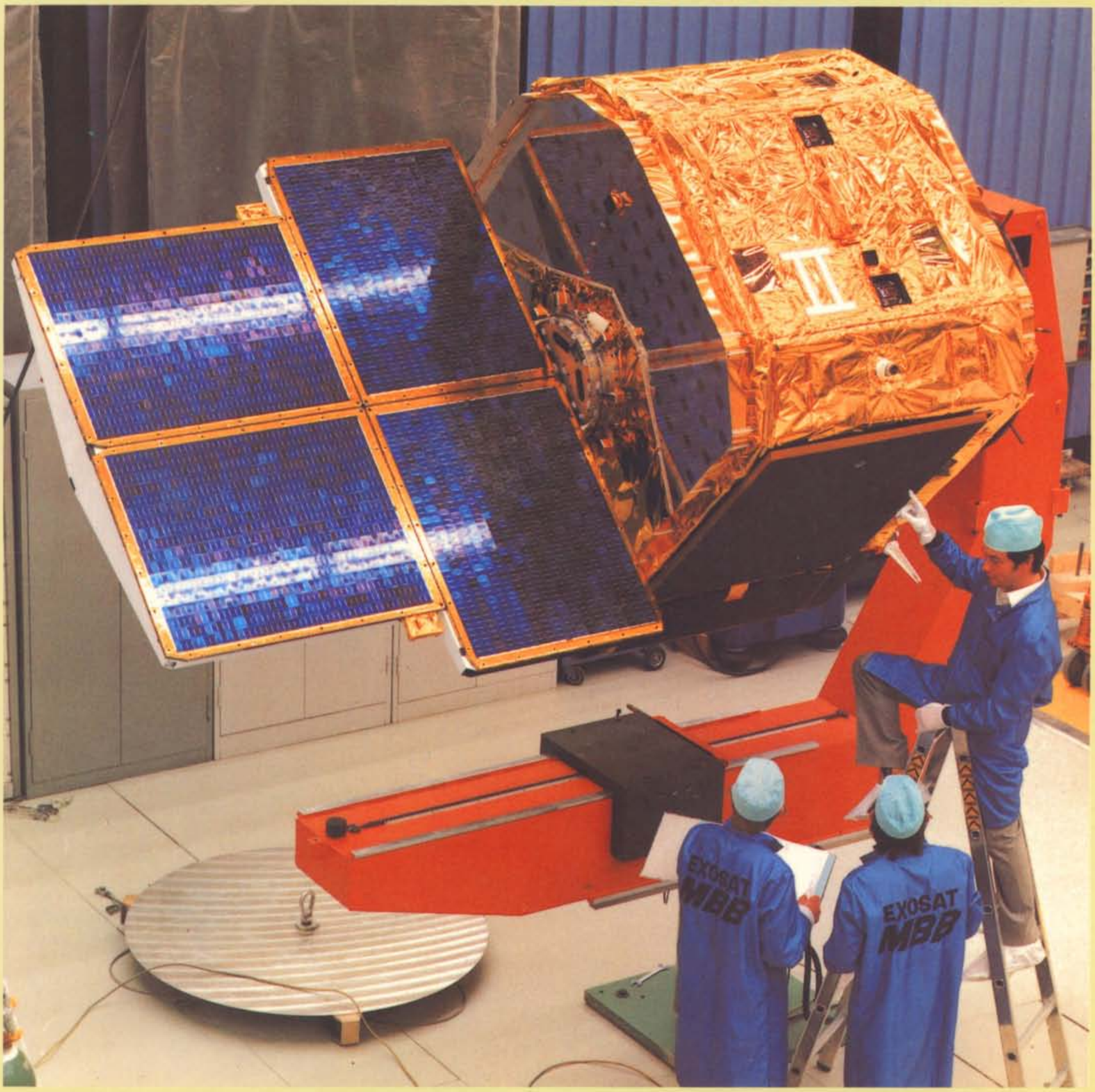
esa bulletin

number 31

august 1982



european space agency

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

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

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

The Agency is directed by a Council composed of representatives of Member States. The Director General is the chief executive of the Agency and its legal representative.

The Directorate of the Agency consists of the Director General; the Director of Scientific Programmes; the Director of Applications Programmes; the Director of Space Transportation Systems, the Technical Director, the Director of ESOC, and the Director of Administration.

The ESA HEADQUARTERS are in Paris.

The major establishments of ESA are:

THE EUROPEAN SPACE RESEARCH AND TECHNOLOGY CENTRE (ESTEC), Noordwijk, Netherlands.

THE EUROPEAN SPACE OPERATIONS CENTRE (ESOC), Darmstadt, Germany.

ESRIN, Frascati, Italy.

Chairman of the Council: Prof. H. Curien (France).

Director General: Mr. E. Quistgaard.

agence spatiale européenne

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

Selon les termes de la Convention: L'Agence a pour mission d'assurer et de développer, à des fins exclusivement pacifiques, la coopération entre Etats européens dans les domaines de la recherche et de la technologie spatiales et de leurs applications spatiales, en vue de leur utilisation à des fins scientifiques et pour des systèmes spatiaux opérationnels d'applications:

(a) en élaborant et en mettant en oeuvre une politique spatiale européenne à long terme, en recommandant aux Etats membres des objectifs en matière spatiale et en concertant les politiques des Etats membres à l'égard d'autres organisations et institutions nationales et internationales;
(b) en élaborant et en mettant en oeuvre des activités et des programmes dans le domaine spatial;
(c) en coordonnant le programme spatial européen et les programmes nationaux, et en intégrant ces derniers progressivement et aussi complètement que possible dans le programme spatial européen, notamment en ce qui concerne le développement de satellites d'applications;
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esa bulletin

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Editorial/Circulation Office
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c/o ESTEC, Noordwijk, The Netherlands

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La Presse Technique SA
3 rue du Vieux-Billard
CH-1211 Geneva 4

Printed in The Netherlands by ESTEC Reproduction Services
ISSN 0376-4265

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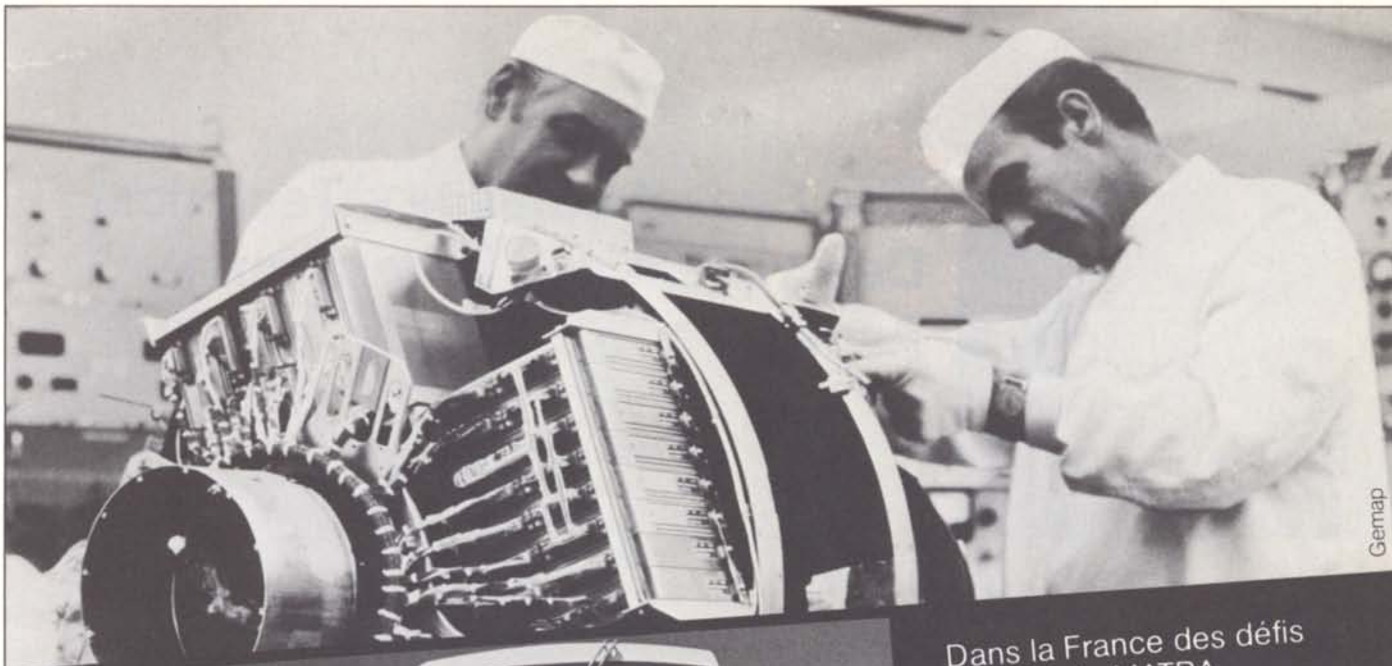
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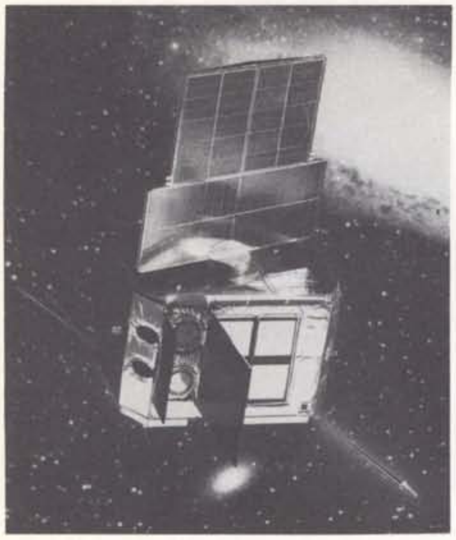


The Exosat Satellite – Technical Description and Programme Aspects

G. Altmann, G. Scoon, C.B. von Stieglitz & J.L. Tracy, Exosat Project Division, ESA Scientific Projects Department, ESTEC, Noordwijk, The Netherlands

Industrial definition and development of the Exosat spacecraft started at the beginning of 1977 and entered a decisive phase at the end of last year with the flight-model acceptance test programme at the Munich premises of the consortium leader MBB. In the meantime the flight-model satellite has been shipped to ESTEC, where final functional and environmental testing will be conducted until September. Launch, by Ariane, is presently foreseen for the second half of November, from the ESA launch range in French Guiana.

Introduction

The mission objectives for a European X-Ray Observatory Satellite evolved gradually from 1968 onwards. What was conceived of at that time as a combined X- and gamma-ray mission (Cos-A) became a gamma-ray observatory mission (Cos-B) in 1969. The concept of X-ray only mission was, however, not discarded, but was actively studied further and ultimately given approval by Council in 1973. Budget limitations resulted in initiation of work in industry being delayed until early in 1977.

Exosat will provide X-ray astronomers with a unique tool with which to enhance their knowledge and understanding in a relatively new branch of high-energy astrophysics. Existing knowledge has been established over the past decade mainly from earlier scientific satellite missions, the first being Uhuru, a NASA satellite launched at the end of 1970, which was to be followed later by the European UK 5 and UK 6 missions and the Dutch ANS satellite. Major progress was made when a more sensitive sky survey and identification of X-ray sources was carried out by HEAO-A, launched by NASA in 1977, and by the even more powerful HEAO-B, the Einstein Observatory, launched at the end of 1978. A catalogue of over 2100 galactic and extragalactic X-ray sources is in the process of being established from the data acquired so far, providing an ample 'hunting ground' for the Exosat mission.

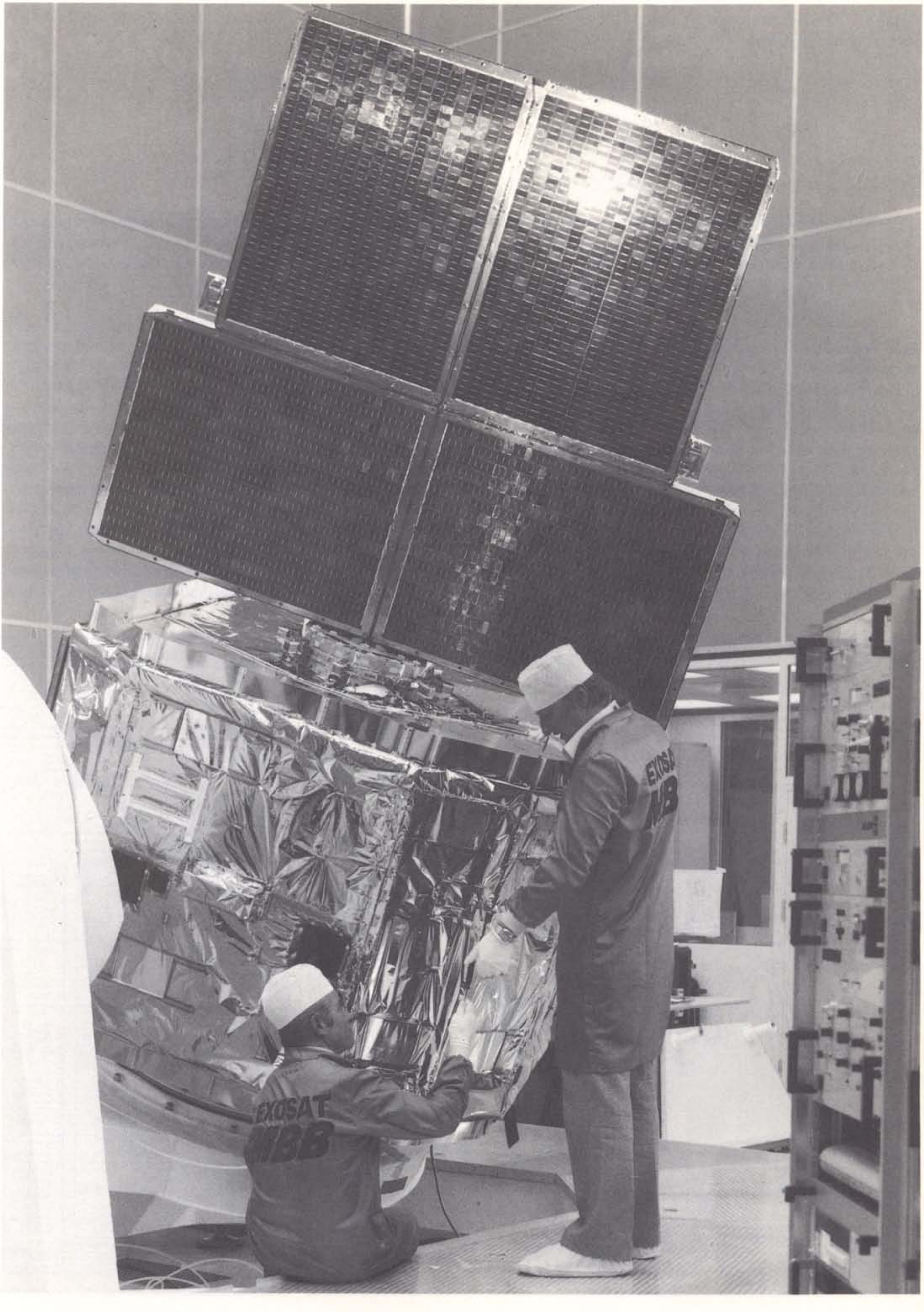
As a small but powerful X-ray observatory, satellite, Exosat will study the X-ray emission from individual sources.

More specifically Exosat will measure the locations of cosmic X-ray sources, their structural features and spectral as well as temporal characteristics in the wavelength range from the extreme ultraviolet (EUV) to hard X-rays.

To satisfy the dominant Exosat mission requirements, outlined in the accompanying article on the mission and its scientific instruments (see page 20), a highly eccentric orbit (perigee 500 km, apogee 200 000 km nominal) with its line of apsides almost perpendicular to the Moon's orbital plane has been selected. This allows the occultation of X-ray sources by the Moon or Earth and the operation of the satellite from a single ground station in real time. When not used for occultations, the satellite can be trained in any direction (i.e. arbitrary pointing), except for a 60° region about the satellite/Sun line to avoid blinding the imaging experiments. The observing time available is dictated by the orbit configuration, and roughly 80 h of the 96 h orbital period, corresponding to the flight path outside the Van Allen belts, will be useful for scientific observations. With its accurate onboard time-keeping Exosat can continuously determine regular and irregular X-ray intensity variations over periods ranging from microseconds to a maximum of 80 h.

The system needed to achieve the scientific mission objectives consists of three major elements:

- the satellite, which acts as a service platform for the scientific payload
- the Ariane launcher, uprated by a fourth stage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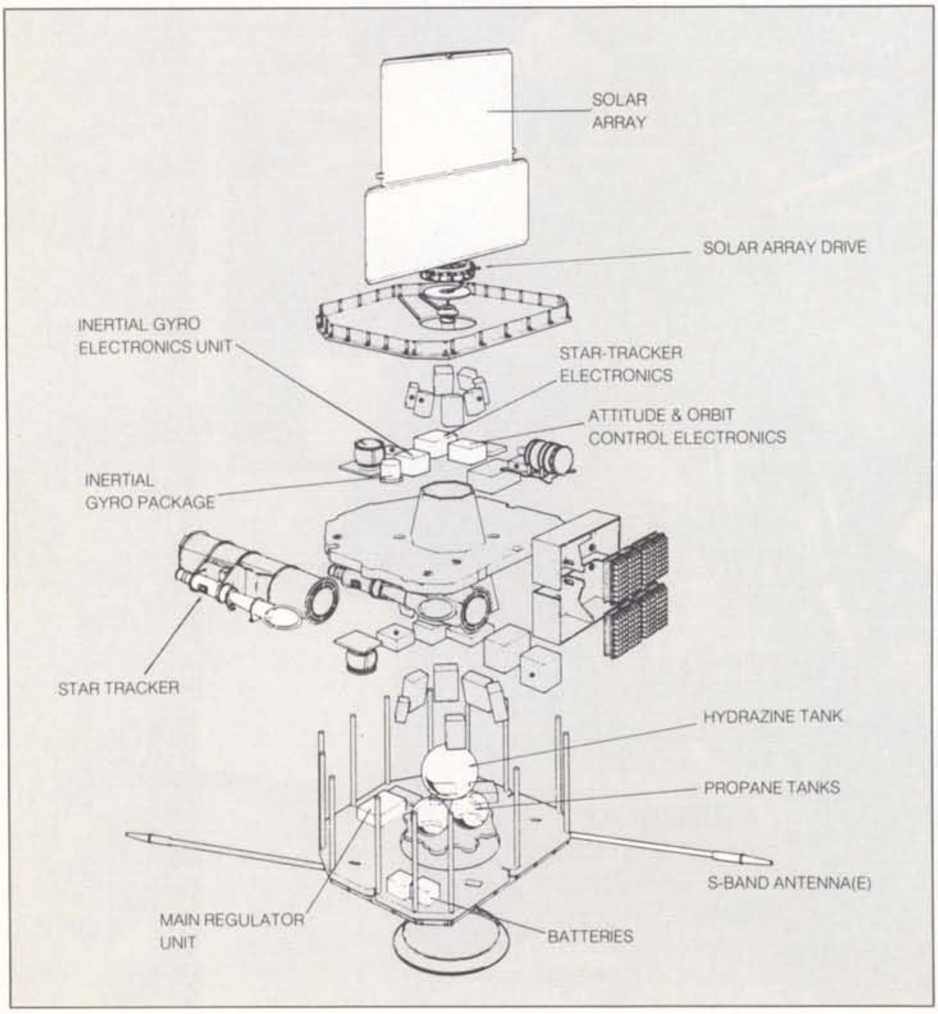


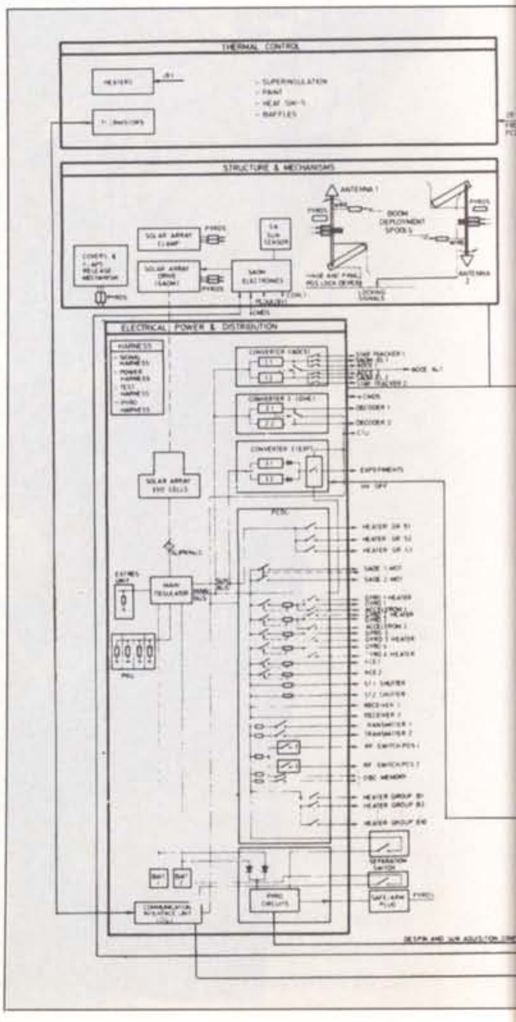


Figure 1 – The Exosat spacecraft's major systems and subsystems

– the ground segment, with the Estrack ground station at Villafranca (Spain) and ESA's Space Operations and Control Centre (ESOC) in Darmstadt (Germany).

Satellite configuration and functional performance

The satellite design (mass = 500 kg; diameter = 2.1 m; height = 1.35 m excluding the solar array, which is 1.85 m high) is characterised by a central body covered with superinsulating thermal blankets, and a one-degree-of-freedom rotatable solar array. The central body houses all satellite subsystems and the scientific instruments, whose entrance apertures are all located on one face of the central body, viewing along or parallel to the X-axis. Flaps cover the entrances to the low-energy imaging telescopes and medium-energy experiment during launch. After deployment in orbit these flaps act as thermal and stray-light shields for the telescopes and star tracker, respectively. Two booms, each carrying an S-band antenna giving hemispherical coverage are to be deployed in orbit following initial Sun acquisition.

The primary satellite structure consists of a central cone supporting one main and two secondary platforms, as well as the solar array (Fig. 1). All alignment-sensitive units, i.e. the scientific instruments and the fine attitude-measurement units, are mounted on the highly stable main platform. The individual components of the telescopes are integrated into an all-enveloping clean bench, to which the star tracker is also mounted to achieve alignment stability.

Less alignment-sensitive equipment, such as the reaction control equipment and electronics, is mounted on the central cone or on the lower platforms. The reaction control equipment (RCE) for attitude and orbit control is installed inside the central cone, allowing independent integration into the structure and a selfcontained thermal design approach. The RCE has two spherical tanks and plenum chambers for propane and a spherical tank for hydrazine. Attitude-control thrusters are mounted at the rim of the main and lower platforms. The orbit thrusters are attached to the main platform in such a way that the thrust vector acts through the satellite's centre of gravity.

The concentration of all experiment apertures on one face of the satellite, together with the requisite alignment accuracy, results in demanding structural and thermal-control requirements. Consequently, the solar aspect angle (SAA) is constrained to 90° ± 3° with respect to the Z-axis and the apertures of the medium-energy experiment and gas-scintillation proportional counter are protected by extremely thin thermal foils of metallised kapton. The imaging-telescope apertures are protected by baffles and are thermally controlled by electric heaters.

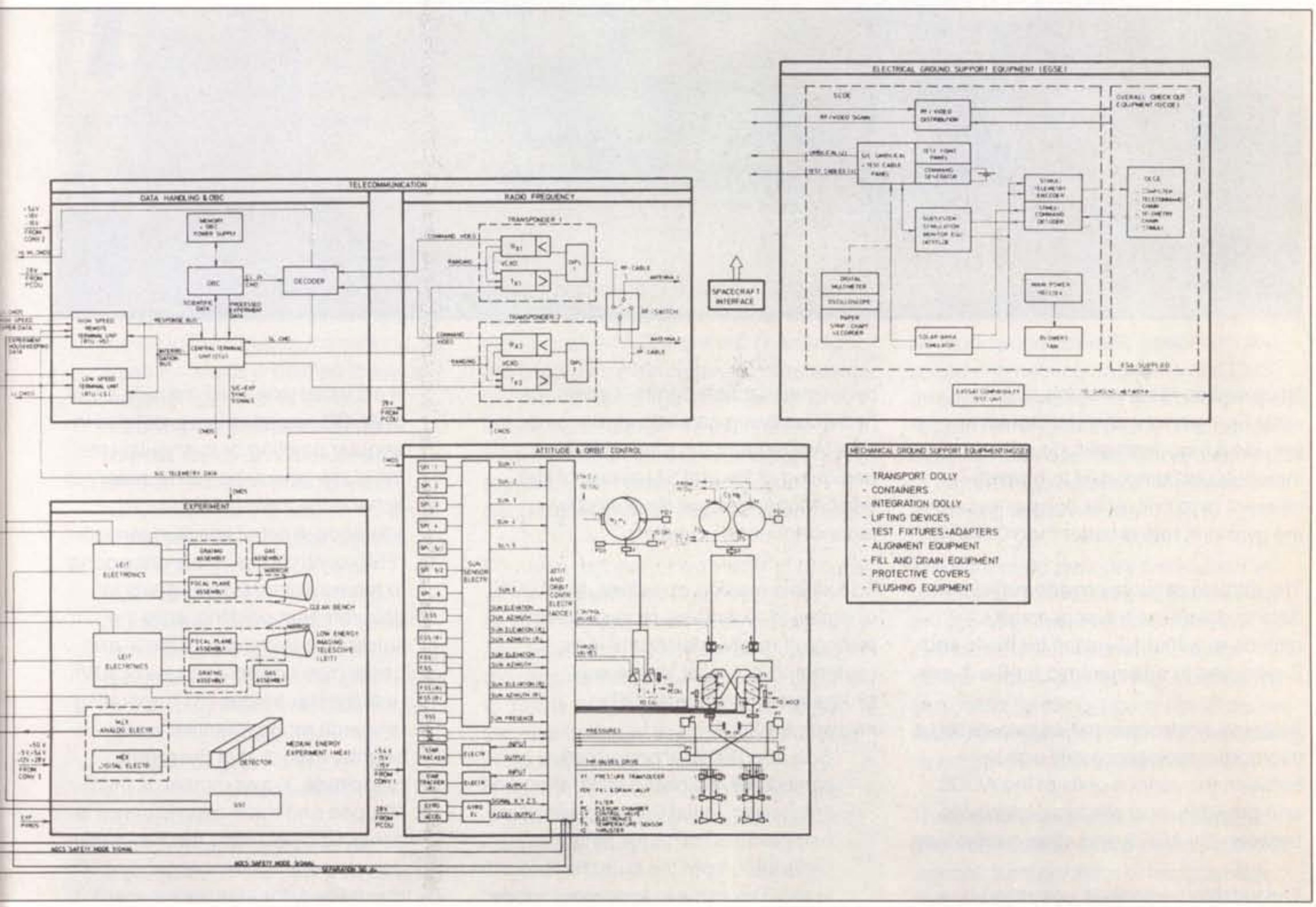
To equalise the varying net heat fluxes passing through the apertures, there are absorber areas on their inner circumferences. The remaining areas of the satellite's side walls are covered with superinsulation. The main radiator areas, located on the upper and lower platforms, dissipate heat into space and thermally decouple the main dissipating components from the alignment-sensitive equipment. The transmitter, main regulator, and two power resistor units are located on the lower platform. The upper platform supports the shunt radiator and external resistor unit. Two further resistor units are located on the underside of the experiment platform to control internal power distribution.

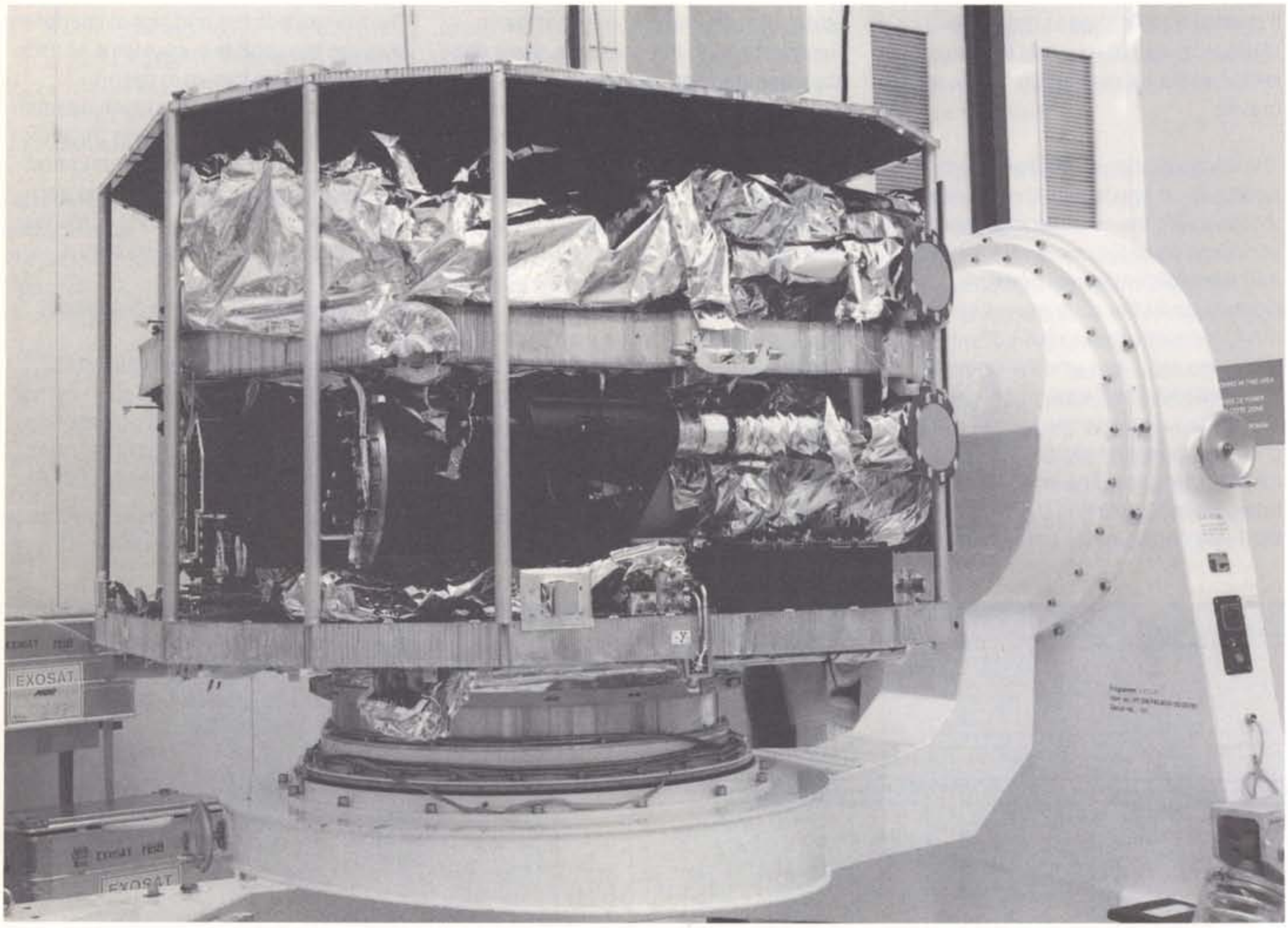
The major electrical and signal interfaces between the satellite subsystems and the experiments are shown in the accompanying functional block diagram (Fig. 2). As the satellite requires three-axis stabilisation with stringent pointing and attitude reconstitution, the attitude and orbit control subsystem is one of the most sophisticated subsystems on board.

Attitude and Orbit Control Subsystem (AOCS)

Attitude control and re-orientation is provided by a propane cold-gas reaction-control system, which incorporates two sets of six mutually redundant thrusters, with a variable thrust capability of 0.05–0.2 N. Attitude is sensed by gyros, Sun sensors and star trackers. Gyros are

Figure 2 – Exosat system block diagram





employed as the short-term reference, while Sun sensors and star trackers provide a long-term attitude reference, their outputs being used to correct inherent gyro drift. After compensation, the gyro drift rate is better than 0.005°/h.

The attitude sensors provide sufficient data to determine the spacecraft's attitude to within 10 arcsec for the Y and Z-axes and to a few arcmin for the X-axis.

A central electronics unit, incorporating a microprocessor, processes signals between the various units of the AOCS and provides most electrical interfaces between the AOCS and other subsystems.

The satellite's velocity is controlled by a hydrazine reaction-control system, the hydrazine being catalytically decomposed in two redundant thrusters (14.7 N at beginning of life and 5 N at end of life). Velocity changes are measured by redundant accelerometers.

To fulfil the mission objectives, the AOCS operates in six primary modes, some relying on hardwired control logic (autonomous mode), and some programmed into the AOCS microprocessor:

- *Sun acquisition* is performed immediately following separation and fine despin. Initial Sun acquisition is completed 30 min after satellite separation from the launcher's fourth stage. The same autonomous mode is activated whenever the safe limits of AOCS operation are exceeded in angular pointing or in angular rate.
- *Initial star acquisition* is necessary to achieve full three-axis attitude reference. A set of fine Sun sensors (FSS) controls the Y-axis orthogonal to the experiment viewing axis for accurate Sun pointing while the satellite is rotated about the Y-axis under gyro control at a rate of 40°/h until the star tracker (ST), operating in search mode, identifies a star brighter than that of the preset magnitude. Y-axis rotation is then stopped and three-axis reference is achieved by pointing the X-axis to the detected star. While this pointing is maintained, the star tracker maps its

complete field of view (FOV), and the star data is transmitted to ground for identification purposes to establish a reference for subsequent operations.

- *Slew manoeuvring*, in moving from one target to the next is performed by up to three consecutive slew rotations about the Z and Y-axes under gyro control. The first rotation, about Z, ensures precise Sun pointing of the +Y axis; the second, around Y, results in the target lying in the X, Y plane, and the third, around Z, results in the X-axis pointing at the target area, while the Sun pointing is kept in the X, Y plane. Star(s) acquisition and tracking then provides an attitude reference for pointing stability.
- The *pointing mode* is used for the majority of the mission. During X-ray source observation an adjacent target star is maintained at the desired location in the star tracker's field of view, while the Sun direction is maintained in the X, Y plane, opto-inertial updating taking place every 2 s.
- *Moon pointing* is used for Moon occultation, in 'normal mode' or 'sky sweeping mode'. In the first the satellite is kept pointing at the X-ray source (point source) while the Moon moves in front of it. In the second, the satellite's X-axis is pointed towards the Moon and tracks it while occulting the source (extended source). Gyros only are used for attitude reference prior to Moon occultation, during eclipse, for Earth occultation and for orbit control. *Orbit control manoeuvres* are required for precise occultation monitoring. The necessary velocity increments are applied close to perigee, within the orbital plane, and vary in magnitude from 0.03 m/s to 10 m/s. The attitude reference is provided by gyros and the acceleration is measured by an accelerometer.
- AOCS *emergency modes* are implemented if the Sun should lie in the forbidden angular range or if the angular rate is excessive. The AOCS initiates a number of functions to safeguard the AOCS proper, to protect the telescopes and to allow the solar array to keep tracking the Sun for power generation.

Electrical power and distribution

Primary electrical power for continuous loads of up to 256 W (end of life) is provided by the rotatable solar array. During launch, the array is clamped and the solar-array orientation mechanism is off-loaded. After separation from the launcher and initial Sun acquisition, the array is released and the off-loading cancelled. Thereafter solar-array orientation equipment (SAOE) points it towards the Sun within ±3° irrespective of satellite attitude or manoeuvres. It provides the mechanical interface between the solar array and the satellite body, allowing bi-directional and unrestricted rotation of the array about the Z-axis. At the same time it provides for transfer of the electrical power from the solar array to the satellite body, as well as of the necessary control and monitoring signals.

From launch until Sun acquisition, for eclipses, and for peak demands, two rechargeable NiCd batteries (7 Ah each) are used. The main regulator regulates the main bus voltage when power is drawn from solar array, the battery or from both sources. It contains the shunt regulator, the battery chargers and dischargers and the main error amplifier.

Fourteen redundant pyrotechnic circuits with protection and automatic firing sequencing are powered by the battery. The separation switch signal is routed to the communications interface unit (CIU) to initiate AOCS Sun acquisition and to the pyro box to activate the pyro circuits. In addition, the CIU handles the temperature sensors and routes some digital housekeeping data into the data-handling subsystem.

The releases of the mechanisms are initiated by telecommands, except for the antenna which is automatically deployed when the satellite is despun.

The power control and distribution unit (PCDU) distributes the 28 V bus, protects the overall bus/battery voltage, monitors status and current, and contains the battery undervoltage protection. The power lines are protected against shorts by current limiters or overcurrent switches, either by the consumers proper or by the power subsystem. A power emergency mode is defined to switch off nonessential loads in the case of an undervoltage. So that one of the two battery-discharge regulators can sustain all the loads, the maximum power supply in this mode is limited to 120 W.

Data handling subsystem (DHS)

In addition to the usual functions of command reception and distribution, data collection and transmission, and provision of time base and information, the DHS provides specific functions like: handling of data to and from the onboard computer (OBC), extensive processing of experiment data, specific operations support of AOCS and SAOE, by data analysis and monitoring.

All high-speed scientific data and low-speed engineering data enter the DHS through the low-speed and/or high-speed remote terminal unit (RTU). The data are then distributed to the onboard computer or formatted to be sent to the transmitter for downlink transmission.

The command decoder distributes the commands to the users as memory load or high- and low-level commands or distributes a serial command to the central terminal unit (CTU). Commands generated by the onboard computer are routed through the command decoder or directly to the central terminal unit.

Three different formats (normal, direct and housekeeping) are available. In the 'normal' format 7/8ths of the downlink data consist of processed scientific data.

The 'direct' format replaces the processed scientific data by direct or raw data from the experiments in case the onboard computer should fail. In the 'housekeeping' format only the engineering and housekeeping data are transmitted, with an 8 times higher sample rate. The DHS provides three selectable bit rates: 2048, 4096 and 8192 bit/s.

RF-telecommunication subsystem (RFS)

The subsystem comprises two S-band transponders and antennas with an RF-switching unit. The transponder provides telemetry transmission via a 6 W RF power amplifier, command reception, coherent operation with an up- and downlink frequency relationship of 240/222, and two-way ranging with a tone delay of ±30 ns. In the downlink, both ranging and telemetry may occur simultaneously without inhibiting or altering the information content of either signal. In the uplink, either telecommand or ranging operations are possible.

The two antenna elements provide omni-directional coverage. Throughout the mission, only that element providing ground-station coverage is switched on. Both receivers are on throughout the mission. The minimum uplink and downlink gains are thus −8 dBi and −3 dBi, respectively.

The scientific payload

The scientific payload, comprising two identical imaging telescopes, energy-detector assembly and a gas-scintillation proportional counter, has been developed to be compatible with the observatory nature of the mission and the intention of providing data to European observers outside the groups directly concerned in the experiment development programme. Prior to placing contracts with industry for the production of engineering- and flight-model hardware, a scientific model programme was completed to demonstrate the feasibility of critical payload aspects within the constraints set by the overall programme.

The payload is described in detail in the companion article on page 20. The summary in Figure 3 shows the detailed design features of the individual packages and their X-ray sensitivities as a function of wavelength or photon energy.

Programme aspects

The industrial development of the Exosat spacecraft has been entrusted to the European COSMOS consortium, led by MBB, the system contractor. Responsibilities at system level cover management, engineering and assembly, integration and test. Subsystem responsibility has been shared by twenty European firms:

- Structure/thermal control/mechanisms/solar array (mechanical)
  SNIAS-Cannes (F)/CASA (E)/Contraves (CH)/BADG (UK)
- Attitude and orbit control & stabilisation
  MBB (D)/SNIAS-LM (F)/MSDS (UK)/SODERN (F)/FERRANTI (UK)/SEP (F)/TPD-TNO (NL)/NLR (NL)
- Data handling and RF telecommunications
  SELENIA (I)/LABEN (I)/SAAB (S)/CROUZET (F)/LM-ERICSSON (S)
- Power supply/solar array (electrical)
  ETCA (B)/TERMA (DK)/SAFT (F)/AEG (D)

Development-model programmes

Hardware production started with initiation of the main development contract, signed in mid-1978. The model philosophy foresaw two development models and a flight model, with a set of spares. The mechanical model (MM) is used for structural design verification and qualification, whilst the engineering model (EM) serves to verify functional interfaces and allows development of test procedures and associated software in anticipation of the FM programme.

Although the phased project plan sought controlled feedback for FM hardware design and production from the MM and EM model programmes, circumstances necessitated a change from this baseline

Figure 3 — Exosat payload summary

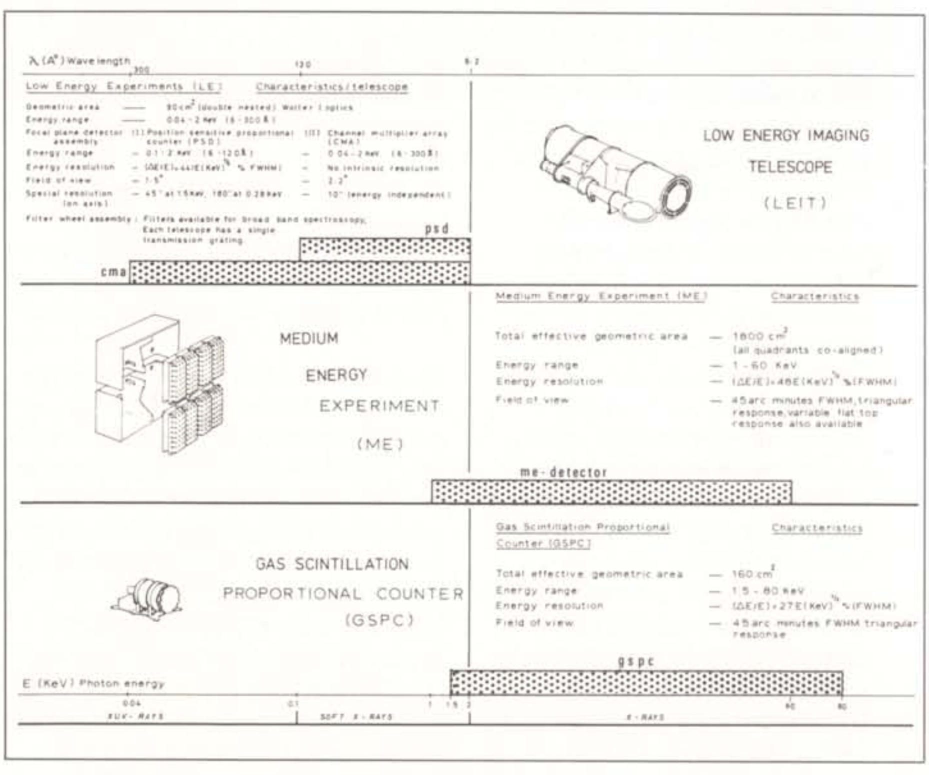
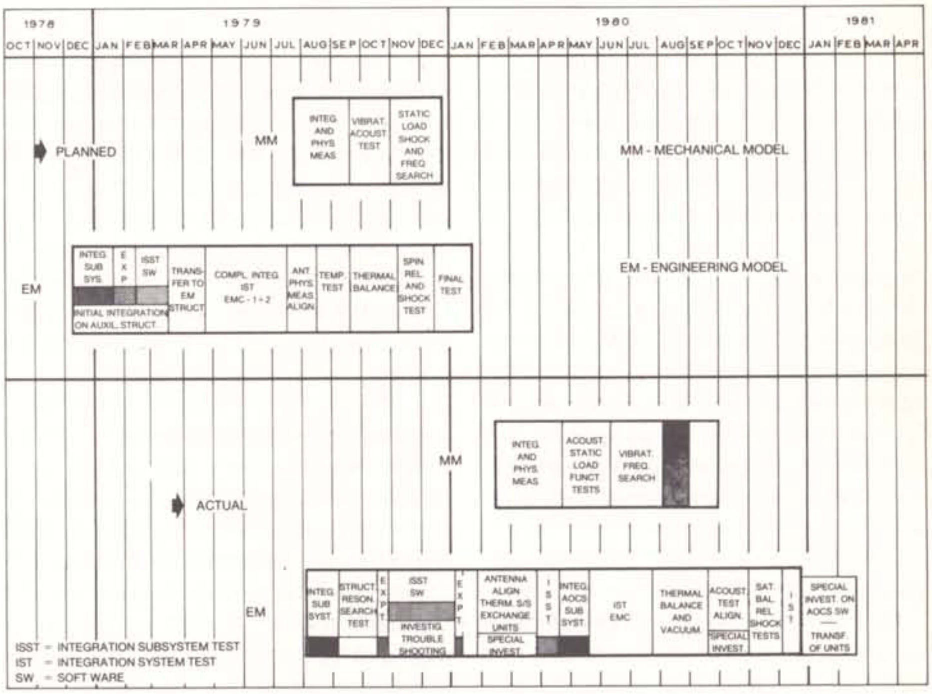
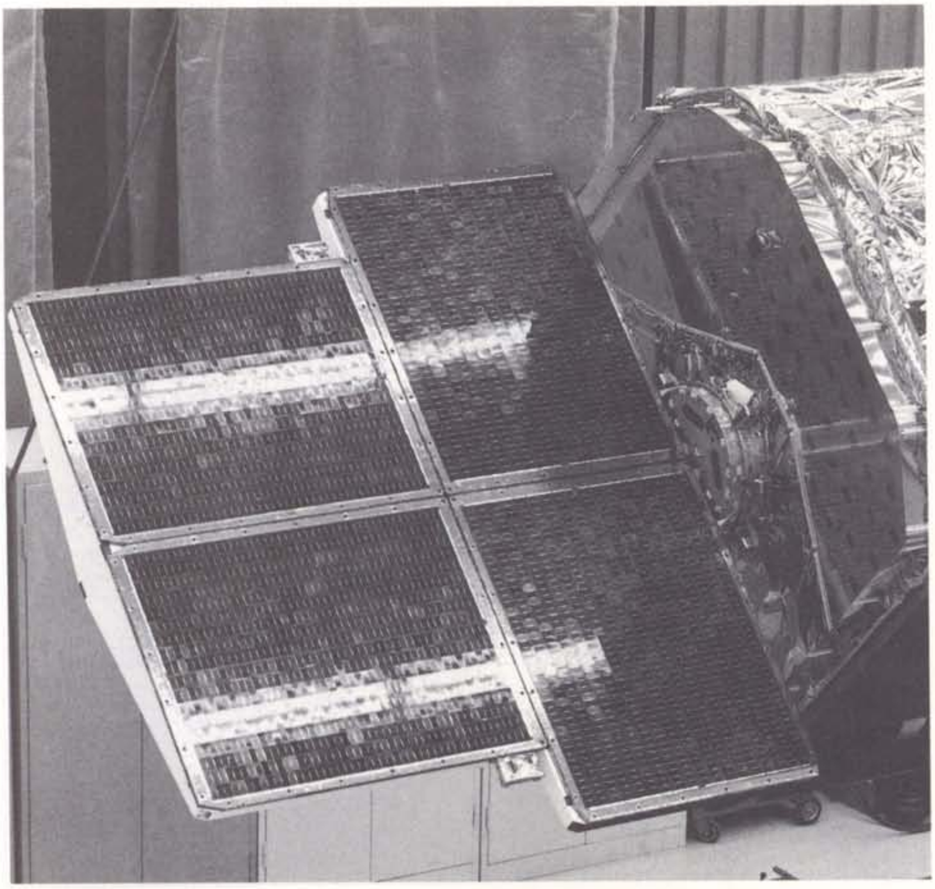


Figure 4 – The mechanical-model and engineering-model development programmes



plan (Fig. 4) and imposed the need for work-around solutions to meet engineering demands and deadlines. In spite of the obvious change in sequence it has been possible to meet all the technical objectives for both development models.

Mechanical-model programme
Satellite structural development is known to be an involved engineering process, not so much because of the tools required for design analysis and verification, but more because of the number of requirements and constraints emanating from or imposed by system elements or subsystems. The Exosat structure and associated mechanisms reflect a high level of stringent, and in some cases conflicting, requirements, accentuated by the fact that design definition had to be undertaken against the background of Ariane launcher development. The need to maintain compatibility on major interfaces with the initially selected Delta launcher drastically limited the scope of design trade-offs. Although the uncertainty connected with the development of the Ariane launcher did not impact on the design process once a reasonable launch environment specification became available, it nevertheless rendered engineering judgement in the definition of the qualification and acceptance test levels extremely difficult whilst awaiting practical data from launcher development flights.



The scientific mission objectives call for long-duration observation (up to 80 h) of X-ray sources to determine their positions and structural features. Consequently, high alignment stability for the telescope optical axes and attitude references of the order of a few arcseconds are called for. Whilst these and other requirements, listed in Figure 5, call for stiffness and thereby additional mass, the launcher constraint of 510 kg imposed a minimum-weight approach for all onboard equipment, the scientific payload being allocated 25% of the maximum allowable satellite mass. Furthermore, requirements for light-tightness, stray-light inhibition, and protection against organic contamination, could not be satisfied without a significant mass penalty.

One special design feature that has had a strong influence on the structure's development, and has called for the application of the most advanced technologies, is the rotatable solar array. Several design changes had to be made early in its development and a coupling problem between main satellite body and array solved.

The overall design approach is reflected in Figure 5. The switch in launch vehicle required a repetition of the dynamic-response analysis. A structural reconfiguration, introduced at the end of the project definition phase, necessitated a repetition of the coupled analysis with the Ariane launcher.

The responses to demanding requirements are reflected in the structural layout, which guarantees that alignment and alignment stability will be maintained under all orbital conditions and will not be jeopardised under test and in the launch environment. This has been achieved by designing the experiment platform as a cantilever without struts and selecting carbon-fibre-faced sandwich for its manufacture. Thermal and mechanical decoupling of primary from secondary structure and of clean bench from the remaining satellite structure is another prominent design feature.

Each clean-bench assembly, consisting of the low-energy imaging telescope experiment, baffle and associated star tracker, is isostatically mounted on common inserts through the 120 mm-thick main platform. The star-tracker baffles are located by soft mounting on the star tracker and fixed mounting on the main platform.

The clean bench is designed in titanium, with a similar thermal coefficient of expansion to that of the mirrors, the main tube wall thickness being 0.4 mm. The clean bench and associated baffle seal system protects the sensitive optical elements against contamination by outgassing material from the remainder of the satellite and the inside of the launcher fairing. The truncated conical baffle in front of each clean bench reduces the amount of stray X-ray radiation.

Engineering-model programme

Due to the variety and novelty of test requirements, mainly generated by the demands of the scientific payload, Exosat, like previous programmes, has had to follow a learning curve to achieve the standards required for later functional testing of flight hardware. With the model philosophy applied, the engineering model offers the sole opportunity to prepare and verify assembly, integration and test procedures prior to their use on the flight model.

Supplementary to the hardware definition, software definition has received a great deal of attention in seeking an effective test concept and in terms of electrical ground-support equipment (EGSCE) hardware and software development.

The checkout software needed by Exosat is more complex than that for previous ESA satellites because an onboard computer (OBC) is being used as an integral part of the data-handling subsystem for the first time. The OBC's two main tasks are:

- Processing and reduction of scientific data onboard the satellite to adapt the high scientific data rate of 20 kbit/s (high-speed mode) to the relatively low, nominal telemetry bit rate of 4 kbit/s.
- Support to satellite subsystems.

Approximately 90% of the OBC's processing power is devoted to the scientific payload and 10% to subsystem support. The OBC uses 7/8ths of Exosat's telemetry capacity, the remaining 1/8th being used for housekeeping.

The application of the OBC software imposed a change from the more usual

Figure 5 — Overall design approach to Exosats' structural development

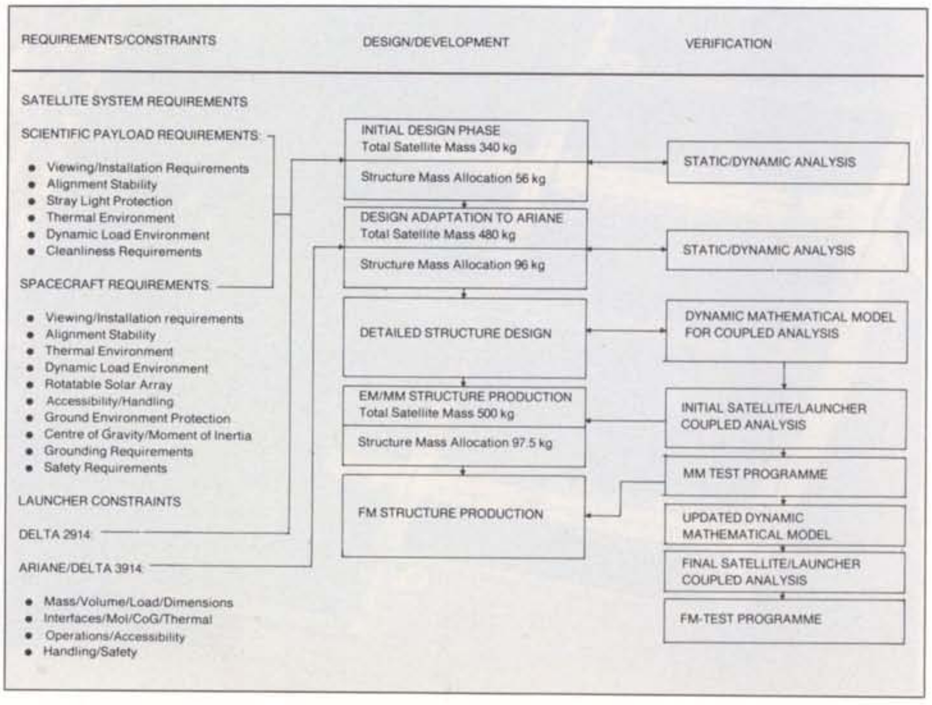


Figure 6 — Exosat software checkout system

fixed-format telemetry to facilitate the 'merging' of data treated by the OBC aboard the satellite at any instant, so that valuable time is not lost for OBC processing. The result is a mixed format composed of 'fixed-format telemetry' data for housekeeping information, and 'floating format telemetry' for the scientific data. The simplified block diagram of Figure 6 presents an overview of Exosat's checkout software system and delineates the influence of the OBC software on the overall checkout equipment (OCOE) software, i.e. identifies those modules partly or totally adapted to the floating-format requirement.

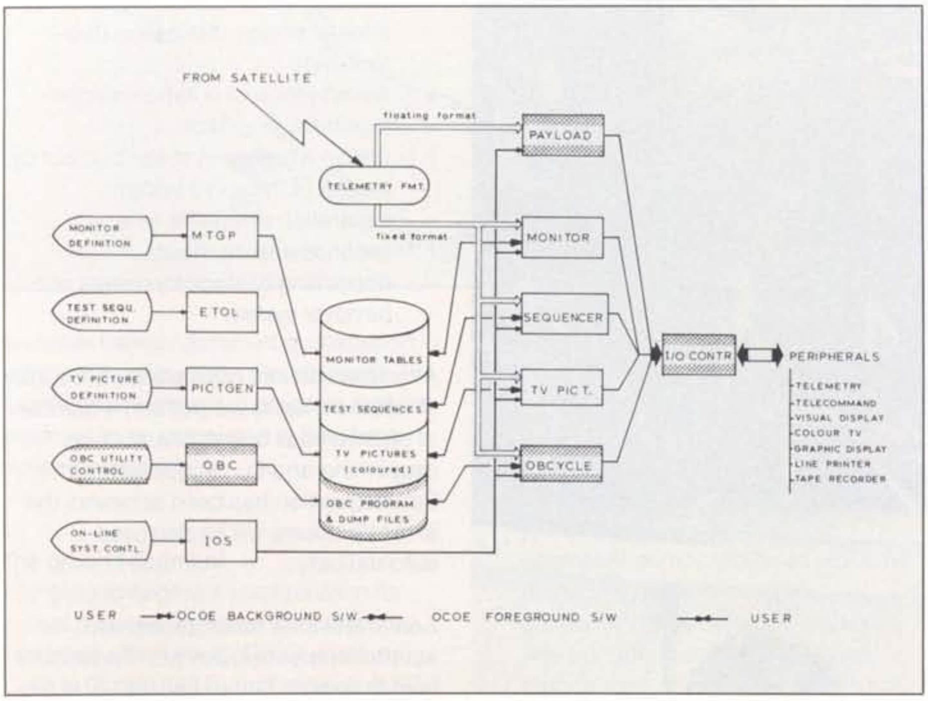
Flight-model programme

The flight-model programme was significantly affected by delayed completion of development work, technological problems with unit production, and modification work as a result of qualification/acceptance tests at subsystem level. Flight-model integration could therefore only start in April 1981 at MBB's premises.

As each major subsystem (power, data-handling, attitude and orbit control, etc.) was integrated into the structure, each was subjected to an integrated subsystem test (ISST) to check functional performance and interfaces with other units. When all units had been integrated, including experiments, an integrated system test (IST) was performed, the results of which are used as a basis for comparison with subsequent functional test results.

At this stage, the status of the satellite would normally have been one of full flight configuration. In practice, however, due to the nonavailability of certain units, flight spares or representative dummies were used as a temporary expedience to enable the flight programme to proceed on schedule; such was the status in December 1981.

The satellite was then subjected to electromagnetic compatibility (EMC) tests, followed by physical measurements (mass, centre of gravity, moment of inertia) and balancing. Results were satisfactory and the satellite certified fit to proceed with the next major test phase,



namely environmental exposure, which includes mechanical-vibration and thermal-vacuum testing. The objective of these tests is to prove the integrity of the flight-model satellite to meet system-level acceptance and qualification requirements.

Using the test facilities at IABG in Munich, the first vibration run was started in mid February 1982 and the last run completed in March. The satellite was subjected to both random and sinusoidal vibrations on each of its three axes. Notching was applied at critical frequencies determined from previous test results using other satellite models. Results were generally good, although some resonances were greater than expected; this was believed subsequently to be due to an incorrect mounting interface between satellite and solar array. Functional checks were also made at strategic points during the vibration testing. Before leaving the test facilities, deployment of satellite flaps, antenna booms, etc. was satisfactorily tested using live pyros.

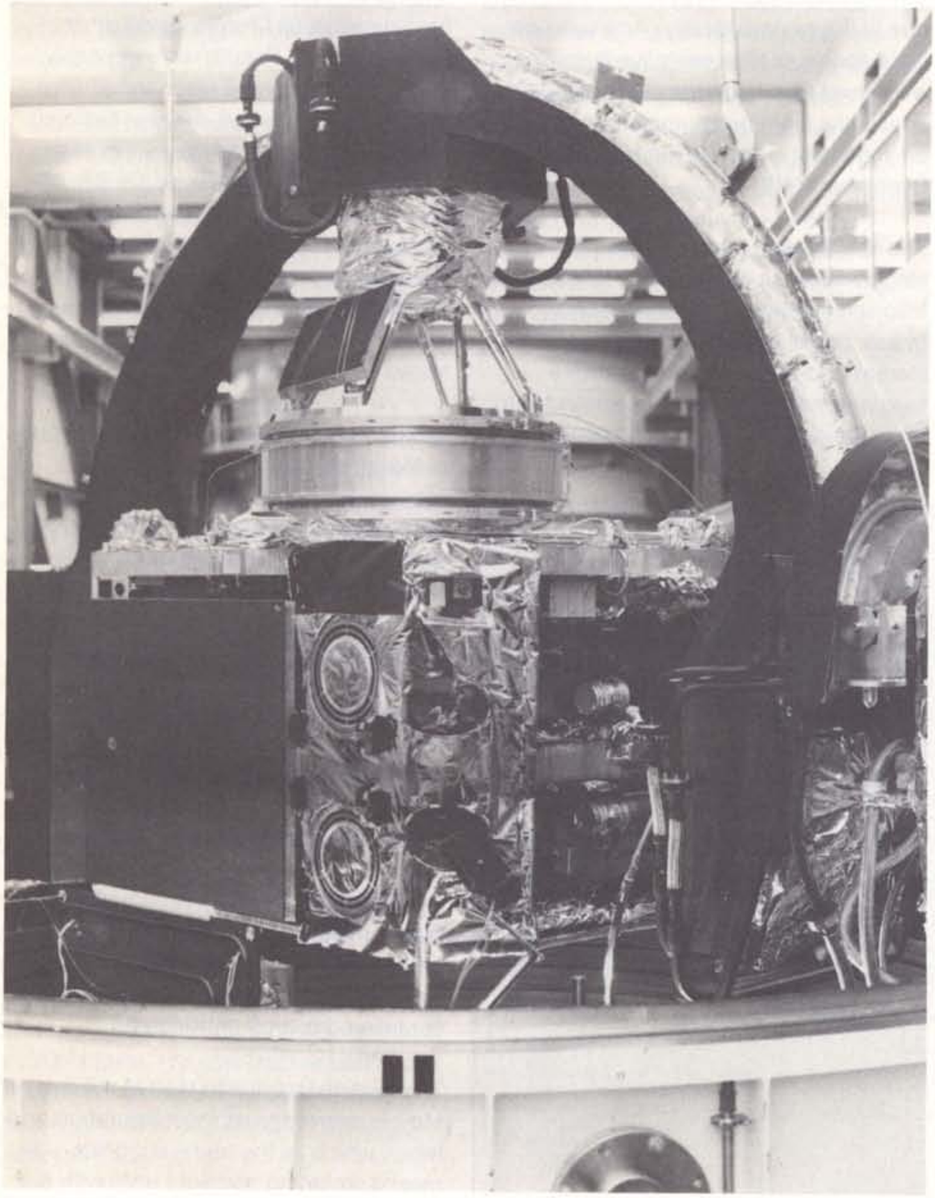
Exosat was shipped to ESTEC at the end of March and prepared for thermal-vacuum testing in the HBF3 chamber. In this test, which started on 20 April, the spacecraft was cycled between hot ambient and cold temperatures under vacuum (1×10^{-5} torr), for both long and short periods. To ensure that units did not exceed their qualification levels during the hot soak phase, an upper limit was imposed on the temperature to which the satellite could safely be exposed. Whilst this was certainly a constraint on the test, it was recognised as being due to the limitations of the test facility to simulate a real space environment (thermal) rather than a malfunction in Exosat's thermal design. No major anomalies were observed and the test results were considered entirely satisfactory.

The next phase, due to start at the end of May, is referred to as reconfiguration and retest, which as the name suggests means replacing nonflight units with real flight hardware. The minimum retest considered necessary is exposure to abbreviated thermal vacuum and, time permitting, mechanical vibration at reduced levels.

The launch operations programme
The two remaining elements essential for achieving the operational phase are the launcher, with the associated facilities in French Guiana (CSG), and the ground segment.

The Ariane vehicle
The initial choice of launcher (Delta 2914) was reconsidered during the project definition phase in 1977, when feasibility studies demonstrated that the European Ariane, augmented by a fourth stage, would satisfy Exosat mission requirements.

Ariane's northerly ascent trajectory from the launch range in French Guiana (Fig. 7), and the lack of a restart capability on Ariane's third-stage motor, necessitate the use of an additional stage to inject the 510 kg satellite into orbit.



The standard Ariane launcher (Fig. 8) has been uprated by adding a solid-propellant motor (P07). Aside from the motor and satellite adapter, this fourth stage includes a timer or sequencer, an active nutation damper, spin-up nozzles, a despin system, and a telemetry package for transmission to ground of essential performance parameters.

After orientation of the composite (satellite + P07 stage) in space by the third stage's attitude and roll-control system for orbit injection at perigee, and upon completion of the extended coast phase, the main fourth-stage events are:
- initiation of timer by third-stage guidance computer;
- separation of composite from third stage;
- spin-up by four nozzles to 47 rpm ±3 rpm, to achieve spin axis stability during the 2.5 h coast phase;
- active nutation damping by redundant pneumatic thrusters to inhibit any increase in nutation angle due to external disturbing forces or internal energy dissipation (fuel-sloshing);
- de-activation of nutation damper;
- fourth-stage ignition;
- despin after fourth-stage burnout by means of the yo-yo system;
- separation of satellite several seconds after burnout;
- depointing of stage by means of a turnover system.

After injection into orbit, some 9845 s after lift-off, the satellite will perform a number of autonomous operations, such as despinning and Sun acquisition. Once Sun acquisition has been achieved, the antenna booms will be deployed automatically.

Ariane launcher development was satisfactorily concluded with the last trial launch (L04) in December 1981 and the

Figure 7 – The Exosat launch sequence, from lift-off to Sun acquisition

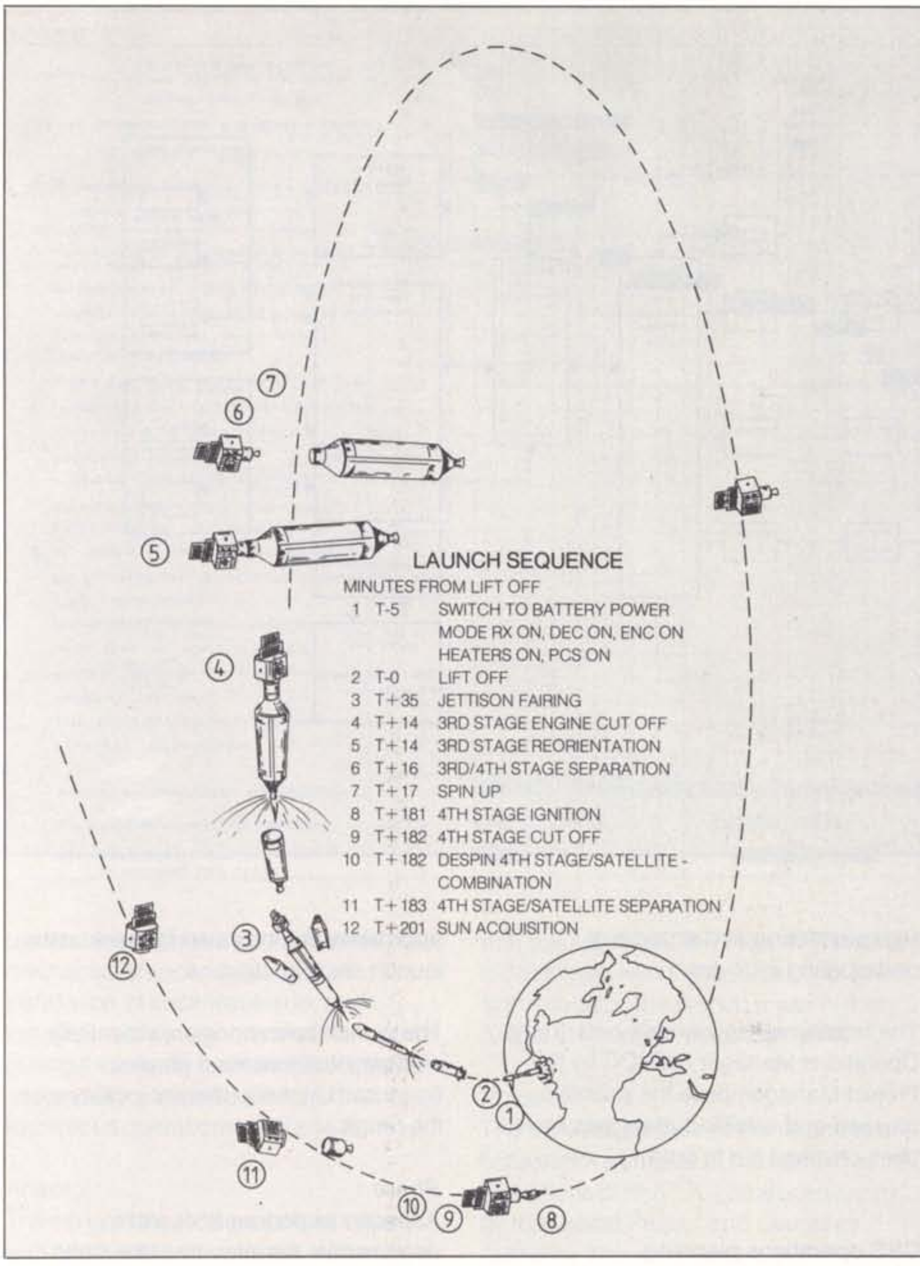
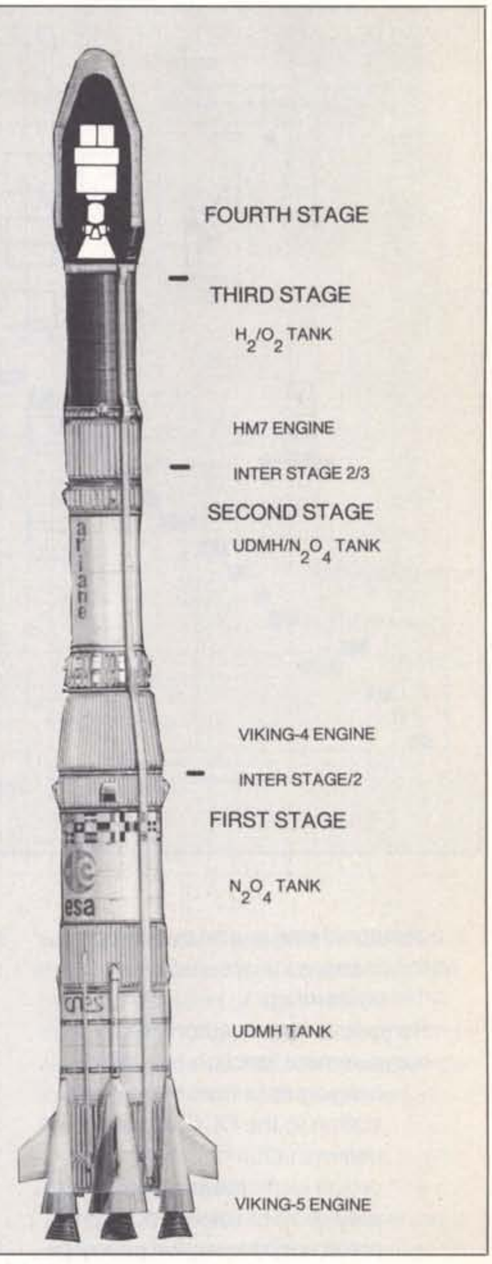


Figure 8 – The Ariane launch vehicle



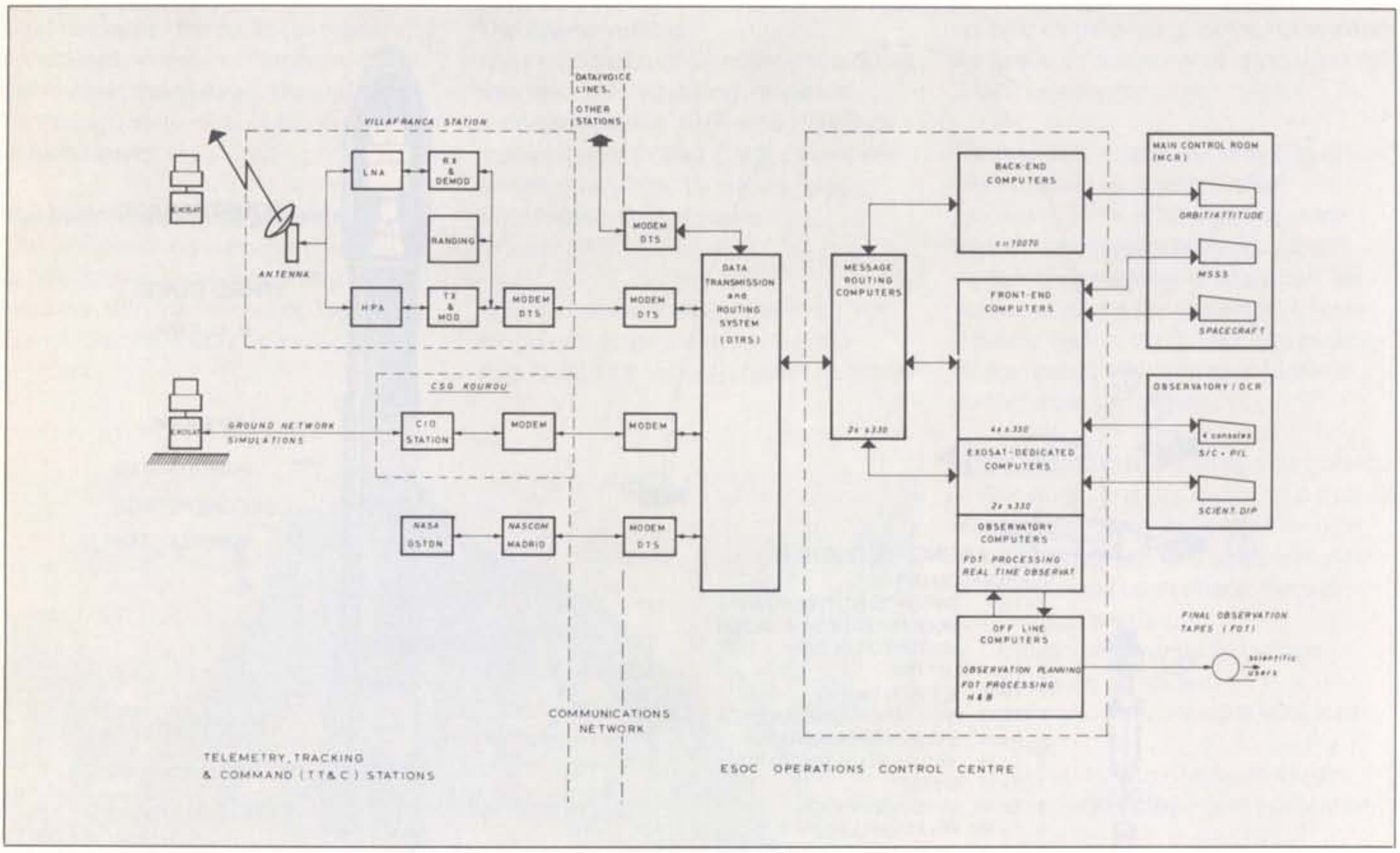
launcher thereby achieved qualification in standard configuration. Fourth-stage qualification tests are in progress and are expected to be completed in time for a November launch.

