsequent phases, along with detailed cost and schedule assessments for these.

Contents of the DRPP
In order to satisfy the objectives of the DRPP as set out above, the programme will contain three basic elements:

— system definition studies
— supporting studies on selected topics
— initiation of technology developments in key areas.

System definition studies
The system definition studies will encompass those activities necessary to establish the preferred system configuration, to detailed subsystem level, for the future operational European Data Relay Satellite System, and to obtain reliable estimates of the cost and schedule associated with the development and implementation of such a system.

The system-definition studies will begin by addressing mission, space-segment, and ground-segment aspects of a DRS system, and determining the inter-relationships between them. Detailed trade-offs can then be performed in order to arrive at a preferred overall system approach that best meets foreseen needs in the most cost-effective manner. Mission aspects covered will include refinements of previous studies in order to arrive at firm and well-substantiated estimates of the probable user requirements, including:
— data-rate requirements for various users (in both the forward and return directions)
— the number of users as a function of time
— the required access times/durations of users (and any particular locations in orbit at which specific users might require contact)
— the types of user orbits most likely to be serviced
— user availability requirements
— system security requirements.

Another major mission-level topic that will be addressed is a determination of the cost/benefit ratio of developing a system that is partially or completely compatible with other data-relay satellites, notably the American TDRS, and that being planned by Japan.

Space-segment configuration studies will be carried out which will provide estimates of the size, mass, power and costs of both geostationary-orbit and user-terminal payloads in order to provide selected capacities at certain frequencies, resulting from the above mission investigations.

Ground-segment aspects must also be addressed in detail as part of the overall system-definition process. A major cost of any DRS system is associated with the hardware and software needed in the ground segment to control the DRS system operations, to schedule the usage of the system by many users, and to receive, process, disseminate, and archive the data received through the DRS satellites. These must be assessed and compared, in particular for both centralised and de-centralised data-distribution approaches.

Supporting studies
During the course of the system-definition studies, a number of specialised topics will undoubtedly be identified which will need to be pursued in greater depth than will be possible within the main studies themselves. These will be undertaken in supporting studies, whose timing will be phased to be compatible with that of the definition studies proper.

The number and content of these supporting studies can only be fully determined once the system-definition studies are underway.

Typical studies so far identified concern:

— modulation and coding techniques
— multiple access at S-band
— analysis and comparison of large S-band antenna technologies
— array antenna software
— S-band telemetry
— optical systems.

Initiation of technology developments in key areas
The system-definition studies are also expected to identify areas in which specific technology developments must take place in order to be available when needed for the development and implementation of the overall DRS system. A number of key technology areas have, however, already been identified for which development activities must commence early, to reduce programme risk by ensuring the availability of sufficiently proven technologies:

— DRS Tracking Antenna

The antenna subsystem on the Data-Relay Satellite will be a key component whose performance directly affects the overall system efficiency. Contractors will evaluate a number of design alternatives from which the most promising will be taken through to the design stage, with some critical components possibly being breadboarded.

— High Speed Codec (coder/decoder)

A high-speed forward error correcting coder for the low-Earth-orbiting spacecraft, and a decoder for the ground terminal, are required to support high channel data rates. Contractors will examine alternative design approaches and identify the technologies to be used. After selection of a preferred approach, the contractors will proceed to complete the required design.

— Optical Transmitter/Receiver

It is envisaged to embark an optical tracking transmitter/receiver on the DRS. This will use either diode or laser technology.

— Solid-State Ka-Band Power Amplifier

The forward link (DRS to LEO spacecraft) at 25 GHz requires an RF power level of 3—5 Watts, depending on the final data and code rates selected. An attractive alternative to a Travelling Wave Tube Amplifier (TWTA) would be a FET (Field-Effect Transistor) amplifier. Contractors will, in parallel, review the latest devices on the market and proceed through alternative design trade-offs, leading up to a preferred design approach, including a plan for any special device qualification required.

— User Terminal Developments

The user terminal (for the RF solution) would consist of the following elements:
o Antenna, which may be of the low-, medium- or high-gain type, functioning at either S-band or Ka-band or both.
o RF communications unit or transceiver, with the option of various frequencies,

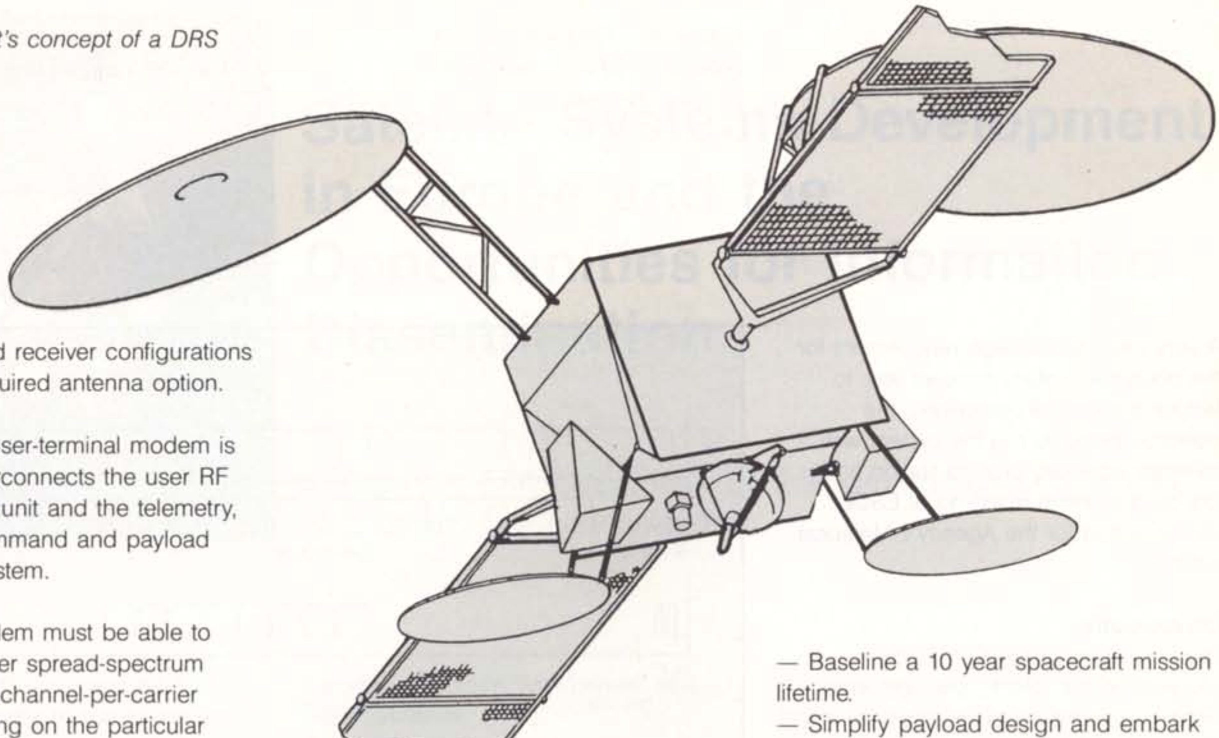


Figure 2 — Artist's concept of a DRS

power levels, and receiver configurations to match the required antenna option.

o Modem. The user-terminal modem is the unit that interconnects the user RF communications unit and the telemetry, tracking and command and payload data-handling system.

The S-band modem must be able to operate with either spread-spectrum access or single-channel-per-carrier access, depending on the particular mission to be supported. The Ka-band modem will be either single or multiple channel type. The user-terminal modem will also contain the intelligence to operate the user terminal, e.g. for acquisition and tracking instructions.

o Deployable/Retractable Boom Mechanisms. Many users will wish to deploy the DRS antenna away from the body of their satellite (where it is normally stowed during launch) to minimise shadowing effects and thus increase the useful field of view and increase contact times with the DRS satellites in geostationary orbit. The mechanisms required for such a boom, to latch it during launch, release and deploy it once in orbit and, for some users, to retract and re-latch it, can be designed to be suitable for a wide range of applications. The definition and design of such mechanisms is expected to be a relatively protracted process, and the designs themselves will be required as inputs to the configuration studies later in the DRPP. Initial development activities are therefore planned in this area at an early stage.

Industrial policy

In order to reap the benefits of competitive bids for the later development phase of the DRSS programme, the system-definition studies will be carried out by two different industrial groups in parallel. Likewise, the initial technology developments will each be carried out under two parallel contracts, at least to the point where competitive binding offers can be obtained for further development and for procurement of future flight hardware.

The supporting studies, on the other hand, are expected to be specific in nature and to not, in general, lead to direct follow-on studies or hardware procurement. These studies can therefore each be carried out under single contracts, without parallel studies being required.

In-house studies

An in-house study has been performed on the configuration of the space segment to serve as a basis for comparison with alternative configurations that will be generated in the DRPP. The study resulted in a concept with the following characteristics:

— Maximise the number of single accesses on each spacecraft; this improves the economic viability and reduces the risk of outages due to jamming.
— Base the spacecraft procurement on a proven bus design which has already been qualified to reduce the non-recurring investment.
— Reduce launch costs with a compact design and the lowest possible geostationary transfer orbit mass.
— Baseline a 10 year spacecraft mission lifetime.
— Simplify payload design and embark adequate redundancy.
— Compatability with TDRSS in S-band.
— A competitive spacecraft procurement.
— Low-cost operation using the minimum number of personnel.
— Operate the system in decentralised manner in order to get the data to the user with the minimum of delay and at the lowest cost.

The concept envisages a spacecraft of the half-Ariane/Spelda class with a microwave payload operating both at S-band (2x5 Mbit/s), compatible with TDRSS, and at Ka-band (2x500 Mbit/s) for the high-data-rate services. It is designed to be compatible with any position in the geostationary orbital arc and to be able to scan up to plus or minus 10 ° about the nadir, which corresponds to being able to track low-earth-orbiting spacecraft to 1000 km altitude.

The conceptual spacecraft design is depicted in Figure 2, a key point being the two large deployed reflectors which, together with their associated feed systems, must provide high gain performance over the scan angle mentioned above in both frequency bands simultaneously with the minimum of blinding effects. The communications transponder envisaged is of the transparent frequency translating type receiving up to four channels of 86 MHz bandwidth per access, each channel being capable of supporting an information transmission rate of 125 Mbit/s (Fig. 3).

A very important design requirement for the reference system concept was to reduce the cost of operations, the objective being to run the system with a remotely operated ground station and low control-centre manning at ESOC similar to that for the Agency's Meteosat system.

Conclusions

The first phase of the ESA DRS programme, the DRPP, is expected to result in competitive proposals from the two groups performing the system definition studies for the detailed design, programme planning, and subsequent development of the space segment of the system. Given the approval for full development of the DRS system at that time, it is envisaged that two parallel contracts for the final definition phase might then be awarded on the basis of these proposals, each lasting approximately one year. These would result in updated proposals for the detailed development and implementation phases (Phase-C/D), from which a choice of one of the two competing groups would be made for execution of that phase (Fig. 4).

In addition, the DRPP will result in a definition of DRS ground-segment requirements, which will be used to initiate procurement actions for the necessary ground-station and control-centre hardware and software.

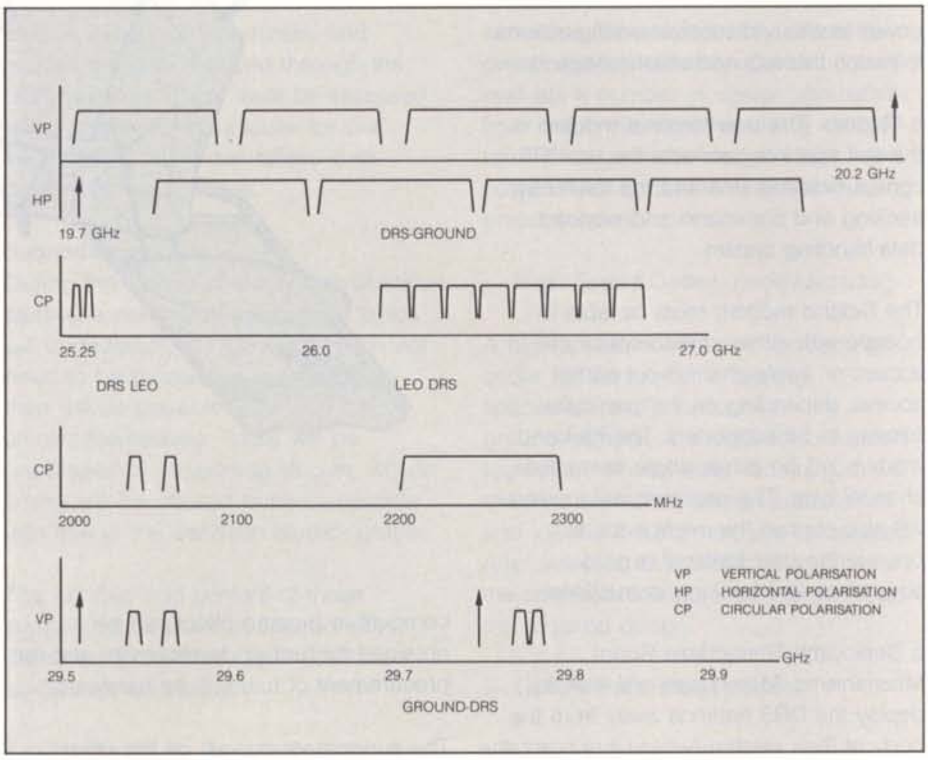


Figure 3 — Frequency plan for ground — DRS — low-Earth-orbit communications

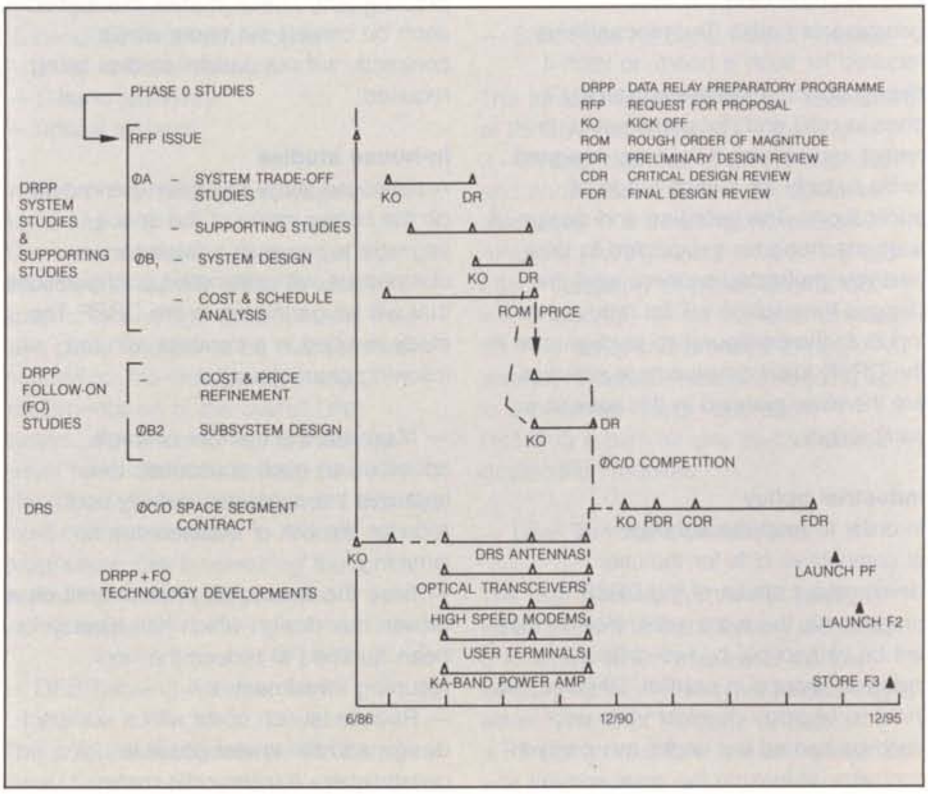
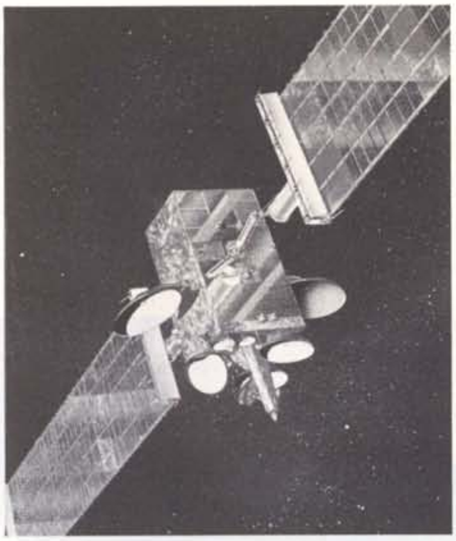


Figure 4 — Tentative overall time scale for the DRS programme



Satellite Systems Development in Europe and the Opportunities for Information Dissemination

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Two distinct types of satellite will provide the supply of transponders for applications featuring point-to-multipoint links to small earth terminals between now and the end of the decade, but it is difficult to be certain which of the two types any particular application might use in a future regulatory environment. It is evident that a mismatch between the supply and demand of satellite capacity must have a significant impact on the way that satellite-delivered information will develop in Europe. The time may now be right for information dissemination to the home and to businesses to be given greater priority and ESA's Olympus satellite (Fig. 1) can play a fundamental role in the demonstration and evolution of these new applications of communication satellites.

Contrast between 'low-power' and DBS satellites

'Low-power' telecommunication satellites

In 1986 the only satellites serving small fixed earth terminals in Europe operate in the FSS (fixed satellite service) bands, particularly 10.95 to 11.7 GHz for the downlink, and use a modest transmit power around 20 W per channel i.e. per transponder. Limited satellite capacity is also available in the 12.5 to 12.75 GHz band. These bands are foreseen to be used for professional or business services to earth terminals with a minimum cost of 500 AU*. The terminals are manufactured by about 50 European companies of small and medium size. In most countries the PTT has the monopoly to install and operate the equipment, although there are signs of deregulation for TV reception by hotels, apartments etc. in a number of countries. The economics of these satellite systems makes them suitable for point-to-multipoint applications with hundreds or thousands of receivers; this implies that the users will be professionals, businesses or 'closed' user groups of a limited size, e.g. subscribers to a financial advisory service.

'High-power' direct-broadcast satellites

1987 will see the launching of the first DBS satellites, which will all operate in the BSS (broadcast-satellite service) frequency band between 11.7 and 12.5 GHz. Channel powers of around 200 W will be the norm for these satellites, and much smaller cheaper earth terminals will be possible. With their lower unit cost — less than 25% of the cost of the FSS receivers — they will be affordable by the general public and manufactured in quantities of millions rather than the thousands of the more professional FSS receivers.

DBS receivers will be an item of consumer electronics obtainable via a highly organised network of shops and dealers. A handful of manufacturers will make most of these receivers, although many others will produce special receivers in smaller quantities. The economics of these DBS systems means that they are mainly suitable in the long term for the broadcasting of TV or information to the general public, with hundreds of thousands or millions of receivers, or to large groups perhaps paying individual subscriptions to receive the signals.

Progress and planning with 'low-power' satellite systems

At the time of writing, more than 30 transponders are available on the Eutelsat, Intelsat and Telecom-1 satellites. The first two international organisations will launch more satellites in the future. They will be joined by the Copernicus satellites of the Deutsche Bundespost in 1988. By then the number of transponders will have risen to nearly 100.

European and trans-Atlantic projects

Most publicity has been accorded to the the government of Luxembourg's project to launch a satellite system to provide

*1 AU = US$ 0.73

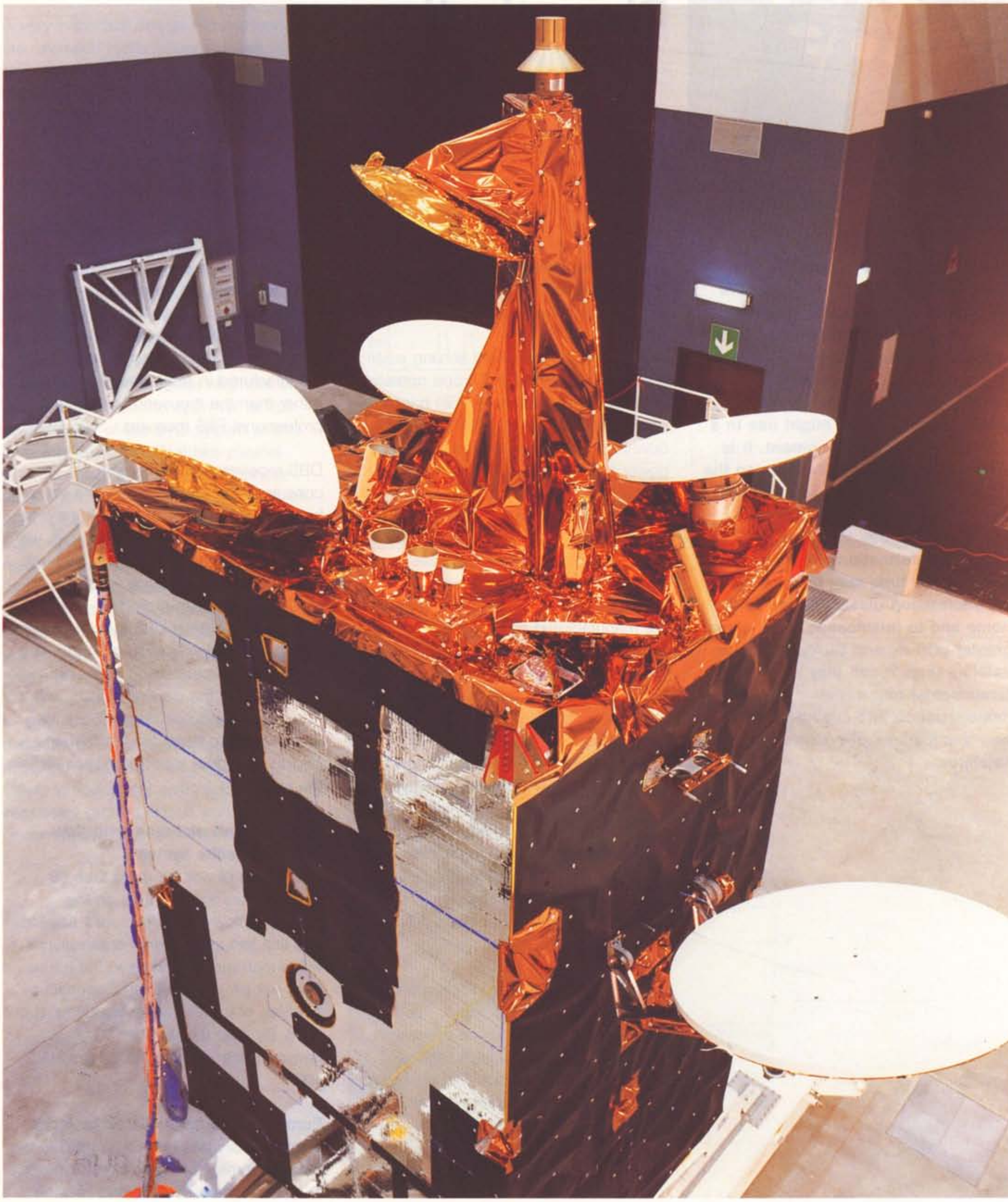


Figure 1 — The Olympus spacecraft

Figure 2 — Growth in low-power European satellite capacity (Transponders suitable for TV distribution and other services to small terminals in Western Europe)

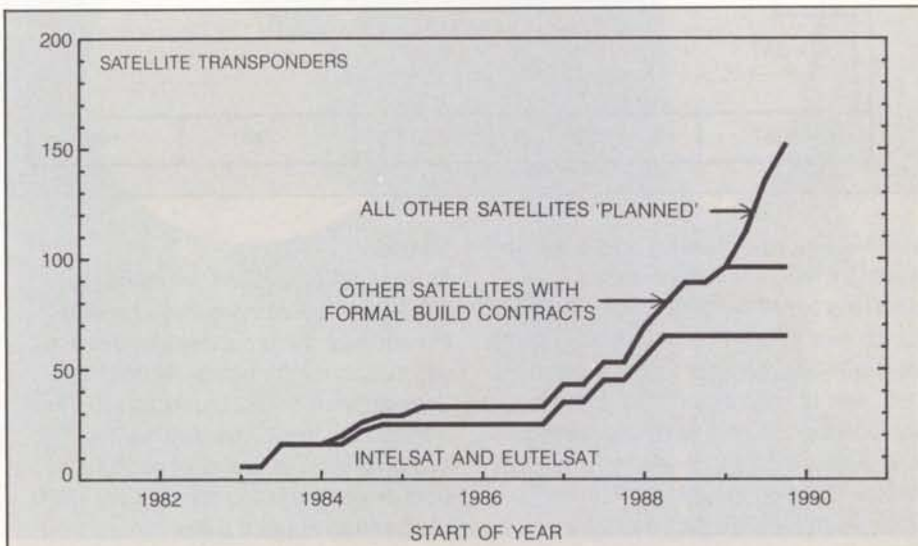
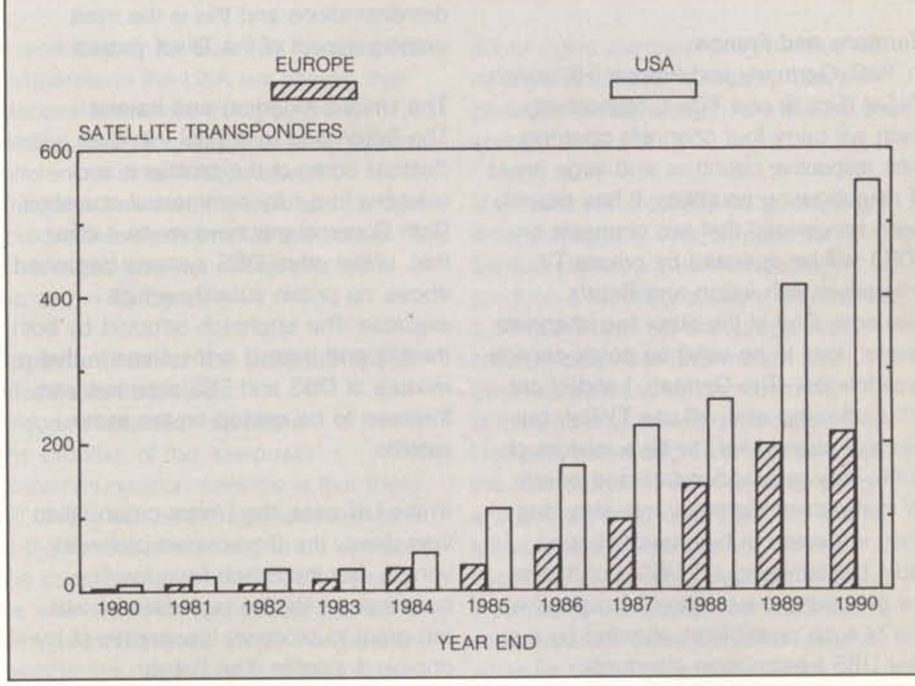


Figure 3 — Comparison of 'maximum' projected growths of 'Ku-band' satellites in Europe and the USA (Excludes 6/4 GHz, 30/20 GHz FSS and mobile)



pan-European TV distribution. At the start in 1982, Coronet, an operating company partly controlled by American interests, was involved, but in 1985 the wholly European Societé Européenne des Satellites (SES) was granted the operating franchise. The project currently foresees 16-channel American-built satellites serving the whole of Europe.

The Reagan Administration has given International Satellite Inc. (ISI) approval to provide two 16-transponder satellites linking the USA and Europe and to compete with Intelsat. Some restrictions are placed on ISI, such as getting the cooperation of a 'foreign authority', meaning the permission of a European Government to land signals, but at least four European Governments have already shown interest.

British Telecom and the French PTT were actually the first to file plans with the ITU to launch 'trans-Atlantic' satellites. More recently, the government of Ireland has also been active, having announced its intention to grant a licence to Atlantic Satellites who propose to operate a satellite at 31°W longitude. This could provide both DBS capacity and FSS European services plus trans-Atlantic links, and would be built by Hughes. British Telecom has been studying the British requirements and plan to acquire a satellite of the Eutelsat second generation.

Growth in total satellite capacity

Other potential operators have also obtained US Government approval, and if all these embryonic ventures survive there could be a total of over 150 FSS transponders serving Western Europe in whole or in part by 1990 (Fig. 2). In any case, the satellites currently in manufacture will provide nearly 100 transponders when launched. While there are now only three European communication satellites in orbit, thirty broadly similar satellites now provide domestic services in the USA, with a total of over 500 transponders.

By 1990, it is projected that over 500 transponders will be provided by American satellites operating in the 10.7 to 11.7 GHz bands (Ku-band) in addition to several hundred more in the 4 GHz bands (C-band).

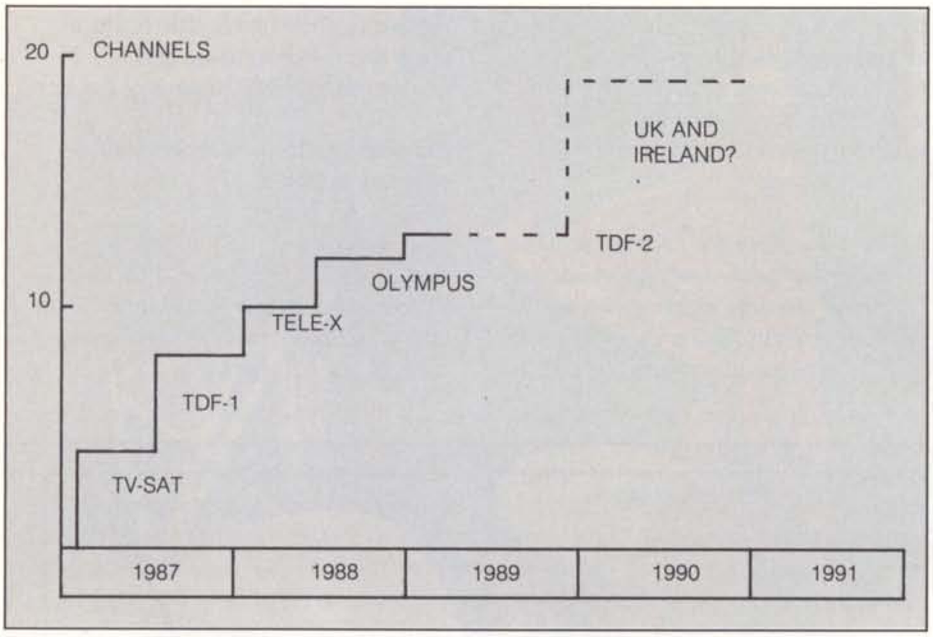
Figure 3 illustrates the contrast between the European and American situations. This large disparity in the application of satellite communications technology can only be explained by examining political, regulatory and cultural differences in these two geographically and economically similar regions of the world.

Progress and planning with DBS satellite systems

1987 — An historic year

The beginning of 1987 should see the start of DBS in Europe, and by 1990 there should be four systems providing a total of 12 DBS channels serving various parts of our continent (Fig. 4). At this

Figure 4 — Growth of European DBS satellite capacity



time the Agency is waiting a little like an expectant father. ESA has seen a promising future for DBS since 1972. The launch year of the heavy communications satellite H-Sat, the very first European DBS, was to have been 1981, but this was abandoned and all its successors have suffered delays. It was only in 1981 that the decision to replace H-Sat by Olympus (formerly L-Sat) was taken.

Germany and France

In 1987, Germany and France will launch TV-Sat (Fig. 5) and TDF-1, respectively. Each will carry four channels covering their respective countries and large areas of neighbouring countries. It has recently been announced that two channels on TDF-1 will be operated by private TV enterprises with Italian and British elements. One of the other two channels seems likely to be used by public-service broadcasters. The German 'Lañder' are still discussing who will use TV-Sat, but this also seems likely to be a mixture of public-service broadcasters and private TV companies. Germany has also long been interested in high-quality sound radio broadcasting via DBS, but this is the only current example of imaginative use of such possibilities afforded by the new DBS transmission standards.

Sweden

In early 1988, Sweden will launch its Tele-X satellite, carrying two channels intended for TV broadcasting, the use of which is currently being debated by Scandinavian public broadcasters. There will also be Tele-X channels for the demonstration of business services. A pool of earth stations has already been procured to support these demonstrations and this is the most exciting aspect of the Tele-X project.

The United Kingdom and Ireland

The British and Irish DBS initiatives illustrate some of the problems and solutions in a fully commercial operation. Both Governments have made it clear that, unlike other DBS systems described above, no public subsidy will be available. The approach adopted by both the UK and Ireland is the same in that a mixture of DBS and FSS channels was foreseen to be carried on the same satellite.

In the UK case, the Unisat organisation was clearly the Government-preferred vehicle, but the British broadcasting corporations felt the business risk was too great to proceed, irrespective of the choice of satellite. The British Government has since reviewed its options and has instructed the Independent Broadcasting Authority to seek operators for a three-channel system once again. This time, however, the rules will be relaxed to improve the prospects of economic viability for the service. It is hoped to select a programme contractor and satellite supplier by the end of this year.

In Ireland negotiations are continuing between the Government and the prospective franchise holder, Atlantic Satellites.

Satellite capacity supply and demand

Supply

The available satellite capacity will rise from around 30 transponders in 1985 to between 100 and 200 at the beginning of the 1990s. 10% of these will be on DBS satellites, but the majority will be low-power transponders of the kind available today, plus some with a little higher power. It is interesting to speculate what the demand for capacity on this basis might be for the rest of this decade.

Demand for TV distribution

To date, all the transponders on the six satellites already in orbit have been allocated to small terminal services, but the situation is confused since some transponders are actually idle. The largest group of users are the 15—20 companies distributing TV to cable networks. This group is growing, but the slow expansion of modern high-capacity cable networks and the fragile economics of the business suggests that no more than 40 channels will be required in Europe for TV distribution to cable networks by 1990, including the more agressive American organisations. By comparison, over 100 transponders are already used in the USA to distribute nearly 50 programmes.

