esa bulletin

number 40

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xx years of european cooperation in space
european space agency
ELDO
1964
1984
ESRO
esa
agence spatiale européenne
xx ans de coopération spatiale européenne

european space agency

The European Space Agency was formed out of, and took over the rights and obligations of, the two earlier European Space Organisations: the European Space Research Organisation (ESRO) and the European Organisation for the Development and Construction of Space Vehicle Launchers (ELDO). The Member States are 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 Operations, 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: Dr. H.H. Atkinson.

Director General: Prof. R. Lüst.

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;
(d) en élaborant et en mettant en oeuvre la politique industrielle appropriée à son programme et en recommandant aux Etats membres une politique industrielle cohérente.

L'Agence est dirigée par un Conseil, composé de représentants des Etats membres. Le Directeur général est le fonctionnaire exécutif supérieur de l'Agence et la représente dans tous ses actes.

Le Directoire de l'Agence est composé du Directeur général, du Directeur des Programmes scientifiques, du Directeur des Programmes d'Applications, du Directeur des Systèmes de Transport spatial, du Directeur technique, du Directeur des Opérations et du Directeur de l'Administration.

Le SIEGE de l'ESA est à Paris.

Les principaux Etablissements de l'ESA sont:

LE CENTRE EUROPEEN DE RECHERCHE ET DE TECHNOLOGIE SPATIALES (ESTEC), Noordwijk, Pays-Bas.

LE CENTRE EUROPEEN D'OPERATIONS SPATIALES (ESOC), Darmstadt, Allemagne.

ESRIN, Frascati, Italie.

Président du Conseil: Dr. H.H. Atkinson.

Directeur général: Prof. R. Lüst.

esa bulletin

no. 40 november 1984

contents/sommaire

Front cover: Launch of ECS-2 and Telecom-1 by Ariane-3 on 4 August (see page 72)

Back cover: Marecs-B2 being readied for the next Ariane launch (together with Spacenet-F2)

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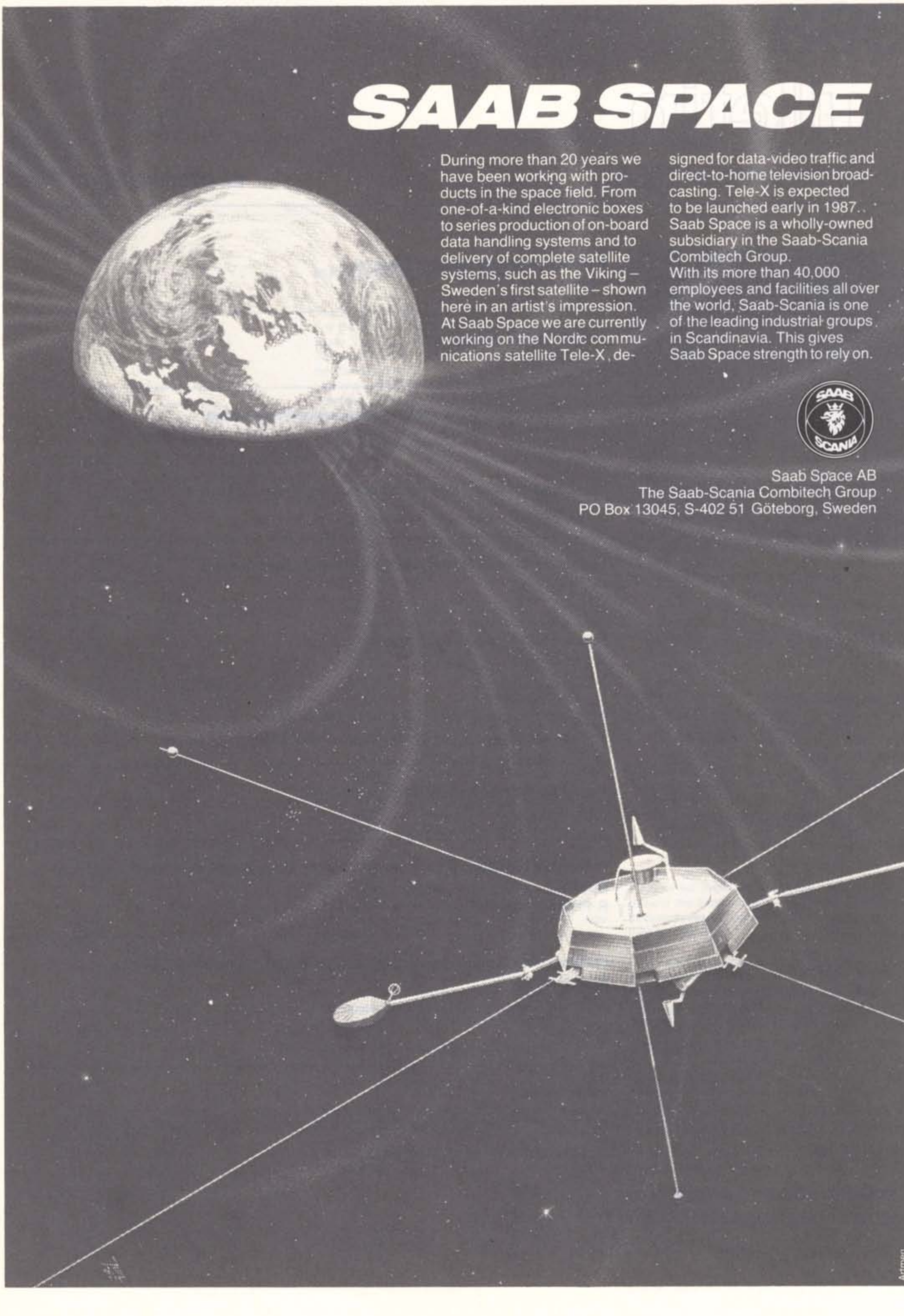