The ground segment

The ground-segment configuration for Exosat is shown in Figure 9, in which the interfaces within the ESOC Operations Control Centre (OCC) and between ESOC and the supporting station(s) are identified. The supporting stations are responsible for the classical functions of:

- *Satellite telemetry reception* at the dedicated ground station and transmission to the OCC where processing and conversion to engineering units facilitates real-time monitoring of satellite status, particularly attitude determination and attitude and/or orbit change manoeuvres. Filing and archiving of technological and scientific data offers the prime users, namely the Exosat scientists, retrieval of up to 24 h of the most recently filed data for further use in the Dedicated Control Room (DCR).
- *Telecommand transmission* and verification through the prime station (Villafranca) or any other station required to assist in controlling the subsystems in real time, reloading the OBC to maintain/update the

Figure 9 – Ground-segment configuration for the Exosat mission



operational status, and supporting orbit changes for occultation and arbitrary pointing.

- *Ranging*, a largely automated radio-measurement function providing:
  - ranging data from the ground station to the OCC's orbit-determination computer;
  - orbital elements for precise prediction of satellite position;
  - predictions for station coverage to enable the spacecraft controllers to schedule operations.

The Observatory Team has at its disposal the Dedicated Control Room, with direct access to the relevant scientific, technological (housekeeping) and operational (mission planning) data.

Apart from the real-time data-assessment facilities, data processing is performed off line, resulting ultimately in data tapes for final processing and analysis at participating institutes.

The satellite will be 'handed-over' to the Operations Manager at ESOC by the Project Manager, once the scientific payload and satellite subsystems have been checked out in orbit.

CSG operations planning

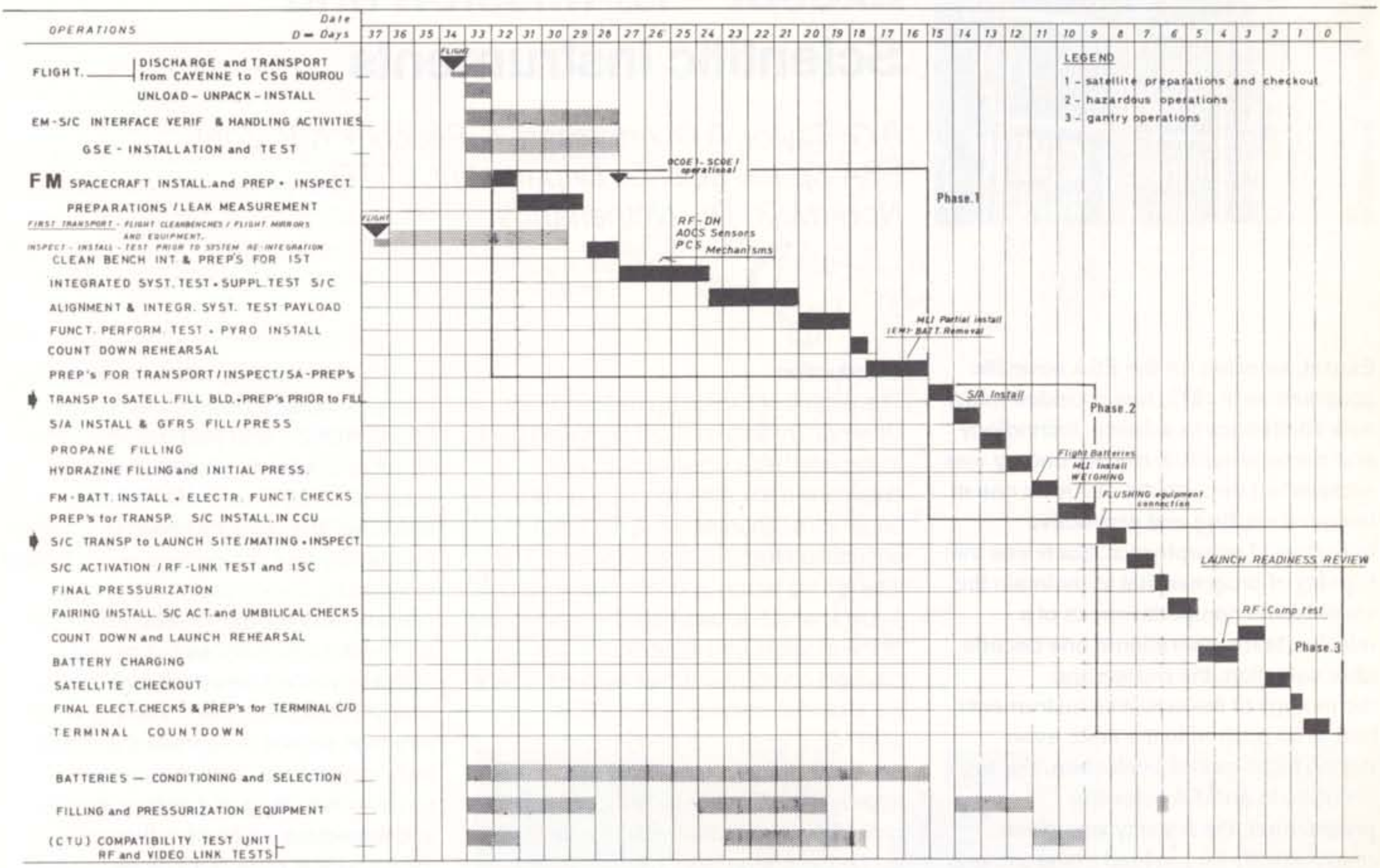
Launch operations will begin immediately after satisfactory completion of the Flight Readiness Review (FRR). To ensure effective and efficient preparatory activities at the launch range, meticulous care and attention have been paid to the detailed definition and specification of the activities to be performed prior to the actual launch. This is reflected in the summary launch-operations plan for a nominal launch campaign of six calendar weeks, preceded by a limited Exosat experiment preparation phase of approximately one calendar week at the launch site (Fig. 10).

The launch operations are essentially divisible into three main phases, conducted at three different locations on the range.

Phase 1

A functional performance test to demonstrate the integrity of the flight model after transport from Europe to CSG, will be performed in Building S1. Measurements will be made to verify alignment parameters after transport. Similarly, an absolute-leak-rate measurement will be made on the reaction control equipment (RCE) propellant system to ensure that no degradation has occurred as a result of handling and transport. The data resulting from these vital tests are to serve as reference data for the subsequent orbital phase. Final checks on

Figure 10 — Exosat launch-operations schedule



pyrotechnics circuitry and adjustments to mechanisms/appendages, partial installation of superinsulation, and installation of pyrotechnics will take place during this phase, for reasons of internal accessibility and prerequisite to the hazardous operations in Phase 2.

Phase 2

The filling of the RCE propellant systems with hydrazine and propane, will be performed in the 'hazardous zone' in Building S3. The experiment gas flushing and replenishment system will be filled and the RCE hydrazine system pressurised in Building S3.

Further completion of external multilayer insulation (MLI) after battery installation, solar-array installation, propellant loading and associated visual inspections will achieve the readiness status compatible with the milestone for transportation of the satellite to the launch tower for mating with the Ariane launch vehicle. This phase is completed with transportation of the flight model to the launch tower in the Ariane payload transport container.

Phase 3

The activities performed in this phase are constituent elements of the combined operations plan (POC) produced jointly by the Exosat Project and Launcher Authority. The main items are:

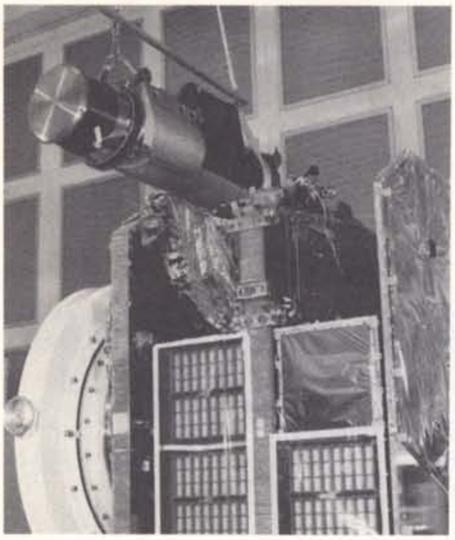
- satellite mating to launcher fourth stage (P07)
- satellite checkout after mating
- satellite monitoring and battery charging
- flight configuration completion, i.e. removal of protective covers, completion of superinsulation and inspection
- countdown dress rehearsal.

After completion of the flight configuration, the flight-satellite arming will be conducted just prior to the start of the composite terminal countdown. The planned duration of this terminal countdown, during which all supporting elements (i.e. launcher composite, range and ground network) are activated, is 28 h.

Acknowledgement

The Exosat programme has presented a major challenge to all directly engaged in the project and can be considered a major step forward in European satellite development.

The authors would like to take this opportunity to acknowledge the often considerable efforts made by the industrial contractors' and ESA staff in supporting the Exosat programme.



The European X-Ray Observatory Exosat – Its Mission and Scientific Instruments

B.G. Taylor, R.D. Andresen, A. Peacock & R. Zobl, ESA Space Science Department, ESTEC, Noordwijk, The Netherlands

Exosat, selected for the ESA scientific programme in 1973, has provided many new challenges in science, technology and management. X-ray astronomy was established through the 1970s as one of the most exciting and productive branches of astrophysics. Such was the rapidity of progress that to maintain the viability and competitiveness of a mission being operational one decade after selection, the design and technology of the scientific instruments had to be pushed to the limit, even during flight-model production. For the first time in an ESA scientific programme, the Agency was given responsibility for payload management. Also for the first time Exosat, as a completely European venture, is to be operated from ESOC as a space observatory with observations conducted largely through a guest investigator programme. The interest of the scientific community in the programme is clearly exemplified by the fact that the first observation period was oversubscribed, in time, by a factor of six.

Introduction

The origins of Exosat (European X-ray Observatory Satellite) can be traced back to the late 1960s when a mission to determine accurately the location of bright X-ray sources using the lunar occultation technique was studied. The intervening history is briefly highlighted in Table 1, which shows how the main thrust of the mission, and in particular the payload complement, has evolved. Due to the financial limitations of the ESA scientific programme budget, the definition phase (phase-B) for the mission, approved by Council in 1973, did not start until 1977. During that year, the decision to use the Ariane launcher was taken. However, in view of the requirement to maintain compatibility with the Delta-3914 vehicle (as back-up), the mass and envelope constraints, dictated by the Delta, were to be observed, meaning that the technical advantages offered by Ariane could not be fully exploited.

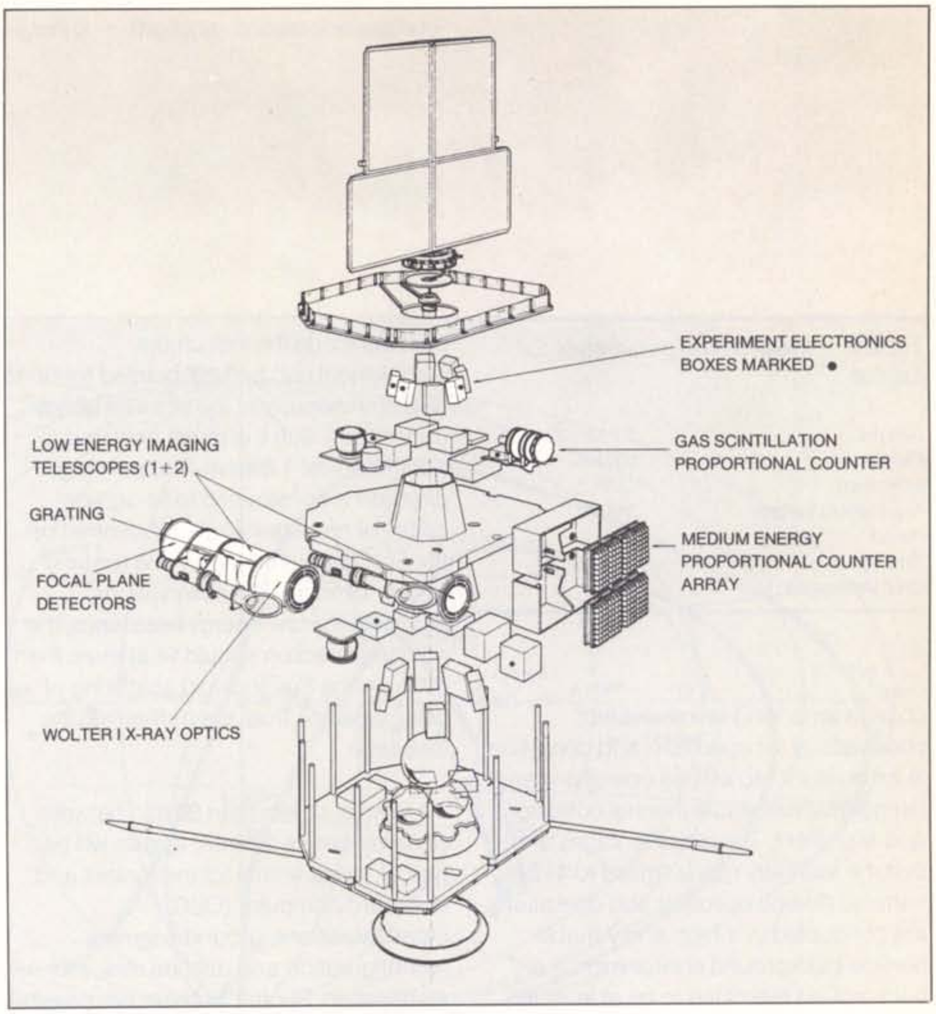
During the 1970s many X-ray astronomy missions, notably Uhuru, Ariel 5, ANS, SAS-3, HEAO-1 and the Einstein Observatory were successfully accomplished. Thus one of the major tasks over the years has been to maintain the viability and competitiveness of Exosat in following these missions for orbital operations in the early 1980s, within the technical constraints and of course budgetary envelope established at the time of project approval. This has led to a very high degree of sophistication and technological innovation within the payload, including all-beryllium bodies and lead-glass collimators (based on microchannel plate technology) for the medium-energy detectors and X-ray reflecting optics manufactured by a replication process for the imaging telescopes.

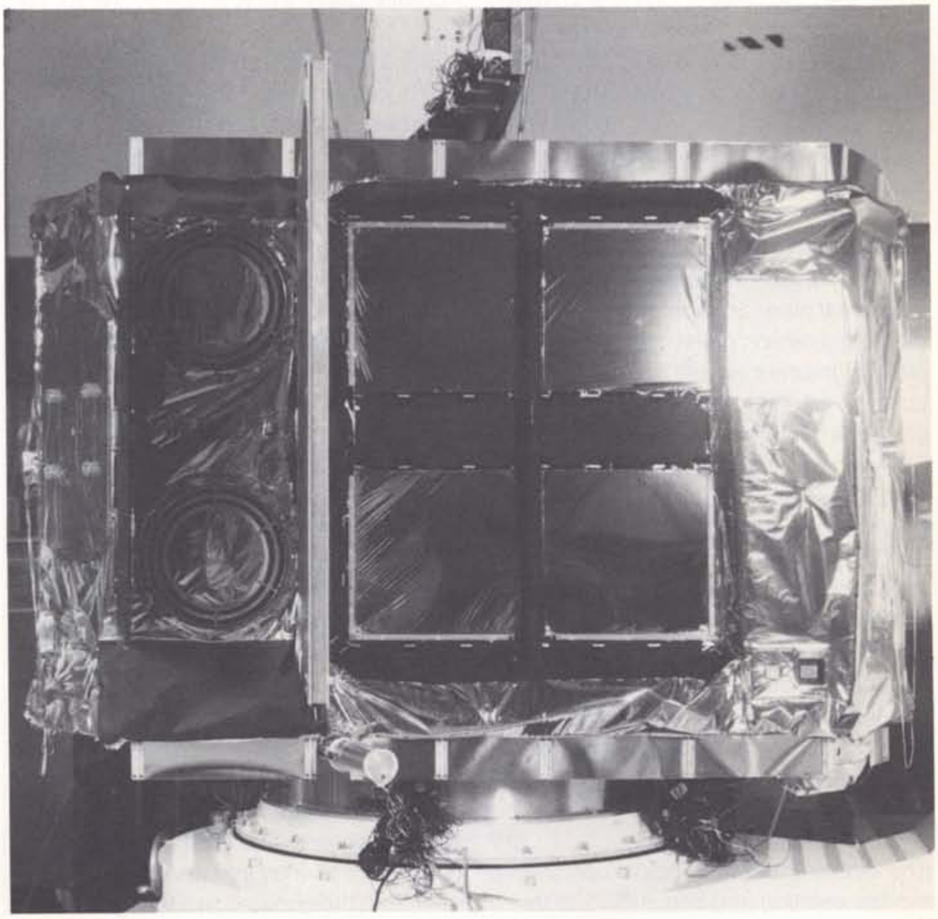
The observatory nature of the mission was recognised early on in that

Table 1 – Evolution of the Exosat mission

Year	Mission	Payload	Vehicle	Mass, kg (total satellite/payload)
1969	Lunar occultation (Occ.)	Large-area proportional counters (ME)	Delta (D)	150
1973	Occultation, lunar offset pointing	ME, low-energy flux collectors	Delta-2914	300/46
1974	Occultation, inertial pointing (Point.)	ME, nonimaging telescope (LB)	Delta-2914	300/46
1975	Occultation, pointing (Northern orbit)	ME, LB, imaging telescope (IT)	Delta-2914	340/65
1977	Pointing, occultation, (Ariane)	ME, 2IT,GSPC	Ariane	480/100
1981	Pointing, occultation	ME, 2IT, GSPC	Ariane	500/120

Figure 1 — Exploded view of Exosat showing the payload elements and principal spacecraft subsystems





observations and data should be made available to a wide community and not be restricted to a few groups. This led, for the first time in an ESA (ESRO) programme, to the approach of payload funding and management by the Agency and hence a shared responsibility between ESA and the experiment or hardware groups for instrument design and development.

Given the final payload complement of large-area proportional counters (in Exosat known as the Medium-Energy Experiment), imaging telescopes and gas-scintillation spectrometer, and its particular design features, the Exosat mission objectives may be summarised as follows:

1. **The precise location of sources,** in the energy band 0.04–2 keV (6–300 Å), to 10 arcsec or better using the imaging telescopes and, in the energy band 1.5–50 keV, to about 2 arcsec using the proportional counters with lunar occultation.
2. **The mapping of diffuse, extended sources** at low energies using the imaging telescopes.
3. **The broad-band spectroscopy of sources** with the full payload complement over the range 0.04–80 keV.
4. **The dispersive spectroscopy** of point-like sources using transmission gratings with the imaging telescopes.
5. **The study of the time variability** of sources over time scale from submilliseconds to days.
6. **The detection of new sources** in medium or deep surveys or in error-box searches.

Satellite characteristics and operational modes resulting from mission requirements

To permit lunar occultation of sources over a reasonable part of the celestial sphere, a highly eccentric orbit with the parameters given in Table 2 has been selected. The advantages of this orbit for pointing-mode operation are: little Earth obscuration and hence efficient

Table 2 — Initial orbital parameters for Exosat

Apogee	2×10^5 km
Perigee	500 km
Inclination	72.5°
Argument of perigee	286.5°
Period	99 h
Time above 5×10^4 km	80 h
Orbit lifetime (min.)	2 y

observations, long uninterrupted observations for up to 80 h and operation in full sunlight (no eclipse operation) and hence relatively stable thermal conditions and alignment. The disadvantages are that the telemetry rate is limited to 4 kbps nominal (8 kbps optional) and operations are conducted in a high and variable particle-background environment – a background estimated to be at least ten times higher than for a low-Earth-orbiting satellite on the basis of Cos-B and Apollo 15 measurements. The instruments are only operated when the satellite is outside the radiation belts, i.e. above 50 000 km.

Figure 1 shows an exploded view of the satellite. The salient features to note are as follows. The rotatable solar array is kept normal to the solar vector and the solar vector kept in the satellite's equatorial plane, independent of the pointing direction of the instruments. This offers significant advantages for thermal control and alignment stability. Attitude control is effected through a propane cold-gas thruster system for both slew manoeuvres and fine pointing with three-axis limit cycling within 5 arcsec. The attitude measurement system, which includes two star trackers, (mounted one per imaging telescope) enables the attitude to be reconstituted, a posteriori, to 10 arcsec or better. The star trackers have 3° square fields of view and are sensitive down to eighth magnitude. Orbit control for occultation timing is by a hydrazine thruster system.

The satellite has two principal operational modes: pointing and occultation. In the pointing mode the instrument complement can be kept pointed for up to 80 h continuously at the celestial target under study with the target acquired to within approx. 1 arcmin. The pointing direction is constrained to lie outside cones of half apex angle 15° centred on the Sun, Earth and Moon due to star-tracker blinding. For observations including the low-energy telescopes, the pointing direction should lie at more than 60° from the Sun to avoid scattering of solar radiation from the baffles into the telescope.

An interval of less than 90 min between observations of different targets will be typical, to allow time for instrument and on-board-computer (OBC) reconfigurations, ground-segment reconfiguration and attitude slew and stabilisation. Shorter intervals are possible using high slew rates, but these involve a greater drain on the propane gas supply.

With the chosen orbital parameters, some 20% of the celestial sphere can be occulted by the Moon and some 1% by the Earth. The occultation strips, shown in Figure 2, contain close to one hundred sources from the fourth Uhuru and third Ariel catalogues. The brightest sources may be positioned to within 2.5 arcsec (5σ), this limit resulting from uncertainties in the knowledge of the spacecraft's position and the profile of the lunar limb.

The total orbital velocity-change capability will allow some 50 occultation measurements to be made. The precision in the velocity-change capability is such that the satellite can be correctly located along its orbital path to provide the X-ray source position in one dimension on entry and the orthogonal dimension on exit from the occultation as shown in Figure 3.

Given the drift rate of the attitude-measurement-system gyros and their updating requirements, an X-ray source can be observed for approximately one hour prior to entry into and one hour after exit from the occultation. During this period, a filter is inserted into the star tracker's field of view.

The medium-energy experiment will be the principal instrument used for occultation studies and its field of view can be adjusted prior to the occultation to yield a flat-topped collimator response, the angular extent of the flat top being just larger than the angular extent of the source to be occulted. This is done to ensure that the flux from the source is uniformly collected, to maximise signal-to-noise ratio, and to ensure that any attitude jitter will not be reflected as a modulation of count rate via the collimator's angular response function.

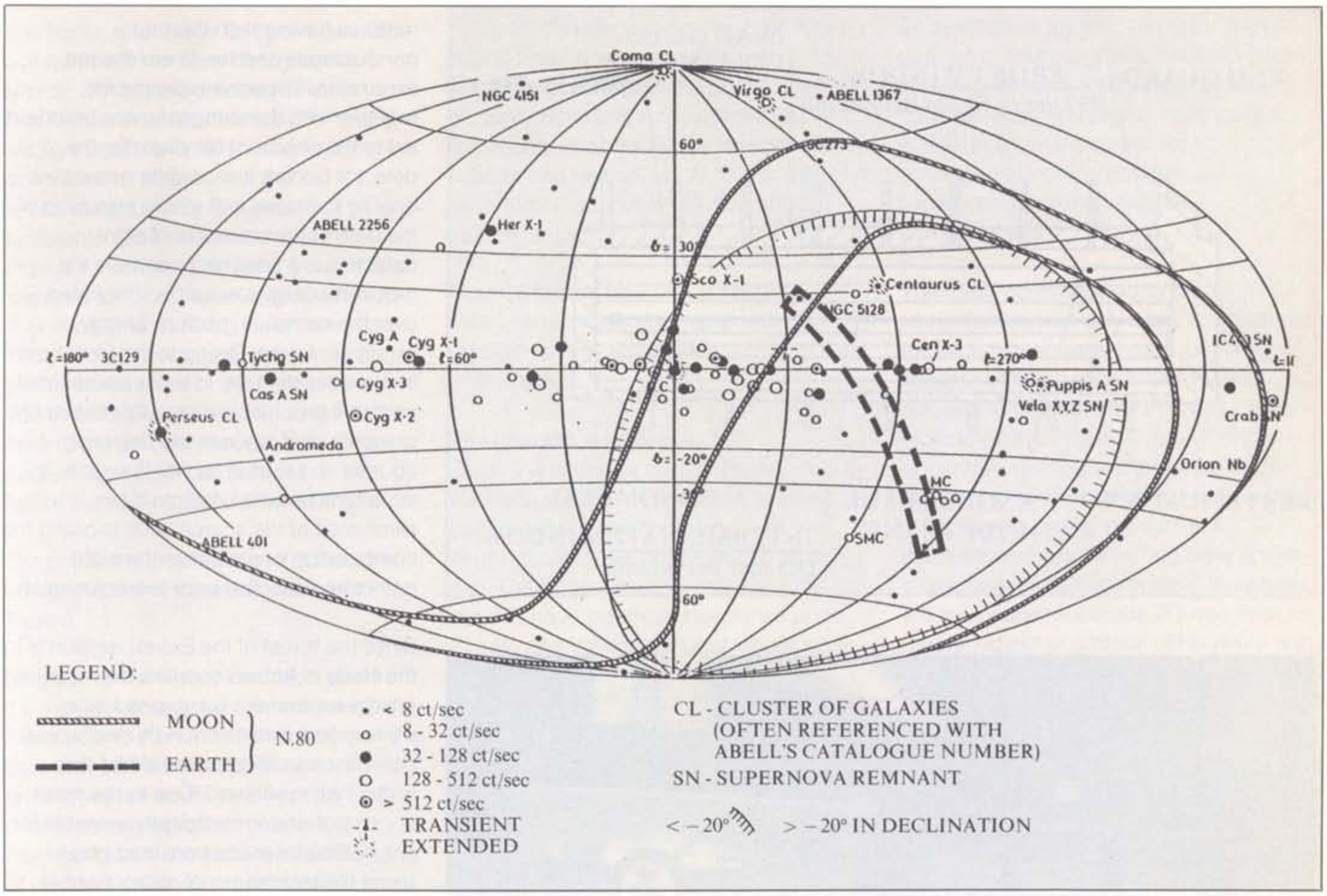
The medium-energy experiment

An effective area of 2000 cm^2 was set as the design goal for the proportional counters of the medium-energy experiment, being the maximum possible with the envelope and mass constraints. This area is divided between eight separate detectors, each detector comprising two multiwire-proportional-counter chambers (Fig. 4). The front and rear chambers are 4 cm deep and are filled to 2 bar with argon/CO_2 and xenon/CO_2 respectively, the chambers being separated by a 1.5 mm beryllium window. With a front window of 37 or 62 μm of beryllium and a 4.5 μm aluminised kapton foil for thermal-control purposes, the medium-energy experiment covers the range 1.5–50 keV.

The argon chamber has two layers of anode wires, the xenon chamber, three, with interleaved cathode-wire planes. The outer wires of the anode planes are used as guard anodes, while end-guard cathodes are incorporated for the two argon and upper xenon layers. The various layers are operated in anticoincidence. With such 'five-sided' anticoincidence possibilities and with the incorporation of rise-time discrimination against non-X-ray events, a background rejection efficiency of better than 99% for 95% X-ray acceptance is achieved in the argon detector in the range 2–6 keV, this

Figure 2 — Lunar and Earth occultation strips

Figure 3 — The lunar occultation method



range being the most sensitive for occultation and time-variability measurements. A residual background counting rate for the full experiment of 12 counts $s^{-1} keV^{-1}$ is expected.

The mechanical design of the detector was governed by the stringent mechanical tolerances and geometrical stability requirements imposed by the multiwire principle adopted. The gain and resolution of such an array, averaged over a single detector area, are strongly dependent on the precise positioning of each wire, and anode-plane to cathode-plane distances and tolerances. Temperature changes and temperature gradients across the detectors, which will result in gain variations, must be minimised by appropriate thermal control and the selection of a detector body

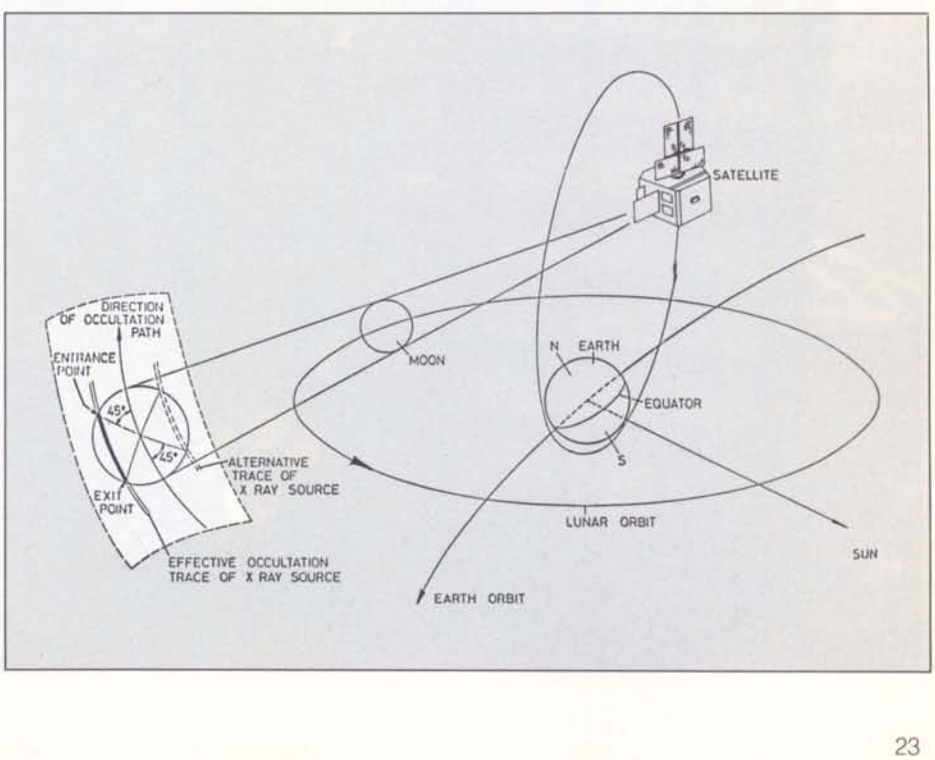
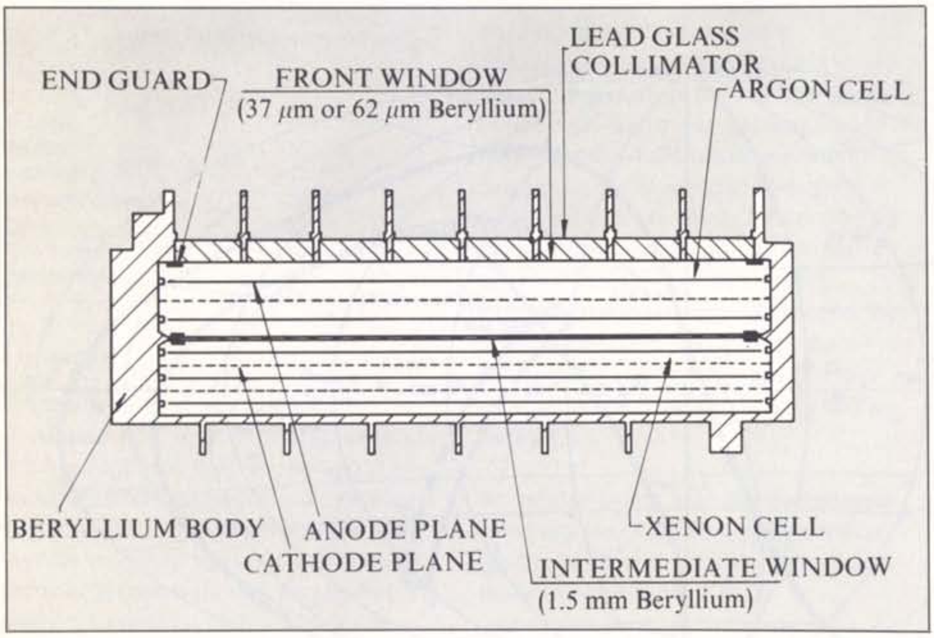
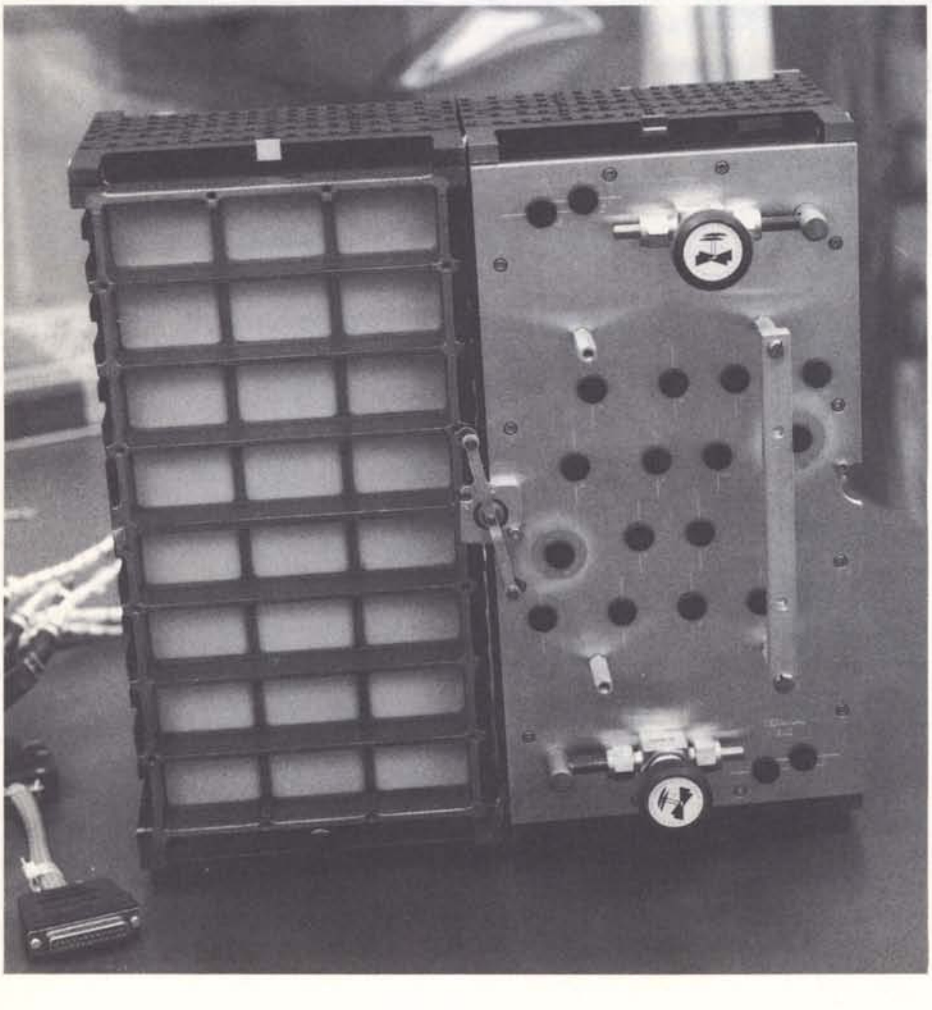


Figure 4 — Cross-section of a medium-energy detector





material having high thermal conductance and low linear thermal expansion. These considerations, together with the stringent mass limitation, led to the choice of beryllium for the detector bodies. It should be noted that only by the close and stable matching of the gain of the assembly of eight detectors is it possible to achieve the required energy resolution, integrated over the complete medium-energy experiment area. Owing to the limitations in the telemetry rate, in some operational modes it is not always possible to identify uniquely an X-ray with the detecting counter. It is thus essential that gain variations between detectors be eliminated at the source, thus allowing the combination of data from the eight detectors on-board prior to transmission.

Since the thrust of the Exosat mission is in the study of known sources, the medium-energy experiment is equipped as a narrow-field instrument with mechanical collimation to 45 arc min FWHM (full width, half maximum). Due to the mass constraint and limited depth available for it, a collimator made from lead glass using the techniques of microchannel plate production is employed. Starting from a cylindrical tube of lead glass and proceeding through a series of drawing and fusing operations, a 35 mm × 47 mm collimator element with 150 μm square channels, 30 μm septa and 11 mm depth is produced. Twenty-four such elements equip one detector. The mass/unit area of the collimator is approximately 1 g/cm^2 and it provides a stopping power of greater than three radiation lengths at 50 keV outside the field of view. The X-ray transmission of 65% achieved is slightly smaller than expected, resulting in a total effective area for the medium-energy experiment of 1800 cm^2.

The eight detectors, each weighing just 3.5 kg, are mounted in pairs to form quadrants and the four quadrants are mounted onto the spacecraft to form two experiment halves (Fig. 1). Two mechanisms, each operating on a pair of

Figure 5 – Timing measurements with the medium-energy experiment

quadrants, enable the fields of view of the four quadrants to be offset by up to approx. 2° from the pointing direction. This feature enables the monitoring of the background in two off-source regions with the same statistics as the background seen by the onsource quadrants. (The same mechanisms provide for the variable flat-top collimator response for occultation measurements). Until such time as it may be shown that the anticoincidence guards provide an adequate measure of the background and its variability, it is anticipated that the most common operational mode for the medium-energy experiment will be with half of the array offset from the target.

The physical parameters of the medium-energy experiment are summarised in Table 3.

Because of the high information rate from the medium-energy experiment it will be impossible to transmit all the data over the downlink and data-compression techniques are employed. For very fast phenomena a set of commandable hardware functions includes: time tagging of events, a stack discriminator with four programmable energy channels, 2048 element time profiles with integration times of 16–128 μs, and the 'basic observation mode' facility, which detects significant changes in source intensity and compresses the data, so that it provides a full time monitoring function. Software functions within the on-board computer include: period folding, time-interval histograms, intensity profiles and energy spectra with varying precision and integration times. Some modes can provide combinations of functions such as time profiles and energy spectra.

The time tag at 10 μs accuracy will allow the study of pulsars and other periodic and quasi-periodic sources. Period folding and the determination of spectra as a function of phase can be carried out in the on-board computer. A combination of hardware and software modes will allow intensity profiles to be built up in the milliseconds region, counting both X-ray events and background. For the submillisecond region the profiles cannot be continuous because of telemetry limitations. At about 50 ms, low-precision spectra can be built up. At time scales of a second or more, full-resolution spectra can be taken.

Figure 5 shows how timing/spectral measurements can be made with the medium-energy experiment as a function of time scale.

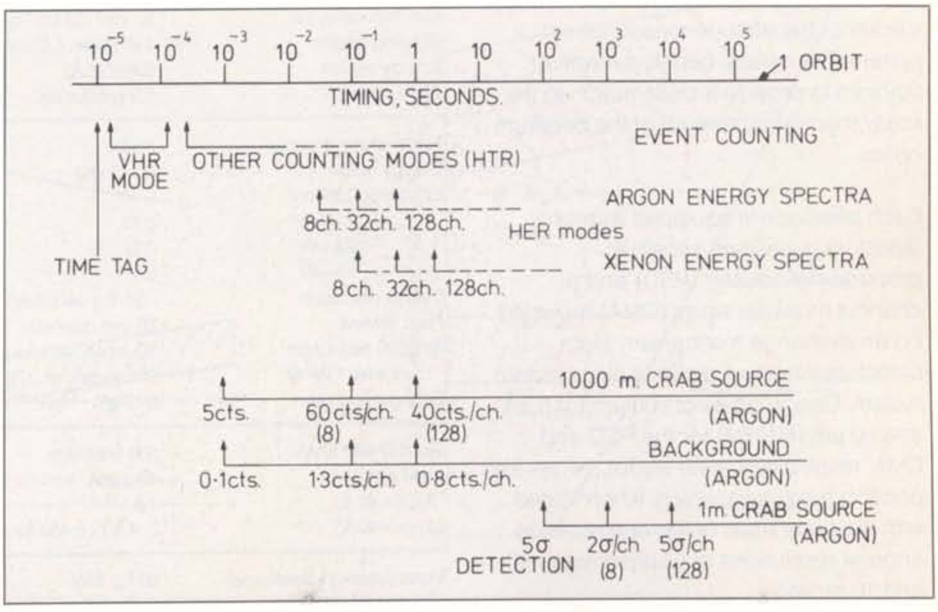
The imaging telescopes

Given the envelope constraint imposed by the Delta vehicle and possible satellite configurations, the focal length of the imaging telescope was limited to about 1 m. The limitation on frontal area, the need to have significant response up to 21 keV, and the limited focal length led to an aperture of approx. 28 cm for a total geometric collecting area of about 90 cm^2 for one telescope. Two similar systems could be accommodated, each optical system comprising a nest of two grazing-incidence paraboloidal/hyperboloidal mirrors (Wolter-1 configuration).

The mass constraint led to the apportionment of only a few kilogrammes for each mirror system and, following the success of some early trials, it was decided to fabricate the mirrors by the replication technique. A glass mandrel is accurately shaped and polished to the profile and surface finish required for the reflecting surface of the mirror. A nonadherent gold reflecting layer is then evaporated onto this mandrel. In parallel, the mirror shell substrate, 3.5 mm thick, is machined out of a block of beryllium with

Table 3 – Physical parameters of the medium-energy experiment

Total effective area	1800 cm (quadrants co-aligned)
Energy range	1.5–15 keV argon, 5–50 keV xenon
Energy resolution (FWHM)	21% at 6 keV argon, 18% at 22 keV xenon
Field of view	45 × 45 arcmin FWHM triangular
Background rejection	99% in argon, 98% in xenon
Background rate	12 counts s^{-1} keV^{-1}
Total mass, power	48 kg, 17 W



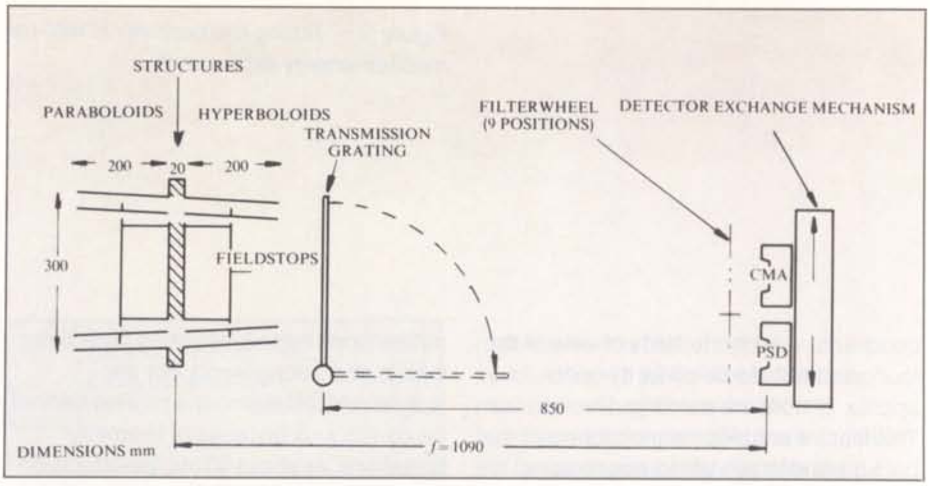
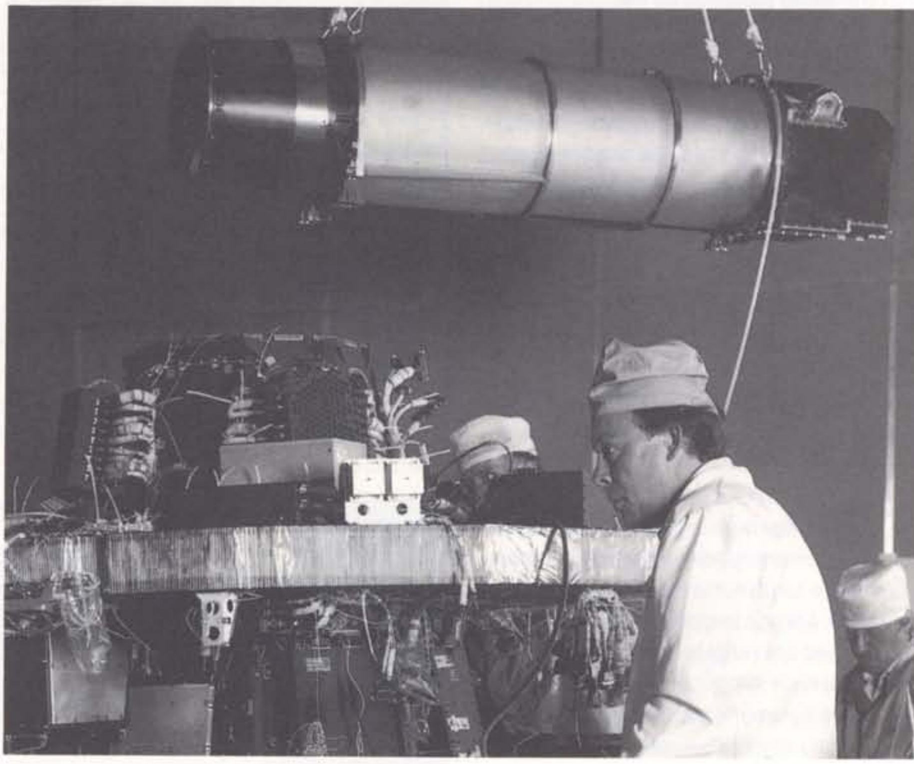


Figure 6 – A single telescope system



an accuracy of a few microns. Beryllium is chosen not only for its rigidity, long-term dimensional stability, and low density, but also for its high thermal conductivity, to minimise distortions resulting from temperature gradients. The mandrel is accurately located within the beryllium shell and a layer of epoxy some 30 μm thick is injected between mandrel and shell. The gold layer adheres to the epoxy and the mandrel is removed after curing; the geometry and surface finish of the mandrel being transferred to the substrate without degradation. Four mandrels, one each for the four different mirror shells, per telescope have been produced and each mandrel can be used repeatedly. Including structural elements and field stops, each Exosat mirror assembly weighs only 7 kg (Table 4).

The mirror system has been tested in a long-beam facility and shown to achieve an angular resolution of some 8 arcsec FWHM on axis. It should be noted that the a posteriori attitude determination accuracy will be $\leqslant 10$ arcsec (3σ) and that the plate scale of the optics is 5.3 μm/arcsec.

The elements of the imaging telescope, i.e. the mirrors, focal-plane assembly and grating (Fig. 6), are housed in an optical bench, onto which is also mounted a star tracker of the attitude-measurement system. The optical bench is made of titanium to provide a close match to the linear thermal expansion of the beryllium optics.

Each telescope is equipped with two detectors, a position-sensitive proportional counter (PSD) and a channel multiplier array (CMA) mounted on an exchange mechanism. Both detectors employ a resistive-disc readout system. Design goals of 200 μm (at 8.3Å) and 50 μm (FWHM) for the PSD and CMA, respectively, were set for the on-axis position resolution, which, when folded with the plate scale of the optics, yields angular resolutions of approximately 40 and 10 arcsec.

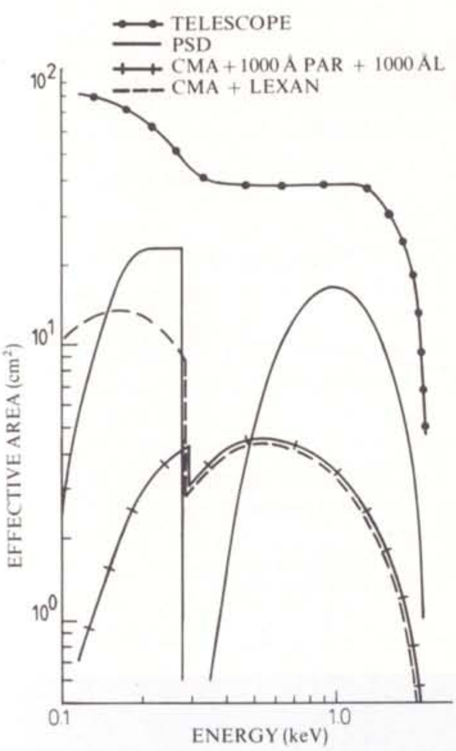
Table 4 – Physical parameters of a low-energy imaging telescope

Geometrical area	90 cm² (52 cm² outer, 37 cm² inner) for one telescope	
Grazing angles	1.8° outer, 1.5° inner (averages)	
Energy cut-off	2 keV (6Å)	
Plate scale	5.3 μm/arcsec	
Focal-plane detector	PSD	CMA
Energy range	0.1–2 keV	0.04–2 keV
Efficiency 0.05 keV	–	0.28
0.15 keV	0.19	0.24
0.8 keV	0.37	0.12
1.5 keV	0.17	0.05
Energy resolution	$\Delta E/E = 44/E(\text{keV})^{1/2}$ % FWHM	(no intrinsic)
Field of view	28 mm diameter, 1.5°	42 mm diameter, 2.2°
Angular resolution	50 arcsec at 1.5 keV	
(on-axis) FWHM	210 arcsec at 0.28 keV	8.5 arcsec
Background rate	0.12 $cm^{-2} keV^{-1} s^{-1}$	1 $cm^{-2} s^{-1}$
Grating with CMA	500 lines/mm	1000 lines/mm
Plate scale	43 μm/Å	85 μm/Å
$\Delta\lambda(\lambda < 40Å)$	1Å	1Å
$\Delta\lambda(\lambda > 40Å)$	2–4Å ($\lambda < 430Å$)	1–2Å ($\lambda < 250Å$)
Mass, power (1 telescope)	30 kg, 5 W	

Figure 7 – Effective area of a single telescope alone, and with the PSD and CMA at the focus, as a function of photon energy

Figure 8 – Variation in telescope spatial resolution with X-ray photon energy, with the CMA or PSD at the focus

Figure 9 – Variation in the telescope spatial resolution with off-axis angle

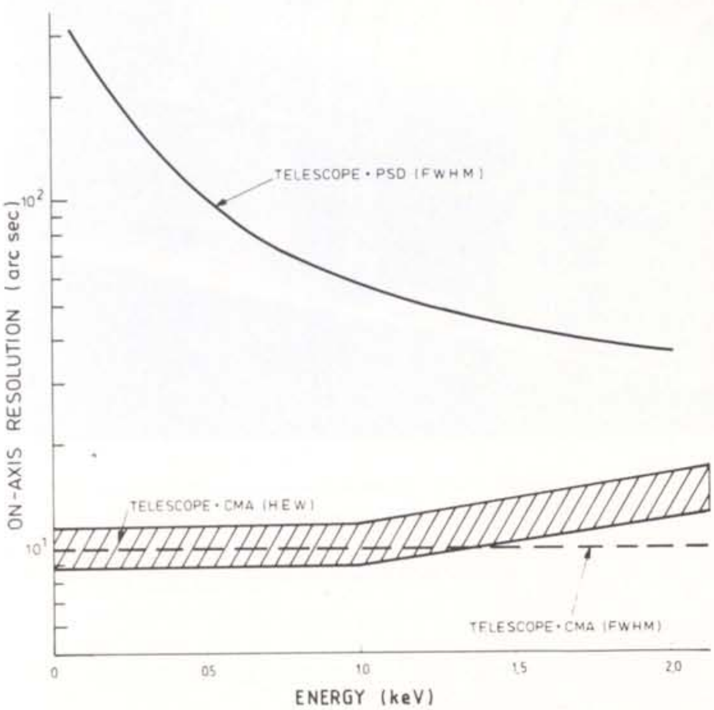


The PSD is configured as a parallel-plate proportional counter with a resistive disc readout system. It has an area of 28 mm diameter, a main entrance window of 0.8 μm of polypropylene and a 4.5 mm-deep absorption region of argon (80%) methane (20%) at 1.1 bar. A second entrance window of 0.4 μm Lexan-coated polypropylene is placed just in front of the main window. The enclosed volume between is vented to space to prevent the gas that diffuses through the main window raising the pressure in the optical bench to the detriment of the CMA.

Emphasis has been placed on the achievement of good energy resolution in the PSD (e.g. 40% FWHM at 8.3Å) to permit the multicolour mapping of diffuse sources to resolutions of 1–2 arcmin and the determination of spectra to a degree not achievable with the Einstein imaging proportional counter. The gain of the PSD is regulated by a density control on the gas-supply system, down to the equivalent of 3 mbar at 20°C. In addition, there is an automatic gain-control system using a radioactive source within a calibration cell in the detector gas volume which, in controlling the detector's high voltage, counteracts gain drifts caused by the different leak rates of argon and methane through the thin main window. A gain stability of better than 1% is achieved.

The CMA consists of a chevron arrangement of two microchannel plates with diameters of 50 mm. The channel diameter is 25 μm. The front plate has a zero bias angle and its front surface is coated with magnesium fluoride to achieve an adequate quantum efficiency.

Figure 7 shows the effective area of the mirror along with the PSD and with the CMA at the focus as a function of energy. The variation in spatial resolution with energy is shown in Figure 8, and with off-axis angle in Figure 9. High angular resolution work with the CMA will thus be limited to some 10 arcmin off-axis.



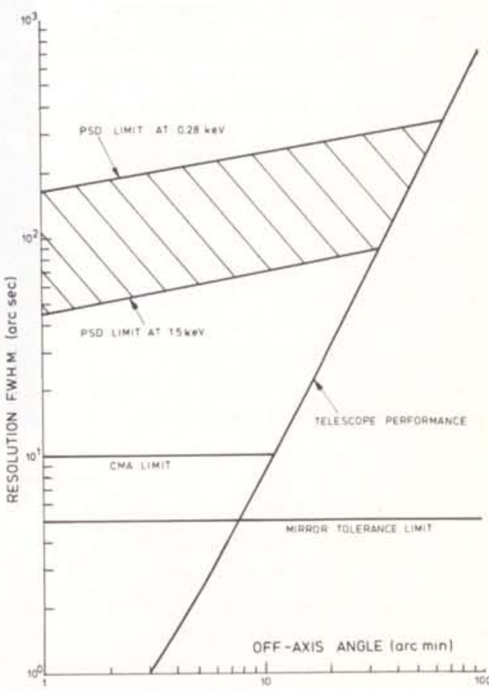


Figure 10 – Schematic of the gas scintillation proportional counter (GSPC) experiment

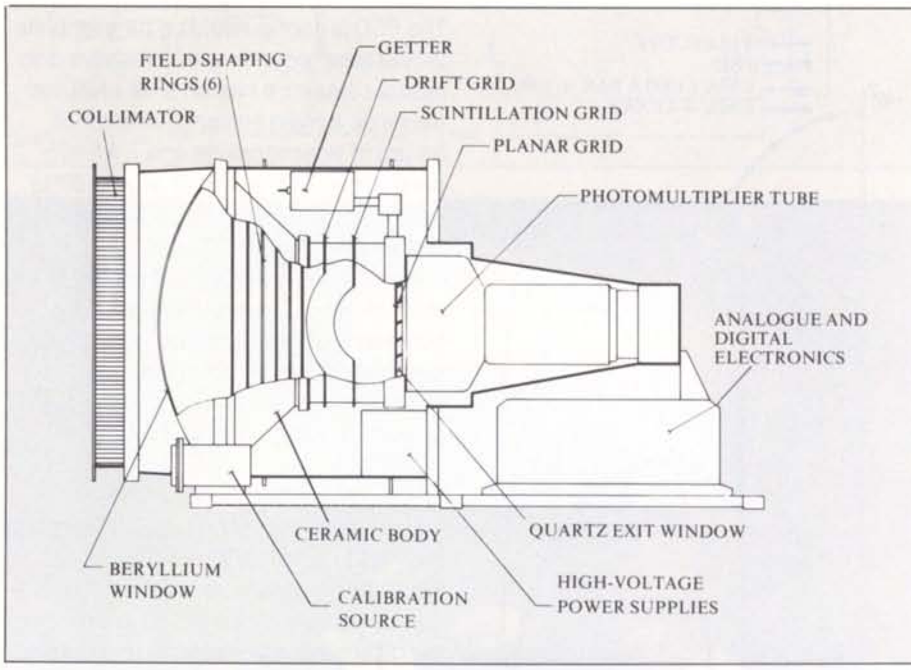
Mounted just in front of the focal plane is a wheel containing a set of filters (to provide a broadband spectroscopic capability when used in conjunction with either detector), various apertures to limit the field of view, and a calibration source. The CMA will always be used in conjunction with a filter to avoid UV contamination.

Each telescope is equipped with a transmission grating, one with 500 lines/mm, the other with 1000 lines/mm, either of which can be placed at the exit aperture of the optics and provide for spectroscopy of strong point sources. These gratings provide plate scales of 43 μm/Å and 85 μm/Å, respectively, and will be used in conjunction with the CMA for the best spectral resolution. Resolutions $\Delta\lambda/\lambda$ of 0.025 to 0.01 from the shorter wavelengths out to 430Å can be achieved.

The gas-scintillation proportional counter

The gas-scintillation proportional counter (GSPC) for X-ray spectroscopy has seen rapid development in recent years. A first-generation, simple instrument was included as the last iteration in the Exosat instrument complement and a prototype version has been successfully flown on an Aries sounding rocket. Its advantage over conventional proportional counters (e.g. the medium-energy experiment) is that its superior energy resolution (by a factor 2–3) will permit spectral features such as iron-line complexes at ~7 keV to be resolved from the continuum emission for the first time. A schematic of the instrument is shown in Figure 10, and its physical characteristics are given in Table 5.

The gas cell of the GSPC is comprised of a conical/cylindrical body made from machinable ceramic sections, a spherical section 175 μm-thick, free-standing beryllium entrance window, and a 4 mm-thick UV-transmissive exit window. The cell is filled with a one-atmosphere mixture of xenon (95%) and helium (5%). The



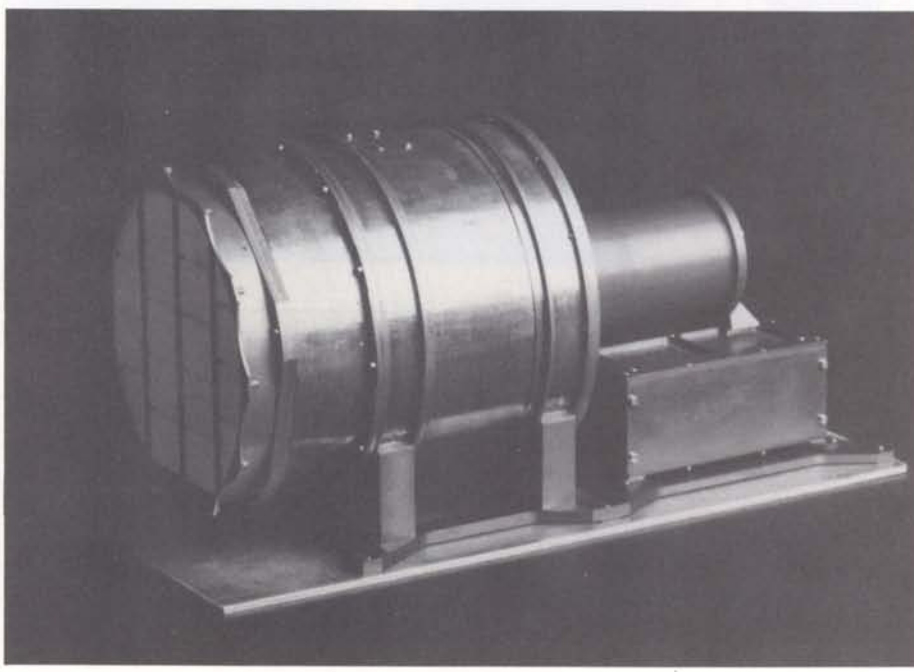


Table 5 – Physical parameters of the gas-scintillation experiment

Total effective area	160 cm for 80% X-ray acceptance
Total energy range	2–80 keV
Energy resolution FWHM	27/E (keV)$^{1/2}$%, 10% at 7 keV
Field of view	45 × 45 arcmin triangular
Background rejection	97% (2–10 keV), 96% (10–20 keV)
Background rate	10 s^{-1} keV^{-1} (2–10 keV)
Total mass, power	8 kg, 1.5 W

detector is assembled using ultrahigh-vacuum techniques and baked-out at ~300°C to minimise contamination of the highly purified noble gases by outgassing. Getters are also included to maintain the high gas purity throughout the duration of the mission.

In the gas cell the electrons produced by X-ray photo-absorption are drifted into a spherical, high-electric-field region. Here they acquire sufficient energy to excite the noble gas atoms. These excited atoms form diatomic molecules through collisions, which de-excite by the emission of UV photons in the waveband 1500–1950Å. This burst of UV photons is subsequently observed by a photomultiplier tube, the integrated anode signal of which has an amplitude proportional to the energy of the absorbed X-ray photon. The energy resolution depends on the variance in the number of UV photons observed by the photomultiplier tube as well as the variance in the initial number of electrons produced in the photo-absorption process. The energy resolution is at least a factor of two better than that of the conventional proportional counter, being ~10% FWHM at 6 keV.

The UV photon burst time depends on the depth of the scintillation region, the drift velocities in the photo-absorption and scintillation regions, and the size of the electron cloud prior to its entry into the scintillation region. The burst-time spectra of X-ray events are dissimilar to the spectra of background events, produced directly by ionising particles or indirectly by gamma-ray-induced Compton electrons, since these will have different electron-cloud sizes. Such differences in burst times are exploited as a means of rejecting background events. Background estimates for the Exosat detector are derived from data from an Aries rocket flight at altitudes below 250 km and from Cos-B and Apollo-15 X-ray measurements in highly eccentric orbits.

The Exosat GSPC will be used primarily to study the spectra of the stronger X-ray sources and particularly the stronger lines to measure line energies, their width, strength and separation from the continuum emission. Such data can provide estimates of temperature, electron densities and elemental abundances in the hot, X-ray-emitting plasma.

X-ray source detection

The most sensitive instruments for the detection of X-ray sources are the imaging telescopes. Their sensitivity depends on the intrinsic source spectrum and on the amount of interstellar absorption, which provides the low-energy cut-off. Source detection is dominated by instrument background for observation times in excess of 3×10^4s and 7×10^2s for the CMA and PSD at the telescope focus, respectively.

The source strength shown in Figure 11 is given in Crab units (the Crab, being one of the brighter known X-ray sources, is often used as a 'standard candle') and the sensitivity is derived for a Crab-like spectrum with spectral index $\alpha = 2$ and an interstellar hydrogen column density N_H ~3×10^{21} cm^{-2}. The Crab spectrum is indicated to highlight the dependence of sensitivity on spectral shape. The data

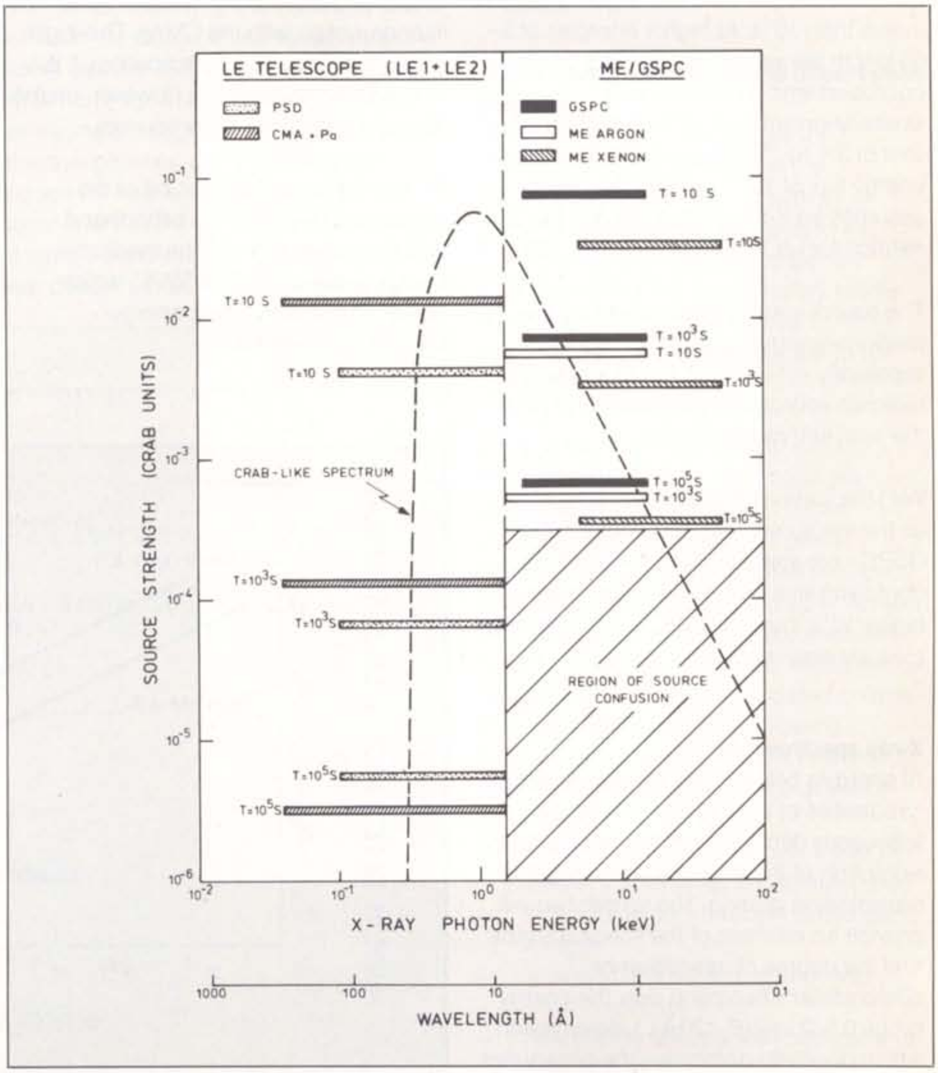


Figure 11 — Source-strength sensitivity of the Exosat payload

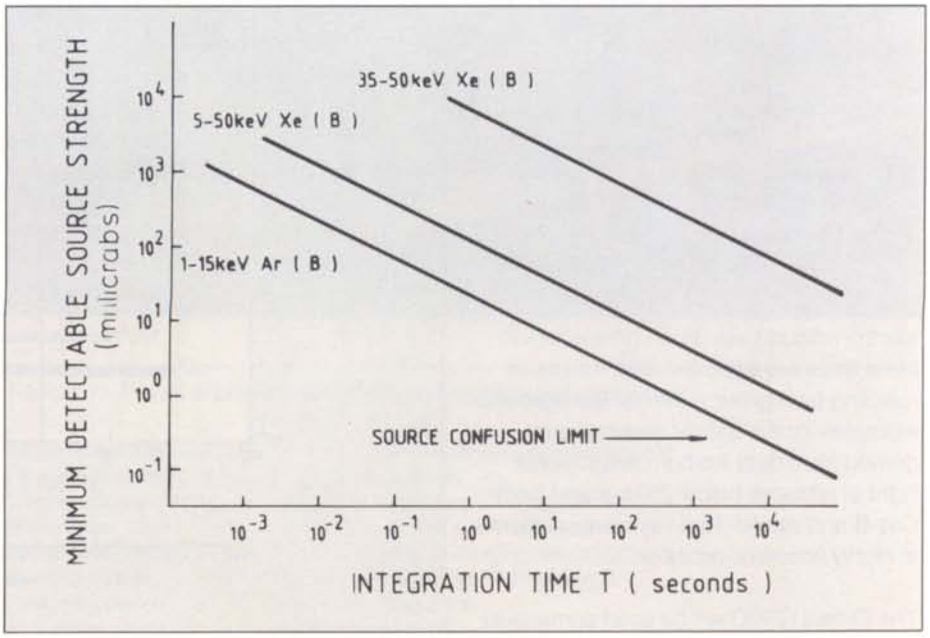


Figure 12 — 5σ minimum detectable source strength in three energy bands for the medium-energy experiment

from the two imaging telescopes with a pair of CMAs or PSDs at each focus have been combined.