The allocation by Eutelsat of transponders on the next ECS (see ESA Bulletin No. 41, pp. 28—35) suggests that

Figure 5 — Europe's first high-power DBS satellite TV-Sat, which will be in orbit in early 1987.

public-service broadcasters are beginning to use satellites for the national distribution of TV programmes. If half the 22 member states of the Council of Europe used two transponders for this purpose and the other half used one, more than thirty transponders would be required.

Where cable networks exist, experience has shown that there is a minority demand for 'foreign TV', both from immigrant workers and viewers seeking a wider choice. Only the problem of artists' rights seems to slow this trend. It should be noted that in the Benelux countries, cable networks have actually been created because of the ease of picking up TV from neighbouring states. This suggests that the availability of satellite-delivered programming is perhaps a pre-condition to cable-network development, not the reverse.

Demand for business services

The development of satellite business services in Europe has been disappointing, due to a number of factors, not least the lack of awareness of the end business user regarding the potential of satellite distribution. However, the tariff policies of PTTs do little to encourage development of business services. There has been much talk in the past of 'roof-top' or 'car-park' earth terminals, but few PTTs will permit this even if they own the terminals. The result is that the satellite service must also pay the price of the 'last mile' via a terrestrial link, and this makes a big difference.

In contrast, in the USA there has been explosive growth in the use of micro earth terminals and the broadcast data services they bring. The idle time of transponders on European satellites now in orbit could readily support a network of privately-owned micro earth terminals, but the PTTs are likely to oblige such services to use ISDN, with all its limitations of capacity, coverage and slow speed of development.

A recent study for ESA has revealed that companies in the USA are halving their telecommunications costs by using satellite links to 'roof-top' earth terminals. Differences in tariff and network structures between the USA and Europe could, however, mean that this sort of advantages may not necessarily be realised in Europe.

Opportunities for the introduction of information services

Telecommunication satellites

The problem of the 'low-power' telecommunication satellites is that there will simply not be enough television to fill all the transponders likely to be available. The constraint is not the creativeness of the writers nor the disposable income of the viewer. There will simply not be more hours in the day to watch more TV. No doubt many specialist programmes will emerge, but it seems unlikely that the gestation period of such fare will be short enough.

The result will probably be a temporary excess of supply over demand for satellite capacity. This will hopefully produce a lowering of tariffs and thereby a climate which will encourage the emergence of new information and business services which recent ESA studies have identified as promising. However, some degree of relaxation of the restrictions on earth-terminal siting and ownership is essential. This should follow logically from the very limited capability of terrestrial systems to carry these point-to-multipoint services over a wide coverage area, but it may take a while for this to be appreciated.

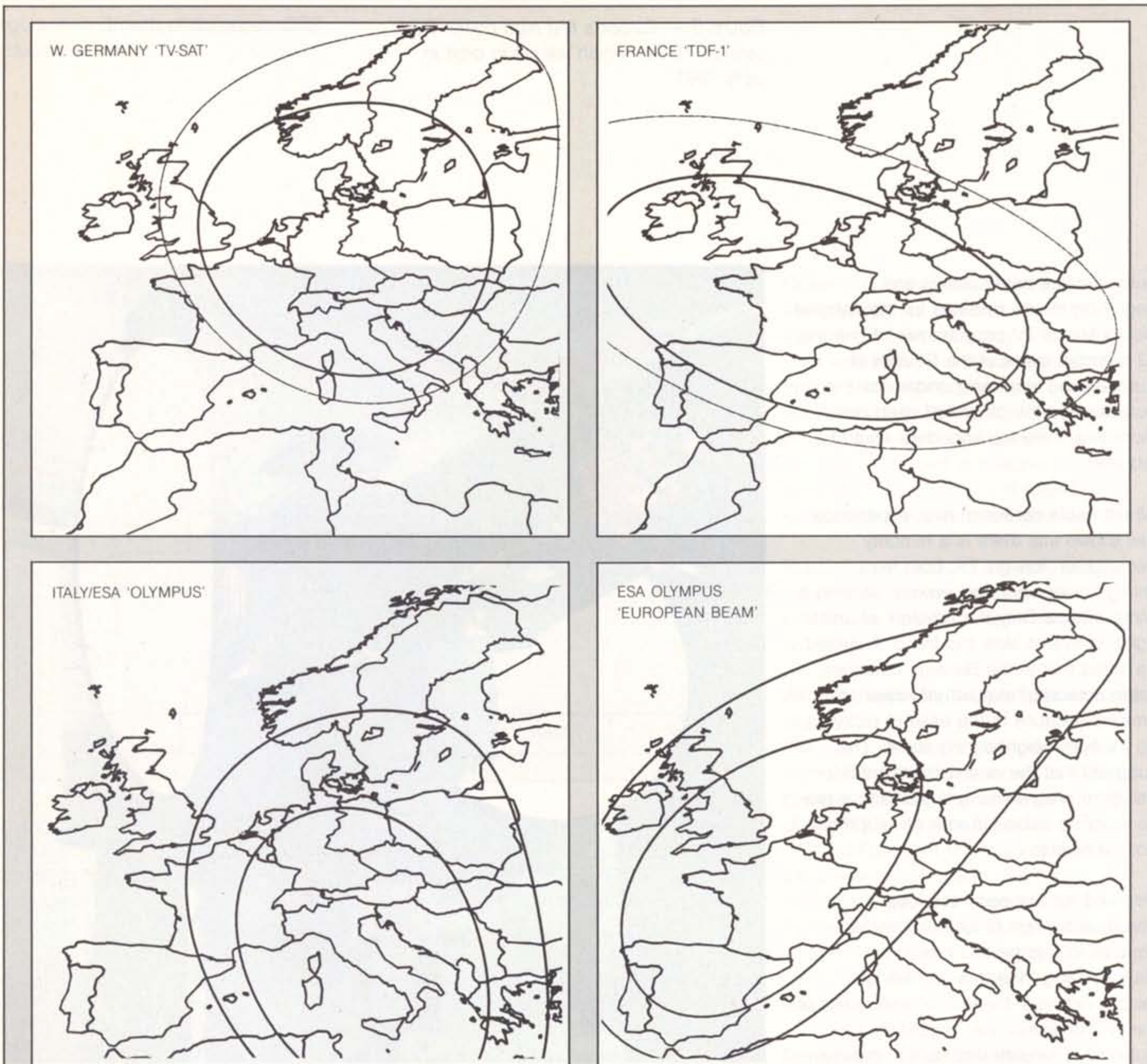

W. GERMANY 'TV-SAT'
FRANCE 'TDF-1'
ITALY/ESA 'OLYMPUS'
ESA OLYMPUS 'EUROPEAN BEAM'
SWEDEN 'TELE-X'
UNITED KINGDOM

Figure 6 — Coverages for 'fair-quality' reception of TV for various European countries by 45 cm (inner contour) and 90 cm (outer contour) diameter individual antennas. ('Fair-quality' is CCIR Grade 3, and assumes MAC video transmission)

Direct-broadcast satellites

The DBS systems have a rather different problem, namely to reduce the risk of launching the service, i.e. to reduce the 'abort' costs that have to be met if the service should fail to reach maturity. DBS carries high operating costs associated firstly with the high-power satellites required to reduce the cost and size of the home receiver to an attractive enough level, and secondly with the programmes that have to be good enough for the home owner to take the trouble to acquire one of these small receivers. In the long term, advertising revenue can be confidently estimated to cover these costs, but at the start of the service there are few receivers and so advertising revenue is correspondingly small.

From European cable TV experience, Pay-TV looks an ever greater risk at this stage, since the average European viewer already receives TV 'free', or after paying a modest receiver licence fee. The rate of growth of the number of DBS receivers and the resultant advertising revenue can be estimated from historical data on the introduction of colour-TV sets and videorecorders, but the negative cash flow in the early years is alarmingly high. Information services to relatively small user groups could provide a steady, predictable and significant level of revenue that could build up quickly in the early years and offset the high fixed costs of the satellite system. These users could be businesses or closed user groups that use the system in the hours in which entertainment TV is unlikely to be transmitted.

Service demonstrations

Some of these information services could benefit from demonstrations or pilot trials before being introduced operationally. It is hoped that ad-hoc leasing of spare telecommunications satellite capacity could be arranged to support such trials. DBS is more difficult, since the total capacity will be much more limited, but the Agency's Olympus satellite is a convenient vehicle with which to prove the value of some applications before commercial capacity on national or pan-European satellites becomes available.

What are the problems of the development of new services and why are service demonstrations useful? Who will they help and why? In some cases technical feasibility is in doubt, but satellite communications itself must now have proved its technical feasibility even to the most sceptical. In other cases commercial-service providers need a demonstration of an experimental system to encourage them to invest in the establishment of the more complex operational system. Equipment manufacturers need the chance to test their products and the market demand for them, as is the case also with the service providers and their services. End users need hands-on experience or just the chance to observe others participating in a demonstration, without any commitment. They want to find out what the proposed service might do for them. Does it really work? What are the costs of this practical demonstration system and will they differ with an operational follow-on? Prospective financial backers of the full-scale operational service want to know the reactions of all concerned, the service providers, equipment makers and end users.

Finally, an experimental service demonstration can draw attention to the need for regulatory and legal reform much more effectively than a mountain of documents. The pace of technical and business development does seem to be greater than the speed of reform in regulatory matters. Something has to be done to permit advances that are seen to be desirable, but are inhibited by the law as it now stands. This is particularly true in the case of pan-European services and the European Commission drew attention to this in a 'green paper' in 1984 and recently published a draft directive intended to ease the constraints on transnational broadcasting.

The role of ESA's Olympus satellite

Olympus objectives

The Olympus programme has as its major objectives the development of a large multipurpose satellite platform design, of greater capacity than TDF-1, the development of key elements of satellite payload technology and the in-orbit operation of their payloads in a comprehensive test demonstration and utilisation programme.

Olympus payloads

Olympus will carry two high-power DBS channels, one covering Italy and the second covering most of the rest of Europe. Four medium power 'specialised-service' channels are provided by a second payload with features that permit the coverage of most of Europe with a signal strength similar to that provided by Telecom-1 over only France and the immediately adjacent territory. It thus represents the generation of satellite technology to follow that used by the satellites now in orbit. A third limited-capacity payload using the millimetre waveband will also permit video-conferencing and various technical experiments to be carried out*.

Status of demonstration planning

ESA has already concluded agreements with the Italian public broadcaster RAI and the European Broadcasting Union (EBU) regarding the prime-time use of the DBS channels. EBU has delegated its interest to Europa TV, an initiative of a group of European public broadcasters. This pan-European TV channel started broadcasting in October 1985, via a Eutelsat ECS transponder, to cable networks and terrestrial transmitters. An application from the Dutch media company VNU to demonstrate a 'home information service' has also been accepted in principle by ESA. However, it

* Further details are to be found in the Olympus Users' Guide, ESA Document CCF/38776/sed, April 1985

is not anticipated that these organisations will use all the satellite capacity 24 h per day. It is also desirable to mount many other demonstrations to get maximum benefit from the large investment in Olympus.

Thus ESA is inviting proposals for demonstrations using Olympus. Full details are given in the Users' Guide, but essentially applicants are advised to contact ESA informally and discuss their ideas with their Government's Delegation to ESA, before making a formal proposal. The Agency will evaluate all the proposals submitted, decide which are acceptable and prepare annual utilisation plans for the satellite. It is anticipated that some flexibility will be necessary in week-by-week routine operation.

Examples of new information-service applications

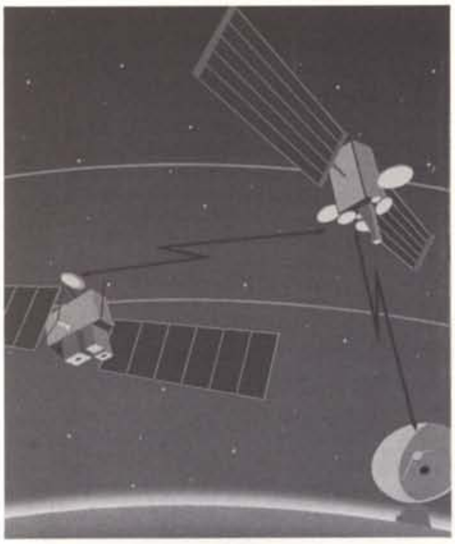
Recent studies conducted for ESA of 'Information Dissemination by Satellite' identified a number of interesting possibilities and enabled first contacts to be made with prospective users. These studies showed that corporate video could be a major user of satellite capacity, but this is already starting and may need no further demonstration. A commercial service is now available on Eutelsat ECS. The remote printing of newspapers at multiple and seasonal sites is another candidate long studied, and this looks likely to be carried by ECS within the context of the Apollo project, a joint venture between ESA, the European Commission and Eutelsat.

Distance learning, direct marketing and 'electronic newspapers' all look promising, but many individual applications or users would need only a fraction of a satellite transponder. Various ways need to be found to overcome this difficulty of 'small' users. One sample solution that the Agency is currently investigating concerns education and training. The study mentioned above showed that most organisations involved in distance teaching individually lacked the resources to exploit satellite technology. Either they failed to appreciate its potential, found difficulties in using this 'big' new technology, or simply needed only a very limited amount of satellite transmission time. An association for these potential users of satellites could be the answer in this particular sector and a study of the European Satellite Users' Association (EUSA) is being made to get a measure of the interest of the educational community.

With many image and data services, the same problem applies in that the packaging of a large number of applications looks to be necessary before the full potential of satellites can be realised. European PTT administrations are attempting to provide such services by using interactive access, via the telephone, to large general-purpose database hosts. It is already clear that the general public find difficulties with this approach, such as the uncertainties in the cost. The answer for a public general-purpose information service could be to use full-channel broadcast teletext with conditional access.

Conclusions

In general, low-power satellites will provide services to business and high-power DBS satellites to homes, but the dividing line is thin. The number of satellite transponders available for small terminal services in Europe will grow from about 30 in 1986 to between 100 and 200 at the start of the next decade. 10% of this capacity will be DBS. The majority will be provided by Intelsat and Eutelsat, but private operators and national administrations also have ambitions. The supply of satellite capacity by the late 1980s looks as if it will exceed the demand, which will be mainly for TV distribution, but a pool of idle transponders could help the development of new information services. Demonstrations of these new applications should certainly help. The Agency's Olympus satellite can play its part.



ESA's First Data-Relay Satellite Experiment

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Future satellites and orbital systems will generate high volumes of data which will have to be transmitted to their destinations quickly, safely and, as far as possible, at low cost. To achieve this goal, ESA has started to set-up its Data Relay Satellite (DRS) system, which is described elsewhere in this Bulletin. The workings of such a system are complex and the accumulation of experimental experience will be of great value for the later operational DRS system.

The 'Inter-Orbit Communication'(IOC) package is such an experiment, which will attempt to achieve two goals simultaneously: development of the hardware that will be needed on the user spacecraft, and the gathering of operational experience, including optimisation of link parameters and operational procedures.

The IOC system involves three subsystems: the Olympus spacecraft in geostationary orbit and its control centre, the Eureca spacecraft in a 500 km high orbit with its control centre, and the IOC experimental payload onboard Eureca (Fig. 1) and the associated ground segment. The Agency's Olympus spacecraft, to be launched in 1987, will carry a 20/30 GHz payload equipped with two independently steerable antennas, one of which will be pointed towards the Eureca spacecraft, the other towards the IOC ground station at Maspalomas, on Gran Canaria.

The system supports a two-directional radio-frequency (RF) link: transmission of telecommand or ranging signals from the ground to the IOC experiment via Olympus and transmission of telemetry, test or ranging signals from the experiment to the ground, again via Olympus. The challenging problem of the IOC experiment is to provide accurate pointing of the Olympus and IOC antennas at all times.

A block diagram of the IOC payload is shown on Figure 2. It contains a steerable Cassegrain antenna with a main reflector diameter of 55 cm, which will be pointed towards Olympus. The payload receives at 18.925 GHz and transmits at 28.622 GHz. The received signal is either unmodulated, or modulated with telecommand signals at a bit rate of 2 kbit/s or with ranging signals according to the ESA tone-ranging standard. The received signals are demodulated in a standard S-band transponder. The demodulated telecommand signals are routed to the Eureca telecommand system for decoding and further processing. The demodulated ranging signals are then remodulated and retransmitted.

The IOC experiment receives telemetry signals from Eureca at a bit rate of 512 kbit/s, already convolutionally encoded. The signals are modulated (BPSK modulation) within the IOC payload and, after frequency conversion and power amplification (in a 10 W TWT), are transmitted to Olympus. Instead of the telemetry data, it is also possible to transmit test data generated within the IOC payload at bit rates of 256, 512, 1024 or 2048 kbit/s. These test data allow bit-error-rate measurements to be performed under both favourable and unfavourable link conditions.

The Olympus antenna will be commanded in real time from the ground, using Eureca orbit data for the generation of pointing commands. The IOC antenna can be operated in a similar way, i.e. by commanding it at a pre-determined time into a direction calculated taking into account Olympus' position and Eureca's orbit. However, the IOC payload also contains onboard data storage, which allows storage of pointing commands covering a 48 h operational period. These commands will be executed in a time-tagged manner. The pointing tables can be uplinked to the IOC experiment using the Olympus IOC forward telecommand link or via the Eureca S-band telecommand link.

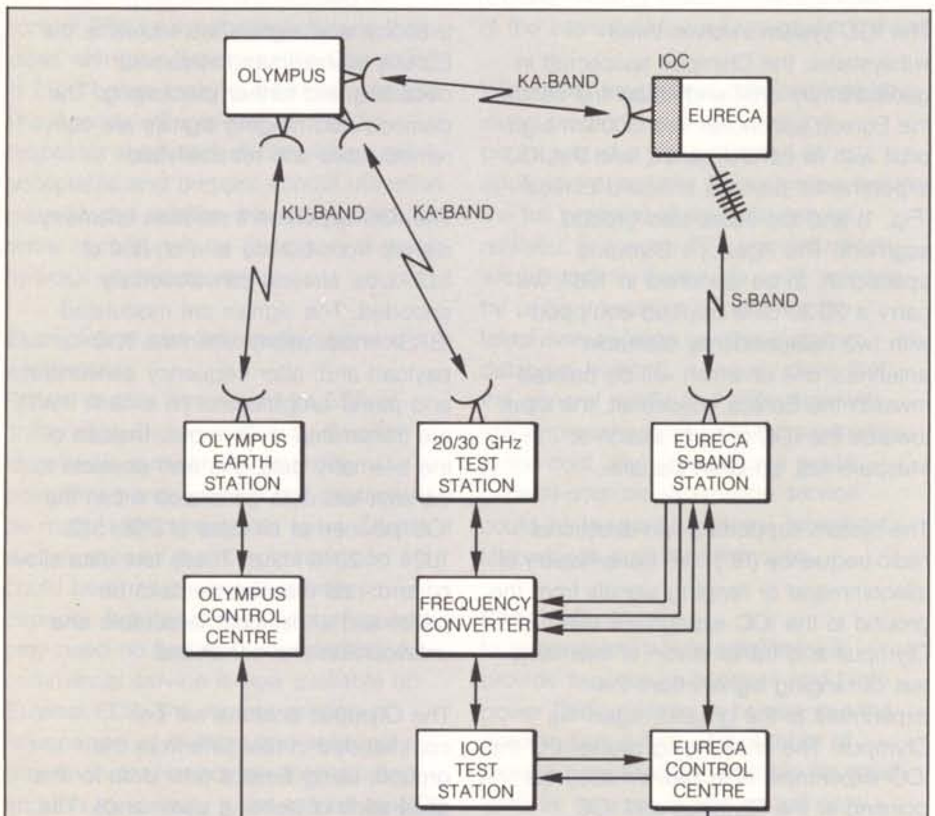
The IOC payload also contains a radio-

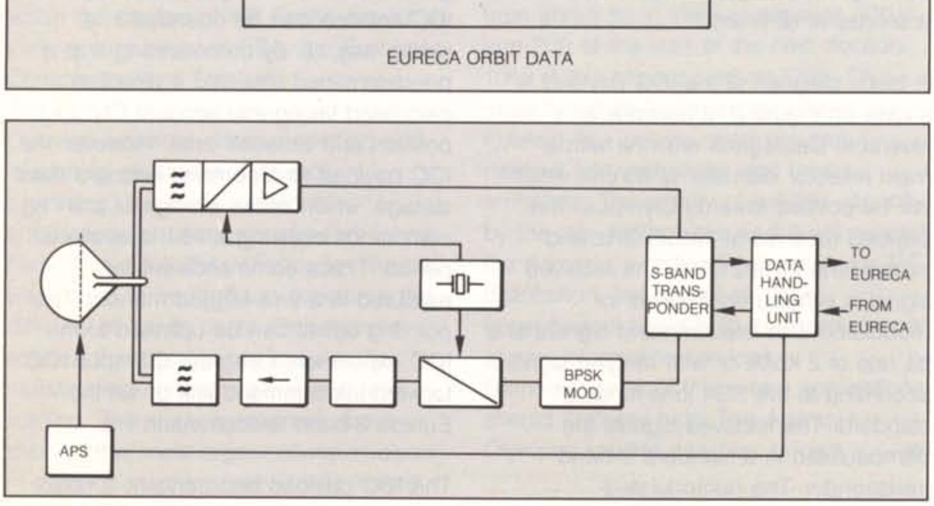
Figure 1 — The structure of the Inter-Orbit Communication (IOC) experiment

Figure 2 — The IOC payload

frequency autotrack system. Classical monopulse systems require heavy and complicated hardware, i.e. additional horns, special receivers and complicated data processing. The IOC experiment, on the other hand, uses a sequential lobing technique. In an ordinary antenna, the feed system generates electromagnetic fields in carefully selected modes such that the resulting overall field propagates in the desired manner and generates the desired antenna beam.

If one adds to the fundamental mode a certain degree of higher order modes, the wavefront will be distorted resulting in a squinted beam. The degree of beam squint depends on the ratio of fundamental and higher order modes. The higher order modes are generated within the IOC antenna feed horn by means of four short-circuited waveguide stubs, which are coupled to the feed system through slots, the coupling factor of which determines the degree of higher order modes.





The beam squint is activated by means of a PIN diode in front of the waveguide short circuit. If the diode is not biased, the phase of the higher order modes is such that the beam is undistorted; if it is biased, the phase is such that the beam is 'squinted'. The four waveguides with switching diodes at convenient angles around the circumference of the feed horn allow the beam to be squinted in four orthogonal directions. An additional feature of this design is a filter in the waveguide stubs that makes the mode generation frequency-sensitive. In the IOC package, only the receive beam is 'squinted' and the transmit beam is (nearly) unaffected.

Figure 3 is a schematic of the IOC antenna system, while Figure 4 shows the antenna diagram, undistorted and 'squinted' to the left and to the right. The IOC radio-frequency tracking system uses these antenna characteristics as follows: the four diodes of the feed system are switched in turn such that a beam squint in four orthogonal directions is generated. Each beam direction corresponds to a radio-frequency receive signal level, i.e. four different levels when the antenna is mispointing. The level information is extracted from the automatic gain control signal in the S-band transponder and transmitted to the IOC Data Handling Unit (DHU), which evaluates it and determines the optimum direction for the antenna beam. The DHU derives the optimum direction and generates commands for the Antenna Pointing System (APS), which then repoints the antenna.

The IOC experiment will demonstrate to the users of low-orbiting satellites the

Figure 3 — The IOC antenna system

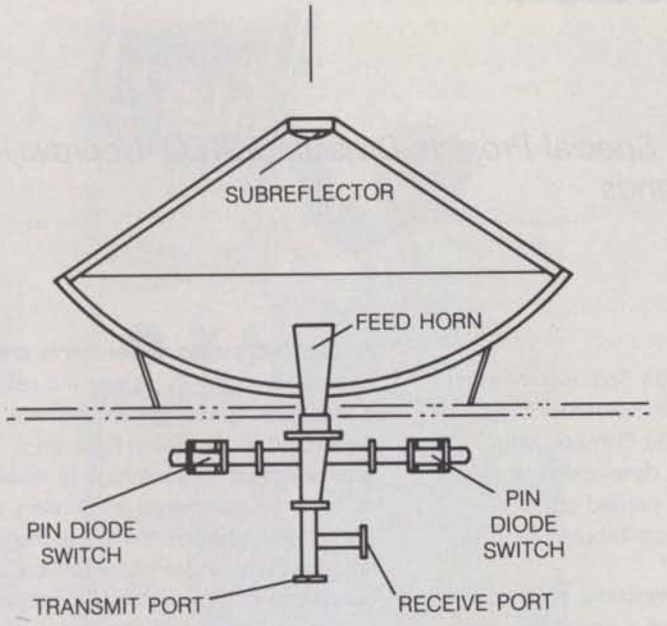


Figure 4 — IOC antenna-pattern diagram

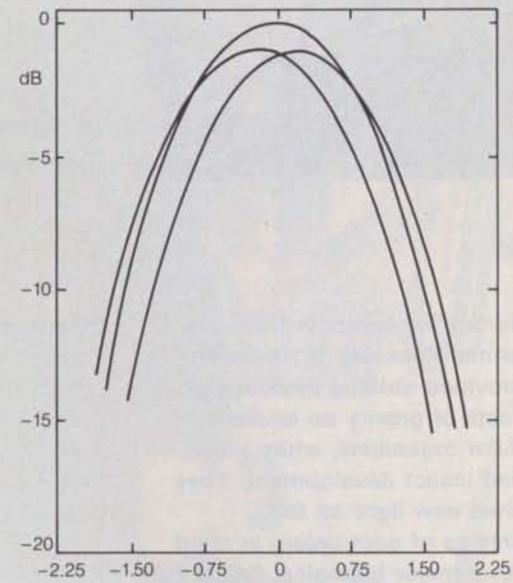
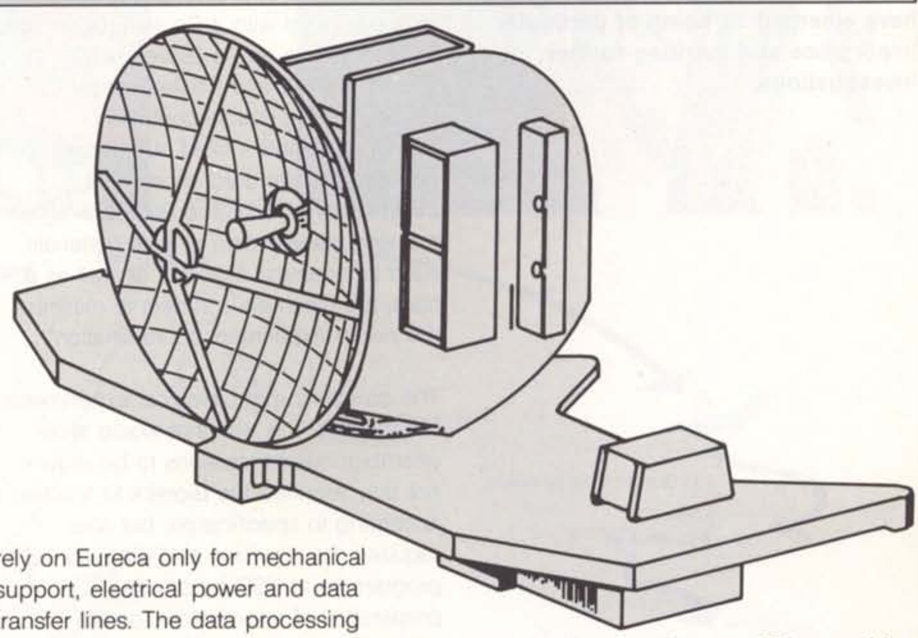


Figure 5 — Artist's impression of the IOC package



feasibility and suitability of a DRS system by providing many of the services foreseen for an operational system: ranging, data transmission to and data reception from the user spacecraft, over periods many times longer than those during which data can be received otherwise at a single location on the Earth. In addition to the service demonstration, an intensive test programme will be executed, consisting mainly of bit-error-rate measurements under varying operational conditions. Parameters that will influence the quality of the link are the antenna-pointing update, the communication performances (pointing, gain setting) of the Olympus satellite, the accuracy of Doppler compensation, the bit rate of the test signals generated onboard by the IOC package, and the orbit prediction accuracy.

The test programme will be executed during the first six to eight weeks of Eureca's period in orbit, the remainder of the operational period being devoted to the service demonstrations.

The IOC payload is conceived as an autonomous add-on package which will rely on Eureca only for mechanical support, electrical power and data transfer lines. The data processing associated with beam switching, antenna pointing and status monitoring will be performed within the IOC payload.

Figure 5 shows an overall view of the IOC package. It weighs about 60 kg and will consume 140 W when fully operational. The ground station has been kept as simple as possible. It will reuse the telemetry/telecommand equipment of the S-band Eureca ground station and, as a novel feature, the pre-launch test and checkout equipment will be used for the execution of the in-orbit test programme.

The IOC experiment is one of the ESA-funded payloads onboard Eureca-1. The Agency has awarded the procurement contract to CNES, which has subcontracts with an industrial team of companies in France, the United Kingdom, Italy, Belgium and Spain.

Flight Results from the Biorack Experiments on the Spacelab D-1 Mission

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The Biorack experiments flown on the German Spacelab D-1 mission have provided striking evidence of the effects of gravity on bacteria, unicellular organisms, white blood cells and insect development. They have shed new light on the mechanisms of geotropism in plant roots. Two major biological fields, cell proliferation and cell differentiation, have emerged as being of particular importance and meriting further investigations.

Introduction

On the first German Spacelab Mission D-1, launched from Kennedy Space Center (KSC) on 30 October 1985, fourteen cell- and developmental-biology experiments were carried out in the Biorack, a facility contributed by ESA.

The Biorack is a reusable, multi-user facility consisting of a single Spacelab rack equipped with a Cooler/Freezer unit, two Incubators and a Glovebox (Fig. 1). The Incubators and Cooler/Freezer provide a temperature-controlled environment and a fixed number of positions for standard experiment containers (Table 1). The Glovebox allows the safe manipulation of toxic materials such as chemical fixatives, as well as a class-100 clean environment to minimise the risk of experiment contamination*.

The conducting of biological experiments in Spacelab in a way that would allow unambiguous conclusions to be drawn not only required the Biorack to function according to specification, but also required the provision and execution of a programme at KSC for on-site preparation of experiments, on-site performance of ground control experiments, data and voice communication with the German Space Operations Centre (GSOC) in Oberpfaffenhofen, Germany, and finally on-site experiment receipt and post-experiment preparations.

At least two control experiments are required to rightfully assess the results of a biological spaceflight experiment: one performed in parallel in flight on a gravity-simulating centrifuge to eliminate all other environmental parameters but gravity, the other performed at the same time on Earth under near-identical conditions to provide the real reference database. The effects of gravity can then be clearly distinguished from all other imposed effects, such as launch and landing-induced acceleration and vibration levels, interference from other instruments, centrifuge effects and the effects of space radiation (Table 2).

The Biorack Incubators were therefore each provided with two 1 g control centrifuges, and a second identical Biorack (training model, as opposed to the flight model) was installed in the Life-Science Support Facility (LSSF) at KSC for conducting the ground control experiments.

This article discusses the operational framework established and reviews the scientific results that have been harvested from this first Biorack mission.

Biorack operations

Pre-mission

Figure 2 shows the overall logistical flow of the Biorack experiments. The training-model Biorack had been installed in the LSSF, together with its Ground Support Equipment, approximately three months before launch for flight-simulation, crew refresher training, and ground control experimentation.

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* A detailed description of the Biorack units and their mode of operation can be found in ESA Bulletins No. 31, p. 46 and No. 36, p. 48.