SAAB SPACE
During more than 20 years we have been working with products in the space field. From one-of-a-kind electronic boxes to series production of on-board data handling systems and to delivery of complete satellite systems, such as the Viking – Sweden's first satellite – shown here in an artist's impression. At Saab Space we are currently working on the Nordic communications satellite Tele-X, designed for data-video traffic and direct-to-home television broadcasting. Tele-X is expected to be launched early in 1987.
Saab Space is a wholly-owned subsidiary in the Saab-Scania Combitech Group.
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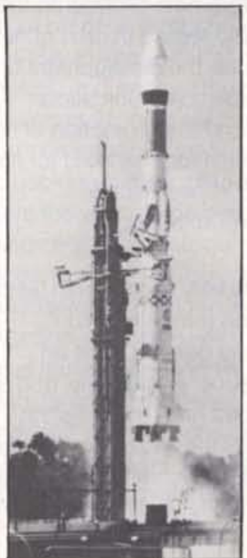

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Sylda

The European launcher Ariane is built by some forty industrial firms in eleven countries.
Its architect? - Aerospatiale.
Design, system testing, stage contracting, technical management, integration.

Aerospatiale also builds the dual launch system. SYLDA. This device increases Ariane's competivity by making the simultaneous launch of two medium size satellites possible.

aerospatiale

Division Systèmes Balistiques et Spatiaux
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Message from the Director General

This is the first opportunity that I have had since taking up office in September to address myself to the wide and varied readership of the ESA Bulletin.

My association with European space activities goes back to the earliest days of ESRO, when as Director of Science I was able to help in setting up the first space-science projects. Although we had our dreams, we could not have foreseen the extent and scope of Europe's place in the worldwide exploitation of space twenty years later.

I have returned to the international space research scene at a most exciting time, and my first two short months have been spent largely in preparing for the Ministerial Conference due to be held in Rome on 30 and 31 January 1985.

I would like, therefore, to explain, in general terms, the proposals and options that the Ministers will be considering as they seek to give Europe a viable, stimulating space programme for the decades ahead.

The significance of the Conference extends far beyond the immediate bounds of ESA or the national space agencies. The extent to which space research touches so many lives today can be judged by the numerous communities which will be affected by the deliberations of the Ministers from our Member States.

At the heart of European space research from its inception has been the space-science community. Space science is acknowledged today to hold an important place in fundamental research. It has, however, lacked a long-term programme, and potential recruits to this branch of science have not necessarily seen an acceptable career ahead of them.