For the detection of weak sources or sources with low interstellar absorptions the CMA is more sensitive than the PSD, whilst for stronger sources or those with higher interstellar absorptions the PSD is more sensitive.

The source-detection capabilities of the nonimaging instruments are radically different. Even with its relatively narrow field of view, the medium-energy experiment is confusion-limited (i.e. there will be several very weak sources in the field of view that cannot be separated) in its most sensitive 1–15 keV argon detector in less than 10^4s. At higher energies of 5–50 keV in the xenon detector the confusion limit is reached with observation times of 10^5s. The confusion limit of 3×10^{-4}Crabs corresponds to an energy flux of 10^{-11} erg cm^{-2}s^{-1} and assumes an X-ray source log N– log S relation for $|b_{II}| > 20°$ of $N(>S) = 200\ S^{-1.5}$.

The source-detection sensitivity for the medium-energy experiment is shown separately in Figure 12. For example a 1 millicrab source can be detected at 5σ in the 1–15 keV range in 500 s.

With the same collimator characteristics as the medium-energy experiment, the GSPC instrument does not reach the confusion limit with observation times below 10^6s, but the GSPC is not intended to study weak sources.

X-ray spectroscopy
At energies below 2 keV the spectroscopic capabilities of the Exosat low-energy telescopes derive from the intrinsic energy resolution of the PSD, the filters and the transmission grating. The former two will provide an estimate of the spectral shape and the degree of interstellar or circumstellar absorption over the energy range 0.1–2 keV (6–120Å). Line emission, which generally dominates the continuum emission for thermal sources radiating most of their power at these lower energies, however, cannot be resolved in this way. An indication of the presence of line complexes, particularly those due to oxygen and iron can, however, be obtained. Colour-colour analysis can be obtained with the CMA, which has no intrinsic energy resolution, when it is used in conjunction with the filters. A parylene-aluminium filter provides a band pass at EUV wavelengths (170–400Å), which allows sensitive estimates of the temperature of a number of nearby low-temperature X-ray sources and their interstellar absorption to be made.

High spectral resolution can only be obtained using the transmission gratings in conjunction with the CMAs. This high-resolution dispersive spectroscopy ($\Delta\lambda \sim$ 1–4Å) is only possible, however, on the *stronger*, point-like, X-ray sources.

At energies above the cut-off of the telescopes (~2 keV) the broadband spectroscopic ability of the medium-energy experiment and GSPC, which derive from their intrinsic energy resolution, is utilised.

The medium-energy experiment, capable of high-precision broadband spectroscopy over the energy range 1–50 keV, is particularly well suited to the following studies:

i. Determination of the shape of the continuum from 1 to 50 keV. For a weak source of 10^{-3}Crab, a detailed spectrum can be obtained within 10^5s using one half of the array offset from the source to monitor simultaneously the background.
ii. Estimation of the degree of interstellar or intrinsic absorption for heavily cut-off sources. Measurements of the degree of interstellar or circumstellar absorption are primarily limited by the low-energy cut-off given by the 37 or 62 μm beryllium windows of the argon proportional counters. At 1.5 keV the X-ray transmission is less than 30%, equivalent to an interstellar hydrogen column density of ~10^{22} atom/cm^2.
iii. Detection of spectral lines of iron, silicon and sulphur. Although the experiment has an energy resolution of ~20% FWHM at 6 keV, this, coupled with the large effective area and high background rejection

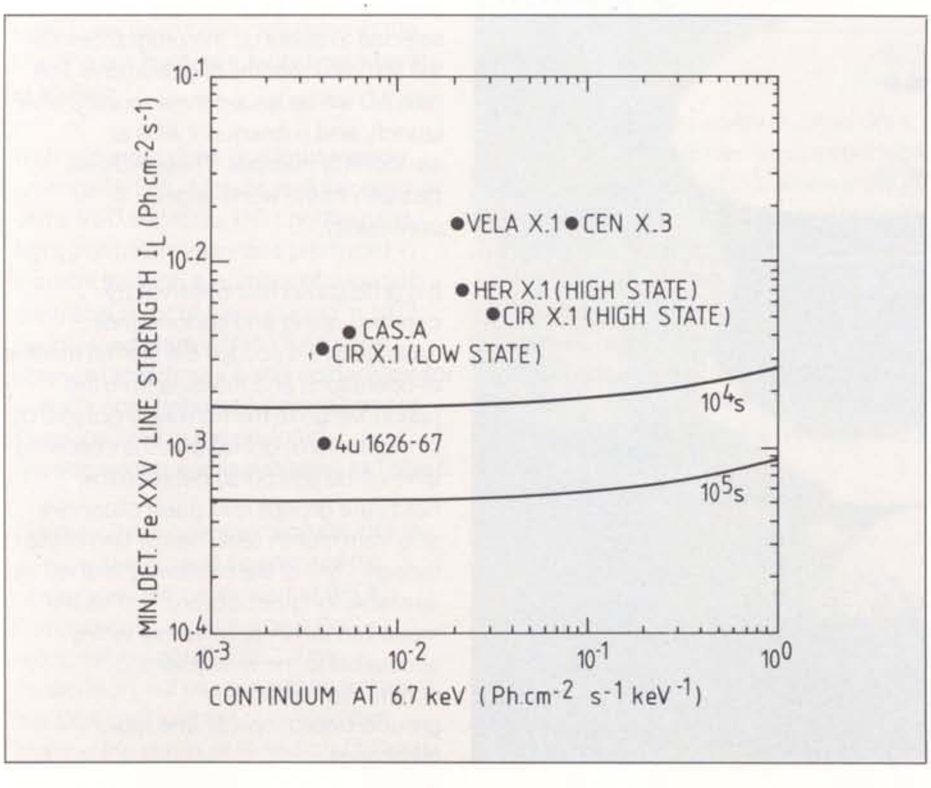
Figure 13 – Sensitivity of the Exosat GSPC spectrometer to the detection of iron lines from helium-like ions

efficiency, makes it sensitive to the detection of spectral lines, particularly in the energy range covered by the argon proportional counters.

iv. Study of spectral variability. The high sensitivity of the experiment for broadband spectroscopy coupled with the ability of the observatory to return frequently to sources (particularly useful for X-ray binaries) makes it well suited for studying of spectral variations in a variety of X-ray sources.

The GSPC spectrometer will be used for the detailed study of strong X-ray source spectra, its principal advantage over to the medium-energy experiment being its higher (factor 2) energy resolution (a disadvantage is its significantly smaller area). The GSPC will therefore be most effective in measuring strong source spectra, including determinations of line energies, line widths and the resolution of line complexes, rather than the measurement of weak source continua or the detection of weak lines. It will be used in conjunction with the medium-energy experiment, which will provide a high-precision measure of the X-ray continuum. The spectrometer is most efficient between 6 and 9 keV for the detection and detailed study of spectral features produced by iron. It has a low efficiency below 2.5 keV, due to the window-cut-off, for the detection of sulphur and silicon lines.

Figure 13 indicates the sensitivity of the GSPC for the detection of lines at ~6.7 keV from helium-like iron ions and indicates the estimated line strengths in a number of source examples.



X-ray source variability

The Exosat observatory is extremely well suited to the study of time variability in the flux of celestial X-ray sources over a wide dynamic range in time scale. Long-term variations, particularly useful for the study of active galaxies, can be adequately studied by frequent returns of the observatory to the same source to sample its activity state over, for instance, a one-year period. On shorter time scales, the repeated sampling can be used to monitor the variation in the flux from binary X-ray sources around one binary orbit. Continuous uninterrupted observations are possible from 10 s up to a maximum time of 80 h, the time the satellite is above the radiation belts.

The ability of the medium-energy experiment to detect fluctuations in source intensity is shown in Figure 14 for two extreme cases. For bright sources (1000 millicrab) a factor of two increase can be seen in 10 ms at 1–15 keV. For the 5–55 keV range, the same change can be seen in 100 ms. For a faint (1 millicrab) source the same change can be seen in about 10 min at 1–15 keV and 12 h at 5–55 keV.

Observatory operations and observation planning

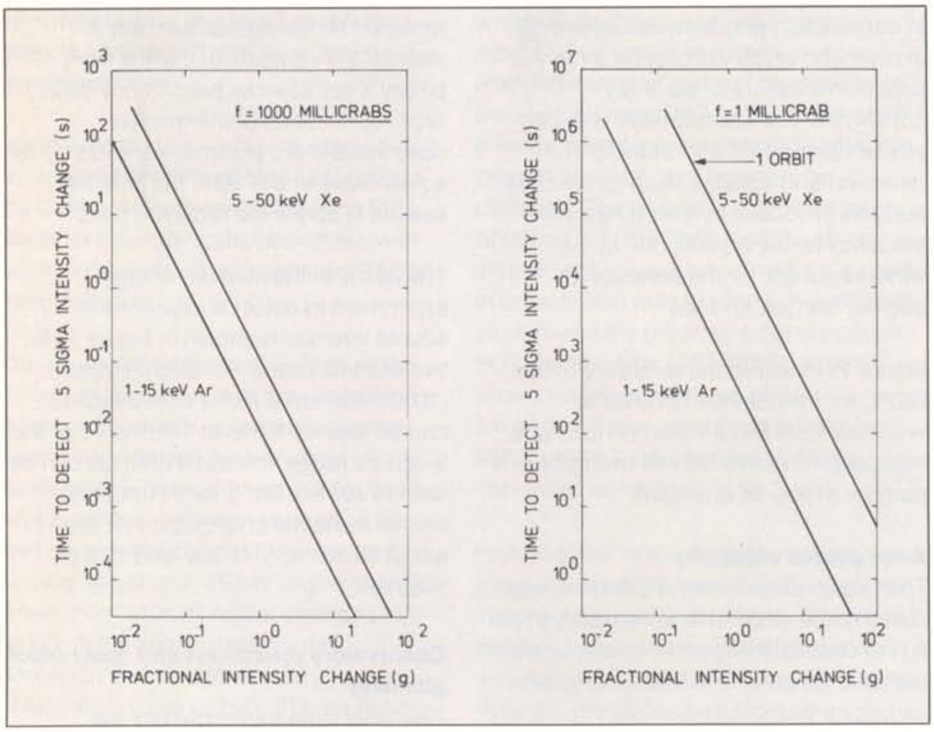
Telemetry data transmitted by the spacecraft will be received at the Villafranca (Spain) ground station (Fig. 15) and routed in real time to the European Space Operations Centre (ESOC) in Darmstadt (Germany), where the Control Centre and Exosat observatory ground segment are to be located.

Extensive computational and display facilities with hard copy will allow an observation to be monitored by an observer in real time and will permit modification of the operational sequence of modes in the light of the results. Access can also be made to data accumulated over the past 80 h (~1 orbit), which will be stored and continuously updated on disk in a short history file. The following examples are indicative of the real-time or near-real-time data displays that will be available:

- raw telescope images over full or part field in colour or as an isometric plot
- orthogonal cuts through telescope images
- intensity/time profiles with period search routines
- raw energy spectra with background subtraction.

Figure 14 — Detection of intensity fluctuations with the medium-energy experiment

Figure 15 — The main Exosat antenna at ESA's Villafranca ground station



The definitive output from an observation will be the Final Observation Tape (FOT) written in a standard format, independent of the on-board-computer mode and telemetry partitioning. Nonlinearities in the focal-plane detectors will be corrected prior to writing the telescope data to the FOT so that these data can be readily transformed to the desired coordinate system, given the final spacecraft attitude in the auxiliary data. The FOT will be released from ESOC some four weeks after the observation, and an observer will be able to request an automatic FOT analysis with hard-copy output to provide a minimum level of scientific analysis, but which goes far beyond that available in real time.

The first Announcement of Opportunity (AO) to participate in the Exosat observation programme was released in July 1981 to the scientific community of the ESA Member States and some 500 observing proposals were received. The available observing time in the first observation period of nine months was oversubscribed by a factor of ~6. From this response, 200 proposals were selected to make up the programme for the first nine months of operations. The next AO will be issued three months after launch, and subsequent AOs at six-monthly intervals. These AOs will be open to the world-wide community.

It is anticipated that observatory commissioning and performance verification will occupy the first 1.5 months of operations and the data from this period will go to the hardware groups. Up to month six of operations, the observing time will be split 50/50 between the hardware groups and guest observers and from month seven to the end of the mission 75% of the observing time will be available for guest observers. This will make Exosat an observatory facility accessible to the wide scientific community, rather like ground-based optical and radio telescopes.

Exosat's science programme management

When the decision was taken in 1973 to embark on the Exosat programme, it was decided that the data should be made available to a broad scientific community rather than be restricted to instrument developers, as had been the case for all previous Agency scientific programmes. It was thus inappropriate for the instrumentation to be funded nationally and funding for instrument development was provided from the Agency's scientific programme budget. A small dedicated team was set up within the High Energy Astrophysics Division of ESA Space Science Department (HEA/SSD) to manage the development of the instrument. However, experimenter or 'hardware' groups were selected in the time-honoured manner and the design and development of the instrumentation became a shared responsibility. Generally speaking, the institutes have been responsible for the scientific design and calibration of specific instruments (Table 6); the Agency for engineering design, development, testing and overall management. The flight imaging telescopes have been calibrated at the Max Planck Institute's X-ray beam facility in Munich.

With two exceptions (the transmission gratings by SRL, Utrecht and the window of the PSD by MSSL, UC London), the flight instrumentation was produced in industry through a number of separate contracts, most of them started in 1977, the payload team within ESA Space Science Department being responsible for overall coordination and management. Firms involved in the payload development are also indicated in Table 6.

For the orbital-operations phase of the mission, the ground segment of the observatory will be located at ESOC, Darmstadt, but will be under the responsibility of HEA/SSD. The observatory will be manned by a team of five ESA staff and ten duty scientists (having the status of Research Fellows).

Table 6 – Institutes and organisations contributing to the Exosat scientific payload

Experiment	Institute	Contractors/Suppliers
1. Low-energy imaging telescopes	– Cosmic Ray Working Group, Leiden (NL) – Mullard Space Science Laboratory, University College London (UK) – Space Science Laboratory, Utrecht (NL)	X-ray optics – **CIT-Alcatel** (F) – Instruments SA (F) (replication) – Optic Fichou (F) (mandrels) Focal-plane assemblies – **Matra** (F) – Sira (UK) (detectors) – (Sias (F) (gas system) – Laben (I) (electronics) Main electronics – **Laben** (I) – Matra (F) (front-end)
2. Medium-energy experiment	– University of Leicester (UK) – Max Planck Institute, Garching/University of Tübingen (D)	Detector assembly – **BAe** (UK) – LND (US) (proportional counters) – GEOC (US) (collimators) Main electronics – **Laben** (I) – Matra (F) (front-end)
3. Gas scintillation spectrometer	– Space Science Department of ESA – LFCTR Milan/University of Palermo (I) – Mullard Space Science Laboratory, University College London (UK)	Experiment assembly – Laben (I) Gas cell – AEG/TFK (D) Collimators – GEOC (US)

This team has been slowly built-up since the end of 1979 and has been responsible for the development of the observatory analysis software. During the operatonal phase it will conduct the observations on behalf of or in concert with the observers. In some respects the operation of the observatory will be similar to that for IUE at Villafranca, one significant difference being that operations will be conducted 24 h per day, seven days a week.

The Materials-Science Element of The First Spacelab Payload (FSLP)

U. Huth, Directorate of Space Transportation Systems, ESA, Paris

The European Materials-Science Payload for the first Spacelab Mission represents a considerable intellectual and financial investment. During its first flight in September 1983, multiple microgravity experiments in the fields of crystal growth, metallurgy and fluid physics will be performed. The flight hardware for the Materials-Science Payload has already been manufactured and is presently being integrated in the United States with other payload elements for the first Spacelab mission. Final preparation of the flight samples and operations planning continues in Europe.

The objectives of materials-science research under microgravity conditions vary widely, their common denominator being the almost complete absence of sedimentation and buoyancy, gravity-driven convection and hydrostatic pressure. These basic consequences of terrestrial gravity have implications for fluid systems in general, and the community actively involved in microgravity experiments therefore includes fluid dynamicists, crystal growers, process engineers and materials scientists.

As in any other experimental field, microgravity research can develop only through the flight of well-prepared experiments in combination with the relevant ground testing and theoretical modelling. This in turn means that a certain minimum of 'mission opportunities' with appropriate user facilities need to be available to researchers to ensure the requisite progress (Fig. 1).

In this context the reusable Shuttle/Spacelab system is a most important 'research tool', providing some seven days of microgravity conditions on each flight.

The first Spacelab mission (present launch date September 1983) will have a major materials-science payload on board, which assembles some 36 pilot experiments in the fields of crystal growth, fluid physics and metallurgy from 28 different research institutions in eight European countries.

These experiments were selected by ESA

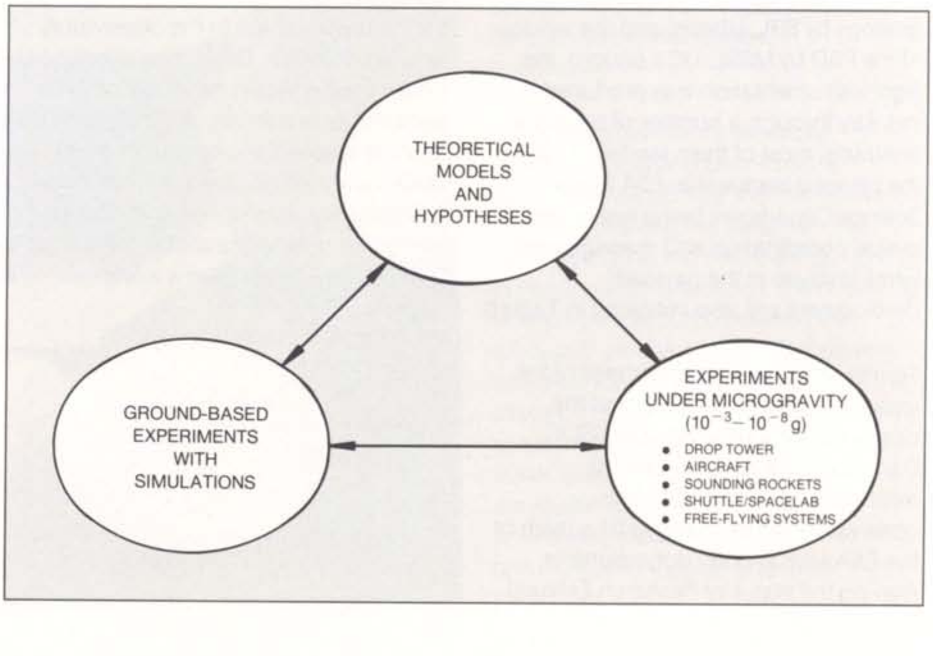
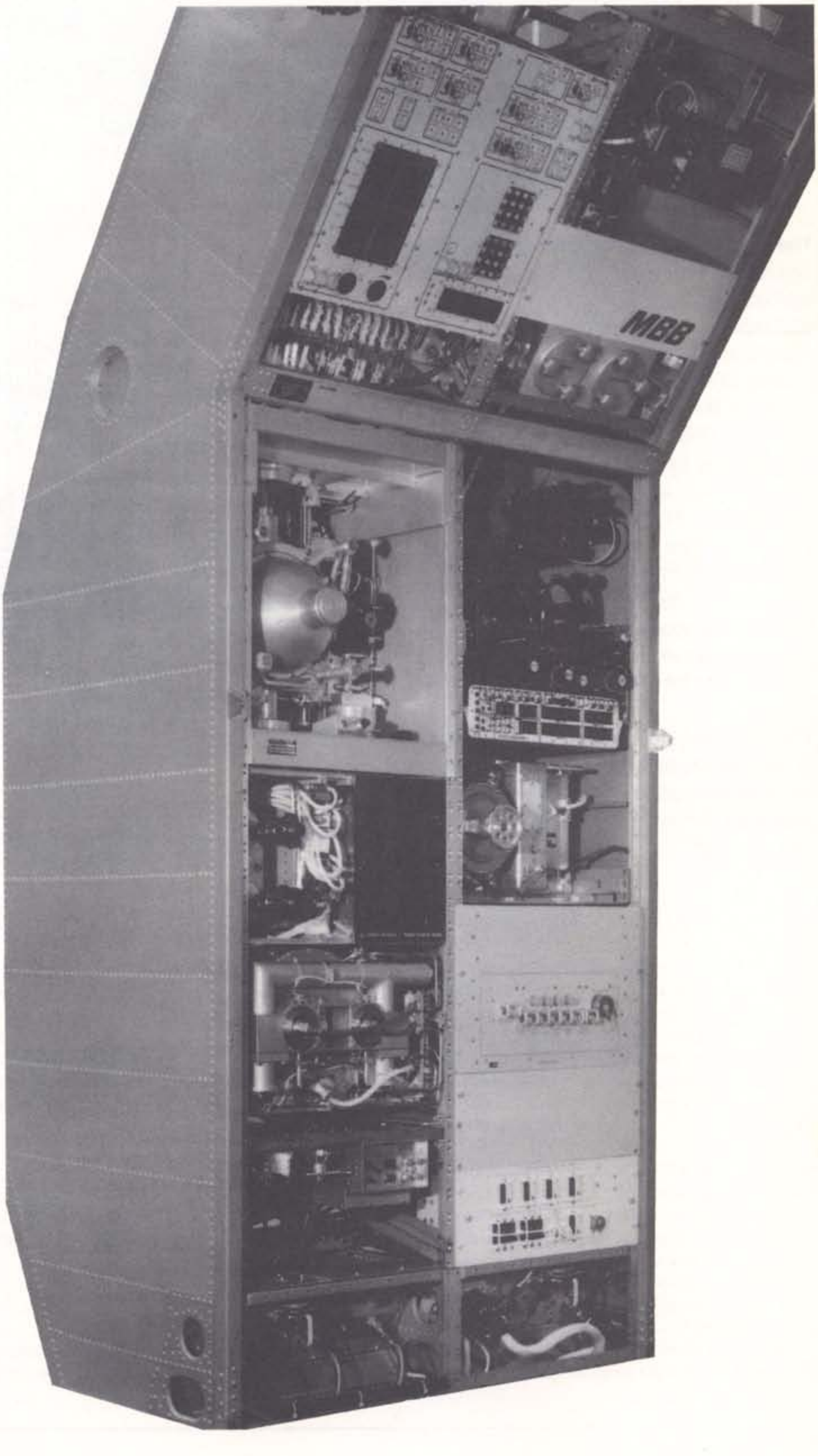


Figure 1 — The interaction between theory, ground-based experiments, and Spacelab microgravity experiments

Figure 2 — The Materials-Science Double Rack (MSDR)



Member States in 1976 from some 100 proposals resulting from a call for experiments the previous year.

Most of the experiments will be performed with the help of so-called 'multiuser facilities' (e.g. furnaces); others require special (autonomous) equipment. All of the hardware, with the exception of two autonomous elements, will be integrated into a Spacelab double rack, called the 'Materials Science Double Rack' (MSDR) (Fig. 2).

The MSDR includes four major multiuser facilities:

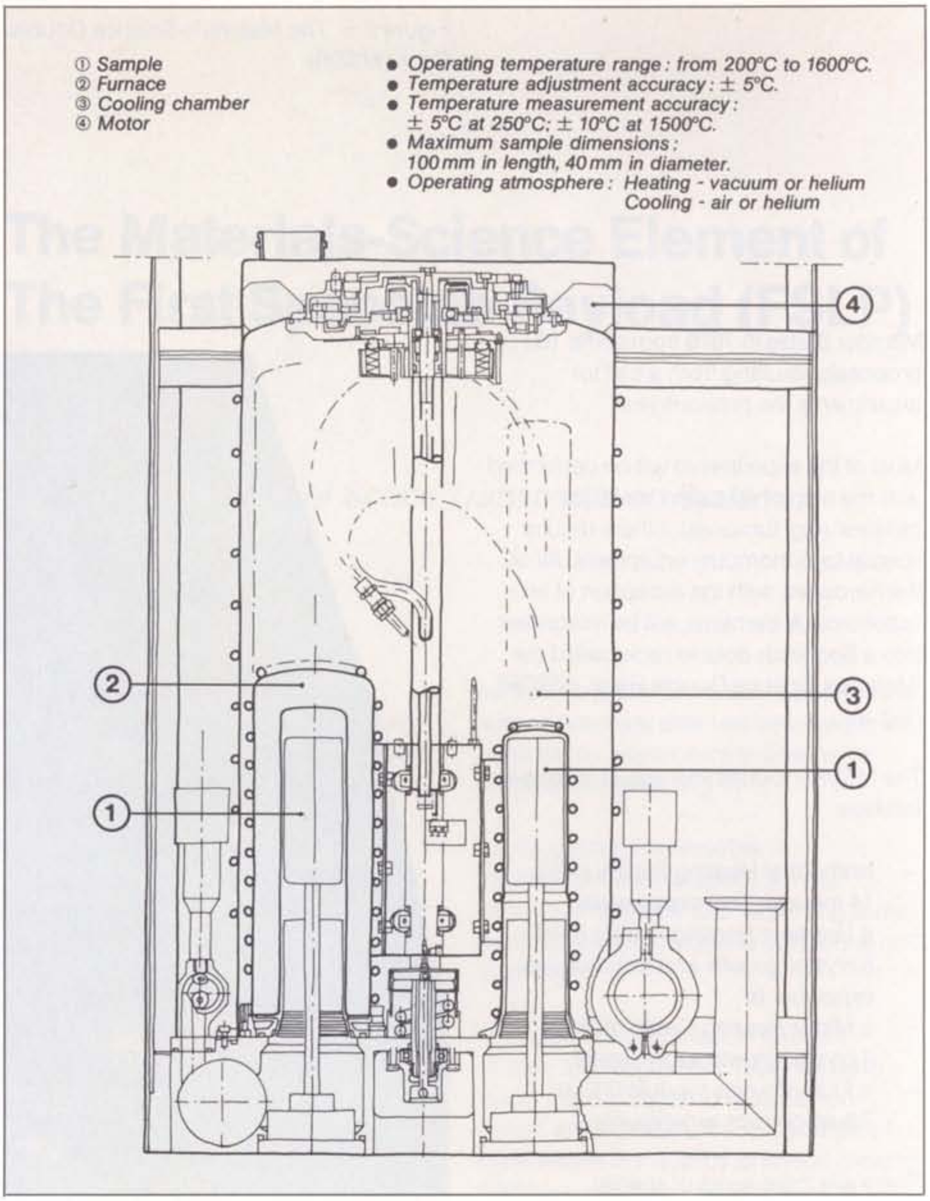
- Isothermal Heating Facility (IHF): 14 metallurgical experiments
- a Gradient Heating Facility (GHF): 5 crystal-growth and metallurgical experiments
- a Mirror Heating Facility (MHF): 4 crystal-growth experiments
- a Fluid-Physics module (FPM): 7 fluid-physics experiments.

There are three items of special experiment hardware within the MSDR:

- a Cryostat: one protein crystal-growth experiment
- a High-Temperature Thermostat (HTT): diffusion in metallic melt experiment
- an Ultrahigh Vacuum Chamber (UHF): adhesion forces of metals experiment.

The Materials-Science Double Rack provides a certain number of 'central services' for the above experiment facilities in the form of a Central Console (used for data conditioning, monitoring, control and status display), a Vacuum and Gas System (used in evacuating and flooding furnaces and to control valves), a Cooling System (consisting of a closed water loop and an open air loop), a Power Supply (to condition Spacelab's unregulated supply voltage), and an Accelerometer, to measure induced vibrations (g-jitter) in three directions.

Figure 3 — The Isothermal Heating Facility



Two items of special experiment hardware are to be provided external to the MSDR:

– a Low-Temperature Thermostat: 2 crystal-growth experiments from solutions
– a Low-Temperature Heat-Pipe Furnace: crystal growth from vapour experiment.

The Isothermal Heating Facility

The Isothermal Heating Facility (IHF) is a multiuser facility with heating (to 1600°C) and rapid cooling capabilities, for experiments in solidification, diffusion, casting of metals, composites, and glass research. The heating and cooling chambers (Figs. 3) can be used in parallel, allowing one sample to be heated up under vacuum whilst another is being cooled down. The heating chamber is an isolated multifoil resistance furnace with a low thermal inertia. Cooling will occur in two steps, the first being flooding of the heating chamber with helium; the final cooling down will be completed by the cooling chamber (Table 1).

The experiment samples will be contained in vacuum-sealed cartridges, which can be either evacuated or filled with gas, depending on the particular experiment's requirements.

Table 1 — Isothermal Heating Facility performance characteristics

Operating temperature	200–1600°C
Measurement accuracy	±4°C at 250°C ±10°C at 1500°C
Temperature constancy	±5°C
Temperature measurement	up to 4 thermocouples
Average heating-up rate (50°C – 1200°C) under vacuum	54–58°C/min
Average cooling rate in cooling chambers (1250°–45°C)	110°C/min in 1 bar helium atmosphere for a standard tantalum sample
Cartridge dimensions	Length: 100 mm Diameter: 40 mm
Maximum sample dimensions	Length: 92 mm Diameter: 39 mm
Gradient-mode operation displacement rate	0.01–0.1 cm/min
Temperature gradient	150°C/cm in copper sample Diameter: 8 mm

Experiments within the Isothermal Heating Facility

ES 301: SOLIDIFICATION OF IMMISCIBLE ALLOYS
H. Ahlborn, University of Hamburg, Germany
The immiscible metallic systems Al-In are to be studied as a follow-up to an earlier space experiment.

ES 302: INTERACTION BETWEEN AN ADVANCING SOLIDIFICATION FRONT AND SUSPENDED PARTICLES
D. Neuschütz & J. Pötschke, Krupp Research Centre, Essen, Germany
The matrix of the suspension of 1% aluminium oxide in copper produced by powder metallurgy is to be melted under microgravity. Particle spacing and size distribution will be determined to investigate the incorporation of the suspended particles in the crystal.

ES 303: SKIN TECHNOLOGY
H. Sprenger, MAN Advanced Technology, Munich, Germany
In the reduced-gravity environment, a very thin skin will be sufficient to retain the shape of a molten component. Directional solidification within a skin should lead to improved microstructures and physical properties for complicated geometries. A sample of a high-temperature eutectic alloy (Ni/Ni_3 Al-Mo) melting at 1310–1315°C will be directionally solidified within a thin Al_2O_3 skin. The gradient heating device will be used.

ES 304/305: VACUUM BRAZING
W. Schönherr & E. Siegfried, Bundesanstalt für Materialprüfung, Berlin, Germany
R. Stickler & K. Frieler, University of Vienna, Austria
Earth-bound investigations of brazing phenomena are restricted to narrow gaps, with interfering influences from the walls. Under microgravity, wider gaps can be filled by capillary-driven flow. The FSLP experiment will consist of an assembly of thin-walled tubes forming different concentric gaps to be brazed.

ES 306: EMULSIONS AND DISPERSION ALLOYS
H. Ahlborn, University of Hamburg, Germany
This experiment is being revised.

ES 307: REACTION KINETICS IN GLASS MELTS
G.H. Frischat, Technical University of Clausthal, Germany
Mass transport on Earth is governed in melts by convection (gravity-driven) and diffusion. The nearly convection-free conditions of space will be used to determine diffusion profiles in glasses.

ES 309: METALLIC EMULSIONS Al-Pb
P.D. Caton, Fulmer Research Institute, Slough, UK
This experiment will improve knowledge of the processing of immiscible materials by investigating effects of cooling rate and alloy composition on particle size and distribution in an aluminium-lead system solidified under microgravity.

ES 311: BUBBLE-REINFORCED MATERIALS
P. Gondi, University of Bologna, Italy
The behaviour of microbubbles and microbubble particles during melting and solidification of metals and two-phase alloys is to be examined.

ES 312: NUCLEATION OF EUTECTIC ALLOYS
Y. Malmejac, CENG, Grenoble, France
The purpose of this investigation is to analyse the first step of solidification: nucleation of a crystal inside the liquid phase. The alloys chosen (Ag-Ge, Al-Si, Al-Ge, Au-Si) are to be studied because of their particular behaviour in the liquid state and during solidification. The eutectics obtained with a metal show extensive clustering and those with a semiconductor show extensive clustering in the liquid just above the melting temperature. The existence of these clusters seems to have a strong influence on nucleation.

ES 313: SOLIDIFICATION OF NEAR-MONOTECTIC Zn-Pb ALLOYS
H. Fischmeister, A. Kneissl, R. Pfefferkorn & W. Trimmel, Montan University, Leoben, Austria
It is proposed to study the solidifcation behaviour and the resulting structures of immiscible Zn-Pb alloys and their dependence on the content and size distribution of lead particles, and on experiment temperature and time.

ES 314: DENDRITIC GROWTH AND MICROSEGREGATION
H. Fredriksson, Royal Institute of Technology, Stockholm, Sweden.
The influence of convection on the formation of dendrite structures will be studied in binary Al-Cu alloys with different copper contents. The formation of dendrite arms as a function of different convection conditions will be examined. The microsegregation picture will also be evaluated as a function of different conditions.

ES 315: MELTING AND SOLIDIFICATION OF METALLIC COMPOSITES
A. Deruyttere & L. Froyen, University of Leuven, Belgium
The aims are: (i) to gain information on the usefulness of the microgravity environment in the production of metallic composite materials by casting, and (ii) to increase knowledge of the behaviour of solid particles dispersed in a liquid metal. The proposed experiments consist of the melting and solidification under microgravity of metallic composite materials (Al-Al_2, Al-SiC, Cu-Al_2O_3, Cu-Mo and Cu-W) prepared by a powder metallurgical technique.

ES 325: UNIDIRECTIONAL SOLIDIFICATION OF CAST IRON
T. Luyendijk, Delft University of Technology, The Netherlands
Unidirectional solidification of pure Fe-C eutectic is to be studied with small quantities of sulphur and phosphorus as impurities. Measurement of sulphur concentrations along the length of the solidified specimen yields information on sulphur transport during solidification. From the segregation profile of sulphur in liquid ahead of the interface, it is possible to calculate the diffusion coefficient of sulphur in liquid iron, and the distribution coefficient (ratio of solubility of sulphur in the solid to the liquid). This has not been possible so far on Earth due to the presence of convection.

The Gradient Heating Facility

The GHF equipment (Figs. 4) consists of:
- an electric multipurpose furnace which can generate different thermal profiles (e.g. isothermal and gradient) inside three identical experiment cartridges
- an electronic control and programming system.

The furnace has a high-temperature and a low-temperature zone. In the high-temperature zone (1250°C), there are three heating blocks, heavily insulated from the others. Optimum thermal efficiency is achieved by using multifoil insulation. A secondary vacuum (10^{-4} torr) is necessary to preserve furnace thermal characteristics. Rapid cooling is achieved by helium injection.

Table 2 — Gradient Heating Facility performance characteristics

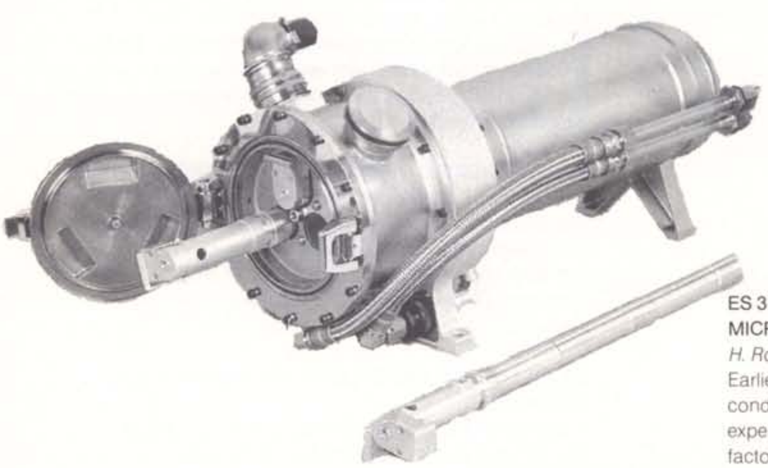
Maximum temperature in sample	1200°C
Heating rate	90°C/min
Cooling rate	60°C/min
Temperature accuracy	±2°C
Temperature constancy	±5°C
Cooling	helium gas

Gradient/zone melting operations
- Fixed sample/fixed furnace, gradient displacement by temperature changes in heating blocks
- Maximum gradient: 100°C/cm
- Displacement length: 34 mm

Isothermal operations
- Length of isothermal zone: 318/150 mm
- Isothermal property: ≤5°C/318 mm at 1200°C

Cartridge dimensions
- Length: 318 mm
- Diameter: 24.8 mm

In the low-temperature zone, in the front of the furnace, is a heat sink which ensures a temperature below 45°C.



Experiments within the Gradient Heating Facility

ES 316: SOLIDIFICATION OF ALUMINIUM-ZINC VAPOUR EMULSION UNDER MICROGRAVITY
C. Potard, CENG, Grenoble, France
The main objective is to analyse the mechanisms of formation of a zinc-vapour emulsion in liquid aluminium-zinc alloys and of its incorporation by solidification in the solid phase.

ES 317: SOLIDIFICATION OF EUTECTIC ALLOYS
J.J. Favier & J.P. Praizey, CENG, Grenoble, France
The reduced thermal convection under microgravity should modify heat and mass transfer, leading to a more regular structure in eutectic alloys. Studies will be performed on Al-Ni, Al-Cu and Ag-Ge. Solidification will be performed with a gradient of 20°C/cm with a rate of 2 cm/h.

ES 318: LEAD-TELLURIDE CRYSTAL GROWTH UNDER MICROGRAVITY CONDITIONS
H. Rodot, CNRS, Meudon, France
Earlier results of semiconductor crystal growth under microgravity conditions have generally shown better quality products. The experiment will elaborate in more detail the influence of the different factors (convection, crucible, seed) on lead-telluride crystals.

ES 319: UNIDIRECTIONAL SOLIDIFICATION OF EUTECTICS (InSb–NiSb)
H. Müller, University of Erlangen, Germany
During unidirectional solidification of a Te-doped InSb–NiSb eutectic, the NiSb needles are expected to grow perpendicular to the liquid/solid phase boundary. Both the length and direction of the NiSb needles and the distribution of the Te dopant are influenced by gravity. Processing under reduced gravity is therefore expected to result in a more uniform needle-growth and homogeneous dopant distribution.

ES 320: THERMODIFFUSION IN LIQUID ALLOYS
Y. Malmejac & J.P. Praizez, CENG Grenoble, France
The thermodiffusion coefficients in different tin alloys will be measured in the absence of gravity. Tin will be used as a solvant. Thermodiffusion of different radioactive solutes will be studied. Thermodiffusion in single and polyphase crystalline growth is important for interface stability as well as the constituant distribution in the liquid and solid alloy.

Figure 4 — The Gradient Heating Facility

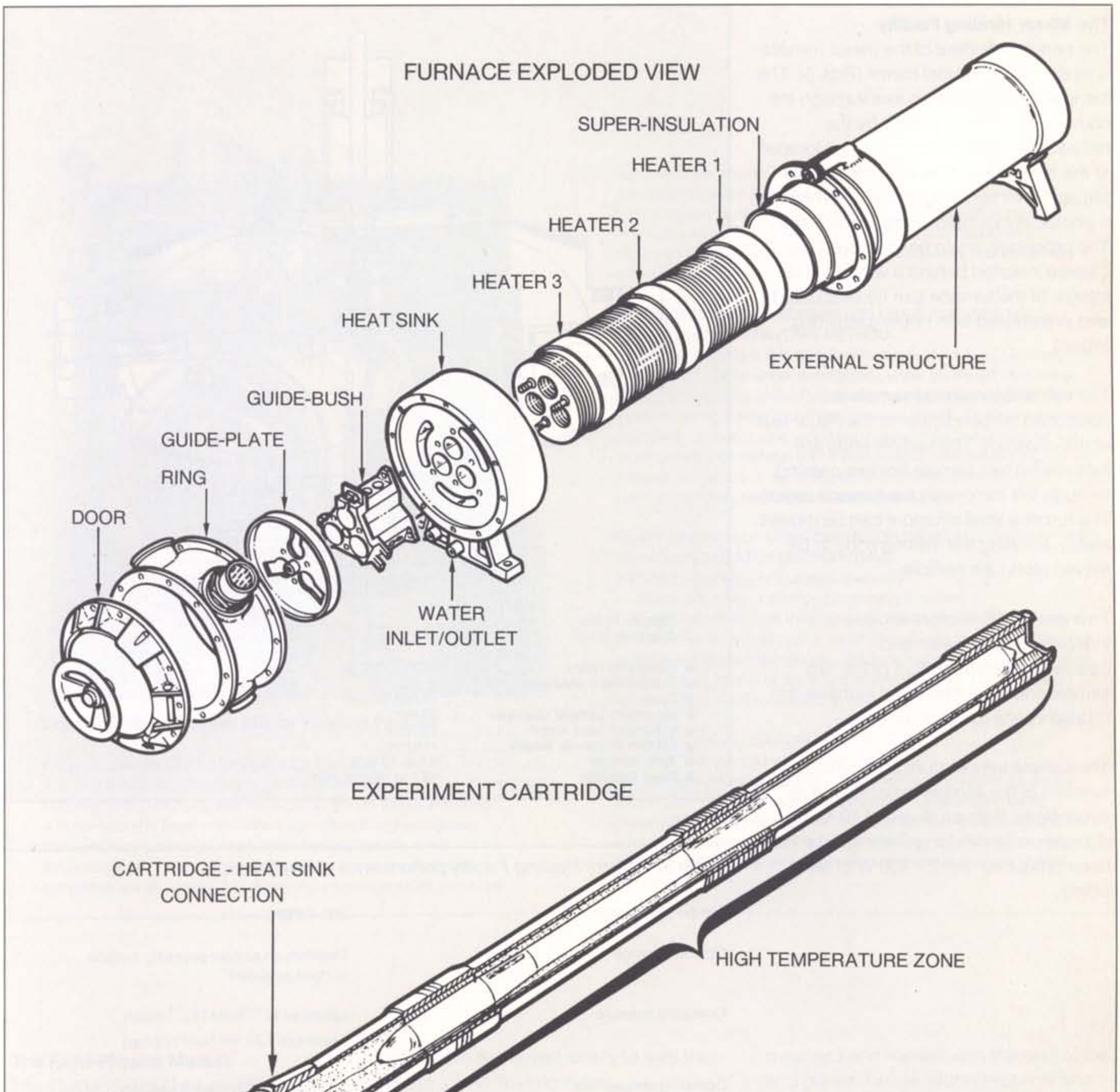


Figure 5 — The Mirror Heating Facility

The Mirror Heating Facility
The principal feature of the mirror furnace is its double ellipsoidal mirror (Figs. 5). The sample is located on an axis through the common focus and heated by the radiation from two halogen lamps located at the two other focusses of the double ellipsoid. The light intensity is controlled by a photocell mounted in the furnace shell. The processes are to be recorded by a camera installed behind a window. The interior of the furnace can be evacuated and pressurised with noble gases (e.g. argon).

The cylindrical material sample is positioned perpendicular to the major axis of the ellipsoids. The sample ends are mounted in two sample holders passing through the mirror into the furnace region. The furnace shell structure can be moved axially, allowing the melting zone to be moved along the sample.

Two geared DC-motors allow independent clockwise and counterclockwise rotation of the two sample ends. Encapsulated samples are rotated in one direction only.

The sample temperature attainable is a function of the sample material and its dimensions. With an Si-rod of 10 mm diameter, a 15 mm long melting zone has been produced with 2 × 400 W of lamp power.

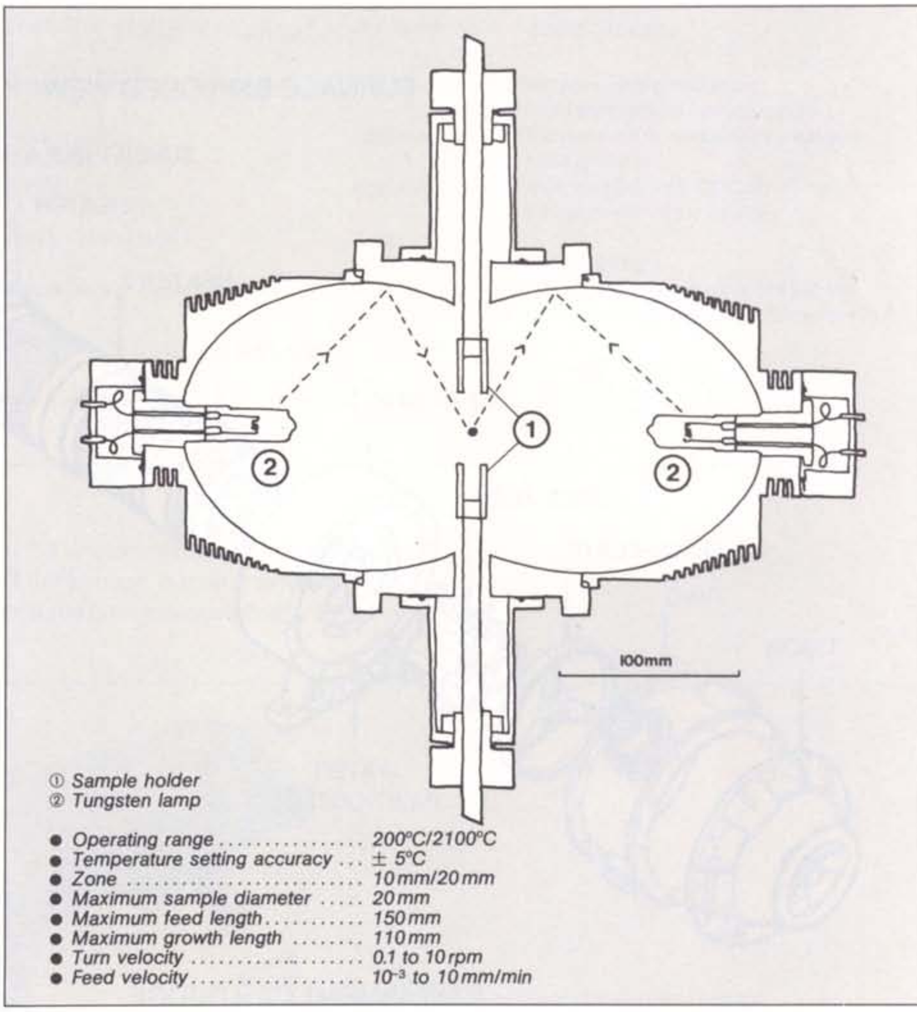
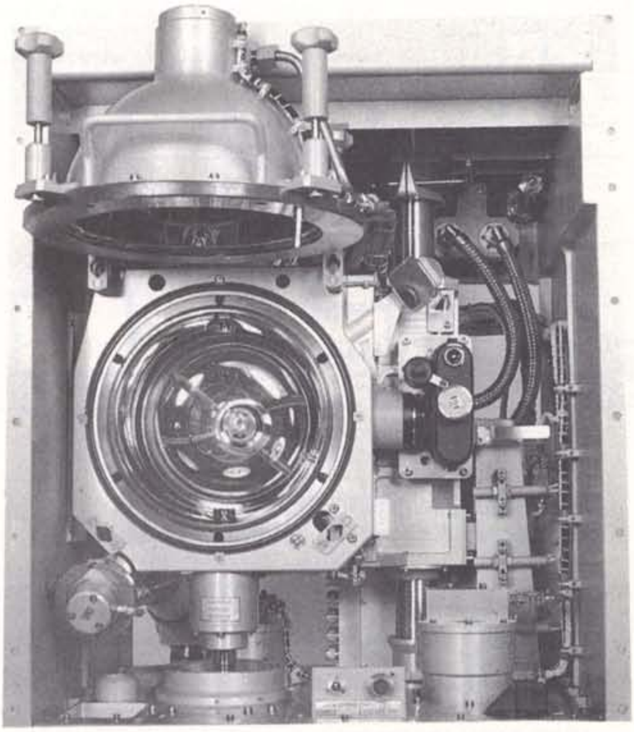


Table 3 — Mirror Heating Facility performance characteristics

Temperature range	200–2100°C
Operating range	Depends on sample geometry, surface, surface treatment
Operating pressure	Minimum 10^{-3} N/m² (10^{-5} mbar) Maximum 1.2×10^5 N/m² (1.2 bar)
Operating atmosphere	Noble gas (e.g. argon) or vacuum
Maximum sample diameter	20 mm
Maximum feed length	150 mm
Maximum growth length	110 mm
Feed velocity	10^3 – 10 mm/min
Rotation	0.1 – 20 rpm
Sample observation	Naked eye or camera



Experiments within the Mirror Heating Facility

ES 321: FLOATING-ZONE GROWTH OF SILICON
E. Eyer & R. Nitsche, University of Freiburg, Germany
Silicon growth (1450°C) under microgravity should produce crystals with considerably fewer micro-inhomogeneities than Earth-grown materials. Ideally, the crystal should be free of striations, since temperature and concentration fluctuations due to gravity-driven convection are eliminated. Any remaining inhomogeneities should be due only to Marangoni convection. The experiment will allow us to distinguish between the (on Earth always combined) influences of buoyancy and Marangoni convection on the formation of micro-inhomogeneities. The use of radiant heat for zone melting also eliminates any turbulence effects (e.g. eddy currents) that an RF field may have on the melt.

ES 322: GROWTH OF CADMIUM TELLURIDE (CdTe) BY THE TRAVELLING HEATER (THM) METHOD
R. Dian, R. Schönholz & R. Nitsche, University of Freiburg, Germany
The growth of CdTe under microgravity, under purely diffusive mass-transport conditions, should produce crystals with considerably fewer micro-inhomogeneities than Earth-grown materials. To ensure mono-crystallinity, a seed crystal, which will initially be partially dissolved, will be employed. The material will be evaluated by selective etching, infrared microscopy, X-ray topography and measurements of conductivity, γ-ray response and trap spectroscopy.

ES 323: GROWTH OF SEMICONDUCTOR CRYSTALS (GaSb) BY THE TRAVELLING-HEATER METHOD (THM)
K.W. Benz, University of Stuttgart, Germany.
G. Müller, University of Erlangen-Nürnberg, Germany
The goal is to investigate the possibility of defined stationary transport conditions in the solution zone, which should lead to more perfect and – in terms of dopant distribution – more homogeneous crystals. During the flight, about 5 mm of GaSb single crystals should be grown at an approx. 500°C solution temperature.

ES 324: CRYSTALLISATION OF AN Si-DROP
H. Kölker, Wacker-Chemie, Munich, Germany
A Si-drop, attached to a Si-rod will be directionally solidified. Furnace temperature oscillations will be avoided and furnace cleanliness preserved. Besides Marangoni convection (surface-tension driven), no convective disturbances will be present, so that its influence can be studied in terms of the inhomogeneities and striations in the crystals grown.

The Fluid-Physics Module

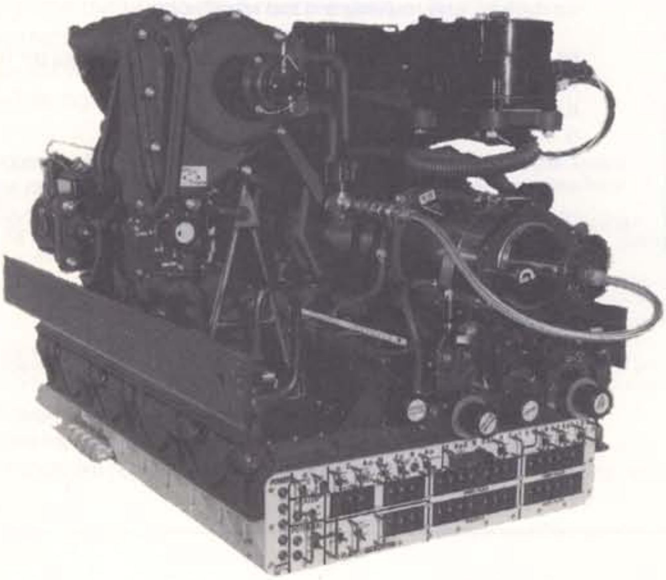
The Fluid-Physics Module (FPM) is a multi-user facility for the investigation of fundamental fluid-physics problems in a microgravity environment (Figs. 6). The Module establishes a 'fluid bridge' between two parallel coaxial discs, allowing disturbances to be applied to the liquid, the behaviour of which can then be investigated. The fluid to be studied can be injected through one of the discs, which can be moved axially to vary the length of the floating zone.

The discs can be rotated separately, at the same or at different speeds, and in either direction. One disc can be vibrated axially at different frequencies and with different amplitudes. The form and diameter of the end plates can be modified according to experiment objectives. Special containers can be mounted and rotated with the help of the end plates. Temperature gradients and a difference in electric potential can be established between the two discs. The test chamber is airtight and will accept different fluids, with and without tracers. An air circulation and liquid recovery system is provided to clean out the test chamber should the floating zone break down, and to control temperature and humidity.

Phenomena developing in the test chamber (shape and size of the floating zone; motions inside the floating zone) can be observed and filmed at right angles to the illuminated meridian plane, to record shape and speed in the meridian plane along the axis of the rotation and to record motions at right angles to the longitudinal axis.

Table 4 — Fluid-Physics Module performance characteristics

Reservoir volume	0–1300 cc (step 0.01 cc/s)
Disc separation	0–130.0 mm (step 0.1 mm)
End-plate diameter	Up to 100 mm (different shapes, sizes and materials)
Plate rotation speed	±5–±99.9 rpm (step 0.1 rpm), separate operation possible
Oscillations	0.1–2 Hz (step 0.01 Hz) 0–0.5 mm amplitude
Thermal capability	Ambient to 60°C (feeding end plate)
Electrical potential	±100 V DC at one end plate
Photographic recording	Two 16 mm cine cameras
Electrical power required	Maximum 360 W
Visualisation	By tracers



Experiments within the Fluid-Physics Module

ES 326: OSCILLATION OF SEMI-FREE LIQUID SPHERES IN SPACE
H. Rodot, Equipe TCC, CNRS, Meudon, France
The effects of vibrations on liquid spheres in contact with a solid surface, simulating crystal growth from a levitated liquid, will be studied. In addition, the damping effect of a dashpot on liquid oscillations and positioning will be studied.

ES 327: KINETICS OF THE SPREADING OF LIQUIDS ON SOLIDS
J.M. Haynes, School of Chemistry, University of Bristol, UK
The major phenomena of spreading of liquids on solid surfaces are to be studied. These are of fundamental interest for physico-chemical hydrodynamics and many technological processes.

ES 328: FREE CONVECTION IN LOW GRAVITY
L.G. Napolitano & R. Monti, Institute of Aerodynamics, University of Naples, Italy
In addition to studying the flow and temperature fields due to surface-tension-driven action induced by one or more disturbances (temperature gradient, electric field, disc rotation), the experiment will also examine the regimes of surface-driven flows (e.g. Stokes, Navier-Stokes, boundary layer).

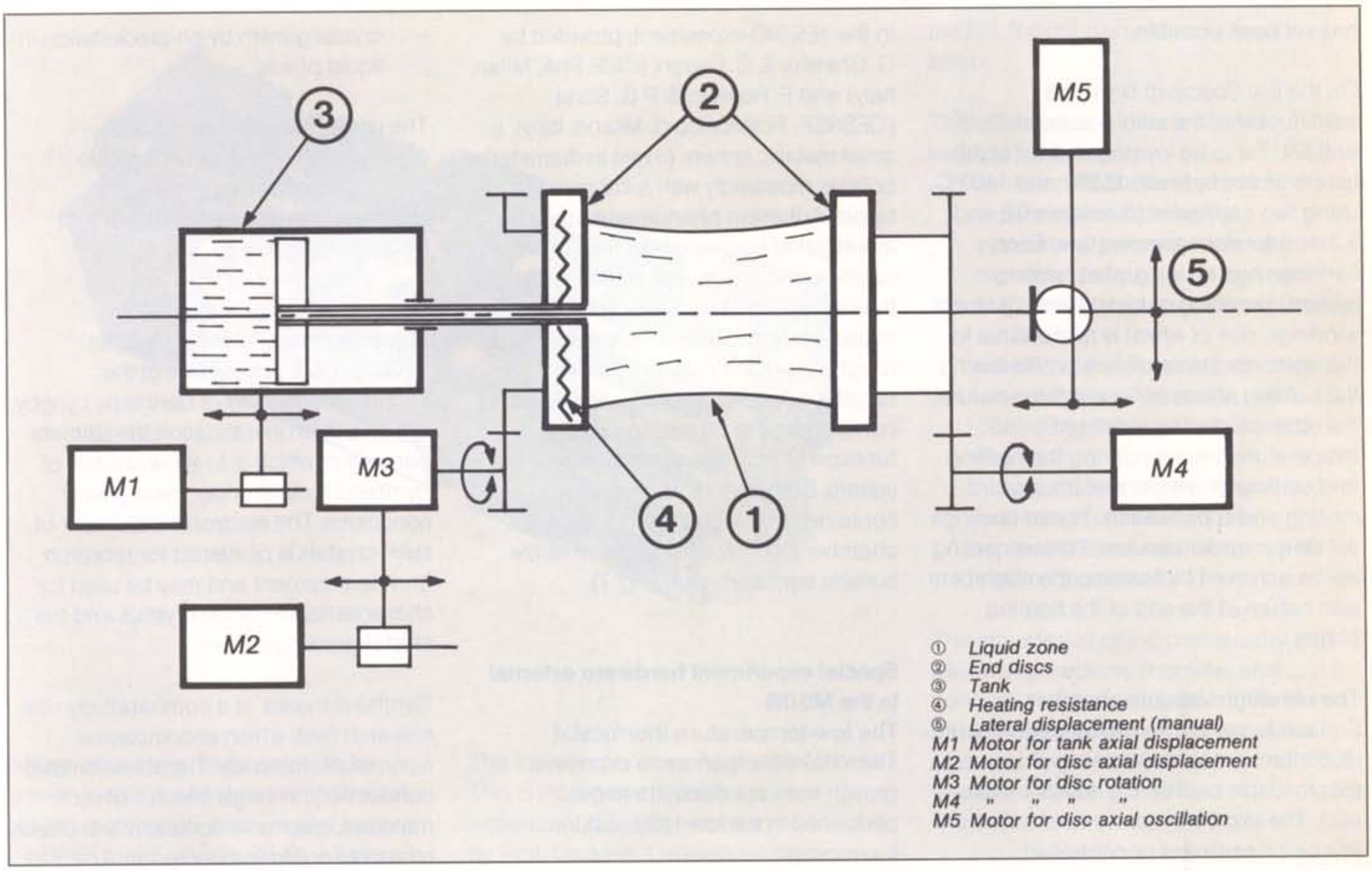
ES 329: CAPILLARY FORCES IN A LOW-GRAVITY ENVIRONMENT
J.F. Padday, Kodak Research Laboratory, Harrow, UK
The main goal is to identify and measure the strength of long-range intermolecular forces between solids and liquids in molecular contact.

ES 330: COUPLED MOTION OF LIQUID-SOLID SYSTEMS IN NEAR ZERO GRAVITY
J.P.B. Vreeburg, National Aerospace Laboratory (NLR), Amsterdam, The Netherlands
As part of a wider program to investigate liquid-solid momentum-transfer mechanics for spacecraft attitude-control purposes, liquid motions in partially filled containers are to be studied. The motions, generated by vibrating or rotating the containers, are strongly affected by capillary forces from the free surface.

ES 331: FLOATING-ZONE STABILITY IN ZERO GRAVITY
I. Da Riva, ETSI Aeronautics, Madrid, Spain
Stability limits can be examined by studying the fluid bridge between two equal discs, subjected to different mechanical perturbations (stretching, vibrating, rotation, etc.). This experiment has relevance for the floating-zone techniques used for crystal growth from the melt.

ES 339: INTERFACIAL INSTABILITY AND CAPILLARY HYSTERESIS
J.M. Haynes, School of Chemistry, University of Bristol, UK
The capillary behaviour of fluids in porous media is dominated by hysteresis phenomena originating from instabilities in the fluid's interfacial configuration. ES 339 will examine both interfacial instability effects and capillary hysteresis.

Figure 6 – The Fluid-Physics Module



Special experiment hardware within the MSDR

The cryostat

The cryostat experiment for protein crystal growth (ES 334), provided by W. Littke of the University of Freiburg, Germany, is designed to permit the growth of simple protein crystals from solution by diffusion. The absence of gravity-driven convection will provide improved growth conditions, avoiding multiple crystal germs which result in small crystals. Large single protein crystals will improve the possibility of X-ray structure analysis of enzyme-proteins.

Two different pairs of proteins are to be investigated: beta-galactosidase in an ammonium-sulphate solution and lysocyme in a sodium-chloride solution. Other parameters to be varied during the microgravity experiments are the contact area between the protein and the solution (0.7 and 0.07 cm²) and the process temperature. The overall processing time will be 60 h.

The hardware consists of a freezer housing a sample container which carries four different samples (two lysocyme and two galactosidase). This freezer is first cooled to − 10°C by Peltier elements, and the temperature is then increased to 20°C at 0.5°C/h. The stabiliser is held permanently at 20°C and houses the same number of samples with the same variations. To avoid proteins diffusing into the solutions before starting the experiment, a buffer slide divides the sample container into two separate chambers. A motor removes the buffer slide to permit contact between the two chambers.

The high-temperature thermostat

The experiment provided by H. Wever, G. Frohberg & K.H. Kraatz, of the Institut für Metallforschung, Technical University of Berlin (ES 335) is intended to investigate the selfdiffusion of the stable isotopes Sn^{112} and Sn^{124} in liquid tin under normal gravity and microgravity conditions.

There are different concepts to describe the mechanisms of selfdiffusion in liquid metals, but because of lack of measurement accuracy – due to the superposition of diffusion and gravity convection under normal gravity – no experimental validation of these theories

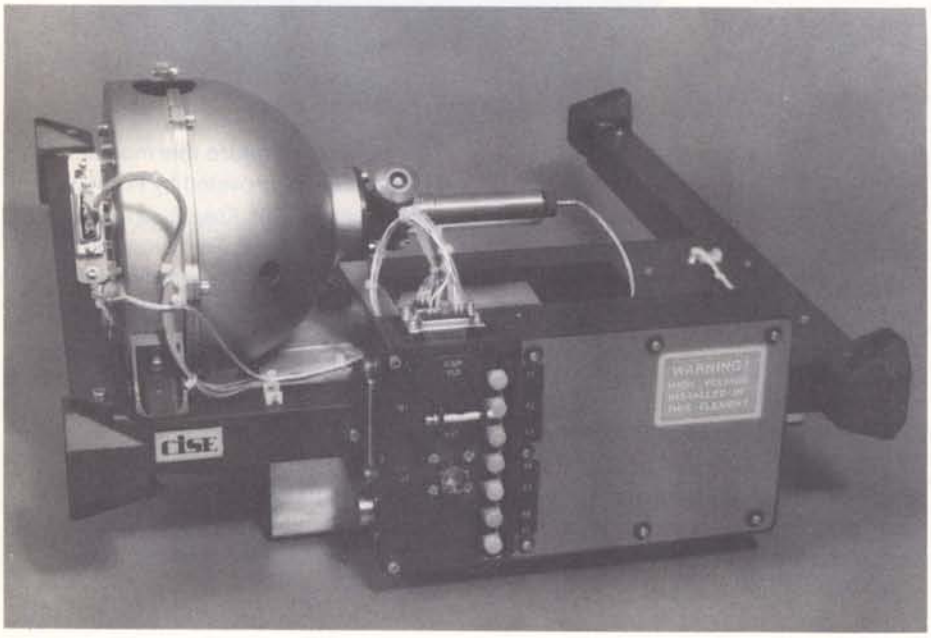


Figure 7 — The Ultrahigh-Vacuum Chamber

has yet been possible.

On the first Spacelab flight, the selfdiffusion of the stable isotopes Sn^{112} and SN^{124} is to be investigated for eight temperatures between 252°C and 1400°C, using two capillaries (diameters 0.8 and 3.2 mm) for each temperature. Each cartridge has an integrated heating system consisting of two different filament windings, one of which is responsible for the isothermal temperature profile during the holding phase (diffusion temperature), the other producing a defined temperature gradient during the heating and cooling phases to ensure upward melting and solidification. The annealings will be run under vacuum. Forced cooling will be achieved by flooding the chambers with helium at the end of the heating phase.

The ultrahigh-vacuum chamber

Surface forces play a fundamental role in all contact problems involving macroscopic bodies (e.g. friction, wear, etc.). The experimental study of adhesion involves cleanliness or controlled contamination of the surfaces, surface topography, and deformation properties. In the 1ES 340 experiment, provided by G. Ghersini & G. Grugni (CISE SpA, Milan, Italy) and F. Rossitto & P.G. Sona (CESNEF, Politecnico di Milano, Italy), a small metallic sphere (3 mm in diameter) collides repeatedly with a flat metallic target. Adhesion phenomena are to be investigated by measuring restitution coefficient, contact time, and evolution of the contact force as a function of the impact velocity of the sphere and surface roughness of the colliding bodies. The target is a force transducer, which allows contact force to be measured as a function of time during each impact of the sphere. Both sphere and target are contained in an ultrahigh-vacuum chamber (10^{-10} torr) to avoid possible surface contamination (Fig. 7).

Special experiment hardware external to the MSDR

The low-temperature thermostat

Two different experiments on crystal growth from solutions are to be performed in the low-temperature thermostat:

- organic crystal growth (from synthetic metals)
- crystal growth by co-precipitation in liquid phase.

The underlying principle of both experiments is to allow two soluble compounds diffusing in a central chamber to precipitate in the form of single crystals (Fig. 8).

Organic crystal growth (ES 332)
This experiment, from K.F. Nielsen, G. Galster & I. Johannsen, of the Technical University of Denmark, Lyngby, is a step in an investigation the ultimate purpose of which is to grow crystals of 'synthetic metals' under microgravity conditions. The electronic behaviour of such crystals is of interest for research and development and may be used for characterisation of the crystals and the crystal-growth process.

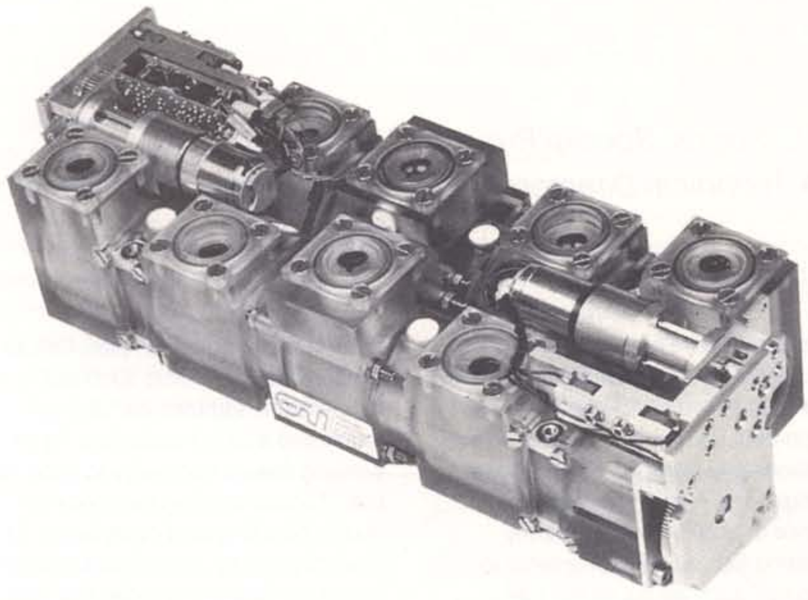
'Synthetic metals' is a comparatively new research field, which encompasses nonmetallic materials that show metallic conductivity. In single crystals of such materials, electronic conductivity is closely related to crystalline perfection. The crystals proposed for investigation are platinum complexes grown from acid-water solutions and charge-transfer salts grown from various organic solutions.

A process for solution crystal growth, i.e. co-precipitation in liquid phase by oppositely oriented diffusion, has been successfully demonstrated by experiment MA-028 (by M.D. Lind) on the Apollo-Soyuz mission.

A total of 12 experiments will be accommodated on Spacelab in three reactor assemblies. The temperature will be controlled to 40±0.1°C.

Crystal growth by coprecipitation in liquid phase (ES 333)
In the proposed experiment by A. Authier, F. Lefaucheux & M.C. Robert, of Laboratoire de Minéralogie Cristallographie, Université P. et M. Curie, Paris, crystals will be grown by co-precipitation from solution in a purely

Figure 8 – The reactor chamber for the crystal-growth from solution experiments (ES 332/333)



the FSLP flight per se are continuing apace.

These preparatory efforts consist essentially of:
- sample preparation by the experimenter, defining the operational parameters for the experiments by extensive ground (1 g) testing in ground-based facilities (at DFVLR);
- training of the Spacelab astronauts, who will play an essential role in controlling the Materials-Science Payload;
- integrated training for the astronauts and the ground-based user representatives according to well defined procedures.