Figure 1a — The Biorack configuration photographed at ESTEC

Figure 1b — Astronaut Bonnie Dunbar working with the Biorack during the Spacelab D-1 flight

Figure 2 — Biorack mission operations

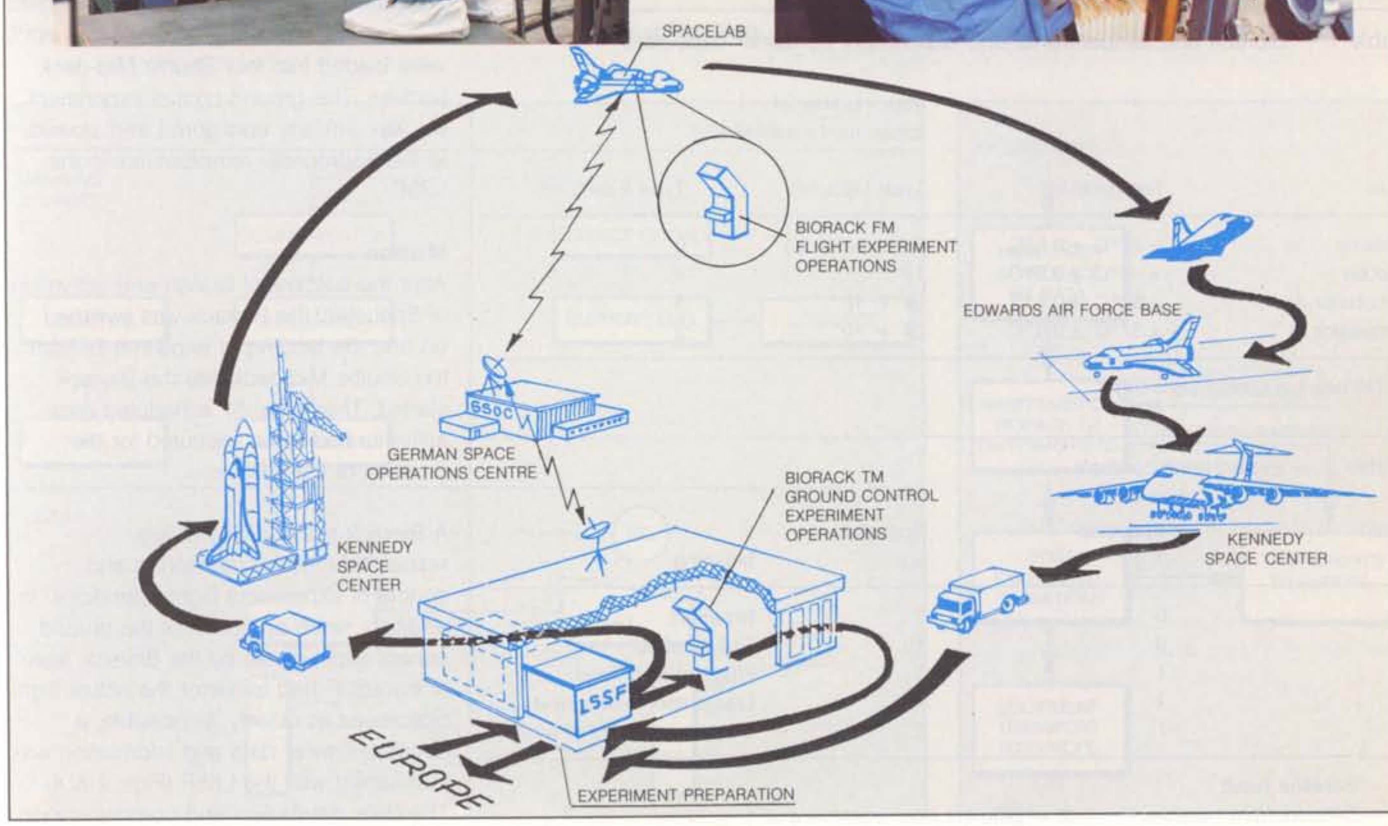
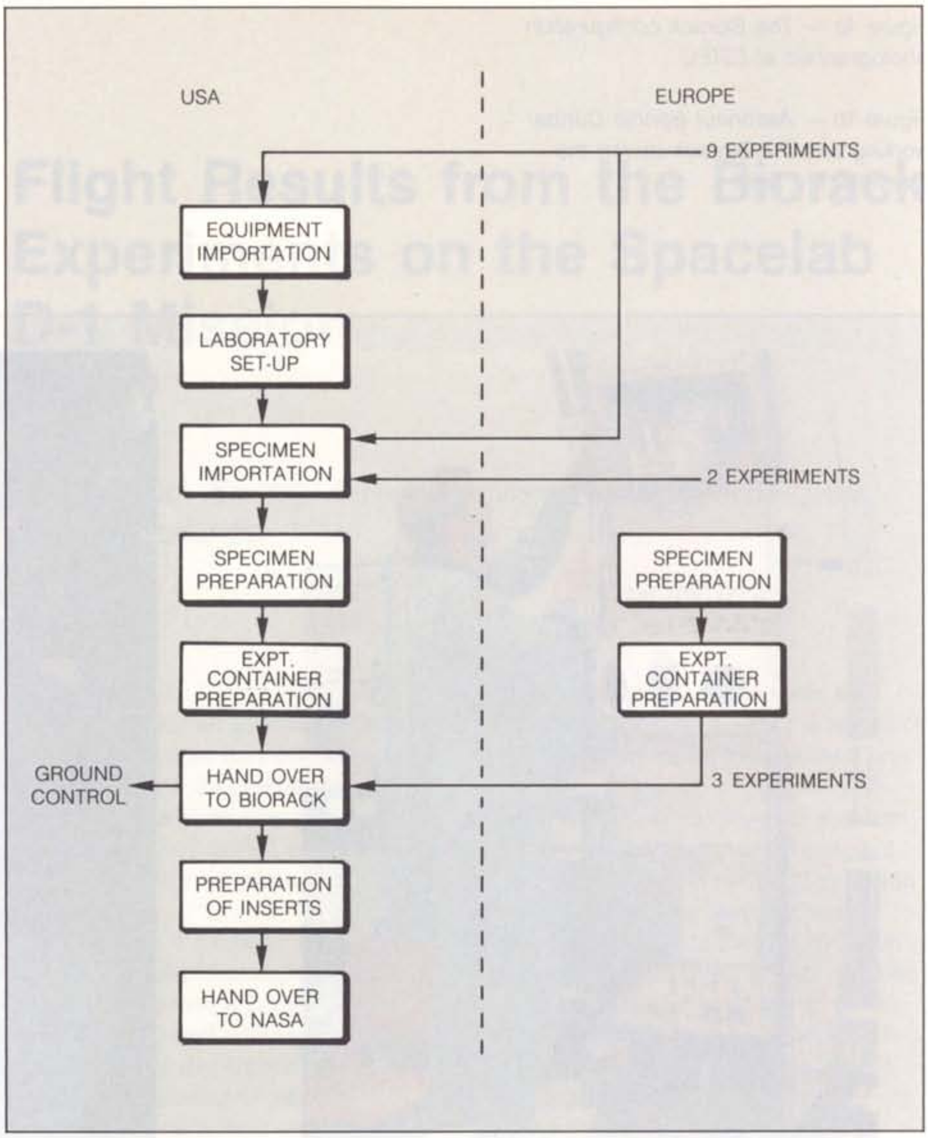


Figure 3 — Pre-mission experiment flow



A large vacuum pump station was also installed to pump down and bake out eight Passive Thermal Conditioning Units (PTCUs) needed for temperature-controlled stowage of experiment containers during the pre-launch, launch, landing and post-landing phases.

The investigator teams arrived at Kennedy anything from four weeks to one week before launch to install their dedicated equipment (Fig. 3). They had to prepare two identical experiment sets: one for flight and one for ground control. In parallel, the Biorack Team prepared the PTCUs, checked-in experiments, loaded them, verified stowage configurations and formally handed over the hardware to NASA approximately twelve hours before launch. These highly critical, concerted operations involving over forty people sharing one facility ran without problems.

The experiments, transported to the launch pad in an air-conditioned van, were loaded into four Shuttle Mid-deck Lockers. The ground control experiment set was similarly configured and stowed at the appropriate temperatures in the LSSF.

Table 1 — Biorack unit temperatures and experiment container capacities

Unit	Temperature	Max. number of experiment containers Type I (65 ml)	Type II (385 ml)
Freezer	−15°C ±0.5°C	9 (12 possible)	0
Cooler	+ 4°C ±0.5°C	18	4
Incubator A	+22°C ±0.5°C	24 + 16*	3
Incubator B	+37°C ±0.5°C	24 + 16*	3

* On two 1 g control centrifuges

Table 2 — Experiment controls

Earth 1 g	Spacelab 1 g	Spacelab μg	Meaning
0	0	0	No effect
0	0	1	Gravity effect
0	1	0	Effect of centrifuge
0	1	1	Environment, not gravity
0	1	2	Environment *and* gravity

0 — Baseline result
1 — Different from baseline
2 — Different from baseline and 1

Mission

After the successful launch and activation of Spacelab, the Biorack was switched on and the loading of experiments from the Shuttle Mid-deck into the Biorack started. Thereafter, 57 scheduled crew activities had to be executed for the duration of the mission.

A Biorack team at GSOC was responsible for the monitoring and control of experiment flight operations. In addition, since operation of the ground control experiments by the Biorack Team at the LSSF had to mirror the actual flight operations as closely as possible, a constant flow of data and information was maintained with the LSSF (Figs. 2 & 4). The data distribution and communication to and from the investigator teams, the operating team and GSOC was controlled from the LSSF. Within this system, 14 requests for re-planning or operational changes were implemented and 15 notes uplinked to the crew. By the end of the mission, almost all planned or re-planned activities had been performed successfully and on time, both in flight and on the ground.

Post-mission

The Shuttle 'Challenger', with Spacelab D-1 aboard, landed at Edwards Air Force Base 167½ h after lift-off. Here the experiments were transferred from the Shuttle Mid-deck to a waiting aircraft, which took off for KSC approximately 9 h later. Sixteen hours after the landing of the Shuttle, the experiments were returned to the investigator teams, including the ground control sets. Some investigators had then to perform immediate post-experiment preparations or analysis on site at KSC; others prepared for a quick return to Europe (Figs. 2 & 5).

Experiment results

Figure 6 lists the Biorack experiments flown on its first mission. The areas of investigation indicated for the various experiments relate to cell biological areas, and thus cell structure, cell proliferation, cell function, etc. The many different organisms flown will be used as a guideline here in presenting the results, starting with the most simple life form, the bacterium, and progressing to the most complicated life form in these experiments, the insect.

The D-1 flight was not the first on which biological experiments had been carried. On a number of previous flights — American, Russian and European — interesting reactions on the part of living organisms to the space environment had been observed. However, it had proved impossible to establish which characteristic of the space environment had caused these reactions: the microgravity, the radiation, the vibration of take-off, or some other factor.

To achieve this delineation, control experiments were performed in flight on Spacelab D-1 with a 1 g centrifuge. To provide the correct reference data, ground experiments were run synchronously with those in flight, in an identical facility located at the launch site. Thus, for the first time it was possible to establish whether a particular reaction to space conditions was due to microgravity or to some other factor. This gives the Spacelab D-1 series of experiments a scientific authoritativeness previously lacking in space biology.

The results have not yet been completely analysed, and from some experiments no conclusions can yet be drawn. In most cases, however, the main features of the results are already clear.

Experiments with bacteria

Bacteria, the simplest life form on Earth, are single cells not much more than one thousandth of a millimetre in length. Most perform functions essential to the very existence of life, though some can cause disease in higher organisms. Under favourable conditions they proliferate

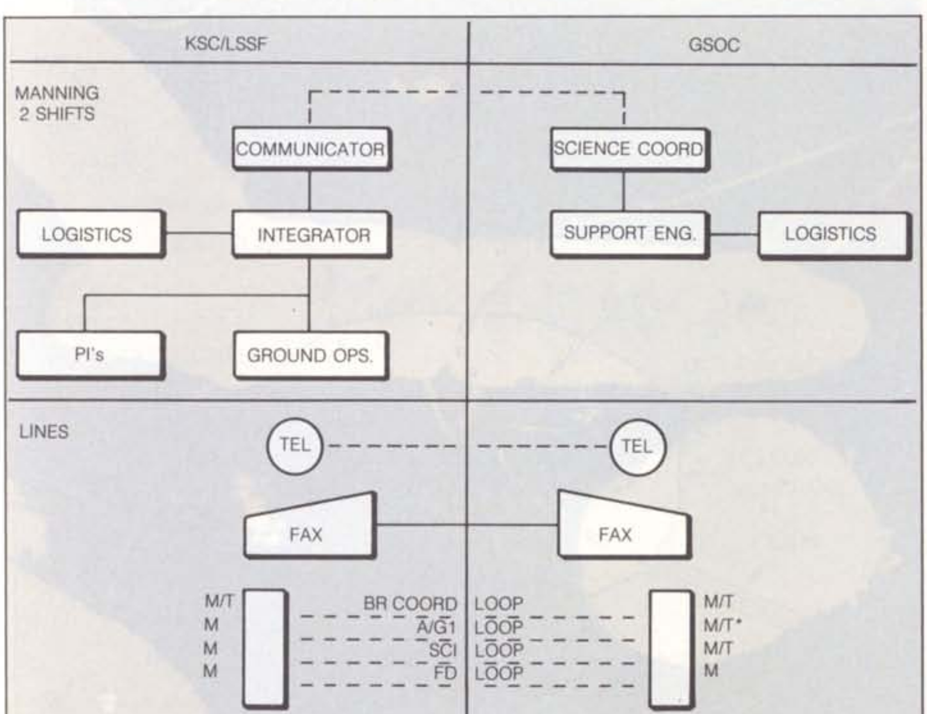


Figure 4 — Communication between the German Space Operations Centre (GSOC) and the Life-Science Support Facility (LSSF) at Kennedy Space Center

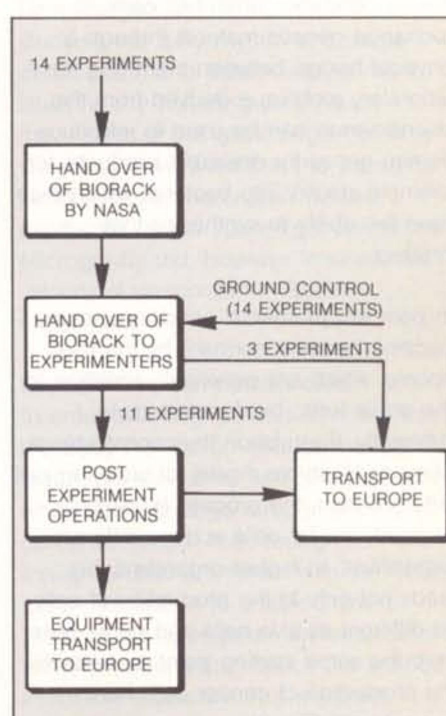


Figure 5 — Post-mission experiment flow

rapidly by repeated cell divisions. In such circumstances disease-causing bacteria can overcome the defence mechanisms of the body and produce a fatal illness. However, it is now generally possible to counteract such overwhelming infections with antibiotics.

Two Biorack experiments on bacteria, by Ciferri and Mennigmann, confirmed a finding that had been made on several previous flights, namely that bacteria proliferate more rapidly in space. The Mennigmann on-board control experiment failed, but Ciferri's experiment demonstrated unequivocally that the increase was due to microgravity. This finding is of interest not only scientifically, but also because it suggests that in space man may be exposed to greater hazards from infectious disease. An additional increase in risk is also suggested by Tixador's experiment, which demonstrated an increased resistance of a very common pathogenic organism, Escherischia coli, to antibiotics.

Some bacteria show a primitive form of sexual behaviour when two cells exchange genetic material through a physical bridge between them (Fig. 7). A laboratory technique derived from this phenomenon can be used to introduce human genes for desirable products, for example insulin, into bacteria, which then have the ability to synthesise that product.

In poor environmental conditions, many bacteria become dormant by forming spores, which are genetically identical to the active form, but function quite differently. Sporulation thus constitutes a convenient simple model for studying cell differentiation, the process by which originally similar cells acquire different capabilities. In higher organisms this leads not only to the production of cells as different as skin cells and nerve cells from the same starting point, but also to the production of cancer cells from normal cells (Fig. 8).

Figure 6 — Biorack experiments flown on the Spacelab D-1 mission

SUBJECT OF INVESTIGATION

EXPERIMENT	INVESTIGATOR	DIFFERENTIATION	STRUCTURE	FUNCTION	PROLIFERATION	INTERACTION	EMBRYOGENESIS	EFFECT OF	ORGANISM
48 F	M.BOUTEILLE	●							PLASMA CELLS
39 F	G. PERBAL	●----	----	●					LENTIL SEEDS
21 F	H. PLANEL	●--	●						PARAMECIUM
28 D	H. MENNIGMANN		●----	----	----	●			BACTERIA
58 F	R. TIXADOR		●--	●					BACTERIA
33 CH	A. COGOLI		●--	●					LYMPHOCYTES
16 D	V. SOBICK			●				MICRO-GRAVITY	SLIME MOLD
32 CH	A. COGOLI			●--	●				HUMAN BLOOD
7 I	O. CIFERRI				●				BACTERIA
52 NL	G.A. UBBELS				●----	----	●		AMPHIBIAN EGGS
15 E	R. MARCO					●--	●		FRUIT FLY EGGS
18 D	H. BÜCKER						●		STICK INSECT EGGS
19 D	H. BÜCKER							● RADIATION	NONE
27 D	D.MERGENHAGEN			●				ORBIT	GREEN ALGAE

Figure 7 — Bacterial conjugation

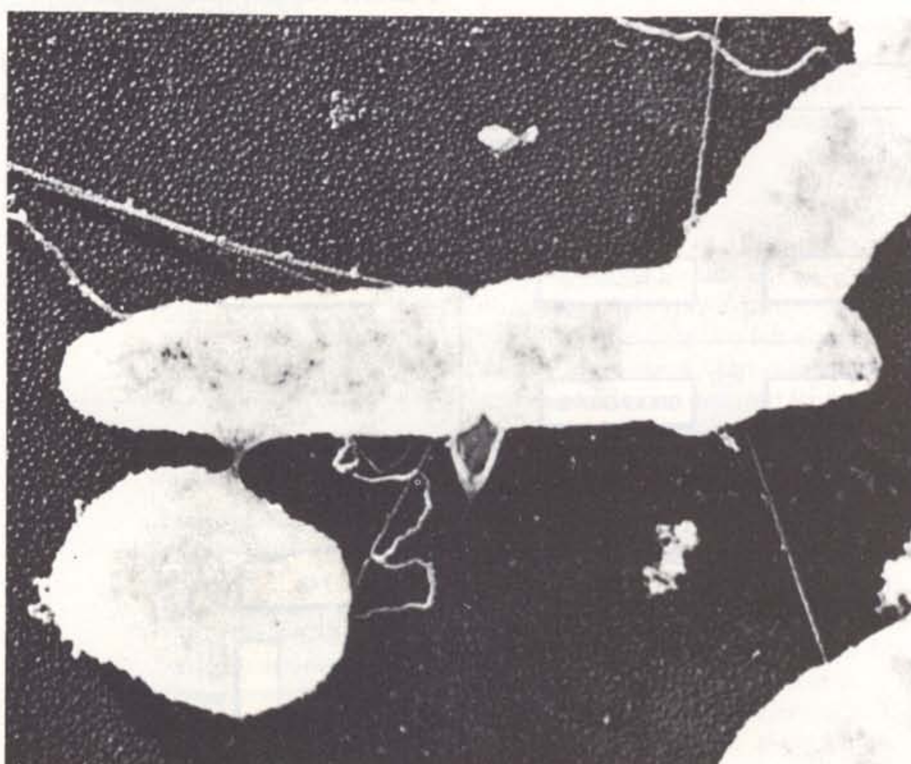
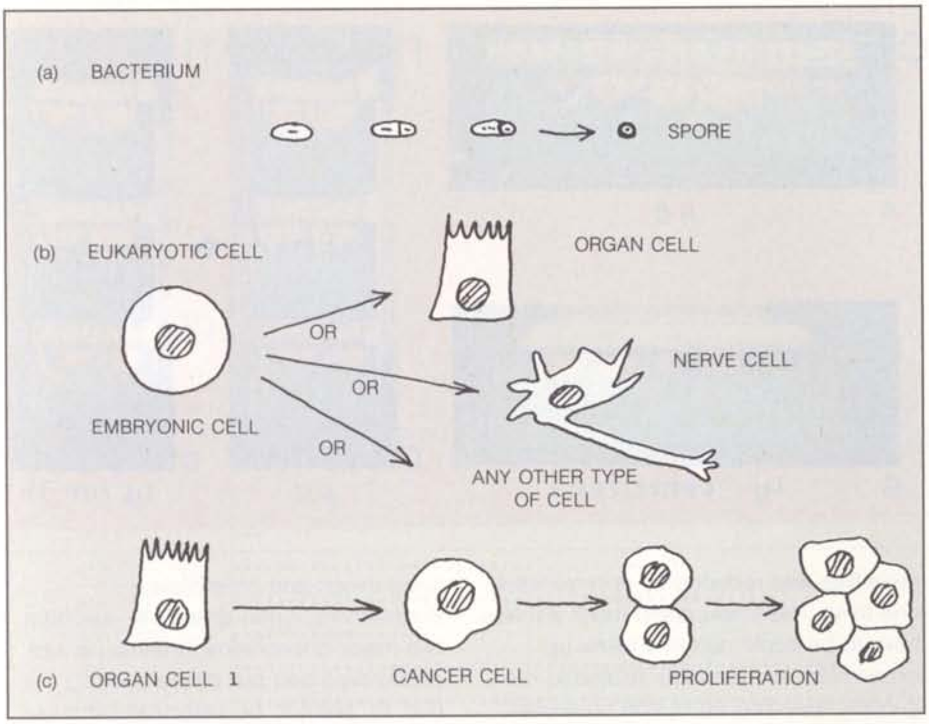
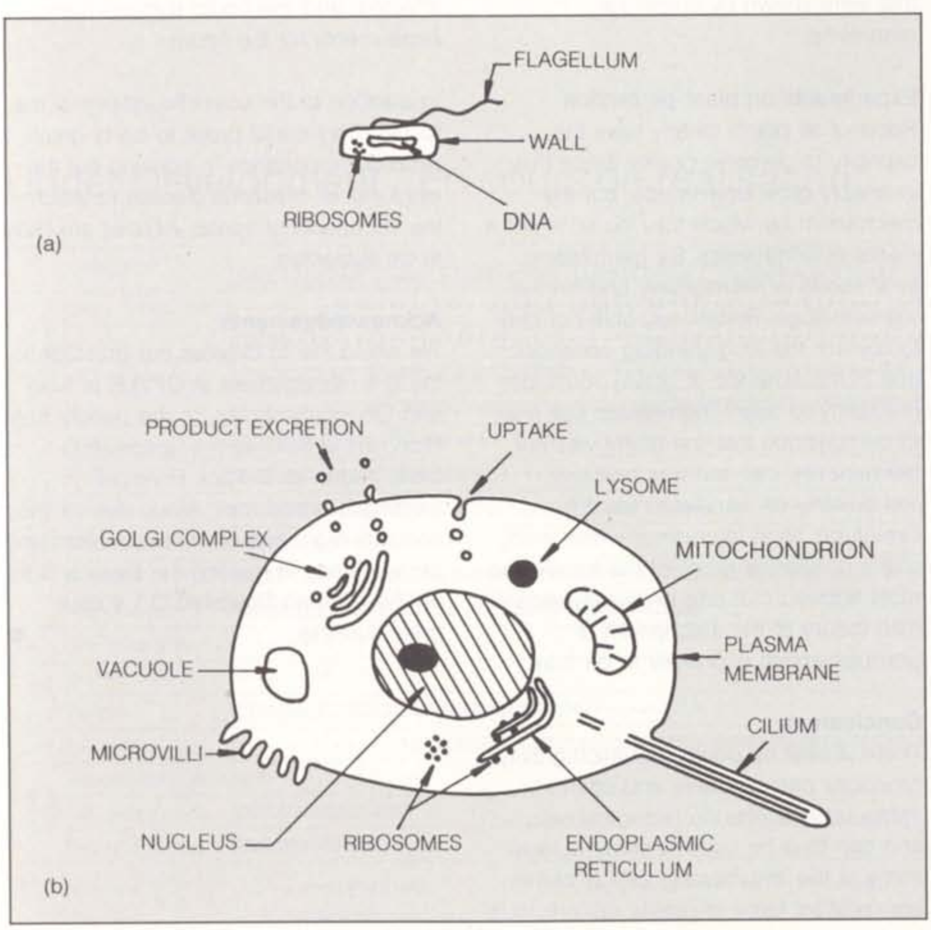


Figure 8 — Highly schematic representations of cell differentiation.
(a) A bacterial cell transforming into a spore.
(b) An embryonic cell developing into an organ cell, or nerve cell, or any other cell type present in a multicellular body.
(c) In cancer, functional cells transform into cells that have lost their meaningful function and enter endless proliferation. Cell differentiation appears to be retarded under microgravity conditions. In contrast, cell proliferation appears to be accelerated in bacteria and unicellular organisms under microgravity

Figure 9 — Highly schematic representations of a typical prokaryotic (bacterial) cell (a) and an eukaryotic unicellular organism (b)





Mennigmann's experiment on B-subtilus showed a striking reduction in sporulation and thus in differentiation. Unfortunately, his control experiment on the 1 g centrifuge failed to function, and so it is not possible to conclude definitively that the reduction was due to microgravity.

Experiments on other unicellular organisms

Many organisms other than bacteria consist of single cells, but cells that are much larger (tens or hundreds of times the size of bacteria) and much more complicated, possessing a variety of internal structures which perform most of the functions of the organs of higher plants or animals (Fig. 9). They may be either plants or animals, but like bacteria they can proliferate simply through repeated cell division.

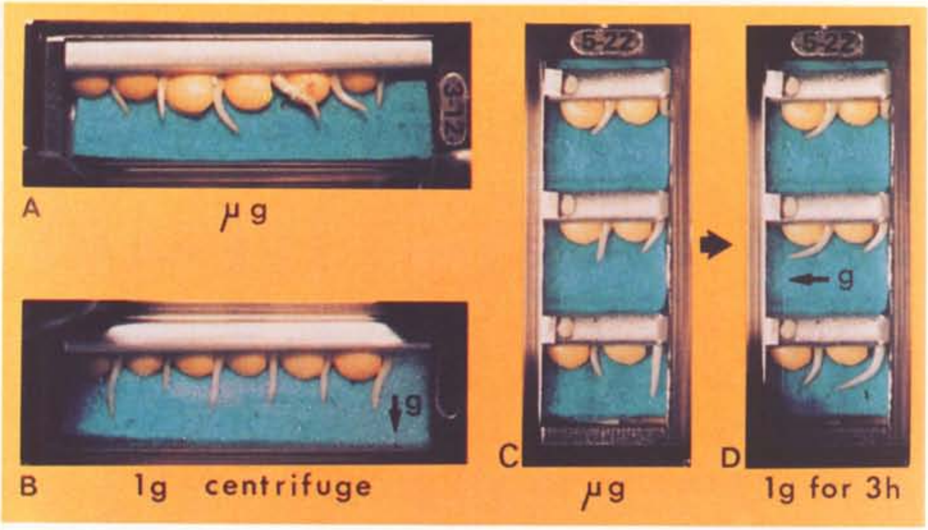
The Biorack experiments of Planel and Mergenhagen showed that in these other unicellular organisms, as in bacteria, microgravity increased the rate of proliferation; in Planel's experiment the increase was fourfold.

Both Mergenhagen's experiment, studying the daily rhythm of a single-celled plant, and Sobick's experiment, studying the pulsating protoplasm movements of the giant single cell of a slime-mould, showed that the biological periodicities of the organism were unaffected by the spaceflight conditions. Microgravity did, however, increase the velocity of protoplasm in Sobick's experiment.

Experiments with human cells

In order to recognise and eliminate from the body the foreign cells or materials that might reduce its well-being, certain white blood cells go through a process called activation. They recognise the foreign protein or interact with the foreign cells, differentiate to enable them to produce the appropriate antibody, and finally proliferate to produce the antibody in sufficient quantity. This extremely complicated process can be carried out

Figure 10 — Lentil roots grown in microgravity (A) or on the centrifuge (B). Roots grown in microgravity first (C) react normally to a 1 g acceleration if put on the centrifuge (D)



in a test tube, and was the subject of two Biorack experiments carried out by Cogoli to follow up observations made on previous flights, both by himself and others.

Cogoli's experiments made it clear that microgravity almost completely inhibits the whole process of activation, whether in cultures of white cells previously prepared on the ground, or in blood samples taken from the crew in flight. The next step must be to discover which stage of the process is affected. In any case, the results already obtained suggest a further increased risk of infectious disease which, in conjunction with the findings of increased proliferation and antibiotic resistance in bacteria, must be taken seriously in planning for future spaceflights.

Experiments on development

Differentiation, besides being relevant to sporulation and blood-cell activation, is clearly of vital importance in the development of the embryo (Fig. 8). Three experiments related to this topic were flown. One, on toad's eggs, failed for technical reasons. The second, carried out by Marco on the eggs of the much-studied fruit fly Drosophila melanogaster, showed that microgravity reduced the rate of development to only 10 % of the normal rate. From the third, Bücker's experiment on stick-insect eggs, only preliminary results are at present available, but these too suggest a similar slowing of development.

It is tempting, although perhaps premature, to regard the inhibition of bacterial sporulation and of white-blood-cell activation, together with this retardation of insect development, as strongly suggestive of a general inhibiting effect of microgravity on cell differentiation. At the very least, these findings open up a promising new field of space research.

Another interesting finding from Marco's experiment was that the lifespan of his male flies was reduced by approximately one third. This unexpected result will also have to be confirmed in a follow-up experiment, and possibly related to the general speeding up of vital processes that were shown by unicellular organisms.

Experiments on plant perception

Roots of all plants clearly have the capacity to perceive gravity, since they invariably grow downwards, but the mechanism by which they do so is still a matter of controversy. By germinating lentil seeds in microgravity and on the 1 g centrifuge, Perbal was able not only to confirm the long-standing observation that in the absence of gravity roots lose the ability to orient themselves, but also to demonstrate that the ability was not permanently lost, but was restored immediately on transfer to the 1 g centrifuge. Most interestingly, later study of the cellular structure of the transferred roots showed that one previously widely held theory of the mechanism of graviperception is unlikely to be true.

Conclusions

There is now no doubt that microgravity produces demonstrable and often measurable effects on biological cells, and can thus be used to study at least some of the innumerable effects of the omnipresent force of gravity on individual living things and on evolution. Furthermore, it can already be said that two major phenomena in particular, cell proliferation and cell differentiation (Fig. 8), seem to be particularly strongly affected, and this could suggest many experiments for the future.

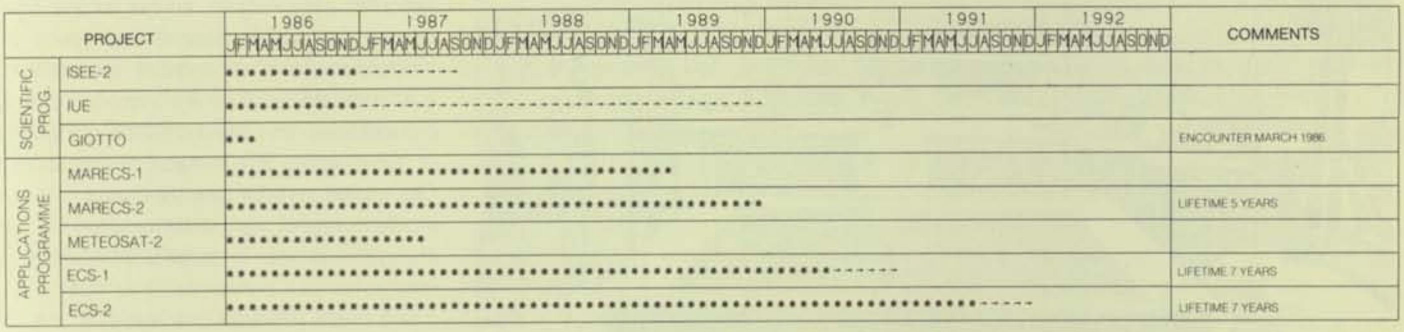
In addition to the scientific interest of the results, they could prove to be of great practical importance in pointing out the extra risk of infectious disease to which the occupants of space vehicles are likely to be subjected.

Acknowledgements

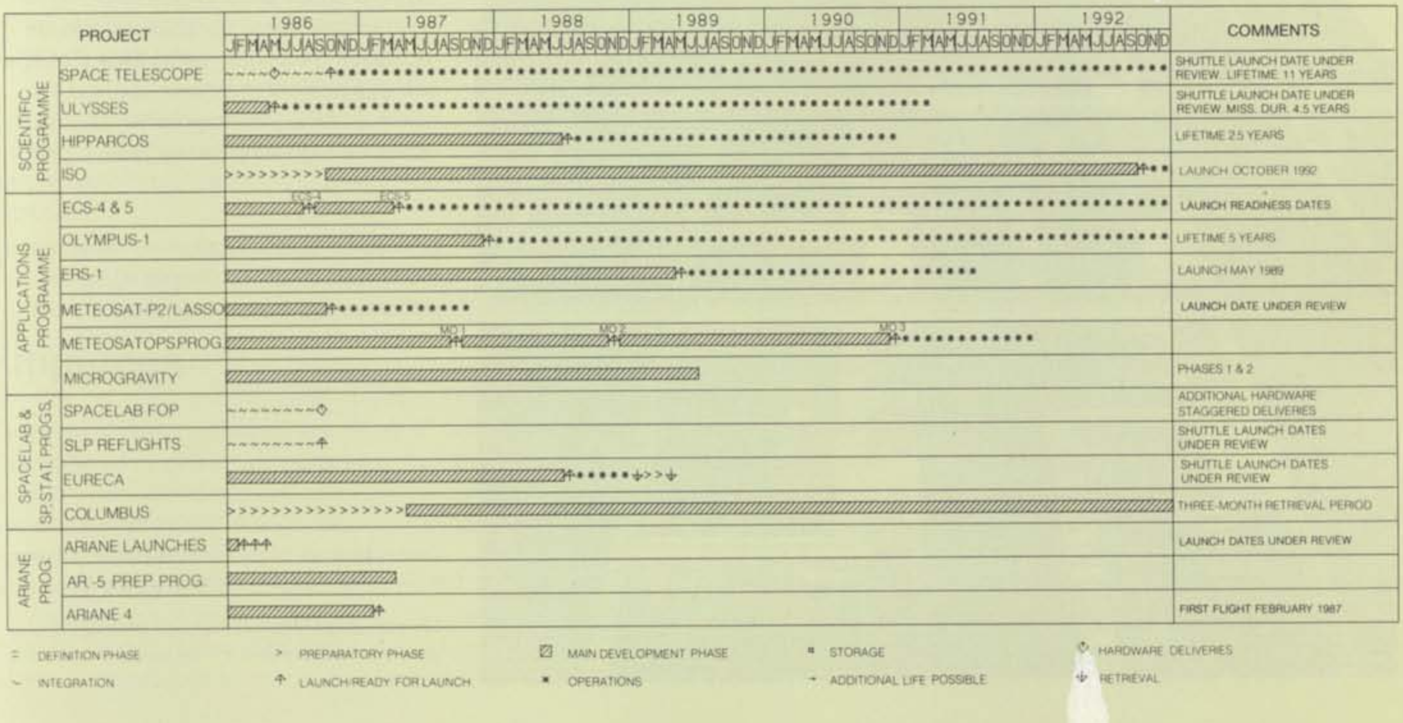
We would like to express our gratitude to the D-1 management at DFVLR in Köln and Oberpfaffenhofen, to the people from Bionetics at KSC, to the Spacelab D-1 crew, and to all Biorack Principal Investigators and their Associates for their constant high level of professionalism and perseverance in making the Biorack flight on the German Spacelab D-1 such a great success.

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

In Orbit / En orbite



Under Development / En cours de réalisation



= DEFINITION PHASE — > PREPARATORY PHASE — ▨ MAIN DEVELOPMENT PHASE — ▪ STORAGE — ♢ HARDWARE DELIVERIES

~ INTEGRATION — ↑ LAUNCH/READY FOR LAUNCH — • OPERATIONS — - ADDITIONAL LIFE POSSIBLE — ↓ RETRIEVAL

Marecs

Marecs-B2, qui a pris la relève de Marecs-A le 28 février, en tant que satellite principal d'INMARSAT au-dessus de l'Océan Atlantique, continue à assurer un service exemplaire.