We hope to see a stable, but flexible, space-science programme established until the year 2000; stable, in that the major programme elements are known, flexible in that there would still be room for later decisions on smaller projects to keep pace with the shifting needs of science.

The science programme has often provided the incentive for the more dramatic technological advances associated with space exploration and the high-technology industries of Europe can look forward to more challenging demands being placed on their ingenuity.

The ESA telecommunications programme has been a success story, not only in the technical achievements of the satellites and their associated ground installations, but also in the way different communities have worked together.

To exploit the ECS satellites, following the trial period with their predecessor OTS, the European PTTs set up their own organisation, EUTELSAT, to interface with ESA. This has enabled ESA, European industry, and the 'customers' to hold fruitful dialogues. ESA is also looking ahead to future needs with its advanced 'Olympus' satellite. The same has been true in the maritime world, with INMARSAT representing a very substantial customer requirement, and ESA providing the Marecs satellites as Europe's contribution to the worldwide maritime communications network.

In this discipline, the first of the so-called application programmes, ESA has shown the merits of a European-level research programme. For the future, we must look to expand the commercial and operational exploitation of space for the benefit of European users, and to consolidate European industry's competitiveness in European and world markets through the development of advanced systems and technology. With this in mind we will be offering the Ministers a programme centred on the development and testing in orbit of new space techniques, the development of a European in-orbit communications infrastructure, and the promotion of new space communications services for the expansion of European space communications activities.

Ariane, after the very minimum of teething troubles for such a mammoth undertaking, has given Europe an independent launcher capacity, and a place in the world market for launch vehicles. Already the basic concept has been extended to accommodate larger satellites destined for geostationary orbit.

The commercial exploitation of Ariane has been entrusted to Arianespace by the Member States, but much work still has to be done if Europe is to remain competitive with other existing or planned space-transportation systems.

The future is inevitably tied to the long-term goal of preparing for an

Prof. R. Lüst

autonomous capability to support man in orbit. It is clear, however, that we should ensure the availability by the mid-1990s of a new-generation launcher, with improvements to existing capacities and reliability and the capability of man-rating for subsequently orbiting a space plane.

This leads inevitably to thoughts of the next major step planned by the USA, to develop a permanently manned Space Station. In my view this is a development that Europe cannot afford to ignore. Europe has shown its capabilities in manned space flight with the highly-praised, and successful Spacelab. Now we must prepare, through co-operation with NASA, to improve that capability, and to develop and acquire the new technologies for both manned and unmanned orbital operations in low Earth orbit. Looking further ahead, we must prepare the way for the decisions on the development of an autonomous European in-orbit infrastructure with the aim of mastering manned in-orbit intervention early in the next century. To achieve these objectives, we foresee two main programme elements: the Columbus programme, involving co-operation with the USA in all phases of their Space Station, and an Advanced Systems and Technology Programme.

The uses of manned-flight capabilities brings me to our 'youngest' activity – microgravity research. I note with satisfaction that ESA has, through its efforts in the life- and materials-sciences disciplines, brought together many scientific communities which might not otherwise have appreciated the potential that space research held for them. Spacelab has opened new vistas for these scientists and, from modest beginnings, their programme is progressing steadily. As part of the long-term plan, we envisage that the materials- and life-sciences communities could become major users of the future low-Earth-orbit infrastructure. They would be encouraged to prepare the maximum number of experiments in space, planning especially to make use of the Space Station (Columbus). The disciplines most likely to make use of the manned laboratory would be life-sciences and fluid-physics research; crystal growth and metals processing could be performed mainly on unmanned platforms.

In terms of regular public impact, the Earth-observation programme leads the way, as Meteosat images are seen nightly on television screens throughout Europe. ESA is deeply involved with the meteorological offices of the participating countries in setting up an operational Meteosat system, and the establishment of EUMETSAT to represent their interests. Now we must ensure continuity of the Meteosat operational system by means of a second generation of satellites to be launched in the mid-1990s.

The ERS-1 satellite represents ESA's other main thrust in the Earth-observation field. Our objective, for the later part of this century, is seen as providing a substantial contribution from space and ground techniques to Earth-observation sciences and their applications. Operational systems covering remote sensing of oceans, ice and coastal zones, the development of all-weather microwave instrumentation, and research tools for solid-Earth sciences and climatology are all needed.