The importance of the preparatory and training procedures (nominal and contingency) is underlined by the fact that the Materials-Science Payload will be operated for some 100 h of the total FSLP mission duration of 160 h.

diffusional system. The crystals to be grown – various phosphates of divalent cations, particularly calcium and lead ($PbHPO_4$ and $CaHPO_4 \cdot 2H_2O$) – have been chosen for their rapid growth (possible to obtain crystal platelets 1 cm across in a few days) and because their shapes allow X-ray topographic studies without any cutting.

Two solutions AB ($NH_4H_2PO_4$) and CD [$Ca(NO_3)_2$ or $Pb(NO_3)_2$] are contained in two compartments, separated by a third containing a neutral solution N. At the beginning of the experiment the first two compartments are put in communication with the third and solutions AB and CD are allowed to diffuse, the reaction being of the type:

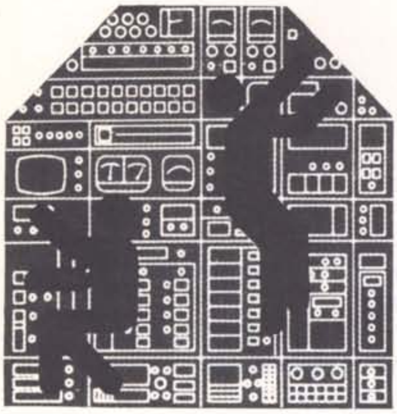
$$AB + CD \rightarrow \underset{\downarrow}{\underline{AC}} + BD$$

Temperature gradients and temperature fluctuations must be avoided, which is why the experiment cell is accommodated in the low-temperature thermostat, where the temperature will be maintained to ±0.1°C.

The low-temperature heat-pipe furnace
This crystal-growth from vapour experiment (ES 338) has been conceived by Prof. Cadoret, Laboratoire de Cristallographie et de Physique des Matériaux, Clermont-Ferrand, France, for the growth of mercuric iodide ($\alpha\,HgI_2$) crystals by physical vapour transport in a closed, vacuum-sealed ampoule. When introduced into the furnace, the growth ampoule provides two isothermal zones separated by a temperature gradient. The vapour is carried to the cold zone where crystallisation takes place. The instrument includes a copper/water heat pipe system, containing three growth ampoules.

This experiment is intended to provide deeper knowledge of the coupling between nucleation growth processes and vapour-transport processes. The absence of gravity-induced perturbations will provide much closer to ideal growth conditions (natural convection).

Flight preparations
Aside from the hardware development work for the experiment facilities, which is now being completed, preparations for



The Biorack Programme: A European contribution to space biology

A.F.L. Soons, Special Projects Division, ESA Technical Directorate, ESTEC, Noordwijk, The Netherlands

The Biorack project has recently been approved by Council as part of the Agency's Microgravity Programme. The Biorack is a multipurpose facility for performing biological investigations on such life forms as plants, tissues, cells, bacteria and insects. It will be used to determine the effects of zero-g and the space-radiation environment, and will carry facilities for: life support; environmental support; experiment-specimen handling, preservation and examination; and also for performing 1-g reference measurements while in orbit. Development work started formally in February 1982 and the aim is to fly the Biorack on the German Spacelab D-1 mission in 1985.

One of Spacelab's most interesting attribute's is the opportunity it offers for performing experiments in an environment unique compared with the conditions prevailing for Earth-bound investigations. The almost complete absence of gravity is a particularly interesting feature for experiments to investigate such issues as the role of gravity in the development and evolution of life, the study of human and animal physiology, fluid physics, crystal growth, etc. ESA's Microgravity Programme, which was formally started in February 1982 (see ESA Bulletin No. 30, p. 71), has exploration and promotion of the possibilities offered by this space environment as two of its major objectives. The Programme includes the development and flight of facilities for performing experiments in such scientific disciplines as biology, medicine, materials science and physics.

The Biorack (Fig. 1), one of the three main initial elements in the Microgravity Programme, is a multipurpose facility that will enable biological investigation of such life forms as plants, tissues, cells, bacteria and insects. Its main purpose is to investigate the effects of microgravity and cosmic radiation, particularly the high-energy (HZE) particles, on the development and behaviour of these species. To be able to discriminate between these two influences, the Biorack will also carry facilities for duplicating the same experiments under 1-g simulating conditions during the actual mission.

Two experiment incubators operating at different temperature levels and a cooling and freezing facility provide a controlled environment for the samples. Critical experiment parameters such as O_2, pH, temperature, turbidity, etc. can be monitored during incubation. A clean working area is necessary to minimise the risk of contaminating the specimen during handling and observation. The Biorack provides this protected working space by means of a glove-box system, in which filtered air is circulated. At the same time the glove box can act as a safety cabinet for unavoidable operations with small quantities of hazardous materials such as chemical fixatives. General-purpose facilities for microscopy and photography are also provided.

The development of the Biorack and the experiment coordination has been delegated to a small project group in the Special Projects Division within the ESA Technical Directorate. The facility is scheduled to fly for the first time on the German D-1 Spacelab mission, currently foreseen to take place in 1985.

Scientific objectives

All experiment proposals that ESA received following the Biorack Announcement of Opportunity were evaluated by a Scientist Peer Group for scientific merit and space relevance. ESA is now in the process of performing an accommodation study for those experiments that were shortlisted as high-priority candidates. Four major categories of candidate experiments can be distinguished:

(i) **Influence of the space environment on cell functions**

Cell proliferation

Experiments flown on Salyut-6 showed an

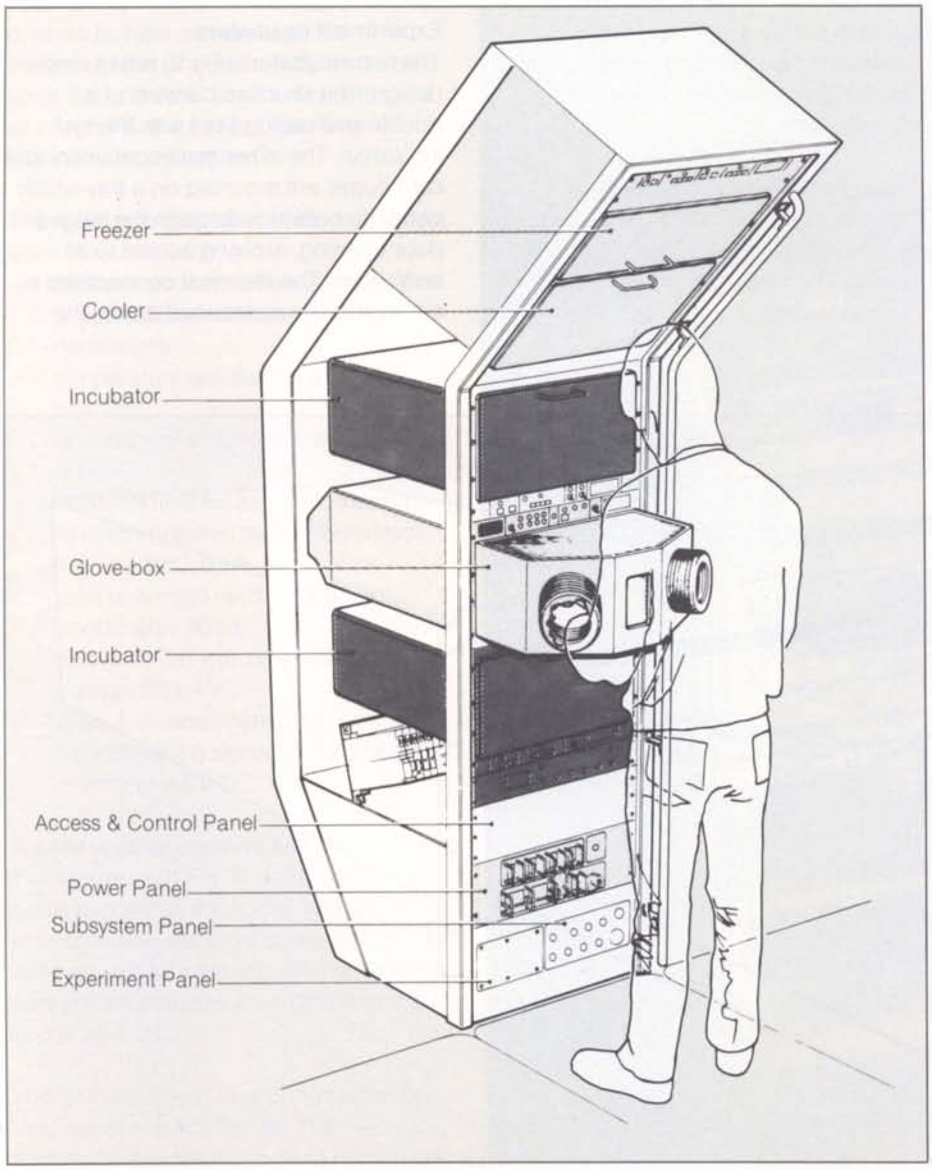


Figure 1 — General layout of the Biorack

increase in cell proliferation in paramecium cultures, but it is not known whether this has to be attributed to the influence of cosmic radiation or to weightlessness. The Biorack offers the opportunity to discriminate between these two influences.

On the other hand, observations of crew members on earlier spaceflights and laboratory tests suggest that human lymphocytes proliferate faster with increasing g-levels and that the process is slowed down under weightlessness. Because these cells are responsible for the immune response, this information is very important for longer manned spaceflights.

Cell resistance
Study of the effect of the space environment on the resistance of bacterial cells to antibiotics is proposed, which would permit progress in the medical treatment of infections. The use of antibiotics also allows the study of more fundamental cell physiological processes, because antibiotics act at different levels of the cell and as such can be considered as biological probes.

Cell polarity
The intra-nuclear organelles of cells are arranged in an orderly fashion. The effects of weightlessness on this cell polarisation may shed light on the roles played by these arrangements, and thereby on the influence of gravity on the evolution of life on Earth.

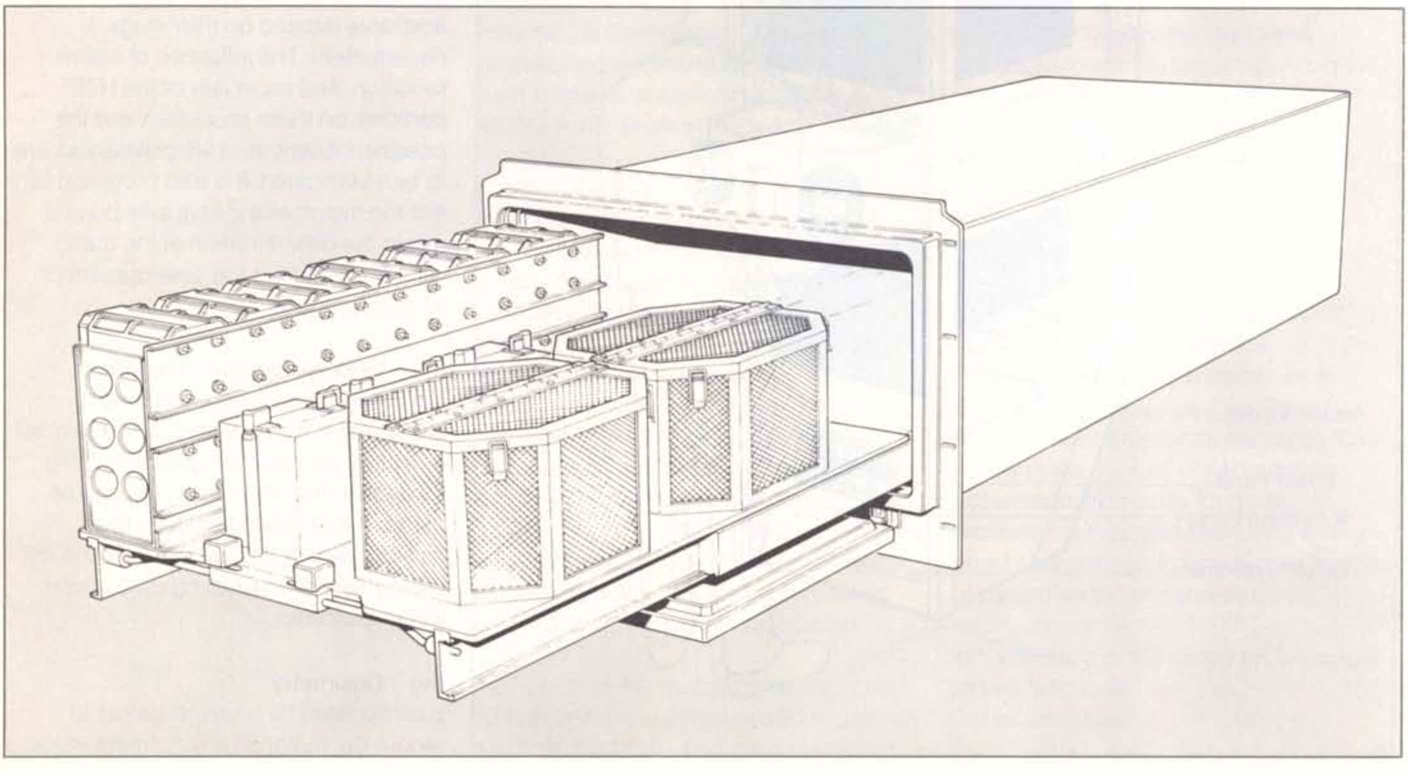
Circadian rhythm
It is still an open question whether an internal physiological clock drives the circadian rhythms in living organisms, or whether they are partly or wholly evoked by external time stimulii. Laboratory tests with a clinostat, which simulates weightlessness, indicate that the frequency of the rhythmic contractions and protoplasmic streaming in slime molds increases under low-gravity conditions.

(ii) Influence of the space environment on development
The sensitivity to radiation damage and the regeneration capability of insect eggs and larva depend on their stage of development. The influence of cosmic radiation, and especially of the HZE particles, on these processes and the possible influences of weightlessness are to be investigated. It is also proposed to test the hypothesis that gravity plays a role in the determination of the dorso-ventral axis during the development of amphibian eggs.

(iii) Gravity-perception research
It is thought that the sedimenting of starch-grain aggregations on certain cell receptors provides the gravity-sensing function in the cells of the root cap of plants. It is proposed to study the development of this cell polarity, and cell differentiation on seedling roots under weightlessness.

(iv) Dosimetry
It is important for all investigators to record the radiation environment inside

Figure 2 — Layout of an experiment incubator



the Biorack and to compare these data with those on other spaceflights and with theoretical predictions.

Several types of dosimeter are proposed for inclusion in the Biorack for this purpose. Present expectations are that experiments from approximately 10–15 different groups will have to be accommodated for the first Biorack mission.

The Biorack system configuration

The core element of the Biorack is a standard Spacelab single rack containing a number modular units (Fig. 1):

- a freezer/cooler combination unit in the inclined upper part of the rack; the freezer maintains a temperature of −15°C and is contained within the cooler, which maintains a temperature of +4°C;
- two incubators which can be set to a controlled temperature, one in the range 18–30°C, the other in the range 30–40°C;
- a glove box facilitating experiment handling and observation, including safe handling of toxic materials;
- standard Spacelab hardware facilities for electrical power distribution, data acquisition and rack cooling.

Experiment containers

Biological specimens will be contained in two types of experiment containers of standard design:

Type I – approx. 50 cc internal volume.
Type II – approx. 300 cc internal volume.

Both types of container will have transparent windows, electrical connectors, and other general-purpose interfaces required by the scientific investigators.

Gravity-simulating centrifuges

The two incubators will each be fitted with two centrifuges to simulate 1-g conditions in orbit. The main characteristics of these centrifuges are:

- diameter approx. 20 cm
- ability to hold eight type-I containers (type-II containers cannot be mounted on centrifuges)
- DC direct-drive torque motor with tachometer for velocity control
- slip-rings and harnesses to supply limited electrical power to experiment containers (electrical data transmission will not be provided from containers on the centrifuges)
- ±3% acceleration accuracy at centre of containers
- smooth acceleration and braking in about 5 seconds.

Experiment incubators

The two incubators (Fig. 2) are of similar design. The structure consists of a double-wall casing filled with thermal insulation. The experiment containers and centrifuges are mounted on a tray which can slide outwards through the hinged door opening, allowing access to all containers. The electrical connections to containers are maintained during the slide-out operation by virtue of an electrical harness roll-out drum mechanism mounted to the rear interior wall of the incubator. Data and electrical power connectors are supplied for a selected number of experiment containers.

The air inside the incubator is circulated by an internal fan system, which blows the air over a heat exchanger, the temperature of which is controlled by Peltier elements. On the opposite side, there is an external heat exchanger in the air stream of the Spacelab-avionics air cooling loop. The avionics loop provides or absorbs heat as necessary for incubator temperature control and it also cools the unit's electronics. The latter are all integral to the unit and allow its autonomous operation.

The main characteristics of the incubators are:
- ability to accommodate 24 type-I and 3 type-II experiment containers and 2 centrifuges
- temperature gradient of air inside unit: 2°C
- accuracy of air temperature control: ±0.5°C
- transient time for air inside incubator to reach nominal temperature from 10°C or 30°C: 0.5 h
- total unit mass (excl. experiment containers): 30 kg
- Spacelab DC bus power-supply voltage: 28±4 V
- output of experiment and housekeeping signals to Spacelab interface: ±5 V DC

Freezer/cooler combination
The freezer unit (Fig. 3) is physically contained within the cooler unit, to economise on electrical power and on the need for avionics cooling air. The freezer controls temperature at −15°C and the cooler at +4°C.

The air inside the cooler is circulated by fans, as for the incubators. The temperature of the experiment containers inside the freezer is controlled, however, by direct conductive coupling to a thick internal metal wall. Both the freezer and cooler use the Peltier effect for internal temperature control. Heat extracted from the freezer is absorbed by the circulating air stream in the cooler and the heat from the cooler is in turn rejected into the Spacelab avionics air cooling loop.

The cooler has a similar sliding-tray arrangement to the incubator. The freezer has only a fixed stowage rack for the experiment containers. The cooler and freezer have no centrifuges and neither can supply power or collect data from the experiment containers. As for the incubator, the power, control and housekeeping electronics are designed for autonomous operation.

The main characteristics of the unit are:
- the cooler can accommodate 18 type-I and 3 type-II experiment containers
- the freezer can accommodate 9

Figure 3 — Breadboard model of the cooler/freezer unit

type-I experiment containers
- temperature gradients, accuracy and stability same as for the incubators
- transient time to reach nominal control temperatures from 30°C start environment: 2.5 h
- total unit mass (excl. experiment containers): 40 kg
- Spacelab power and data interfaces same as for incubators.

Glove box
The glove box should minimise the risk of contamination of sensitive biological cultures and specimens by maintaining at least a class 100 cleanliness level in the working area, where experiments are handled and observed, microscopy takes place, and photographs are taken. This is achieved by continuously circulating the air in a closed loop over a particle/bacteriological/active charcoal filter system.

The layout of this air circulation system is such that a negative pressure differential is maintained in the working area with respect to the Spacelab Module cabin pressure. This gives the glove box the features of a safety cabinet in which small quantities of hazardous materials, such as chemical fixatives for biological samples, can be handled without any risk of contaminating Spacelab's atmosphere in the event of an accidental spillage.

The negative pressure differential is continuously monitored and maintained, even in the event of a major leak between the working area and Spacelab. A fall-back mode of open-loop circulation is automatically activated if the negative pressure differential falls below the preset threshold. The fan of the glove box has adequate capacity in the open loop mode to prevent air from leaking (e.g. via a ruptured glove) from the working area directly into the Spacelab cabin. Instead, the air is forced to pass first through the filter system before flowing back into the cabin. In this way, even in the unlikely event of an accidental spillage, there is no danger to the crew.

In addition to the functions described above, the glove box system will also provide general-purpose facilities for microscopy, photography and the monitoring of similar critical experiment parameters to those sensed in the incubators.

Mission sequence
The performing of biological experiments onboard Spacelab involves:
- preparation of experiment specimens in a ground-based laboratory near the launch site shortly before launch;
- latest possible (6–12 h before launch) transport to and storage in lockers on the mid-deck of the Shuttle Orbiter. The specimens are stored in passive thermal-control canisters on the mid-deck because no electrical power will be available on the D-1 mission for active thermal control on that deck and because the Spacelab Biorack area will not be accessible so close to launch;
- transfer of specimens to the Biorack as soon as possible during the in-orbit phase, once the Biorack has been activated and temperatures have stabilised;
- perform experiment operations at pre-determined intervals throughout the 6-day in-orbit phase;
- return specimens to passive thermal-control canisters on the Shuttle Orbiter's mid-deck immediately prior to the start of the landing phase;
- remove experiments shortly after landing for post-flight experiment observation and evaluation.

It is obvious from this mission summary that it is as important to maintain a controlled temperature environment during launch and landing by passive means as it is during the in-orbit experimental phase when the Biorack's incubators and the cooler/freezer combination are in operation. Sensitive biological material would otherwise not survive the full mission, from preparation on the ground until receipt for further treatment and examination after landing.

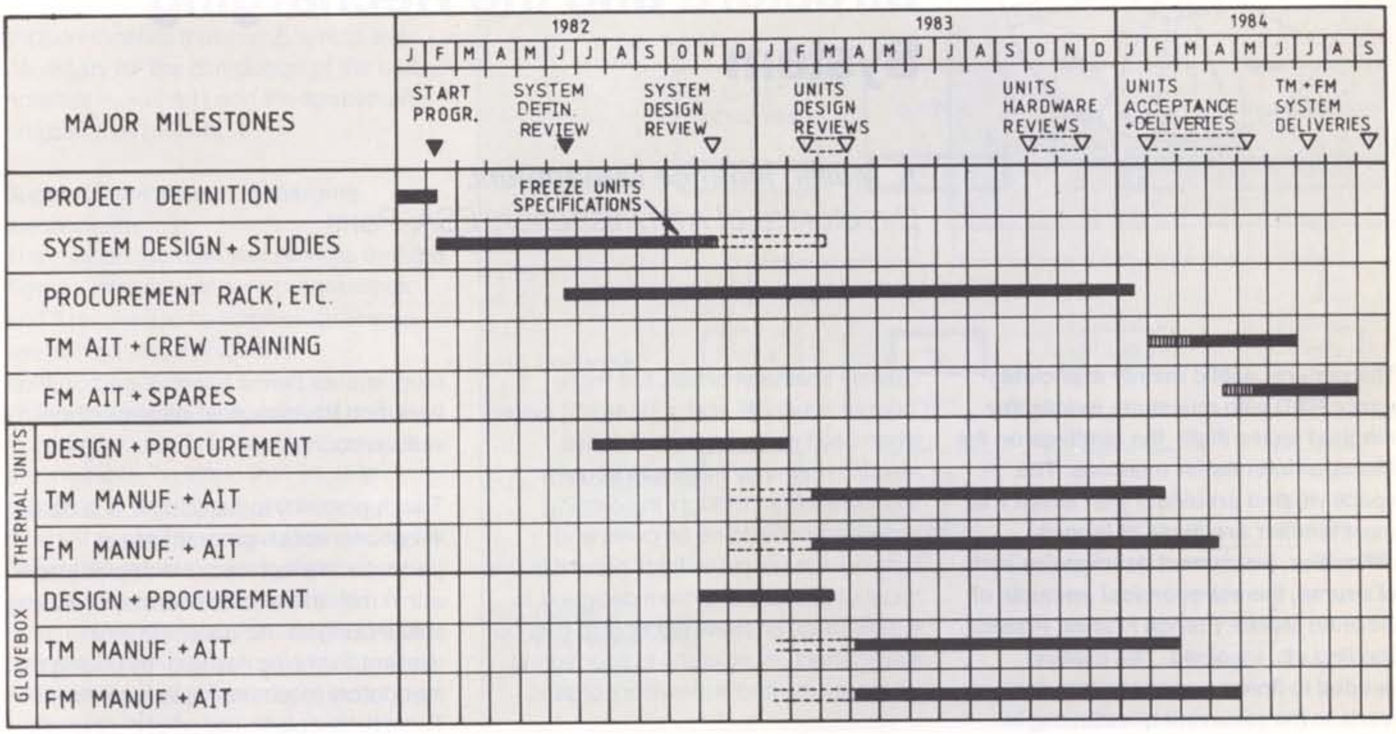
Passive thermal-control canisters
The passive canisters (two per Orb8ter mid-deck stowage locker) are highly insulated containers equipped with exchangeable thermal capacitor cells. The latter control temperature via the principle of latent heat of phase change of materials. Four different materials will be supplied for the first mission to maintain controlled temperatures to within ±2° of −15°C, +4°C, +22°C and +37°C inside the canisters. These temperatures will have to be kept constant for at least 12 d in an environment in which the ambient temperature may be 18°C to 27°C. The extra heat losses incurred in opening the canisters to remove and insert experiment containers have also to be catered for.

Development programme (Fig. 4)
It is planned to place several contracts with industry and institutes to procure the necessary hardware and services. These will include:
- design, development and production of thermal-conditioning units, including centrifuges and experiment containers, and also passive thermal-control canisters for the Orbiter mid-deck stowage;
- design, development and production of the glove box, including experiment handling and observation facilities;
- procurement of a standard Spacelab single rack;
- supply of mission-peculiar hardware and consultancy.

The hardware will be required in two models: a Crew Training Model (TM) and a Flight Model (FM). It is envisaged that the two will be made to the same flight standard, so that TM hardware may serve as spares for the FM. The hardware will be required to be delivered with sufficient spares, ground-support equipment and documentation to support the first mission.

The overall Biorack development schedule is summarised in Figure 4. The

Figure 4 – Summary programme schedule



programme will be carried out in two main phases:

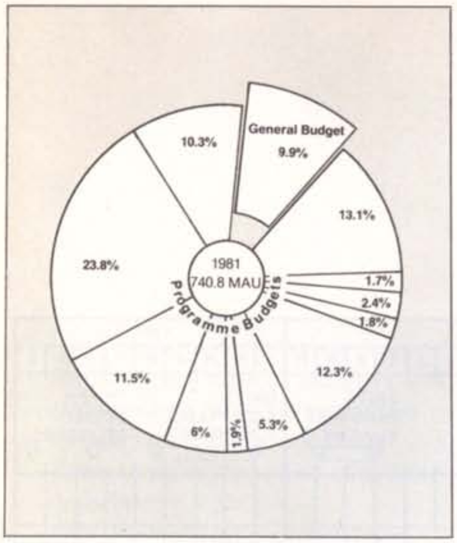
- a design phase (Phase-B) including breadboard testing and procurement of long-lead items;
- a development and production phase (Phase-C/D), including test verification of all deliverable hardware.

It is envisaged that the release for manufacture of the TM and FM will be issued virtually at the same time, i.e. complete verification test results for the TM are not required prior to release for FM manufacture. A significant level of breadboard testing of critical design features is expected in Phase-B and early in Phase-C/D to minimise technical risks to the programme.

It is expected that all parties involved in the Biorack development programme will also be required to support operation of their hardware, such as crew training, Biorack system integration, Spacelab payload integration and the Spacelab flight itself.

Acknowledgement

The Biorack programme is the result of a collaborative effort by several parties involved directly and indirectly in the project. The cooperation of and inputs provided by the experimenter groups, the Spacelab D-1 team at DFVLR, and the ESA staff are gratefully acknowledged.



The Agency's New Budget Structure and the Recharging System

A. Müller, Finance Department, Directorate of Administration, ESA, Paris

The general public mainly associates space R&D with milestone events like manned space flight, the landings on the Moon, or interstellar missions. The space-related problems with which it is most familiar are those of launch difficulties, instrument deficiencies and, of course, the astronomical amounts of German Marks, French Francs, Pounds Sterling etc. involved. The money needed to finance space enterprises leads to the recurrent questioning in newspapers and magazines as to where the money comes from, whether the purposes of its spending are achieved, and whether the investments are made sufficiently cautiously and parsimoniously.

Outside specialist circles, the terms 'budget structure' and 'recharging system' when used in the context of space research certainly meet with some scepticism even though, in soliciting answers to questions on costs and funding, the tax payer finds himself in the midst of a financial system designed to supply these answers not only to him, but also in much more detail to sponsoring governments and supervisory organs.

In the ESA context, the 'Budget structure' can be simply defined as the financial system that determines the way in which the costs incurred in the completion of Europe's space programmes are to be estimated, accounted for, and financed. The term 'Recharging system' is subordinate to the term 'Budget structure' and defines the way in which the costs of common support facilities and services are to be calculated and invoiced to users.

The budget structure in ESA – The aspirations and temptations

Programme orientation and budget structure

The Convention of the European Space Agency defines two categories of space programme: the mandatory activities embodying a scientific and a basic activity programme, and optional programmes aiming at the realisation of further satellite and space transportation systems. The mandatory activities – as the term indicates – require the financial participation of all Member States on a compulsory, pro-rata basis linked to national income. The optional programmes permit financial participation based on the individual interests of the various countries.

The opportunity to participate 'à la carte' in optional space programmes of particular interest leads Member States – within their more or less constant national space budgets – to maximise their relevant financing capacity by limiting the mandatory requirements to essentials. The different participation of countries in optional programmes brought a need for increased precision in the costing of each of these programmes – notably in the apportionment of the common costs – to align costs and funding as closely as possible with the technological interests of each State. A relatively accurate, and hence complex, system of cost identification and allocation therefore evolved. This, has, however, proved difficult to match with another basic requirement, namely the contrasting need to keep the budgetary and accounting systems simple and readily understandable. The reform of the budget structure is therefore aimed at attaining the right balance in the medium term between these extremes for a rapidly evolving and increasingly ambitious space programme.

The previous ESA budget structure, 1976–1982

The ESA budget structure during the years 1976–1982 is reflected in Figure 1.

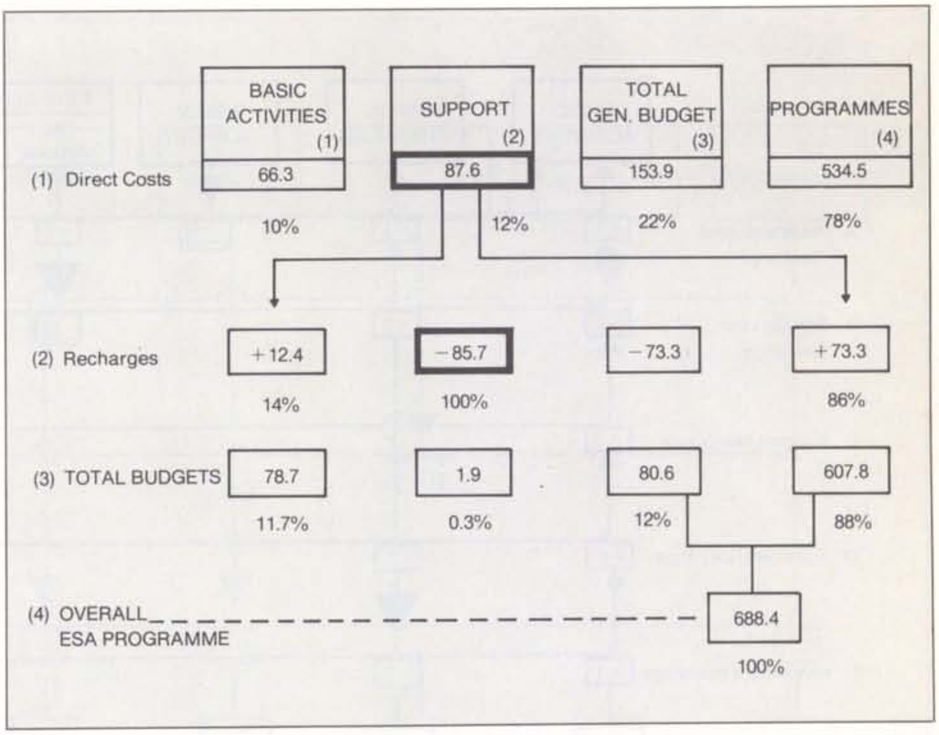
It can be seen from this figure that 88 MAU, or 12%, of the Agency's annual budget is currently devoted to the maintenance and operation of common support facilities (column 2), which are necessary for the completion of the basic activities (column 1) and the spacecraft programmes (column 4).

Support services and recharging mechanisms

The support facilities and services that the Agency affords to its own programmes, and if required to national programmes, are summarised in Figure 2.

Within these main categories, 50 major individual support facilities and services are available. To attain the requisite precision in invoicing customers, some 50 different prices (or usage rates) had to be developed, each including direct costs and various overhead elements for common, administrative and site-service support, distributed across a multitude of cost centres. A highly sophisticated recharging mechanism had to be designed and set into operation, as reflected in Figure 3.

Figure 1 – The Agency's budgetary structure for 1982



The new system – A return to simplicity and clarity

The need for reform

A considerable effort was made in earlier years to achieve realistic recharging for common support facilities, by applying appropriate, industrially proven, accounting methods. In the end, this could only be achieved at the price of a relatively complex and esoteric system which, in the attempt to reconcile a multitude of interests, became less and less transparent and was understandable in detail only to a few specialists. In the light of this evolution, the Agency decided that ability to supply clear evidence of costs and fund utilisation justified renouncing the existing, extremely sophisticated, costing methods. This

Figure 2 – Main categories of ESA support services and annual budgets (Admin. support and ESTEC, ESOC & ESRIN support)

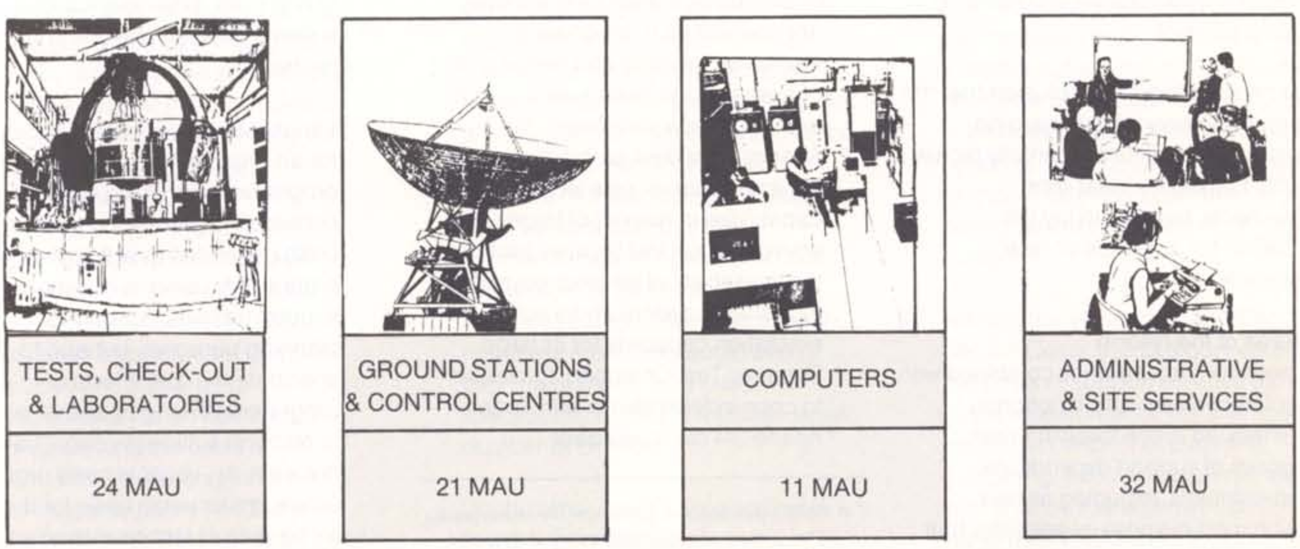
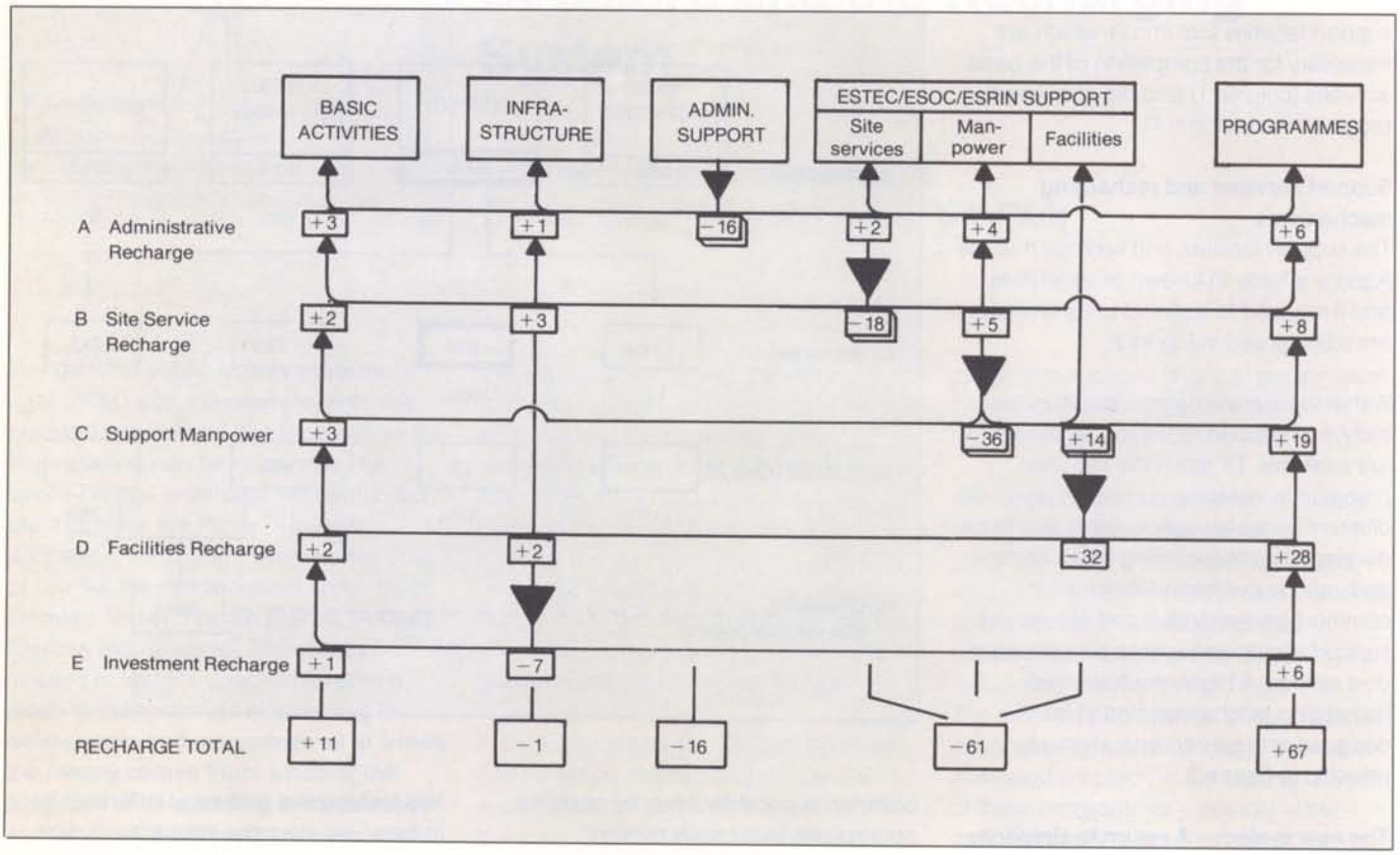


Figure 3 — The superceded budgetary structure, with its 'cross-recharging', excluding special-to-project costs (Figures in MAU)



thinking received further impetus from specific campaigns directed towards limiting and reducing the internal and running costs of the Agency, in order to channel as much of the Member States' contributions as possible into research and development.

It was hence a logical conclusion that the existing budgetary and recharging systems should be fundamentally recast not only to meet the near-term requirements, but also to lay the foundation for a decade of new programmes.

Features of the reform

The need for transparency combined with ease of application and functional usefulness led to the following new categories of support expenditure:

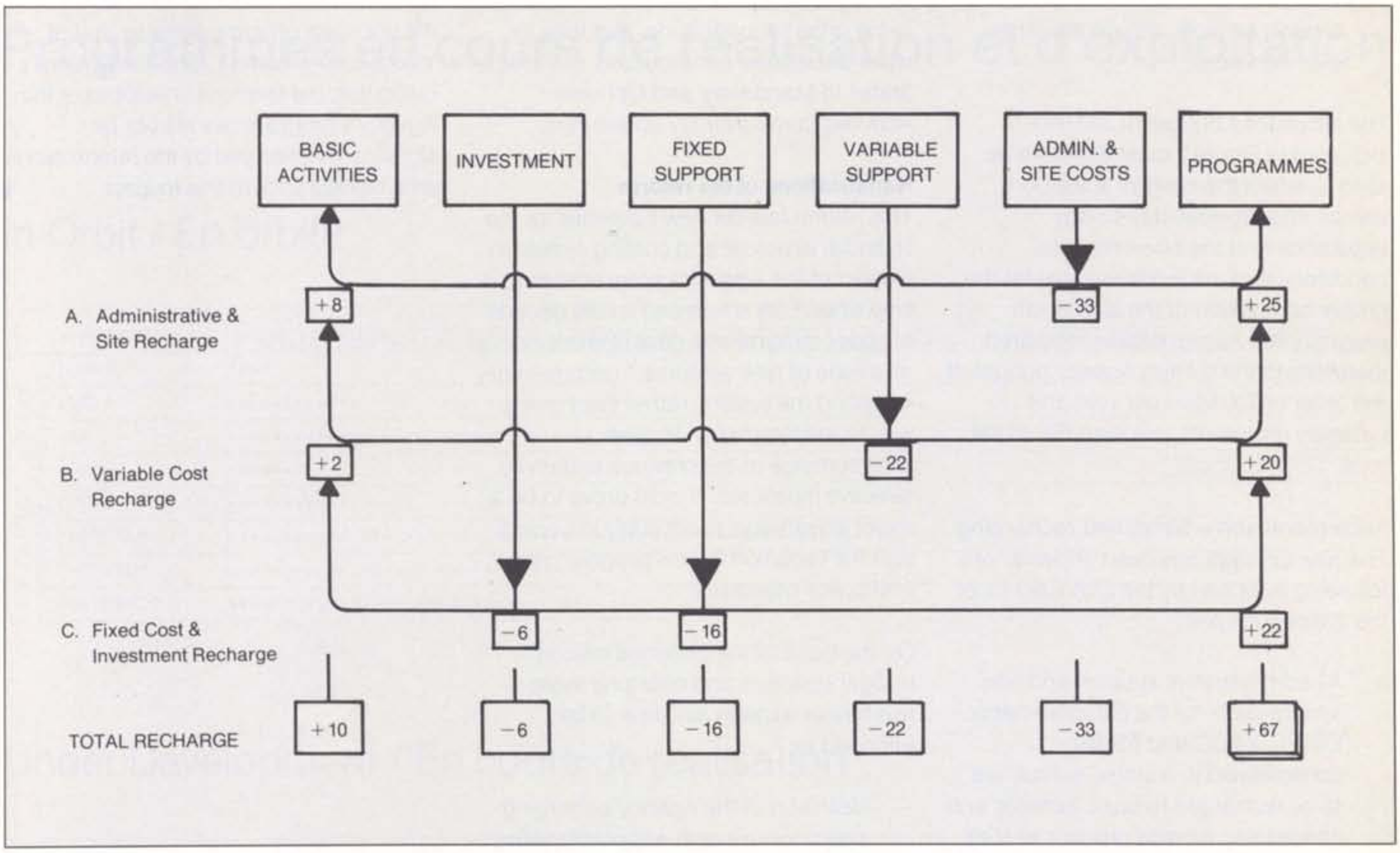
a. Investments: including all new common-purpose investments that extend the Agency's technical capability for supporting space programmes. These are clearly identified and shown in a distinct output*. Investments necessary for the upkeep of existing capacities, and of a relatively steady level annually, are considered to be closer to maintenance costs and hence a part of fixed support costs (see (c)). In the domain of new investment, the Agency considers as indispensable the acquisition of new technical capabilities in respect of large environmental test facilities (notably the availability of an electrodynamic multishaker system and a solar-simulation capability for its large Dynamic Test Chamber), to be able to cope independently with large Ariane-3/4 class payloads.

Furthermore, the general ground-station network capability has had to be increased through the installation of an S-band system, the upgrading of VHF-facilities and the introduction of improved data-communication systems between stations and control centres.

b. Variable Support Costs: it is important for an organisation that manages programmes involving various contributing groups to identify the costs generated directly by each programme using its common-support facilities, not only for planning purposes, but also to anticipate the cost effects of programme changes, and to be able to respond sufficiently soon. Last but not least, the variable costs provide a simple, measurable basis for the recharging of technical overheads. To this end the new Variable Support

* A main organisational unit under the responsibility of a Directorate, normally embracing several cost centres (laboratories, facilities, etc.)

Figure 4 – Streamlining effect of the new budgetary structure (cf. Fig. 3)



Costs output will identify all costs in respect of support manpower, test facilities, laboratories, computers and ground stations where a direct link can be established between the user's demand for support and the costs generated by the support service provided. The annual volume of these costs is, in consequence, subject to variations following the workload contracted by programmes.

c. Fixed Support Costs: these are essentially the costs required to maintain the support facilities described above (under 'Support services and recharging mechanisms') in an operational condition, and the costs of maintaining the managerial and intellectual capacity needed to ensure the viability and relevance of future project support.

Understandably, in an organisation developing space projects, a highly sophisticated infrastructure, with laboratories, test facilities, computers and a ground-station network, is indispensable, and the need to maintain them in an operational condition is largely unaffected by short-term variations in workload. As a consequence, the proportion of the fixed cost element in the cost structure of these facilities is relatively high, i.e. about 65% of the maintenance and operation costs. Since some of these facilities are unique in Europe, their operational readiness must be ensured even if they are currently only used sporadically and by a relatively small number of projects.

On the other hand it is conceivable that the fixed-costs sector, which in future will be clearly identified, could represent a preferred target for cost-reduction campaigns, not only because of its significant cost volume offering, at least at first sight, a vast hunting ground, but also because cost reductions achieved on a substantiated basis will tend to be of a lasting nature, given the recurrent character of the cost items embodied in this category. In other words, the notion of 'fixed costs' is not intended to imply that these costs are permanent in their magnitude or content.

d. Administrative Support and Site Service Costs: this category embodies the costs of support services provided to the research activities and space projects in respect of planning, budgeting, accounting, personnel and finance management on the one hand (Administration), and in respect of site installations, accommodation, security services, etc. on the other (Site Services).

The associated budget of 32 MAU indicated in Figure 2 must therefore be seen to reflect the costs of a support service that provides day-to-day assistance and the environmental conditions that are indispensable for the proper completion of the spacecraft programmes. Appropriately compared, therefore, to the current Agency budget of the order of 700 MAU per year, this category represents less than 5% of the total.

Implementation – Simplified recharging

The new concept has been implemented, following adoption by the ESA Council of the following Rules*:

a. All administrative support and site-service costs for the Establishments – ESTEC, ESOC and ESRIN – consolidated in a single output, are to be recharged to basic activites and space programmes pro-rata to staff costs.
b. The variable costs are to be recharged to those basic activities and programmes that have generated them.
c. The fixed costs, assembled in a single output for the whole Agency, are to be recharged 50% pro-rata to the variable cost allocation (viz. b).
d. 50% of new investments are to be recharged – as fixed costs – on the basis of b.

These measures have provided a major streamlining effect as far as the mechanism for recharging support costs to programmes using support facilities is concerned, as shown in Figure 4. At the same time it has been possible to keep the volume of the General Budget, and of the Mandatory Activities overall, at the same order of magnitude, and thus to leave the relative contributions of Member States to Mandatory and Optional Activities comparatively undisturbed.

Ramifications of the reform

This reform has set new baselines for the financial structure and costing system in respect of the Agency's programmes at a time when ESA is entering a new decade of space-programme development, with a multitude of new ventures. Fundamentally recasting the system, rather than giving way to the temptation to cure shortcomings of the previous system by selective measures, should prove to be a major advantage, particularly in coping with the evolution in new programmes and policy objectives.

On the basis of the reformed internal budget structure and charging system, two further aspects still have to be attended to:

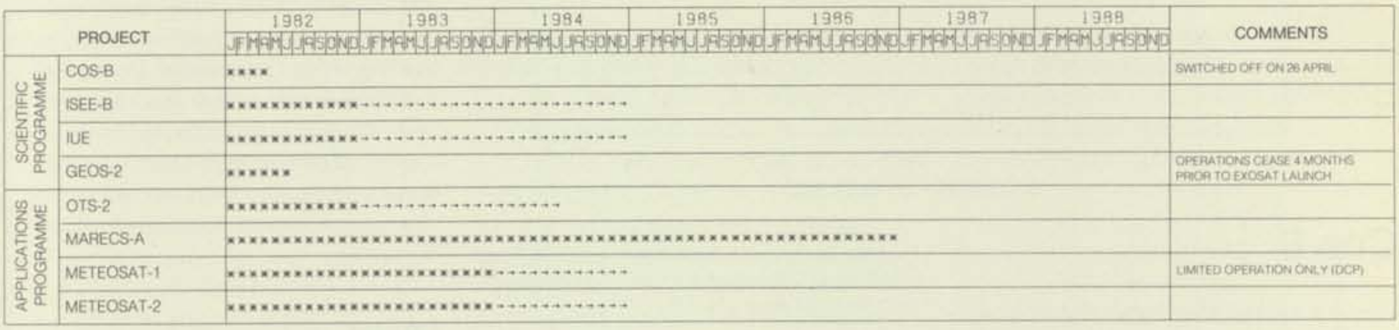
- definition of the Agency's charging policy for use of its support facilities and services by non-ESA projects such as national satellite projects or those developed independently by industry, in both Member States and non-Member States;
- definition of a charging policy for the development and supply of space systems to user communities (operational activities).

The aim of the reform has been to alleviate the budgetary and recharging problems that were essentially those of an international organisation whose budgeting and accounting system derived from national rules of many origins and required adaptation to the Agency's multinational space missions. Costing methods, cost reporting systems and financial schemes are, as we all know, an integral part of contractual arrangements, and underlie commitments or declarations of intent in many forms. Major changes in these areas can, quite naturally, therefore, be a source of apprehension. For the Agency, however, the iron-cast principle remains that of 'pacta sunt servanda', and the Council's ruling that the financial envelopes of the Agency's programmes will not be significantly changed by the reform serves as a reassurance in this respect.

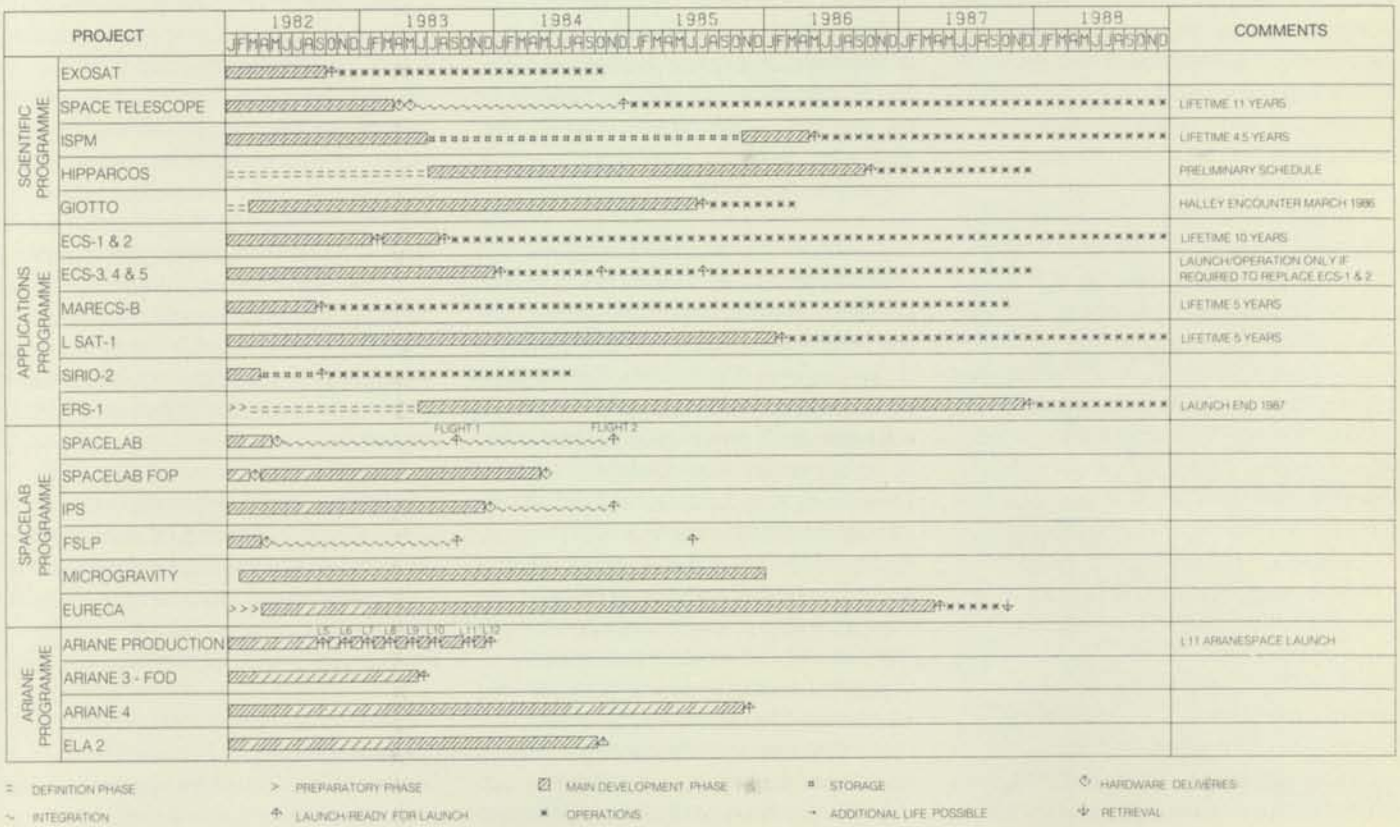
* ESA/C/L/Resolution 3, adopted at the 50th ESA Council meeting.

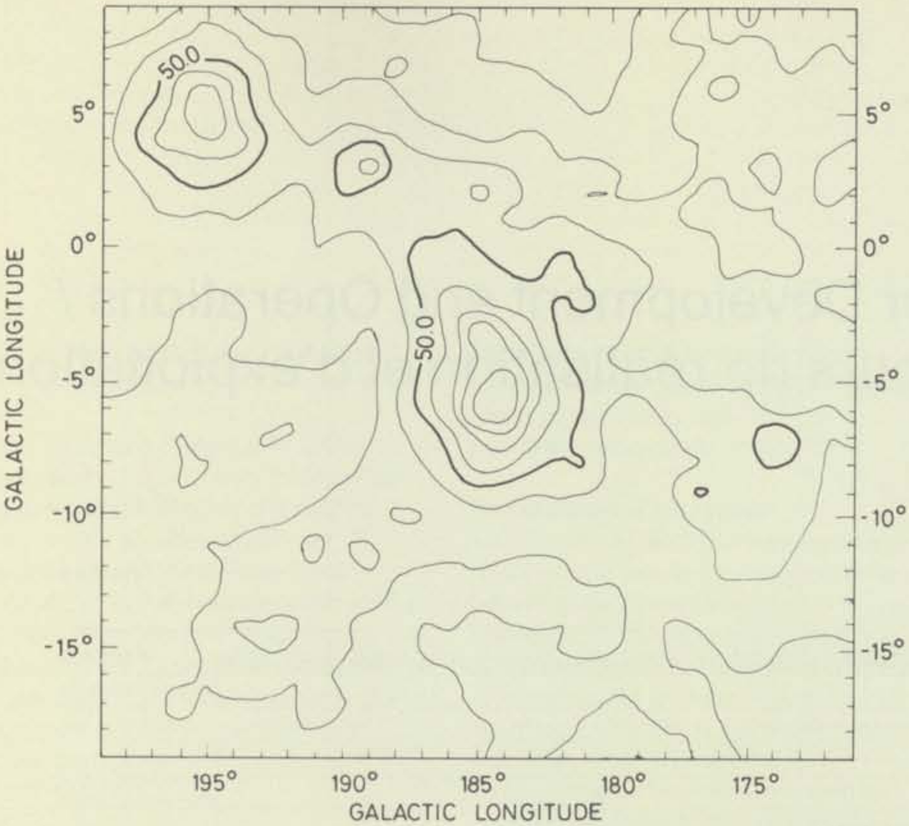
Programmes under Development and Operations / Programmes en cours de réalisation et d'exploitation

In Orbit / En orbite



Under Development / En cours de réalisation





Gamma-ray map of Galactic Anticentre derived from Cos-B data (Crab pulsar at longitude 185°/latitude −5°; Geminga source at 195°/+4°).

Relevé de rayonnement gamma de l'Anticentre galactique dérivé des données de Cos-B (pulsar du Crabe à 185° de longitude et −5° de latitude; source Geminga à 195°/+4°).

Cos-B

Cos-B a achevé sa mission scientifique, comme prévu, dans les premières heures du 26 avril 1982, environ six ans et huit mois après son lancement le 9 août 1975. (voir page 115 de ce Bulletin)

L'objectif de la 64ème et dernière observation était la région de l'anticentre, comprenant à la fois les sources de rayonnement gamma de la nébuleuse du Crabe et de Geminga (CG195+4). Les preuves des variations en fonction du temps de la courbe d'intensité du rayonnement gamma du Crabe, qui apparaissent dans les données de Cos-B, vont être publiées par Wills et al (dans Nature, *sous presse). Cette dernière et longue observation du Crabe (environ 67 jours) prend donc une extrême importance. En dépit du rendement réduit du détecteur par suite d'une légère détérioration de la chambre à étincelles, la Collaboration Caravane espère obtenir, pour cette observation, une courbe d'une excellente précision statistique. En fait, la Collaboration Caravane a pu se convaincre des bonnes performances de Cos-B en examinant les images de la chambre à étincelles présentées en temps réel à l'ESOC quelques jours seulement avant l'arrêt définitif. L'un des points d'interrogation posés par les dernières données est l'effet inconnu de la commutation de l'horloge pendant les arrêts d'alimentation électrique au cours des récentes éclipses. Ce problème est à l'étude à l'ESOC car on a besoin d'une solution afin de pouvoir apporter les corrections de temps requises pour parvenir à la qualité de temps qu'exigent les études du pulsar associé à la nébuleuse du Crabe.*

Les données fournies par la longue observation du Cygne, qui s'est achevée en février (et qui équivaut en durée à trois des premières observations de Cos-B), doivent encore être fournies. Ces données sont attendues avec impatience par les astronomes du rayonnement gamma et du rayonnement X qui font partie de la Collaboration. X-3 du Cygne a été visible pendant toute cette période par le synchroniseur de pulsar à rayonnement X qui fait partie de l'expérience embarquée à bord de Cos-B. Cette observation fournira des données qui permettront d'étudier l'évolution de la périodicité de 4,8 heures, avec une précision sans précédent. Les données sur le rayonnement gamma elles-mêmes fourniront la base de données nécessaire à des recherches sur les variations en fonction du temps des sources de rayons gamma dans la région du Cygne. Le recoupement avec des données antérieures peut apparaître problématique car on ne dispose que de données d'une précision réduite sur l'orientation, pour la plus grande partie des deux dernières observations.

Il convient de noter qu'à la suite de la prolongation de la mission, les statistiques des observations combinées de la source CG 195+4 permettent en principe de tracer une case d'erreur plus petite que celle de l'orientation limite du satellite, qui est au mieux la valeur spécifiée de ±0,5°. C'est donc avec intérêt que la Collaboration Caravane attend le résultat des études technologiques entreprises avec Cos-B au cours de la semaine qui a suivi l'arrêt de l'expérience. On espère que les mesures avec le sous-système de commande d'orientation de Cos-B fourniront des renseignements sur les erreurs systématiques qui entachent la détermination de la direction de pointage du satellite.

ISEE-2

Le satellite ISEE-2 fonctionne toujours bien, quatre ans et demi après son lancement. Il reste encore 2,6 kg d'ergol pour modifier la distance qui le sépare d'ISEE-1. La situation de la charge utile n'a pas changé depuis le dernier rapport et sept expériences continuent de fournir des données utiles. L'activité scientifique est toujours très intense. De nombreux ateliers se sont réunis et de nouveaux symposiums sont prévus en juin et en octobre de cette année. Les études sur la magnétosphère ont largement tiré profit de l'atelier CDAW-6, au cours duquel des données provenant simultanément de Geos-2 et d'ISEE-1, 2 & 3 ont été introduites dans un calculateur et mises à la disposition des scientifiques sur leur demande.

La plus grande partie des dépenses de poursuite des satellites sont supportées par la NASA qui envisage actuellement de prolonger l'exploitation des trois véhicules ISEE, certainement en 1983 et probablement en 1984 et 1985.

L'intérêt de poursuivre l'acquisition des données s'est accru à la suite de l'annonce d'une manoeuvre que la NASA envisage de faire opérer à ISEE-3. Ce

Cos-B

Cos-B ended its scientific mission, as planned, in the early hours of 26 April 1982, about six years and eight months after its launch on 9 August 1975 (see page 115 of this Bulletin).

The target for the 64th and last observation was the Anticentre region, taking in both the Crab and Geminga (CG+195+4) gamma-ray sources. Evidence for time variability in the gamma-ray light curve of the Crab in the Cos-B data is now being published by Wills et al. (1982, Nature, in press). This makes this final, long observation of the Crab (about 67 days) extremely important. Despite the reduced efficiency of the detector due to slight deterioration of the spark chamber, the Caravane Collaboration expect to obtain a light curve for this observation with extremely good statistical precision. In fact, the Caravane Collaboration were able to reassure themselves of the satisfactory performance of Cos-B by examining spark-chamber pictures presented in real time at ESOC only days before the final switch-off. One question mark that surrounds the final data is the unknown effect of clock switching during power losses during recent eclipses. This problem is under study at ESOC and a solution is needed so that the required timing corrections can be made to yield the time quality necessary for the Crab pulsar studies.

Data from the long Cygnus observation which finished in February (equivalent in length to three of the early Cos-B observations) is still to be delivered. The data is eagerly awaited by both gamma-ray and X-ray astronomers within the Collaboration. Cygnus X-3 was visible throughout the period to the X-ray pulsar-synchroniser experiment onboard Cos-B. This observation will yield data that allow studies of the evolution of 4.8 h periodicity to be made with unprecedented precision. The gamma-ray data themselves will provide the data base for a search for time variability of gamma-ray sources in the Cygnus region. Overlapping of the data with previous data may prove problematic since only reduced-accuracy attitude data are available for the larger part of the last two observations.

It is noteworthy that, as a result of the extended mission, the statistics of the combined observations of the source CG195+4 in principle allow an error box to be drawn smaller than the limiting attitude of the spacecraft, specified to be ±0.5° at best. It is with interest, therefore, that the Caravane Collaboration look to the outcome of the technological studies undertaken with Cos-B during the week following the switch-off of the experiment. It is hoped that measurements with the attitude-control subsystem will provide some information about systematic errors in the spacecraft pointing determination.

ISEE-2

The ISEE-2 spacecraft is still operating well 4.5 years after launch and 2.6 kg of propellant is still available for changing the separation distance between ISEE-1 and ISEE-2. The status of the payload has not changed since the last report and seven experiments are still providing useful data. Scientific activity is still very intense. Many workshops have been held and further symposia are being planned for June and October this year. Magnetospheric studies have gained much from the CDAW-6 Workshop, where simultaneous Geos-2 and ISEE-1, 2 and 3 data were computer processed and made available on request to scientists.

Most of the tracking expenses are borne by NASA, which is currently planning to continue ISEE-1, 2 and 3 operations through 1983, and probably throughout 1984 and 1985.

Interest in continuing data acquisition has been increased following the announcement of an ISEE-3 manoeuvre now being considered by NASA. ISEE-3, which is presently orbiting around the first Lagrangian point $\simeq 250\ R_E$ upstream from the Earth in the solar wind, would move into the distant geomagnetic tail to take up station at the second Lagrangian point. This move would occur possibly in spring 1983, when both ISEE-1 and 2 will simultaneously be exploring the near-geomagnetic tail. This manoeuvre should provide us with a first insight into the possibilities for the Open mission. NASA is also exploring the possibility of sending ISEE-3 to a comet (possibly Giacobini-Zinner) after the geomagnetic-tail exploration. The cometary encounter would occur in autumn 1985.

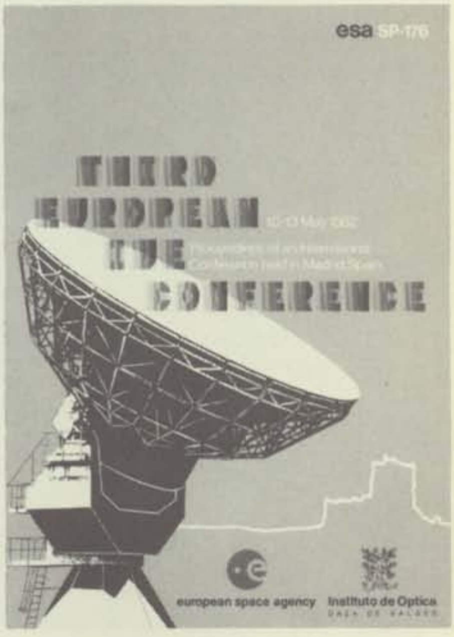
IUE

The fifth year of IUE observations has just started: 162 programmes accepted by the joint ESA-SERC Allocation Committee have been successfully scheduled up to mid-April 1983. A change worth noting in this year's schedule is the disappearance of the alternation of the ESA and SERC programmes, this change resulting from the new agreement between the two Agencies. The SERC Resident Astronomer is also now fully integrated into the Observatory Team.

A new version of the image-processing software has recently been installed at Vilspa. The major change concerns the extraction of high dispersion spectra.

With the planned launch window for Exosat of November 1982, some simultaneous or coordinated IUE-Exosat observations have already been provisionally scheduled for March-April 1983.

The Third European IUE Conference took place in Madrid from 10–13 May. Ten invited reviews and more than 110 contributed papers assessed the impact of four years of successful IUE operations in the different fields of astrophysics. This meeting was also an excellent opportunity for the European community active in the field to discuss future space astronomical programmes. The Proceedings of the Conference are being published by ESA Scientific and Technical Publications Branch (ESA SP-176).



dernier, qui orbite actuellement autour du premier point de Lagrange à environ 250 R_E en amont de la Terre dans le vent solaire, pénétrerait dans la partie éloignée de la queue de la magnétosphère pour être mis à poste au deuxième point de Lagrange. L'opération aurait probablement lieu au printemps de 1983, période au cours de laquelle ISEE-1 et ISEE-2 exploreront simultanément la partie proche de la queue de la magnétosphère. Cette manoeuvre nous fournirait une première indication sur les possibilités offertes par les missions 'libres'. La NASA étudie également la possibilité d'envoyer ISEE-3 en direction d'une comète (probablement Giacobini-Zinner) après l'exploration de la queue de la magnétosphère. La rencontre avec la comète aurait lieu à l'automne de 1985.

IUE

La cinquième année d'observation d'IUE vient juste de commencer. 162 programmes acceptés par le Comité d'attribution conjoint ESA-SERC ont été inscrits au calendrier des observations jusqu'à la mi-avril 1983. Un changement qu'il convient de noter dans le calendrier de cette année est la suppression de l'alternance entre les programmes de l'ESA et du SERC, qui résulte du nouvel accord conclu entre les deux organismes. L'astronome résident (RA) du SERC est en outre devenu membre à part entière de l'équipe d'observation.

Une nouvelle version du logiciel de traitement des images a été installée récemment à Vilspa. La modification principale concerne l'extraction des spectres de grande dispersion.

Etant donné le créneau de lancement envisagé pour Exosat (novembre 1982), certaines observations simultanées ou coordonnées IUE-Exosat ont déjà été inscrites provisoirement au calendrier pour mars-avril 1983.

La troisième Conférence internationale d'IUE a eu lieu à Madrid du 10 au 13 mai. Dix exposés sur invitation et plus de 110 communications attestent de l'impact de quatre années d'exploitation fructueuse d'IUE sur les différents domaines de l'astrophysique. Cette réunion a également offert une excellente occasion à la communauté européenne active dans ce domaine d'étudier des programmes futurs d'astronomie spatiale. Les actes de cette conférence sont en cours de publication par les soins du Service des publications scientifiques et techniques de l'ESA.

Geos-2

La situation du satellite et son régime d'exploitation n'ont pas changé depuis le dernier rapport. Six des sept expériences continuent de fonctionner et l'acquisition des données est assurée au cours des heures de nuit à l'exception de trois jours par mois pendant lesquels on a une couverture continue de 24 heures.

Au cours de la période février-mars, le fonctionnement des spectromètres de masse à bord de Geos-2, ISEE-1, Dynamic Explorer, Scatha et Arcad-3 a été coordonné, de sorte que l'on a pu acquérir des données à haute résolution sur la composition du plasma, simultanément dans différentes régions de la magnétosphère: aux hautes latitudes, sur l'orbite des satellites géostationnaires et dans la queue de la magnétosphère.

L'orbite du satellite Dynamic Explorer a entre-temps évolué, de sorte qu'il balaye le bourrelet de la plasmasphère, en latitude, tandis que Geos-2 est en mesure de fournir des informations sur l'étendue longitudinale de cette région. Afin de pouvoir entreprendre une étude conjointe sur le comportement tridimensionnel du bourrelet, il a été nécessaire de décaler la tranche d'exploitation de Geos-2, des heures de nuit aux heures de l'après-midi/début de soirée. Cette opération a eu lieu et la modification est entrée en vigueur le 15 mai.

Malheureusement, l'installation d'Eiscat n'a pas été en mesure de fonctionner pendant une partie importante de la période couverte par le présent rapport et l'exploitation conjointe de Geos-2 et d'Eiscat n'est pas encore passée au stade de la routine. Les chercheurs déplorent le très court chevauchement opérationnel réalisable entre la période actuelle et la fin de l'exploitation de Geos présentement fixée au 30 juin.