Après une manoeuvre de repositionnement parfaite, à un rythme de dérive de 3°/jour, Marecs-A a été placé à sa nouvelle longitude de service de 178°E, au-dessus des Iles Gilbert dans l'Océan Pacifique le 12 mai. Depuis, il sert de satellite de secours à INMARSAT sur l'Océan Pacifique.

Télescope spatial

Activités de la NASA

Le calendrier des activités à court terme reste inchangé à la suite de la perte de Challenger. Le Télescope spatial a subi une pré-vérification en vide-température en avril 1986 et subit actuellement des essais en vide-température qui dureront un mois et demi. Jusqu'ici, aucun problème majeur n'a été constaté au cours des essais.

Aucune nouvelle date de lancement n'a été fixée, mais pour des raisons budgétaires la NASA a retenu la date de décembre 1987.

Générateur solaire

Les ailes du modèle de vol ont subi leur programme de vérification et ont été remises à la NASA à la mi-mai. Elles seront installées sur le Télescope spatial à l'achèvement de ses essais en vide-température.

Chambre pour objets faibles

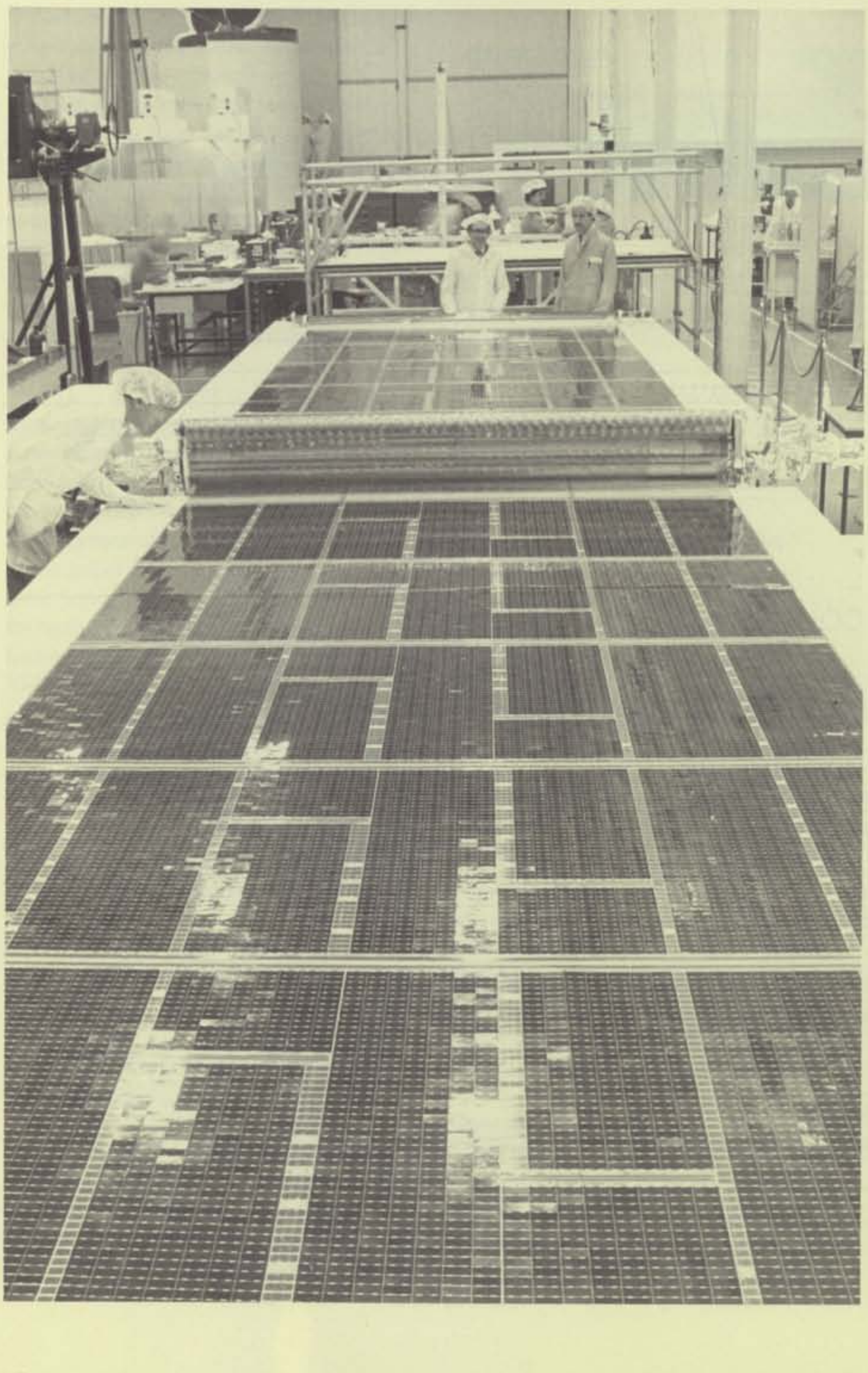
Cette chambre continue à fonctionner sans problème sur le Télescope spatial.

Hipparcos

Un certain nombre d'activités essentielles ont été menées à bien depuis la publication du dernier rapport d'avancement. Les essais optiques et mécaniques des modules séparés charge utile et véhicule spatial ont été exécutés avec succès, ce qui en a permis l'intégration pour réaliser le modèle structurel du satellite. Le satellite a ensuite été expédié à Intespace où a été exécutée une série d'essais statiques et dynamiques aux niveaux qualification. Ces essais se sont déroulés sans incident majeur, les performances enregistrées pour le satellite se révélant conformes aux prévisions. A la suite d'une revue détaillée des résultats d'essais, le satellite a été déclaré qualifié pour la partie mécanique.

Les essais mécaniques ont été suivis par les préparatifs des essais en vide-température. La charge utile a été extraite du modèle structurel et le satellite expédié chez Fokker (Pays-Bas), contractant chargé du sous-système de régulation thermique. Le satellite y a reçu son équipement thermique avant d'être confié à IABG (Allemagne) en vue des essais en vide-température prévus pour juin.

Le modèle d'identification du télescope a été envoyé chez IAL (Belgique) où les performances optiques (erreur de front



Solar-array wings for the Space Telescope, delivered to ESA/NASA by British Aerospace in mid-May

Les ailes du générateur solaire du Télescope spatial ont été remises par BAe à l'ESA puis à la NASA à la mi-mai

Marecs

Marecs-B2, since taking over from Marecs-A on 28 February as INMARSAT's prime spacecraft for the Atlantic Ocean Region, has continued to provide exemplary service.

After a completely nominal relocation manoeuvre at a drift rate of 3°/day, Marecs-A was halted at its new operational longitude of 175°E, above the Gilbert Islands in the Pacific Ocean Region, on 12 May. Since then, it has functioned as the spare INMARSAT spacecraft for this region.

Space Telescope

NASA activities
The near-term schedule of activities remains unchanged despite the loss of the 'Challenger'. The Space Telescope completed pre-thermal-vacuum checkout in April and a month and a half of thermal vacuum testing is now under way. No major problems have surfaced so far during the test.

No new launch date has been set, but for budgetary purposes NASA is using a date of December 1987.

Solar array
The flight wings have completed their verification programme and were delivered to NASA in mid May. The wings will be fitted to the Space Telescope after completion of the ST thermal-vacuum test.

Faint Object Camera
The Faint Object Camera continues to operate without problems in the Space Telescope.

Hipparcos

A number of major activities have been accomplished since the last progress statement was issued. Optical and mechanical testing of the separate payload and spacecraft modules has been successfully achieved, permitting their integration to form the satellite structural model. The satellite was subsequently shipped to Intespace, where a series of static and dynamic tests at qualification levels have been performed. These tests were conducted without major incident, with the satellite measured performances proving to be in accordance with predictions. Following a detailed review of the test results, the satellite has been declared mechanically qualified.

The mechanical testing was followed by preparations for thermal-vacuum testing. The payload was removed from the structural model and the spacecraft shipped to Fokker (NL), the contractor responsible for the thermal-control subsystem. There, the spacecraft was equipped with thermal hardware, before being transferred to IABG (D) in readiness for the thermal-vacuum testing planned for June.

The engineering-model telescope assembly was shipped to IAL (B), where the optical performances (wave-front error) were measured in the 'FOCAL' vacuum facility. Test results seem to be acceptable, but further analysis has still to be carried out.

Testing of the engineering-model Focal Plane Assembly (FPA) has given satisfactory results to date. Electromagnetic-compatibility testing of the Assembly has recently been satisfactorily concluded.

Subsystem integration on the electrical pre-integration model of the spacecraft is well in hand at Aeritalia (I). Harness, telecommunications, data-handling and on-board software have been integrated and are functioning well. Power and AOCS subsystems are experiencing some difficulties, and their anticipated late deliveries are putting strains on the integration schedule.

Payload Proto-Flight Model (PFM) activities are progressing at full speed. The payload is phased somewhat in advance of the corresponding PFM spacecraft activities and many of the PFM units have already been built and delivered, permitting integration of the Focal Plane Assembly to start. Integration of the PFM Telescope Assembly is scheduled to begin in June.

The Critical Design Review is currently in progress. The data pack for the review was delivered in mid-May and is being scrutinised by the review panels. The review board is scheduled to convene in mid June, when its findings will be published.

Solar Terrestrial Programme (STP)

At its meeting on 7 February, the Science Programme Committee (SPC) approved the Solar Terrestrial Programme (STP) as the next scientific project, with a financial ceiling of 400 MAU (1984 prices/1985 exchange rate), plus a contingency.

The STP was studied at Phase-A level in the context of the Soho and Cluster projects, but unfortunately the associated cost estimates significantly exceed the SPC's limit. Subsequent activities have therefore been directed at reducing the ESA funding requirements for STP, to remain below the financial ceiling. Discussions have taken place with both NASA and IKI (USSR) to determine possibilities for extensive collaboration and the response has been encouraging: both avenues will continue to be pursued.

In addition, descoping studies have been initiated and in this context an STP Science Advisory Group has been established, with members drawn from within the scientific community.

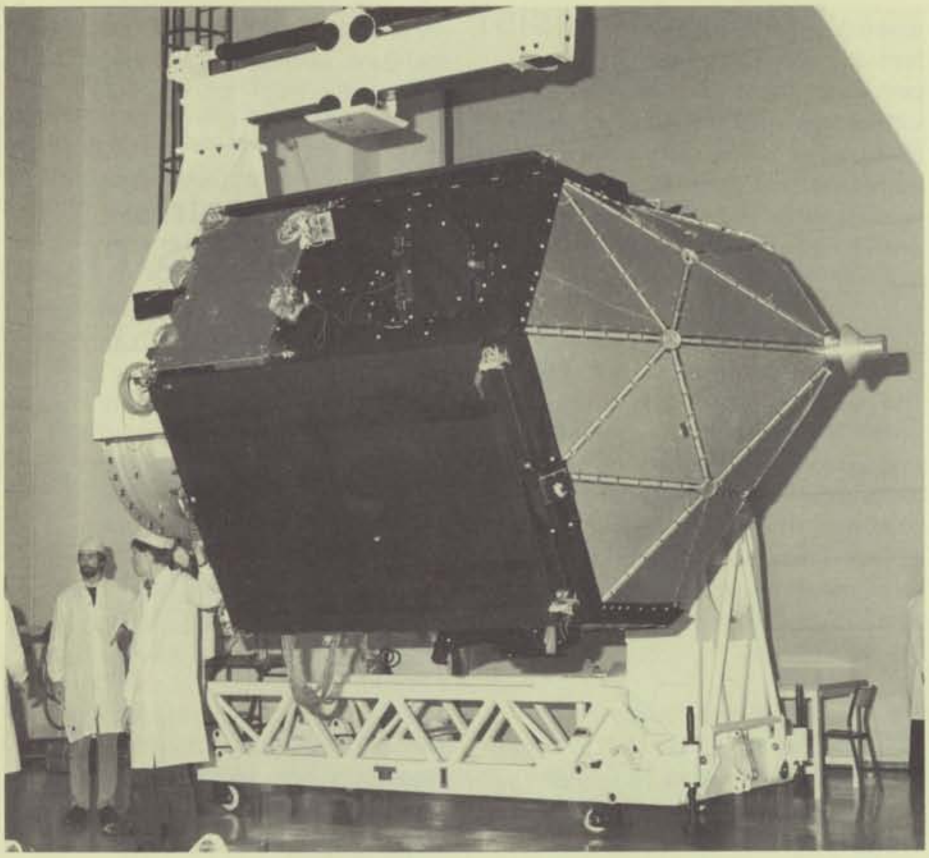
It is currently planned to establish the degree of international cooperation by the end of November 1986. This should permit a Call for Experiment Proposals (CEP) to be issued by the end of February 1987.

Olympus

The Critical Design Review for the 20/30 GHz repeater payload was held in April: this was the last of the four payload critical design reviews. The solar-array subsystem critical design review was held in May.

The planned series of activities with the structural-model spacecraft has successfully been completed. Detailed examinations of the structure and its elements have been made and the final reports are being issued.

An appendage release test under



Hipparcos structural model spacecraft being readied for thermal-vacuum testing at Intespace, Toulouse (F)

Préparatifs pour les essais en vide-température du modèle de structure d'Hipparcos chez Intespace à Toulouse

d'onde) ont été mesurées dans l'installation sous vide FOCAL. Si les performances peuvent être considérées comme acceptables, une analyse complémentaire doit cependant être exécutée.

Les essais du modèle d'identification de l'ensemble au plan focal ont donné jusqu'ici des résultats satisfaisants. Les essais de compatibilité électro-magnétique de cet ensemble ont récemment pris fin avec des résultats satisfaisants.

L'intégration du sous-système au modèle électrique de préintégration du satellite est bien avancée chez Aeritalia (Italie). La distribution électrique, les télécommunications, le traitement des données et le logiciel de bord ont été intégrés et fonctionnent de façon satisfaisante. Les sous-systèmes d'alimentation et de commande d'attitude et d'orbite soulèvent quelques difficultés, et le retard prévu pour leur livraison risque de se répercuter sur le calendrier d'intégration.

Les activités du prototype modèle de vol de la charge utile se déroulent à un rythme soutenu. La charge utile est prévue un peu en avance des activités correspondantes relatives au satellite, et de nombreuses unités destinées audit modèle ont déjà été réalisées et livrées, permettant ainsi d'entamer l'intégration de l'ensemble au plan focal. L'intégration de l'ensemble télescope devrait commencer en juin.

La revue de conception critique est en cours. Le dossier de la revue a été communiqué à la mi-mai et les responsables sont en train de l'étudier. Le comité de revue devrait se réunir à la mi-juin, date à laquelle ses constatations seront publiées.

STP

Lors de sa réunion du 7 février 1986, le Comité des programmes scientifiques a retenu le programme d'étude des relations Soleil—Terre comme prochain projet scientifique avec un plafond financier de 400 MUC (prix 1984/taux de change 1985), plus une marge de sécurité.

Le rapport STP a été étudié au niveau phase A dans le contexte des projets Soho et Cluster, mais malheureusement les estimations de coûts correspondantes dépassent nettement la limite fixée par le comité. Les activités ultérieures ont donc visé à réduire le financement de l'ESA pour le programme STP afin de rester en deçà du plafond financier fixé. Des discussions ont eu lieu avec la NASA et l'IKI (URSS) pour étudier l'éventualité d'une collaboration étendue et la réponse est encourageante: les deux voies seront poursuivies.

En outre, des études de réduction de projet ont été lancées, et dans ce contexte a été créé un groupe consultatif dont les membres sont issus de la communauté scientifique.

Il est prévu de déterminer le degré de coopération internationale d'ici la fin novembre. Ceci devrait permettre de lancer un appel aux propositions d'expériences d'ici la fin février 1987.

Olympus

La revue de conception critique concernant la charge utile du répéteur à 20/30 GHz s'est tenue en avril; il s'agissait de la dernière des quatre revues de conception critique de la charge utile. La revue de conception critique du sous-système de panneaux s'est tenue en mai.

La série d'essais concernant le modèle de structure s'est déroulée normalement. On a procédé à un examen détaillé de la structure et de ses éléments et les rapports finals ont été établis.

Un essai de libération des appendices sous vide thermique avec utilisation du modèle thermique du satellite a confirmé que les photopiles, les antennes déployables et autres dispositifs de maintien se libèreront correctement dans les conditions les plus défavorables. L'essai a également permis de vérifier la technique d'un essai similaire qui sera exécuté ultérieurement sur le modèle de vol du satellite.

Les modules d'intervention et de communication du modèle d'identification thermal vacuum using the reconfigured thermal-model spacecraft has confirmed that the solar array, deployable antennas and other hold-down devices will release successfully under predicted worst-case environmental conditions in orbit. The test also verified the technique for a similar test to be made later on the flight-model spacecraft.

Service and communication modules of the engineering-model spacecraft have been mechanically and electrically integrated, each having completed its own test programme. The spacecraft was then installed at the beginning of April in the anechoic chamber at Selenia, where it has been undergoing baseline testing as part of the overall payload test programme.

Integration of the flight equipment units into the flight-model spacecraft has continued at module level. The harness and telemetry, tracking and command subsystems have been installed on the service module, the propellant tanks have been fitted to the propulsion module, and the four payload repeaters are being assembled and tested with their respective communication module panels.

Construction of the in-orbit control station and control room by Telespazio is virtually complete and contracts are being placed for the transportable ground stations for the in-orbit testing of the 20/30 GHz and television-broadcast payloads.

ERS-1

Basic agreements have been reached with industry on the overall contract, together with the associated major specifications and plans.

The successful launch and operation of SPOT-1 have confirmed the platform design to be used for ERS-1. ESA is being kept closely informed by CNES of the in-flight results and experience with SPOT-1.

Manufacturing for the structural model is advancing well. Static and dynamic analyses have confirmed that specifications are being met. Design and development work on the payload is proceeding close to plan. Many subsystems are already breadboarded or have been built as development models and are being tested. The first Mechanical Ground Support Equipment (MGSE) items for satellite integration have been delivered.

The Design Baseline Review for the Kiruna station is scheduled to take place on 26/27 June.

The second part of the C-band scatterometer campaign over the Mediterranean has been performed in the Straits of Sicily. A very good data set has been obtained with the airborne scatterometer, with measurements of wind speeds up to 30 m/s. Preparations for the Autumn Amazonian rain forest campaign are proceeding according to schedule.

Meteosat

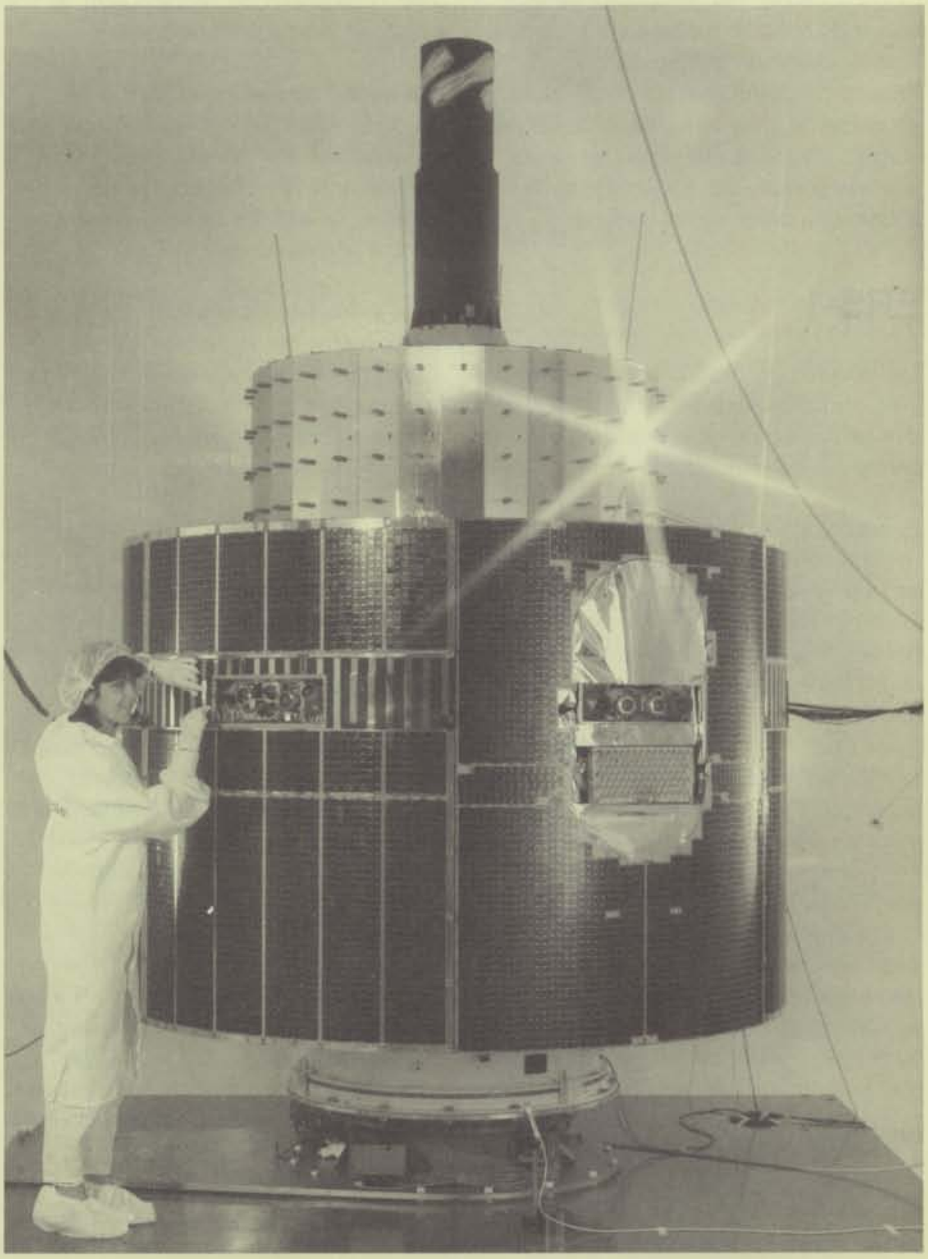
Pre-operational programme

The final phase of testing on the P2 satellite, which started at the beginning of the year with integration of the Lasso flight equipment, has proceeded smoothly.

Performance tests were carried out after the acoustic/vibration tests at Ariane-4 levels. No major anomalies were detected. The satellite will now be stored until launch.

Le satellite Météosat P2 à l'Aérospatiale, Cannes

Meteosat P2 spacecraft, photographed at Aerospatiale in Cannes (F)



du satellite ont subi leur intégration mécanique et électrique, chacun ayant terminé son propre programme d'essais. Le satellite a ensuite été installé, début avril, dans la chambre anéchoïque de Selenia où il a commencé à subir les essais de base dans le cadre du programme d'essais global de la charge utile.

L'intégration des unités de vol dans le modèle de vol du satellite s'est poursuivie au niveau des modules. Les sous-systèmes de câblage électrique et de TM/TC/LOC ont été installés dans le module d'intervention, les réservoirs d'ergols ont été placés sur le module propulsif et les quatre répéteurs de la charge utile sont en cours de montage et d'essais avec leurs panneaux respectifs du module de télécommunications.

La construction, par Telespazio, de la station de contrôle en orbite et de la salle de contrôle est pratiquement terminée et des contrats sont en cours de passation pour des stations terriennes mobiles destinées aux essais en orbite des charges utiles à 20/30 GHz et de diffusion de programmes télévisés.

ERS-1

Des accords de base ont été conclus avec l'industrie au sujet du contrat d'ensemble et des spécifications et plans principaux correspondants.

Le succès du lancement et de l'exploitation de SPOT-1 a confirmé la conception de plate-forme à utiliser pour ERS-1. L'ESA est tenue informée en détail par le CNES des résultats obtenus et de l'expérience accumulée en vol sur SPOT-1.

La fabrication du modèle structurel progresse correctement. Les résultats des analyses statiques et dynamiques confirment le respect des spécifications. Les travaux de conception et de développement de la charge utile se déroulent conformément aux prévisions. De nombreux sous-systèmes sont déjà au stade de maquette ou existent sous la forme de modèles de développement et sont en cours d'essai. Les premiers éléments du matériel d'assistance mécanique au sol destinés à l'intégration du satellite ont été livrés.

La revue des bases de référence de la conception de la station de Kiruna est prévue pour les 26/27 juin.

Le second volet de la campagne 'diffusiomètre' en bande C sur la Méditerranée a été exécuté dans le Détroit de Messine. Les données recueillies par le diffusiomètre embarqué sur avion sont très intéressantes et l'on a mesuré des vents de 30 m/s. Les préparatifs de la campagne sur la forêt tropicale amazonienne prévue pour l'automne se déroulent selon le calendrier.

Météosat

Programme préopérationnel

La phase finale des essais du satellite P2, commencée au début de l'année avec l'intégration de l'équipement de vol Lasso, se déroule normalement.

Des essais de performances ont été exécutés après les essais acoustiques et de vibrations aux niveaux Ariane-4. Aucune anomalie majeure n'a été décelée. Le satellite va être entreposé jusqu'à son lancement.

Suite à l'échec d'Ariane V18 du 31 mai, la campagne de lancement Météosat P2 a été reportée à une date ultérieure. Le nouveau Manifeste Ariane devrait être connue début juillet avec la nouvelle date de lancement de P2.

Lasso

Après la vérification sur satellite, on a testé la compatibilité de l'équipement Lasso avec les autres sous-systèmes. Aucun problème n'a été constaté.

Le rétroréflecteur de vol a été admis en recette et placé dans un conteneur spécial. Il sera installé sur le satellite à l'achèvement des opérations d'intégration au centre de lancement, pendant la campagne de lancement.

La proposition de Telespazio relative à la création et à l'exploitation du centre de coordination Lasso a été soumise à l'ESA. L'évaluation de cette proposition est terminée et des négociations sont en cours.

La réunion des utilisateurs Lasso, prévue pour les 3 et 4 juin à San Fernando, Espagne, a été repoussée aux 17 et 18 septembre.

Programme opérationnel

Secteur spatial

La fabrication des sous-systèmes du premier satellite opérationnel est en cours, l'intégration devant commencer en septembre. La revue des bases de référence de la production a eu lieu en avril et le Conseil s'est réuni à la mi-mai.

La recommandation finale concernant le feu vert pour l'intégration attend la communication de données complémentaires de la part du maître d'oeuvre et leur évaluation.

Secteur terrien

Le réaménagement du secteur terrien s'est déroulé selon le calendrier; tous les éléments essentiels seront prêts pour le lancement de P2 et celui de MOP1.

Météosat F2 a subi un incident les 29 et 30 avril, une forte interférence ayant été constatée sur le canal de diffusion WEFAX. L'enquête a révélé que celle-ci était probablement due à une anomalie temporelle au niveau du répéteur terrien implanté à Kourou. Ce répéteur, qui sert à la mesure de la distance du satellite, fonctionne correctement depuis plus de huit ans. Le reste du système fonctionne normalement. Il reste suffisamment de combustible pour exploiter le satellite F2 (commandé en inclinaison) pendant 18 mois supplémentaires.

La mission de collecte de données est toujours assurée par le satellite GOES-IV. Cette opération se poursuivra jusqu'au lancement de Météosat P2.

Le secteur terrien a continué à donner toute satisfaction. Les produits météorologiques tirés des images recueillies ont été élargis. Les vecteurs de mouvement de nuages sont désormais également fournis à 06.00 GMT.

Les préparatifs de lancement du satellite P2 et de sa mise en service ultérieure sont bien avancés. Le simulateur de la phase de lancement et de première satellisation nécessaire à la formation de l'équipe de lancement, a été livré et contribue déjà au soutien des préparatifs de lancement.

As a result of the failure of the Ariane launcher on 31 May, the launch campaign for P2 has been postponed. The report on the launch failure, and possible consequences on the launch manifest, should be known in early July, at which time the launch date for P2 can be re-established.

Lasso

After checkout on the satellite, the Lasso equipment was tested for compatibility with the other subsystems and no problems were found.

The flight retroreflector has been accepted and placed in a special container. It will be installed on the satellite at the end of integration operations at the launch centre, during the launch campaign.

The Telespazio proposal for the setting up and operation of the Lasso coordination centre has been submitted to ESA. Evaluation of the bid has been completed and negotiations are now underway.

The Lasso users' meeting scheduled for 3—4 June, at San Fernando in Spain, has been postponed until 17—18 September.

Operational programme

Space segment

Manufacture of the subsystems for the first operational satellite is well underway, with integration due to start in September. The production baseline review took place in April, and the Board met in mid-May.

Final recommendation for integration go-ahead awaits delivery and evaluation of supplementary data from the prime contractor.

Ground segment

The refurbishment of the ground segment has progressed according to schedule, i.e. all major elements will be available to support both the P2 and MOP1 launches.

The Meteosat F2 satellite suffered a system anomaly on 29/30 April when severe interference was observed on the WEFAX dissemination channel. Investigations showed that this interference was probably caused by a temporary anomaly in the Land-Based Transponder located in Kourou. This transponder is used for satellite ranging and has operated successfully for over eight years. The rest of the system has been performing normally. There is enough fuel left to operate the F2 spacecraft (inclination-controlled) for another 1.5 years.

The data-collection mission is still being supported by the Goes-IV satellite and this will continue until the Meteosat P2 satellite is successfully launched.

The ground segment has continued to perform extremely well. The meteorological products extracted from the imagery data have been extended. Cloud-motion vectors are now also produced at 06.00 GMT on an experimental basis.

Preparations for the launch of the P2 satellite and its subsequent commissioning are well under way. The Launch and Early Orbit Phase (LEOP) simulator, required for launch-team training, has been delivered and is already being used in support of the preparatory launch activities.

Spacelab and IPS

Work is continuing on the remaining open tasks for both Spacelab and the Instrument Pointing System (IPS).

For Spacelab, both formal completion of system qualification and close-out of all exceptions from the acceptance of the Spacelab systems from the prime contractor have been achieved. The remaining work in progress is related to hardware failures that have occurred during the Spacelab missions.

ESA has been advised by the contractor that IPS activities will extend into September. A contractual change has been negotiated with Dornier to include financial coverage for the contractor's support to the Spacelab-2 mission and for several other post-delivery support tasks.

The formal Qualification Review for the Payload Interface Adaptor (PIA) has been completed, with a joint ESA/ERNO/Laben Board meeting in March 1986. Review actions are still in progress. Further testing has been performed to investigate performance outside specification at the data-bus interface and for EMC. The EMC problem has been confirmed; a design change affecting the qualification model and the eight flight units is required and is in preparation.

Additional tests are being performed on the Remote Acquisition Units (RAUs) procured for the Eureca programme, to verify their performance under the more severe environmental conditions affecting this application.

Discussions with MBB/ERNO are under way to close the Spacelab-C/D contract.

Follow-On Production (FOP)

On the Spacelab side, ESA's involvement has been limited to completion of activities agreed to be dealt with by ESA after the phase-over of responsibility to NASA at the end of January 1986. The last IPS items to be delivered to NASA (actuators) have been delayed by a test-chamber failure during acceptance testing.

Eureca

The Eureca System Design Review has been completed and major work is now concentrated on possible failure modes and their effects on critical operational sequences, as well as flight hardware and software interactions.

Manufacture and assembly of the Eureca flight structure is well under way and its delivery to BPD for further integration of the Reaction Control (RCA) and Orbit Transfer (OTA) Assemblies will start in July.

Integration of the Overall Check-Out Equipment (OCOE) is progressing well and delivery is planned for the beginning of August.

The thermal-vacuum test and the electromagnetic interference tests for the qualification model of the Magnetic Bubble Memory (MBM) have been successfully completed, although the vibration and power-interrupt tests have to be repeated.

The final presentation of the study addressing the development potential of Eureca towards space-based Space-Station-compatible platforms was held at

Spacelab et IPS

Les travaux se poursuivent sur les tâches restantes de Spacelab et du Système de Pointage d'Instruments (IPS).

Pour Spacelab, l'achèvement officiel de la qualification du système et la résolution de toutes les objections s'opposant à l'acceptation des systèmes Spacelab fournis par le maître d'oeuvre ont eu lieu. Les autres travaux en cours concernent les pannes de matériel qui se sont produites pendant les missions Spacelab.

L'ESA a été informée par le contractant que les activités IPS se prolongeront jusqu'en septembre. Une modification du contrat a été négociée avec Dornier pour que l'assistance du contractant pour la mission Spacelab-2 et plusieurs autres tâches de soutien postérieures à la livraison soient couvertes financièrement.

La revue de qualification officielle concernant l'adaptateur d'interface de charge utile est achevée, un comité conjoint ESA/ERNO/Laben s'étant réuni en mars. Des activités de revue sont toujours en cours. De nouveaux essais ont été exécutés pour analyser les performances ne respectant pas les spécifications au niveau de l'interface avec l'artère de données et en matière de compatibilité électromagnétique. Le problème posé par cette dernière s'est trouvé confirmé; la modification nécessaire, en cours de préparation, intéressera le modèle de qualification et les huit unités de vol.

Des essais complémentaires sont en cours sur les unités d'acquisition décentralisée fournies pour le programme Eureca afin de vérifier leurs performances dans les conditions d'environnement les plus sévères propres à cette application.

Des discussions avec MBB/ERNO sont en cours pour la conclusion du contrat Spacelab-C/D.

Production ultérieure
Côté Spacelab, la participation de l'ESA s'est limitée à l'achèvement des activités dont l'Agence avait accepté de se charger après le transfert de responsabilité à la NASA à la fin janvier 1986. Les derniers éléments du système de pointage d'instruments devant être livrés à la NASA (dispositifs d'actionnement) ont été retardés par une panne de la chambre d'essais pendant les essais de recette.