Nor must we forget that all of these programmes can only materialise if the basic technological research programme is developed ahead of the operational satellites. The more challenging the demands of the scientists, the more the technologists need to have time and scope to devise ways of bringing the data back to Earth.

Of course, one of the most difficult tasks will be to find the correct balance between the different programme elements. There are political, industrial, operational and indeed social considerations, which will enter into the deliberations of the Ministers as they prepare for the Conference. Nor can we think of Europe in isolation. While we aim for the right degree of independence, we are all aware that co-operation and understanding with other major space users is essential, and desirable.

These then are our main preoccupations as we approach the meeting of Ministers. There is a busy time ahead as we seek to reconcile and blend the various national points of view.

Of one thing I am certain. Europe has forged for itself a strong place in space research and exploitation; it is our objective to enhance that position, and to ensure that Europe is at the forefront of the peaceful use of space as we plan for the end of the twentieth and the beginning of the twenty-first century.

I intend to make increasing use of the ESA Bulletin in future for explaining our policies and actions, as well as keeping you abreast of current scientific and technical developments. I am delighted at the interest shown in ESA's activities, as witnessed by the Bulletin's distribution to more than 10 000 readers in 103 countries. I appreciate that the readership is varied in background, culture, and nationality, but we are bound by a common interest in the peaceful use of space, and the belief that mankind can use space research to further knowledge of the Universe, and to understand and use more beneficially the resources of Earth.

Prof. R. Lüst


esa
PRESIDENT

Tribute to Erik Quistgaard

I would like to express the Agency's and my own gratitude to my predecessor, Mr. Erik Quistgaard, and to pay tribute to his work for ESA in the four years 1980–1984 as Director General. During his term of office he has been responsible for much of the ground work on which I hope to build during my own tenure.

Erik Quistgaard took up duty in 1980, at a time when the ongoing programmes of the Agency were nearing fulfilment, new programmes had yet to be formulated, and further thought needed to be given to the role that the Agency should play in the coming decade. One of his first tasks was to take up the discussions on ESA's future, including definition of the role that the Agency should play in the European space community. This called for difficult and wide-ranging negotiations, negotiations that were to constitute an important policy task.

All in all, 1980 was to prove a year of change and fluctuating fortunes for the Agency. Some long-standing issues that had hampered its smooth running were finally resolved, including the so-called IMF problem and the Italian return deficit. The failure of the second Ariane test flight was a serious setback, but fortunately it did not discourage the steady flow of orders for Europe's new launcher. In the scientific field, both the Giotto and Hipparcos projects were embarked upon. The Spacelab project moved forward steadily with the acceptance by NASA of the engineering model. NASA's purchase of a second Spacelab that year and Inmarsat's contract with the Agency to lease two Marecs spacecraft served to boost European confidence that it could compete effectively on the world market.

Erik Quistgaard's second year in office, 1981, must rate as one of ESA's most productive years, with two flawless Ariane launches, the handover of the first Spacelab flight unit to NASA, and the successful debuts of Marecs-A and Meteosat-2. Together, these five events served as irrefutable proof of Europe's determination to prepare itself for a future of space exploration and exploitation. Indeed, 1981 proved to be a year in which the world was to be very conscious of the success of European endeavours.

During 1982, the ESA Council took a number of very important decisions, which included the initiation of the microgravity programme, the undertaking of Ariane-4's development and that of the retrievable carrier Eureca, and the setting up of the European remote-sensing programme with ERS-1 as the focus. As 1982 progressed, the Agency's future programmes became sufficiently defined, under Mr Quistgaard's stewardship, for it to be confirmed that the technological research effort being undertaken was commensurate with the needs of the coming generation of spacecraft that ESA would be called upon to build.

The last full year of Erik Quistgaard's term, 1983, saw the successful completion of Spacelab's development, the first use of Ariane by a commercial customer, and the launch of the Exosat scientific satellite. A major milestone in ESA's history was reached at the end of the year, with Ulf Merbold's flight, as the first ESA Astronaut, aboard Spacelab-1. Finally in his last month in office, he had the great satisfaction of the successful launch of Ariane-3 on 4 August, carrying the two satellites ECS-2 and Telecom-1.