Les données de Geos continuent de fournir la base à de nombreuses publications. En fait, près de 200 publications ont eu lieu dans des journaux très connus et dans les actes, largement diffusés, des conférences. Des documents de synthèse intéressants sur des sujets tels que la composition, les paramètres du plasma froid et la morphologie des ondes, ont paru récemment, ainsi que toute une série d'articles portant sur des aspects spéciaux des interactions ondes/particules (ondes harmoniques gyromagnétiques des ions ou des électrons).

OTS

Alors qu'il entre dans sa cinquième année d'exploitation, OTS continue de bien fonctionner et ses ressources en matière d'ergols, d'énergie électrique et de régulation thermique apparaissent comme suffisantes pour au moins deux années d'exploitation supplémentaires. La souplesse offerte par un degré élevé de redondance et des modes de fonctionnement de remplacement ont permis à OTS de continuer à répondre de façon satisfaisante à tous objectifs de mission pendant au moins quatre ans. Ceci confirme la validité des concepts sur lesquels OTS reposait, lesquels ont été, dans une grande mesure, incorporés dans la série suivante de satellites d'ECS et Marecs.

L'utilisation des moyens de télécommunications offerts par OTS a continué de s'étendre dans certains domaines. Des expériences de transmission de données et des expériences de vidéophonie ont pris une partie de plus en plus grande du temps du satellite. Ce dernier est toujours utilisé pour des transmissions régulières du programme de télévision français d'Antenne 2 à destination de la Tunisie, et des émissions régulières des programmes de la télévision britannique ont maintenant lieu à destination de Malte, de la Finlande et de la Norvège. Ces signaux de télévision sont cependant chiffrés pour répondre aux impératifs des administrations des PTT visant à empêcher leur réception sans autorisation. En outre, des essais de transmission entre 15 pays (de studio à studio) de signaux de télévision comprenant des signaux sonores en plusieurs langues ainsi que des sous-titres en plusieurs langues, entre lesquels un choix peut être fait, ont eu lieu sous les auspices de l'Union européenne de Radiodiffusion.

Parmi les démonstrations de télévision les plus connues, on peut citer la visite du Pape au Royaume-Uni, au cours de

Geos-2

The status of the spacecraft and the operational scheme is unchanged since the last report. Six of seven experiments are still functioning and data are acquired during night-time hours, with the exception of three days per month when 24 h continuous coverage is obtained.

In the period February/March, the operation of mass-spectrometers on Geos-2, ISEE-1, DE, Scatha and Arcad-3 was coordinated so that high-resolution plasma-composition data were acquired simultaneously in different regimes of the magnetosphere: at high latitudes, in geostationary orbit, and the geomagnetic tail.

The orbit of the DE spacecraft has in the meantime evolved so that it scans the plasmaspheric bulge in latitude, while Geos-2 is able to provide information on the longitudinal extent of this region. In order to undertake a joint study on the three-dimensional behaviour of the bulge, it was necessary to shift the Geos operational interval from the night-time hours to the afternoon/early evening hours. This was done on 15 May.

Unfortunately, the Eiscat facility was unable to operate for a significant part of the reporting period and joint operations by Geos-2 and Eiscat have not yet been routinely conducted. The community regrets the very limited operational overlap which can be achieved between now and the end of the currently agreed termination of Geos operations (30 June).

Geos data continue to be the basis for numerous publications. Valuable survey papers on topics such as composition, cold-plasma parameters and wave morphology have recently appeared, as well as whole series of papers dealing with special aspects of wave/particle interactions (ion or electron-cyclotron harmonic waves).

OTS

As it enters its fifth year of operations OTS continues to operate well, with adequate fuel, power, and thermal control capability remaining for at least another two years of operation. The flexibility provided by the presence of a high degree of redundancy and of alternative system operating modes has allowed OTS to continue to satisfy all its mission objectives over the last four years. This performance has validated the design concepts upon which OTS was based, and which have been incorporated to a large extent into the subsequent ECS and Marecs spacecraft series.

OTS's communications capacity has continued to increase in some areas. Data experiments and Videophone experiments have increased in their requirements for satellite time. The satellite is still used for regular TV broadcasting to Tunisia of French Antenne-2 programmes, and regular TV broadcasts of British TV programme material are now made to Malta, Finland and Norway. These television signals are, however, coded to satisfy the PTT administrations' requirements for prevention of unauthorised reception. In addition, test transmissions between 15 countries (studio-to-studio) of television signals employing selectable multiple language sound signals and selectable multiple language subtitle information, have been made under the auspices of the European Broadcasting Union.

Une image de l'Europe prise récemment par Météosat dans le canal visible à 11.55 TU.

Recent Meteosat image of Europe taken in the visible band at 11.55 UT.

Among the most publicised of TV demonstrations, the Pope's visit to UK, for which TV signals were relayed to national TV networks from Canterbury and Edinburgh via OTS, is worthy of note.

OTS was also used in a similar mode to provide a TV link from the Versailles Summit Conference to the world's TV networks.

Eutelsat has requested availability of the satellite until at least mid-1983 (date of the ECS-1 launch). Furthermore, there are currently plans for additional earth stations for data-transmission experiments, in at least the UK and Germany, which would require use of OTS beyond mid-1983.

Meteosat

Space segment

A number of anomalies were experienced by Meteosat-2 in mid-March. The malfunctions caused the radiometer mechanism to stop during retrace. As a precautionary measure, a reduced mode of operation was initiated with image taking only once every 3 h instead of the standard half-hourly cycle. As no further anomalies had been recorded by the end *laquelle les signaux de télévision ont été relayés de Cantorbéry et d'Edimbourg sur les réseaux de télévision nationaux via OTS.*

OTS a également été utilisé de façon similaire pour assurer la liaison de télévision entre Versailles, où avait lieu la Conférence au sommet, et les réseaux mondiaux de télévision.

Eutelsat a demandé à disposer d'OTS au moins jusqu'à la mi-1983 (date du lancement d'ECS-1). En outre, on prévoit dans les plans actuels d'utiliser de nouvelles stations terriennes pour des expériences de transmission de données, au moins au Royaume-Uni et en Allemagne, ce qui impliquerait l'utilisation d'OTS au-delà de la mi-1983.

Météosat

Secteur spatial

Météosat-2 a présenté un certain nombre d'anomalies à la mi-mars, des défauts de fonctionnement arrêtant le mécanisme de balayage du radiomètre pendant le retour à la position de départ. A titre de précaution, on a opéré en mode réduit avec prise d'images toutes les trois heures au lieu de toutes les demi-heures. Aucune anomalie n'ayant été enregistrée après la fin du mois de mars, on est repassé progressivement au mode de fonctionnement automatique normal et celui-ci s'est retrouvé rétabli le 6 mai. Il a été maintenu ainsi depuis, sans que l'on enregistre de nouvelles anomalies dans la fonction de balayage. La qualité des images n'a pas été affectée.

Météosat-1 continue d'assurer la mission de collecte de données (DCP). Au cours de la période d'équinoxe, l'orientation a été modifiée pour éviter que le système d'alimentation en hydrazine n'ait à subir les effets de cycles thermiques excessifs.

Secteur sol

La mini-configuration du calculateur a été déconnectée et le système fonctionne désormais en utilisant la configuration 'définitive'. L'essentiel du logiciel a été converti selon une norme qui permet d'extraire et de diffuser automatiquement tous les produits météorologiques. Ceux-ci comprennent: température de la surface de la mer, jeu de données climatologiques, néphanalyse, humidité de la troposphère, altitude du sommet des nuages, et vecteurs vent.

Bien que la qualité des produits soit généralement satisfaisante, des améliorations dans certains domaines sont encore souhaitables; elles seront introduites dans les mois qui viennent.

Avec le rétablissement de la prise d'images normale toutes les demi-heures, la disponibilité de service du système a atteint 95%.

Le service de collecte de données assuré par Météosat-1 continue d'intéresser environ 25 plates-formes sur des emplacements aussi éloignés que le Groenland et l'Antarctique.

Programme opérationnel

Comme certains Etats membres n'ont pas encore pris de décision quant à leur participation, la Conférence intergouvernementale prévue n'a pas encore pu être réunie.

Télescope spatial

Réseau solaire

Tous les essais de réalisation/qualification d'une aile du réseau solaire se sont achevés de façon satisfaisante.

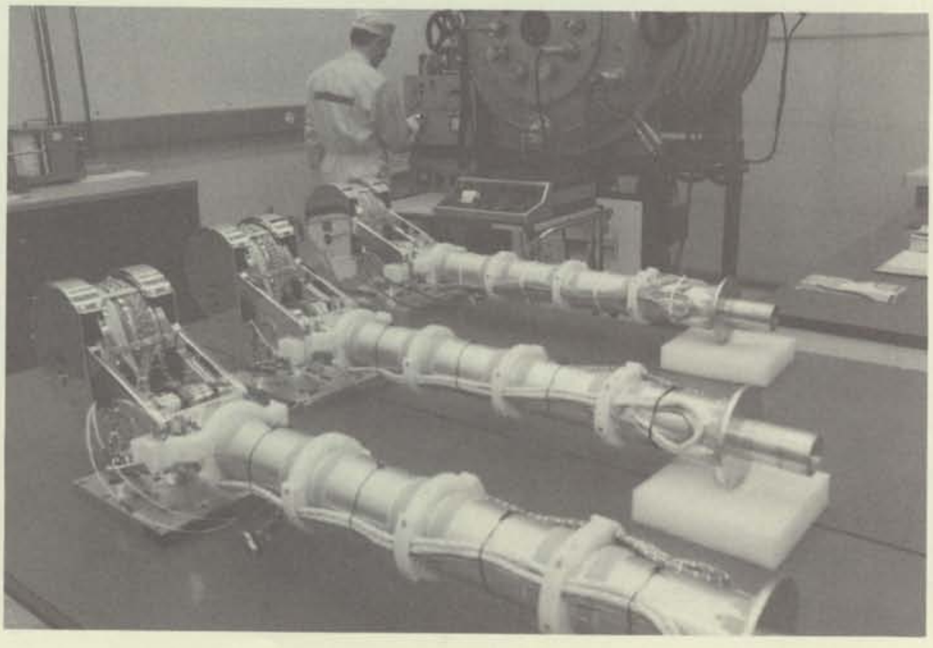
Les préparatifs concernant l'assemblage du matériel de vol progressent correctement dans la plupart des domaines. Le matériel de vol a été livré pour le mécanisme de déploiement primaire, l'adaptateur d'entraînement du réseau solaire et les nappes aux normes de vol. Tous les éléments de l'exemplaire de vol du mécanisme de déploiement secondaire sont disponibles, à l'exception des cassettes bi-stem, pour lesquelles il reste encore à effectuer des investigations et à procéder aux essais de recette.

Un certain nombre d'essais et de simulations supplémentaires ont été effectués au sujet des performances de l'entraînement du réseau solaire. On a réduit le couple du câblage souple et procédé à des mesures de couple à basse température. Plusieurs modifications de l'électronique d'entraînement du réseau solaire ont été mises en oeuvre. La répétition de l'essai dynamique du système avec l'entraînement modifié est prévue pour août 1982.

Le premier essai de qualification de cinq échantillons de nappes, sur 30 000 cycles thermiques entre − 100 et + 100°C s'est achevé avec succès. Le deuxième essai devrait démarrer en juin.

Chambre pour astres faibles

L'intégration du modèle de vol de la FOC avec tout le matériel de vol du module chambre et le modèle structure/thermique du détecteur de photons s'est achevée. Le premier essai thermique sous vide de ce modèle, en vue de qualifier le système de régulation thermique active, a été



Space Telescope solar-array primary deployment mechanisms (two flight models and one spare) prior to thermal vacuum testing at Contraves.

Les mécanismes de déploiement du réseau solaire du Télescope spatial (deux modèles de vol et un rechange) avant les essais thermiques sous vide chez Contraves.

of March, operations were gradually stepped up and were returned to the normal automatic mode on 6 May. This mode has been maintained since, with no further anomalies recorded in the scanning function. Image quality has not been affected.

Meteosat-1 continues to support the DCP (Data Collection Platform) mission. During the equinox period, the satellite's attitude was adjusted to prevent thermal cycling in the hydrazine systems.

Ground segment

The computer mini-configuration has been disconnected and the system is now running in its final form. The bulk of the software has been converted to a standard that enables all meteorological products to be extracted and disseminated operationally. This includes sea-surface temperatures, climate data sets, cloud analysis, upper-troposphere humidity, cloud-top height, and wind vectors.

Although product quality is generally satisfactory, improvements in some areas are still desirable and will be introduced within the next few months.

With normal, half-hourly imaging resumed, service availability of the system has reached 95%.

The data-collection service provided by Meteosat-1 continues to support some 25 platforms, located as far apart as Greenland and Antarctica.

Operational programme

As some Member States have still not decided on their participation, the Intergovernmental Conference has not yet been reconvened.

Space Telescope

Solar array

All tests with the development/ qualification solar-array wing have been completed satisfactorily.

Preparations for flight-hardware assembly are proceeding well in most areas. Flight equipment has been delivered for the primary deployment mechanism, the solar-array adaptor, and flight blankets. All elements for the flight secondary-deployment mechanism are available, with the exception of the bi-stem cassettes, for which further investigations and acceptance testing remain to be conducted.

A number of additional tests and simulations have been carried out to study the solar-array drives' performance. The torques of the flexible wire harness have been reduced, and torques have been measured at low temperatures. Several modifications to the solar-array-drive electronics are being implemented. A repetition of the dynamic system test with the modified solar-array drive is foreseen for August 1982.

The first thermal-cycling qualification tests on five blanket samples, over 30 000 cycles from −100°C to +100°C, have been completed successfully. The second test run is scheduled to start in June 1982.

Faint-Object Camera

Integration of the FOC flight model, comprising all Camera Module flight hardware and the structural/thermal model of the Photon Detector Assembly, has been completed. The first thermal vacuum test for this model, aimed at qualifying the active thermal control system, has been carried out. Several areas require further investigation. Power consumption to maintain the chosen thermal conditions in the optical bench enclosure appeared to be somewhat too high, and the measurements of the image stability of the f/96 optical chain showed some unexpected, and as yet unexplained results.

Photon Detector Assembly

Tests to verify electrical and software interfaces have been carried out with the Camera Module electronics bay assembly and the Photon Detector Assembly engineering model, with satisfactory results.

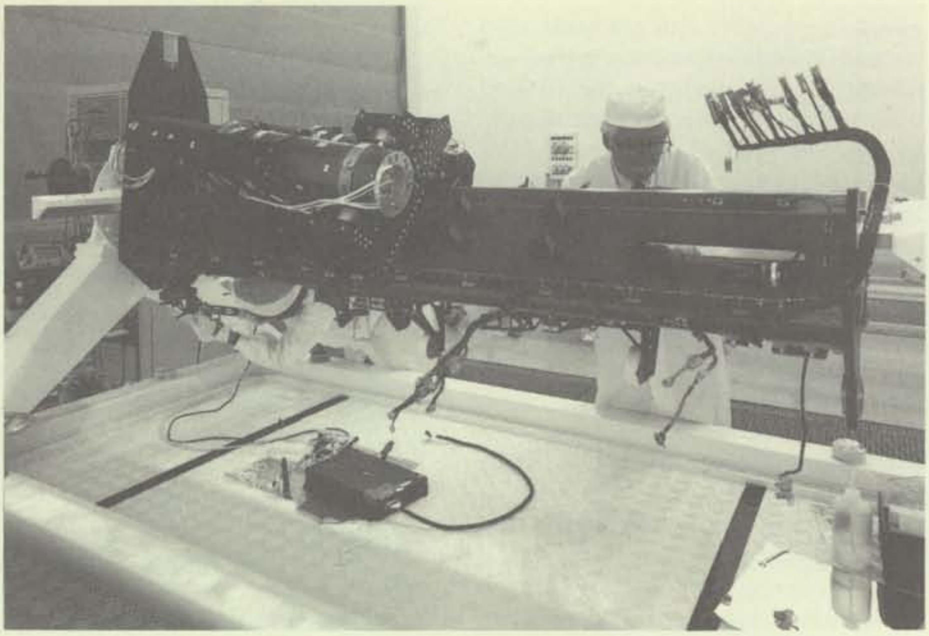
Investigation of the fracturing of the camera tubes has led to an improved design for the glass of the gun section. New tubes are being manufactured and should be delivered by the end of July 1982. This implies a significant delay compared with the earlier schedules, resulting in an overall delay in FOC delivery of approximately five months. New programme schedules are being established.

Préparation aux essais thermiques sous vide de l'adaptateur des mécanismes d'entraînement et de déploiement du réseau solaire du Télescope spatial à l'ESTEC.

Space Telescope solar-array-drive adaptor and primary deployment mechanism being prepared for thermal vacuum testing at ESTEC.

Space Telescope Faint-Object Camera optical bench (flight model) during integration at Matra.

Banc optique de la Chambre pour astres faibles au cours de son intégration chez Matra.



effectué. Plusieurs domaines nécessitent des investigations. La consommation d'énergie électrique pour maintenir les conditions thermiques du banc optique apparaît un peu trop élevée et les mesures sur la stabilité de l'image pour le parcours optique à f/96 a donné quelques résultats assez inattendus qui restent à expliquer.

Détecteur de photons

Les essais destinés à vérifier les interfaces électriques et de logiciel avec le détecteur de photons ont été effectués en mettant en oeuvre l'électronique du module chambre et le modèle d'identification du détecteur de photons. Les résultats ont été satisfaisants.

Des recherches effectuées sur les raisons de la rupture des tubes analyseurs ont conduit à élaborer une conception améliorée de la lentille du canon. De nouveaux tubes sont en fabrication; ils devraient être livrés vers fin juillet. Ceci entraîne un retard important par rapport aux calendriers antérieurs, ce qui se traduit, pour la livraison de l'ensemble de la FOC, par un délai supplémentaire d'environ cinq mois. On établit actuellement les détails du nouveau programme.

Hipparcos

Situation technique

L'étude de définition de la phase B1 d'Hipparcos a commencé le 25 janvier par l'attribution d'un contrat à Matra, chef de file du consortium MESH.

L'accent a été mis, dans les travaux effectués jusqu'à ce jour, sur les études de compromis au niveau système et sous-système, afin d'établir la configuration optique de la charge utile et la conception du système de référence du satellite.

La documentation disponible sera étudiée de façon approfondie par l'Agence lors de l'examen de définition de système (SDR) prévu pour début juillet. A la suite du SDR, les liasses pour la soumission des sous-systèmes seront produites, le démarrage de ce travail conduisant à l'examen de définition des sous-systèmes prévu pour fin septembre.

Consortium pour l'établissement du catalogue d'étoiles

Comme les observations d'Hipparcos ne peuvent porter que sur des étoiles faisant partie d'un programme choisi à l'avance, l'établissement d'un catalogue contenant toutes les informations nécessaires à l'exploitation du satellite, et représentant les intérêts des spécialistes de l'astrométrie et de l'astrophysique, constitue un travail important qui fait partie intégrante du projet. Un consortium comprenant 26 instituts scientifiques dans sept pays de l'ESA, et trois instituts dans sept Etats non membres, a maintenant été mis sur pied pour effectuer ce travail, à la suite de l'approbation donnée par le SPC à sa réunion du 18 mars. L'élaboration du catalogue des étoiles à observer a officiellement démarré à la suite du feu vert donné par l'Agence le 25 mars et l'on procède actuellement à la mise au point finale des plans détaillés du Consortium applicables jusqu'à l'achèvement du catalogue.

Consortiums de dépouillement des données

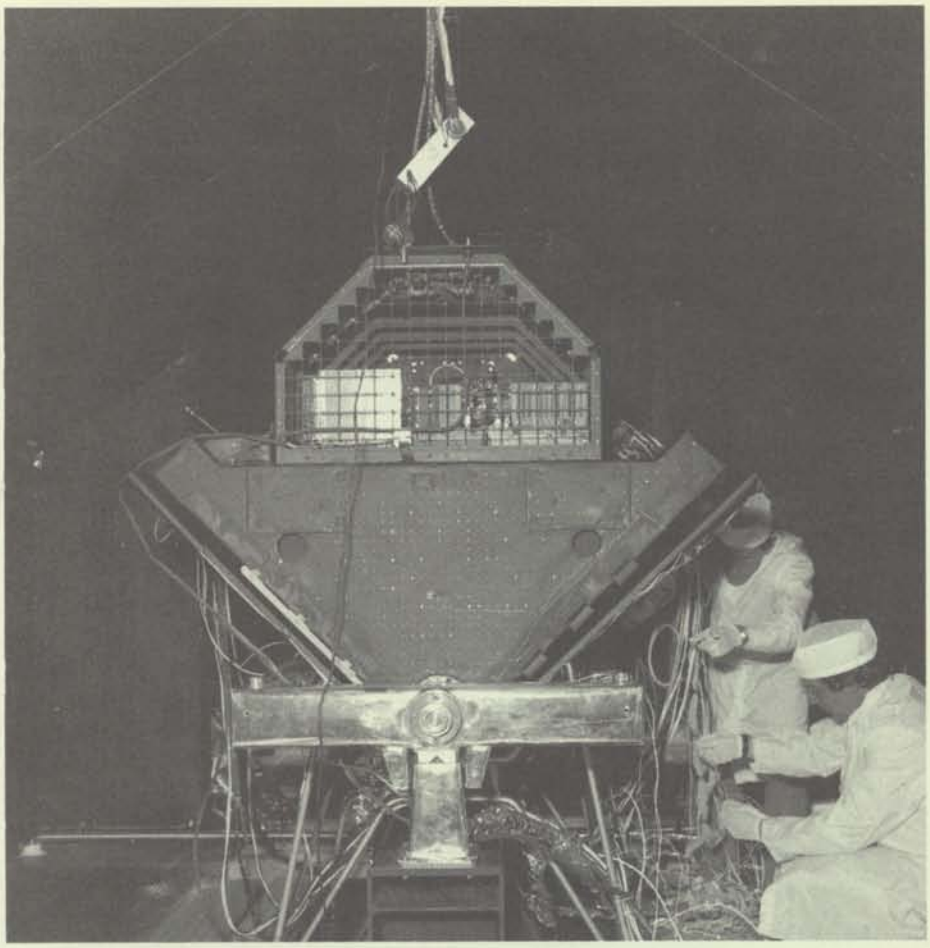
A la suite de l'approbation donnée par le SPC à sa réunion du 18 mars, deux consortiums indépendants d'instituts scientifiques ont été choisis pour entreprendre les tâches de dépouillement des données; les travaux ont démarré à la suite du feu vert donné à la réunion qui s'est tenue le 24 mars. Ce n'est que par l'analyse des données de la totalité de la mission que l'on pourra extraire les paramètres astrométriques requis pour toute étoile donnée. L'objectif des consortiums est d'entreprendre un dépouillement indépendant et intégral de données simulées avant le lancement du satellite.

Dans les deux consortiums, 22 instituts européens au total procèdent actuellement aux préparatifs qui s'imposent pour le dépouillement des données fournies par le satellite.

Giotto

Satellite

La phase B2 du programme Giotto s'est achevée avec succès en février par l'examen de conception de système (SDR) qui a fait apparaître quelques difficultés techniques, mais aucune d'entre elles n'a été jugée critique pour le projet. La phase C/D (approvisionnement du matériel) a effectivement démarré immédiatement après l'achèvement de la phase B2 grâce à un financement anticipé de la phase C/D en attendant l'approbation officielle du SPC et de l'IPC qui devrait intervenir en juin. Le satellite a une masse totale de 950 kg, y compris le propulseur de transfert à poudre pour sa satellisation sur l'orbite de transfert choisie en vue d'atteindre la comète. La masse des instruments scientifiques constituant la charge utile est d'environ 53 kg. La conception électrique est maintenant gelée et le premier modèle de



Modèle de vol de la Chambre pour astres faibles du Télescope spatial au cours des essais thermiques à l'ESTEC.

Representative flight model of the Space Telescope Faint-Object Camera during thermal testing at ESTEC.

Hipparcos

Technical status

The Hipparcos Phase B1 definition study commenced on 25 January 1982 with the award of a contract to Matra, leading the MESH consortium.

The major emphasis in the work to date has been on trade-off studies at system and subsystem level to establish the payload optical configuration and the satellite baseline system design.

Available documentation will be reviewed in depth by the Agency at the System Definition Review (SDR), planned to take place early in July.

Following the SDR, subsystem bid packages will be issued, initiating work leading to the Subsystem Definition Review, planned for late September.

Input Catalogue consortium

As the Hipparcos observations are made only on pre-selected programme stars, the construction of an Input Catalogue containing all the information necessary for the satellite operations and representing the interests of astrometrists and astrophysicists is an important and integral part of the project. A consortium consisting of 26 scientific institutes from seven ESA countries and three institutes from non-ESA member states has now been selected to perform this task, following its approval by the Agency's Science Programme Committee (SPC) at its meeting on 18 March 1982. The Input Catalogue task was formally initiated by the Agency on 25 March and the consortium's detailed plans up to the completion of the Input Catalogue are presently being finalised.

Data-reduction consortia

Following the SPC approval at its meeting on 18 March 1982, two independent consortia of scientific institutes have been selected to undertake the data-analysis tasks and work was initiated at a kick-off meeting on 24 March. It is only by reducing the entire mission data that the required astrometric parameters of any given star can be extracted, and the goals are for the consortia to undertake full and independent reductions of simulated data before satellite launch.

With the two consortia, a total of 22 European institutes are presently involved in preparations for the analysis of the satellite data.

Giotto

Spacecraft

Phase-B2 of the Giotto Programme was successfully completed in February with the System Design Review, which identified some technical problems but none of a project-critical nature. Phase-C/D (hardware procurement) started following the completion of Phase-B2 using advance C/D funding pending formal SPC/IPC approval, which is to be sought in June 1982.

The spacecraft is designed to have a total mass of 950 kg, including the solid kick motor that will insert it into the cometary transfer orbit. Experiment payload mass is about 53 kg. The technical design is now frozen and the first spacecraft development model (electrical model) will be assembled and tested next year.

Payload

Work has been proceeding in collaboration with the Science Working Team to provide additional capabilities that were not offered by the Phase-A mission design. These include:

- provision of cruise science and pre-encounter science
- provision of multiple science telemetry formats such that instrument science return can be maximised depending on the spacecraft's position relative to the Comet nucleus
- studies of the Comet environment with a view to improving scientific return and instrument survival
- inclusion of the radio-science experiments within the mission.

Although the inclusion of the radio-science experiments has been agreed, the need to preclude any modifications to the transponder design which is the basis for *développement du satellite (modèle électrique) sera assemblé et essayé l'année prochaine.*

Charge utile

Les travaux se sont poursuivis, en collaboration avec l'équipe de travail scientifique, pour que la mission offre des possibilités supplémentaires qui n'étaient pas prévues dans le cadre de la conception de la phase A de la mission. Il s'agit essentiellement des points suivants:

- *fourniture de données scientifiques pendant la phase de croisière et la phase de prérencontre;*
- *fourniture de formats multiples de télémesure des données scientifiques, de façon que la production de données scientifiques des instruments puisse être maximalisée en fonction de la position relative du satellite par rapport au noyau de la comète;*
- *études sur l'environnement de la comète, en vue d'améliorer la production de données scientifiques et la survie des instruments;*
- *inclusion, dans la mission, d'équipements expérimentaux de la science des rayonnements.*

Bien que l'inclusion des expériences de la science des rayonnements ait été approuvée, la nécessité d'empêcher que des modifications soient introduites dans la conception du répéteur qui est à la base de Giotto implique que les impératifs énumérés dans les propositions de 1980 ne pourront pas tous être satisfaits.

Lancement et opérations

Le SPC ayant opté pour un lanceur Ariane-3 partagé, des négociations détaillées ont eu lieu avec Arianespace.

On a prévu une extension des opérations initiales dans les domaines ci-après:

- *La NASA assurera le soutien en matière de navigation/ d'éphémérides, ainsi que le soutien en matière de stations sol de secours pour les phases critiques de la mission; elle assurera également le moyen de secours en matière de télécommande d'urgence pour la rencontre.*
- *Pour assurer à la navigation la précision requise, la télémétrie à partir de stations dans l'hémisphère nord et dans l'hémisphère sud est actuellement jugée nécessaire.*
- *La visualisation rapide des données sera assurée sur l'équipement d'expérimentateurs installé à l'ESOC.*
- *Les programmes d'éphémérides de la comète, établis par la NASA, seront introduits dans les calculateurs de l'ESOC pour la mise à jour en temps réel, en utilisant les données d'observation de la Veille internationale de la Comète de Halley.*

Marecs

Le 1er mai à minuit, le satellite Marecs-A, qui est loué à Inmarsat, a été mis en service opérationnel. Les performances du satellite et de sa charge utile se situent correctement dans les limites des spécifications, ce qui permet au satellite de contribuer notablement à améliorer les communications entre les navires et la terre dans la zone de l'océan Atlantique.

Le lancement de Marecs-B par Ariane L5 est maintenant fixé au 10 septembre à 23 h 09 (heure de Kourou). Ce retard est dû à la nécessité d'apporter quelques modifications au satellite afin de réduire l'effet des décharges électrostatiques qui avaient provoqué un mauvais fonctionnement de la télécommande dans le sous-système de commande d'orientation de Marecs-A en février dernier. Ces modifications consistent essentiellement à améliorer la conductibilité et la mise à la masse, des surfaces extérieures du satellite, d'une part, et à protéger les circuits d'entrée de plusieurs boîtiers électroniques contre les pointes de courant élevées, d'autre part.

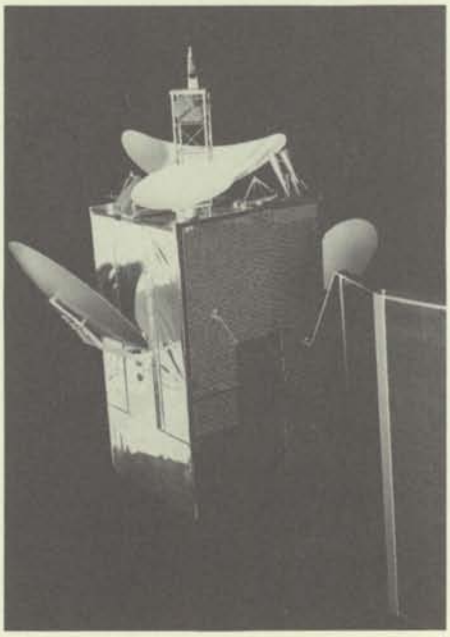
Parallèlement à son exploitation commerciale, le satellite Marecs-A sera l'élément clé d'un programme expérimental appelé Prosat qui a été approuvé en mai et auquel participent, actuellement, la Belgique, l'Espagne, la France, l'Italie, la Norvège et le Royaume-Uni. Le programme Prosat vise à améliorer le soutien expérimental requis pour analyser, évaluer et valider les caractéristiques du système de base qui pourrait être adopté pour un secteur spatial du service mobile de la deuxième génération, capable de desservir des terminaux mobiles légers — maritimes, aéronautiques et terrestres — ainsi que les terminaux de navire de norme A actuellement utilisés.

L-Sat

Les activités industrielles qui se sont déroulées au cours des trois premiers mois de la phase de réalisation principale (phase C/D) ont conduit à l'examen de la conception de référence (BDR), qui a été effectué par l'Agence début avril. Les problèmes potentiels identifiés au cours de cet examen sont actuellement traités par l'équipe industrielle du contractant principal et de ses sous-traitants; la clôture officielle de cette étape est maintenant prévue pour fin juin ou début juillet.

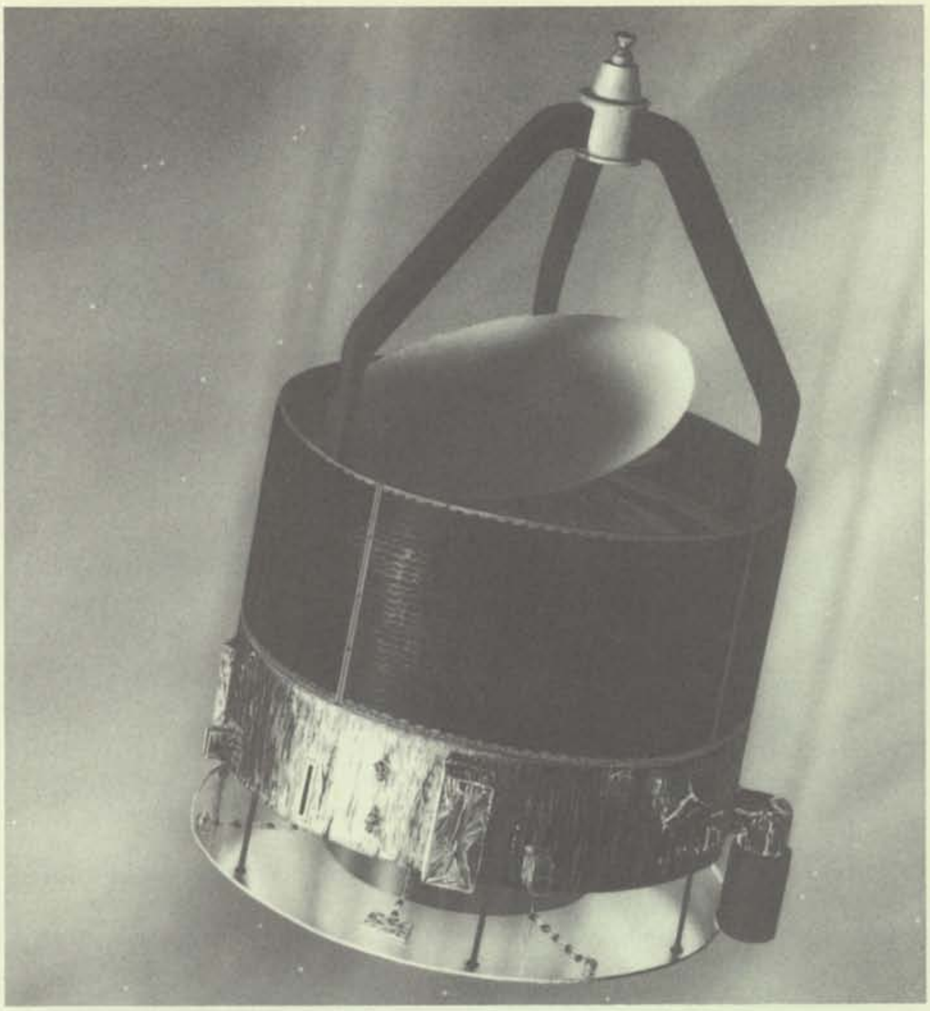
Les travaux progressent de façon satisfaisante dans certains des domaines qui ont de l'importance pour que le début de la phase de réalisation principale respecte le calendrier; la préparation des dessins a bien progressé en ce qui concerne la mécanique et des montages de table sont en cours pour de nombreux équipements électriques. Toutefois, d'une manière générale, la mise en route des travaux à l'échelon équipement a été plus lente que prévu. La réattribution de certaines tâches à la suite de la décision de la Suisse de ne pas participer au programme a pris plus longtemps que prévu mais elle est maintenant presque achevée. Dans le cas d'un équipement, il a été nécessaire pour le contractant principal, British Aerospace, de procéder à une nouvelle mise en concurrence.

La documentation de la configuration de référence, qui est constituée par les plans du système et des sous-systèmes et les



Model of L-Sat, produced by British Aerospace Dynamics Group.

Modèle de L-Sat, produit par British Aerospace Dynamics Group.



Modèle de Giotto, produit par British Aerospace Dynamics Group.

Model of the Giotto spacecraft, produced by British Aerospace Dynamics Group.

Giotto has meant that not all the requirements that were listed in the 1980 proposals can be fulfilled.

Launch and operations
Following the SPC decision in favour of a shared Ariane-3 launch, detailed negotiations have been taking place with Arianespace.

Planned initial operations have been expanded in a number of areas:
- NASA will provide navigation/ephemeris support, together with backup ground-station support for mission-critical phases and emergency command backup for the encounter itself.
- For navigation accuracy, ranging from both northern and southern hemisphere stations is now considered necessary.
- Quick-Look Data Display will be performed at ESOC on experimenter-installed equipment.
- Comet-ephemeris programs established with NASA will be installed on ESOC's computers for real-time updating using observational data from the International Halley Watch.

Marecs

At midnight on 1 May 1982, the Marecs-A spacecraft, which is being leased to Inmarsat, was put into operational service. The performance of the spacecraft and its payload are well within specification, contributing to a substantial improvement in communications between land and ships in the Atlantic Ocean area.

The launch of Marecs-B on Ariane L5 is now scheduled to take place on 10 September 1982 at 23.09 h (Kourou time). The delay is due to the need to modify the Marecs-B spacecraft to reduce the effect of electrostatic-discharge phenomena, which caused a command malfunction in the Marecs-A attitude-control subsystem last February. These modifications involve both improving the conductivity and the grounding of the spacecraft external surfaces, and hardening the input circuitry of several electronic units against sharp current spikes.

In parallel with its commercial-service operations, the Marecs-A satellite will be the key element in an experimental programme called 'Prosat', approved in May 1982, in which Belgium, France, Italy, Norway, Spain and the United Kingdom are already participating. The Prosat programme is aimed at providing the experimental support needed to analyse, assess and validate the basic system characteristics that may be adopted for a second-generation mobile space segment capable of serving lightweight maritime, aeronautical and land mobile terminals, as well as the standard-A ship terminals currently in use.

L-Sat

Industrial activities in the first three months of the main development phase (Phase-C/D) led to the Baseline Design Review (BDR) being conducted by the Agency at the beginning of April. Potential problems identified in conjunction with the review are being addressed by the industrial team of prime and subcontractors. Formal close-out of this milestone is now expected in late June or early July.

Work is already proceeding well in some of the areas significant for achieving the early part of the main-development-phase schedule, with preparation of drawings well advanced for mechanical areas and breadboarding underway for many items of electrical equipment. However, in general terms, initiation of work at equipment level has been slower than expected. The reallocation of certain tasks following Switzerland's decision not to participate in the programme has taken much longer than expected, but is now almost complete. In the case of one equipment item, it has been necessary for the prime contractor, British Aerospace, to conduct a further competitive phase.

spécifications, est actuellement dans la phase finale de mise à jour afin d'établir la première configuration de référence du projet. On prévoit que l'approbation officielle de la documentation sera donnée prochainement par l'Agence dans le cadre de la clôture du BDR.

Des négociations se sont poursuivies entre l'ESA et British Aerospace sur divers aspects commerciaux et contractuels, parallèlement à l'exécution des travaux techniques, mais il n'a pas encore été possible d'entamer les négociations contractuelles définitives. Le programme se poursuit sur la base de l'autorisation préliminaire accordée dans l'attente d'un accord sur les détails contractuels. Un rapport complet sur la question sera fait au Conseil directeur commun des Programmes de Télécommunications (JCB) fin juillet.

Une maquette grandeur nature de L-Sat conforme à la configuration du premier modèle de vol a été exécutée. Elle est utilisée pour les travaux de réalisation en ce qui concerne la conception du sous-système de propulsion combiné. Des discussions préliminaires ont eu lieu entre les Etats membres sur les directives concernant l'utilisation en orbite des charges utiles de L-Sat 1 et ces discussions se poursuivront jusqu'à l'automne.

Sirio-2

La campagne de lancement de Sirio-2 a commencé le 23 février. A la suite du retard intervenu ultérieurement dans la date de lancement, l'équipe de lancement est revenue en Europe le 23 mars après avoir assuré un rangement adéquat pour le satellite et l'équipement de vérification. Le personnel du Centre spatial a assuré la surveillance quotidienne de l'équipement tandis que le contractant principal a envoyé une petite équipe à Kourou toutes les six semaines pour procéder à une évaluation plus complète de la situation. Tout est prêt pour reprendre la campagne de lancement le 28 juillet en vue du lancement du 10 septembre.

Parmi les activités intérimaires se rapportant à la phase d'exploitation, on a procédé à des simulations de Lasso faisant intervenir les utilisateurs, ainsi qu'à l'amélioration de la qualité de certains composants dans les prototypes de stations MDD. Des simulations ont également eu lieu à l'ESOC pour valider le logiciel et les procédures du lancement et des premières orbites.

Télédétection

Campagne SAR 580
Le nombre total des lignes-canaux traitées optiquement est de 291. 20 lignes-canaux supplémentaires correspondant à des sites non encore demandés vont être traitées dès que les expérimentateurs auront exprimé leurs besoins.

Le RAE a complété le traitement des données d'étalonnage, soit 61 scènes. Parmi les 68 scènes prioritaires définies en février 1982, le DFVLR a déjà une trentaine de scènes: la bande test de données numériques a été envoyée à tous les expérimentateurs et 27 scènes déjà traitées ont été distribuées aux investigateurs concernés.

Offre de participation à la mission ERS-1
Conformément aux souhaits exprimés par les Délégations lors de la 18ème session du Conseil Directeur, l'Exécutif a analysé avec le Rutherford Appleton Laboratory la proposition (suite à l'Avis d'offre de participation lancé en mai 1981) d'un ATSR modifié (Along-Track Scanning Radiometer-radiomètre à balayage dans le sens de la trace au sol), incluant des canaux hyperfréquences: cet ATSR/M fera l'objet des études de phase-B. Quant à un système de localisation précise, les contacts ont été maintenus avec les Etats-Unis sur l'utilisation du GPS et de stations laser. Pour les stations laser, la NASA est prête à étudier l'utilisation de leur réseau (18 stations) pour ERS-1.

Lors de la dernière session du RS-AG, il a été confirmé que le PRARE (Precise Range and Range Rate Equipment — équipement de télémétrie et de vélocimétrie de précision), avec deux stations au sol, pourrait être envisagé pour inclusion sur la plate-forme, l'engagement définitif de l'Allemagne ne pouvant survenir qu'en fin de phase B en fonctions des informations de coût, à la fois du PRARE et du programme global.

Phase-B ERS-1
Après l'IPC du 30 mars 1982, la demande de proposition pour la phase-B industrielle a été envoyée à Dornier. Les réponses sont arrivées le 7 juin. L'évaluation est en cours pour présentation des résultats à l'IPC du 30 juillet et début des travaux début août.

Le Conseil de l'Agence lors de sa session du 28 avril a approuvé le plan de transfert de ESA/Toulouse à ESTEC présenté par le Directeur général, transfert qui devra être terminé pour le début de la phase-C/D.

Au 15 mai, la Déclaration relative à la phase B d'ERS-1 a été souscrite par 10 Etats représentant 88,18% des contributions:
- *L'Irlande a décidé de ne pas participer,*
- *Le Danemark et les Pays-Bas n'ont pas encore souscrit à la Déclaration.*

Le 27 mai, l'AFC a approuvé le Règlement d'Exécution du programme, et le budget pour 1982.

Les activités de technologie nécessaires au programme ERS-1 et financées au titre de la phase B ont démarré par l'engagement des contrats relatifs aux deux options d'amplificateurs de puissance de l'AMI (TOP, Klystron).

Expériences de Télédétection de la FSLP
La caméra métrique a subi avec succès les essais de recette en Europe et a été délivrée à la NASA fin mai 1982 pour intégration dite de niveau IV.

Le MRSE a été intégré avec le reste de la charge utile européenne sur le porte-instruments et a été envoyé au Centre spatial Kennedy (KSC). La prochaine étape est la mise en place du banc de contrôle au KSC.

Le lancement de la FSLP est prévu pour fin septembre 1983.

Autres événements importants
Une réunion de travail entre experts de la télédétection par détecteurs hyperfréquences de l'océan et de la glace s'est tenue à Igls (Autriche) les 20 et 21 avril.

La 1ère réunion de coordination des opérateurs de satellites de télédétection maritime (CORSS) a eu lieu les 10 et 11 mai à Paris entre le Japon et l'ESA.

La 2ème réunion multilatérale sur la télédétection s'est tenue à Paris les 12 et 13 mai 1982.

The key documentation, consisting of the system and subsystem plans and specifications, is in the final stages of updating to establish the initial project baseline. It is expected to be approved formally by the Agency shortly, as part of the BDR close-out activity.

Negotiations have continued between ESA and British Aerospace on various commercial and contractual aspects, in parallel with the technical work, but it has not been possible yet to make the full contractual release. The programme is continuing on the basis of the preliminary authorisation to proceed, pending agreement on the contractual details. A full report is to be given to ESA's Joint Communications Board (JCB) on this subject at the end of July.

A full scale mock-up of L-Sat in first-flight-model configuration has been completed and is being used for development work on the design of the propulsion subsystem.

Preliminary discussions have taken place between the Agency's Member States on the guidelines for the utilisation in orbit of the L-Sat 1 payloads, and these discussions will be further pursued in the autumn.

Sirio-2

The Sirio-2 launch campaign started on 23 February 1982. As a result of the subsequently announced launch delay, the Sirio-2 launch team returned to Europe on 23 March after having placed the satellite and the checkout equipment in suitable storage. Guiana Space Centre personnel have been responsible for day-to-day surveillance of the equipment, while the prime contractor has sent a small team at six-weekly intervals to Kourou for a more thorough status assessment. All is ready for a resumption of the launch campaign on 28 July, for the launch on 10 September 1982.

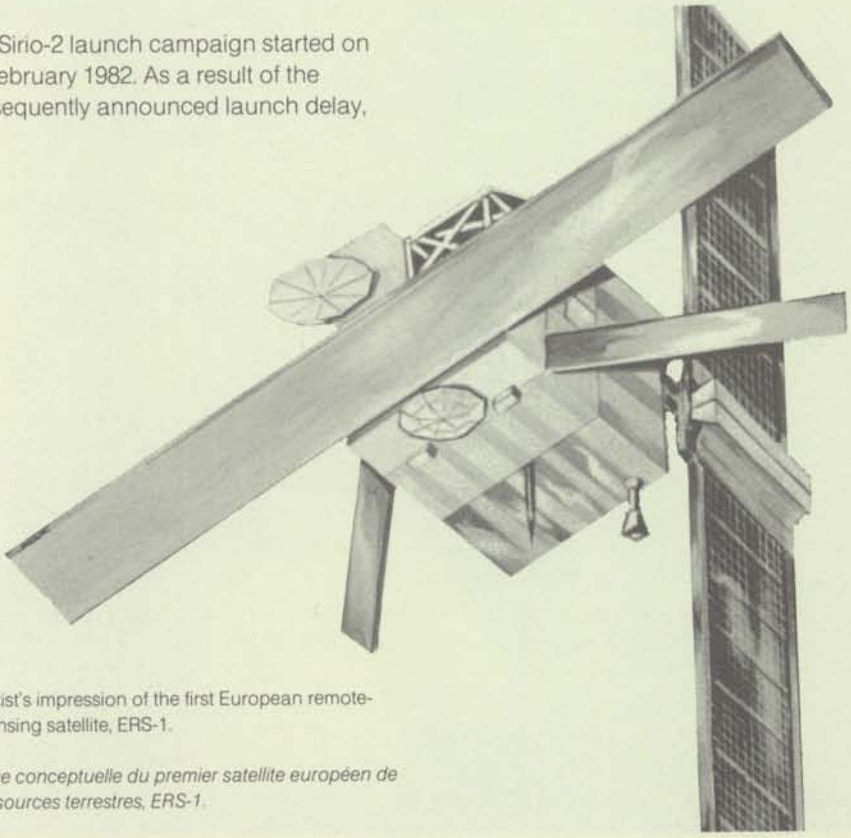
Standby activities related to the exploitation phase have included Lasso simulations with user involvement, as well as quality improvements in certain components in the MDD prototype stations. Simulations have also been carried out at ESOC to validate launch and early-orbit software and procedures.

Remote Sensing

SAR-580 campaign

The total number of lines/channels processed optically so far is 291. A further 20 lines/channels corresponding to sites not yet requested will be processed as soon as the experimenters have formulated their requirements.

The Royal Aircraft Establishment (Farnborough) has completed the processing of the calibration data, representing 61 scenes. DFVLR has already processed some 30 of the 68 priority scenes defined in February 1982. The digital-data test tape has been sent to all the experimenters, and 27 scenes already processed have been distributed to the investigators concerned.



Artist's impression of the first European remote-sensing satellite, ERS-1.

Vue conceptuelle du premier satellite européen de resources terrestres, ERS-1.

Offer of participation in the ERS-1 mission

As requested by the delegations at the 18th meeting of the Programme Board, the Executive has analysed with the Rutherford Appleton Laboratory the proposal (following the announcement of opportunity issued in May 1981) for a modified ATSR (Along-Track Scanning Radiometer) including microwave channels; this ASTR/M will be the subject of Phase-B studies. Regarding the system of precise position determination, contacts have been maintained with the USA on the use of the GPS and of laser stations. NASA is prepared to consider allowing its network of 18 laser stations to be used for ERS-1.

At the last meeting of the Remote-Sensing Advisory Group it was confirmed that the PRARE (Precision Range and Range Rate Equipment, with two ground stations) could be envisaged for inclusion on the platform, but a firm commitment by Germany could not be given until the end of Phase-B, and would depend on the costs of both the PRARE and of the programme as a whole.

ERS-1 Phase-B

Following the Industrial Policy Committee (IPC) meeting of 30 March 1982, the Request for Proposal for the industrial Phase-B (definition phase) was sent to Dornier. The replies arrived on 7 June. Evaluation is underway with a view to presenting the results to the IPC on 30 July and starting the work early in August.

At its meeting on 28 April, the ESA Council approved the plan submitted by the Director General for the transfer of ESA Toulouse to ESTEC, which will need to be completed by the start of Phase-C/D (main development phase).

By 15 May, the Declaration for Phase-B of ERS-1 had been subscribed to by ten States, representing 88.18% of the total contribution:

- Ireland has decided not to take part
- Denmark and the Netherlands have not yet subscribed to the Declaration.

Spacelab flight unit in the operations and checkout building at Kennedy Space Center.

L'unité de vol du Spacelab dans le bâtiment d'opérations et de vérification du Centre spatial Kennedy.

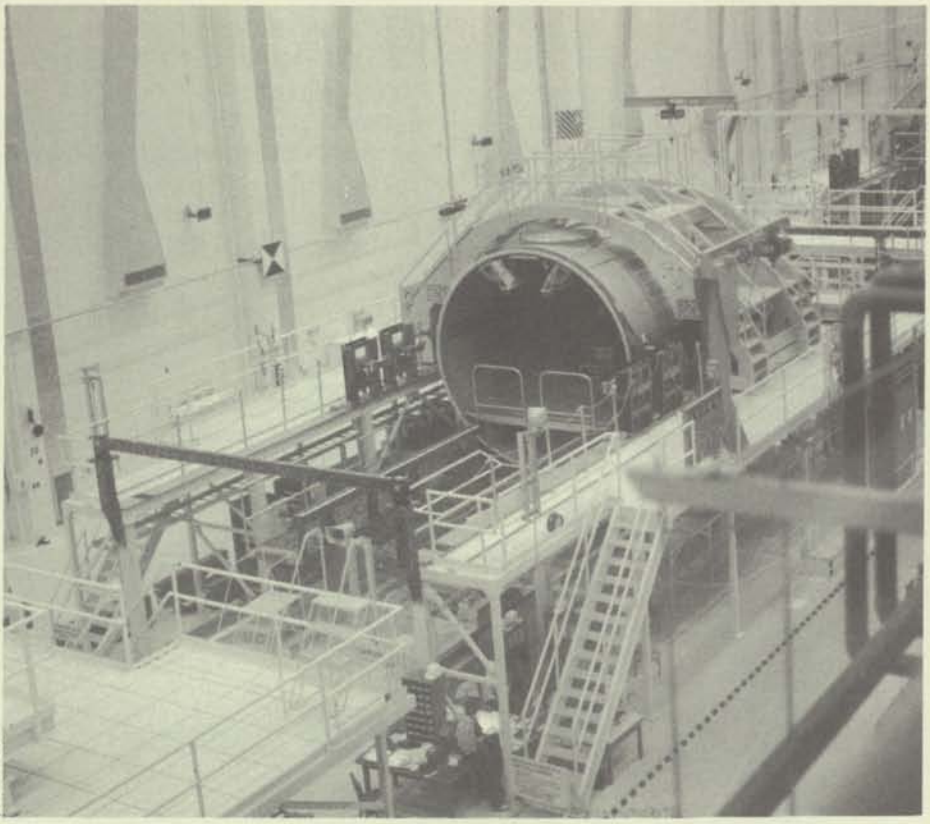


photo nasa

Une réunion entre la Direction des Programmes d'Applications de l'ESA et des représentants de la NASA et de la NOAA s'est tenue le 27 mai à Washington pour étudier les possibilités de coopération entre l'Agence et les Etats-Unis dans le cadre du programme ERS-1.

Spacelab

Les travaux sur la première unité de vol du Spacelab (FU-I), en configuration module + porte-instruments, se poursuivent activement au Centre spatial Kennedy depuis sa livraison en décembre 1981 – janvier 1982. Le réassemblage est pratiquement terminé et les essais de sous-système se poursuivent de façon satisfaisante. Certaines modifications rétroactives qui étaient prévues sont en cours sur des éléments du système de télécommande et de gestion des données mais l'enregistreur de données à grand débit est en retard. Toutefois, le rythme de l'intégration est maintenu pour le premier vol du Spacelab fixé au 30 septembre – 1 octobre 1983.

La charge utile OSS-1 (Bureau des Sciences spatiales de la NASA) installée sur le porte-instruments du deuxième modèle d'identification de Spacelab a accompli un vol parfaitement réussi à bord du troisième vol de la Navette (STS-3) du 22 au 30 mars dernier. La NASA a félicité l'ESA pour l'excellent fonctionnement du porte-instruments qui a été soumis à des conditions thermiques extrêmes.

Les activités d'intégration et d'essai sur la deuxième configuration du modèle de vol (FU-II: configuration igloo/porte-instruments seulement) sont terminées. On prépare la documentation pour l'examen de recette définitif qui doit avoir lieu le 2 juillet. L'expédition par avion du matériel au Centre spatial Kennedy.

photo nasa

Spacelab rack no. 7 being fitted out at Kennedy Space Center.

Assemblage du bâti no. 7 du Spacelab au Centre spatial Kennedy.

On 27 May the AFC approved the programme implementing rules and the 1982 budget.

The technology activities needed for the ERS-1 programme and funded under Phase-B have started with the placing of the contracts relating to the two power-amplifier options (TOP, Klystron) for the AMI.

FSLP remote-sensing experiments
The metric camera has successfully completed acceptance testing in Europe and was delivered to NASA at the end of May 1982 for level-IV integration.

The Microwave Remote-Sensing Experiment (MRSE) has been integrated with the rest of the European payload on the pallet and sent to Kennedy Space Center (KSC). The next step will be the setting up at KSC of the checkout system.

The First Spacelab Payload (FSLP) is scheduled for launch at the end of September 1983.

Other major events
Experts in ocean and ice microwave remote sensing held a meeting in Igls (Austria) on 20 and 21 April.

The first Japan/ESA meeting of the CORSS (Coordination of Oceanic Remote-Sensing Satellites) was held in Paris on 10 and 11 May. The Second Multilateral Meeting on Remote Sensing was held in Paris on 12 and 13 May 1982.

A meeting between ESA's Director of Application Programmes and NASA and NOAA representatives was held in Washington on 27 May to consider the possibilities of cooperation between ESA and the USA within the ERS-1 programme.

Spacelab

Processing at the Kennedy Space Center (KSC) of the Spacelab Flight Unit Configuration-I (FU-I), the module-pallet configuration, is in full swing, following its delivery in December 1981/January 1982. Reassembly is virtually complete and subsystem tests are proceeding satisfactorily. Some planned retrofitting of CDMS elements (Command and Data-Management System) is going on and the HDRR (High-Data-Rate Recorder) is late. The integration flow can nevertheless be maintained for the Spacelab-1 flight scheduled for 30 September/1 October 1983.

The OSS-1 payload (NASA Office of Space Sciences), mounted on the second Spacelab engineering-model pallet, made a very successful flight on the Space Shuttle's third flight (STS-3) on 22–30 March 1982. NASA has congratulated ESA on this excellent performance of the engineering-model pallet, which was subjected to an extreme thermal environment.

Integration and test activities on Spacelab Flight Unit Configuration-II (FU-II), the igloo-pallet-only configuration, have been completed. Documentation is being readied for the Final Acceptance Review on 2 July 1982. The hardware, including Ground-Support Equipment and spares, will be flown to KSC, on two aircraft in the second half of July.

Design work on the Instrument Pointing System (IPS) is progressing satisfactorily. Documentation, particularly that concerning analysis of system performance and structural engineering, has required increased effort, leading to an extension of the Critical Design Review (CDR) into August 1982. Delivery of the IPS is still scheduled for December 1983.

The Spacelab Follow-On Production (FOP) programme, under which NASA agreed in the Memorandum of Understanding (MOU) to purchase a second Spacelab, is proceeding satisfactorily. The first hardware has been presented for acceptance to ESA and NASA and has been passed successfully. ESA acts on NASA's behalf in these activities. The hardware items will be delivered during the period 1983 to 1984.

IPS Follow-On Production is still on hold, awaiting a successful IPS CDR in August 1982.

FSLP

European integration of the First Spacelab Payload (FSLP) was successfully completed at ERNO, and the payload was transported to NASA's Kennedy Space Center (KSC) on 24 May 1982, in accordance with the schedule agreed with NASA a year ago. The Grille Spectrometer had been sent to KSC in advance, to permit early installation on the NASA orthogrid structure. The remaining item in the payload, the Material Sciences Double Rack, will be sent to KSC in early July, following finalisation of refurbishment and testing at MBB.

After the initial offline activities, the European payload will join the NASA integration chain in July, and it is planned to complete combined ESA-NASA payload integration by December 1982. The first members of the ground operations team at KSC, consisting of staff from SPICE and ERNO, have taken up duty.

The flight-operations team from SPICE, GSOC, ESOC, and contractors has transferred to NASA's Marshall Space Flight Center (MSFC) according to plan, in order to prepare the mission in close cooperation with the NASA team.

The Spacelab-1 (SL-1) crew returned to Europe for training on:
- the vestibular-sciences experiment, 1ES201
- the ballistocardiographic experiment, 1ES028
- the Fluid-Physics Module (part of the Material-Sciences Double Rack).

Regarding the Sled payload element to be flown on German Spacelab flight D1, the definition of all interfaces and detailed accommodation work has progressed and working meetings with the European and US experimenters have confirmed that the engineering and operational efforts have reached a satisfactory stage.

Biorack

Industrial offers for the Biorack thermal-conditioning units have been evaluated and a recommendation has been prepared for approval by the Industrial Policy Committee at the end of June 1982. The main activities at present concern the accommodation of the recommended experiment payload, safety evaluations, and construction of a full-scale test model of the freezer/cooler combination unit, the most complex Biorack active thermal unit. It is planned to test this unit during July 1982.

The article on page 46 of this Bulletin describes the Biorack development programme and design.

(équipement de soutien au sol et pièces de rechange compris) s'effectuera en deux envois pendant la deuxième quinzaine de juillet.

Les travaux conceptuels progressent de façon satisfaisante sur le système de pointage d'instrument (IPS). La documentation, notamment en ce qui concerne l'analyse du fonctionnement du système et de l'ingénierie structurelle, a nécessité des efforts accrus qui ont abouti à prolonger l'examen critique de la conception jusqu'en août. La livraison de l'IPS est toujours fixée à décembre 1983.

Le programme de production ultérieure du Spacelab (FOP), dans le cadre duquel la NASA a fait l'acquisition d'un deuxième Spacelab comme prévu au Mémorandum d'accord, se poursuit normalement. Les premiers matériels ont été présentés pour recette à l'ESA et à la NASA et ont été acceptés. L'ESA participe à ces activités pour le compte de la NASA. La livraison des matériels aura lieu en 1983 et en 1984.

La production ultérieure de l'IPS est toujours en suspens, la décision dépend du résultat de l'examen critique de la conception qui doit avoir lieu en août 1982.

FSLP

L'intégration en Europe de la première charge utile du Spacelab (FSLP) s'est achevée avec succès chez ERNO et la charge utile a été expédiée au Centre spatial Kennedy (KSC) le 24 mai, conformément au calendrier arrêté avec la NASA il y a un an. Le spectromètre à grille avait été envoyé au KSC à l'avance pour en permettre plus tôt l'installation sur la structure orthogrille de la NASA. Le dernier élément de la charge utile, le bâti double des sciences des matériaux, sera envoyé au KSC début juillet, après achèvement de sa remise en état et de ses essais chez MBB. Après les premières activités hors circuit, la charge utile européenne rentrera dans le circuit d'intégration de la NASA en juillet et l'on prévoit que l'intégration combinée ESA/NASA de la charge utile s'achève vers le mois de décembre. Les premiers membres de l'équipe des opérations au sol, au KSC, constituée par des agents du SPICE et d'ERNO sont entrés en fonction. L'équipe des opérations de vol, composée de membres du SPICE, du GSOC, de l'ESOC et des contractants a été transférée au Centre spatial Marshall conformément aux plans arrêtés, afin de préparer la mission en étroite collaboration avec l'équipe de la NASA.

L'équipage du SL-1 est rentré en Europe pour y recevoir une formation sur les expériences suivantes:
- *expérience des sciences vestibulaires (1ES201)*
- *expérience de ballistocardiographie (1ES028)*
- *module de physique des fluides (qui fait partie du bâti double des sciences des matériaux).*

En ce qui concerne l'élément de la charge utile 'traîneau spatial' (Sled) de la mission D-1, la définition de toutes les interfaces et l'implantation détaillée ont progressé et des réunions de travail avec les expérimentateurs européens et américains ont confirmé que les aspects d'ingénierie et d'exploitation sont parvenus à un stade satisfaisant.

Biorack

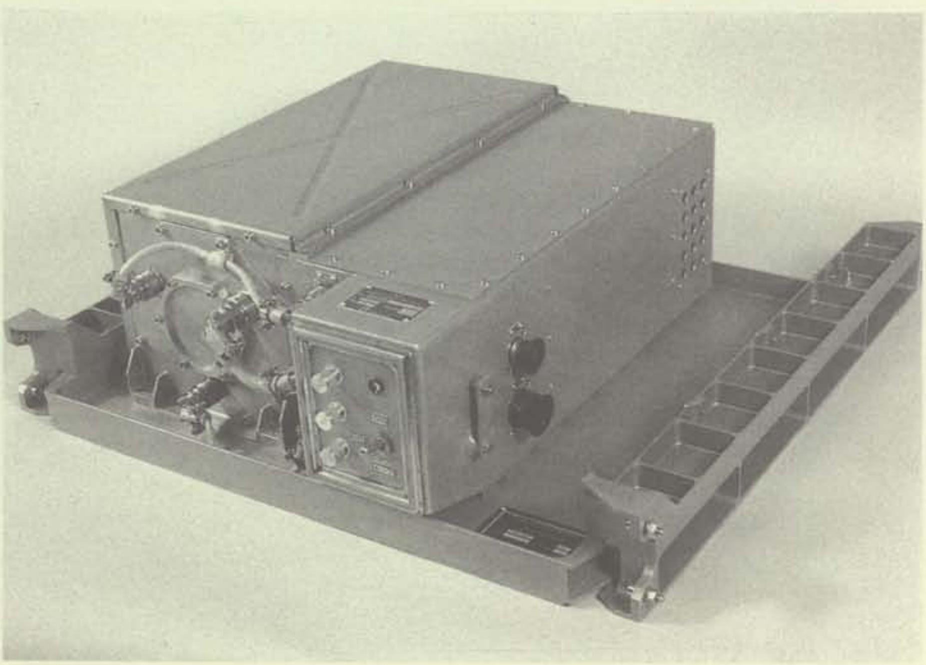
Les travaux industriels relatifs aux enceintes de conditionnement thermiques du Biorack ont été évalués et une recommandation a été préparée en vue de son approbation par le Comité de la Politique industrielle à la fin de juin. Les principales activités en cours concernent le logement des équipements d'expérience recommandés pour la charge utile, les évaluations de sécurité et la construction d'un modèle d'essai en grandeur nature de la combinaison congélateur/réfrigérateur, qui est l'équipement thermique actif le plus complexe du Biorack. Des plans sont prévus pour essayer ce dernier au cours du mois de juillet.

L'article à la page 46 de ce Bulletin décrit la conception et le programme de réalisation du Biorack.

Microgravité

Le 15 janvier 1982, les contributions de dix Etats participants (Allemagne, Belgique, Danemark, Espagne, France, Italie, Pays-Bas, Royaume-Uni, Suède et Suisse) ont atteint 72,23%, dépassant ainsi le niveau minimum fixé par le Conseil (70%), ce qui a permis le démarrage immédiat du programme.

Les recherches porteront sur deux principaux domaines: les sciences de la vie, dont les spécialistes pourront étudier l'influence d'une force gravitationnelle considérablement réduite sur des organismes vivants (des cellules les plus simples aux plus développées, y compris l'homme), et les sciences des matériaux, dont les spécialistes étudieront l'influence de la microgravité sur le comportement



Crystal growth from vapour experiment (ES 338) to be flown in the materials-science payload on the first Spacelab mission (FSLP).

Expérience de cristallogénèse sous vapeur (ES 338) destinée à voler à bord de la première charge utile Spacelab (FSLP).

Microgravity

On 15 January 1982, the contributions of the ten participating Member States (Belgium, Denmark, France, Germany, Italy, The Netherlands, Spain, Switzerland, Sweden and the United Kingdom) reached 72.23%, surpassing the minimum level set by the Council for this programme (70%), and thereby enabling the programme to commence immediately.

The science proposed can be divided into two main areas: life sciences, in which researchers can study the effects of greatly reduced gravitational forces on living organisms, from the most simple cells to the most highly developed ones, including man himself; and materials sciences, in which the effects of microgravity conditions on the behaviour of fluids, on crystal growth and on metallurgical systems, can be studied.

Because 27.77% of the budget remains blocked, only the Biorack, Improved Fluid-Physics Module, and sounding-rocket programme elements are currently underway.

The Improved Fluid-Physics Module (IFPM)

The Improved Fluid-Physics Module is a multi-user experimental facility to be flown on the first Spacelab mission in 1983 and designed for the study of phenomena connected with the hydrodynamics of floating liquid zones. It is planned to improve the initial version of the Fluid-Physics Module to take account of a change in user requirements due to a recent evolution in the microgravity sciences, and to fly this improved version on the German D-1 mission (see page 34 of this Bulletin).

The tender action for the work for Phase-B of the IFPM has been completed.

Sounding rockets

The sounding-rocket element of the microgravity programme consists of a series of experiments in the fields of solidification and fluid physics (further details can be found in ESA Bulletin No. 27).

An acoustic mixer developed within the framework of the ESA Technology Programme was successfully flown on a Texus-V flight on 29 April 1982. This acoustic unit is capable of mixing immiscible alloys, powder/metal mixes and fibre/metal mixes in the microgravity environment to produce homogeneous metallic samples.

The Texus-VI sounding-rocket flight, which carried six ESA materials-science experiments, took place on 8 May 1982. The rocket systems and all experiments worked successfully and detailed scientific analysis of the recovered experiment samples will follow.

A second Announcement of Sounding-Rocket Flight Opportunity has been issued by ESA to select experiments for the next flight opportunity in April/May 1983 (Texus-VII/VIII). Further sounding-rocket missions for materials-sciences experiments under microgravity are planned for 1984 and 1985.

Eureca

The Spacelab Follow-On Development (FOD) programme went ahead on 15 April 1982 when contributions from eight participating Member States (Belgium, Denmark, France, Germany, Italy, Spain, Switzerland and the United Kingdom), reached 80.8% of the financial envelope of 155.9 MAU (mid-1980 prices), thus enabling work to start immediately.

The most important element of this new programme is the development of a European Retrievable Carrier – called 'Eureca' – to be launched and retrieved by the Space Shuttle. This programme element also includes the development of a core payload for a first mission mainly oriented towards microgravity research, with particular emphasis on material and life sciences. Launch and retrieval are scheduled for the spring and autumn of 1987, respectively.

Eureca is a reusable payload carrier designed to suit European user requirements. Able to carry up to 1500 kg, it can stay in orbit for six months or more. It will provide essential services for its payload including high electrical power (1.5–2 kW continuous) and heat-rejection capabilities. A basic performance characteristic of the carrier will be its low gravity disturbance level, an essential feature for microgravity research.

After deployment into space by the Shuttle, an on-board propulsion unit will propel the carrier into a higher orbit (about 500 km high) where the drag on its large solar arrays will be low. Once in its operational orbit, the payload will be switched on and operated by remote control. Although the experiments will be highly automated, they will nevertheless be monitored from the ground.

At the end of its mission, Eureca will return to low orbit, where it will be recovered by the Shuttle Orbiter and brought back to Earth, together with its payload equipment and processed material samples, for refurbishment for its next mission. Eureca can thus be described as a reusable 'free flyer', which will allow longer duration missions to be carried out economically.

The other two elements of the Spacelab Follow-On Programme include improvements to Spacelab itself to make it compatible with higher electrical powers and suitable for longer missions (2-3 weeks), and preparatory studies for future space-platform elements. However, parts of these two development programmes are blocked for the time being, awaiting NASA decisions on Shuttle improvements, and due also to funding limitations.

MAGE

The MAGE-II qualification review was successfully completed at the end of May 1982. The Review Board recommended pronouncement of qualification subject to the completion of a few minor items. It also complemented industry on the quality of work done on the programme.

The MAGE-II flight motor for ECS-1 has been put into storage pending some minor work still to be done (e.g. installation of spacecraft heater mats). A new replacement case is being made for the spare motor. The previous case had an unacceptably large crease in the internal thermal insulation, which was revealed by X-ray inspection after propellant loading. Both the flight and spare motors are expected to be delivered by the end of September 1982, well in advance of the recently rescheduled ECS-1 launch date.

des fluides, la croissance des cristaux et les systèmes métallurgiques.

Avec 27,77% du budget bloqués, seuls pourront être développés les éléments suivants du programme: Biorack, le module de physique des fluides amélioré et les expériences à bord de fusées-sondes.

Le module de physique des fluides amélioré (IFPM)
Il s'agit d'une installation expérimentale à utilisateurs multiples qui fera partie de la première mission du Spacelab en 1983 et qui a été conçue pour l'étude des phénomènes relatifs à l'hydrodynamique des zones liquides flottantes. On envisage d'améliorer la première version du module de physique des fluides pour tenir compte des modifications intervenues dans les besoins des utilisateurs à la suite d'une évolution récente des sciences de la microgravité, et d'embarquer cette version améliorée sur la mission allemande D-1 (voir page 34 de ce Bulletin).