Eureca

La revue de conception de système Eureca est achevée; désormais, les travaux portent essentiellement sur les modes de défaillances possibles et leurs effets sur les séquences d'opérations critiques ainsi que sur les interactions entre matériel et logiciel de vol.

La fabrication et l'assemblage de la structure de vol Eureca sont bien avancés et la livraison de cette structure à BPD en vue de l'intégration des ensembles de pilotage par réaction et de transfert orbital débutera en juillet.

L'intégration des équipements de vérification générale progresse et leur livraison est prévue pour début août.

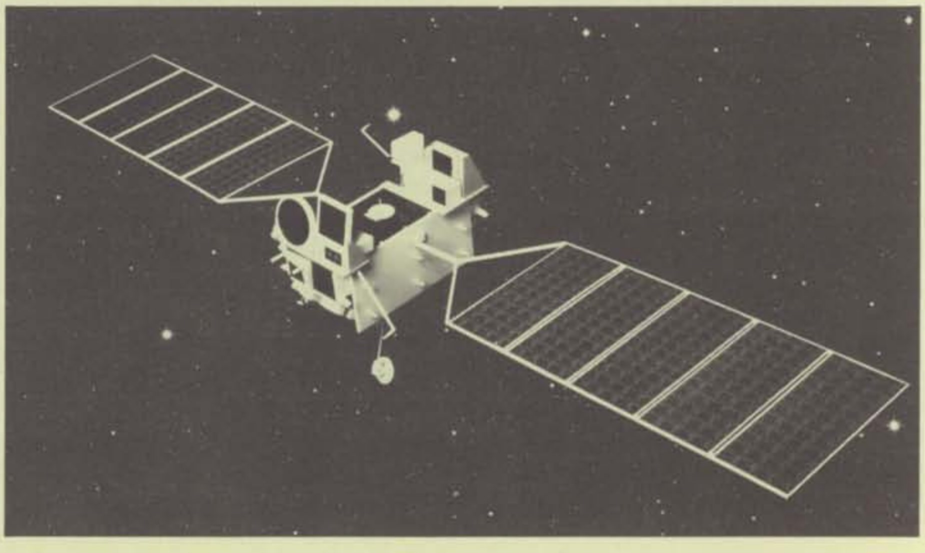
L'essai en vide-température et les essais d'interférence électromagnétique pour le modèle de qualification de la mémoire à bulles magnétiques ont été exécutés avec succès, bien que les essais de vibrations et de coupure d'alimentation doivent être répétés.

La présentation finale de l'étude concernant le potentiel qu'offre Eureca pour le développement de plates-formes spatiales compatibles avec la future station spatiale s'est tenue à l'ESTEC le 30 mai. Cette étude a apporté des données techniques et financières importantes, tant pour l'adaptation logique de la plate-forme en microgravité actuelle aux missions de science spatiale qu'en ce qui concerne l'éventualité d'une intervention limitée en orbite sur Eureca comme plate-forme co-orbitant avec la Station spatiale.

Une autre étude concernant les possibilités d'intervention d'Hermès sur des plates-formes du type Eureca, commencée en janvier, a déjà fourni des résultats intéressants à moyen terme.

Le contrat avec le DFVLR concernant l'utilisation du Centre de soutien aux utilisateurs de la microgravité (MUSC)de Porz Wahn, Allemagne, pour les installations de base du premier vol Eureca a démarré le 13 mai. En relation avec ce contrat, une réunion du groupe de travail sur la charge utile s'est tenue au DFVLR pour familiariser les chercheurs avec le centre en question et avec les services offerts.

Le développement des cinq installations multi-utilisateurs se déroule comme prévu; leurs revues de conception critiques devraient être terminées d'ici à septembre. L'essai des installations du modèle technologique commencera en novembre. Le planning actuel du projet Columbus comprend désormais l'acquisition, en option, d'une seconde plate-forme Eureca adaptée spécialement aux besoins de la science spatiale pour le système co-orbitant avec la Station spatiale internationale. Des discussions sont en cours avec la NASA et les autorités japonaises en ce qui concerne l'utilisation partagée des futurs vols Eureca.



Conceptual layout for a Eureca-based gamma-ray telescope model payload

Modèle d'arrangement de la plate-forme Eureca équipée d'un télescope en rayons gamma

ESTEC on 30 May. This study provided important technical and cost data for both the logical adaptation of the present Eureca microgravity platform for space science missions and the potential incorporation of limited in-orbit servicing for Eureca as a co-orbiting Space-Station platform.

A further study on the servicing of Eureca-type platforms by Hermes started in January and has already provided interesting mid-term results, establishing the feasibility in principle of using Hermes for servicing of platforms in the Eureca class.

The contract with DFVLR concerning the use of the Microgravity User Support Centre (MUSC) at Porz Wahn, Germany, for the core facilities on the first Eureca flight was initiated on 13 May. In connection with this contract, a meeting of the Payload Operation Working Group was held at DFVLR (Porz Wahn) to familiarise the investigators with the MUSC and the services offered.

The development of the five multi-user facilities is proceeding according to plan and they should complete their Critical Design Reviews by September. The testing of the Engineering Model Facilities will begin in November. The current planning for the Columbus Project now includes the optional procurement of a second Eureca Carrier, specifically adapted to space-science needs for the co-orbiting system with the International Space Station. Discussions are in progress with NASA and the Japanese authorities regarding the shared use of future Eureca flights.

Space Station/Columbus

Study Review 2 was held in February, and concentrated mainly on technical issues. One significant result was the technical recommendation to delete the Service Vehicle.

At the Columbus Programme Board in April, it was decided that the following elements will be included in Phase-B2 and preliminary design work:

- A pressurised module for permanent attachment to the NASA Space Station, to be launched by the Shuttle. This pressurised module will be used primarily for material sciences, fluid physics and life sciences.
- A Man-Tended Free Flyer (MTFF) consisting of a pressurised module and a resource module to be designed and developed for launch by Ariane-5. The MTFF is to be used for material sciences, fluid physics and life sciences.
- A polar platform primarily dedicated to Earth-observation user requirements and designed for launch by Ariane-5.
- An enhanced Eureca carrier to be deployed as a co-orbiting platform dedicated to a wide range of missions, in particular microgravity and space sciences. Furthermore, the early deployment of this carrier would allow experiments to be flown and operational concepts tested prior to availability of the Space Station.

The main criteria in selecting Columbus candidate elements were:

- compliance with the financial envelope
- responsiveness to European utilisation needs
- compatibility with NASA requirements
- enhancement of the overall Space-Station capability
- contribution to eventual European autonomy (i.e. utilisation of Ariane-5 and later Hermes).

Ariane

The Ariane V18 failure

Ariane V18, carrying an Intelsat V (F14) as its payload, was launched from the ELA-1 pad at 00 h 53 mn GMT on 31 May.

The flight of the first and second stages was nominal, and so was the second/third-stage separation. The third stage did not ignite, however, and it had to be destroyed together with the payload by the CSG range safety officer.

Evaluation of the first flight measurements showed:

- All commands for valve operation during the third-stage ignition phase were delivered by the onboard computer at the correct times, and valve status signals confirmed normal operation.
- The commmands to the third-stage igniter and turbopump starter were delivered correctly. Operation of the former was confirmed by the usual signal from the vibration transducer on the engine gimbal and that of the latter by the turbine rotation speed transducer.
- Tank pressures were normal until well after the nominal ignition time.
- The gas generator did not take over from the turbopomp starter because of a lack of LH_2 supply, resulting from LH_2 pump cavitation.

ESA and Arianespace have set up an independent Failure Enquiry Board to determine the cause of the V18 failure and to propose remedial action. The first report is to be available on 30 June (see page 73 of this issue).

The full consequences of the failure will be known only when the Board has reported its findings and made recommendations, and when the latters' implications have been assessed.

Ariane-4

Development and qualification

The development programme is progressing according to plan; the material qualification reviews are being completed with the final qualification tests on the equipment bay structure and on the SPELDA.

Due to the V18 failure, the launcher qualification review has been resheduled.

Material for the first flight

The solid strap-on boosters have been delivered, while the other elements of the launcher, except the 3rd stage, are in the final integration and test phase prior to shipment from Le Havre to Kourou on 21 July. The 3rd stage is to be transported, as in the past, by air.

Launch campaign

Prior to the V18 flight, the campaign was scheduled to start in August to culminate in a launch at the end of October 1986. This plan is likely to be modified in the light of the enquiry into the causes of the V18 failure and the recommendations made by the Board.

Station spatiale/Columbus

La deuxième revue d'étude qui s'est tenue en février a porté essentiellement sur les aspects techniques. Une de ses conséquences importantes est la recommandation technique de supprimer le véhicule d'intervention.

Lors du Conseil du programme Columbus d'avril 1986, il a été décidé que les éléments suivants seraient inclus dans la phase B2 et les travaux d'étude préliminaire:

- *Module pressurisé destiné à être associé en permanence à la Station spatiale de la NASA et qui sera lancé par la Navette. Ce module sera utilisé essentiellement pour les sciences des matériaux, la physique des fluides et les sciences de la vie.*
- *Une plate-forme autonome (MTFF) comprenant un module pressurisé et un module de ressources sera conçue et réalisée pour un lancement par Ariane-5. Elle sera utilisée pour les sciences des matériaux, la physique des fluides et les sciences de la vie.*
- *Une plate-forme méridienne destinée essentiellement à l'observation de la Terre et conçue pour être lancée par Ariane-5.*
- *Une plate-forme Eureca améliorée devant constituer une plate-forme co-orbitale destinée à un vaste éventail de missions, en particulier dans le domaine de la microgravité et de la science spatiale. De plus, le développement de cette plate-forme permettra d'embarquer des expériences et de tester des concepts d'opérations avant l'avènement de la Station spatiale.*

Les principaux critères de sélection des éléments pressentis pour le programme Columbus ont été les suivants:

- *respect de l'enveloppe financière*
- *respect des besoins des utilisateurs européens*
- *compatibilité avec les exigences de la NASA*
- *amélioration du potentiel global de la Station spatiale*
- *contribution à une autonomie européenne ultérieure (à savoir utilisation d'Ariane-5 et ultérieurement d'Hermès).*

Ariane

Echec du vol V18

Ariane V18, emportant le satellite Intelsat V F14, a été lancé de l'ensemble de lancement ELA-1 le 31 mai à 00 h 53 min TU. Le vol des deux premiers étages s'est déroulé comme prévu, de même que la séparation 2ème/3ème étages. Cependant l'allumage du moteur du 3ème étage n'ayant pas eu lieu, cet étage avec sa charge utile ont été détruits en vol sur ordre télécommandé par le responsable de la sauvegarde du CSG.

L'analyse des premiers résultats du vol a montré que:
- *toutes les commandes envoyées aux vannes moteur au cours de la phase d'allumage du 3ème étage ont été effectuées par le calculateur de bord aux moments prévus, et les signaux de position des vannes ont confirmé que ces commandes avaient été correctement exécutées;*
- *les commandes de l'allumeur du 3ème étage et du démarreur de la turbopompe ont été correctement effectuées. Leur fonctionnement a été confirmé pour le premier par le signal habituel du transducteur de vibrations installé sur le cardan du moteur et, pour le second, par les variations de la vitesse de rotation de la turbine;*
- *la pression dans les réservoirs était nominale pendant toute la durée normale de l'allumage et même au-delà;*
- *le générateur de gaz n'a pas pris la relève du démarreur en raison de l'absence d'alimentation en hydrogène liquide, due à une cavitation dans la pompe LH_2.*

Une commission d'enquête indépendante a été mise sur pied par l'Agence et Arianespace pour rechercher les causes de cette défaillance et proposer les remèdes appropriés. Un premier rapport d'enquête devait être soumis le 30 juin.

Les répurcussions de cet échec ne seront évaluées qu'une fois connus les résultats de l'enquête et les recommandations de la commission.

Progrès d'Ariane 4

Développement/qualification

Le programme de développement avance normalement; les revues de qualification des matériels sont en voie d'achèvement, avec la réalisation des derniers essais de qualification qui sont terminés sur la structure de la CASE et qui vont se terminer en juin sur SPELDA.

La Revue de qualification du lanceur est retardée suite à l'échec V18, un nouveau calendrier des réunions sera établi.

Matériels pour le premier vol

Les propulseurs d'appoint à poudre ont déjà livrés: les autres parties du lanceur sont en fin d'intégration et d'essais et étaient prévus d'être embarqués le 21 juillet sur le bateau au départ du Havre, à l'exception du troisième étage dont l'acheminement à Kourou devait être effectué, comme à l'accoutumée, par avion.

Campagne de lancement

Avant l'échec du vol V18, la campagne devait débuter courant août, pour aboutir à un lancement fin octobre 1986.

Ce plan sera très vraisemblablement remis en cause, suite aux investigations sur les causes de la défaillance du troisième étage et à l'introduction des remèdes éventuels résultant des conclusions de l'enquête.

ESA's Experience in Using Incentives as a Management Tool

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Incentive provisions are much more widely applied in contracts in the USA than in Europe, where ESA is one of their main proponents, with some twenty years of experience in this domain. Incentive clauses are used as a management tool in the majority of ESA projects. A number of the Agency's service contracts also contain incentive clauses, tying the profit margins applicable to the quality of the services rendered.

An incentive contract is a contractual agreement containing incentive provisions which ensure that the final price paid is dictated by a combination of three main parameters:

- technical performance
- the extent to which schedules are met
- total cost.

Why does ESA use incentive provisions?

The reason is simple. One of ESA's main tasks is to promote European space technology. Almost all of the Agency's projects are development programmes which test the limits of existing technology. There have been many instances in the past where the similarly ambitious programmes of other organisations have run into problems and mission requirements had to be compromised or the cost overruns were so excessive that the programme became financially endangered. Incentive provisions have therefore been adopted by ESA as one of the few reliable managerial tools available for promoting good technical results within well-defined cost and schedule constraints.

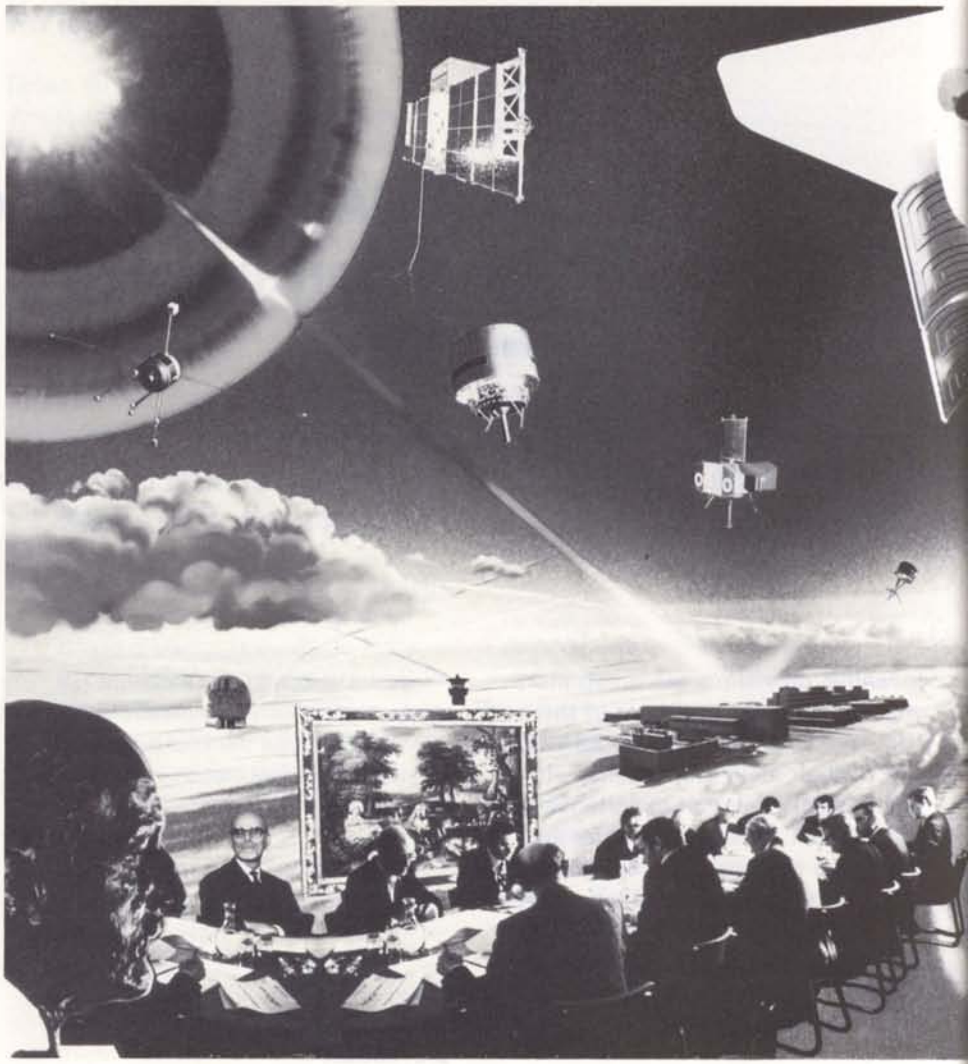
Classical contract management embraces a number of provisions designed to help to achieve the goals of the contract: namely to obtain the envisaged product on time for the price foreseen. Such provisions include clear specifications, a realistic price, payment conditions based on a negotiated cost development plan, including milestone payments (for fixed prices), an efficient modification procedure, etc. In addition, modern project-control methods, on which there is an extensive literature, provide us with procedures for controlling technical, schedule and cost performance. In spite of this, some well-known technology development projects have run into serious problems. Moreover, most European space companies are involved in public-expenditure contracts — defence, telecommunications, etc. — which very often lack the competitive environment of the nongovernmental market.

ESA is suffering from this same phenomenon, and incentive provisions are therefore considered a necessary supplement to contractual clauses and project control.

The provisions specific to ESA

The basic ESA incentive philosophy and its implementation have been explained in detail in a number of earlier Bulletin articles*. As noted above, three parameters are of prime relevance: technical performance, schedule, and cost.

* — Le Contrat avec intéressement comme instrument de gestion, by G. Van Reeth, ELDO/ESRO Bulletin, October 1969.
— Le Système de Contrat avec intéressement: l'exemple d'ESRO-IV, J.F. Lafay & S. Laurentie, ELDO/ESRO Bulletin, July 1974
— Partners in Risk - Cost Incentives in Development Contracts, by S.G. Kahn, ESA Bulletin No. 26, May 1981.



Technical performance

In contract performance terms, all ESA (and ESRO) programmes to date have been extremely successful, there not being a single ESA/ESRO spacecraft for which European industry has not received a performance fee close to the maximum attainable. (This leaves aside launcher development which is not subject to incentive contracting, and launch failures, which are beyond the control of the spacecraft manufacturer).

This record stands as a testimony to the high quality of European space products over the years, but it also brings to mind a number of associated questions:

- Do performance incentives lead to technical over-specification?
- Do they provoke technical-change requests from industry?
- Does industry really need technical-performance incentives to motivate it to deliver a good product?

Let us first consider the question of possible over-specification caused by incentives. There are normally at least four levels of specification for a project:

- requirements specifications (ESA's responsibility)
- technical specifications (Prime Contractor's responsibility)
- technical subsystem specifications (Prime Contractor's responsibility)
- equipment specifications (Subsystem Contractor's responsibility).

It is true that ESA contractors often try to involve the Agency in the establishment of the technical system and subsystem specifications for projects. This can be seen as an attempt to create co-responsibility, but it has nothing to do with the incentive scheme. On the contrary, it is our experience that the timely establishment of performance incentive criteria can be a useful means of putting clarity into specifications, as the parties become more eager to eliminate ambiguities.

Incentive provisions — not only on performance but also on schedule and cost — could be leading industry to invoke the ESA contractual change procedure. This, however, should also be considered a positive result as changes require the agreement of both parties and the discussion of such changes helps ESA's project managers to achieve the required visibility. On such large projects it is essential to discuss problems in the open rather than to have them swept under the carpet. Incentive provisions help the Agency to achieve this.

The space industry in general has a vested interest in the high quality of its space products and does not like to put its reputation at stake. One might therefore ask oneself whether the same technical success rate could not be achieved without performance incentives? Admittedly, it is difficult to measure the impact of performance incentives in absolute terms, but it is certainly true that they play an important psychological role. Industrial project staff and company managements are extremely keen to score a high marking, and the effect of this on the technical quality of the product should not be underrated.

There is an important difference between the practical approaches for scientific and applications programmes. On most ESA scientific projects, the experiments are furnished by the scientists themselves. The role of industry is then confined to supplying the spacecraft and integrating the payloads with it. It is therefore difficult to establish meaningful performance criteria that would invoke the responsibility of industry. Performance criteria therefore need to concentrate on the quality of acceptance testing, where failures or deficiencies tend to be a major cost driver.

Applications satellites, on the other hand, are normally built under the full responsibility of the Prime Contractor, and the Agency's prime interest, apart from successful acceptance testing, is

therefore the satellite's operational lifetime and its performance throughout that lifetime. Extended lifetime should therefore be rewarded with an incentive bonus for industry.

In summary, when performance incentives are applied, they should be:

- *simple*, to avoid lengthy calculations and to provide continuous profit-situation visibility to industry
- *not too dispersed*, to make the profit inducement work
- *large enough*, to impress not only the success-driven project manager, but also higher management
- agreed at an *early* stage in the project.

Schedule performance
The schedule incentive is growing in importance for reasons that are fairly obvious. 'Time is money' and space development contracts are extremely labour intensive. Any delay is therefore extremely costly because of the added labour costs alone. In addition, launching-authority charges for launch slippages impact heavily on programme budgets.

The increasing number of ESA, national and commercial space programmes is putting a heavy strain on the existing resources of European space industry and timely project execution has to viewed in this light.

The growing importance of schedule incentives therefore needs to be reflected in a more flexible approach in applying major awards tied to specific milestones that are considered crucial to a project.

Cost performance
Cost incentives are only relevant for cost-reimbursement contracts. Fixed prices can reasonably only be applied to contracts with well-defined risks. For most of ESA's main development contracts, this is not the case, and the Agency therefore employs cost-sharing formulae that encourage contractors to remain cost-conscious. In ESA's experience, cost performance (over- or under-spending) cannot be treated in isolation and has to be linked directly to technical and schedule performance. Moreover, the target costs have to be negotiated as carefully as possible. The 'neutral zone', which does not lead to cost sharing but influences the profit margin, should include provision for the technical risk. Deviation from this principle and the imposition of unrealistic targets and neutral zones can lead to endless discussions on modifications submitted by the contractor in an attempt to recover anticipated losses.

Conclusion
All in all, it can be said that ESA has generally had a very successful project-management record and that the incentive provisions employed have played a substantial role in this.

The Agency's experience over the years has shown that for incentive rules to be effective, they must be:

- simple and quickly accessible, which is important for the industrial management
- quickly agreed (arrangements just before or during a launch campaign do not serve the purpose)
- large enough in money terms to provide the necessary motivation
- not dispersed over too many criteria
- involve the company's project team where legally possible.

The Crew Work-Station Test-Bed for Columbus

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Manned spaceflight involves both man and machine. The interface between them plays an essential role in determining how the capabilities and effectiveness of each can be enhanced by working together. Because of the importance of the Man/Machine Interface (MMI) and its susceptibility to rapid advances, ESA is establishing a reference facility for the assessment and validation of new MMI technology for manned space systems. It will initially be used as a crew-work-station test-bed for the Columbus Project.

What is the test-bed?

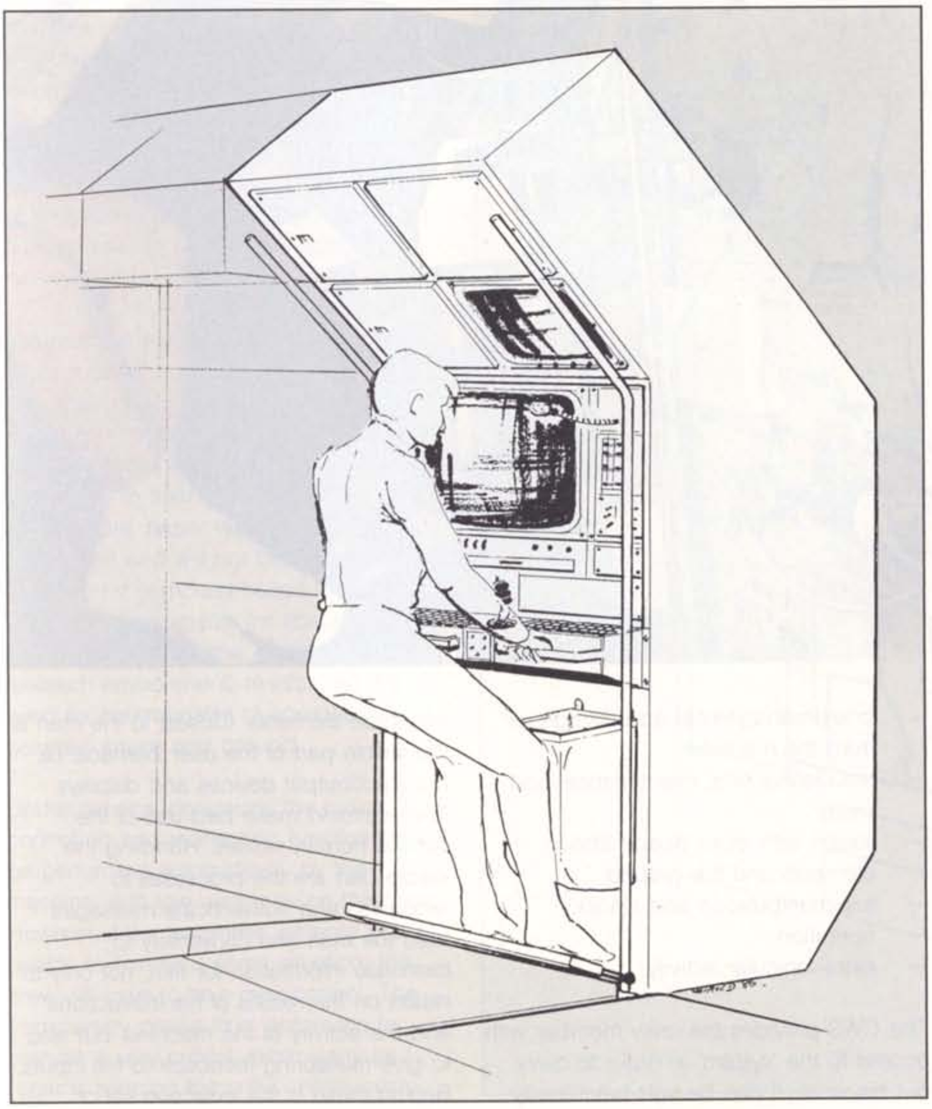
A Crew Work Station (CWS) in a space laboratory provides the interface between the astronaut and the complex system with which he (or she) is required to interact to carry out his work. Its role is somewhat similar to that of the cockpit information system of a modern commercial aircraft such as the Airbus A320, but designed to suit the specific tasks and operating environment of manned space missions. Types of CWS range from a multi-purpose console (Fig. 1) with portable extensions, to dedicated work stations for particular applications such as tele-manipulation and extra-vehicular activity. In the interests of commonality, CWS derivatives are also foreseen on the ground for such purposes as testing, training, mission control, and payload operation.

So that ESA and industry can carry out their respective responsibilities for CWS specification and design on the basis of proven technology, a CWS 'test-bed' is being established at ESTEC. This facility will serve as a technology reference tool for the various MMI applications which may require study during a project's life cycle. Although primarily intended to support the onboard segment, the test-bed will also be available to validate concepts and designs for ground facilities in other institutions and in industry. The term 'technology' in this context is not restricted to hardware and software elements and techniques, but also includes the more abstract aspects of man/machine interaction; indeed the application of human-factor engineering to CWS design is of major technological interest. The test-bed will initially be used for Columbus, to identify and advance critical CWS technology during the project-definition phases.

The test-bed is neither a simulation nor a prototype of a particular CWS. Rather, it is a generic applied research facility suitable for:
- exploring what is possible through the man/machine combination
- deriving a CWS architecture and concepts that offer online adaptability, independence from advancing technology, and system transparency to and system penetration by the man
- allowing early identification of critical areas of CWS technology
- advancing CWS technology through repeated demonstration, evaluation, and upgrading
- providing facilities for definition of the User Interface Language (UIL), investigation of software ergonomics, and development of a flexible MMI for a broad range of payload operations and data presentation
- providing facilities to support liaison between ESA and its international partners on common standards
- fostering European MMI developments for space applications.

To achieve these objectives, use is being made of ESA's Spacelab experience and satellite-checkout expertise, office automation technology, computer-aided design and manufacturing technology, aircraft cockpit technology, artificial intelligence, internationally agreed and

Figure 1 — Artist's impression of a multi-purpose console, highly integrated and designed for zero-gravity body positioning



commercially adopted standards, and the experiences of those responsible for managing large ships and aircraft.

The CWS operating environment

The starting point for CWS design must be the man:

— Why is he onboard?
— What are his roles and responsibilities, and how can he best exploit the vacuum and weightlessness of space?
— What are his objectives in doing his work?
— How best does he interact with machines?

Past experience in manned spaceflight has shown that system designers have often had too much confidence in their own ability to predict the future needs of system users, and too little confidence in the ability of future system users to deal with the unforeseen. This has resulted in systems that have tended to be physically, electrically, and informatically too closed for easy adaptation and repair.

Man's venture into space should be perceived as the latest extension to his terrestrial domain. The living and working environment in space should therefore be as close as possible to that he has developed on the ground. Any other approach risks loss of the huge advantage of his being able to use what he already knows and is familiar with.

Consequently, his role in a laboratory in space should be seen as basically the same as on the ground — that of complementing the machine through exploitation of his human intelligence and skills. These are particularly useful for dealing with unforeseen situations, not only for overcoming problems, but also for investigating new phenomena. Spacelab missions have already benefitted greatly in this respect, with astronauts repairing the materials-science furnaces, operating a partly failed Metric Camera, and investigating free-floating fluid zones exhibiting unexpected behaviour (Marangoni effect). Moreover, on a pure cost basis, it is more effective for a man to carry out certain tasks than to provide the equivalent machine-based capability.

Various roles can be foreseen for man in the laboratory:

— As Mission Commander, holding onboard executive authority. Responsible for liaison and cooperation with his counterparts in space and on the ground, enforcement of mission rules and agreements, planning and scheduling, safety, security, and crew well-being.
— As Mission Scientist, operating and supervising all of the scientific experiments in his laboratory, liaising and cooperating with principal investigators on the ground and pursuing their scientific objectives, detecting correlations between experiments, adapting experiments for new science, and generally sustaining and enhancing the scientific return.
— As Visiting Scientist, for carrying out a particular major scientific investigation, possibly only for a relatively short duration, e.g. for operation of an experiment cluster

Astronaut Bonnie Dunbar, using one hand to steady herself and unconcerned about her 'vertical' orientation, reading a telex from the ground to the rest of the crew of Spacelab-D1. Her thick socks are excellent space footware, being warm yet still allowing the feet to be used as non-damaging 'touch sensors'

for observation of a solar eclipse.
- As Production Engineer, for operation and management of sponsored production facilities such as those for the manufacture of alloys and semiconductor materials.
- As Flight Engineer/Servicing Specialist, holding engineering responsibility for systems, subsystems, and payloads. This includes overall system operation, logistics, provision of resources to onboard users, inflight integration and test, maintenance and repair, and laboratory 'housekeeping'.

In common with airline practice, these roles can be seen as different 'hats' rather than separate crew members, in much the same way as the flight engineer has disappeared from the cockpits of many commercial aircraft. Moreover, as the burden of system-operation is progressively reduced by automation, the expertise needed by the crew will be driven more by payload than by system requirements.

The crew's prime objectives are to carry out their work productively and efficiently, accurately and safely, without undue stress or tedium, using a minimum of onboard resources and without interfering with other activities. They must also be able to cope with the unexpected and unplanned, and must protect the results of their work by maintaining a log and by appropriate storage or transmission of data and products.

The tasks inherent to achieving these objectives are diverse:
- system and subsystem operation and management
- payload operation and management, including 'policing' of payload activity and usage of general resources
- support for tele-science and adaptive research
- mission planning and timelining
- integration and checkout
- crisis management and taking over from the machine
- troubleshooting, maintenance, and repair
- liaison with other Space Station elements and the ground
- tele-manipulation and airlock operation
- extra-vehicular activity.