During the last years, the emphasis that my predecessor placed on striving for a clear and coherent plan for Europe's activities in space has brought us considerable success. Now, as we prepare for next January's Ministerial Conference, we are in a position to capitalise on the ground work that Erik Quistgaard has so carefully laid.

Prof. R. Lüst

The ESA Spacecraft Propulsion Technology Programme

W. Berry, Spacecraft Technology Department, ESA Technical Directorate, ESTEC, Noordwijk, The Netherlands

The goal of the Agency's Spacecraft Propulsion Technology (SPT) Programme is to develop propulsion equipment and systems for use in its spacecraft projects and to promote an independent European capability in the analysis, design, development, testing and operation of such systems. In the 20 year lifetime of the Agency (ESRO and ESA), the needs for spacecraft propulsion have grown dramatically to meet the requirements of increasingly demanding missions with heavier and longer life spacecraft. The Agency's SPT Programme is designed to anticipate and fulfil these current and future technological needs.

Spacecraft propulsion is defined as that needed for the orientation (attitude control) and positioning (orbit control) of spacecraft after delivery into their nominal orbits by the launch vehicle. It is quite separate and distinct from launcher propulsion. The need for spacecraft propulsion begins with its separation from the launch vehicle and terminates at the end of its useful service life. Indeed, it is usually the depletion of the spacecraft's propellant that terminates its mission.

Twenty years ago spacecraft propulsion was a new technology. It differed substantially from the established technology base of rocket propulsion systems for military launchers, by introducing the need for:
- very low thrust (0.1 N typically)
- a pulsed operational mode for attitude control
- a continuous operational mode for orbit control
- accurate and repeatable performance and reliable leak-free operation.

These fundamental requirements remain unchanged today.

The performance demanded from spacecraft propulsion systems has increased dramatically over the intervening 20 years, as a comparison of the propulsion requirements for ESRO's first spacecraft, ESRO-II, and for one of ESA's newest telecommunications spacecraft, Olympus, readily shows (Table 1). Spacecraft lifetimes have increased by a factor of 14, dry masses by a factor of 16, and propellant mass percentages by a factor of 720. The simple cold-gas system for spin control on the scientific ESRO-II spacecraft has grown into a complex, unified, storable-bipropellant system for fine attitude and orbit control on Olympus.