L'appel d'offres couvrant les travaux de Phase-B de l'IFPM a été lancé.

Expériences à bord de fusées-sondes
Cette partie du programme Microgravité consiste en une série d'expériences en physique de la solidification et en physique des fluides embarquées sur fusées-sondes (pour de plus amples détails sur cette question, voir Bulletin ESA no. 27).

L'emport sur Texus-V, dont le vol a eu lieu le 29 avril, d'un mélangeur acoustique réalisé dans le cadre du programme technologique de l'ESA, a été couronné de succès. Ce mélangeur est capable de préparer des alliages de métaux non miscibles, des mélanges poudre-métal et des mélanges fibre-métal en conditions d'impesanteur pour produire des échantillons métalliques homogènes.

La fusée-sonde Texus-VI, emportant six expériences ESA en sciences des matériaux, a été lancée le 8 mai. Les systèmes de la fusée et toutes les expériences ont bien fonctionné d'après les indications des signaux de télémesure. L'analyse scientifique détaillée des échantillons récupérés sera effectuée ultérieurement.

Un deuxième avis de possibilité de vol sur fusées-sondes a été envoyé par l'ESA de façon à sélectionner des expériences pour le prochain vol qui aura lieu en avril – mai 1983 (Texus-VII et VIII). On prévoit également pour 1984 et 1985 des missions pour des expériences dans le domaine des sciences des matériaux dans des conditions de faible pesanteur.

EURECA

Le programme de développement ultérieur du Spacelab (FOD) a fait un pas en avant le 15 avril 1982: à cette date, en effet, les contributions souscrites par huit Etats membres participants (Allemagne, Belgique, Danemark, Espagne, France, Italie, Royaume-Uni et Suisse) ont atteint 80,8% de l'enveloppe financière de 155,9 MUC (au niveau des prix de la mi-1980), ce qui a permis de faire démarrer immédiatement des travaux.

L'élément le plus important de ce nouveau programme est la mise au point d'un porte-instruments récupérable européen – baptisé EURECA – qui sera lancé et récupéré par la Navette spatiale américaine. Cet élément de programme couvre également le développement d'un noyau de charge utile pour la première mission qui sera principalement axée sur les recherches en microgravité et plus particulièrement sur les sciences des matériaux et les sciences de la vie. Le lancement et la récupération prévus pour le premier vol sont programmés respectivement pour le printemps et l'automne 1987.

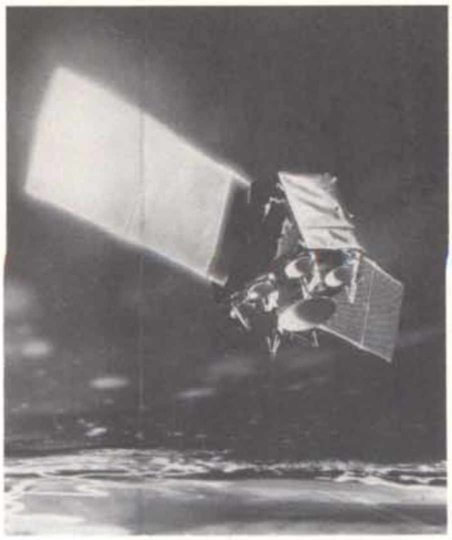
EURECA est un porte-instruments réutilisable étudié en fonction des besoins des utilisateurs européens. Avec une masse de charge utile pouvant atteindre 1500 kg, il pourra rester six mois ou plus en orbite en assurant à sa charge utile les servitudes essentielles, notamment une puissance électrique élevée (1,5–2 kW) et une capacité de dissipation de la chaleur. L'une des caractéristiques fondamentales du porte-instruments est son faible niveau de perturbation des forces gravitationnelles qui, pour les recherches en microgravité, est indispensable. Après avoir été déposé dans l'espace par la Navette, le porte-instruments sera propulsé par le moteur dont il est équipé sur une orbite plus élevée (environ 500 km) où les effets de la traînée subis par ses grands réseaux solaires seront très affaiblis. Dès que le porte-instruments aura atteint son orbite opérationnelle, la charge utile sera mise en service et exploitée par télécommande et, malgré leur haut degré d'automatisation, les expériences seront néanmoins contrôlées du sol. A la fin de sa mission, EURECA sera renvoyé sur une orbite plus basse où l'Orbiteur de la Navette pourra le récupérer et le ramener à terre avec sa charge d'instruments et d'échantillons de matériaux traités, afin d'être remis en état pour sa prochaine mission. Comme on le voit, EURECA est donc un porte-instruments réutilisable 'autonome', grâce auquel on pourra effectuer de façon économique des missions de longue durée.

Les deux autres éléments du programme ultérieur du Spacelab concernent les améliorations à apporter au Spacelab lui-même de façon à le rendre compatible avec un renforcement de l'énergie électrique de bord et une prolongation des missions jusqu'à deux ou trois semaines, ainsi que des études préparatoires portant sur des plates-formes spatiales futures. Un blocage partiel de ces deux éléments a cependant été décidé pour le moment, d'une part, dans l'attente des décisions que prendra la NASA sur les améliorations de la Navette et, d'autre part, en raison de restrictions financières.

MAGE

L'examen de qualification du moteur MAGE-II s'est achevé avec succès fin mai. La commission d'examen a recommandé que l'on prononce la qualification, sous réserve que quelques détails mineurs soient réglés. Elle a également complimenté les entreprises industrielles pour la qualité du travail effectué au titre du programme.

L'exemplaire de vol du moteur MAGE-II pour ECS-1 a été entreposé dans l'attente de l'exécution de quelques travaux mineurs (par exemple: installation de réchauffeurs alimentés par le satellite). Une nouvelle enveloppe de remplacement est en fabrication pour le moteur de secours. L'isolement thermique interne de l'enveloppe précédente présentait un pli d'une dimension inacceptable, qui a été révélé par examen aux rayons X après le chargement en ergols solides. On prévoit la livraison de l'exemplaire de vol et de l'exemplaire de secours du moteur vers la fin septembre, c'est-à-dire bien avant la date de lancement d'ECS-1 qui vient d'être modifiée récemment.



One Year of Solar Sailing with OTS

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Attitude control by solar sailing can be applied to geosynchronous satellites with rotating solar arrays extended north/south, assuming that the satellite is stabilised by a significant momentum bias. The OTS experiment has confirmed that this satellite, and probably many more, can fulfil the basic requirements for application of this control principle. After almost one year of successful operation, solar sailing is no longer regarded as an experiment for OTS, but is being continued as the 'normal' mode of attitude control.

The control principle
The principle relies on control of the direction of the spacecraft's momentum vector (external exchange of momentum). On satellites that have a single, fixed momentum wheel (e.g. OTS), attitude in roll and yaw is controlled as well due to the rigid coupling between the satellite and the wheel. In cases where multiple or gimballed wheels provide additional degrees of freedom between the satellite and its momentum vector, additional control loops for the internal exchange of momentum have to be foreseen.

At geostationary altitude the only significant source of disturbance torque on the spacecraft is solar pressure. If the satellite were perfectly balanced to this disturbance source, the momentum vector would maintain its direction and no control would be necessary. Since a residual misalignment cannot be avoided, the momentum vector changes its direction with a drift rate proportional to the degree of misalignment. The idea behind the solar-sailing control concept is to observe the magnitude and direction of the drift rate and to take the appropriate actions to re-establish a balanced configuration.

Since an accurate attitude reconstitution is possible only once per day, the control method is based on the assumption that the day-to-day repeatability of any misalignment with respect to solar pressure is high and that any measure to re-balance the configuration shares the same degree of reproducibility. The main purpose of the OTS solar-sailing experiment was to verify the validity of this assumption.

This article discusses the main elements of the control system, namely the attitude and drift rate reconstitution, the basic manoeuvres with the solar arrays to produce the requisite control torques, and finally the strategy for closing the control loop.

Attitude and drift-rate reconstitution
Figure 1 shows the OTS satellite in its typical in-orbit configuration with its yaw axis Earth-pointing and its roll axis pointing in the flight direction. These axes are fixed to the body of the satellite.

An array-fixed coordinate system can be defined with an out-of-plane axis alpha that is nominally Sun-pointing and an in-plane axis beta.

The direction of the momentum vector is usually expressed in terms of body-fixed-system roll and yaw because the attitude-control thrusters are also body fixed. Since in the case of solar sailing the control torques are produced by the solar arrays, it is more convenient to use the array-fixed system here.

Typically, the only available attitude information for satellites of this class is the roll angle, which in the case of a single fixed-momentum wheel is measured by the roll channel of the Earth sensor (e.g. infrared Earth sensor). In the case of an additional degree of freedom between the momentum vector and the sensor axis due, for example, to gimbals or multiple wheels, where the inner control loop

Figure 1 – In-orbit configuration of OTS

Figure 2 – Windmill control torque

Figure 3 – Imbalance control torque

maintains the yaw axis Earth-pointing, the roll angle of the momentum vector has to be measured either by the appropriate gimbal angle resolver or by the wheel tachometers.

Once per day, at 6.00 h spacecraft time when Sun and Earth directions are orthogonal to each other, the roll axis coincides with the alpha axis. At this moment the roll angle is recorded and stored for the next 24 h as the alpha angle.

At a second time every day, namely 12.00 h spacecraft time when Sun and Earth direction are antiparallel, the roll axis coincides with the beta axis. At this time the roll angle is recorded again, but is then stored as the beta angle for the next 24 h.

The average drift rate of the momentum vector during the previous 24 h can be calculated as the difference between the new and the previous reading of alpha or beta, divided by the period of 24 h.

Control torques

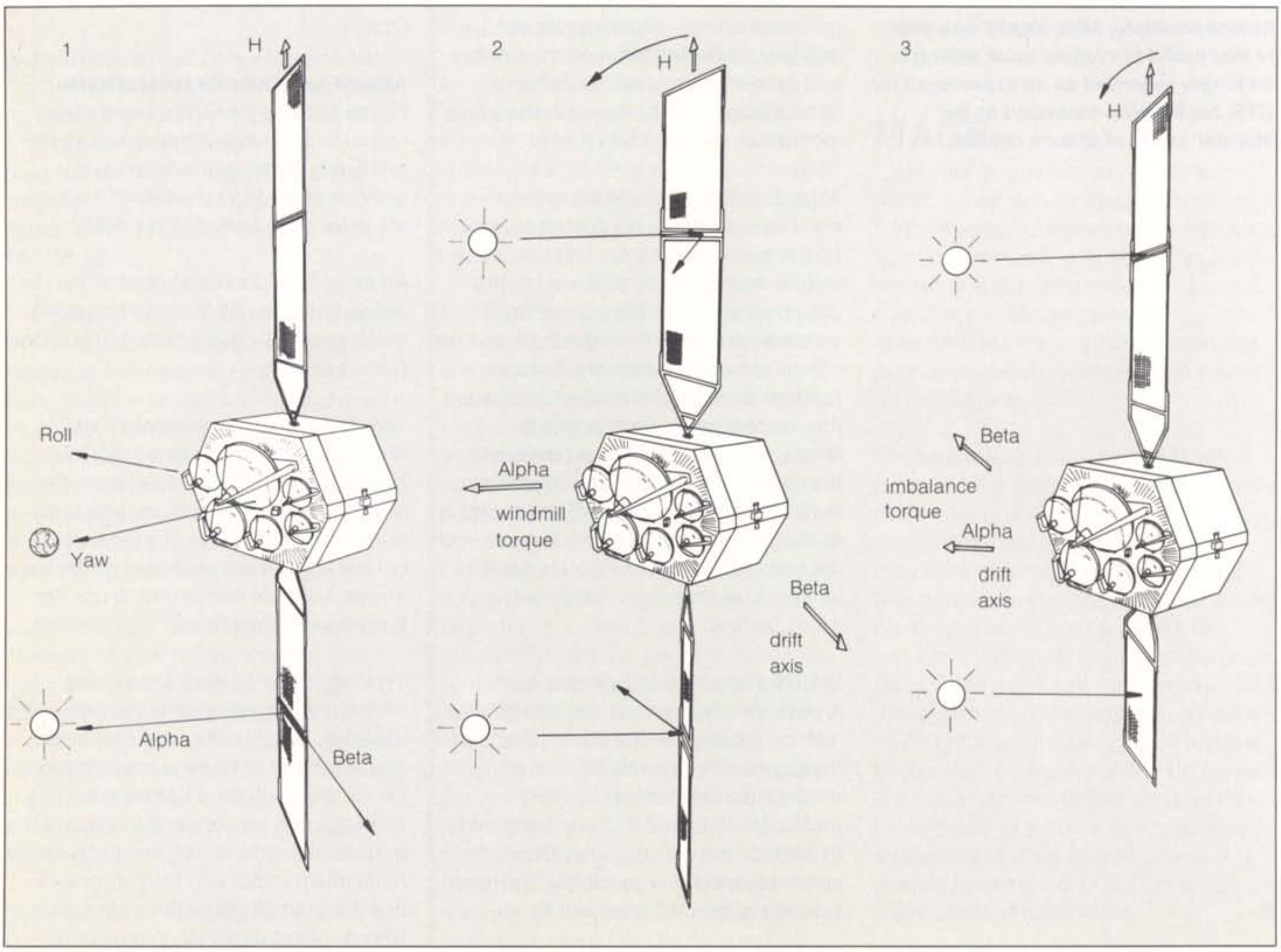
The solar arrays of OTS or those of any other satellite of similar configuration can be used to generate control torques about the alpha or beta axes separately: the so-called 'windmill control torque' for control of beta and the 'imbalance control torque' for control of alpha.

Windmill control torque

If, as shown in Figure 2, the arrays are skewed to each other by a permanent positive offset in the array-drive loop of one array and the same negative offset in the other, the solar pressure forces on the arrays remain balanced, but the reflected sunlight (typically 15°) produces a windmill torque around the alpha axis, causing a constant drift rate in the momentum vector H around the beta axis. This manoeuvre can be used to control beta.

Imbalance control torque

If, as shown in Figure 3, the array area exposed to the Sun is reduced on one side only, the solar-pressure distribution



becomes nonsymmetrical and a control torque can be generated around the beta axis equivalent to a drift rate around the alpha axis, which can be used to control alpha.

Whereas the generation of a windmill torque is straightforward, permanent reduction of the projected solar array area on one side without at the same time introducing additional windmill torques requires special equipment, such as motor-driven hinges to deploy the solar panels or dedicated flaps.

What can be achieved, however, without additional equipment, is an average reduction in a solar-array area, associated with an average compensation of the associated windmill torques, simply by advancing and delaying the array on one side in a symmetrical duty cycle. This concept is used on OTS.

Control loops

Alpha and beta are controlled separately. Alpha is measured by the roll sensor at 6.00 h spacecraft time and controlled by the application of imbalance control torques. Beta is measured by the roll sensor at 12.00 h spacecraft time and controlled by the application of windmill control torques.

At the time when the relevant angle is measured, it is compared with the previous reading to establish the drift rate, as described above. This is followed by a prediction of the angle 24 h ahead, using the present reading and the drift rate.

If the next day's predicted angle falls between predefined thresholds, no resetting of the control parameters is necessary. If the angle, as in Figure 4, falls outside the permitted area, the control torque has to be modified by the minimum step that can be commanded (one bit).

The windmill control torque can be modified by one bit by changing the constant bias in the array drive loops by the lowest commandable step.

The variation in imbalance control torque by one bit is achieved in the same way, if for example, stepper motors are used to drive the solar-array hinges or dedicated flaps. In this case one bit means one step of the stepper motor. In the case where the average array area is reduced by a number of oscillations of one array per day, this number will have to be modified by one.

In summary, the use of the drift-rate information ensures stability of the loop, whereas the restriction to one bit at a time reduces the loop gain, and filters the day-to-day variation of the Earth sensor, due mainly to meteorological disturbances.

Advantages of attitude control by solar sailing

Due to its typical low-gain characteristic, this method of attitude control offers a number of significant advantages.

Reduced hardware complexity

As long as the loop is closed on the ground, no additional onboard equipment is required, as verified by the OTS experiment. Instead, a number of onboard items can be saved; for example, on OTS four dedicated roll/yaw control thrusters, the associated control electronics, and typically a few kilogrammes of propellant.

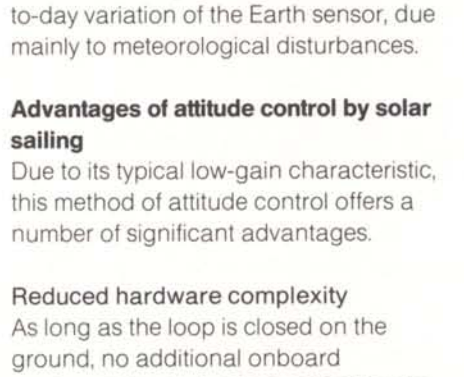


Figure 4 — Solar-sailing control strategy

In addition, during the normal mode of operation the reaction control system can be completely disabled, e.g. by closing the latching valves, so that the risk of a thruster leaking after operation can be removed and the automatic protection logic can be simplified accordingly.

Increased pointing accuracy in roll and yaw

Since this method operates in inertially fixed coordinates, the yaw pointing accuracy is as high as the roll accuracy compared with conventional systems, where the yaw accuracy is typically rather low.

A further improvement can be achieved by using the periods between observations for calibration of the roll sensor. In particular, the sensor can be switched to various modes of operation to identify meteorological disturbances in a single channel.

Daily roll-sensor variations (significant for some types of sensors) can be excluded because the observation always occurs at the same time of day. In particular, systematic sensor disturbances due to Sun blinding or Sun reflection around spacecraft midnight (a major source of concern) can be neglected, because the relevant observation time is outside this period.

Simplified ground operation

The time-critical commands to reconfigure the Earth sensor to avoid Sun blinding at spacecraft midnight can be eliminated. This outweighs the addition of a few daily (non-time-critical) commands to execute the solar-sailing manoeuvres.

A further advantage is that even if the Earth lock is lost, due to some unforeseen event, the angular-momentum prior to the anomaly can be easily recovered since all thrusters are disabled. The recommended attitude reacquisition is then based on wheelspeed variations and not on the use of control thrusters. This type of manoeuvre is simpler and faster than the conventional sequence: Sun acquisition followed by Earth acquisition at the next orthogonality between Sun and Earth directions.

Power saving

A significant power saving can be achieved in the thermal control of the reaction control system, which has to be activated only for station-keeping manoeuvres, typically once every six weeks. In between, it can remain in hibernation mode. The same applies to the power saving in the areas of thruster drivers and roll yaw control electronics. This power saving outweighs the power loss due to the reduction in projected solar-array area inherent in the principle of solar sailing.

The OTS experiment

The idea behind this experiment was to verify the general feasibility of solar sailing on a satellite that was not specifically designed for it and to investigate its potential performance.

Controlling beta was comparatively easy because the array drive loop provides a constant bias capability in steps of 1.28°, which proved rather convenient.

Controlling alpha caused more problems, since there is no special equipment on board for reducing the projected area of the solar arrays. Instead, as discussed earlier, a duty cycle for the array drive was introduced. Again the preferred trapezoidal duty cycle shown in Figure 5a was not achievable because the OTS array drive loops are unidirectional. Instead a saw-tooth-shaped duty cycle (Fig. 5b) is used whereby the array is advanced quickly by the array motor, followed by a period in which the drive is disabled, and hence the array rotates backwards with respect to the Sun at the orbital rate of 15°/h.

The maximum amplitude of the duty cycle is constrained on OTS by the maximum bias capability of 19.2°. This amplitude has proved to be rather convenient and hence a standard duty cycle with this amplitude, and consequently a typical duration of almost 3 h, was defined at the beginning of the experiment. The parameters that remained open were the number of duty cycles per day, and the distribution of manoeuvres over the following 24 h period.

A preliminary experiment was performed over a period of six consecutive days, from 29 October to 3 November 1978. The validity of the control principle was thereby verified during a period with rather low external disturbance torques. The experiment was resumed almost three years later, on 2 October 1981, with the intention of continuing through the changing seasons, under all disturbance-torque conditions.

In-orbit experience

A number of valuable observations have been made: for example,

(i) The disturbance torque around the alpha and beta axes is very predictable from one 24 h period to the next. The torque around the beta axis is constantly in the order of 10^{-7} Nm and can be explained by a constant misalignment between the solar arrays of 0.6°, due to, for example, deformation of the array structure, sensor misalignment, or differences in bearing friction. Consequently, the beta control loop is limit-cycled between no bias at all and 1 bit of bias, i.e. 1.28°, to the north array only. Strictly speaking, both arrays should be biased, but experience has shown that the cross-coupling into the alpha control loop is negligible if the bias is restricted to a few degrees. The resulting duty cycle is very smooth; typically 3 d of bias followed by 3 d of no bias.

(ii) The disturbance torque around the alpha axis is sinusoidal over a period of one year (Fig. 6), with a maximum torque of 1.5×10^{-6} Nm around summer solstice and a minimum of 0.5×10^{-6} Nm around Winter solstice. Around 20 February and 20 October each year there are periods with virtually no disturbance torques at all, i.e. less than 10^{-7} Nm, during which the satellite maintains its attitude for several days without any roll/yaw control.

Accordingly, the number of duty cycles to reduce the array area projected to the Sun varies sinusoidally through the seasons as shown in Figure 7. During Summer solstice, up to four duty cycles with the south array are required, whereas the opposite, extreme situation around Winter solstice requires up to two duty cycles with the north array.

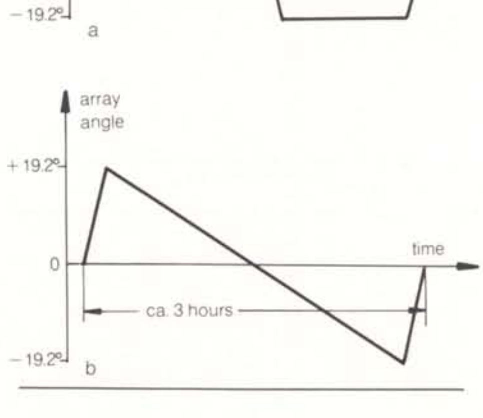


Figure 5 — Duty cycles: (a) Trapezoidal, (b) Saw-tooth

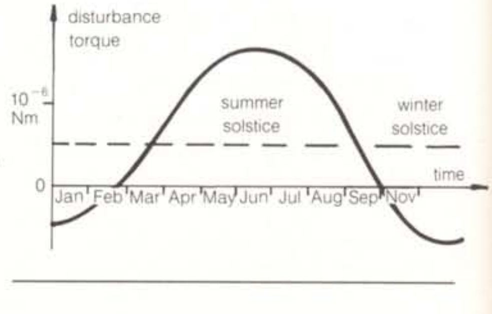


Figure 6 — Yearly disturbance-torque variation

Figure 7 — Yearly control-manoeuvre variation

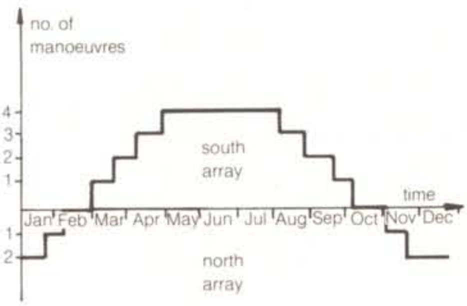


Figure 8 — Thruster control mode

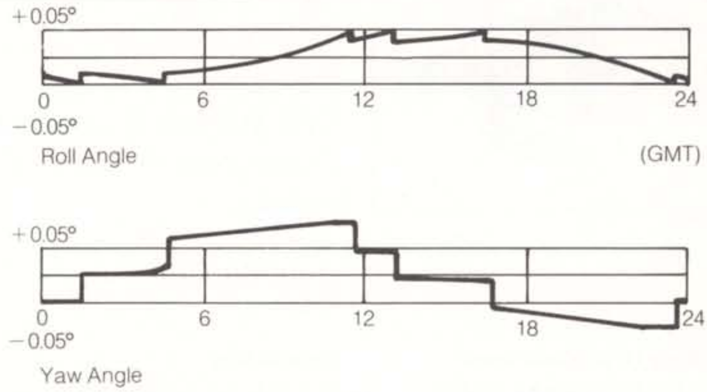
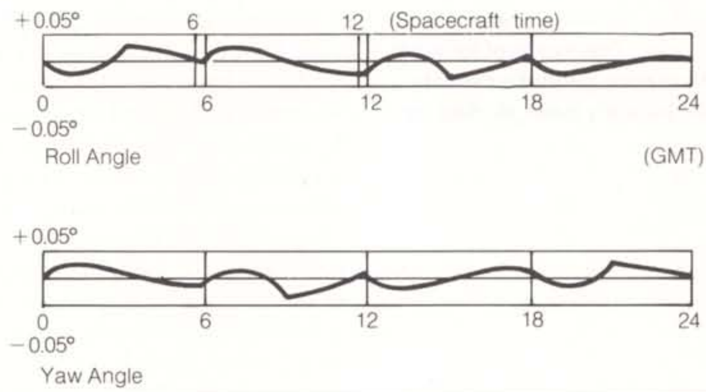


Figure 9 — Solar-sailing control mode



The sinusoidal character of the control torque can be explained by a bending of the array tips towards the Sun by a few centimetres. The zero shift can probably be explained by the inclination of the antenna platform. Observations in October 1978 (during the first test period) and in October 1981 (during the ongoing test) have confirmed that year-to-year reproducibility is better than the resolution of the Earth sensors.

(iii) A high reproducibility in the disturbance-torque compensation is achievable if a well-defined time line is followed for the execution of commands. In this way it is possible to base the attitude control on two observations per day and to operate in open loop in between.

(iv) Any residual nutation at the end of a station-keeping manoeuvre damps out naturally with a time constant of 10 to 20 h.

(v) Figure 8 shows the typical roll-angle variation during June 1978 when OTS's attitude was controlled by six double control-thruster pulses per day. It can be seen that, although the roll angle is controlled within a deadband of approximately 0.05°, the yaw accuracy is less well governed because this angle is only indirectly controlled.

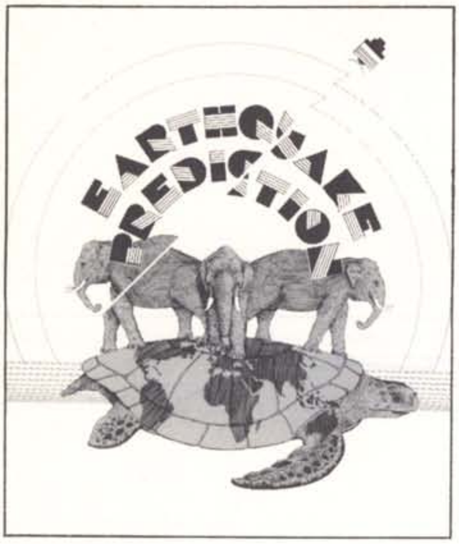
Figure 9 shows the roll-angle variation four years later, in June 1982, when the attitude was controlled by four duty cycles of the south array per day. In comparison with Figure 8, it can be seen that: (a) the roll angle remains comfortably within the thresholds of plus and minus 0.05°, and (b) yaw performance is systematically as good as roll performance.

The control manoeuvres, each lasting approximately 3 h, were evenly distributed over the 24 h period and executed at 0, 6, 12, 18 h GMT.

(vi) A comparison between Figures 8 and 9 shows that thruster pulses produce abrupt changes in roll and yaw angle, whereas the array manoeuvres produce a smooth attitude correction. This fact is important if calibration techniques or gimballed antennae are to be introduced to further improve pointing accuracy.

Conclusion

Attitude control by solar sailing is a simple and accurate disturbance-torque compensation technique, as long as the disturbance torques are reasonably reproducible from day to day. One must therefore avoid sudden deformations of the arrays (centre of pressure) or sudden mass shifts, due for example, to fuel sloshing (centre of gravity). Also to be avoided are additional control torques that are not sufficiently predictable, such as thruster torques or magnetic torques.



Popsat – A Tool for Earthquake Research

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Space-geodesy techniques have improved to the point where routine monitoring of the motion of the Earth's crustal plates by satellites could soon become a reality. One concept for such a high-performance geodetic satellite, 'Popsat', has recently been studied by ESA.

Introduction

Geodesy, the science of measuring physical dimensions on the Earth and of the Earth and interpreting their significance, is probably as old as humanity. More than 2000 years ago, Eratosthenes travelled south along the Nile to compare the Sun's elevation at noon on a given day at a given hour at different latitudes, and thereby derived the Earth's circumference in terms of the distance he had travelled. To be able to translate the observed elevation differences, he needed to know the Sun's distance from his measurement position. He had already determined the Earth-Moon distance to within a few percent by parallax observation, i.e. by observing the Moon from different points on the Earth against the background of stars, whose distances he had (correctly) assumed to be very great compared to the Earth-Moon distance. When he tried to apply the same method to measure the Earth-Sun distance he found this distance too great for the method to work and made the quite valid approximation of assuming the Sun to be infinitely distant. He applied an art developed and refined over thousands if not tens of thousands of years, astronomy, to a geodetic problem, and thereby created a new discipline: space geodesy.

Modern space geodesists are replacing the natural celestial object utilised by Eratosthenes with artificial satellites to improve on his accuracy by many orders of magnitude, but their ultimate goal has not changed. The Earth's radius, or more correctly, the exact shape of the Earth in terms of the gravitational equipotential surface closest to the mean sea surface (the geoid), is now being refined almost daily.

Repeated, precise measurements of three-dimensional locations of points on the Earth's surface in terms of an Earth-centred reference frame are needed to determine the Earth's kinematics, i.e. the movements of its spin axis and variations in its rotation rate, which are indications inter alia, of large-scale mass shifts in and on the globe. More and more, precise measurements of relative distances on the Earth are needed to make monitoring of global, regional and local movements in the supposedly 'solid Earth' a reality.

Satellite geodesy

How then can a satellite serve as a tool for geodesy, and therefore for earthquake research? The satellite orbit serves as a bench mark for the space geodesist just as the plane table does for the land surveyor or the Sun did for Eratosthenes. The surveyor's bench mark is static however, so that a measurement he cannot make today he can equally well make tomorrow. Likewise, all Hipparchos had to do was to keep track of the calendar and the hour of the day. A satellite on the other hand is a moving bench mark (several kilometres per second) and accurate knowledge of its path is of no use unless its time dependence is also known. A plane table's location can be described by just the three spatial coordinates; the satellite orbit, if it is to be used as a bench mark, must be described in terms of a four-dimensional, time-space coordinate system.

Figure 1 – Trilateration tracking of a satellite

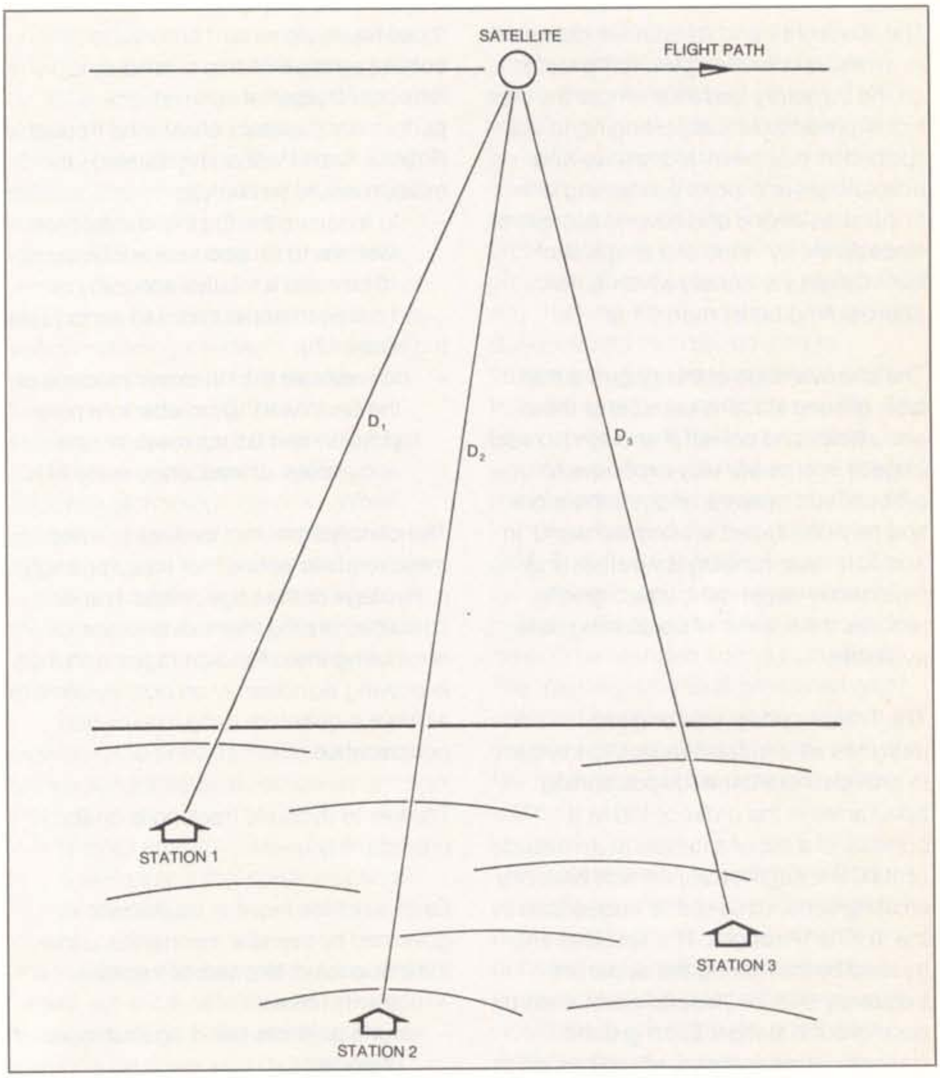


Figure 1 shows three ground stations measuring the distance to the satellite. Its location can be determined by simple geometry, if the locations of the ground stations are known. All three ground stations must perform their measurements at the same moment, otherwise their measurements cannot be geometrically combined. The three ground-station clocks must therefore be synchronised very accurately in view of the satellite's high speed.

In practice, the ground stations, rather than making simultaneous distance measurements, would continuously track the satellite as long as it is visible. They would either monitor its distance ('ranging'), or the change in distance with time ('range-rate'). Either measurement gives the required information, and sometimes both techniques are used simultaneously to improve measurement accuracies.

In Figure 1 the problem has been turned around compared with what we set out to do: the satellite orbit was to serve as a bench mark to measure the positions of ground points. However, to determine the satellite's orbit, ground points with known positions are needed, leading to something of a chicken-and-egg problem! This poses no problem though for the space geodesist, for whom the two parameters, satellite orbit and ground-point position, are but two unknowns in a set of equations. These he solves, with ever-increasing refinement, by using the literally millions of tracking data points acquired during the life of a geodetic satellite. For his task he uses the physical laws governing satellite trajectories, celestial mechanics, geodynamics, gravitation, satellite-surface forces, etc., to develop programs for execution on powerful modern computers.

Figure 1 shows what space geodesists call the geometric method: the satellite position at a given instant is determined by purely geometric means (trilateration). Only relative station positions can be measured. Dynamic methods take into account models of the satellite's orbital motion and do not require simultaneous tracking from stations. In fact, the better the orbital predictability, the better tracking data taken at different times can be tied together and therefore the greater can be the gaps in ground-station coverage for a given tracking accuracy. Powerful computer programs have been developed to combine all these tracking data into useful data sets. Station coordinates are then computed in an absolute reference frame (with the Earth's mass centre as its origin) identical to the one in which the satellite orbit is described.

Existing satellites for geodesy

Geos-3, Starlette, Lageos and Transit are geodetic satellites already in orbit. The last two can be considered the workhorses of point positioning from space. Roughly speaking, the two have yielded comparable accuracies in point positioning, though they differ fundamentally in such important aspects as tracking method and orbital altitude.

Lageos is a dense (small and heavy) satellite with a high mass-to-cross-section ratio, in a high orbit at 5000 km altitude. It is completely passive, the only payload being an array of laser retroreflectors.

The spacecraft and its orbit are designed to minimise unknown perturbing forces on the trajectory and thus render the orbit highly predictable. Laser ranging to the spacecraft has permitted relative and absolute ground-point positioning with accuracies of one and several decimetres, respectively, by virtue of a single-shot laser ranging accuracy which is now approaching better than 0.1 m.

The disadvantage of the system is that laser ground stations capable of these accuracies and powerful enough to reach Lageos in orbit are very expensive to procure and operate, and are therefore sparsely-distributed around the world. In addition, laser ranging is weather and time-of-day dependent, which greatly reduces the volume of positioning data available.

The Transit system was originally designed as a ground navigation system to provide instantaneous positioning accuracies in the order of 100 m. It consists of a set of satellites at an altitude of 1000 km, each equipped with beacons emitting continuous stable frequencies in the VHF/UHF ranges. The satellites are tracked by monitoring the apparent frequency shift, or Doppler effect, seen by each ground station. Such ground stations are inexpensive, which has led to the availability of literally thousands of ground points. In addition, tracking is not weather or time-of-day dependent. This has led to an abundance of positioning data, which with proper processing (despite the fact that the satellite is significantly affected by air drag and gravitational perturbations) has, surprisingly, provided positioning accuracies in the order of several decimetres, that is approaching those of the Lageos system, but for a much higher number of ground points.

The Popsat concept

Why then study a new geodetic satellite concept? Useful as Lageos and Transit are, the modern goals of space geodesists are now much higher than those two systems can achieve. In consequence, ESA has carried out feasibility studies of such a high-performance system, christened Popsat (Precise Orbit Positioning Satellite). Its mission would be twofold:

- to measure the Earth's crustal plate motions to an absolute accuracy of 10 cm, and a relative accuracy of 1 cm (with applications to earthquake research).
- to measure the kinematic motions of the Earth with 10 cm absolute pole-position and 0.5 ms rotation-rate accuracies, at least once every 24 h.

The concept that has evolved to meet these requirements is, not so surprisingly, a marriage of the Lageos and Transit concepts, uniting their advantages, eliminating their disadvantages, and thus improving significantly on both systems to achieve a quantum jump in expected performance.

The key to dynamic tracking is orbit predictability.

Earth satellites move in trajectories governed by celestial mechanics under the influence of two sets of forces:

- gravity forces
- surface forces (air drag and radiation pressure).

How do they arise and how do we live with them?

Gravity-field uncertainties

The dominant gravity field acting on Earth-orbiting satellites is that of the Earth itself, and this is where the problems start. The Earth's mass is distributed rather unevenly over a volume that is not quite spherical, pole flattening being the most significant deviation. Continents and mountains are visible anomalies, but mass inhomogeneities continue deep into the Earth's mantle and perhaps beyond. The Earth's gravity field, therefore, is rather more complex than that of a point mass or a perfectly homogeneous sphere. In the mathematical description of this field in so-called 'spherical harmonics', there are higher order terms of significant amplitude present, significant that is for the tracking accuracy needed for a geodetic satellite. Determining the fine structure of the field, i.e. the values of the harmonic terms, is not trivial. Existing models are far from perfect and are being continually, but slowly, improved using satellite tracking data and ground-based gravimetry. As Hieber pointed out in an article published in an earlier ESA Bulletin (No. 28, November 1981), only a dedicated gravity mission (e.g. Slalom, Gravsat) would answer most of the present questions and uncertainties.

The only way to minimise the gravity uncertainties is to move further away, literally. The higher order harmonic amplitudes decrease rapidly as one moves away from the Earth; appraised from say Mars, the Earth is effectively a point mass. Unfortunately, it also looks, optically, rather like a point from such distances, so no matter how well, in the absence of gravity field uncertainties, the position of such a faraway vantage point can be determined, it would be of little use for geodetic purposes. The measurement geometry would be too unfavourable.

The Popsat studies have shown that the best orbit would be at an altitude of 6930 km with an inclination, also for reasons of gravity-field uncertainties, of 70°. This is in fact a similar orbit to that of Lageos. Even at that orbital altitude, however, residual orbital perturbations, or more correctly orbital unpredictabilities, though small, are still significant. Fortunately, techniques are available by which the first few months of the mission could be spent in deriving, from tracking data, a gravity model tailored to the orbit, sufficiently accurate to account for the above residuals.

Surface forces

Unfortunately, the task of achieving good orbit predictability is far from being solved. Nongravitational perturbing forces, namely particle drag and radiation pressure, act constantly on satellites.

Particle drag, or mechanical braking of the satellite's orbital movement, is significant only for low-flying satellites (think of the spectacular re-entry of Skylab). It decreases approximately exponentially with increasing altitude.

At Popsat's altitude, chosen on the basis of gravity considerations, particle drag is so low that it can be neglected. Radiation pressure, on the other hand, is a more serious problem. Impinging electromagnetic radiation exerts a pressure. Like a paddle wheel suspended in vacuum in a Crooke's radiometer, which turns as soon as it is illuminated, Popsat would be subjected to various sources of radiation pressure:

- direct sunlight
- sunlight reflected from the Earth
- Earth's thermal radiation
- satellite thermal radiation.

Although solar radiation is the dominant component for the Popsat orbit, its direction and amplitude are very well known, and virtually constant. In addition, the Earth directly reflects part of the radiation energy received from the Sun in the visible part of the spectrum; the other part is re-radiated into space in the form of thermal radiation in the infrared. These two components are of the same order of magnitude, but vary with time over the Earth's surface. Modelling these variations is extremely difficult and for Popsat they would need to be measured onboard to let one model the resulting pressure forces sufficiently accurately.

Finally, the satellite itself radiates heat in the form of infrared radiation, and this creates a recoil force which has to be allowed for.

Satellite configuration

To monitor and compensate for the effects of all of these different kinds of surface forces, use of an onboard micro-accelerometer had been proposed. As long as the satellite moves on a purely ballistic trajectory, i.e. one determined by gravity only, the accelerometer would be unaffected. It would, however, respond to any nongravitational acceleration caused by, for example, surface forces. Such an accelerometer (called Cactus) has already been flown on the French Castor satellite and measured not only particle drag, which was its primary mission, but also radiation pressure. An improved version (Supercactus), sensitive enough for Popsat, has also been studied. It has very demanding interfaces and would put severe constraints on the satellite. The feasibility of achieving the required sensitivity, accuracy and resolution has not yet been established, making its adoption technologically risky. When studies showed that only radiation forces were significant for Popsat, and that they could be modelled with an accuracy of the same order as that of Supercactus, the latter option was not considered further.

However, the need to model surface forces accurately puts two constraints on Popsat:

- a small area-to-mass ratio
- a need to control surface optical properties.

It is therefore necessary to have a small, heavy, spherical satellite with an optically uniform surface. Since electrical power can only be generated by solar cells mounted on the satellite skin, the onboard power requirements set a lower limit to the satellite's size of a 1.9 m diameter. To keep the area-to-mass ratio low enough, ballast masses would be added.

A prime requirement for the Popsat tracking system is an all-weather capability. This dictates a high-performance, radio-frequency tracking system, which in fact would become the satellite's principal payload. In addition, a laser reflector would be required for calibration purposes.

The radio-frequency antennas and laser reflectors would be mounted on the Earth-pointing side of the spherical three-axis-stabilised spacecraft. The main method of stabilisation is foreseen as gravity gradient, achieved by proper distribution of the ballast masses. This completely passive method of attitude control would permit use of the satellite for laser ranging beyond the end of the satellite's active life. On Popsat the problem of time synchronisation between ground stations would be avoided by two-way tracking. The function of the ground station would then be reduced to transponding the tracking signal emitted from the satellite back to the satellite. The time correlation of the tracking data would be performed onboard the satellite, using a common time reference derived from the onboard clock for all tracking data. The ground station, reduced to a transponder, would be inexpensive to procure and operate, since it should not need to be manned during operations. The tracking data thus generated and collected onboard would be stored in an onboard memory and downlinked every few orbits to a central data-acquisition station.

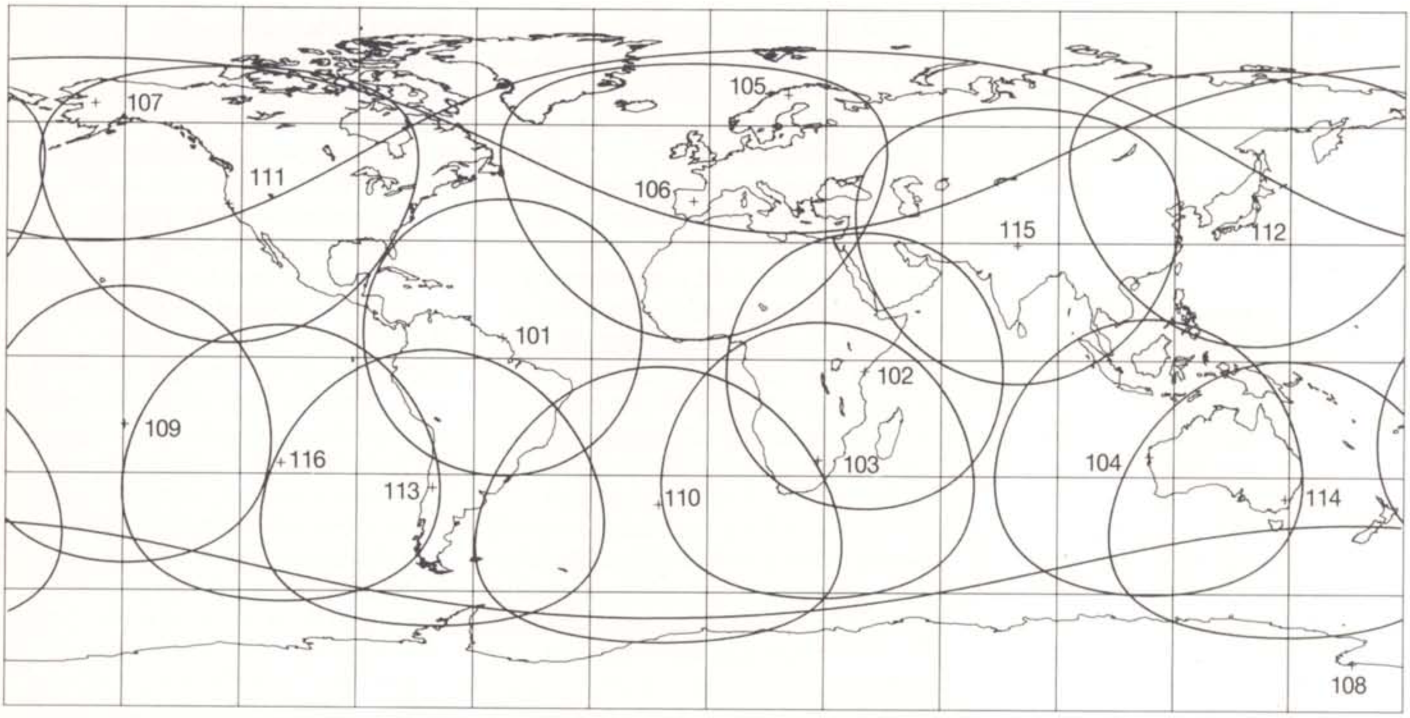
The Popsat space segment has thus emerged as a heavy-core satellite at a high orbital altitude, equipped with onboard radio-frequency tracking equipment and a laser reflector array. It would therefore share the good orbit predictability of Lageos, and the all-weather capabilities and low ground-station costs of the Transit system. At the same time it would improve on the performance of RF tracking systems by employing round-trip measurements and using higher RF frequencies to reduce errors introduced by the Earth's atmosphere and ionosphere.

Popsat system configuration

Let us now look at how to complete the system to exploit all its advantages and employ it for geodetic purposes, particularly earthquake research.

The Popsat orbit and the geocentric reference frame in which it is moving would be established by a network of only 16 ground stations, sited to ensure almost

Figure 2 — Possible Popsat ground-station tracking network (MEX network) with complete global coverage, showing visibility curves and ground tracks during a single day



continuous visibility as the satellite moved in its orbit (Fig. 2). This basic tracking network which we call the 'Mission EXecution (MEX) network', includes the central data-acquisition station mentioned earlier.

The system composed of the Popsat satellite and the MEX would establish the geodetic reference frame and fulfil, by continuously monitoring station coordinates, two of the principal goals of the Earth-kinematics mission, monitoring both the orientation of the Earth's spin axis (polar motion) and variations in its rotation rate. Given a single-shot-measurement range error of 10 cm, MEX station coordinates would be determined to within 10 cm in the Earth-rotation-centred reference frame, and to within 5 cm relative to each other. Resulting accuracies for earth kinematics are predicted to be:

- 10 cm for absolute pole position
- 500 μs for Earth rotation period

with a time resolution of 24 h.

Secondly, there are the GEO stations, the type of Popsat ground stations whose performances would be optimised for determining relative point positions over short distances (less than 300 km) with an accuracy approaching 1 cm. Stations would be used in arrays to monitor movements of the Earth's surface over very short time scales (hours to days) in tectonically active areas.

Finally, the coordinates of particular ground points could be determined by equipping them with autonomous, receive-only stations; so-called 'USER' stations. Their sophistication could vary; there could be stations making full use of the system capabilities, whereas other stations, for users with less stringent position-accuracy requirements, might use simpler equipment.

System errors

The principle of satellite ranging is the measurement of the time it takes for an electromagnetic signal to travel between observer and satellite. As the observer is almost invariably located on the Earth's surface, the signal has to travel through the Earth's atmosphere, which introduces errors. Electromagnetic waves are subject to bending and changes in apparent path lengths, due to a variety of effects, some of which are frequency-dependent.

First, dry air has a refractive index slightly greater than the vacuum refractive index of 1. An electromagnetic wave travelling vertically through the atmosphere is therefore delayed by about 10 ns, corresponding to a path lengthening of about 3 m. Obviously, this value increases as the elevation angle is lowered from zenith and depends on the amount of air traversed, of which the air pressure on the ground is some measure.

Secondly, radio waves are sensitive to water vapour in the atmosphere. For average air humidities, this effect causes zenith delays of about 1 ns, corresponding to a path lengthening of about 30 cm. Measuring the humidity at the ground location is insufficient to correct for this effect to an accuracy of a few centimetres, so that radiometers (co-located with MEX stations) would have to measure total water-vapour content along the propagation path.

However, by far the most perturbing effect is that of the ionosphere. At frequencies in

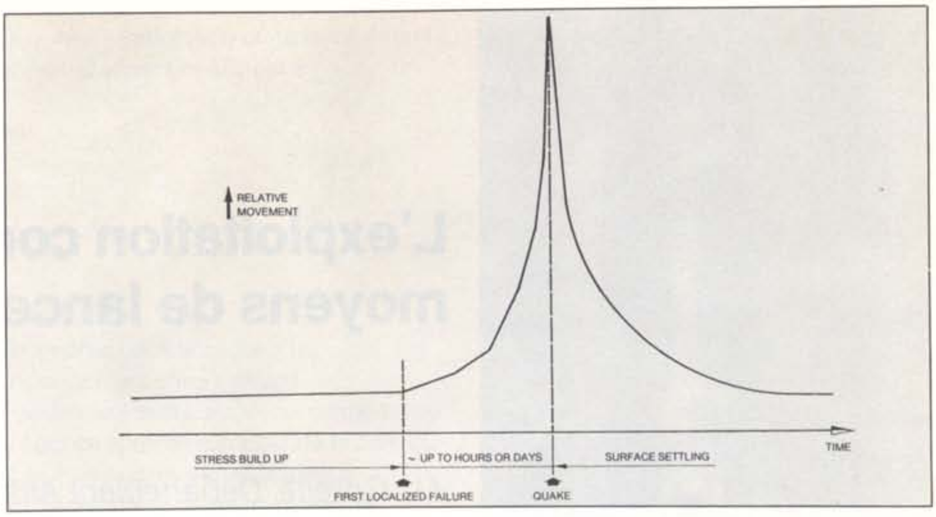


Figure 3 — Soil movements before, during and after an earthquake

the megahertz region, path bending can be so pronounced that the radio wave is effectively reflected from the ionosphere (worldwide shortwave radio communication is based on this effect).

At VHF frequencies, path-length errors can still be of the order of kilometres at zenith. The effect depends on the total free electron content along the path, which varies over three orders of magnitude with time of day, season, and solar activity. Fortunately, the effect varies with frequency, decreasing very nearly with the square of the frequency. One way, therefore, of reducing the error is to increase the frequency, but limits to this are set by increasing atmospheric absorption. Correction of the remaining error, to meet Popsat accuracy requirements, would be achieved by two-frequency techniques.

All errors due to atmospheric and ionospheric effects are strongly elevation-angle dependent, since the length of the signal path increases as one moves away from the zenith direction. The Popsat studies have established that tracking data taken at elevation angles of less than approximately 30° would not contribute significantly to the overall tracking accuracy. This has been allowed for in the coverage circles of Figure 2.

Role of Popsat in earthquake research

The manifestation of what is commonly called an earthquake is a sudden displacement of the Earth's surface, imparting accelerations to everything attached to it, including man-made structures. Displacements of sufficient amplitude have disastrous effects.

The driving mechanism for earthquakes is tectonic-plate movement. The Earth's crust consists of several large (and some smaller) plates that 'float' on the underlying semi-liquid mantle, just like ice sheets on water. The plates move independently in different directions. It is now well established that the plate motions are driven by convective currents in the Earth's mantle. These are extremely slow (~ centimetres per decade) by man's standards and go completely unnoticed to an unaided human observer anywhere on the surface of such a plate.

It is at the edges where plates touch each other that plate motions become tangible. Stress builds up in the adjacent rocks of the different plates and unless the rock begins to flow under high pressure (which leads to gentle movements, 'silent earthquakes' as geodesists call them) the rock will eventually break, resulting in an earthquake.

The build-up of stresses due to the unrelenting steady motion of the plates is accompanied by crustal deformations which are at best difficult, and more usually impossible, to measure by ground-based survey methods. As with any failure in an inhomogeneous mechanical joint, an earthquake is not a sudden event. First, the flow limit or break limit is exceeded in a very localised area, which leads to increased stress in adjacent areas, and then eventually to a major tremor or earthquake. Precursor phenomena such as minor tremors, release of gases, etc. have been observed before many major earthquakes.

After the quake, the crust material settles and adjusts to the new distribution of rock masses in the crust. This can take days or weeks. Figure 3 shows what could be the relative movements of surface points in an earthquake zone, before, during and after a major quake.

By deploying a large number of GEO stations in seismically active areas, the Popsat system should have both the time resolution and accuracy required to monitor such movements. This would contribute not only to a better understanding of earthquake mechanisms, but also, if one considers the movements preceding a quake, to the eventual provision of an earthquake warning service.

These local phenomena are not the only manifestations of an earthquake. A major quake has global repercussions. The shift in rock masses in the Earth's crust beneath the epicentre during a quake not only changes the local gravity field, but also upsets the Earth's rotation. The spin axis will change both in position with respect to the Earth's surface and in its orientation in space, and the rotation will be perturbed, detectable as changes in the rotation rate.

The Earth-kinematics mission of Popsat with its high time resolution is ideally suited to investigate such phenomena, and improve our understanding of the relationship between all the processes occurring.

Conclusion

The Popsat system outlined would be a powerful tool for earthquake research and prediction; its mission of point positioning would monitor overall tectonic-plate movements (the driving mechanisms for earthquakes) and crustal distortions in earthquake-prone areas; its earth kinematics mission would contribute to the understanding of earthquake mechanisms.

Popsat alone would not provide all the answers, but could reasonably be expected to constitute a major step forward in our understanding of earthquakes, measurement of their precursor phenomena, and hence their eventual prediction.

L'exploitation commerciale des moyens de lancement

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Si l'on considère que l'histoire du transport spatial, qui a débuté en 1957, comprend trois périodes – la découverte et la démonstration (1957–1969), l'exploration utile (1970–1980) et l'exploitation commerciale qui commence avec la présente décennie – il faut observer que seuls les Etats-Unis et l'Union soviétique disposaient de toute une gamme de moyens de lancement opérationnels au cours des deux premières périodes de cette histoire.

La situation dans le passé
La disposition de moyens de lancement opérationnels par les Etats-Unis et l'Union soviétique était considérée avant tout comme une priorité nationale à plusieurs titres: prestige, sécurité, recherche scientifique et technologique, développement économique. On remarquera à cet égard que si l'industrie aérospatiale des Etats-Unis a assuré la production des lanceurs américains, c'est l'Administration américaine de l'Aéronautique et de l'Espace (NASA) qui a toujours eu le monopole, en s'appuyant par contrats sur l'industrie, des opérations de lancement, toutes effectuées à partir de bases de lancement gouvernementales (Cap Kennedy, Western Test Range, Wallops Islands) et utilisant des installations également propriété du gouvernement (Centre de contrôle de Houston, réseau de poursuite et de communications, etc.). On pourrait donc dire que ce n'est qu'accessoirement que les Etats-Unis ont fourni des services de lancement à des utilisateurs privés (télécommunications) et étrangers (programmes de l'ESA, d'Etats membres de l'ESA, du Japon...), même s'il est vrai que de tels lancements ont été de plus en plus fréquents au fur et à mesure que les techniques spatiales se développaient en dehors des frontières des Etats-Unis. (Il faut noter que l'Union soviétique n'a offert la fourniture de lancement à des tiers que dans des cas exceptionnels).

Initialement, ces services de lancement étaient souvent fournis au titre d'un programme coopératif bilatéral ou multilatéral avec les Etats-Unis, lorsque ceux-ci trouvaient un intérêt scientifique ou technologique dans la mission du satellite à lancer. Dans ce cas, les Etats-Unis fournissaient gratuitement le lancement, le partenaire du programme coopératif fournissant le satellite et tout ou partie de la charge utile. Par la suite, les services de lancement fournis par les Etats-Unis firent l'objet de contrats en remboursement de frais. Mais il faut reconnaître que le remboursement se limitait généralement aux frais spécifiques exposés par la NASA pour une mission considérée, les frais fixes d'infrastructure et d'opérations faisant l'objet d'une imputation forfaitaire à l'utilisateur, dont le montant était certainement inférieur à l'amortissement économique de la totalité de ces frais. Comme on le constate, la NASA n'a pas visé dans le passé une exploitation commerciale de ses moyens de lancement.

D'autre part, la 'politique des Etats-Unis régissant la fourniture d'une assistance en matière de lancement' formulée par le Président Nixon le 9 octobre 1972, et toujours en vigueur aujourd'hui, introduisait des restrictions aux lancements effectués pour le compte de pays étrangers et d'organisations internationales. Elle précisait en effet que 'l'assistance américaine en matière de lancements sera mise à la disposition des pays et des organisations internationales intéressés pour les projets de satellites exécutés à des fins pacifiques et qui sont compatibles avec les obligations prévues par les Accords et les Arrangements internationaux'. Le lancement de satellites de communications dont l'exploitation est régie par les Arrangements INTELSAT étaient particulièrement visés. De plus, 'en ce qui concerne les applications futures de satellites opérationnels qui ne font pas l'objet d'une large acceptation internationale, les Etats-Unis examineront favorablement les demandes d'assistance en matière de lancement une fois cette large acceptation internationale obtenue'.

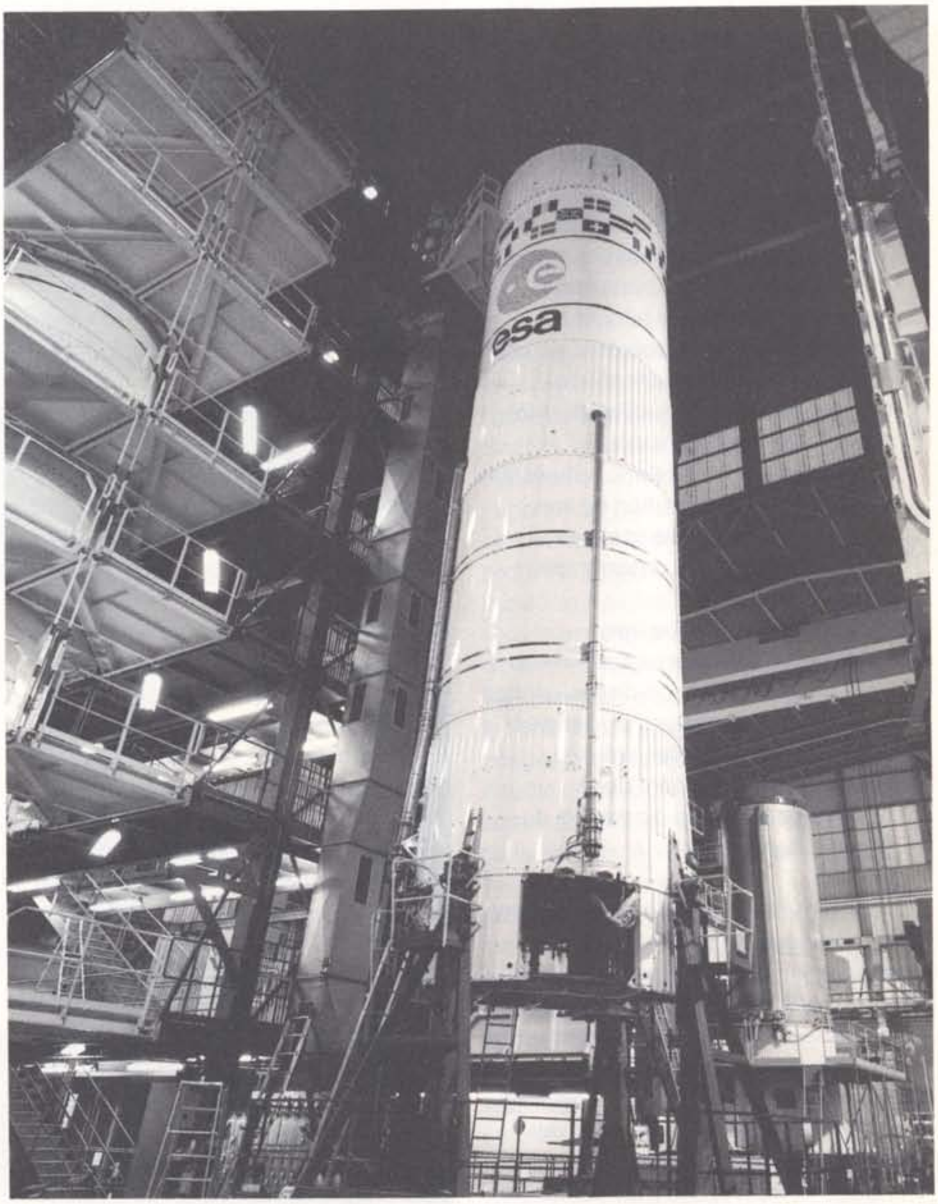
Telle était la situation il y a dix ans lorsque les Etats-Unis entreprirent le projet de Navette spatiale, et certains Etats européens, membres de l'Agence spatiale européenne, encouragés dans cette voie par la France, le développement du lanceur lourd européen Ariane.

La situation présente
Alors que durant les deux premières périodes de l'histoire du transport spatial, seuls des lanceurs à étages, non récupérables, étaient disponibles, la période d'exploitation commerciale de l'espace qui s'ouvre aujourd'hui voit s'affronter la Navette spatiale récupérable – appelée à supplanter les lanceurs américains non récupérables – et la toute jeune fusée européenne Ariane dont la qualification a été prononcée en janvier 1982. Et paradoxalement, c'est en Europe qu'a été créée la première société privée de transport spatial à qui les Etats membres de l'ESA ont confié la production, la commercialisation et les opérations de lancement du lanceur Ariane.

Nous examinerons donc successivement:
- comment les Gouvernements européens ont été amenés à prendre cette initiative exemplaire et comment les industriels et les banquiers du vieux continent y ont répondu;
- comment s'effectue la fourniture de lancements par la NASA au moyen de la Navette;
- comment certains milieux de l'industrie privée américaine envisagent l'exploitation commerciale de la Navette.

Production et commercialisation des lancements Ariane
L'exécution du programme Ariane a été entreprise dans le cadre d'un Arrangement entre certains Gouvernements européens, membres de l'Agence spatiale européenne et celle-ci. Les Participants s'engageaient à entreprendre la première phase du programme ayant pour objet le développement du lanceur incluant sa qualification. Les Participants confiaient, par l'intermédiaire de l'Agence, au Centre national d'Etudes spatiales (CNES) l'exécution de cette première phase du programme, et à l'Agence, le contrôle de son exécution, pour leur compte. Ils finançaient les coûts de la phase de développement au moyen de contributions provenant de leurs budgets publics nationaux. Cet Arrangement prévoyait d'autre part que ceux des Participants qui se déclaraient intéressés à participer à la phase de production concluraient un nouvel Arrangement définissant le contenu de cette phase, les modalités financières de son exécution

Figure 1 – Intégration du lanceur Ariane à l'Aérospatiale, Les Mureaux



ainsi que l'attribution des travaux qu'ils maintiendraient dans toute la mesure du possible identique à celle définie pour la phase de développement.

En 1979, alors que la phase de développement touchait à sa fin, les Etats ayant participé à cette phase ont été amenés à rechercher les moyens les plus appropriés pour valoriser au mieux les efforts financiers et industriels consentis par l'Europe pour disposer d'un lanceur. Bien que la phase de développement fût suivie d'une série de promotion de six lanceurs affectés à des utilisateurs dont les satellites étaient d'ores et déjà en cours de réalisation, la production et la commercialisation du lanceur Ariane représentaient un type d'activité totalement différente de son développement et de sa qualification.

- En effet, s'il était normal que le développement du lanceur soit financé par les Etats participants, le plus souvent sur leur budget de recherche et développement, il n'était pas normal qu'ils financent ou préfinancent la production dont la finalité est à prédominance commerciale. Il était donc naturel que l'industrie, qui a vocation de tirer bénéfice des activités spatiales, prenne le relais des organismes publics.
- De plus, l'Agence spatiale européenne, de par sa Convention, n'a pas pour vocation d'effectuer des activités commerciales et n'est pas équipée pour de telles activités, notamment en matière de préfinancement, de marketing, de crédit-clients, etc...

C'est pourquoi la France a proposé à ses partenaires dans la phase de développement du lanceur de confier la production, la commercialisation et les lancements d'Ariane à une structure industrielle qui aurait les responsabilités techniques, financières et commerciales correspondantes. Cette solution avait l'avantage de ne plus demander d'engagements financiers aux Etats participant au programme Ariane pour le préfinancement de la production du lanceur.

Cette structure industrielle a été mise en place sous la forme d'une société anonyme de droit français dénommée 'Arianespace'. Elle regroupe les équipes chargées de la coordination technique du programme de production et des lancements et celles chargées d'assurer les fonctions commerciales et financières correspondantes.

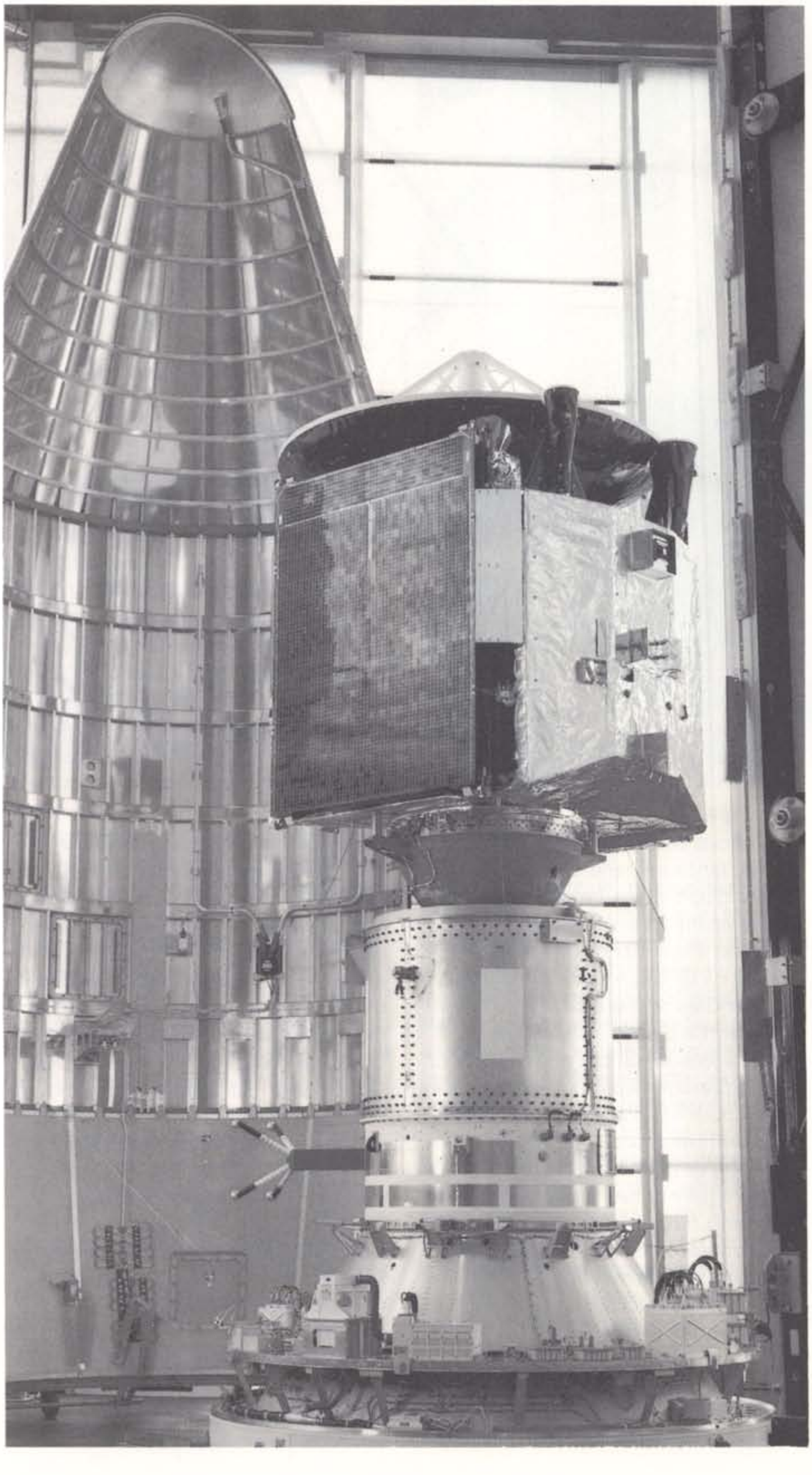
Le CNES, les industries participant à la construction du lanceur Ariane et des banques européennes en sont actionnaires. Le capital a été couvert pour approximativement 75% de source française, tandis que les 25% restants provenaient de sources privées d'autres Etats européens.