The CWS provides the crew member with access to the 'system' in order to carry out his work. It can be split functionally into three elements. Closest to the man is the visible part of the user interface, i.e. the input/output devices and displays. These should make best use of the various human senses. Handling the visible part are the processes to recognise and authenticate messages from the man and conversely to formulate information for him, not only to report on the results of his instructions and the activity of the machine, but also to give reassuring feedback to his inputs. Behind these is the extensive set of

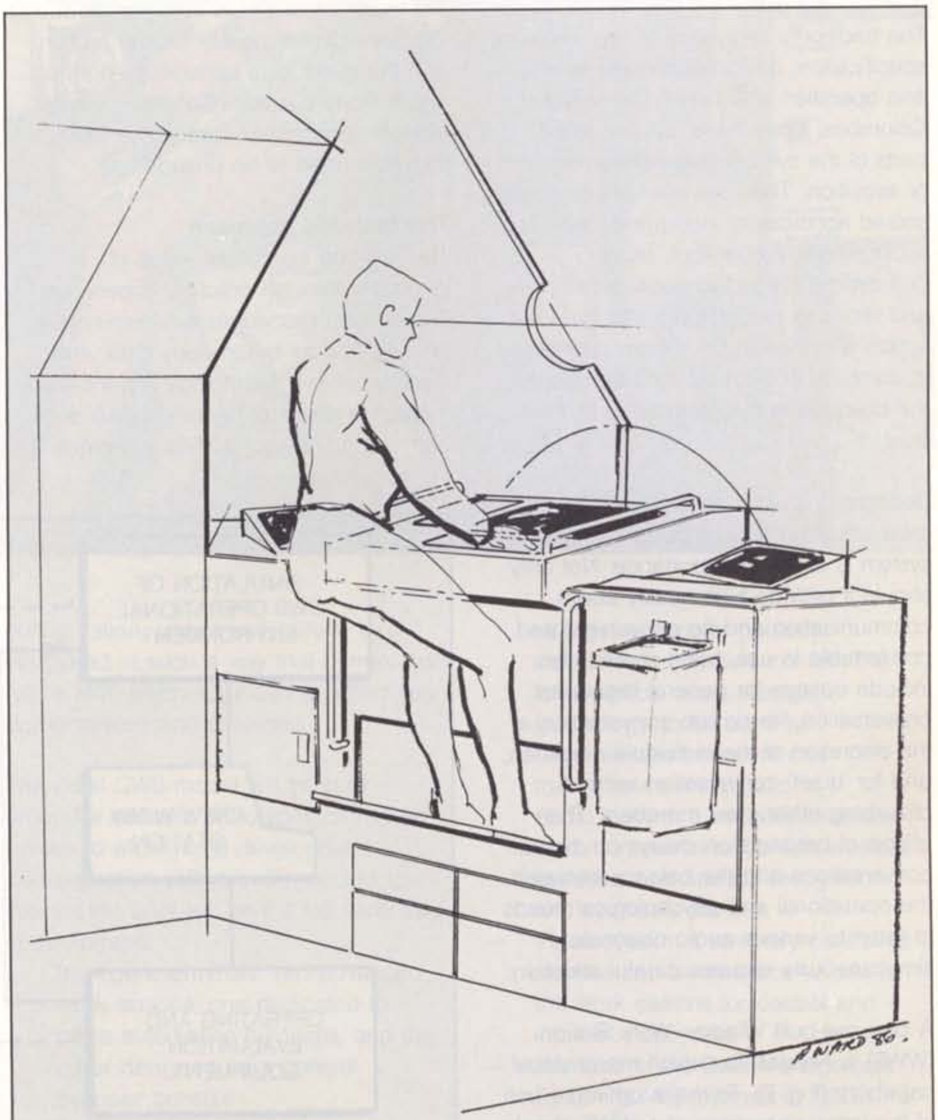


Figure 2 — Artist's impression of a Window Work Station (WWS) at a module end cone, enabling man/machine interaction and at the same time allowing the astronaut to view through the window. A head-mounted display could further enhance this capability

application processes carrying out work for the man, in some cases self-contained within the CWS, and in others calling up processes elsewhere in the system — initiating and controlling subsystem and payload activity, retrieval and processing of data, etc.

CWS design considerations
Much information from the past, particularly from Spacelab, is available as a guideline for the Columbus CWS design. Some of the most important aspects are addressed below. They are individually rather diverse, but collectively they provide good insight into the real CWS requirements.

The crew will be working in a shirt-sleeve environment and will operate in space in much the same way as they would on the ground in control stations and laboratories. For payload operation, the crewman will work as part of a space/ground team, cooperating with the payload user in his ground facility by means of data, video, and audio links.

The next generation of scientist astronauts will not undertake years of specialist training for their missions, but will expect to be able to apply the same working methods and use the same facilities as in their ground laboratories. For example, paper will certainly continue to be used and will not be completely replaced by computer-based techniques. Moreover, experiments for space will be developed in the same ground-based research environment, re-inforcing the need for commonality of approach between space and ground.

Under nominal conditions the major controlling and monitoring functions will be performed automatically by the machine, with low demands on the crew. However, if the automatic systems prove unable to handle a given situation, the crew will have to take over control. The transitionary phase from automatic to manual is very critical, particularly as regards keeping the crew continuously informed about what is going on and the reasons why. There should always be the possibility for the crew to break into a pre-defined sequence by putting it on hold, inspecting it, and executing it step by step.

Much more information about the system will be available at any given time than can be continuously displayed or monitored by the crew — current status of subsystems and payloads, automated activities in progress, flight plan, mission scheduling, time, maps, consumables usage, trend analysis of experiment data, and so forth. Efficient and user-friendly ways of informing the crew about what is available, and how to access it, need to be provided.

A range of facilities should be available to support the generation of reports — speech recognition combined with word processing, access to ground-based secretarial services, etc. The onboard log is still likely to be operated in a fairly conventional laboratory manner, i.e. firstly generated on paper and then put into the onboard database by the crew or via ground services. The ground should also have write as well as read access to the log.

The means to consult documentation stored in the database should include the equivalent of such procedures as quickly flipping through a number of pages, making notes in the margin, and skipping a few pages by estimating the document's thickness. Database content need not be restricted to only text and diagrams, but may also include 'videoclips' of critical or complex operations. These would be accessed interactively in much the same way as the documentation.

The traditional sequence of requirements specification, design and implementation, and operation is not really applicable to Columbus, since there will always be parts of the system under development or evolution. The user interface language should accordingly incorporate tools to support inflight checkout, rapid prototyping of modifications, servicing, and repair. A natural language type of syntax is preferred for system operation, in combination with facilities for adapting the dialogue to the experience of the user.

Because it is used continuously by the crew whilst on duty, a good intercom system is of prime importance. Not only should it provide high-quality audio communication and be convenient and comfortable to use, but it should also include options for general broadcast conversation, for private conversation at the discretion of the individual crewman, and for 'quiet' conversation without disturbing other crew members. The effects of propagation delays on 'human' conversations and the balance between the operational and psychological needs to listen to various audio channels simultaneously requires careful attention.

A purpose-built Window Work Station (WWS) is needed to exploit man's visual capability (Fig. 2). To make optimum use of the latter, operations at a WWS should be possible with little need to look at the controls, and it should be possible for feedback and data to be presented on a device such as a head-mounted display.

In order to maintain crew readiness and expertise for infrequent operations during long-duration missions, there should be inflight facilities for crew training. The scope of these is potentially very wide, but the minimum requirement would be for 'refresher courses' on system operation.

The positioning of loose items and of the crewman's body whilst working at a CWS are major problems in zero-gravity due to the three-dimensionality, lack of friction and the need for a conscious effort to adjust body position. General-purpose retainers and energy-absorptive tethers therefore need to be provided.

The test-bed approach

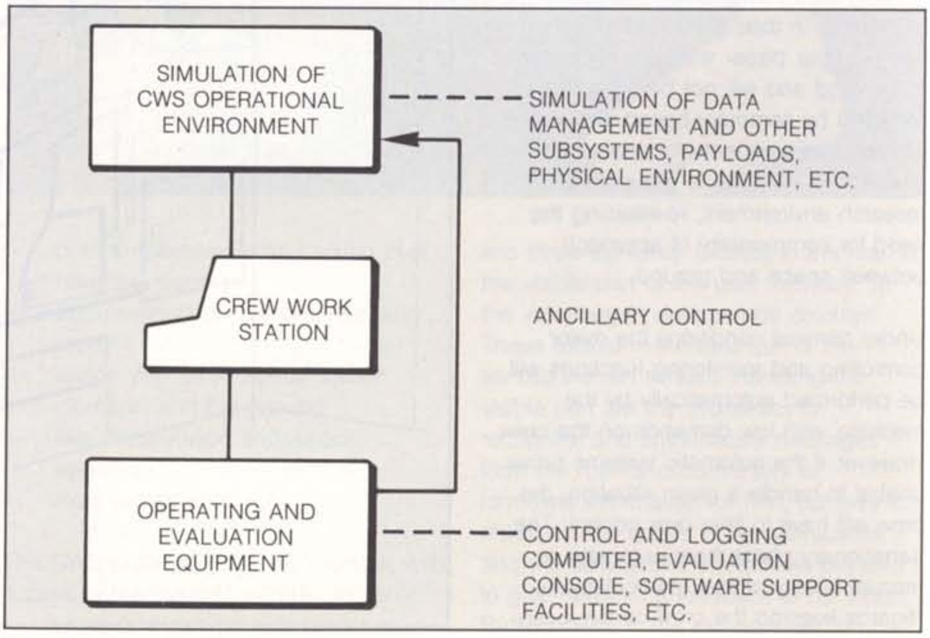
The test-bed approach is one of discovery through practical experience. The chosen procedure is to implement an initial model by an early date, and then to achieve technology advancement through a series of hands-on evaluation and upgrading cycles. This technique is considered to be particularly beneficial where MMI technology and ergonomics are of key interest, since it provides an early means of demonstrating and evaluating state-of-the-art technology and investigating how man's unique capabilities can best be exploited. Its validity has already been well-proven in the US for space applications and also in Europe in the aircraft industry. Although the general trend of project requirements must of course be followed, a certain measure of unsolicited exploration should also be carried out, since this can result in new knowledge beneficial to the project, which can then be fed back to update the requirements.

The basic architecture of the test-bed is shown in Figure 3. The middle block is the model of the CWS itself, but this alone does not constitute a test-bed. Two other blocks are required, one to simulate the rest of the onboard system and the operational environment, and the other for control and support facilities.

The ESTEC test-bed configuration

The test-bed will be based on the existing ESA Checkout Reference Facilities at ESTEC, including a

Figure 3 — Basic test-bed architecture



Astronaut Wubbo Ockels working with the Fluid-Physics Module aboard Spacelab-D1. He is free-floating and, contrary to mission intentions, has had to pull out the Module for easier operation. All the paper in view is related to the specific task that he is performing

broadband local-area-network (LAN) for test-bed interconnection. These will be configured to provide both a simulation of the CWS inflight operational environment based on an evolved form of the ESA Test Operations Language (ETOL), and also support facilities for test-bed control, software development, and assessment of a prototype expert system. Part of a Spacelab functional model will be used to provide a representative mock-up of the Columbus physical environment.

The additional equipment required to represent the CWS itself will be provided by an industrial consortium. The overall configuration, shown in Figure 4, is structured in such a way that current and future MMI technology can be effectively demonstrated and assessed.

The initial CWS model will be built around a versatile prototyping computer system to allow rapid development of demonstration software. Connected to this via the LAN will be the following sets of equipment:

- Intelligent terminals: two advanced work stations, one dedicated to office automation functions, and the other designed as a general-purpose console.
- Personal computer with optical storage: a popular personal computer in combination with the latest optical mass storage technology, to be used for documentation retrieval and maintenance investigations.
- Audio system: a versatile intercom system in combination with wireless headsets and speech-recognition and synthesis devices.
- Video system: a remotely controlled camera and an interface to one of the work stations for control and input of video data.
- Interface to the Data-Management System (DMS) test-bed in ESTEC: a data-communications interface,

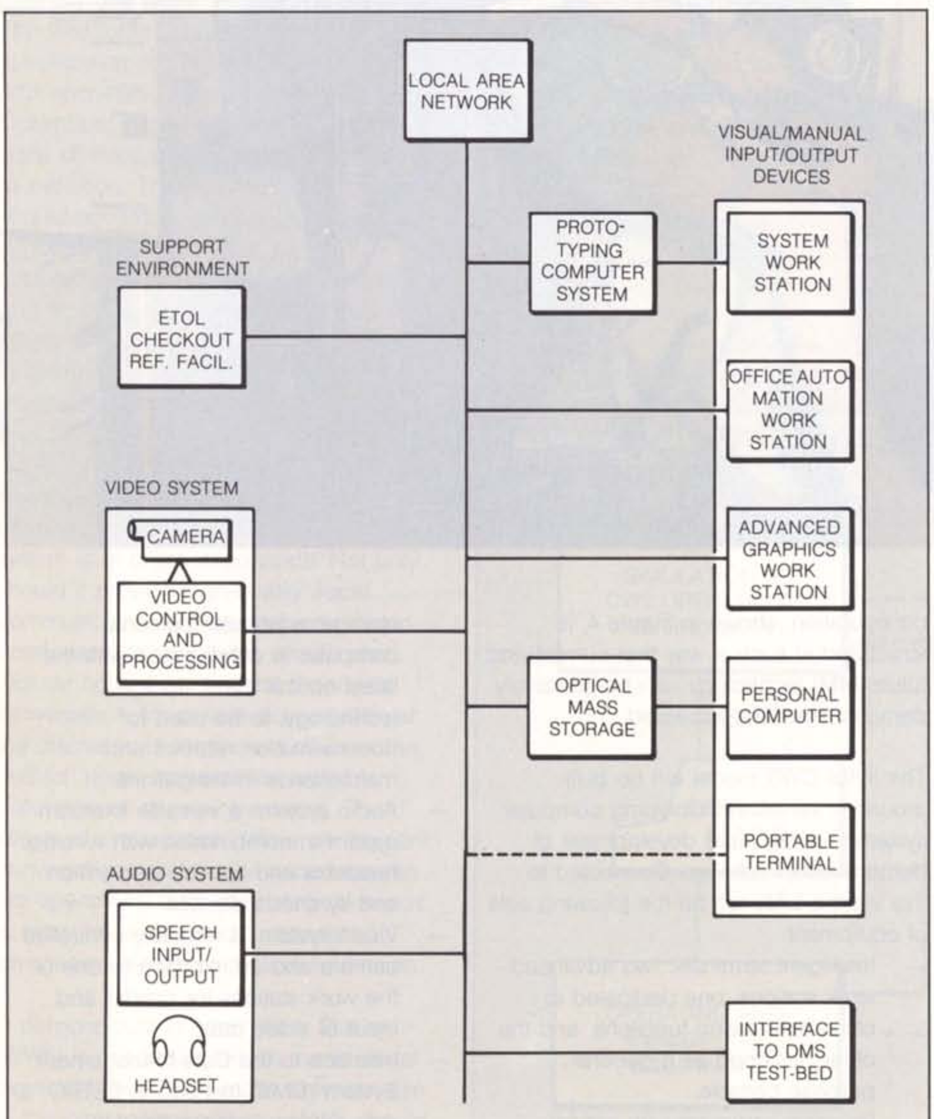


Figure 4 — The initial ESTEC test-bed configuration

enabling validation of the CWS/DMS connection and the end-to-end user interaction via the DMS.

Initial experiments

A number of initial critical areas have been identified which will be investigated through experiments on the test-bed, with the participation of ESA's astronauts:

— User interfaces to onboard systems and payloads. Investigations will be conducted on:
  - user interface languages
  - command language style, using different menu techniques, function keys, joystick, mouse, and suchlike
  - use of virtual control panels and data input through the manipulation of icons.

A functional environment for all these tests will be achieved by using ETOL applications on a checkout reference system, and by simple simulations of Spacelab subsystems. A portable terminal will be used to demonstrate remote access to the system.

— Intelligent terminal features. Features such as window management, graphical input/output, and offline text processing will be demonstrated on different work stations and terminal prototypes.

— Documentation retrieval and maintenance. Investigations will be carried out on documentation retrieval and maintenance techniques for material containing both text and pictorial data. This will use a relational database implemented on a personal computer with an optical disc. A second experiment will be performed to assess the suitability of semantic networks and natural language interfaces for documentation consultation and manipulation.

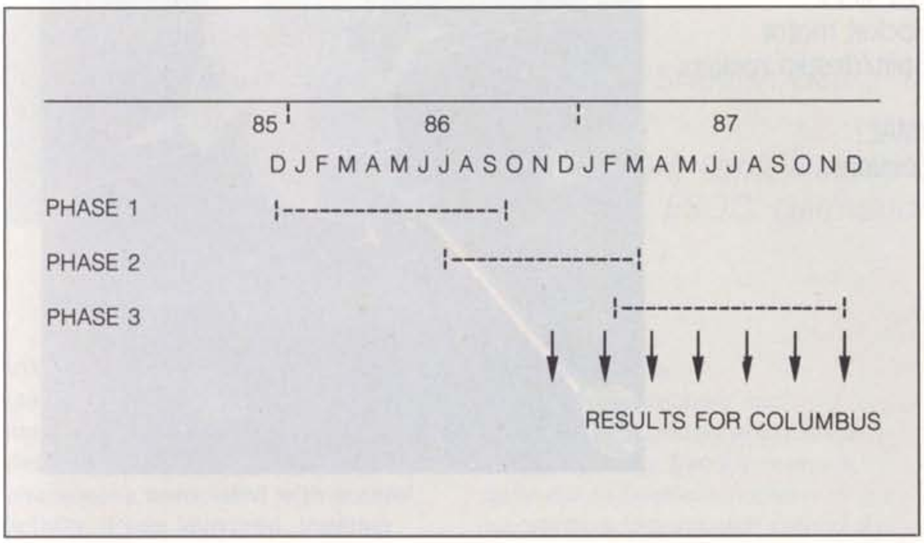
— Audio system. This experiment will show how speech recognition and synthesis can be used in the space environment for caution and warning and for control (e.g. of a remote camera). The use of wireless headsets (using infrared and/or radio-frequency transmission) will also be demonstrated as part of an integrated audio system.

— Knowledge-based diagnostic system. A demonstration of an expert system for fault diagnosis will be conducted to assess the use of this technology to support the crew with failure management.

— Video system. Investigations will be carried out on:
  - the display of video data in a work-station screen window, for example to support control of a remote camera from a robotics/tele-manipulation work station
  - a high-resolution colour CCD camera with digital video enhancement
  - interactive video retrieval from optical media.

— Ergonomics. Investigations of CWS equipment layout will be carried out by constructing different work stations in several locations of the mock-up. A window work station will

Figure 5 — CWS test-bed planning



be placed in one end of the mock-up and single- and double-rack work stations will also be installed and assessed.

Investigations of these areas will doubtless uncover additional topics to be investigated in further rounds of experiments.

Current status and future planning
Under the leadership of MBB/ERNO in Bremen (Germany), four subcontractors are contributing to the setting-up of the CWS test-bed:

- Alcatel Espace (France)
- Fokker (Netherlands)
- Laben (Italy)
- Marconi Space Systems (United Kingdom).

This industrial team combines a high degree of experience in the field of overall space systems engineering, together with competence in particular areas of CWS technology for the design, implementation, and use of the test-bed.

Establishment of the test-bed and its initial use for Columbus is currently planned in three phases (Fig. 5):

Phase 1: Analysis of requirements, identification of critical CWS technology for Columbus, design of the first model of the test-bed, and supply of elements.

Phase 2: Integration of the test-bed, conduct of initial experiments, and test-bed upgrading.

Phase 3: Subsequent technology advancement cycles.

A preliminary design review was held at the beginning of May 1986, at which the results of the initial study work and the design specifications were presented. From this initial work has already emerged the need for more detailed study of certain aspects, e.g. of a space-qualified high-resolution colour display, and a bi-directional multi-channel infra-red data link to support the audio system and portable terminals.

One of the most difficult problems facing a project such as Columbus is how to avoid technology obsolescence during the lengthy development and implementation phases. Columbus is being designed to accommodate progressive change, and work on the CWS test-bed for the Project is expected to continue beyond the current commitment in order to facilitate the ongoing assimilation of evolving technology.

Once established, the test-bed must continue to evolve with the relentless tide of new advances. To keep abreast of these advances, it will be operated as an open facility, offering a forum for demonstration and assessment. Companies who feel they can contribute improvements will be invited to visit the facility at ESTEC to present their ideas and products on commercially neutral ground.

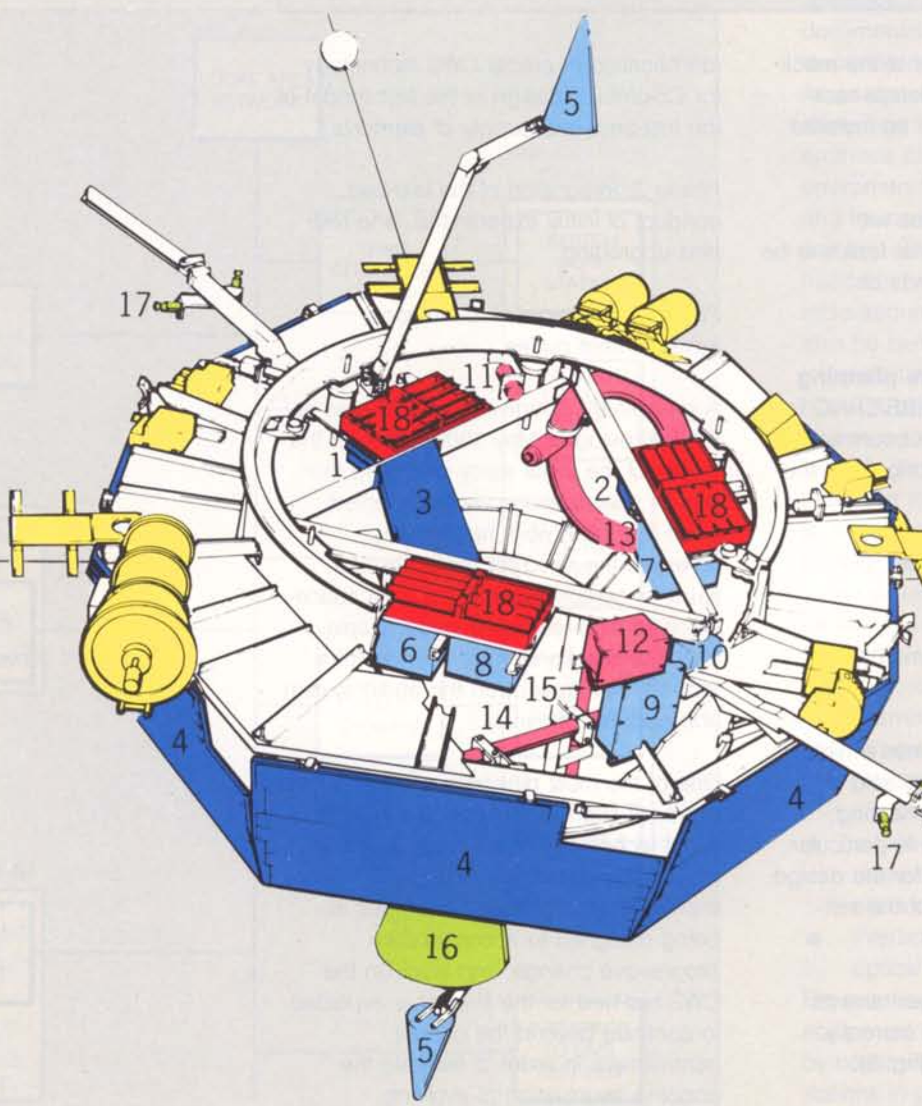
ELECTRICAL POWER:
1. Battery
2. Voltage limiter
3. Resistors
4. Solar panels

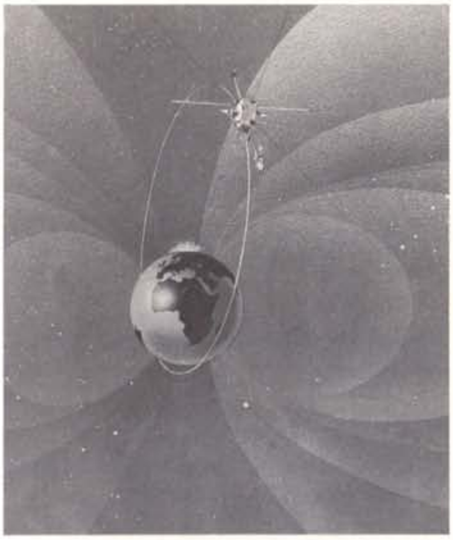
TRACKING, TELEMETRY AND COMMAND:
5. Antennas
6. Transponder
7. Decoder
8. Encoder
9. Converter
10. Timer

ATTITUDE CONTROL:
11. Earth sensor
12. Control electronics
13. Nutation damper
14. Spin coil
15. Precession coil

PROPULSION:
16. Rocket motor
17. Spin/despin rockets

THERMAL:
18. Louvers





Sweden's First Satellite 'Viking' and its Orbit Determination by ESA

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Viking, the first satellite to be launched as part of the Swedish national space programme, is designed to investigate space plasma phenomena associated with auroral activity. It was launched, together with the French remote-sensing satellite SPOT, on an Ariane-1 launcher (V16) on the 22 February 1986. All satellite operations are being performed in real time from the Esrange satellite station at Kiruna in northern Sweden, where the Viking Scientific Centre has been set up. Viking's orbit determination, however, is performed at ESA's Space Operations Centre (ESOC) in Darmstadt based on tracking data from Esrange in Kiruna.

Viking's mission

Study of the ionosphere and magnetosphere traditionally holds a strong position in Swedish research, partly due to Sweden's northerly geographical location, with parts of the country lying within the northern auroral zone. It is therefore not surprising that the first Swedish research satellite should be aimed at studying ionospheric and magnetospheric phenomena at high latitudes.

Viking will, however, address a variety of scientific problems, but with particular emphasis on those related to auroral processes (Fig. 1). Viking is currently making simultaneous measurements of electric and magnetic fields, the energy and mass distributions of accelerated particles, plasma-wave activity and auroral ultraviolet emission.

The low-cost goal set for the project was the key to the design, development and test philosophy that was followed. One of the first and major design drivers in the project was the decision to accept the offer from the French national space agency, CNES, to launch Viking as a piggyback passenger with the SPOT (Satellite Probatoire d'Observation de la Terre) satellite. In this way, a relatively inexpensive launch was assured, the penalty being loss of influence on the launch date. The main dimensions of the satellite were also set by the launch mode:

- the 52.5 cm in height available between SPOT and the Ariane adapter
- the 550 kg mass limit
- the dimensions permitted by the available fairing volume.

As the mission requirements dictated that a rather large orbit manoeuvre be made to raise Viking's apogee from 830 km to 14 000 km, a sizeable portion of the satellite launch mass had to be used for propulsion. This led to another of the major design decisions, namely the choice between a redundant or a non-redundant platform. With the proposal of a very ambitious payload weighing about 80 kg, the mass budget did not allow the addition of redundant units for the platform subsystems. Rather than reduce the payload, it was decided to build a non-redundant satellite.

The Swedish Space Corporation (SSC) was responsible for system design and project management under contract to the Swedish Board for Space Activities. Saab Space was prime contractor to SSC for the development and delivery of the satellite.

A protoflight satellite concept was adopted in which the flight structure was subjected to qualification-level structural tests (static load, acoustic vibration) with equipment represented by mass dummies. Following final assembly at Saab's facilities in Linköping, Sweden, a comprehensive programme of environmental acceptance tests and performance tests was conducted over a period of about a year. The majority of these tests were performed at ESTEC in Noordwijk.

The Viking operations are designed to

Figure 2 — The Viking satellite's orbital history for the first 8 h after its separation from the Ariane-1 launcher

meet the scientific requirements of flexibility in the commanding of the satellite and the wish to make data available in the shortest possible time. Hence, changes in operational mode requested by the scientists are normally executed immediately, and the scientific data are analysed, plotted, copied and ready for distribution to the scientific groups within one orbit of acquisition. Viking is not equipped with an on-board memory, so all satellite operations must be performed in real time at the Viking Operations Center (VOC), which is also located at Esrange in Kiruna.

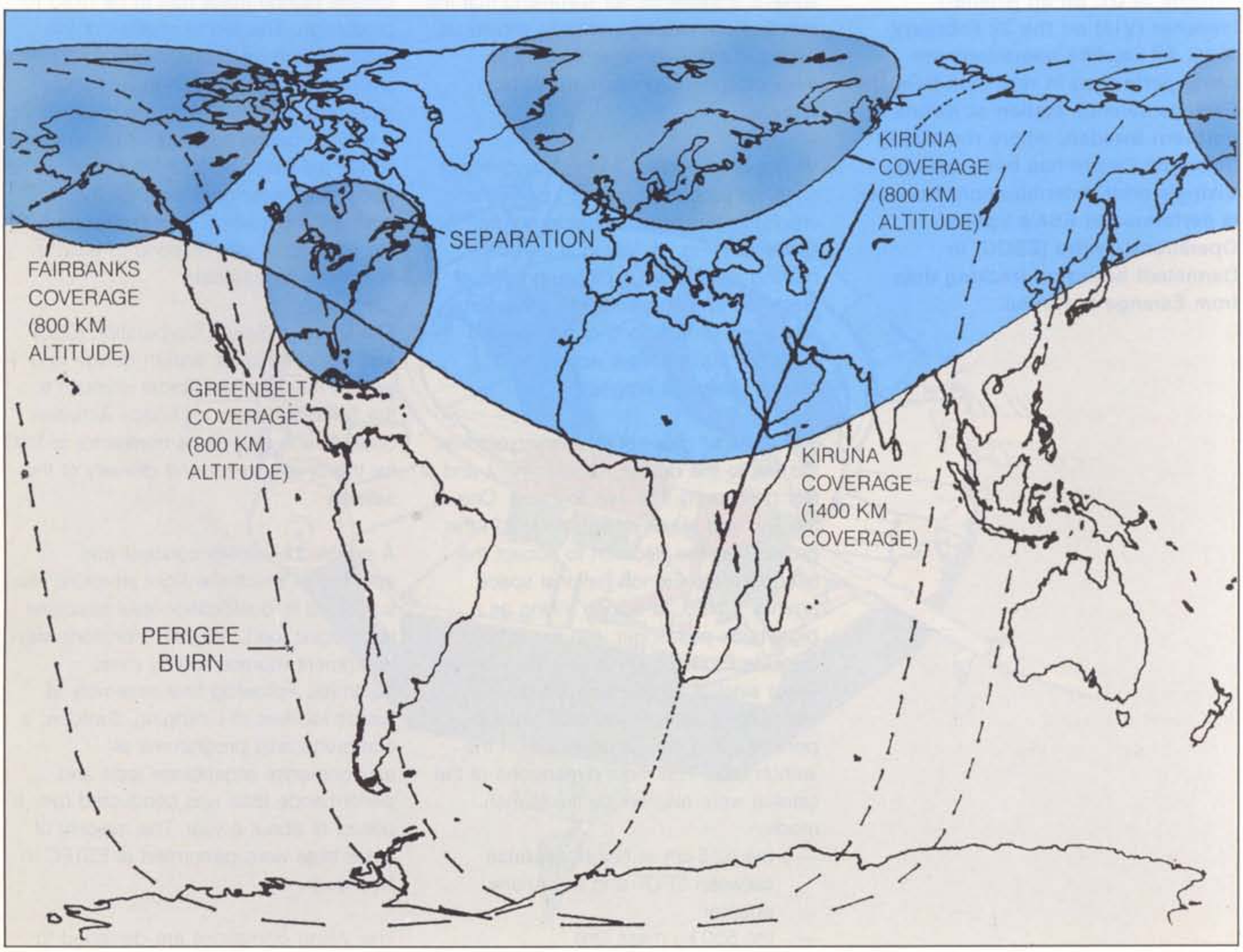
The Viking launch

Viking was launched, together with the French SPOT satellite, by an Ariane-1 launcher on 22 February 1986. Because of orbit restrictions for SPOT, the launch window was rather narrow, remaining open for just 10 min. The launch took place at the beginning of the launch window at 01:45 GMT and after a 15 min northward ascent phase, the two satellites were separated and injected into a near-polar Earth orbit. Whereas this was still a transfer orbit for Viking, it was the final orbit for SPOT. Viking remained in this close Earth orbit for almost two complete revolutions, lasting about 3 h. Then the satellite was accelerated by its perigee boost motor in order to reach the target orbit, which is an eccentric near-polar orbit with an apogee altitude (in the northern hemisphere) of almost 14 000 km.

Figure 2 shows the satellite's orbital history for the first 8 h after its separation from the Ariane launch vehicle.

Viking's orbit determination

The determination of a satellite's orbit is based on tracking measurements carried out by various ground stations. The raw tracking data are not directly suitable for this purpose and must first be preprocessed. To streamline the orbit-determination process for Viking, the Esrange ranging data are preprocessed at the station and the smoothed observations (range, range rate and



pointing data) are transmitted by telex to ESOC in Darmstadt.

ESOC's MSSS* orbit-determination program uses a weighted-least-squares method to apply differential corrections to an a priori estimate of orbital parameters and to other parameters such as station coordinates, measurement bias, etc. (Fig. 3).

As Viking is tracked only from Esrange in Kiruna, any systematic offset in the Esrange ranging data, which it is difficult to identify with single station tracking, would degrade the orbit determination. It was therefore found desirable to include data from the Agency's Carnarvon (Australia) tracking station during the first two Viking passes as a further validation of the Kiruna system.

Although the pointing of Viking's on-board antenna was by no means ideal for the Carnarvon station and some measurements could not be used, the correctness of the Esrange ranging data could still be verified.

Prior to the Viking launch, the Esrange tracking system had already been verified by using ESA's Exosat satellite on several occasions.

During the first 30 h after Ariane's lift-off, a total of 39 ranging passes were taken from Esrange. Each was about 2 min long and represented 12 observations. The 468 individual observations showed a mean error (r.m.s.) of about 20 m.

As the number of observations increased with time, the orbit-determination results improved, as shown in Table 1. The beginning of the observation arc for these examples is always the perigee motor firing time, and the first measurement was carried out about 40 min after that event, at 05:47.

* Multi-Satellite Support System

Evolution of Viking's orbit

Even though Viking's apogee altitude is rather high, the orbit's perigee is still comparatively close to the Earth, which means that the latter's oblateness can be expected to be the main contributor to orbit perturbation. Further perturbations caused by solar and lunar gravity result in a sinusoidal-type variation in the perigee and apogee altitudes.

Whereas the coverage from Esrange was primarily within the first half of the orbit (perigee towards apogee) at the end of February 1986, it was symmetric around apogee about four months later, in June 1986. After another four months (October 1986), the coverage area will have moved towards the second half of the orbit and then for the next couple of months it will deteriorate as the spacecraft's apogee moves into the Southern Hemisphere.

With the apogee in the Northern Hemisphere, sufficient tracking can be obtained from the single station at Esrange to maintain our knowledge of Viking's orbit with the use of the ESOC MSSS system to an accuracy of:

- ± 10 m in semi-major axis
- $\pm 0.003°$ in inclination, and
- ± 1 km in satellite position.