Compte tenu des termes de l'Arrangement initial, les Etats qui avaient pris part à la phase de développement souscrivirent une Déclaration par laquelle ils confiaient à cette structure industrielle l'exécution de la phase de production du lanceur. Les principales dispositions de la Déclaration sont les suivantes:

- Les Etats conviennent que la phase de production a pour but de satisfaire l'ensemble des besoins du marché mondial en matière de lancements, sous réserve d'être conduite à des fins pacifiques et en conformité avec les traités et accords internationaux pertinents. Les Etats ayant souscrit la Déclaration et l'Agence spatiale européenne s'engagent à utiliser le lanceur Ariane pour leurs programmes, dans certaines conditions, tandis que la Société industrielle leur accorde certaines priorités d'utilisation.
- De même, les Etats s'engagent à participer, selon des modalités à définir, au financement du Centre spatial guyanais (CSG), en prenant note qu'un accord spécifique sur ce sujet devrait intervenir ultérieurement entre les Etats membres et l'Agence; la structure industrielle, pour sa part, se voit imposer l'obligation de verser à l'Agence, au titre de l'utilisation du CSG, et pour chaque vente, une redevance progressive représentant un pourcentage du prix de vente des lancements, qui vient en déduction des contributions des Etats au financement du CSG.
- Les Etats participants invitent l'Agence à conclure avec la structure industrielle une Convention mettant en oeuvre les dispositions de la Déclaration et organisant leurs relations. Ils confient à l'Agence certaines missions vis-à-vis de la structure industrielle, telles que la mise à la disposition des outils de fabrication et de lancement, financés lors de la phase de développement et de la série de promotion, ainsi que le suivi, pour leur compte, des activités de la phase de production et la coordination des activités de l'Agence dans le domaine des moyens de lancement avec la structure industrielle qui les utilisera ultérieurement.
- Enfin, les Participants conviennent de se concerter sur les mesures à prendre, si des difficultés techniques ou financières, mettant en cause l'avenir de la structure industrielle ou celui de la production du lanceur Ariane, apparaissaient.

Le lanceur Ariane dans sa version initiale peut mettre en orbite de transfert géostationnaire des masses de l'ordre de 1800 kg et offre la possibilité de lancements doubles. Des prix différents s'appliquent aux lancements simples, qu'ils utilisent ou non la pleine capacité du lanceur, et aux lancements doubles lorsque deux satellites sont effectivement embarqués. La Déclaration fixe un barème de prix de lancements applicables à l'Agence et aux Participants pour les contrats signés avant le 1er juillet 1983, ou pour des lancements prévus avant le 1er juillet 1986. Ces prix constituent des prix conseillés en ce qui concerne les lancements à l'exportation

Figure 2 – Le satellite Marecs-A peu avant le lancement à bord d'Ariane le 19 décembre 1981 (on aperçoit à l'arrière-plan la demi-coiffe du lanceur)



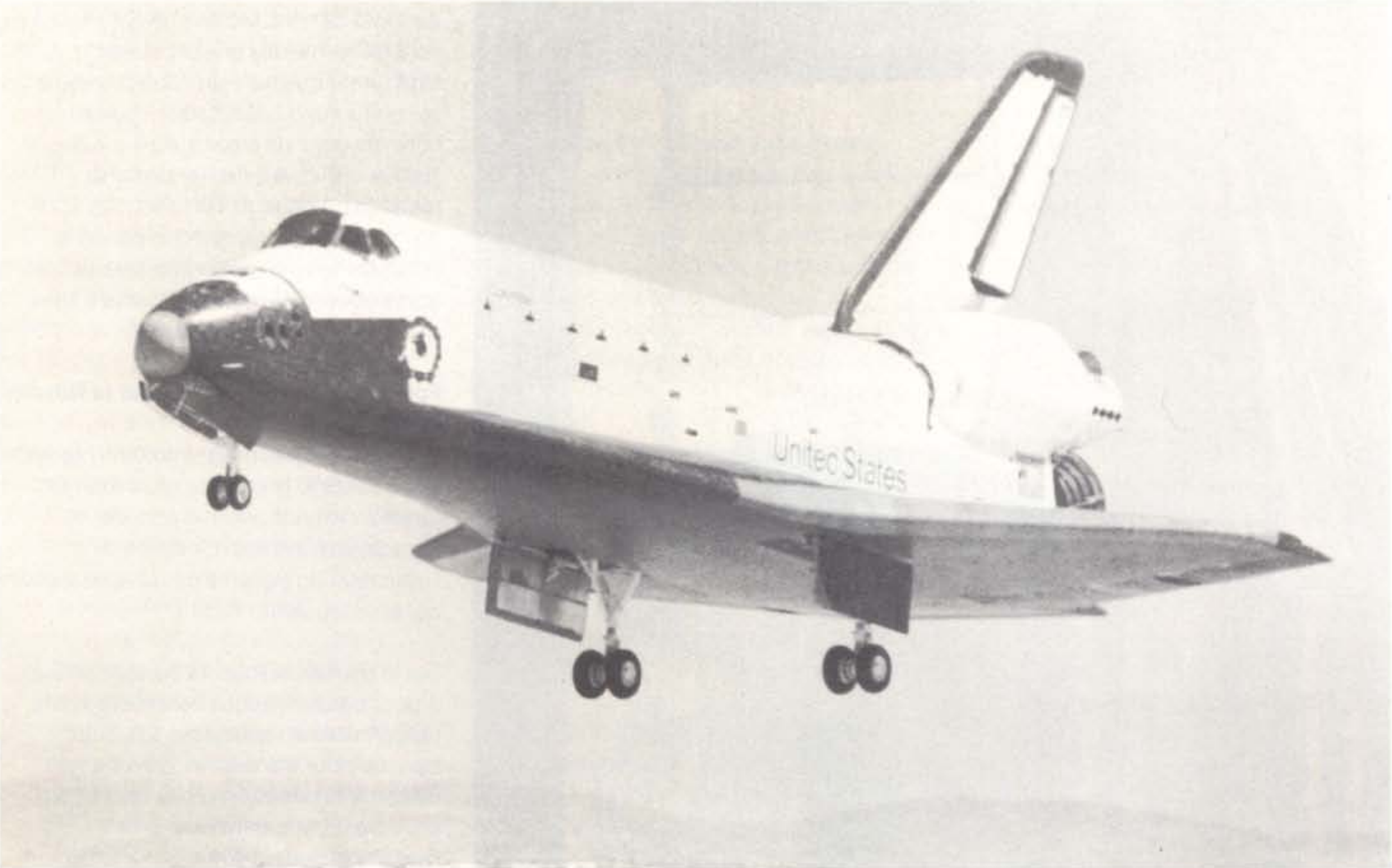
au profit de tiers. Même si les prix facturés sont différents des prix conseillés, la structure industrielle en supporte seule les conséquences financières. Pour les contrats conclus à partir du 1er juillet 1983 et prévoyant des lancements planifiés au-delà du 1er juillet 1986, une politique de prix, tenant compte de la concurrence internationale, sera définie après concertation et applicable à tous les utilisateurs des lanceurs.

Fourniture de lancements par la Navette spatiale

On étudiera ici le programme de Navette spatiale sur le plan de la technique de fonctionnement, avant d'aborder les caractéristiques économiques de l'utilisation du système de Navette spatiale qui en découlent.

Sur le plan technique, la Navette spatiale a pour caractéristique essentielle d'être récupérable et réutilisable. Elle a été conçue pour transporter des charges utiles importantes en orbite basse (260 km environ), notamment en vue de l'assemblage de grandes structures ou stations spatiales automatiques ou habitées. Le lancement de masses aussi importantes par des lanceurs conventionnels non récupérables eût été prohibitif du point de vue du coût. Par contre, la Navette ne peut pas atteindre l'orbite géostationnaire (36 000 km) où doivent être placés les satellites opérationnels d'application. Pour ce faire, la Navette doit emporter un étage de périgée (dont la masse est supérieure au double de celle du satellite) sur une orbite basse où ceux-ci sont sortis de la soute de la Navette. Après l'éloignement de la Navette, on procède alors à la mise à feu de l'étage de périgée, pour injecter le satellite sur une orbite de transfert géostationnaire. On constate donc que la Navette, malgré ses performances d'engin habité, joue en fait, pour ce type de satellite, le même rôle que celui des deux premiers étages d'un lanceur conventionnel, alors que les lanceurs non récupérables sont conçus pour atteindre directement les orbites hautes. Il résulte de

Figure 3 – Retour de la Navette Columbia de son vol inaugural



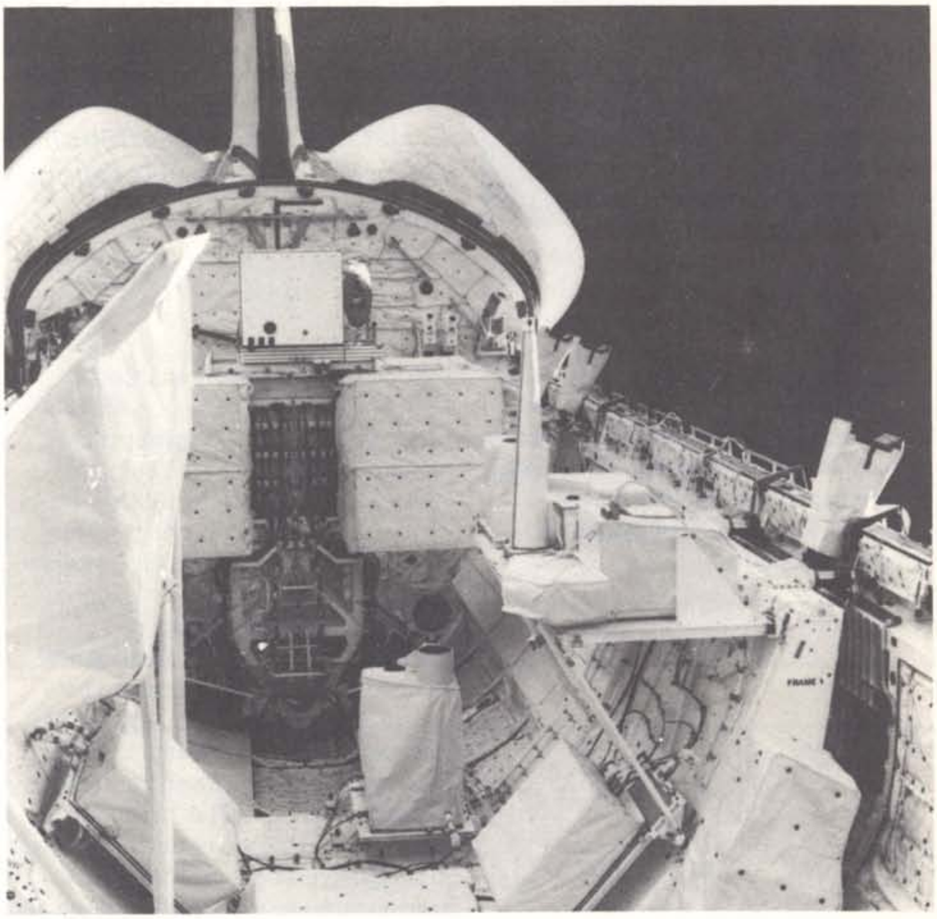
ce mode de fonctionnement que, si la Navette est effectivement plus économique pour le lancement de masses importantes en orbite basse, son avantage économique s'efface presque entièrement pour le lancement de satellites en orbite géostationnaire.

La Navette spatiale américaine est un engin d'une capacité telle (30 tonnes en orbite basse) que, pour la plupart de ses vols, elle emporte simultanément plusieurs satellites appartenant à plusieurs utilisateurs. L'exception est évidemment le laboratoire spatial Spacelab, développé par l'Agence spatiale européenne, qui est un véritable précurseur des futures stations spatiales en orbite basse. La NASA, qui opère le système de transport spatial des Etats-Unis, a donc dû tenir compte de cette situation pour définir les caractéristiques économiques de l'utilisation de la Navette.

La politique de prix de la Navette, comme celle du lanceur Ariane, distingue deux phases d'opérations. La première phase couvre les trois premiers exercices financiers à compter du début des opérations (STS-5) et la seconde phase comprend les neuf exercices financiers qui suivent la première phase. On distingue ensuite un prix applicable pour les vols particuliers à un seul utilisateur et un prix pour les vols partagés entre plusieurs utilisateurs. Pour un vol particulier de la Navette, exécuté au cours de la première phase, le prix fixé par la NASA est une quote-part des coûts prévisionnels correspondant aux trois exercices de la première phase. Pour un vol particulier, exécuté au cours de la seconde phase, le prix fixé est une quote-part des coûts totaux d'opérations prévues pour les douze exercices des deux phases.

Le prix des vols exécutés pendant la première phase d'opération de la Navette demeurera fixe. Pour les vols exécutés pendant la seconde phase, le prix sera ajusté annuellement, de manière à assurer le recouvrement des coûts totaux d'opérations sur la période de douze ans. Le prix d'un vol partagé de la Navette est une fraction du prix d'un vol particulier. Cette fraction est déterminée en fonction de la longueur et du poids de la charge utile et de la destination de la mission. Enfin, des blocs expérimentaux, pesant moins de 100 kg et mesurant moins de 1,5 dm^3, qui ne font pas appel aux ressources de la Navette (alimentation en énergie, etc.) et qui sont destinés à des travaux de recherche et de développement, pourront être embarqués, en fonction de l'espace disponible, pendant les deux phases des opérations, pour un prix modique négocié sur la base de l'encombrement et du poids.

Figure 4 – Le porte-instruments du Spacelab (expériences OSTA-1) à bord de la Navette Columbia. La photographie a été prise par l'équipage à partir de la cabine de la Navette au cours du 2ème vol de Columbia (STS-2)

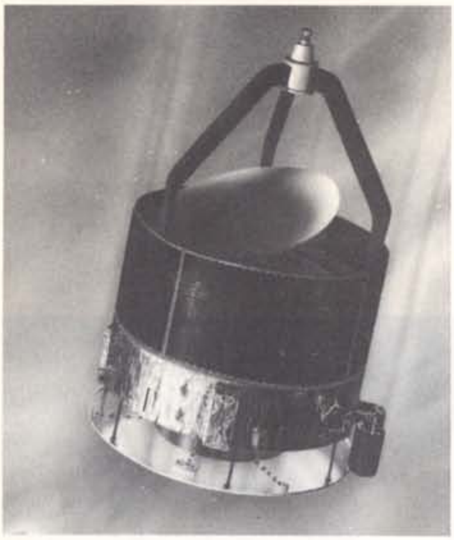


L'industrie américaine et l'exploitation commerciale de la Navette

Comme on le voit, alors qu'en Europe, l'industrie a pris le relais des gouvernements pour produire et commercialiser les lancements Ariane, aux Etats-Unis, la NASA s'est organisée pour assurer cette tâche elle-même. Face à la complexité de la politique des prix et à son application uniforme à tous les utilisateurs – qu'ils soient gouvernementaux américains (à l'exception du Ministère de la Défense qui a contribué au programme), commerciaux, ou étrangers – certaines voix se sont élevées aux Etats-Unis pour dénoncer le financement ou le préfinancement par le gouvernement d'investissements supplémentaires dans le système de la Navette spatiale au profit d'utilisateurs commerciaux. Impressionnés par les premiers succès commerciaux remportés aux Etats-Unis même par le lanceur Ariane, les milieux industriels d'abord, les milieux financiers ensuite, se sont intéressés à l'exploitation commerciale de la Navette spatiale. Récemment, une société (la 'Space Transportation Company Inc.') s'est constituée avec la participation d'un important groupe financier et a proposé de faire les investissements nécessaires pour satisfaire les besoins des utilisateurs commerciaux de la Navette en échange de la commercialisation des lancements pour ces utilisateurs. Bien entendu si le gouvernement des Etats-Unis donnait suite aux propositions faites par cette société, celle-ci devrait, sans doute encore pour longtemps, s'appuyer sur l'infrastructure financée par le gouvernement et mise en oeuvre par la NASA, mais le relais du financement public des investissements et des coûts d'opération serait assuré par l'industrie et des capitaux privés. Avec l'avantage supplémentaire qu'à la suite de cette prise en charge par le secteur industriel, l'Etat pourrait réorienter tout ou partie des crédits ainsi rendus disponibles vers des activités de recherche et de développement dont nul ne songe à lui contester la vocation.

Conclusion

Il serait prématuré de vouloir dresser un bilan de la compétitivité entre les moyens de lancement non récupérables comme le lanceur européen Ariane et les moyens de lancement récupérables comme la Navette spatiale américaine. Mais il est intéressant de constater que même dans l'exploitation de l'espace, une des plus récentes techniques maîtrisées par l'homme, l'innovation visant à la fois à la rationalisation de l'usage des crédits publics et à l'efficacité des opérations spatiales, est venue de la vieille Europe, et a immédiatement trouvé un écho outre-Atlantique. Souhaitons que cet exemple se pousuive et se développe pour le plus grand bien des peuples.



Deep-Space Navigation – A New Flight-Dynamics Discipline for ESA

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From the mid-80s onwards, ESA will be launching and supporting spacecraft carrying experiments into interplanetary space. One of the associated challenges is 'deep-space navigation', a new discipline for ESA's flight-dynamics support repertoire.

ESA's first interplanetary spacecraft, Giotto, will be launched in July 1985, by which time a total of 25 spacecraft will have been operated by the European Space Operations Centre (ESOC). These spacecraft have been orbiting in near-earth, geostationary and highly eccentric orbits, their distances from the Earth's surface varying from 200 km to 300 000 km. However, the distance from Earth to a deep-space probe can be several Astronomical Units (AU), one AU being about 150 000 000 km, corresponding to the mean Earth-Sun distance (light travels 1 AU in about 8 min). These extreme distances will result in stringent requirements for the radio-communications link with the ground and make highly directive spacecraft antennas a necessity. Ground control is only possible as long as the antenna is kept pointing to the Earth with an accuracy of typically about 1°. The requirement of maintaining this pointing accuracy also during manoeuvres is a major design driver for the attitude and orbit control system.

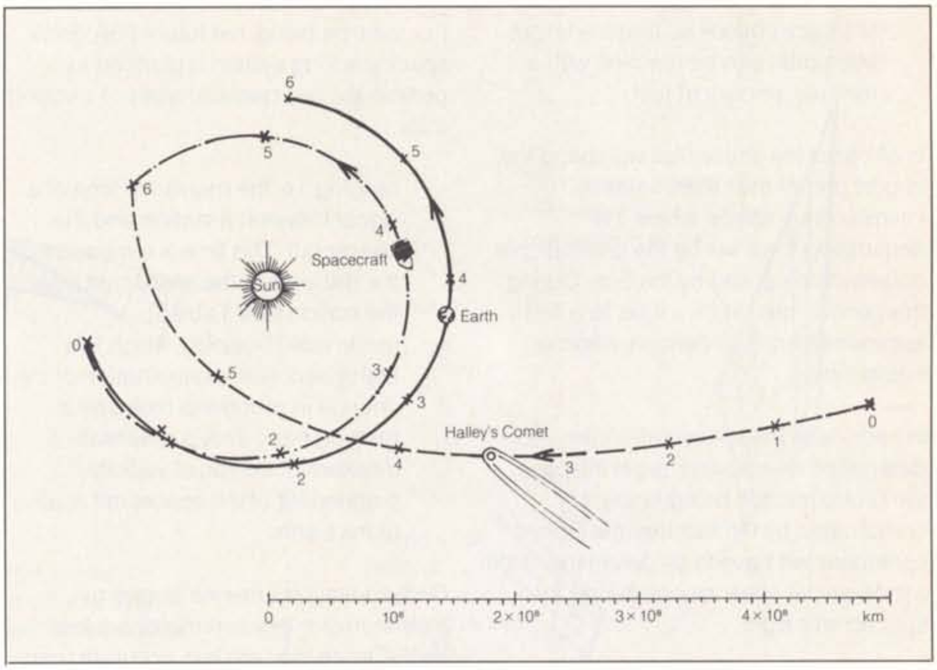
Spacecraft navigation, i.e. determination and control of the spacecraft's trajectory, is also affected by these large distances as the orbit determination is based on radiometric measurements (range and range rate) made at the ground stations.

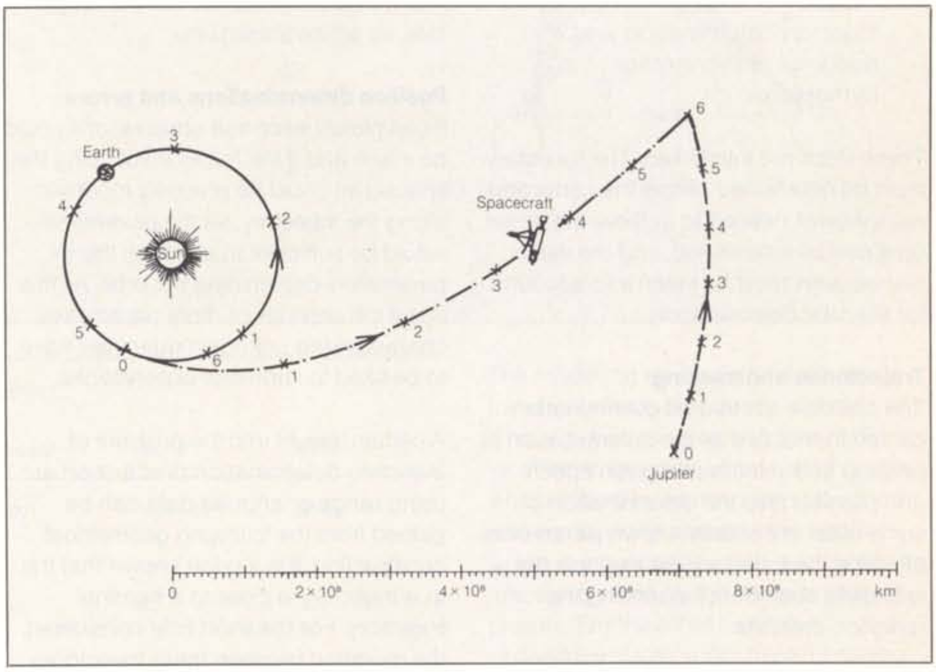
The mathematics associated with the control of interplanetary trajectories has a number of special characteristics compared with typical trajectory-control tasks for Earth-orbiting satellites. The latter are always, to a first approximation, Earth-centred Kepler orbits, while for deep-space probes gravitational accelerations from different heavenly bodies dominate the spacecraft trajectory in different phases of a mission.
This article sets out to highlight the special features characterising the determination and control of deep-space trajectories.

ESA's future deep-space missions
Two approved ESA projects presently under development call for deep-space navigation. The first is Giotto, a spin-stabilised spacecraft that will make a close flyby of Halley's Comet. Giotto will be launched in July 1985 by an Ariane launcher, together with a geostationary spacecraft. From a standard geostationary transfer orbit, Giotto will be injected into an interplanetary orbit to encounter the Comet by firing a high-thrust, solid-propellant motor close to a perigee pass. Several mid-course correction manoeuvres using a hydrazine propulsion system will subsequently be necessary to compensate for the injection dispersion and to retarget the spacecraft for successive updates of the cometary ephemeris, which can be accurately determined only after the launch. At the time of injection into interplanetary orbit, the uncertainty in the cometary orbit could be as much as 25 000 km; this will reduce to roughly 1000 km at encounter, corresponding to the required targeting accuracy. The orbits of the Earth, the Comet and the spacecraft, projected on the ecliptic plane, are shown in Figure 1. The Comet's orbit is retrograde, its ecliptic inclination is about 162°, and the flight time to Halley from Earth is about 8.5 months.

Figure 1 – The interplanetary orbit of Giotto, with the 8.5 month flight shown divided into six equal parts

Figure 2 – The interplanetary orbit of ISPM to Jupiter, with the 13.5 month flight shown divided into six equal parts





The second ESA project to call for deep-space navigation is the International Solar-Polar Mission (ISPM) which will perform measurements far out of the ecliptic plane. The spin-stabilised spacecraft will be launched in mid-1986 from the Space Shuttle. It will be mated with an Inertial Upper Stage (IUS) to inject it into an interplanetary orbit intersecting Jupiter's orbit. The injection dispersion will be compensated for by several midcourse corrections and the swingby geometry adjusted so that the deflection caused by Jupiter's gravitational field results in an orbit with a high ecliptic inclination and a perihelion radius of about 1.2 AU. The orbits of the Earth, Jupiter and the spacecraft up to encounter are shown in Figure 2. ISPM's flight time to Jupiter will be about 13.5 months.

A possible future ESA satellite project involves inserting a spin-stabilised spacecraft into a polar Mars orbit. The orbital concepts for this mission, known as Kepler, are not yet fully established (direct injection into interplanetary orbit or via an Earth orbit, as in the two missions described above). Mid-course trajectory corrections will be necessary to achieve an interplanetary orbit from which the spacecraft can be injected into a high-inclination Martian orbit by firing a high-thrust motor. The exact target orbit will then be obtained by relatively small trajectory control manoeuvres in Martian orbit. In contrast to Halley's Comet, the orbits of Jupiter and Mars are known with high accuracy, the positional uncertainties being of the order of a hundred kilometres or less.

Characteristics of deep-space navigation

The spacecraft described above are examples of some of the most common classes of deep-space missions:

- Giotto is a *flyby mission* where the targeting requirements are directly generated by the observational requirements of the scientific payload. The low mass of Halley's Comet and the large flyby velocity (about 68 km/s) mean that the gravitational influence of the Comet on the spacecraft trajectory will be negligible.
- ISPM is a *swingby mission* where the gravitational field of Jupiter is used to obtain the desired change in interplanetary orbit. The targeting requirements relative to Jupiter are therefore derived from the basic requirements for the post-Jupiter orbit.
- Kepler is a *planetary orbiter* for which the targeting requirements relative to

Mars are chosen so that the target Mars orbit can be reached with a minimal amount of fuel.

In all cases the spacecraft will spend the largest part of their flight times in interplanetary space, where the dominating force will be the gravitational acceleration caused by the Sun. During this period, their orbits will be, to a first approximation, Sun-centred, elliptical Kepler orbits.

In each case the spacecraft's intended destination is a moving target in space, the Giotto mission being further complicated by the fact that the Comet ephemeris will have to be determined from astronomical observations during the spacecraft's flight.

The two steps inherent in the navigation process are:
- trajectory determination, and
- design of orbit-correction manoeuvres.

These steps are interlinked. The trajectory must be determined before the correction manoeuvres needed to achieve the target orbit can be established, and the earlier manoeuvres must be taken into account for the orbit determination.

Trajectories and tracking
The objective of the orbit determination can be formulated as the determination of position and velocity at a given epoch and possibly also the determination of some other imperfectly known parameters affecting the trajectory, for example the reflectivity coefficient influencing the radiation pressure.

Having determined these quantities, the position and the velocity of the spacecraft at any time can be computed using the mathematical model for the forces influencing the spacecraft.

The input data for the orbit determination are tracking measurements from ground stations.

For the time being, the future ESA deep-space tracking system is planned to provide the two classical types of tracking data:

- ranging, i.e. the round-trip time of a signal between a station and the spacecraft. This time is a measure of the distance of the spacecraft from the station (see Table 3),
- range rate (Doppler), which is a highly accurate determination of the change in round-trip time over a ranging pass. This is essentially a measure of the radial velocity component of the spacecraft relative to the Earth.

Ground-station antenna angles or interferometer measurements are less useful, since they are less accurate (error $\sim 10^{-5}$ rad) than the directional information obtainable from the range rate, as will be shown later.

Position determinations and errors
If completely error-free observations could be made and if the forces influencing the spacecraft could be precisely modelled along the trajectory, six measurements would be sufficient to establish the six parameters determining the orbit. As this is not the case, six or more parameters characterising unknown quantities have to be fitted to imprecise observations.

A certain insight into the problem of trajectory determination over a short arc using range or angular data can be gained from the following geometrical construction. It is a priori known that the true trajectory is close to a nominal trajectory. For the short time considered, the deviation between these trajectories can, in a first approximation, be considered constant. Taking a point moving along the nominal trajectory as reference, the ground stations are moving with velocities that are the superposition of the motion of the Earth's centre relative to the spacecraft and the rotation of the Earth, while the position of the spacecraft is almost constant but unknown.

The motion of the ground stations relative to the reference point defines the tracking geometry.

The vector between the two station positions S_1 and S_2 at the two, not necessarily different, times t_1 and t_2 is called the 'base' of the tracking geometry.

Figure 3 outlines in two dimensions how the constant offset of the spacecraft to the reference point can be determined from ranging data, while Figure 4 shows the equivalent principle for directional or angular measurements. In the three-dimensional case, the two circles about the station locations in Figure 3 have to be replaced by three 'ranging spheres' about three station positions.

It can be seen from these two figures that, for a constant tracking error, the error boxes for the spacecraft positions increase:

- if the spacecraft's distance from the station increases, or
- if the base decreases.

Both these effects are due to the same variation in the tracking geometry. The figures reveal, furthermore, that the maximum position errors in the two uncertainty regions point in almost perpendicular directions. A combination of range and angular observations, i.e. an intersection of the error boxes, should therefore reduce the total error.

From the figures shown one can derive the maximum and minimum positional errors. Table 1 lists quantitative results for a typical ranging error of 10 m and an angular error of 10^{-6} rad, or 0.6×10^{-4} deg. The base was taken to be the diameter of the Earth. The figures for ESA's Meteosat geostationary meteorological satellite are presented for comparison purposes.

Model errors
The observation errors are differences between modelled and observed data.

Figure 3 – Position determination from distance observations

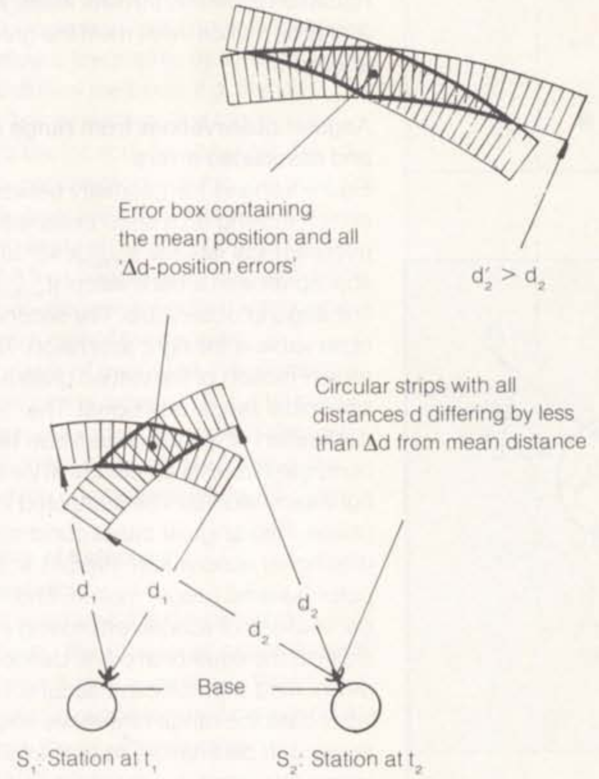


Figure 4 – Position determination from angular observations

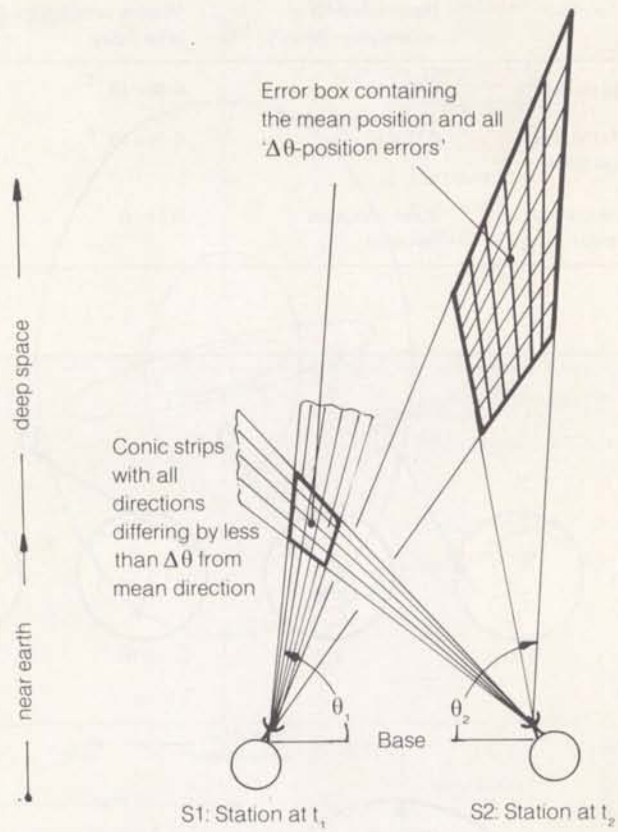


Table 1 – Examples of extremes of position errors

Satellite	Formula	Meteosat	Giotto	ISPM
Maximum distance from station (km)	d	42600	1.05×10^8	8.98×10^8
Max. position error due to range error (km)	$\frac{\Delta d \times d}{base}$	0.033	82	704
Max. position error due to angular error (km)	$\frac{2\Delta\theta d^2}{base}$	0.284	1.73×10^6	1.26×10^8
Min. position error due to range error (km)	Δd	0.010	0.010	0.010
Min. position error due to angular error (km)	$\Delta\theta \times d$	0.043	105	898

The modelling errors depend, on the one hand, on effects that do not increase with time; e.g. modelling errors in the station location, in the path of the tracking signal, which is bent by atmospheric refraction, and errors in the speed of the signal, which is influenced by free electrons in the ionosphere and by the interplanetary plasma. On the other hand, the observations also suffer from modelling errors in the trajectory dynamics. The effect of these errors on position and velocity may increase quadratically with time.

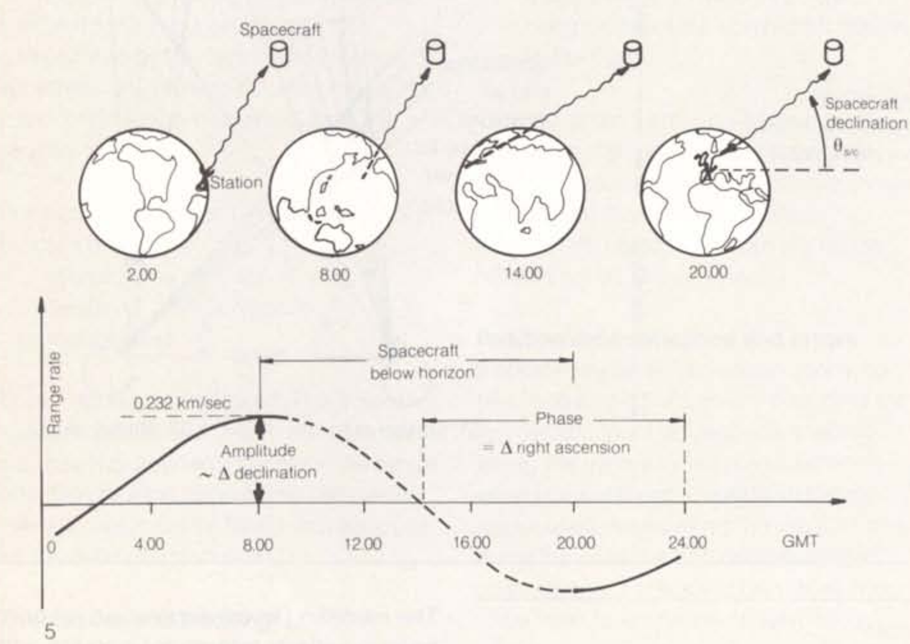
Table 2 shows some typical modelling errors for Giotto. Some of these dynamic effects expand the position-error box linearly with time.

Figure 5 — Range rate due to proper ground-station motion

Figure 6 — Giotto range rate 34 days before Halley encounter

Table 2 — Modelling errors for the Giotto cruise phase

Error source	Maximum error in acceleration (km/s²)	Velocity error (m/s) after 1 day	Position error (m) after 1 day
10% of radiation	0.46×10^{-11}	0.40×10^{-3}	16.6
10^{-6} N thruster leakage force	0.17×10^{-11}	0.15×10^{-3}	6.4
Attitude-control imbalance	quasi-impulsive variation	0.1×10^{-2}	86



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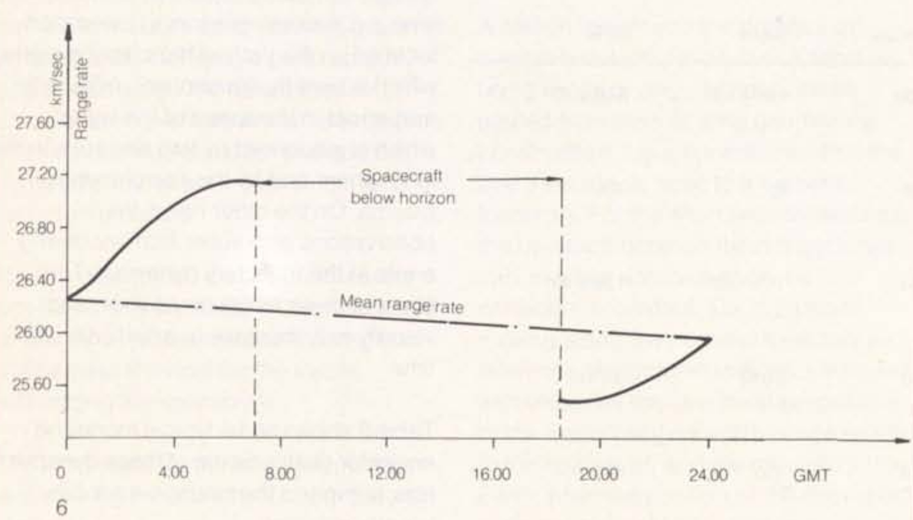

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There will be a time limit at which inaccuracies in the trajectory-dynamics modelling exceed all other errors. Very accurate modelling is therefore a prerequisite for deep-space missions. Radiation pressure, thruster leakages, and orbit manoeuvres merit the greatest attention.

Angular observations from range rates and associated errors

Figure 5 shows the geometry between a station moving on a small circle with geographical latitude $\theta_{station} \approx 45°$ and a spacecraft with a declination $\theta_{spacecraft}$, the first angular observable. The second observable is the right ascension. The proper motion of the station gives a sinusoidal range-rate signal. The declination of the spacecraft can be computed from its amplitude while the right ascension can be computed from its phase. Two singular cases constrain the directional observation: stations at the poles have no proper motion, and the declinations of spacecraft moving in or close to the equatorial plane cannot be determined with sufficient accuracy. In the latter case the range rate varies very slowly with declination, so that small range-rate errors are drastically amplified into large declination errors.

The range rate of Giotto relative to a station in Australia 34 days prior to the end of the mission is plotted in Figure 6. The signal emerges from a superposition of a periodic component due to the rotation of the Earth, and a slowly varying component due to the changing velocity of the spacecraft with respect to the Earth's centre. A comparison of Figures 5 and 6 provides the direction to the spacecraft and its relative velocity. This information is also important in the trajectory-determination process, and in particular for manoeuvre calibration.

The accuracy of angular observations obviously depends on the precision with which the proper motion of the station can be modelled. It therefore depends on three main factors. The first is the quality

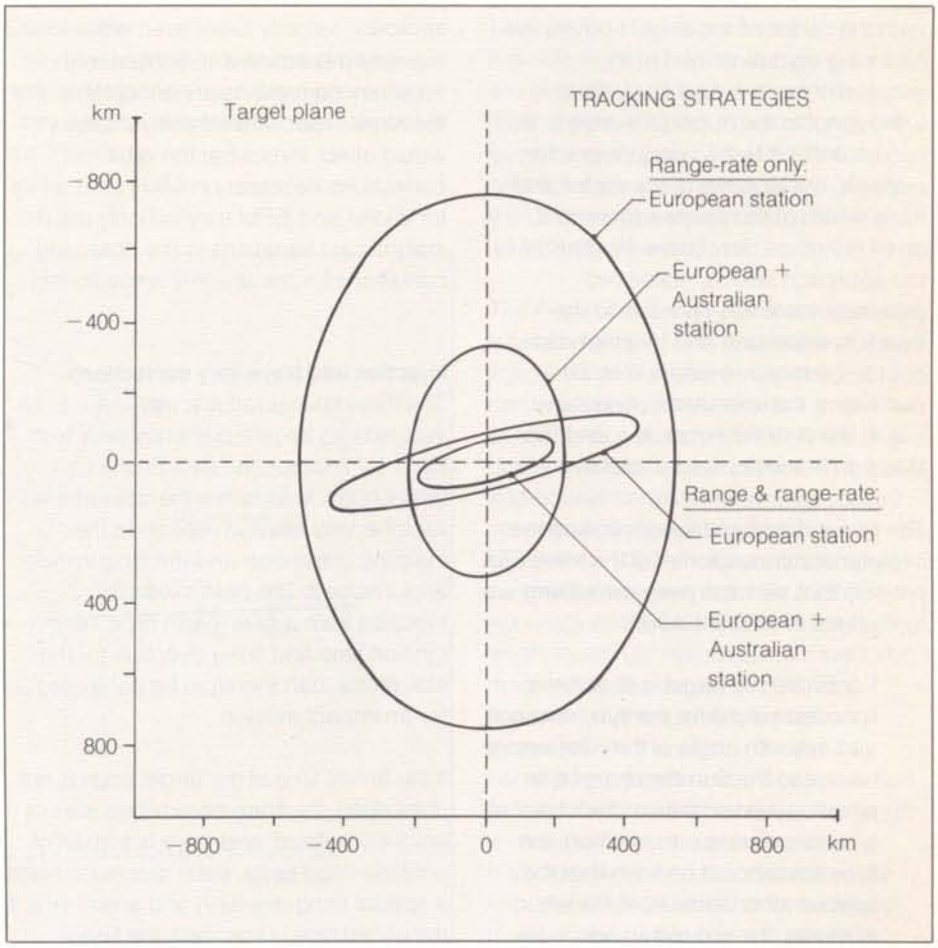


Figure 7 — Uncertainty regions for the point at which Giotto's trajectory intercepts the target plane (75% error-level ellipses)

of the astrometric data used for modelling the rotation of the Earth and its motion in space. The second is the accuracy with which the station coordinates are known. Both these errors can be combined into an equivalent station-location error. Nowadays, station-location errors can be kept below a few metres by utilising satellite-survey methods, e.g. the US Navy's Transit system. The third prerequisite for accurate angular data is again a precise model of the spacecraft velocity. As column 3 of Table 2 shows, the range-rate errors can be kept below 0.4 mm/s in a manoeuvre-free period. The ratios between the modelling errors and the amplitudes of the periodic components of the range-rate signal are therefore of the order of 10^{-6}. It turns out that station-location errors and dynamic errors combine into an overall angular error which can be kept below 10^{-6} rad.

Accuracy of trajectory determination

Table 1 illustrated the difficulties of determining the spacecraft position using observations over a short arc. When observations over a longer time period are available, the situation is more favourable.

Assuming realistic dispersion in range and range-rate measurements and inaccuracies in the mathematical modelling, the position of the spacecraft at a given time can be deduced to be in a certain error ellipsoid. Of special importance is the projection of the error ellipsoid associated with an epoch shortly before the encounter on the target plane orthogonal to the approach velocity (see below).

Figure 7 shows typical results for a numerical filter that takes into account all Giotto-specific modelling errors. This filter predicts that the trajectory will pass, with a 75% probability, through an elliptical window in the target plane. Figure 7 contains several different windows, the shapes and sizes of which depend on the observation strategy selected. A comparison of the results verifies once more that a combination of range and range-rate or angular data drastically reduces the size of the window.

Arrival geometries

The motion of the spacecraft relative to a nearby celestial body is essentially a hyperbolic Kepler orbit. When discussing the requirements for targeting, it is therefore useful to introduce the concept of the osculating Kepler orbit relative to this target body. Specifying the pericentre passage time and the osculating Kepler orbit relative to the target body at this time completely defines the trajectory. Six parameters are needed to define a Kepler orbit. For the five parameters needed in addition to the time of perigee passage, it is convenient to use the three components of the 'hyperbolic approach velocity vector' and two parameters defining the size and direction of the 'miss-vector' displayed in Figure 8.

The hyperbolic approach velocity vector is essentially the velocity vector of the spacecraft at an intermediate distance from the target body, where the gravitational attraction from this body is still small, but the spacecraft is close enough to the body for the gradient effects of the solar gravitational field to be small. Computing this vector means effectively that the direct gravitational effect of the target body on the velocity is eliminated. As it is rather insensitive to the injection dispersion and to minor mid-course correction manoeuvres, it is useful for the formulation of the control problem.

The miss-vector is the vector pointing

from the centre of the target body to the incoming asymptote and lying perpendicular to it. As this vector is orthogonal to the approach velocity, it can be defined by two parameters; for example, the length *b* of the vector and the azimuth of the vector relative to a given reference direction α. In contrast to the approach velocity, these two parameters are very sensitive to the injection dispersion and to minor mid-course-correction manoeuvres. By controlling the miss-vector, one can adjust the pericentre radius r_p and the direction of the departure velocity.

The target definitions for controlling the interplanetary trajectories of the three ESA projects that we have been discussing are formulated in different ways:

- For Giotto the target is to achieve specified values for the flyby distance and azimuth angle of the miss-vector relative to the Sun direction, i.e. to pass to a certain side of the comet at a certain distance. In addition, the flyby time should be such that the spacecraft is visible from Parkes in Australia, the ground station to be used for telemetry reception during encounter.
- For ISPM, the target will be to achieve a predefined direction for the departure velocity (northward deflection). NASA's full deep-space network is available (joint NASA-ESA mission), and no stringent requirements regarding flyby time are foreseen.
- For Kepler the target would be to attain a prescribed miss-vector azimuth angle and pericentre radius, chosen so as to allow injection into a Martian polar orbit. There would probably be flyby time constraints to ensure injection during ground-station coverage.

The approach-velocity vector is not actively controlled in any of the three cases. Given that the targets formulated above are achieved, the variations in approach velocity associated with injection dispersion and subsequent trajectory corrections are acceptable. For the Kepler spacecraft these variations would affect somewhat the orbit corrections necessary in Mars orbit, while for Giotto and ISPM they will only result in insignificant variations in the observing conditions for the scientific experiments.

Injection and trajectory corrections

The three spacecraft discussed are to be injected into an interplanetary orbit from Earth for a direct ballistic transfer to a target body. In all cases the desired miss-vector is very small in relation to the injection dispersion and the long transfer arcs involved. The parameters for injection from a near-Earth orbit, i.e. ignition time and firing direction for the kick motor, can therefore be computed as for an impact mission.

If the arrival time at the target body is not prescribed, the firing parameters are not uniquely defined, and there is a span of possible firing times, each associated with a special firing direction and arrival time. If the arrival time is specified, the firing parameters are uniquely defined locally, but generally there are still two different injection possibilities per revolution in the near-Earth orbit.

Once the spacecraft have been injected into interplanetary transfer orbit and their trajectories determined, the injection dispersions will be compensated for by performing a series of trajectory-correction manoeuvres.

Any of the aforementioned three target types could, in principle, be reached by a single manoeuvre at any point in the orbit, provided a sufficiently large velocity increment can be imparted in any direction with unlimited accuracy. With the flyby time prescribed, this velocity increment is uniquely defined. Otherwise, there is a range of possible velocity increments, each associated with a different flyby time.

The baseline plans for Giotto and ISPM foresee making the main orbit-correction manoeuvre soon after injection, within the coverage of the omnidirectional antenna, by firing axial thrusters in a continuous mode. In this case the manoeuvre needed for Giotto is not larger than four times the dispersion of the motor used for injection into interplanetary orbit. It can be shown that this method of compensating for the injection dispersion requires the least amount of fuel.

In special contingency cases, major orbit-correction manoeuvres may be necessary outside the range of the omnidirectional antenna. One reason for this could be that the rather tight timeline for the orbit determination in the near-Earth phase could not be followed. The navigational support should therefore have the capacity to design fuel optimal multi-pulse manoeuvre strategies satisfying the antenna-pointing constraints.

Taking Giotto as an example, the spacecraft will be equipped with a despun, high-gain antenna, inclined 44.2° to the spin axis. The requirement of keeping the antenna continuously pointing to the Earth limits the allowed spin-axis directions to a cone around Earth's direction. A fuel-optimal trajectory correction to achieve the required miss-vector will consist of up to three manoeuvres of the following type:

- a precession of the spin axis around the Earth vector by operating an axial thruster in pulsed mode (unbalanced thrust to have a net acceleration);
- a main orbit correction in the new attitude by firing an axial thruster in continuous mode or a radial thruster in pulsed mode;
- a precession around the Earth vector by operating an axial thruster in pulsed mode to achieve the desired cruise attitude.

After the main orbit-correction manoeuvre(s), fine 'touch-up' manoeuvres will be necessary. For these, optimal fuel use is generally less important than accuracy. They will therefore mostly be made in cruise attitude, by operating axial thrusters in continuous mode and/or radial thrusters in pulsed mode.

Conclusion

The most important features of deep-space navigation have been presented. They are the determination and control of the trajectory.

The specific challenges associated with this new flight dynamics discipline for ESA are best reflected by comparison with the more classical types of mission, e.g. the geostationary ones. Table 3 lists some characteristic parameters that highlight the differences between ESA's Meteosat and Giotto missions.

The Giotto encounter accuracy serves as a good example. The dispersion of the injection into interplanetary orbit corresponds to an inaccuracy in position at encounter of up to 3 000 000 km. This dispersion has to be compensated for by mid-course correction manoeuvres to achieve a final targeting accuracy of better than 1000 km. As a manoeuvre cannot be implemented with a relative accuracy of 1000/3 000 000 = 0.3‰, small 'touch-up' manoeuvres have to be made when the results of the main trajectory manoeuvres have been evaluated. As the whole mission only corresponds to a fraction of a revolution around the Sun, and a certain arc length is required to obtain an accurate trajectory determination, it is extremely important that the number of touch-up manoeuvres needed be minimised by making each as accurate as possible.

Figure 8 – Jupiter arrival geometry for ISPM

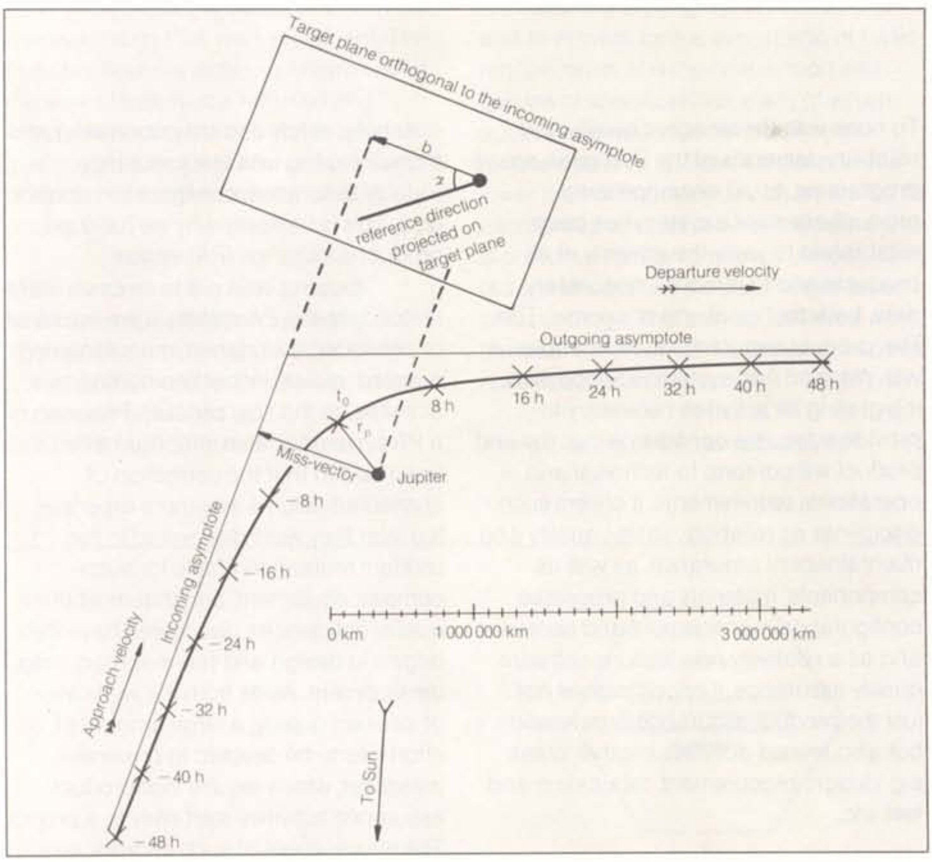


Table 3 – Comparison of geostationary and interplanetary satellite missions

	Meteosat	Giotto
Central acceleration (Earth)	2.24×10^{-4} km/s²	(Sun) 1.03×10^{-5} km/s²
Main perturbation/central force (J_2)	2.24×10^{-5}	(Jupiter) 2.01×10^{-5}
Faintest perturbation modelled	$\leq 10^{-10}$ km/s²	$\leq 10^{-12}$ km/s²
Max. distance from Earth centre	42165 km	1.27×10^{8}
Roundtrip time for light	0.28 s	846 s
Spacecraft targeting accuracy – position (Δp)	10 km	100 km
Spacecraft targeting accuracy – velocity	1 cm/s	no requirement
Δp/distance	2×10^{-4}	0.8×10^{-6}

The New Product-Assurance Documentation System

M. von Hoegen, Product Assurance Systems Section, Product Assurance Division, ESTEC, Noordwijk, The Netherlands

The modern satellites and their equipment designed and developed for ESA under contract call for creative engineering and sound execution of the latest technologies. These satellites can have operational lifetimes of up to 10 years. High reliability is therefore a prerequisite, which implies stringent control over design reliability and hardware quality.

To cope with the stringent quality and reliability demands of the European space programme, an all encompassing product-assurance system has been established to verify the integrity of all products and to remove unnecessary risks, both technical and economic. The title 'product-assurance system' implies a well-planned and systematic approach, integrating all activities necessary to provide adequate confidence that the end product will conform to technical and operational requirements. It covers such disciplines as reliability, safety, quality and maintainability assurance, as well as components, materials and processes, configuration management and control, and as a relatively new feature, software quality assurance. It encompasses not just the product-assurance organisation, but also related activities in other areas, e.g. design, procurement, fabrication and test, etc.

The product-assurance effort must be performed by a function-independent unit working with the responsible function management to establish the required level of quality and means of verification to safeguard the project. The degree of product-assurance effort expended on a given project must be related to the mission constraints and technical risks involved. The product-assurance specifications and procedures are designed as a tool to assist contractors in their design and manufacturing tasks (and procurement of materials and components, etc.). They also enable ESA to exert control over these aspects and to ensure that the work is carried out correctly in terms of design assurance (reliability, safety and maintainability) and manufacturing and test assurance (quality assurance, configuration control, etc.). This is basically why we have a product-assurance (PA) system.

Historically, the PA system is the extension of previously established, manufacturing-oriented, quality inspection/control type activities on the final product. Provision of a PA system became important when it was realised that the correction of spacecraft failures was more expensive the later they were discovered in the product realisation phase for such complex equipment, and that most of the quality deficiencies discovered have their origins in design and pre-manufacturing development. Aside from the verification of inherent quality, a large amount of effort has to be devoted to preventive measures, which require that product-assurance activities start early in a project. The effectiveness of such efforts is very dependent on the rigorousness of the requirements as defined in the Product-Assurance Documentation System and the means to implement these requirements in a cost-effective manner.

Due to the variety of ESA's satellite projects and development contracts, the requirements of the product-assurance specifications had to be wide ranging and their comprehensive nature could place an undue burden on the economies and development schedule of those projects subject to special constraints or those that are less demanding; for example those in which the end product is not required to be of flight standard. The specification system has therefore been

Figure 1 — Product-assurance specification tree

structured in a way that facilitates the controlled selection by ESA of the combination of requirements most appropriate to the type, phase of development, purpose and other features of each project. The applicability of the specifications, or parts thereof, selected for a given project, is clearly stated in the corresponding ESA work statement. This provides flexibility without compromising the level of assurance required and without reducing the economic benefits that should ultimately accrue from the use of the same basic system for all ESA projects.

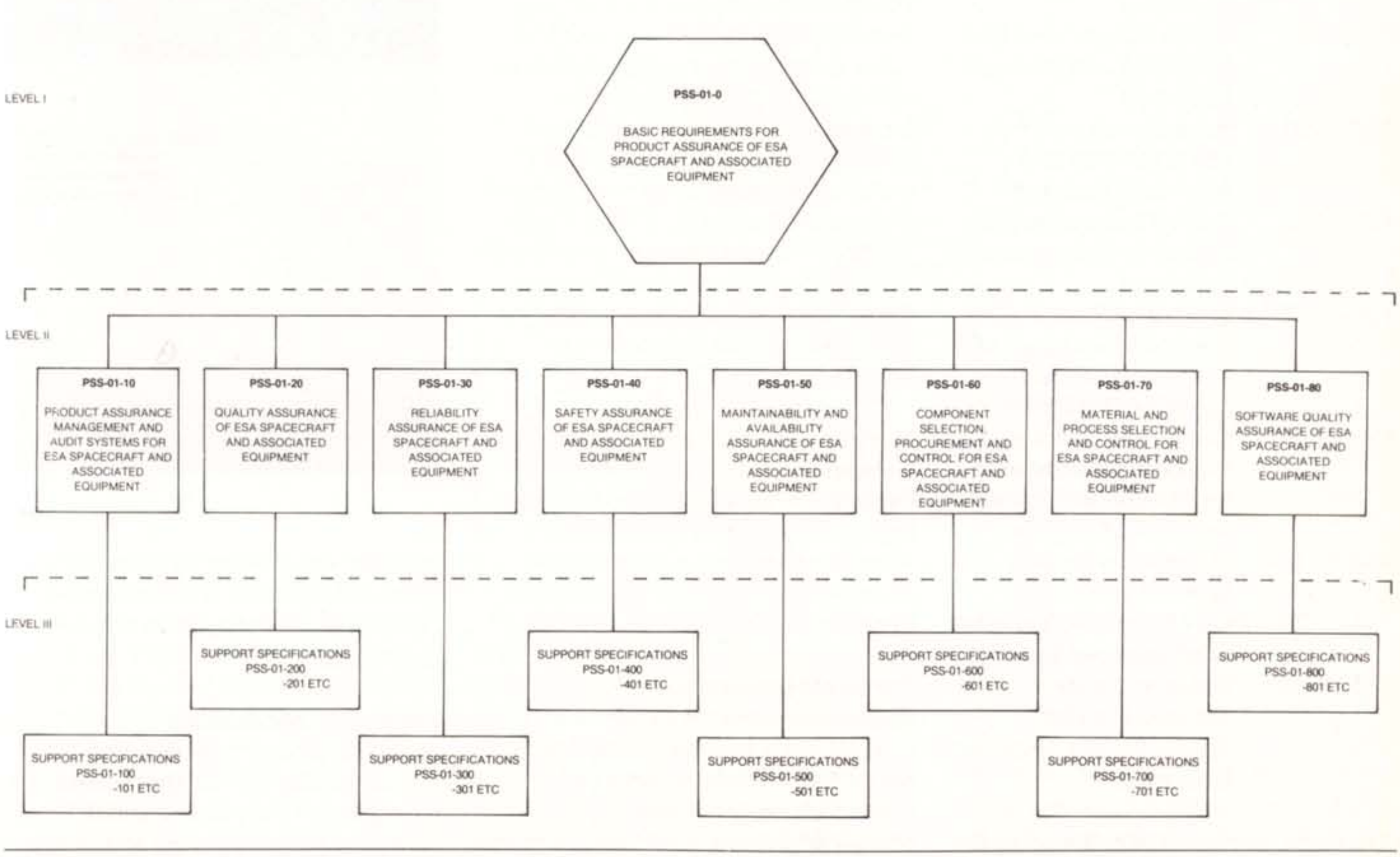
Main features of the new product-assurance specification system

The earlier development of ESRO and ESA specifications for product-assurance – variously published as ESTEC QRA, QRC, QRM or PSS series documents – has evolved over a period of 12 years, with a widespread authorship, and with documents being issued as the need arose, e.g. for project-specific application. These specifications have now been rewritten and re-identified to fit into a three-level structure, to achieve greater homogeneity among the specifications and to provide for the separation of basic requirements and their expansion into groups of specifications, each of which applies to a major discipline or field of technology (Fig. 1). Specifications with a lower level of importance can be added to each group and, as the need arises, there is provision for the formation of new groups to cover new disciplines or areas of technology. This can be achieved with the bare minimum of modification to other specifications in the system.

The grouping of PA disciplines into separate specifications is intended to:
- facilitate a controlled selection of requirements
- increase flexibility in their use by different projects
- facilitate their use as standards for assessment of contractor's PA systems and facilities.

A new document numbering system has been adopted which provides an alphanumeric identity: ESA PSS-01-... as the basic Product Assurance Identification Number together with a blue (instead of green) band on the cover. The numbers following the basic product-assurance identification indicate the level, discipline-group and identity of each document.

The document PSS-01-0, 'Basic Requirements for Product Assurance of



ESA Spacecraft and Associated Equipment', is the only level-I document and as such forms the cornerstone of the complete specification system, which contains the basic requirements for the whole spectrum of PA activities and disciplines. It aims at a contractor PA programme that is properly planned and executed with sufficient authority and expertise, and in which emphasis is placed on the optimisation of design, timely prevention of deficiencies and verification of adequate quality of the end item.

A detailed expansion of each of the product-assurance disciplines contained in the level-I specification is given in the level-II specifications, which currently comprise eight specifications:

PSS-01-10	Product Assurance Management and Audit Systems for ESA Spacecraft and Associated Equipment
PSS-01-20	Quality Assurance of ESA Spacecraft and Associated Equipment
PSS-01-30	Reliability Assurance of ESA Spacecraft and Associated Equipment
PSS-01-40	Safety Assurance of ESA Spacecraft and Associated Equipment
PSS-01-50	Maintainability and Availability Assurance of ESA Spacecraft and Associated Equipment
PSS-01-60	Component Selection, Procurement and Control for ESA Spacecraft and Associated Equipment
PSS-01-70	Material and Process Selection and Quality Control for ESA Spacecraft and Associated Equipment
PSS-01-80	Software Quality Assurance of ESA Spacecraft and Associated Equipment.

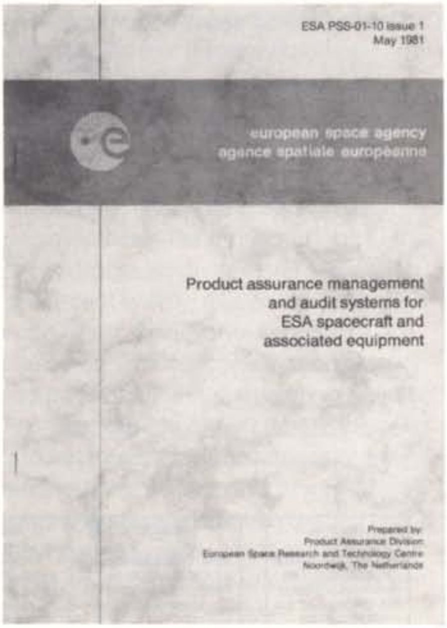
The level-III documentation comprises the remainder of the specifications (e.g. PSS-01-708, PSS-01-603). These support the level-II specifications and variously cover ESA preferred methods, supporting data, critical processes and procedures.

Introduction to the new specifications
An extensive effort has been made to achieve greater uniformity in the presentation and progressive exposition of requirements and relevant information. In the level-I and II specifications, requirements have been divested of amplifying statements and data. Those of the latter that remain necessary or useful are being embodied in level-III specifications. Statements regarding the applicability of other documents in the system have been removed. They have been replaced by a standardised form of reference to related documents. These are to be found at the end of each Section in PSS-01-0, and in the preliminary pages of the level-II and III specifications.

The updating arrangements have also been simplified. In the great majority of cases, a specification will be updated by raising and publishing a new issue. Exceptions to this rule will be strictly limited to certain documents whose revision is envisaged to be more frequent. At present this will apply to PSS-01-603, The ESA Preferred Parts List, and PSS-01-701, Data for Space Material Selection. These will be bound loose-leaf to permit their revision by the replacement or addition of pages.

There has also been a substantial transposition and amalgamation of material in what is believed to be a more logical and economical arrangement. This is illustrated in the more detailed descriptions of individual specifications that follow.

The level-I specification
PSS-01-0 replaces the former PSS-01/(QRA-01) specification, which formed the PA baseline requirements for ESA projects for the last 10 years. It is now somewhat reduced in content, giving only

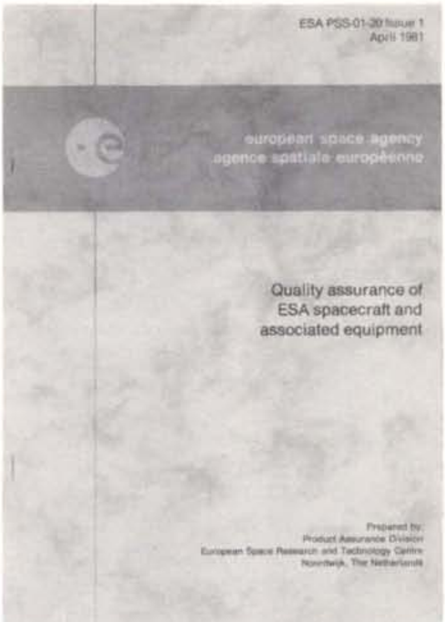


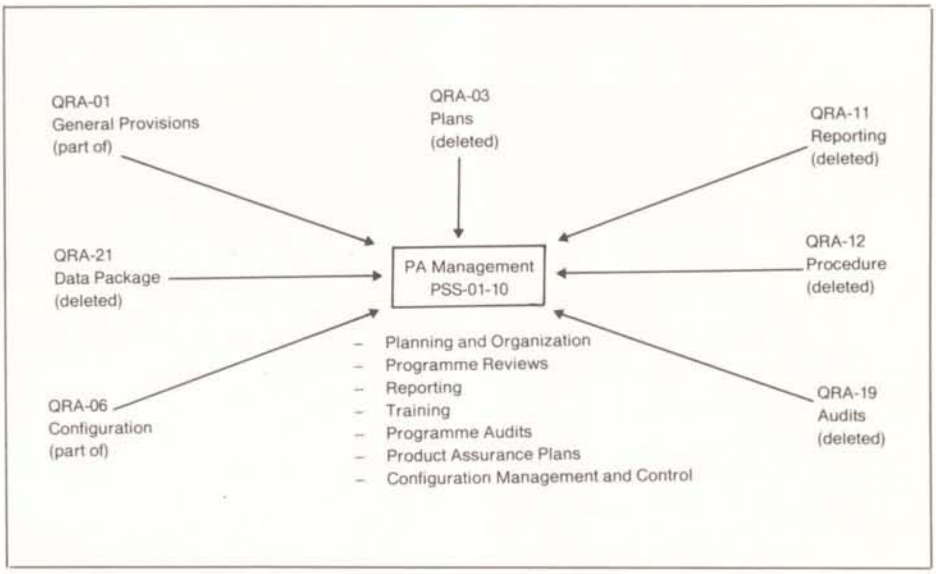
the basic requirements for each product-assurance discipline. A notable addition is the inclusion of a chapter on software quality assurance.