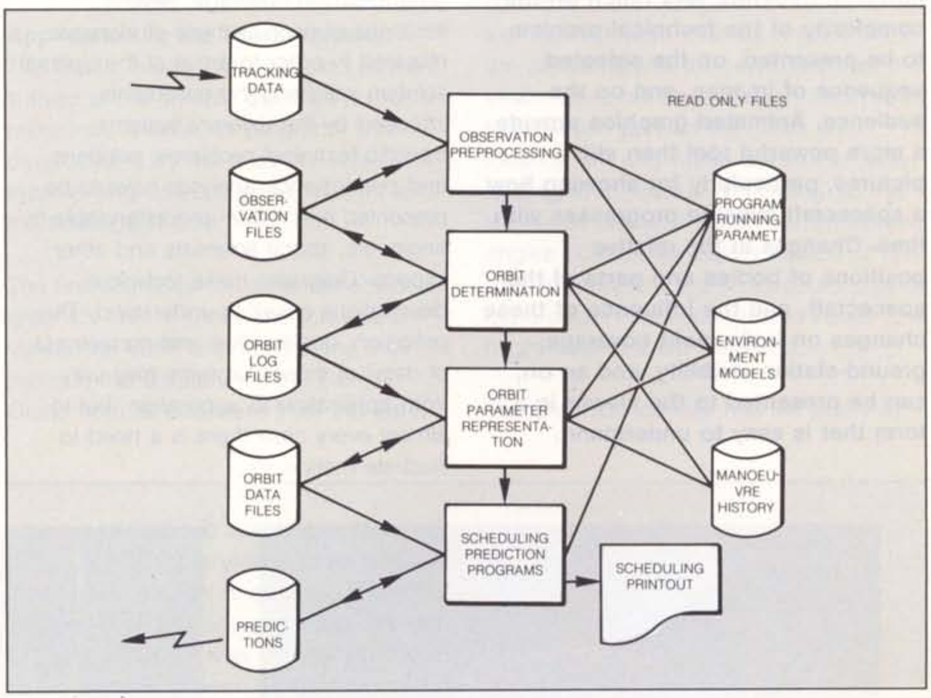
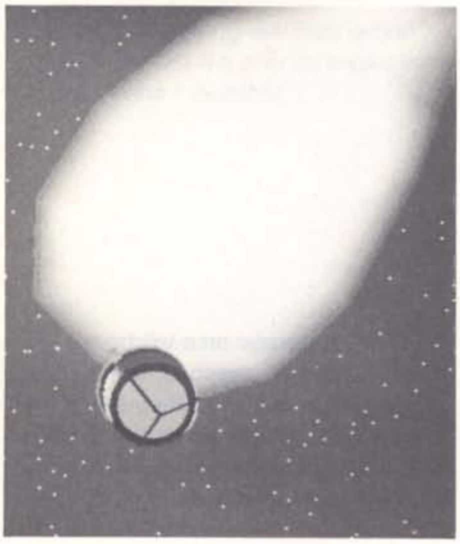


Figure 3 — Structure of ESOC's Multi-Satellite Support System (MSSS) orbit-determination program suite

Table 1 — Results of the ESA orbit determination for Viking

Orbit number	End time of observation arc	No. of measurements Esrange	Carnarvon	ESA-determined orbit Semi-major axis (km)	Inclination (deg)
2	86/02/22 06:49	62		13 548.1	99.10
2	07:51	108		13 555.3	98.95
3	11:58	168		13 559.5	98.80
3	13:57	168	15	13 559.71	98.80
4	16:08	228	15	13 559.67	98.80
7	86/02/23 05:18	468	27	13 559.65	98.80



Animated Computer Graphics as a Tool for the Analysis of Space Missions

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For some years, simple computer-produced graphics have been used to illustrate the orbits of spacecraft, and motion has been suggested by sequences of still pictures. The perception of motion obtained, however, depends very much on the complexity of the technical problem to be presented, on the selected sequence of images, and on the audience. Animated graphics provide a more powerful tool than still pictures, particularly for showing how a spacecraft mission progresses with time. Changes in the relative positions of bodies and parts of the spacecraft, and the influence of these changes on instrument coverage, ground-station visibility, and so on, can be presented to the viewer in a form that is easy to understand.

The analysis of space missions requires the investigation of such orbital and attitude aspects as: orbit selection and evolution; launcher configuration and injection procedure; manoeuvre optimisation; and instrument and ground-station coverage. Several iterations of each of these studies are required in order to arrive at the optimal solution satisfying the constraints imposed by the different systems. Specific technical problems, solutions and performance analyses have to be presented and made understandable to engineers, space scientists and other experts. Diagrams make technical descriptions easier to understand. The precision, quality, level and correctness of detail of these diagrams may vary from application to application, but in almost every case there is a need to illustrate motion.

Early last year, it was decided to extend the existing capability at ESOC for computer graphics to include animation, and the users' requirements were studied to determine what new hardware and software would be needed. Picture quality, computing performance and system architectures have greatly improved in recent years. The range of products in this area is very wide, varying from the 'Space Invaders' type of animation seen in many microcomputer games, to the highly realistic displays of real-time moving scenery in an aircraft simulator.

Use of an intelligent graphics terminal

An important question was how the workload should be distributed between the existing mainframe computer and any new graphics terminal. One option is to use software in the mainframe to do all the work for drawing a picture, and send the result to an unintelligent graphics display. The alternative is to employ an intelligent terminal, which can obey a set of graphics commands to produce representations of three-dimensional objects, with rotations, etc.

A graphics terminal with extensive local intelligence was chosen for reasons of speed and efficiency. These factors are particularly important for animated graphics, because of the very large numbers of pictures that must be produced. A rate of 20 to 30 frames per second is needed to give an impression of smooth motion. The European PAL/SECAM television standards, for example, use 25 frames per second. At this rate, even a short sequence lasting 60 s requires 1500 frames. Differences of a couple of minutes in the time taken to output one frame accumulate to hours or days when one comes to output a complete sequence.

The graphics terminal is faster than an equivalent mainframe software package for two reasons. One is the purpose-built hardware, which can execute the highly repetitive drawing algorithms more efficiently than software on a general-purpose mainframe. The other is the very greatly reduced volume of data that has to be transferred from the mainframe to the graphics device. At a resolution of 640 by 512 points (pixels), a single frame contains more than 300 000 pixels; if the mainframe draws the pictures, more than 300 000 pixel values must be sent for every frame. When a frame is sent in the form of graphics commands, the volume of data depends on the complexity of what is shown, but is typically in the range of 200 to 2000 bytes per frame, i.e. there is some 400 times less data to be transmitted.

The software

Programs are needed in the mainframe to send the commands to the graphics terminal. To show an animation of the orbits of the inner planets about the Sun, for example, a program has to:

- calculate the scaling factors so that the ellipses representing the orbits are the correct size on the screen
- send the commands for drawing the ellipses
- calculate the positions of the planets in each frame of the sequence according to the time steps being used
- send the commands for drawing each frame, and for drawing the frames as a sequence.

A separate program could be written for every animation, though it would involve unnecessary duplication because of the features which are common to many of them: planets, orbits, spacecraft, the Sun and the Earth, etc. A graphics-animation software package for mission analysis could avoid the duplication. Users would specify their requirements via parameters on an interactive interface, and additional information such as the trajectories of spacecraft would be input via data files.

Before attempting to produce a general software system of this nature, it was necessary to gain experience in graphics production for some sample cases.

Application to the Giotto mission

The Giotto mission was selected as the subject of the sample graphics animation programs. A series of programs was developed to try out a variety of ways of representing objects, orbits, motion, and the passage of time.

The first animation uses two-dimensional graphics only. It shows the motions of Venus, the Earth and Mars along their orbits in the ecliptic, and the path of Giotto from its departure from the Earth to its encounter with Halley (Fig. 1). The sequence uses a date scale with a moving pointer to indicate the passage of time during the mission. A different method of indicating the time is used in a sequence to illustrate the orbit of Comet Halley from shortly before its perihelion passage of 1835 until the present (Fig. 2). Here the time is shown by the year number.

The orbit of the comet is inclined at approximately 17° to the ecliptic and the animation in Figures 3a,b attempts to use simple three-dimensional graphics to illustrate this feature. The orbits are defined as lines in three-dimensonal space, and the viewpoint is moved to look at them from different angles. There are problems with the result because the viewer does not have enough information to tell which parts of the orbits are towards him and which are further away, leading to an illusion of 'flipping' as the sequence passes through certain viewing angles. Ribbon-like bands instead of thin lines to represent the orbits could provide more depth information to the viewer and might help to avoid this effect.

The graphics terminal has the ability to

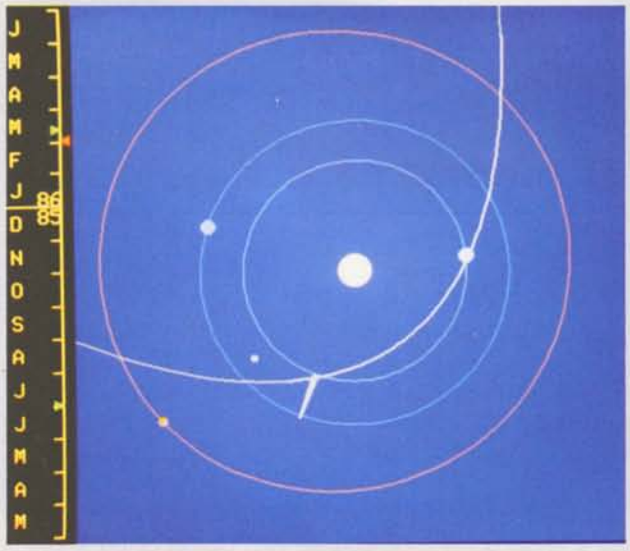


Figure 1 — The Giotto/Halley encounter

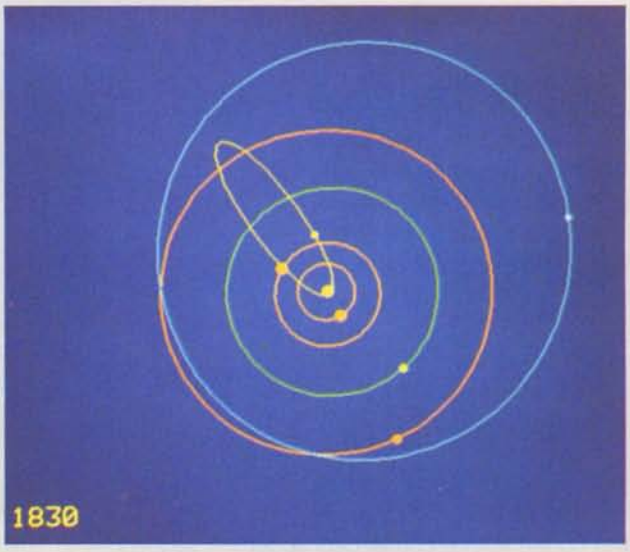


Figure 2 — Halley's orbital history

Figures 3a,b — Halley's orbit

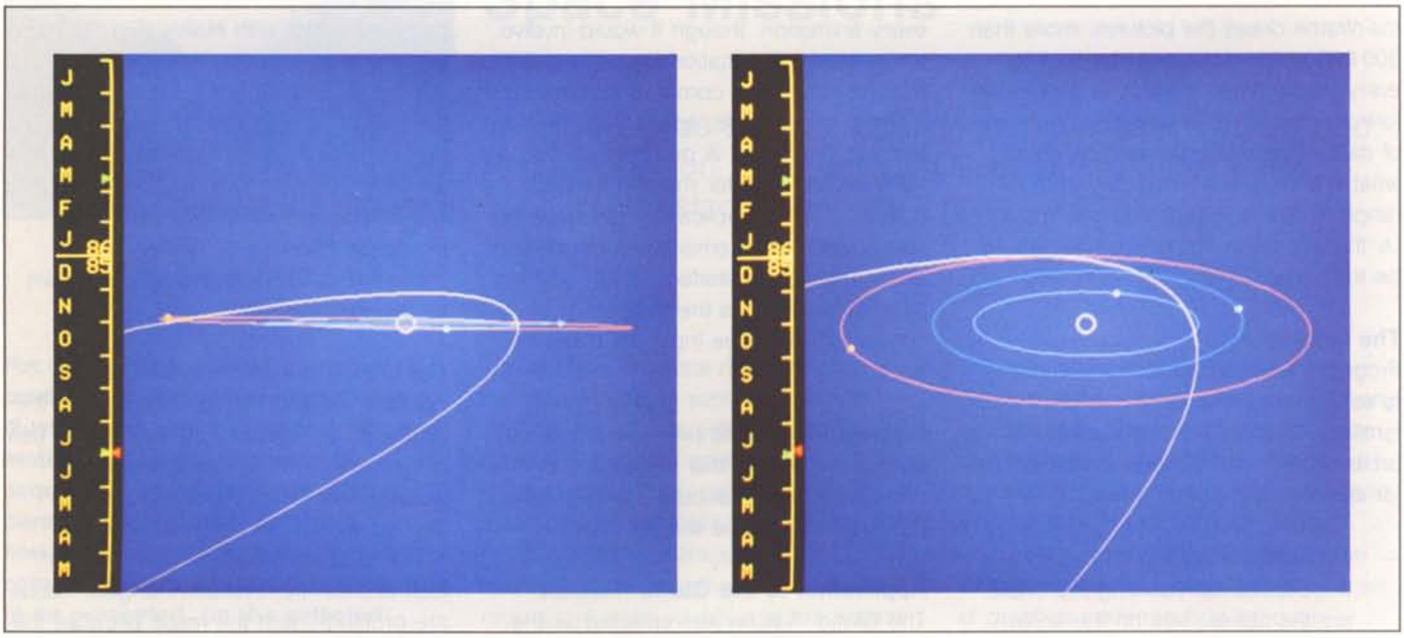
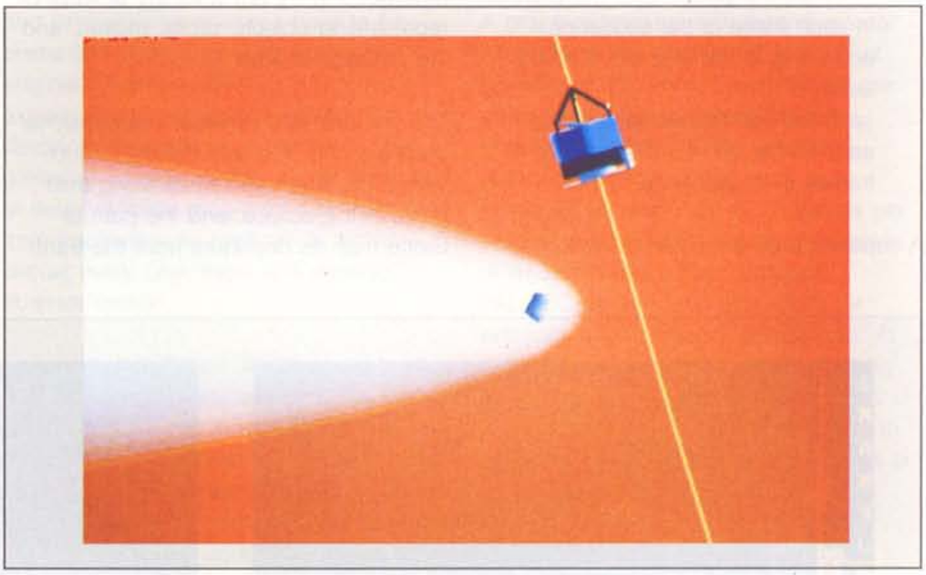


Figure 4 — The encounter geometry



draw a solid object so that the parts that are closer to the viewer hide the parts behind, as they do when looking physically at an object. The object has to be defined as a series of polygons which make up its surfaces. A model of Giotto has been defined in this way for the three-dimensional graphics sequences.

Figure 4 is taken from a sequence made to explain the geometry of the encounter. The angles are correct, but the relative sizes of the objects and of the distances between them are not. It is often necessary to use false sizes because the true sizes and distances differ by many orders of magnitude. For example, the comet coma diameter is more than a million times the diameter of Giotto.

Scaling problems are avoided in the animation of the hours leading up to the encounter by choosing a viewpoint close to the spacecraft (Fig. 5). The viewer has the impression of following along behind Giotto, so that the spacecraft's size remains constant. The comet gets larger as it gets closer, until it fills the screen in the final stages. A moving background of imaginary stars strengthens the illusion of motion, and the passage of time is indicated indirectly by a reducing count of the remaining kilometres to the encounter.

Figures 6 and 7 are frames taken from sequences to illustrate the analysis of possible post-encounter missions for Giotto. The first shows the trajectory of Giotto for an encounter with Comet Schwassmann-Wachmann-3. This mission was in fact rejected because of a lack of recent observational data on the comet's orbit. In the other, the spacecraft is targetted for an Earth flyby in 1990, and continues to an encounter with Comet Grigg-Skjellerup in 1992.

Figures 5a-d — The Giotto/Halley approach sequence

Giotto manoeuvres for the Earth flyby have in fact been executed, and the spacecraft placed in hibernation mode, with the Grigg-Skjellerup encounter as one of the possible objectives.

Application to the Data-Relay Satellite
A system of two Data-Relay Satellites (DRSs) will be launched in the 1990s and positioned in geostationary orbit, from where they will relay data between spacecraft in low Earth orbits and the ground segment.

The system-analysis and mission-profile programs for the mission will involve many variables: space, time, types of communication, percentage loading of communication capacities, etc. Animated colour-graphics sequences can make these results easier to understand and are currently being produced to illustrate the changing relative positions of the spacecraft and the varying loads on the transmission capacity of the relay satellites.

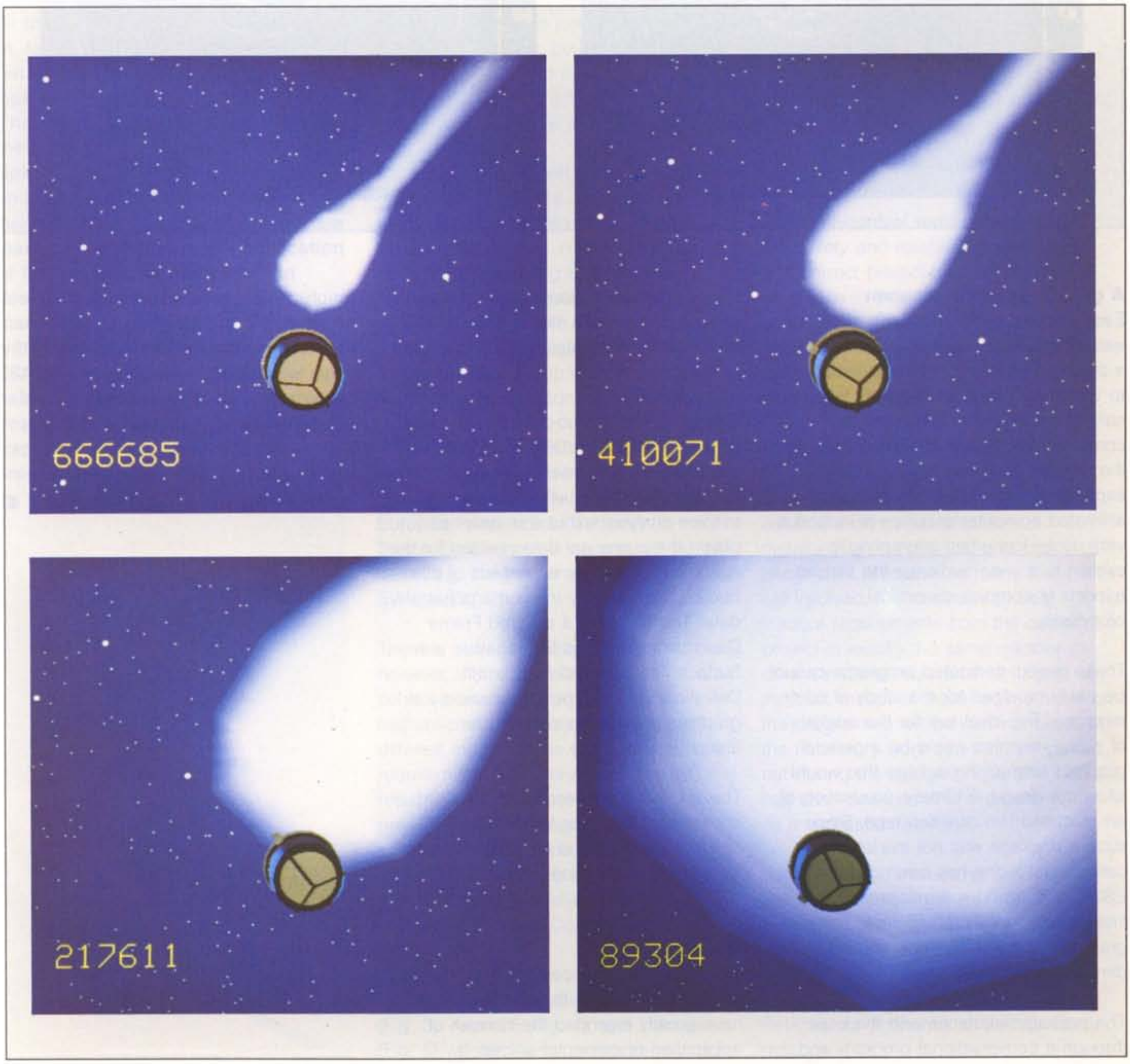
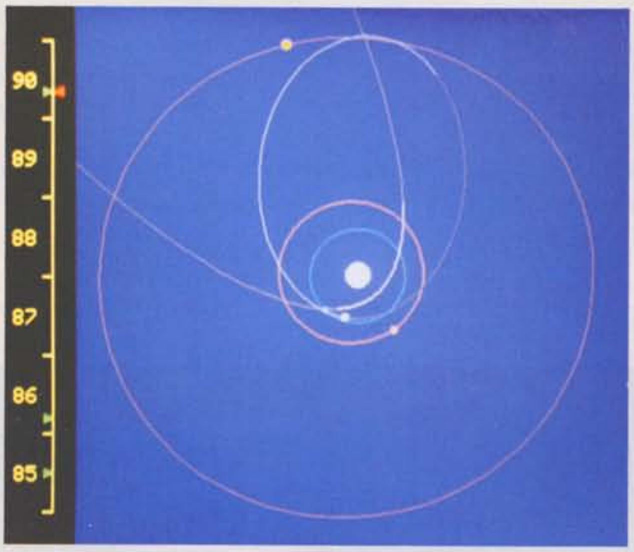
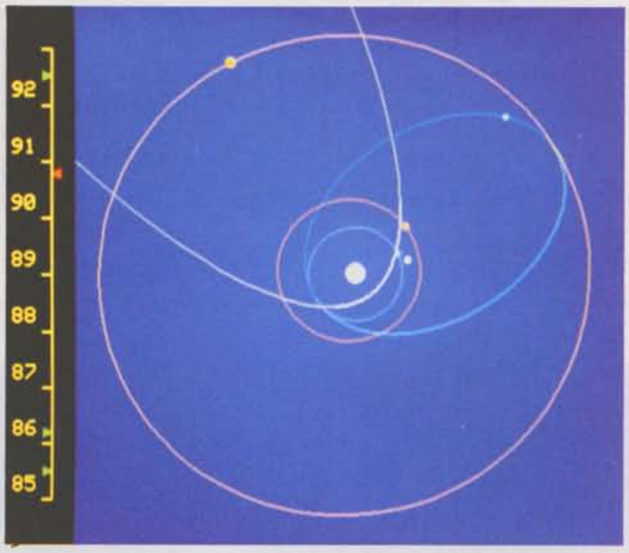


Figure 6 — Visualisation for the Schwassmann-Wachmann mission

Figure 7 — Visualisation for the Grigg-Skjellerup mission





A general graphics program

Each of the programs described so far was designed to illustrate some aspect of a current ESA mission, and they served to validate a variety of methods for solving some typical problems of computer-graphics animation applied to the analysis of space missions. The experience obtained has shown that animated computer graphics is indeed a very useful tool when attempting to explain to a wide audience the various aspects of complex dynamical processes.

These project-dedicated programs cannot be easily modified for the study of other missions. The ideal tool for the analysis of space missions would be a general graphics animation package that would allow the almost automatic production of an animated film or video tape. Since such a package was not available commercially, one has been designed at ESOC and is under development, with a first stage supporting two-dimensional graphics, and a later stage for three dimensions.

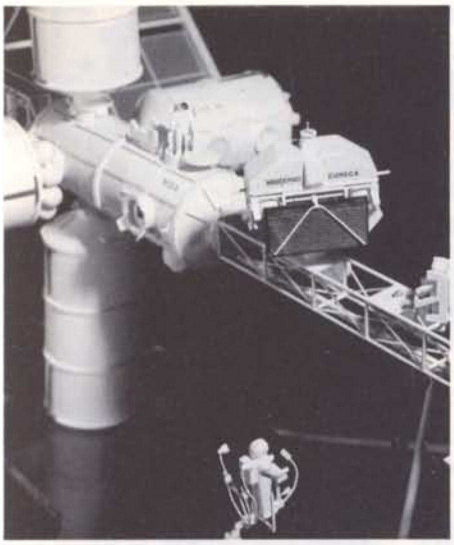
The package interfaces with the user through a conversational program and the user describes the 'script' for the animated sequence, but without having to specify all the data associated with it.

The script forms a so-called 'High-Level Description File' (HLDF). The HLDF is used to drive a Frame Definition Program that communicates with the available mission-analysis software in order to obtain the numerical data needed for the spacecraft trajectory, ephemeris of other bodies and auxiliary mission-analysis data. The output is a detailed Frame Description File. This file, together with Surface Features and Spacecraft Definition Files, will be processed by a graphics program to produce an animated sequence.

The animated sequence can then be shown on a graphics terminal at ESOC, or it can be recorded on film or video tape to be shown elsewhere.

Conclusion

The high performances achieved by graphics systems in the last few years have greatly extended the domain of application of computer-animated graphics, as the several aspects of its application to the analysis of space missions that have been outlined here serve to illustrate. The technique is proving very useful for illustrating complex dynamical problems to a wide audience, and it will soon be a standard tool in the analysis of space missions.



The Agency's Fracture-Control Technology Programme

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At the Ministerial Conference in Rome in January 1985, the European nations approved the European Space Agency's long-term future planning. The future programmes now foreseen include the development of: the Space Station/Columbus, Ariane-5, and the reusable space plane Hermes. All of these programmes are manned and therefore the application of fracture-control procedures in designing the space hardware is mandatory for crew safety. To cope with these challenging programmes, ESA has planned a cost-effective and balanced Fracture-Control Technology Programme which unifies all of the fracture-related areas of the previous programmes.

Fracture control has long been used in the aircraft industry, but its application in space has increased in importance only in the last ten years with the coming of the US Space Shuttle programme.

In general, all manned, reusable spacecraft require the application of fracture-control procedures to prevent any inherent defects in the materials used from generating catastrophic failures, with consequent loss of the vehicle and loss of life. All payloads carried inside the cargo bay of the Space Shuttle have to comply with mandatory fracture-control procedures.

Spacelab (Fig. 1) was the first European space programme to use fracture-control procedures and since then many other European payloads to be flown on the Space Shuttle have done and will do the same, e.g. the Instrument Pointing System (Fig. 2).

There is currently a major problem, however, in that a proliferation of fracture-control plans and interpretations of fracture-control requirements exists in different industries, as the original NASA requirements were very general. The result is a very confused situation at the present time. A management scheme designed to streamline and clarify this whole issue for space applications has therefore been conceived and forms part of the ESA Fracture-Control Technology Programme.

The fracture-control efforts for Columbus (Fig. 3), Ariane-5 (Fig. 4), and Hermes (Fig. 5) will involve considerable research and development work. Maximum use will therefore be made of common technologies in order to minimise costs, hopefully accompanied by the transfer of knowhow from other industries, such as the nuclear, offshore and civil domains.

Fracture-control methodology

The safety and reliability of structures and correct prediction of their overall resistance to premature failure through brittle fracture, fatigue or stress corrosion is best assessed by applying a fracture-control plan in conjunction with fracture-mechanics studies.

To be successful, a fracture-control programme must be multidisciplinary, since failure in a structure is often the result of a complex interaction of metallurgical, mechanical and chemical parameters. Because so many disciplines are involved, it is desirable to treat fracture requirements from the outset of a project in exactly the same manner as other structural requirements. In this way the cost impact of these requirements on the programme will be minimal because the necessary work can then be carried out during the design phase, and not, as has often been done in the past, solely as a verification exercise.

Because of the increasing lifetimes foreseen for future generations of spacecraft and the substantial growth in the dimensions of future space structures, it will be increasingly important to ensure maximum structural lifetimes, for economic as well as safety reasons.

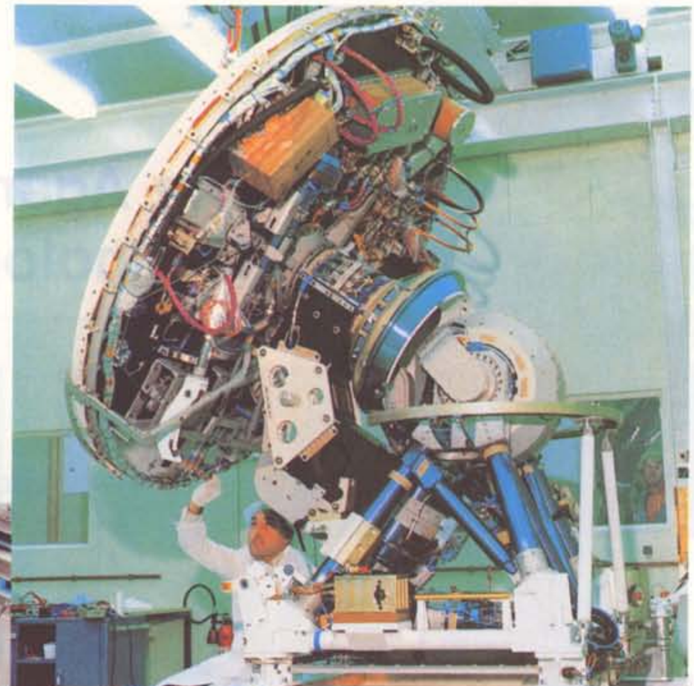
Figure 1 — The European Spacelab during integration

Figure 2 — The ESA Instrument Pointing System (IPS) payload

Figure 3 — Model of Columbus

Figure 4 — Model of Europe's man-rated Ariane-5 launcher

Figure 5 — Model of Hermes, the proposed manned re-usable space plane



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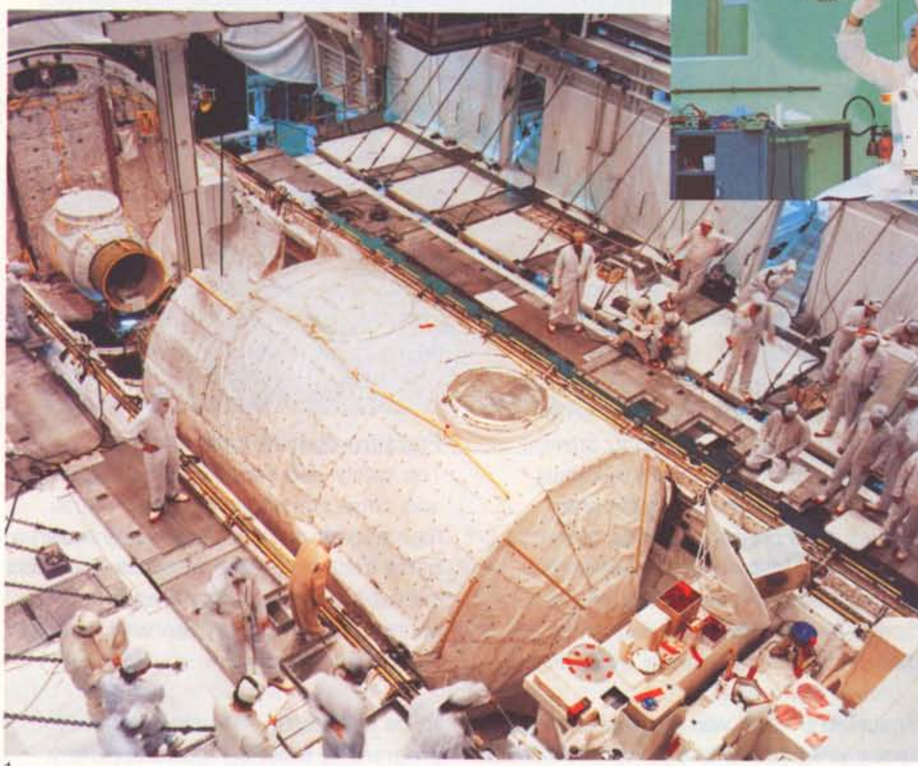

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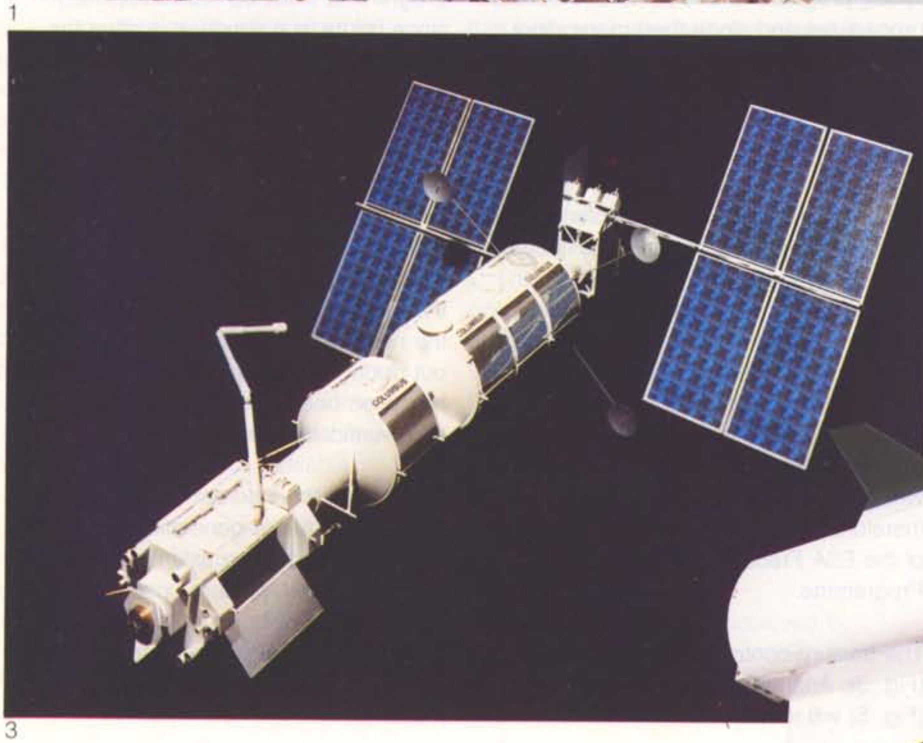

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Fracture-control management

To cope with the present proliferation of fracture-control plans and to establish a definitive fracture-control technology for its future programmes, ESA has set up a Fracture Control Board at ESTEC to act as a focal point for all fracture-control issues. The Agency's overall objectives are to:

— establish fracture-control requirements and guidelines, leading to cost-effective application

— streamline and unify European fracture-control policy

— create a European exchange of information in the space domain on fracture matters

— standardise analytical tools

— give Europe substantial autonomy for present and future programmes.