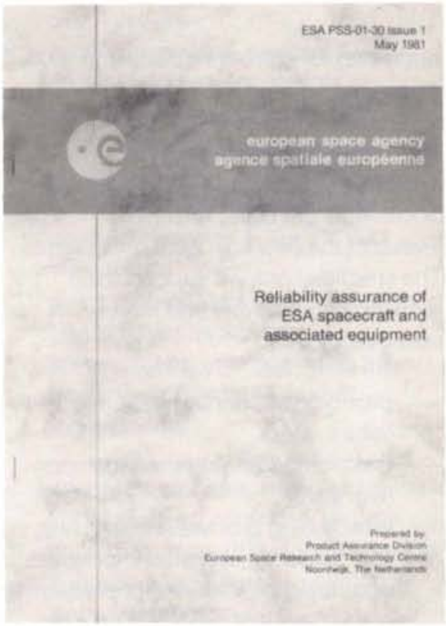
The level-II specifications
PSS-01-10 groups those requirements concerned with the managerial aspects of a programme and includes audits, configuration management and control,

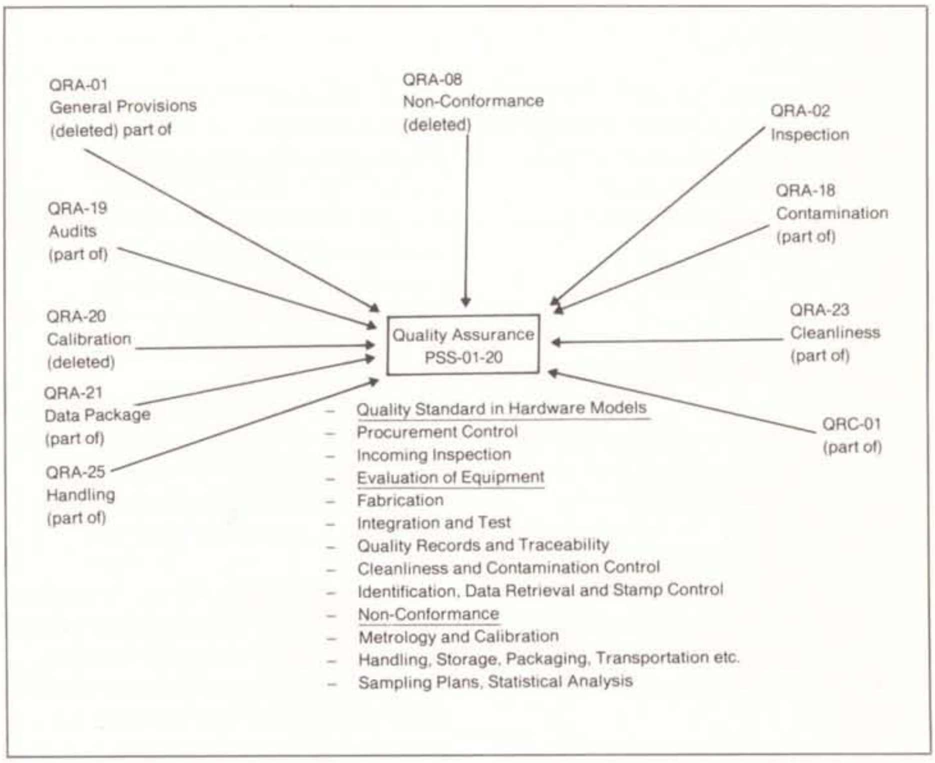
Figure 2 – Content of ESA PSS-01-10: 'Product-assurance management and audit systems for ESA spacecraft and associated equipment'

Figure 3 – Content of ESA PSS-01-20: 'Quality assurance of ESA spacecraft and associated equipment'





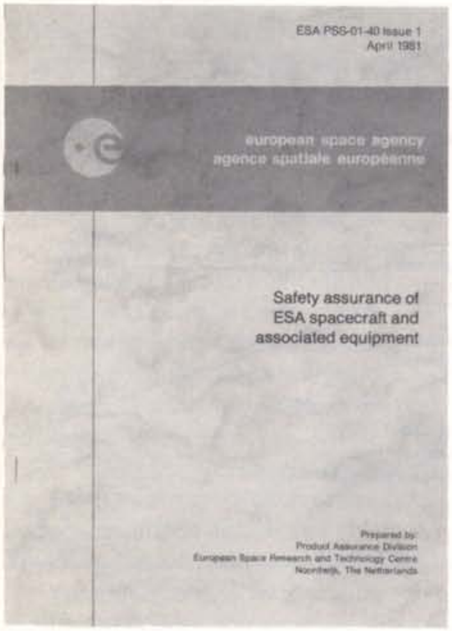


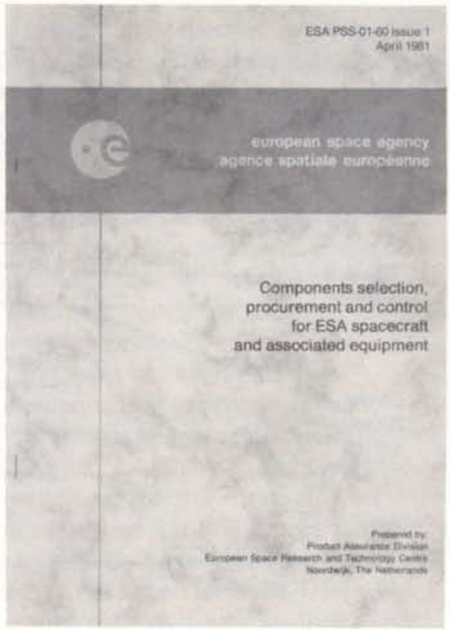


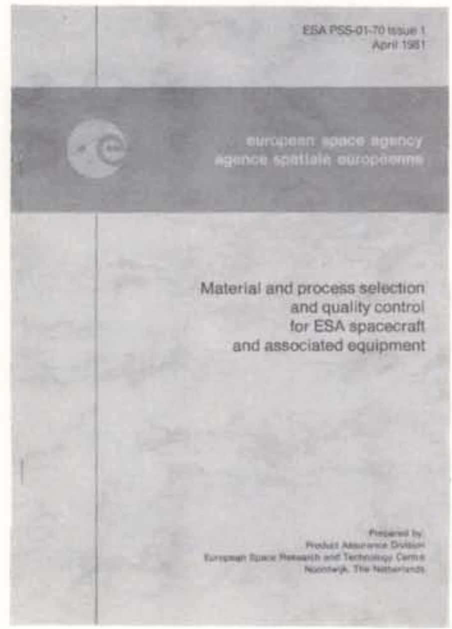
training, planning, reporting, plans and programme reviews. Various former QRA and PSS documents have contributed to the content of this specification, as indicated in Figure 2. Generally speaking, this specification, or parts thereof, will be applicable in conjunction with any of the disciplines defined in other level-II specifications.

The Agency's quality-assurance requirements that were previously defined by several individual specifications have been grouped together and updated in a single document, PSS-01-20 (Fig. 3). Procedural detail has been reduced and, where necessary, will be given in lower level documents. Notable features are that the nonconformance requirements have been reduced and simplified, and the need to evaluate equipment used on previous projects has been added.

PSS-01-30 consists of those requirements drawn from various previous documents which are necessary to ensure, define and







measure the probability of achieving a successful mission. It is emphasised in this document that reliability tools are an essential part of the assurance programme. It includes new features, such as:

- outage analysis
- contingency analysis
- critical-item identification and control.

The requirements for safety assurance are defined in document PSS-01-40. However, requirements dictated by launcher authorities are not covered by this specification. For these, the user is referred to the relevant documentation of the launcher authority concerned. The addition of manned safety assurance requirements is under consideration.

PSS-01-50 will be issued in the near future. It will consider all pertinent operations, storage and mission requirements during all project phases from the maintainability, maintenance and availability points of view. It will concern primarily those projects whose missions provide a continuous service and where satellites have to be in standby, either on the ground or in orbit.

PSS-01-60 is generally similar to the previous electronic-components requirements specification PSS-54 (formerly QRC-01), but the quality-assurance requirements have now been incorporated in ESA PSS-01-20, and the requirements for plans, reporting planning, etc. are covered by ESA PSS-01-10. Other new features are:

- an ESA Preferred Parts List (PPL) is a primary components selection basis;
- the requirements for components drawn from the stocks of previous projects have been redefined.

The new specification PSS-01-70 defines requirements for materials and processes selection. It will fulfil a role for materials and processes similar to that of PSS-01-60 for components. Requirements have been derived from various QRM documents, as can be seen from Figure 4.

PSS-01-80 will be issued in the near future. The purpose of this document will be to define the various phases and activities connected with the implementation and the assurance of a software system and to establish requirements that lead to a standardised approach for software quality and reliability assurance.

The level-III specifications

The body of existing QRA, QRC or QRM documents are being rewritten to fit into level-III of the new specification system. The specifications will support the requirements of level-I and level-II specifications by:

- providing supporting data (e.g. PPL, failure rates)
- describing ESA preferred methods (e.g. tests)
- establishing process requirements (e.g. soldering, repair, crimping, etc.)
- describing procedures for performing certain tasks (e.g. FMECA)

In the majority of cases there will be little change in technical content, but several specifications will be amalgamated under a new title and number.

Existing supporting specifications will continue to be published and used in conjunction with the new level-II specifications until the former are replaced by their level-III counterparts (PSS-01-101 through PSS-01-801, etc.).

The implementation arrangements

It is important to exercise greater control over the selection and application of elements of the new specification system to new projects. A start has been made, and coordination has been developed progressively on recent new spacecraft projects, in collaboration with the respective project managements. It has anticipated and preceded the Procurement Review function now exercised by the System Engineering Department of ESA in which we are also involved and which, consequently, provides an additional overview of the fit of the product-assurance material in the ITT (Invitation to Tender) package.

The main coordination tasks exercised by the Product Assurance Division's System Section are and will be to:

- ascertain the type, complexity and special features, constraints, proposed management system, etc. of the project;
- advise on reliability and lifetime objectives;
- select the appropriate combination of ESA product-assurance specifications, and determine any additional or partially-relaxed requirements;
- ensure appropriate statement in the ITT of required contractor actions on such matters as (PA) documentation submissions, ESA involvement or approval functions, etc;
- determine the product-assurance inputs to the project work statements;
- consolidate the above as the total product-assurance input to the ITT package;
- participate in the aforementioned ESA Procurement Review.

During this process, the technology sections and other specialists in the Product Assurance Division are consulted.

To ensure a regulated approach to the tasks that have been described, to facilitate training, reduce subjectivity, etc. an internal manual of instructions and guidelines is being prepared. In particular, it will identify the various combinations of requirements from the specification system that apply to a wide range of projects and how to accommodate their special characteristics (Fig. 5).

Figure 4 — Content of ESA PSS-01-70: 'Material and process selection and quality control for ESA spacecraft and associated equipment'

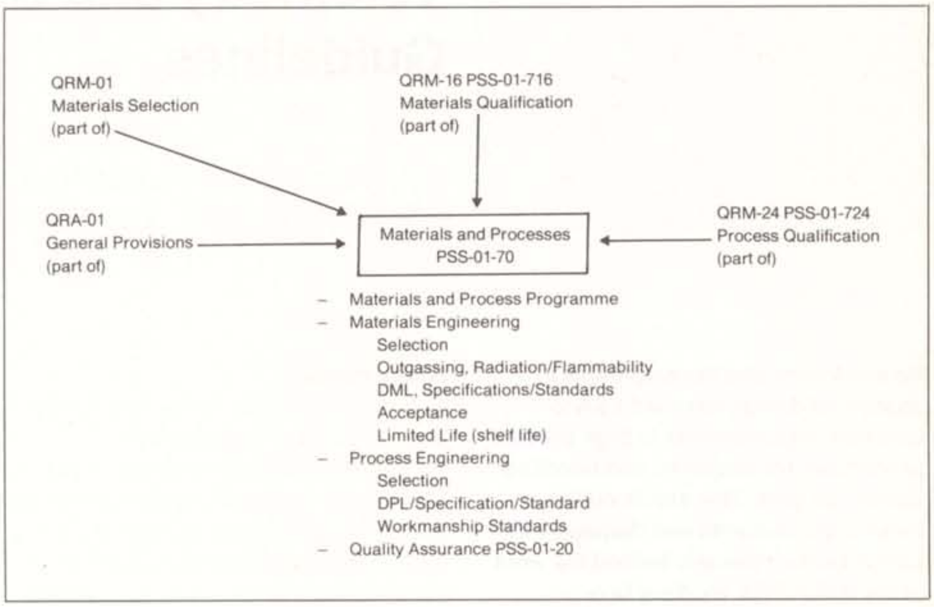


Figure 5 — Implementation arrangements for the new product-assurance documentation system

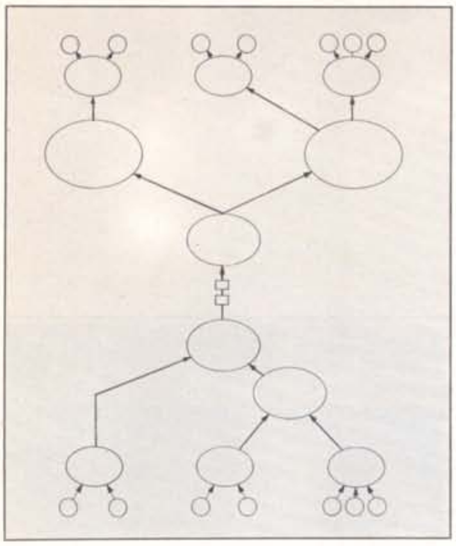
IMPLEMENTATION ARRANGEMENTS

SELECTION OF REQUIREMENTS FOR NEW PROJECTS

– FLEXIBLE APPROACH TAILORED TO SPECIFIC PROJECTS, E.G.:

	P.A. SPECIFICATIONS:	TYPICAL EXAMPLES:
PROJECT A	LEVEL I ALL LEVEL II SELECTION OF LEVEL III	APPLICATION TYPE PROJECT
PROJECT B	LEVEL I MOST LEVEL II SELECTION OF LEVEL III	SCIENTIFIC PROJECTS EXPERIMENTAL PAYLOAD
PROJECT C	LEVEL I FEW LEVEL II SELECTION OF LEVEL III	SCIENTIFIC PROJECTS EQUIPMENT DEVELOPMENT EXPERIMENTAL PAYLOAD SCIENTIFIC EXPERIMENT
PROJECT D	LEVEL I NO LEVEL II SELECTION OF LEVEL III	EQUIPMENT DEVELOPMENT SCIENTIFIC EXPERIMENT

– IN ADDITION APPLICATION MAY VARY THROUGHOUT DIFFERENT PROJECT PHASES



The Rationale behind Packet-Telemetry and Coding-Standard Guidelines

R. Creasey, Data-Handling & Signal-Processing Division, ESTEC, Noordwijk, The Netherlands

Recent trends and developments in spacecraft design have led ESA to consider improvements to their present procedures for acquiring and handling spacecraft data. This article outlines these improvements and discusses in particular the rationale behind the work of the NASA/ESA Working Group (NEWG) on space data standardisation, and the reasons for introducing Packet-Telemetry and Coding-Standard Guidelines.

Future trends

Until the early to mid 1970's, NASA, ESA and other space agencies were concerned mainly with scientific missions. These were characterised by relatively low data rates (generally less than 100 kbit/s), fixed nonadaptive payloads, and use of the acquired data by a small community of users, with few constraints on the timeliness of the data's delivery. The data from these early scientific missions were acquired by a geographically dispersed set of ground stations, and routed back to a central facility over specialised communications networks (e.g. NASCOM) which relied on their own dedicated communications protocols. Since then several significant developments have taken place as far as the nature of missions is concerned, giving rise to a number of distinct sets of requirements for particular types of mission.

Earth-resources missions

The first significant (and obvious) development has been the introduction of Earth-resources satellites with their high data rates, ranging from 15 Mbit/s for Landsat-1 to nearly 100 Mbit/s or more for Landsat-2 and Europe's ERS-1. As the resolution and complexity of the payloads of these missions increase, the data rates used can be expected to increase still further, to several 100 Mbit/s by the mid 1990s.

In addition to this increase in data rate, the products from such missions are disseminated to a wide community of users; distribution is no longer 'one-to-one' as was often the case for a scientific satellite, but rather 'one-to-many'. A further development is the requirement by many users to combine data from several different spacecraft which do not necessarily belong to same agency. This gives rise to a 'many-to-many' distribution problem.

Widespread operational use of Earth-resources data will only be achieved if the data are easily and economically accessible compared with other data sources. This will be difficult to achieve, particularly in the 'many-to-many' case, if the raw data products from the various spacecraft use different data structures, each requiring different acquisition procedures and hardware.

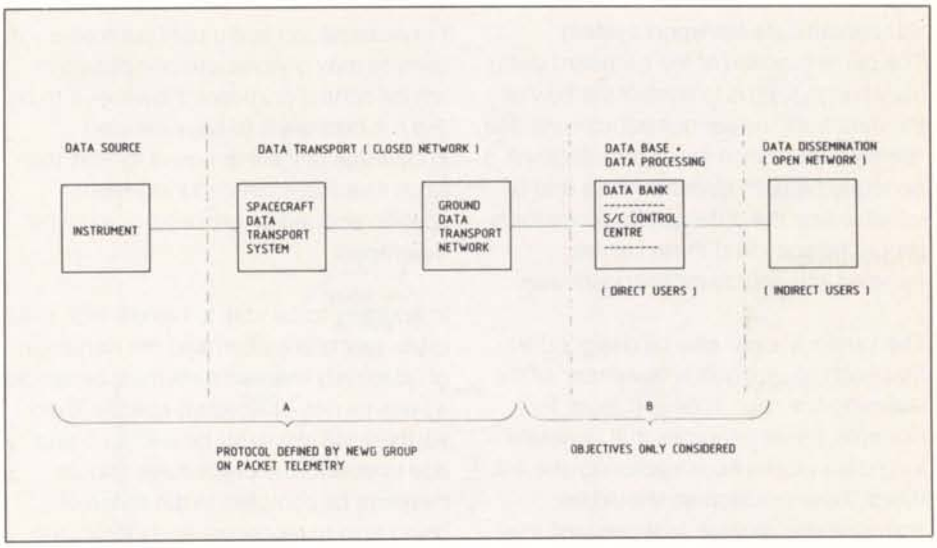
A prime objective of any new standard should therefore be to harmonise the acquisition procedures for such data, which are at present sensor- and spacecraft-unique.

Scientific missions

A second trend, currently associated mainly with scientific missions, is increasing use of payloads with the ability to store and process their own data. Since this in effect makes the payload more 'adaptive', it leads to greater variety in the data structures produced by the payloads on a given mission. This in turn not only implies that the data-transport network must be capable of acquiring and distributing such data, but also leads to a requirement for close, near-real-time interaction between the spaceborne payload and the payload operator.

A further feature of this type of transmitted data is that its value is enhanced by the

Figure 1 — Space data flow functional model for telemetry



on-board processing (redundancy removal) and higher quality links are then often desirable.

Any future standard should therefore be defined to work with adaptive, asynchronous data sources and to allow the acquisition of such data in a data-source-independent manner. It should also permit the optional implementation of higher quality links.

Services and network architectures

It will be clear from the above that different users require different services from the data network. Multi-user, multi-satellite missions such as Earth-resources surveying will probably require the distribution of standard data products to users from a small number of processing centres, possibly using a broadcast-type service for economic reasons. On the other hand, many missions, including those of a scientific nature, require that the user be provided with a 'virtual channel' between the on-board instrument and his ground processing facility. In this case the data-transport system should be transparent to the user and provide a point-to-point (as opposed to broadcast) type of service.

Figure 1 shows the major stages in the data-generation and transport process. A distinction is made here between 'direct users', who receive a 'virtual channel' service, and 'indirect users' who may only receive a (processed) data product. Examples of direct users would be spacecraft controllers, principal investigators, and Earth-resources processing centres. An example of an indirect user would be an operational user of processed Earth-resources data products. As far as packet telemetry is concerned, the important distinction is that its protocol has been designed to serve the 'direct users'.

A further consideration is that when a standard is used by different agencies, those agencies may have different network architectures and operating philosophies. Some agencies may use a 'bent pipe' philosophy for example, whereby the ground station is treated as a 'repeater' and the spacecraft-to-ground protocol is terminated at a central facility; other agencies may follow an approach that terminates the spacecraft-to-ground protocol at the ground station, transferring the data from the ground station to the direct users via an internationally agreed protocol (e.g. X-25). In this case the ground station acts as a 'protocol converter'.

This implies that the packet-telemetry protocol should be network-architecture independent, and in particular should not assume massive, centralised processing facilities for centralised protocol termination. Since in practice this imposes a simple procedure, it is compatible with the desire to handle high data rates.

An ideal solution would have been to adopt an existing protocol for the spacecraft-to-ground channel. It was found, however, that the characteristics of this channel, particularly the lack of a permanent return link, make it difficult to define a complete, efficient procedure using available protocols.

Objectives

The above considerations define the environment for the protocol, but its detailed design depends on major functional requirements within the data-transport process.

Whilst it is possible to generate these requirements using a model such as the Iso-7-Layer open system interconnection model (indeed this has been done for the packet-telemetry protocol), the approach followed here is to relate the protocol design details to the particular problems and requirements of the functional blocks shown in Figure 1.

Instrument

Typically, integrating an instrument into a spacecraft system at present involves the expenditure of considerable time and effort to define the interfaces and to understand the ramifications of all instrument operating modes on the system. It would be preferable if the instrument could be designed in a 'built-to-operate' manner, without requiring detailed knowledge of the spacecraft system. Essentially, this requires:

- a single user/instrument data interface throughout instrument life;
- instrument independence, with data outputs being defined by the instrument operating modes and with minimum constraints from the (data) system.

Spacecraft data-transport system
The prime function of the on-board data-transport system is to control the flow of the data from the various sources into the telemetry link. Since the source data will generally be both asynchronous and of variable size, the data system procedures should be such that these can be handled in a source-independent way.

The system should also be designed so that each source gets a 'fair share' of the telemetry-link resources and must, for example, prevent sources that generate long data blocks from 'capturing' the link. Whilst these procedures should be complete and mission independent, they should not introduce a large, protocol-induced overhead. This requires:
- instrument-independent interfaces and procedures;
- ability to match allocated link bandwidth to instrument demands;
- ability to avoid link 'capture' by a single source;
- data-independent identification and sequence control.

This last point is important because although the source is asynchronous with respect to the telemetry, it must still be possible to ascertain, in a data-independent manner, whether data collection is continuous or not, i.e. loss of data due to buffer overflow or link loss must be identifiable. Typically this can be done using a sequential count of data from the source. Likewise, the data itself must be identified in a data-independent and position-independent manner, by assigning a unique source ID.

Ground data transport
The function of the ground data-transport system is to acquire data from various spacecraft and distribute it to multiple end users. Because many missions have high data rates, it is not always economic, or necessary, to retransmit all data immediately from the acquiring ground station to the user. It should therefore be possible to select for transmission only that data which is needed.

For example, an instrument such as a camera may only require one picture in ten for control purposes. However, if to do this it is necessary to have detailed knowledge of the instrument format, then each time this is needed instrument-specific acquisition procedures must be developed.

In addition, to be able to handle high data rates, synchronisation and the extraction of adaptively inserted data must be simple as well as non-spacecraft-specific. Even so, there will inevitably be a loss of data due to errors. The procedures should therefore be complete in the sense of being able to recognise and identify the data loss in a data-independent manner and should also allow a 'clean' recovery from such situations. This requires real-time measurement of the quality of the receive process.

Summarising, then, the protocol must provide:
- *Standard procedures and interfaces for all missions*
  - no instrument or spacecraft-dependent decommutation procedure
  - network-architecture independence
- *Selectivity*
  - should not have to dimension communications capacity to carry all data to all users in real time
- *Completeness and measurability*
  - no 'repeat' possible; hence procedure must act on inevitable data loss
  - protocol should provide the performance of the receive process in real time
- *Simplicity*
  - should not require massive processing for protocol termination, thereby allowing decentralised network architectures.

The NEWG packet telemetry guideline
Figure 2 is a functional diagram of the telemetry data flow from the creation of a data set by an application process operation within a spacecraft 'source', through to the delivery of the same data set to a user 'sink' on ground. Rather than discuss the details of the protocol, the intention here is to show that the data structures within the protocol are designed to enable the objectives indicated previously to be met.

The data structures themselves, shown in Figure 3, are split basically into data-driven structures (Source Packet) and communications-driven structures (Transfer Frame). These structures are provided:

a. To allow the user to optimise the size and structure of his application data set with a minimum of constraints imposed by the spacecraft-to-ground transport system. The user should thus be able to define his data organisation independently of other users, and to adapt this organisation to the various modes of his experiment.

   The data structure that allows this independence is the Source Packet. Within the packet the user data are encapsulated within a standard primary header, which is used by the data-transport system to route the data through the system. A secondary header structure is provided which enables more application-unique specification of the user data.

b. To allow the spacecraft terminus of the data-transport system to be designed and tested without a detailed definition of all user data organisations.

   This is particularly important since at the time of specifying the onboard spacecraft-data-system design this knowledge is usually not available from the experimenter, and attempts to force an early agreement with present systems often lead to nonoptimum, fixed-format telemetry designs.

Most space communications systems are capacity-limited and multiple users must somehow be guaranteed access to the link. It is therefore important for the spacecraft to be able to manage the data flow to the ground in an orderly manner. For example, users who generate long data packets could, if allowed unrestricted access, 'hog' the link for long periods, forcing increased buffer capacity and response times for other users.

The proposed packet-telemetry system solves this problem by permitting two methods for controlling data flow. The first, *virtual channelisation*, is a logical mechanism for allowing a small number of packets from independent sources to co-exist on the same physical link: it allows complete separation of groups of sources. The second, *segmentation*, is a mechanism for transmitting long source packets as a series of short segments, avoiding capture of the link by one source.

Virtual channelisation will normally be used to separate sources with very different characteristics. If, for example, a payload contains an imaging instrument that produces a regular scan line packet containing many thousands of bits, and a number of processor-based experiments which periodically generate smaller packets of processed data, a possible system architecture would be to assign the imaging instrument to one virtual channel and to handle the rest by segmentation or direct multiplexing on a second virtual channel.

c. To allow the ground data-acquisition system to retrieve the packets in a standard way, with a data-

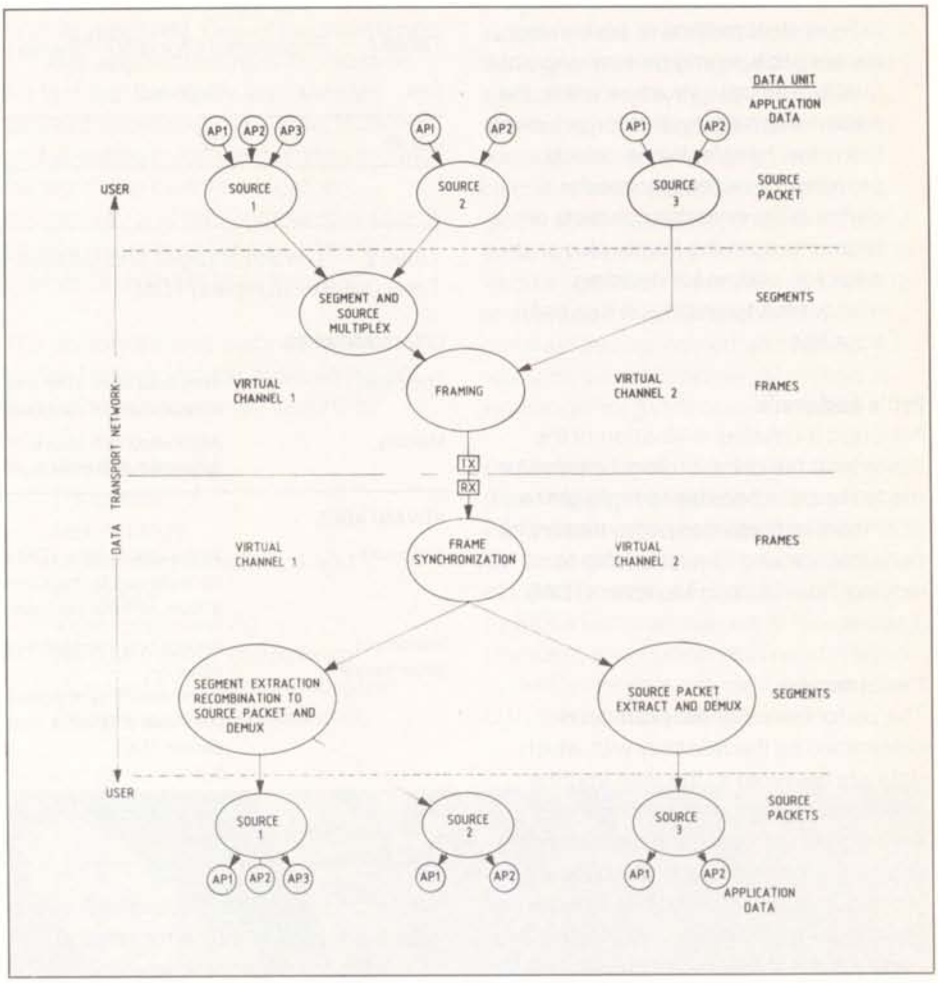


Figure 2 — System concept

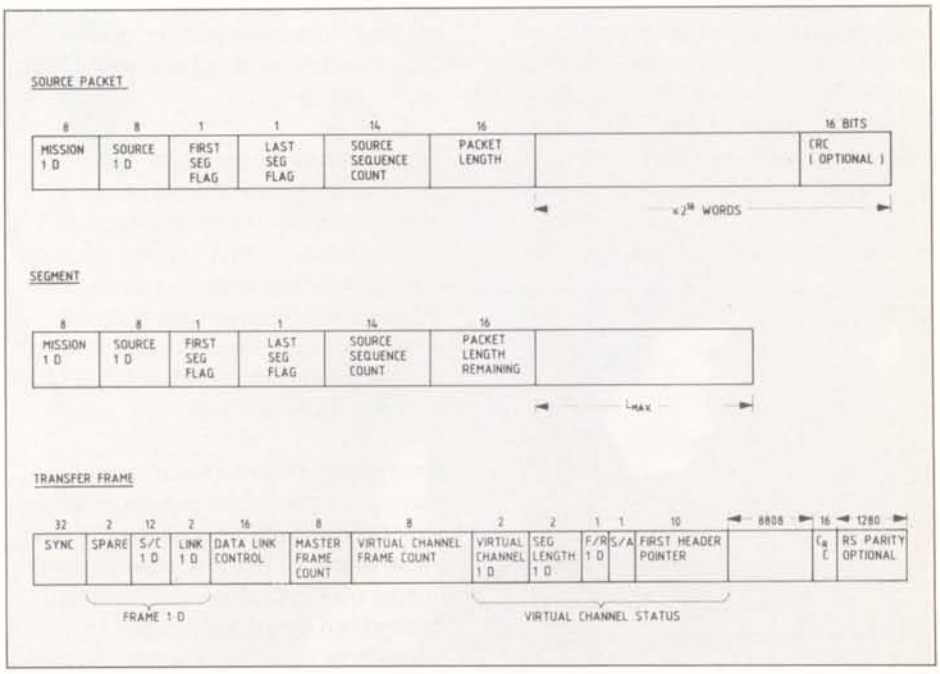


Figure 3 — Data structures

Figure 4 — Overhead as a function of maximum source packet length

independent method of performing packet capture and determining data quality. The data structure within the packet-telemetry system for achieving this is the 'transfer frame', which provides the necessary header elements for extracting packets or segments from the frame, plus error-detection coding for deciding whether the transmission has been error free.

Pro's and con's

Although a detailed evaluation of the major features of the protocol cannot be made here, it is possible to highlight two of its more important aspects, namely its performance and its relationship to existing Time Division Multiplex (TDM) systems.

Performance

The performance of the protocol is determined by the reliability with which data are delivered to the user and the overhead involved in achieving this. Although to the user the most interesting criterion is 'packet loss' probability, the ground acquisition chain has to work on a frame-by-frame basis, and thus protocol performance is essentially determined by frame-acquisition performance. For high-speed operation it is necessary to have a simple acceptance/rejection criterion, chosen here to be the (HDLC) error detection code; the frame-rejection criterion must be kept to 10^{-3} if a significant loss of data is to be avoided.

However, since the frames are long to

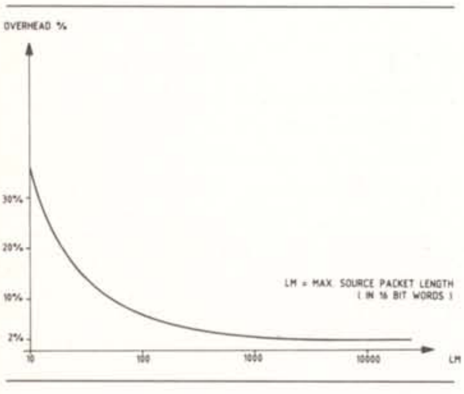


Table 1 — Requirement for a 10^{-4} frame-reject rate

Link	Uncoded	Convolution	Concatenated code
E/N dB	12	5.8	2.8

Table 2 – The advantages and disadvantages of packet-telemetry compared with Time-Division Multiplex (TDM)

DISADVANTAGES	
Overhead:	With fixed data, TDM can potentially be made efficient (3% overhead), independent of data block size.
Memory:	Associated with above, TDM does not require buffers in source. Packet telemetry requires 2–300 word buffers for reasonable efficiency.
ADVANTAGES	
Adaptivity:	With variable data, TDM requires either multiple formats (extra complexity) or a few nonoptimum formats (increase in overhead). Packet telemetry automatically adapts, without increase in overhead or complexity.
Instrument dependence:	Source only identified by position in TDM format; hence instrument data must either be: 1. forced into synchronism with TM (extra memory) 2. include additional, instrument dependent, sync. markers (halfway house to packet TLM) 3. not extracted by ground network (no selection possible). Packet telemetry, by forcing standard headers, explicitly identifies data blocks at all times.

reduce overhead, this requires inter alia a reasonably high raw bit error rate (10^{-7} to 10^{-8}) if the full network services of acquisition, selection and validation are required. To achieve such error rates requires either more signal power or the use of coding.

Table 1 shows the technical performances of different schemes. In practice, concatenated coding (Rate 0.5 Convolutional Code with Reed Solomon Code) allows higher performances to be achieved with little increase in signal power; moreover the channel is 'cleaned up', removing many disadvantages of the lack of a return channel.

Another performance parameter of interest is overhead, and in the proposed protocol there are two sources: the fixed frame overhead and the packet/segment-header overhead. The exact overhead depends on the packet-length distribution; Figure 4 shows the overhead for a uniform packet-length distribution between 1 and L (max), with an upper segment length of 4096 bits. Other distributions give similar results. It is important to note that with present TDM systems an overhead of typically 3% (frame header and ID) is incurred; to achieve this with the present protocol requires an average packet length of 100–200 words.

Comparison with TDM

The advantages and disadvantages of TDM are summarised in Table 2.

Conclusion

The proposed protocol has been developed taking into account the spacecraft operating environment expected in the 1980s and 1990s. It has also been designed to be compatible with a variety of network architectures, and to provide a range of standard network services.

In Brief

ESA Technology Demonstrations at UNISPACE '82

Several 'live' demonstrations will be given in the course of UNISPACE '82, the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space, to be held in Vienna from 9 to 21 August 1982. One of the main goals of these demonstrations is to underline the fact that the highly sophisticated satellites now being developed, launched and operated by different entities around the world can be linked together successfully and with comparative ease to provide a variety of services offering substantial benefits to all mankind.

The demonstrations planned by the United Nations include applications of state of the art space techniques to:

- Remote sensing
- Education
- Meteorology
- Mobile communications and navigation
- Video conferencing
- Remote medical consultation
- Videotext transmission/reception
- Remote access to databanks.

As outlined below, ESA will play a prominent role in conducting several of these demonstrations.

Remote sensing

Systematic surveying of the Earth from space has already been proved to be of immense value, not least by the achievements of the American Landsat programme. The myriad applications include ocean and hydrological surveying, ice mapping, geological and agricultural surveying, and pollution monitoring. With satellite-based remote sensing, we can arrive at an accurate inventory of the Earth's resources on a global scale. By distributing the acquired data, in raw and/or processed form, to the world's scientific centres, we can hope to encourage the national scientific communities concerned with natural-resource and environmental matters to work together to the common good.

As an example of the type and quality of data that can be obtained from a typical Earth-observation satellite, the UNISPACE '82 demonstrations will include a display of Landsat data collected and processed by ESA's Earthnet stations at Kiruna (Sweden) and Fucino (Italy) and relayed to the Conference site via the Agency's OTS telecommunications satellite.

Landsat-2 multispectral scanner image of northern Iceland (original in colour). The data were acquired and processed by ESA's Kiruna (Sweden) Earthnet station.

Education

There is a basic need, particularly in large countries and/or those with low population densities, for the broadcasting of educational programmes via a satellite system. Many tests have already been performed in a variety of countries to prove the feasibility of such a system.

The live demonstration at UNISPACE '82 is intended to give Conference participants the opportunity both to observe the types of programmes being broadcast in some countries (e.g. India and Indonesia) and to monitor the reaction of student viewers in remote areas. A two-way voice link in parallel with the TV transmission will permit interviews with the students to be conducted from Vienna, thereby giving Conference delegates first-hand reaction to the service provided. Live transmission of these programmes to the Conference requires the interlinking of up to three satellites. For example, Palapa, Intelsat (Indian Ocean) and OTS will have to be connected to beam the Indonesian programmes to Vienna. A key role will be played by ESA's OTS satellite, as it will provide the essential link, at the Fucino earth station, between the Conference site and the global Intelsat system.

Meteorology

Meteorologists around the world already use satellites on a day-to-day basis for short- and medium-term forecasting. Once operational, such systems tend to lead to co-operation across national boundaries and a need to present the information being gathered by the satellites and associated data-collection platforms in a standardised format facilitating reliable data exchange.

Near-real-time data from several different meteorological satellites will be on display at UNISPACE '82, to emphasise the applications aspects of meteorological data processing.

Images from ESA's Meteosat spacecraft will be received and processed at ESOC, Darmstadt (Germany) and then retransmitted via Meteosat to Vienna. Goes images will be received at CMS, Lannion (France), converted to Meteosat standards, and then also retransmitted via Meteosat.

A demonstration of image processing of digital Meteosat images as provided by a Meteosat Primary Data User Station will also be given, including facilities for changing colours and contrast levels and expanding images to identify particular meteorological phenomena. A meteorologist will be on hand to give detailed explanations.

Meteosat's data-collection and relay capabilities will be further demonstrated by displaying messages received from remote platforms installed around the world.

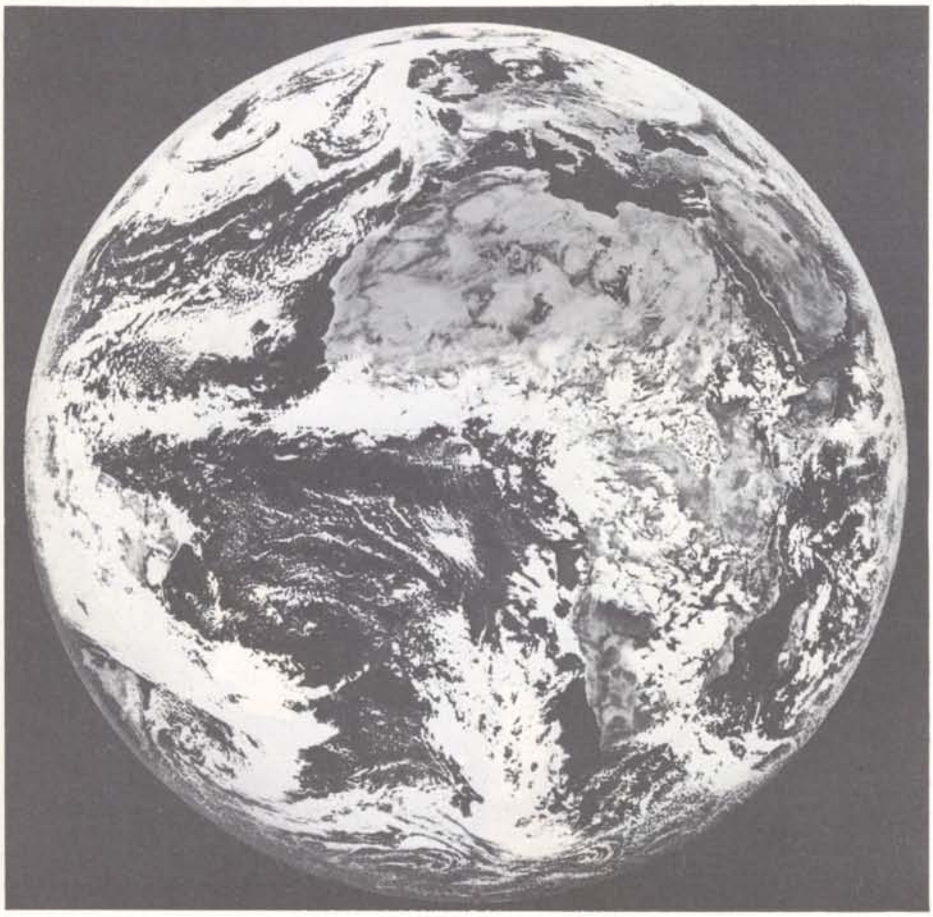
Mobile communications and navigation

Maritime systems, such as that provided by Inmarsat, already allow world-wide ship-to-shore and shore-to-ship communications, and will soon also provide very high accuracy position determination. These services have facilitated a major step forward in navigation techniques and will represent a substantial contribution to the rapid setting in motion and coordination of maritime rescue operations as soon as the precision navigation capabilities are provided. Wristwatch transceivers that will provide world-wide communication and allow the wearer's exact position to be pinpointed virtually instantaneously are perhaps two decades away at most. Demonstrations of the features and benefits of Inmarsat's maritime satellite communications system, using the Marecs-A spacecraft built by ESA and leased to Inmarsat as part of its multisatellite space segment, will be given throughout the Conference.

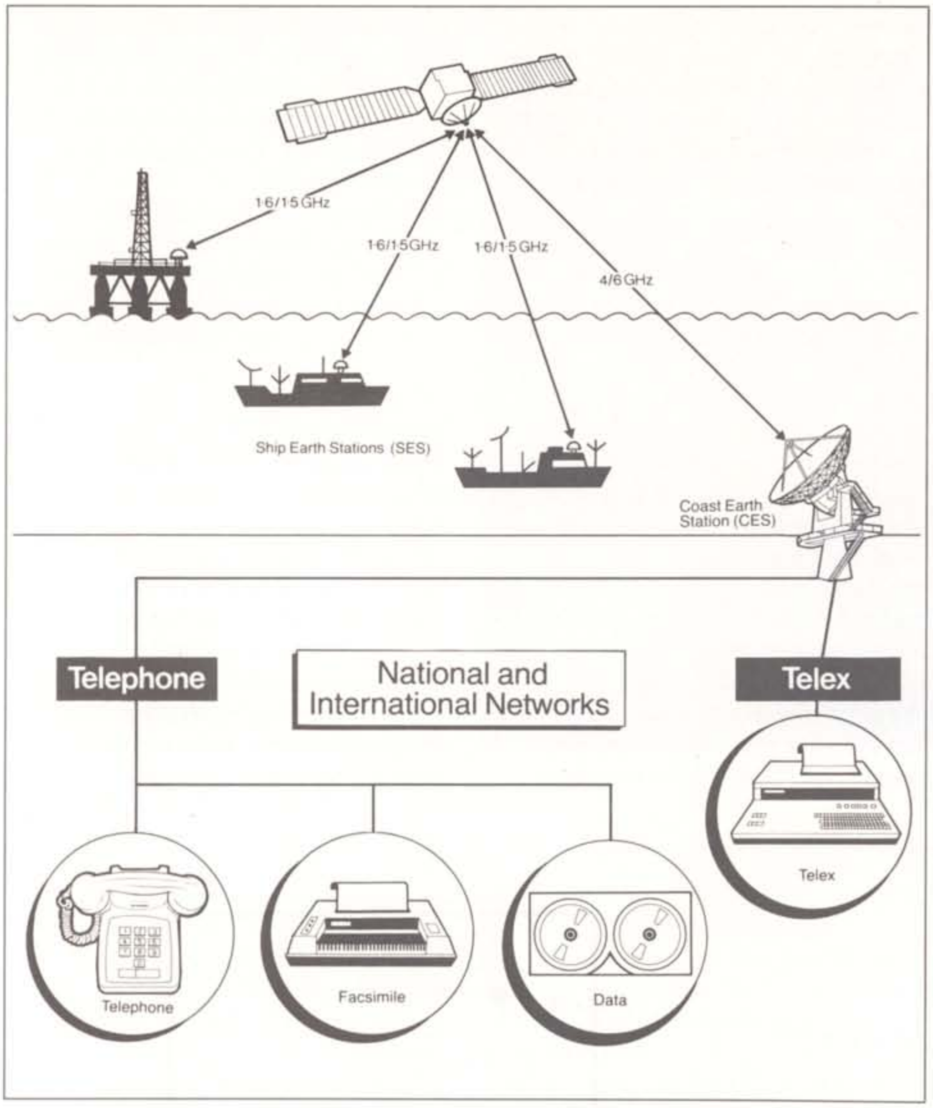
Video conferencing

With more and more decentralisation of business activities across national boundaries, video conferencing is beginning to play an increasing role in modern corporate management. Coordination of international activities often requires 'on-the-spot' discussions which, until recently, were only possible by arranging meetings. With the exception of Concorde, the speed of air travel has changed little over the past decade, though the number of passengers has increased enormously. The already complex problems of handling large numbers of passengers efficiently are further aggravated by the need for immigration and customs controls.

With increasing competition in business, the efficiency of communication has to be



Meteosat-2 image (visible channel) received and processed at ESOC, Darmstadt (Germany).



Schematic of maritime satellite communications via ESA's Marecs spacecraft.

further improved, and video conferencing provides a practical answer. A live example of video conferencing will therefore be one of the ESA demonstrations, and a number of Heads of State will address the Conference from their home countries via the video conferencing facility.

Two further demonstrations will feature remote interpretation of UNISPACE discussions and remote translation of UNISPACE documentation as the Conference progresses.

During two, pre-scheduled four-hour periods, the Conference sessions will be interpreted simultaneously into the UN's six official languages by the UN Secretariat in New York. A split-image video system will provide the interpreters in New York with pictures of the speaker and audience in Vienna, together with the original sound.

The remote-translation demonstration will make use of the time difference between New York and Vienna, in that all documents generated during the Conference will be translated in New York and transmitted back to Vienna prior to the start of the next morning's Conference session. For English, French and Spanish, word processor-to-word processor links will be used, while for the Russian, Arabic and Chinese languages a datafax system will be employed.

Remote medical consultation

One very attractive potential application of modern satellite communications systems is the possibility for a medical practitioner in a remote village or, for example, on an ocean drilling platform, to consult a medical expert in a specialised hospital in the case of an emergency.

The system allows all medical data, including X-rays, to be relayed to the hospital in real time, permitting the expert to consult all available data and to provide the medical practitioner with immediate advice.

An already operational telehealth system, namely the Canadian one provided via the Anik-B satellite, will be demonstrated at the Conference with the help of ESA's OTS satellite.

Videotext transmission/reception

Videotext systems are already operational in several countries, but the majority of these systems do not yet include the possibility of interactive operation (i.e. the recipient cannot communicate with the centralised system that provides the information). An interactive videotext system enables the operator at the receiving station, which could be an ordinary TV set linked to a simple, low-cost keyboard, to pre-select the information that he receives.

To demonstrate the feasibility of such a system it is planned to link the Conference building with some of the major news databanks and to request transmissions of the world's news headlines at regular intervals in Russian (TASS), English (Reuters) and French (Inter Press).

Remote access to databanks

Rapid developments in electronics and the micro-miniaturisation of complex circuits, together with the steadily improving quality of communications channels, now permit the establishment of networks that make available sophisticated electronic storage media and various associated services to remote locations at acceptable cost.

The services provided by these systems will not be limited to electronic newspapers and journals, but will ultimately provide access to electronic libraries the world over. The traveller will be able to consult airline schedules and make reservations from home, for example, and electronic banking, electronic mail and remote shopping services will soon be widely available. Further applications might include medical databanks and computerised ordering and dispatch services for urgently needed medicines and drugs.

Two of the demonstrations to be given at UNISPACE in this domain will be those of ESA's Space Informatics Network Experiment (SPINE), and that by ESA's Information Retrieval Service (IRS).

SPINE

The Space Informatics Network Experiment was created in 1980 as a special ESA project. The present participants in the project are Germany, Sweden and the United Kingdom.

The main objective of SPINE is to investigate experimentally the on-line retrieval and transmission via the Agency's Orbital Test Satellite (OTS) of earth-resources data from the archiving facilities of Earthnet in Frascati (Italy) and Kiruna (Sweden) to national processing centres such as the Royal Aircraft Establishment (RAE) in the United Kingdom, and the Swedish Space Corporation (SSC) in Stockholm.

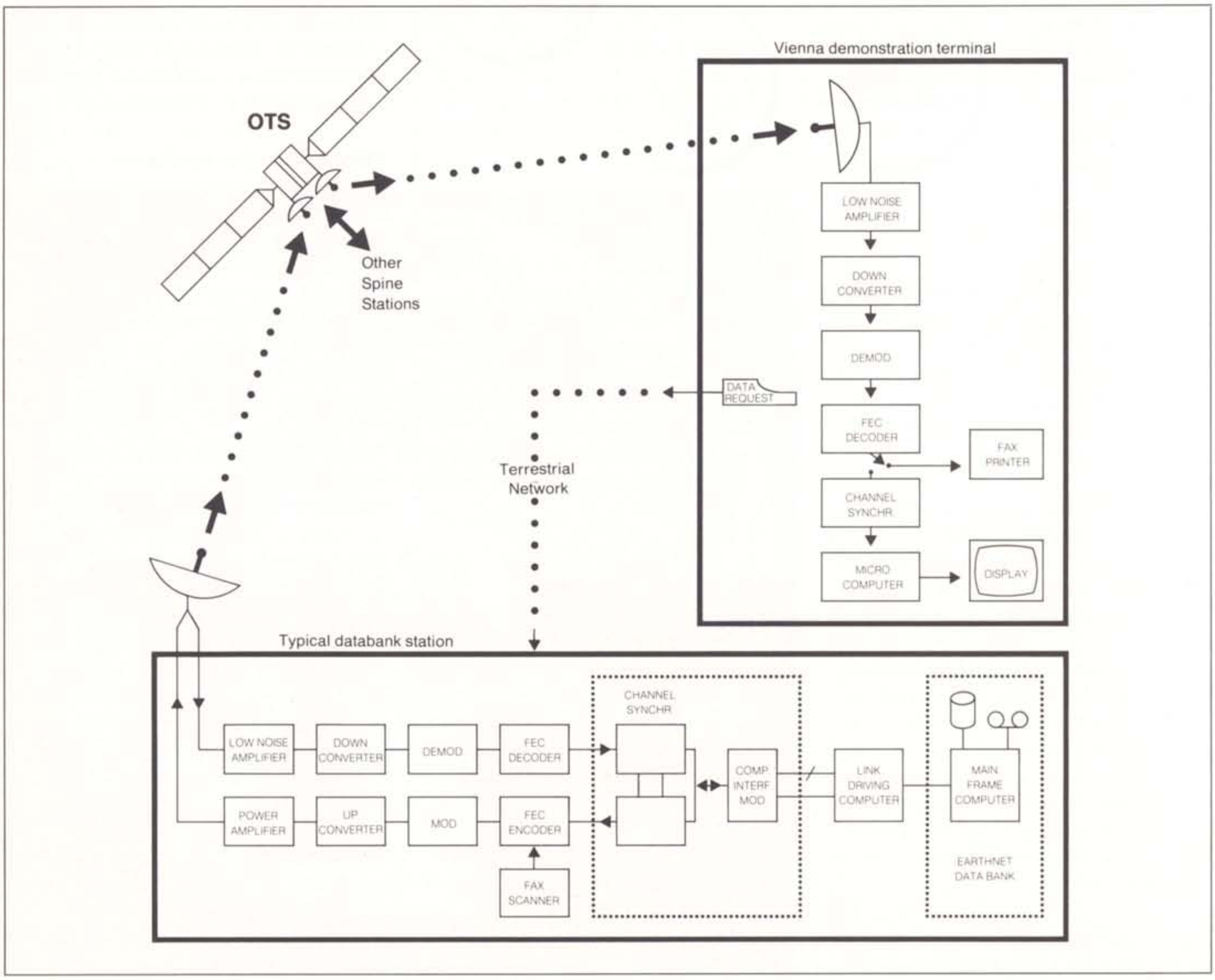
Satellite earth stations equipped with 3 m-diameter, fixed-mount antennas and capable of transmitting and receiving information at a rate of 2 Mbit/s have been developed and installed at the participating establishments. It is possible, through the satellite network, to interrogate the catalogue files of another location, ask for immediate transmission of quick-look data, examine the data for suitability, and request transmission of the full-resolution image contained on the high-density tape.

This initial phase of SPINE has been running since July 1981 and involves transmit/receive earth stations at the four locations. Efforts are now being concentrated on giving access to data from the network to rather simple, inexpensive, receive-only user stations. Since communications-satellite footprints tend to cover a very wide geographical area, there are no special restrictions on the user's location. One of these user stations will be demonstrated in Vienna. From the Conference site it will be possible to select sample data sets from the SPINE databanks in the United Kingdom, the Netherlands, Italy and Sweden and have them transmitted in real-time for immediate display. Three of the examples to be demonstrated have already been mentioned:

- digitally coded pictures from earth-resources satellites (Landsat, Seasat and Meteosat)
- selection and transmission of Conference papers by high-speed facsimile (1 Mbit/s)
- regular transmission of newspaper pages by high-speed facsimile.

IRS

The IRS demonstration is intended to show how European industry and Government departments can make use of the information provided by ESA's Information Retrieval Service to search the state of the art in the fields of aerospace technology, medical information, biological information, electronics, computers, energy, agriculture, metallurgy, plastics and a number of other related subjects.



Cos-B Switched Off

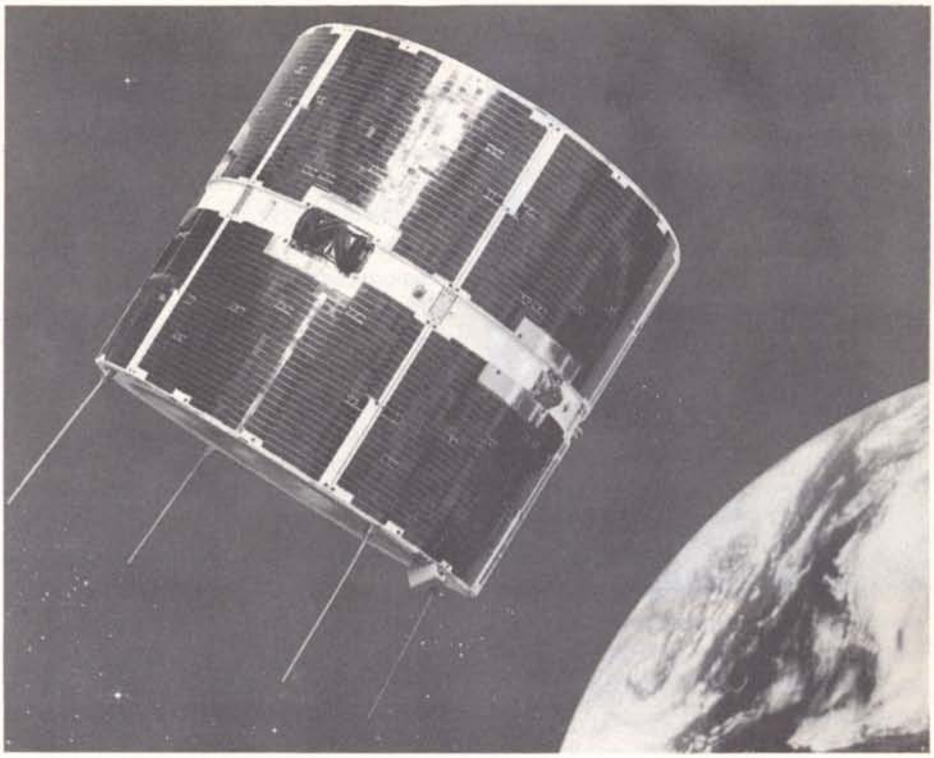
Cos-B, the scientific satellite launched by the European Space Agency in 1975 for a planned two-year lifetime, was finally switched off on 26 April 1982 after six years and eight months of operation. The mission has produced outstanding scientific results (see ESA Bulletin No. 28, November 1981), discovering, inter alia, a new class of galactic objects, known as gamma-ray sources.

Cos-B was launched on 9 August 1975 (see ESA Bulletin No. 2, August 1975) into a highly eccentric orbit (apogee 100 000 km, perigee 350 km). It carried a single scientific instrument, a telescope to observe celestial gamma-rays at energies greater than 20 MeV. This telescope was the result of a successful collaboration – the 'Caravane Collaboration' – by six European institutes: the Cosmic-Ray Working Group, University of Leiden, The Netherlands; the Max-Planck Institut für Extraterrestrische Physik, Munich, Germany; Istituto di Fisica Cosmica of the CNR, Milan, Italy; Istituto di Fisica Cosmica e Informatica of the CNR, University of Palermo, Italy; Service d'Electronique Physique, Centre d'Etudes Nucléaires de Saclay, France; and ESA's Space Science Department, ESTEC, The Netherlands.

Cos-B's gamma-ray telescope performed flawlessly throughout the mission, showing only minor signs of degradation, a feat all the more remarkable since it was originally designed for a two-year mission.

The spacecraft, built for ESA by the CESAR consortium, led by MBB, also performed completely to specification throughout the mission.

The scientific results from Cos-B have been outstanding and full advantage has been taken of the extended mission to make more detailed observations of interesting regions of the sky discovered during the first two years of operation. In particular, a complete survey of the galactic disc has been performed with unprecedented precision. A new class of galactic object, known for the time being as gamma-ray sources, have been discovered. These sources are much brighter at gamma-ray wavelengths than normal stars; with the exception of the pulsars, they have not been identified with objects seen at other wavelengths. Detailed studies have been made of the Crab and Vela pulsars. The pulsation patterns at radio and optical wavelengths are seen to persist to gamma-ray wavelengths, although their detailed form differs for gamma-rays. In particular, the pulsation pattern shows a long time variation in the Cos-B data. The first observed extragalactic source, namely quasar 3C273, was seen by Cos-B to emit gamma-rays. It turns out that the bulk of the energy emitted by this quasar lies in the previously undetected gamma-ray region. Detailed correlations of gamma-ray emission with local galactic features and interstellar gas have revealed considerable new information about the distribution of cosmic rays in the Galaxy.



Cos-B

Throughout the Cos-B mission, its data were received by the ESA ground-station at Redu in Belgium, and satellite control and data processing were carried out at the ESA Space Operations Centre (ESOC) in Darmstadt (Germany).

ESA Remote-Sensing Programme Underway

On 15 May 1982, contributions from Participating States – Belgium, France, Germany, Italy, Spain, Sweden, Switzerland, the United Kingdom, Norway and Canada – reached the level laid down for starting the system definition phase (Phase-B) of the first ESA Remote-Sensing Satellite Programme, known as ERS-1. A final decision on whether to proceed with Phase-C/D (hardware development) is to be taken at the end of 1983.

The main goal of the ERS-1 programme is to give Europe the means to participate in both the management of the Earth's resources and the monitoring of its environment, in particular by establishing, developing and exploiting the coastal, ocean and ice applications of remote-sensing data.

The nominal payload of the satellite, to be launched into a circular, 700 km high, Sun-synchronous orbit at the end of 1987, consists of:

- Active Microwave Instrumentation (AMI) combining the functions of a Synthetic Aperture Radar (SAR), a wave scatterometer and a wind scatterometer, with the aim of measuring wind fields and the wave image spectrum, and of taking all-weather images of coastal zones, open oceans, ice areas and over land;

- Radar Altimeter (RA) with the aim of measuring significant wave-height and of providing measurements over ice and of major ocean currents;
- laser retroflectors for accurate tracking from the ground;
- the Along Track Scanning Radiometer (ATSR), an additional package, to be provided and funded by the UK and resulting from an announcement of opportunity to the scientific community. This is a three-channel infrared radiometer for accurate sea-surface-temperature measurements. The final decision as to whether to fly the ATSR will be taken at the end of Phase-B.

The above payload will be carried on a platform based on another model of the multi-mission platform developed within the framework of the French Spot programme.

Apart from the scientific results expected from the mission, which will be of great interest to researchers in the fields of physical oceanography, glaciology and climatology, ERS-1 will provide information that will help to develop commercial applications of immediate practical use to mankind. Better short and medium-term weather and ocean-state forecasts can be expected; these are of particular importance not only for shipping, but also for the siting and operation of offshore industrial complexes, such as oil rigs. More accurate sea-surface-temperature measurements will assist the location of fish species living close to the surface (e.g. tuna), thereby improving the management of fish resources. The monitoring of sea-ice and icebergs will also contribute to increasing the safety of shipping and offshore oil activities in far northern areas. Another area of interest where ERS-1 is expected to provide useful information is the detection and monitoring of marine surface pollution. Lastly, high-resolution SAR imagery over land will be used as an all-weather complement to optical data provided by other satellites such as Landsat and Spot.

ERS-1 will permit worldwide coverage, with direct data transmission to ground stations. Onboard recorders will provide access to data from any part of the world, except for that from the SAR, the very high data rate of which will allow only real-time transmission.

ERS-1 will be both an experimental and a pre-operational system, preparing the way for a fully operational multi-satellite system in the 1990s.

ESA's Presence at ILA'82

The ESA stand at the International Aerospace Exhibition (ILA'82) held in Hanover, Germany, from 18 to 25 May, highlighted the importance of the Agency's activities and programmes in the fields of space transportation, telecommunications and Earth observation. Among the models exhibited were full-scale reproductions of the communications satellites ECS and Marecs and the meteorological satellite Meteosat and of the scientific satellite Exosat to be launched later this year (see articles on Exosat elsewhere in this issue). In the section of the stand devoted to Spacelab, there was also a model of the Space Shuttle Orbiter carrying Spacelab in its cargo bay.

Meteosat pictures were received directly on the stand from the satellite via a small antenna set up in the Exhibition grounds.

Two eminent visitors to the ESA stand during the Exhibition were Parliamentary Secretary M. Grüner (far left in photo below left) and Federal Minister for Post and Telecommunications, H. Matthöfer (far right in photo below right).

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 on page 123 and using the Order-Form on page 124.

ESA Journal

The following papers have been published in ESA Journal Vol. 6, No. 2 (June 1982):

LASSO EXPERIMENT SCHEDULING AND DATA PROCESSING AT THE SIRIO-2 LASSO COORDINATION CENTRE
DE AGOSTINI A., POLUTAN F. & D'AMORE F.

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Special Publications

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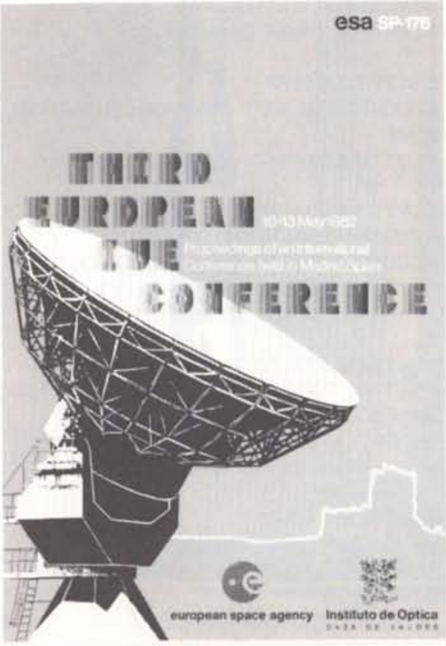

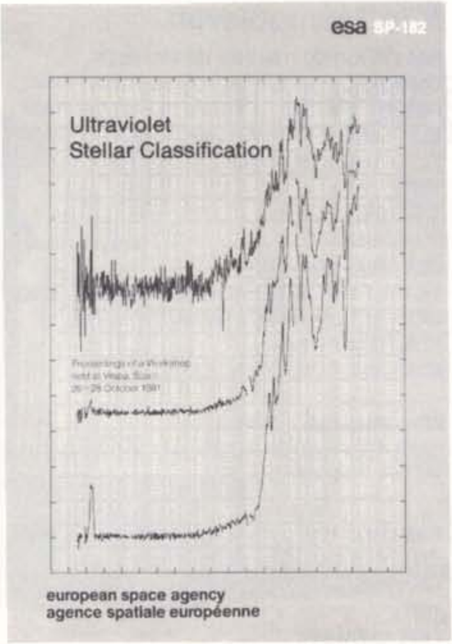

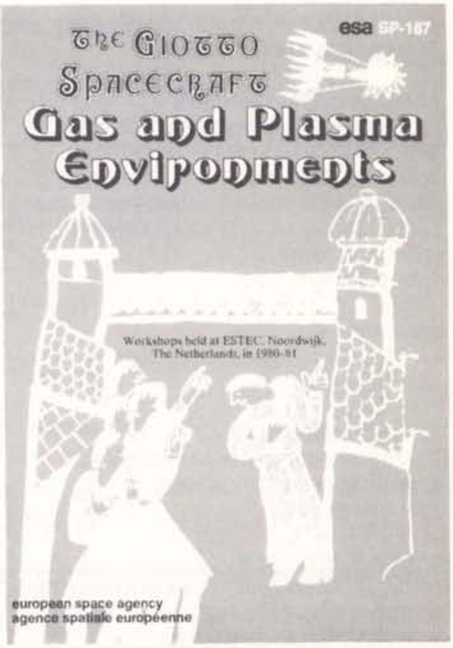

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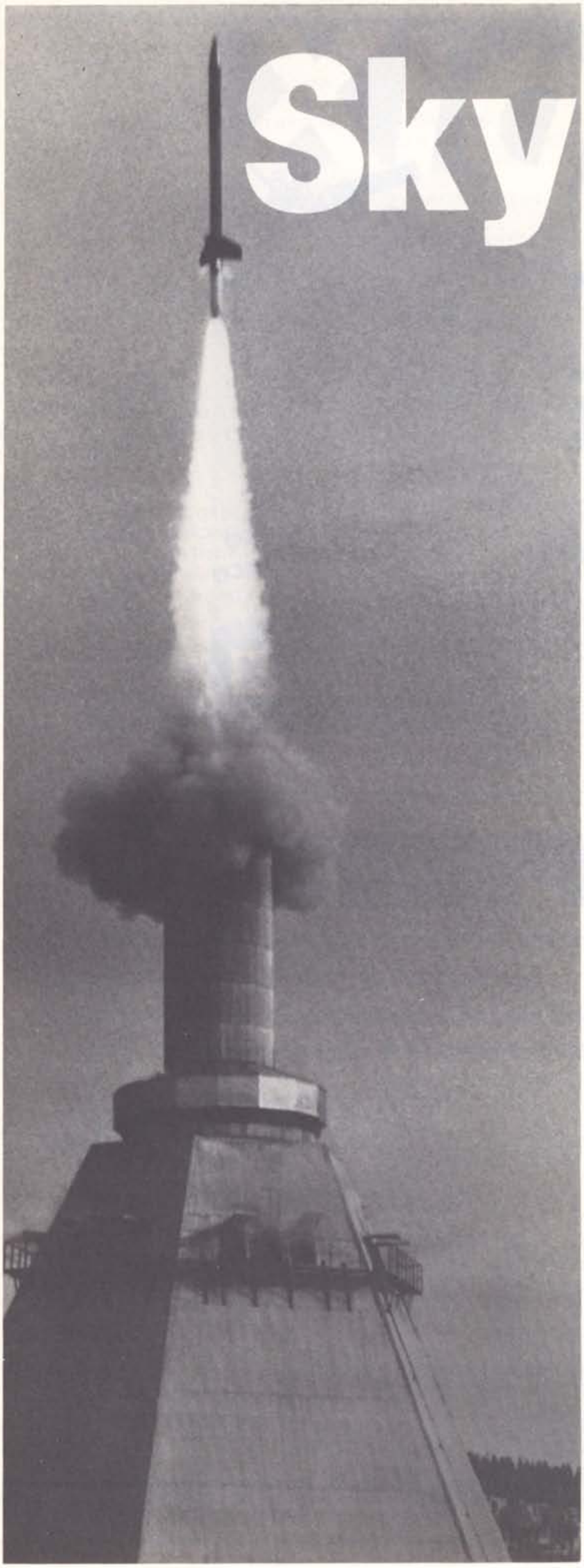

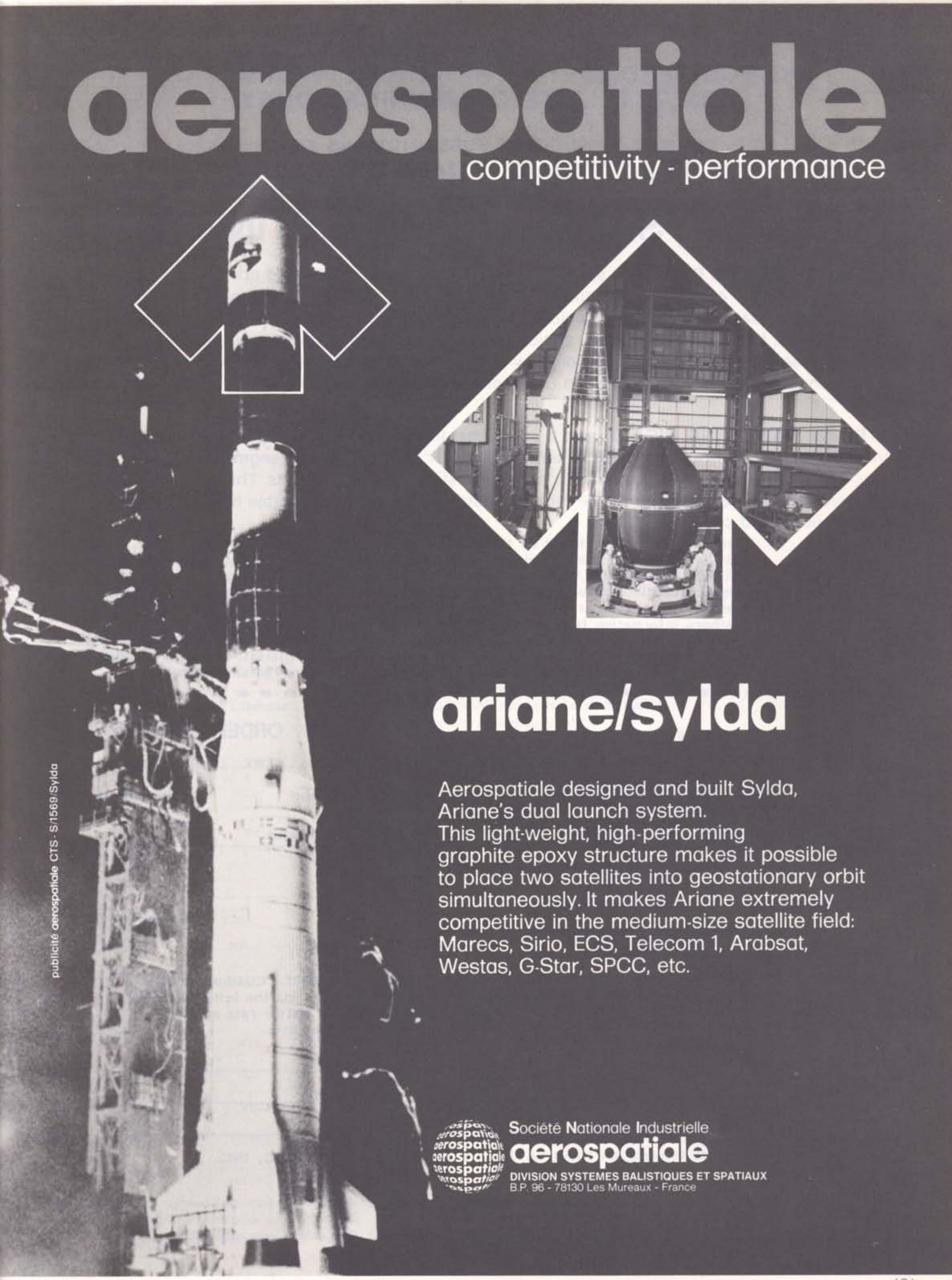
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