The need to apply fracture-control procedures in order to avoid catastrophic in-flight structural failures was first highlighted by NASA in document NHB 1700.7A, titled 'Safety Policy and Requirements for Payloads using the STS'. The implementation of these requirements is monitored in the US by the NASA centre responsible for the payload being developed, e.g. Marshall Spaceflight Center for Spacelab, and Goddard Spaceflight Center for Space Telescope.

NASA's Johnson Space Center is ultimately responsible for the complete Space Shuttle Programme and carries out the payload safety reviews, which include the fracture-control documentation. In general, there are two NASA centres involved in any development of European payloads to be launched on the Space Shuttle . ESA/ESTEC acts as the focal point for Europe.

The ESA policy for complying with the NASA NHB 1700.7A requirements will thus be basically formulated in a Fracture Control Requirements Document. To facilitate compliance with these requirements, a Fracture Control Guideline Document will also be issued. Both of these documents will be agreed with NASA, in order to standardise the approaches and the analytical tools employed by the two agencies. With this goal in mind, an Analytical Fracture Control Technology Panel has been established by NASA with ESA participation. In addition, ESA/ESTEC has been working very closely with NASA/JSC on common analytical tools for crack-growth analysis.

European industry is directly involved by ESA through the medium of workshops and technical meetings. A formal Industry Advisory Group will eventually be created in order to maintain regular and direct contact with as many companies as possible, and not just with those that happen to be involved in a current project. This improved industrial contact will facilitate exchange of technical information, lead to the creation of a common European database, and provide feedback concerning potential problem areas to be investigated by ESA via technology contracts.

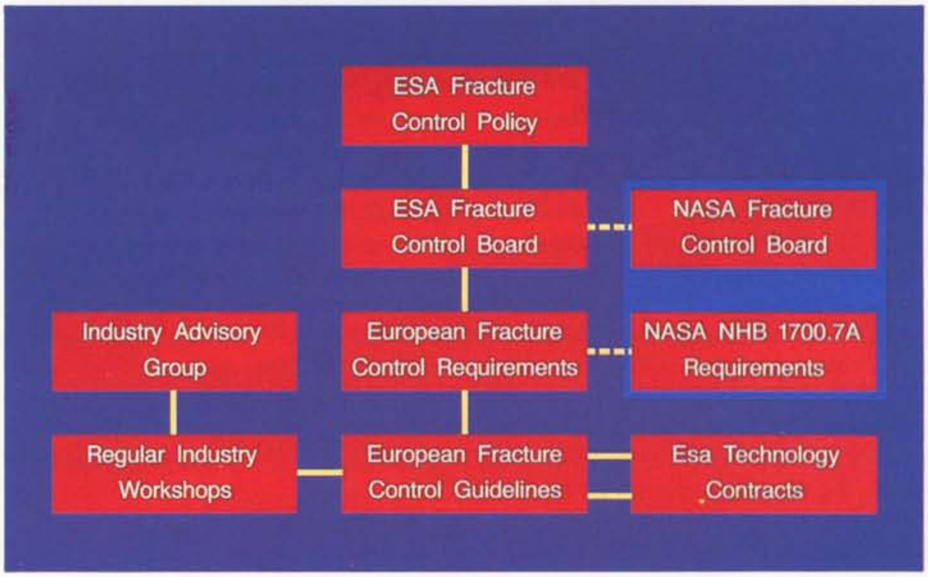
The ESA Fracture Control Board will deal directly with its NASA/JSC counterpart, regardless of which NASA centre is responsible for the particular payload under development, in order to simplify the interfacing process on fracture-control matters. Figure 6 shows the overall management scheme that will be implemented. Blue boxes are valid only for payloads using the US Shuttle system.

For Ariane-5, which will be designed for man-rated flights with the Hermes space plane, only the ESA requirements will apply, i.e. the blue boxes will no longer apply. Detailed requirements have yet to be formulated, but a number of areas in which modifications with respect to the NASA-oriented requirements may be made have been identified. Compatibility with NASA requirements is needed for Hermes, given that it will dock with the International Space Station.

Fracture-control technology

Although all of the Agency's new programmes have basic features in common, each has particular characteristics of its own (Fig. 7):
—Columbus/Space Station: The long in-orbit lifetime (30 years) foreseen for the structures leads to a need for in-orbit

Figure 6 — The overall management scheme for ESA's Fracture-Control Policy



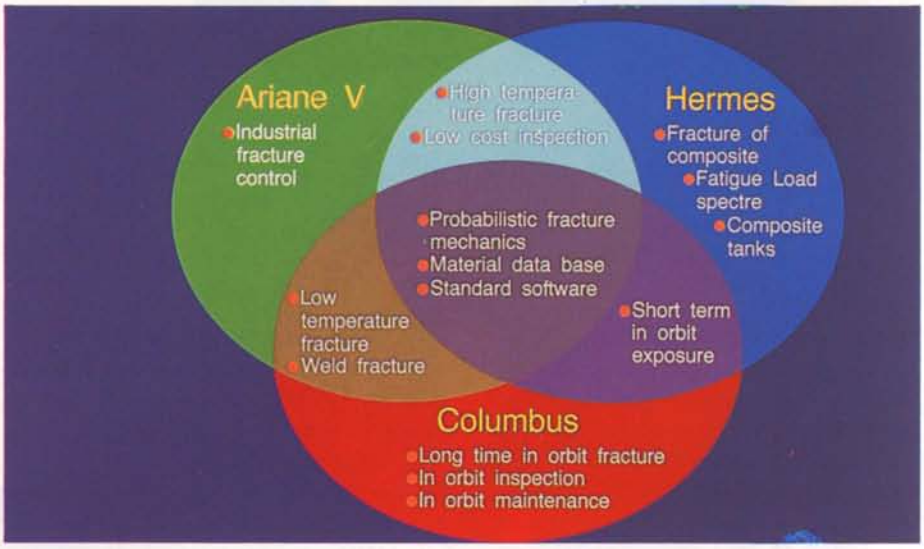


Figure 7 — Overview of ESA's Fracture Control Technology Programme

inspection and maintenance, vis-a-vis environmental materials degradation, debris damage tolerance, etc. Standardisation with the NASA Space Station is also mandatory for in-orbit compatibility.

— Ariane-5: Even if the baseline configuration of the launcher is not reusable, its man-rating means that very high reliability must be ensured. All main engines and tanks need to be designed and verified according to fracture-control procedures. Residual stresses in welds also need to be studied. Low-cost acceptance procedures and methodologies need to be developed to cope-cost effectively with the high production rate envisaged.

— Hermes: This manned, reusable space plane will need some technologies common to Columbus and Ariane, but many of its needs will be different. In particular, the following aspects must be addressed:

(i) Fracture of composites. Many of the materials proposed for use will be derived from the aircraft industry. There will therefore be a need to extend the temperature ranges of application of these materials and hence to re-investigate their fracture methodology.

(ii) High-temperature fracturing needs to be addressed also in connection with engine components. The need for frequent engine changes during the Shuttle programme has indicated a requirement for greater conservatism in design.

(iii) Fatigue load spectra need to be generated to simulate the mission profile. In view of the large number of measurements involved — wind direction, gusts during ascent, roughness of the runaway, etc. — this will be a time-consuming process.

(iv) Low-cost non-destructive inspection and monitoring.

(v) Fracture control in composite tanks. The current proof-test methodology is not considered valid for composite tanks, and special algorithms need to be developed for their design and special test procedures for their acceptance testing.

A number of technological areas are common to all three programmes (Fig. 7):

(i) A computerised materials database is in the process of being generated, with the incorporation of all data generated in Europe

(ii) Standard software will be used for the evaluation of crack propagation, including possible closure models. This software, which will also include stress intensity factors, is being developed jointly with NASA

(iii) Probabilistic fracture mechanics. For safety and cost reasons, it is important to estimate the reliability of particular components subject to cracking.

A planned structural laboratory at ESTEC will be used to carry out materials fracture tests (i.e. fracture toughness, crack-growth propagation). This new laboratory will be used to check new materials and solve specific fracture problems that arise during the current and future programmes.

Interdisciplinary approach

Fracture control has been widely applied in industries other than the aerospace business for many years. Each of these industries has developed expertise in a particular field relevant to its own activities. In the nuclear/energy industry, for example, sophisticated analysis techniques have been developed for deriving fracture criteria and in radiation shielding. Extensive data exchange has been taking place between the European industries for many years. Probabilistic fracture mechanics is also widely used.

In the offshore industry, load spectra prediction techniques are well advanced, as are fast on-site non-destructive inspection techniques. Corrosion prevention and control is also mandatory in such an industry.

In the transport industry, fracture-control techniques are applied to reduce the cost of automobile parts, and to increase their reliability.

In view of the fact that these and many other areas of technology that will be needed for the Agency's future space programmes are already used or are under development in other industries, closer interdisciplinary cooperation should be exploited to reduce development costs.

Conclusions

To cope with the increasing need for the application of fracture-control techniques in the Agency's future programmes, a balanced and cost-effective Fracture Control Technology Programme has been conceived. This programme will attempt to derive maximum benefit from the common technology needs of the different programmes and from the experience available in industries working in other than the aerospace domain, i.e. nuclear, offshore and civil.

A management scheme has also been developed to establish direct contact between industry and ESA, and between the latter and NASA for payloads to be launched with the Space Shuttle. A similar scheme will be used within Europe for the future European space-transportation system based on Ariane-5 and Hermes.

In Brief

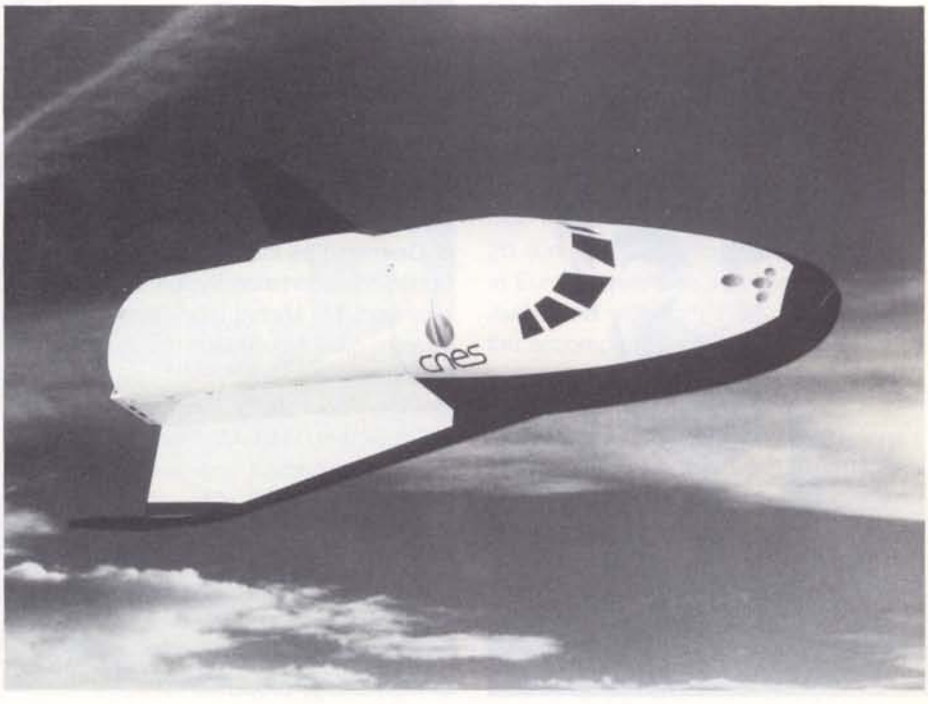
The 'Hermes' Manned Spaceplane to become an ESA Programme

At its 74th Meeting, on 25 to 27 June 1986, the ESA Council approved the Europeanisation of Hermes, the French manned spaceplane project, by adopting an enabling Resolution for a Preparatory Programme.

This decision responds positively to the Recommendation made at the Ministerial Council in Rome on January 1985 that this programme be included, as soon as feasible, in the optional programmes of the Agency. During the intervening eighteen-month period, France has advanced its studies on Hermes and has presented a detailed dossier on the programme to ESA's Member States. ESA too has progressed with its studies of the various elements of the future European space infrastructure (Columbus, Ariane-5, and the Data-Relay Satellite), in which Hermes will play a key role.

Council's approval of the Resolution once again confirms the political will of the Agency's Member States to work towards an autonomous European infrastructure in space. During the coming weeks those ESA Member States that wish to participate will work out the details of the Preparatory Programme, including in particular the level of contribution of each Member State and the technical content of the programme. This information will be laid down in a document known as the Declaration. Once this Declaration has been finalised and signed by a sufficient number of States to put it into force, the Hermes Preparatory Programme will be undertaken by those Participating States.

The schedule foresees that this programme, designed to follow on from the studies previously undertaken by France (CNES) under bilateral agreements, will cover the period from Autumn 1986 until June 1987. The Hermes Preparatory Programme will include a series of industrial activities aimed at the detailed definition of the spaceplane and the requirements for the ground segment, together with the necessary basic-technology studies. This initial phase will prepare the way for ESA's Member States to take a decision in mid-1987 on a Hermes development programme, at the same time as they decide on the execution of other elements of the European space infrastructure. Based on this schedule, the first launch of Hermes could be expected to take place in 1995/1996.



COSPAR International Cooperation Medal awarded to the Inter-Agency Consultative Group

COSPAR, the Committee on Space Research established by the International Council of Scientific Unions, has presented the International Cooperation Medal, awarded for distinguished contributions to international cooperation in the field of space sciences, to the Inter-Agency Consultative Group (IACG) for its cooperative effort in the missions to study Halley's Comet. The award was presented on 30 June 1986 during the inauguration of the XXVI Plenary Meeting of COSPAR in Toulouse (France).

The IACG was set up in 1981 by ESA, the Japanese Institute of Space and Astronautical Science (ISAS), the Intercosmos of the USSR Academy of Sciences and NASA to coordinate the activities of the four Agencies associated with their space missions to Comet Halley.

The Group has held its meetings each year alternately in Europe, Japan, the USSR and the USA. It will hold its next meeting on 3 and 4 November 1986 in Padua (Italy), home of the frescoes painted by Giotto di Bondone, after whom ESA's mission to Halley's Comet was named. The International Halley Watch, responsible for coordinating all ground-based observations of the Comet, has also participated in the IACG meetings.

Three Working Groups were set up within the framework of the IACG: a Halley Environment Working Group; a Plasma Science Working Group; and a Spacecraft Navigation and Mission Optimisation Working Group later known as the 'Pathfinder' Working Group. The aim of the Pathfinder concept was to improve the targetting accuracy of Giotto to ensure that the European space probe flew by the nucleus of the Comet at a distance of about 500 km. This was done by using data from the two Soviet missions to Halley's Comet, Vega 1 and 2, and by tracking these spacecraft very precisely with the NASA Deep-Space Network. It was thanks to this concept that Giotto achieved a final flyby distance of 600 km from the nucleus, with a residual uncertainty of only some 40 km. This remarkable success was entirely due to the excellent spirit of cooperation at all levels between the four Agencies participating in the IACG.

The IACG provided a unique opportunity for cooperation between the world's four main space agencies in the peaceful exploration of space and ESA is extremely proud to have shared in the COSPAR award with its partners in the IACG.

ESA at the Hannover International Aerospace Show (ILA)

ESA once again, took advantage of Hannover International Aerospace Show (6—15 June 1986), one of the major European aerospace forums, to make its activities better known to the general and specialised public alike.

This year, the Agency showed full-scale models of: its space probe, Giotto which encountered Halley's Comet in March; its X-ray astronomy satellite Exosat, whose mission terminated in May; and one of its European Communications Satellites (ECS-2), identical to the fourth flight unit scheduled for launch this year. Also on display was a 1:10 model of Ariane-5, Europe's man-rated launcher for the 1990s.

There was also a continuous audio-visual programme running on the ESA stand, designed to illustrate the very wide range of ESA's present and future activities in all the various fields of space endeavour.

Appointment of ESA Director of Space Transportation Systems

At its 74th Meeting on 25—27 June 1986, the Agency's Council has appointed Mr. Jörg Feustel-Büechl (Federal Republic of Germany) as the new Director of Space Transportation Systems, to take over from Mr. Michel Bignier, who is due to retire on 1 November.

Born in Regensburg, Germany, on 6 September 1940, Mr. Feustel-Büechl studied mechanical engineering at The Technical University of Münich, graduating in 1967 (Dipl. Ing.).

He began his career with MAN Turbo as a design engineer, where his responsibilities included feasibility studies of high-energy propulsion systems. In 1969, he joined MAN AG Advanced Technology, where he was involved, among other things, in manufacturing the Viking engine and in other Ariane-related technologies.

Since 1984, Mr. Feustel-Büechl has been Senior Vice-President and General Manager of MAN Technology. In this capacity, he is responsible for the development, production and quality assurance of space projects, and the management of projects in the new-energy-system, electronics and composite-materials fields. He is a member of the Board of Arianespace SA.

Mr Feustel-Büechl will take up his appointment with ESA in the Autumn.

Ariane V18 Enquiry Board Reports

The Board of Enquiry set up by ESA and Arianespace on 31 May 1986 following the failure of the Ariane V18 launch presented a preliminary report to both organisations on 2 July 1986.

No manufacturing fault in any item of hardware of the engine or propulsion unit came to light during the Enquiry. Several factors led the Board to believe that a first partial ignition occurred, but that propagation of combustion did not take place normally. A second ignition occurred at an abnormally high pressure 0.12 s later, which caused a high-pressure peak and extinction of the engine.

The Board submitted fourteen recommendations, mainly involving:
- complementary studies on the ignition conditions
- re-definition and qualification of a more powerful third-stage ignitor
- a schedule of firing tests under simulated flight conditions designed to validate the new ignition conditions and the engine for the next flight (V19)
- a review of the third-stage-engine (HM7) acceptance process.

After concerting its position with ESA and CNES, Arianespace will now request that the propulsion manufacturer, Societé Europeénne de Propulsion (SEP), with the support of Societé Nationale d'Etudes et de Construction de Moteurs d'Avions (SNECMA), determine under what conditions the 14 recommendations will be fulfilled, and define a test programme.

Arianespace is now analysing the consequences of these actions for the launch schedule for the months to come.

ESA Participates in 'Space Commerce 86'

The space business is now entering a commercial era, with the market for satellite communications and for launchers already booming and the commercial interest in information provided by Earth-observation satellites growing rapidly, not to mention the potential opened up by recent microgravity research (see article on page 32 of this issue).

Although ESA remains essentially a research and development organisation, it is nevertheless following these new trends closely. The need for this was already clear in January 1985, when the Ministers of the Agency's Member States approved ESA's Long-Term Plan of activities, taking into account the future commercial applications of space, particularly in the Earth-observation field and, even more, in the microgravity sciences, with the decision to participate in the International Space Station.

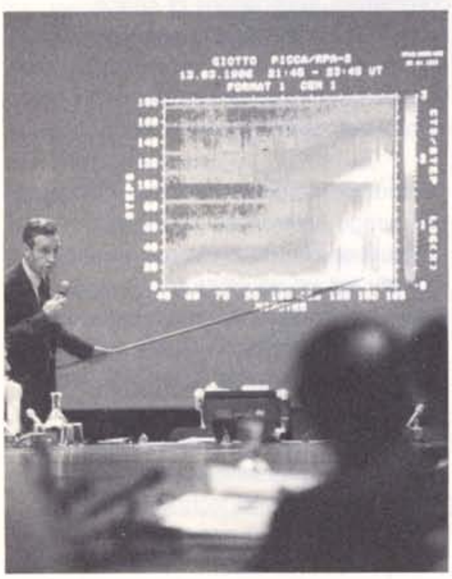
As another indication of ESA's intention to encourage enterprises to benefit from the possibilities offered by space, it has recently set up an office for Space Commercialisation, the major activity of which is the promotion of the Agency's services and products among potential customers. This Office is also active in creating the conditions that will facilitate and stimulate the sale and the use of space products and technologies by space-oriented and non-space industries on a profitable basis.

It was against this background that ESA decided to endorse the first International Conference and Exhibition on the Commercial and Industrial Uses of Outer Space, known as Space Commerce 86, held in Montreux, Switzerland from 16 to 20 June 1986. The main aerospace firms in Europe were also very closely associated with both the Conference and the accompanying Exhibition.

Prof. Reimar Lüst, ESA's Director General, spoke at the opening Plenary Session and several other ESA staff presented papers at the Conference. ESA also participated in the Exhibition in the pavilion devoted to the European space effort.

Exhibition in Barcelona

The accompanying photograph shows one corner of the ESA stand on the opening day of the exhibition ASTRO 2000 in Barcelona, in Spain, on 7 April 1986. This exhibition, which lasted one month, was staged by 'la Caixa de Barcelona', a national banking chain, as part of its cultural and social promotion programme.



Giotto Press Conference at ESA Headquarters

The accompanying photographs were taken on 15 May during a Press Conference at the Agency's Paris Headquarters, called to coincide with the publication of a special issue of 'Nature', the international weekly science journal, and attended by some seventy journalists. This issue (Volume 321, Number 6067, 15—21 May 1986) contains the first detailed and comprehensive assessment of the scientific results of the Giotto, Vega, Suisei and Sakigake spacecraft encounters with Comet Halley.

During the Press Conference, hosted by ESA's Director General, Prof. Reimar Lüst, and the Director of Scientific Programmes, Dr. Roger Bonnet, the Giotto Principal Investigators and the Giotto Project Scientist, Dr. Rüdeger Reinhard, were on hand to provide the assembled journalists with brief accounts of the primary results from Giotto's eleven scientific experiments and to respond to questions.

Giotto's Encounter with Halley's Comet as Envisaged by the Children of Europe

In January, ESA invited children under ten years of age to send in a drawing or painting illustrating the encounter between Giotto and Halley's Comet as they imagined it, with a view to sharing their vision of the event with them again at the time of Halley's next apparition in 2061. The response to this competition was overwhelming, with 16 483 entries in all.

Choosing winners from so many colourful and imaginative entries proved an incredibly difficult task. It was finally decided to reward 27 children for their particularly outstanding pictures.

They were invited to Paris on Sunday 15 June to visit ESA Headquarters, where they were welcomed by: Prof. Reimar Lüst, ESA's Director General; Dr. Roger Bonnet, ESA's Director of Scientific Programmes; and ESA Astronaut Dr. Wubbo Ockels. They were presented with a diploma certifying that they had participated in the ESA competition and that their pictures have been archived at the Agency's European Space Operations Centre in Darmstadt (Germany) until Halley's Comet reappears again in 2061, when they will be put on show again. The children were then invited to lunch on a river boat on the Seine, before receiving their prizes.

The 27 prizewinners (in alphabetical order of their home countries) were:

Rainer Plöb	aged 6	Vienna, Austria
Isabel Schleining	aged 8	Vienna, Austria
Philippe Chateau	aged 5	Bierges, Belgium
Edwin Boeckxstaens	aged 7	Bonheiden, Belgium
Stéphane Crommelynck	aged 10	Brussels, Belgium
Charlotte Dreyer	aged 9	Lyngby, Denmark
Franck Drouin	aged 7	Evry Village, France
Josef Marion	aged 9	Fox-Amphoux, France
Nadine Breier	aged 7	Wiesloch, Germany
Tobias Salzmann	aged 8	Hannover, Germany
Natalie O'Shea	aged 9	Tralee, Ireland
Lynne Kearns	aged 9	Strokestown, Ireland
Kyran Carroll	aged 10	Sandycove, Ireland
Luca Protetti	aged 6	Settebagni, Italy
Sandra Gaudi	aged 10	Caselle, Italy
Martijn and Renate Tol	aged 4 & 8	Volendam, Netherlands
Ramon van der Kaap	aged 7	Zuidland, Netherlands
Torbjorn Hergum	aged 8	Ranheim, Norway
Susana Gutierrez	aged 7	Suances, Spain
Inmaculada Murcia Serrano	aged 8	Alcala la Real, Spain
Ester Sanchez Sanchez	aged 10	Salamanca, Spain
Camilla Kacner	aged 8	Sollentuna, Sweden
Ganymed Stanek	aged 6	Arth, Switzerland
Serge Zaugg	aged 10	Bern, Switzerland
Christopher Grove	aged 6	Marlborough, United Kingdom
Christopher Stonely	aged 7	Horsham, United Kingdom

New ESRIN Building Officially Opened

Minister Luigi Granelli, Italian Minister for Research and Technology, officially opened a new building complex at the Agency's establishment in Frascati, near Rome, during an inauguration ceremony on 24 July 1986. ESA's Director General, Prof. Reimar Lüst, accompanied by other members of the ESA Directorate and senior Agency staff, welcomed Minister Granelli and the other guests on their arrival at the establishment.

The new building complex will provide approximately 2000 square metres of much needed additional office space for the two Agency services currently housed at ESRIN, namely the Earthnet Programme Office and the Information Retrieval Service. It will also allow ESRIN to house new activities now under consideration based on the recommendations made at the ESA Council Meeting at Ministerial Level, held in Rome in January 1985.

Minister Luigi Granelli performing the official opening, in the company of ESA's Director General, Prof. Reimar Lüst

Minister Luigi Granelli touring the ESRIN facilities

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. 10, No. 2:

AN ATMOSPHERIC-CORRECTION SCHEME FOR OPERATIONAL APPLICATION TO METEOSAT INFRARED MEASUREMENTS
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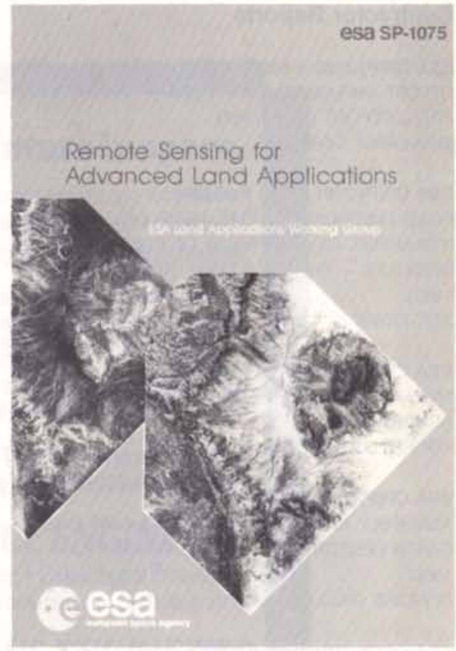

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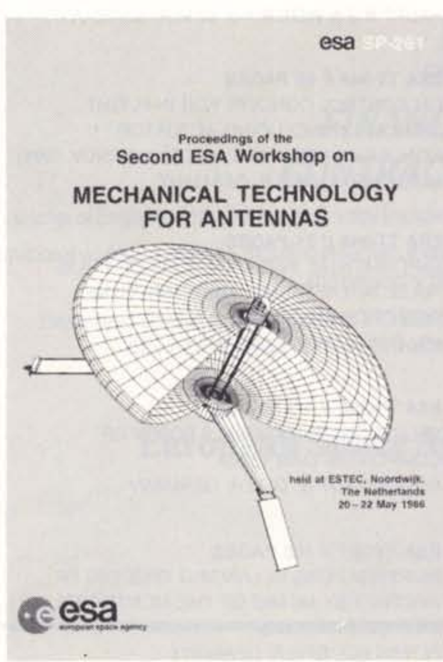

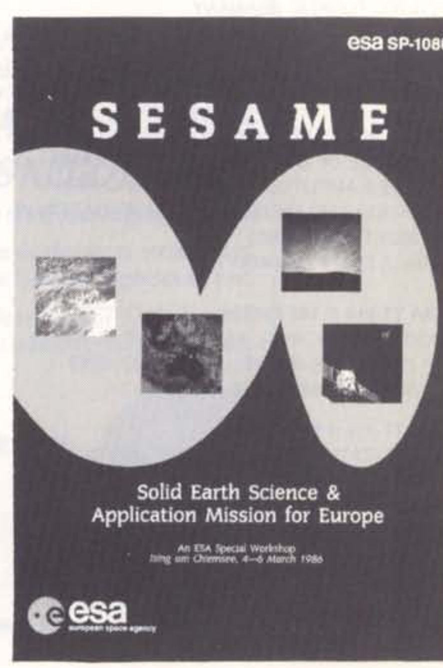

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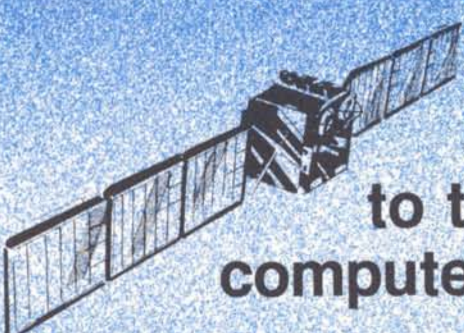

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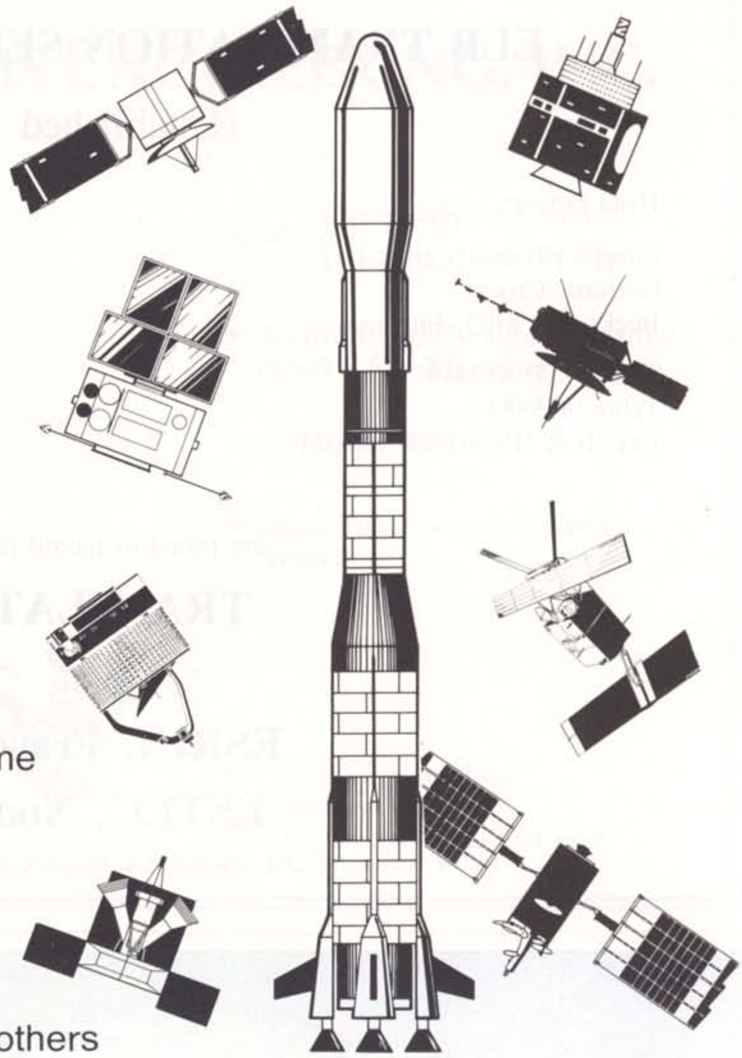

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The Bulletin is the Agency's quarterly magazine that helps to fulfil this obligation, carrying information on ESA, its activities and its programmes, on-going and future.

The ten or so articles that go to make up each issue (approximately 100 pages) are drafted by professional scientists and technologists. They are original and significant contributions on space technology, space science, space missions and space systems management and operations. The goal is to bring the results of ESA's space research and development activities to the notice of professionals concerned with the exploration and exploitation of space, many of whom are senior politicians and those responsible for government contracts.

Every Bulletin also carries some 16 pages of 'progress information' that comprehensively describe the last three months' developments in all the major European space programmes (telecommunications, meteorology, earth observation, and scientific satellites, the Spacelab/Space Shuttle programme and the Ariane launch-vehicle programme). Newsworthy events, conferences, symposia and exhibitions associated with the European space programme are also featured in every issue.

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Through the nature of its content and the role that the Agency plays in shaping Europe's space research and development activities, the Bulletin has come to have a fast-growing (currently 10 500 copies per issue) but *select* distribution among 'decision makers' in space matters not only in Europe but around the World. The Bulletin is now distributed in more than 100 countries. It is read by managers and senior staff in space-oriented organisations – both national and international – in ministries, in industry, and in research institutes. It forms a fundamental part of the continual dialogue between ESA and its national counterparts and between ESA and the industrial firms to whom the contracts and subcontracts are awarded that account for the major part of the Agency's $950 million per year budget (contract awards on a geographical-return basis linked directly to the financial contributions of the individual ESA Member States).

Advertising Potential

The Bulletin therefore offers the commercial company – large or small – which already provides space-related products and/or services or which wishes to develop its markets in that direction, a direct entrée to a very special readership with a much *higher than average* rating as far as *market potential* is concerned. This commercial market potential is growing steadily each year with a constantly increasing percentage of readers being faced with a need to apply in their own environments the technologies that ESA, the national agencies, and industry have been developing to meet European needs.

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