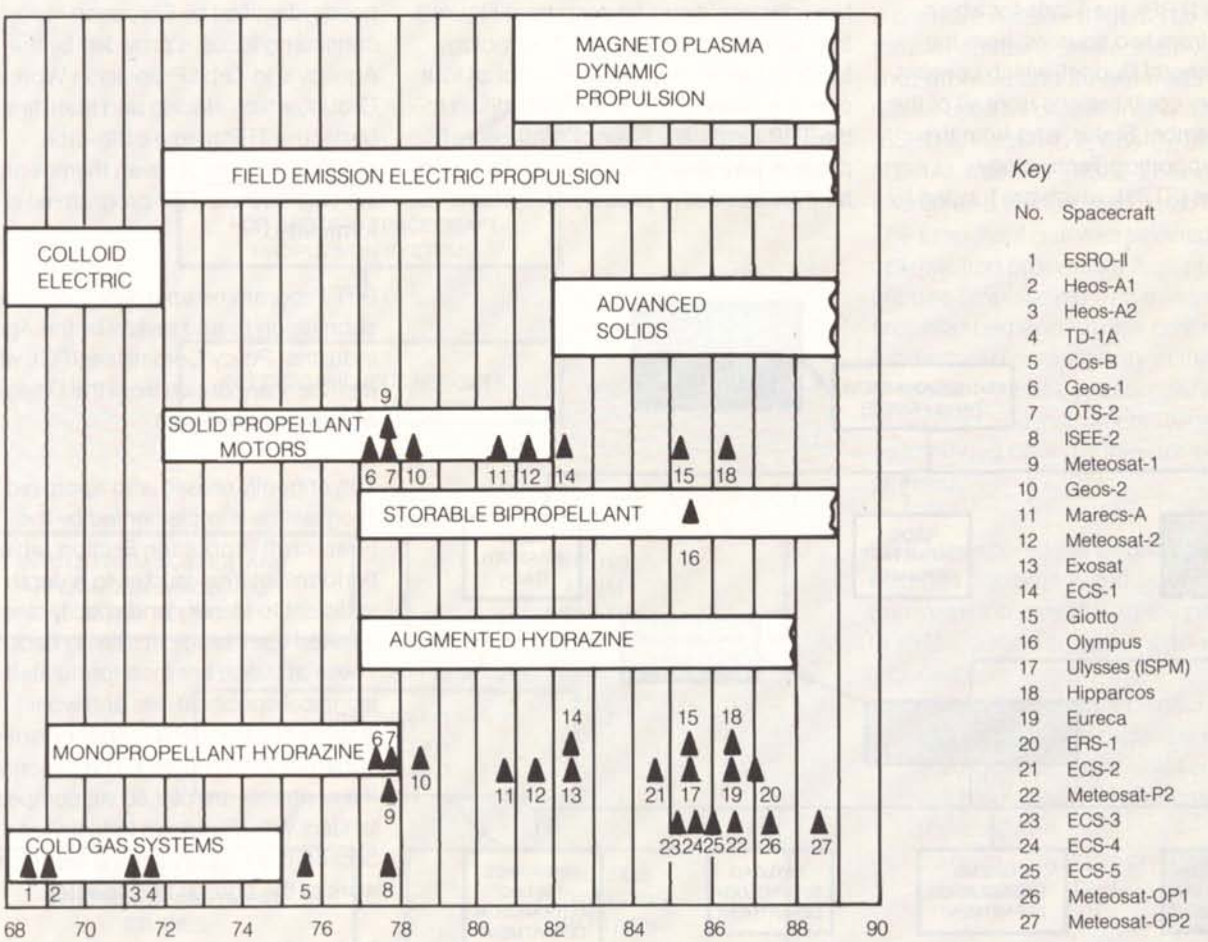
Starting with the simple cold-gas propulsion system for ESRO-II in 1968, ESRO/ESA has sponsored the development of successive propulsion systems, both chemical and electrical, with increasingly better performance to meet Europe's growing needs. In the chemical-propulsion field, cold-gas systems were developed first, followed by monopropellant hydrazine systems, solid-motor technology and finally storable-bipropellant systems. Consequently, European industry now has a fully developed capability in all of these technologies. In the electric-propulsion field, colloid thrusters have been superseded by Field-Emission Electric Propulsion (FEEP) and Magneto-Plasma Dynamic (MPD) propulsion, and High-Thrust Radio-Frequency Ionisation Propulsion developments have been initiated. The phased progressive development of all of these technologies, and the ESA spacecraft using each type of propulsion, are highlighted in Figure 1.

To date, excluding collaborative projects with the USA, ESRO/ESA has launched a total of 16 spacecraft. Of these, 15 have needed a spacecraft propulsion system, the exception being ESRO-I, launched in 1969. A further 14 spacecraft, all requiring substantial propulsion, are in the course of preparation for launch between now and 1991.

Figure 1 – Classification of and evolution in spacecraft propulsion technologies

Table 1 – Propulsion-system data for ESA's first spacecraft, ESRO-II, and one of its newest, Olympus-1

Spacecraft	Launch date	Lifetime (years)	Spacecraft dry mass (kg)	Propellant mass (kg)	Propellant % of dry mass	Propulsion system	Propellants
ESRO-II	17 May 1968	0.5	75	0.1	0.13	Cold Gas	Nitrogen
Olympus	Early 1986	7	1250	1170	93.6	Storable Bipropellant	Nitrogen Tetroxide / Monomethyl Hydrazine



It can be said with pride, and acknowledgement of the skills and efforts of the propulsion engineers in ESA and in European industry responsible for these spacecraft, that no serious problems have been encountered with any of the propulsion systems flown to date. There have, of course, been some problems on some spacecraft, which have necessitated work-around solutions by changes in spacecraft operational procedures. The most significant of these problems, addressed briefly later, were caused by unforeseen phenomena in the space environment or by the limitations of the then current technology. Many lessons have been learned and solutions since determined through further research.

Programme organisation and budget

The SPT Programme is managed by the Propulsion Section, within the Agency's Technical Directorate, at ESTEC, in The Netherlands (Fig. 2). Launcher propulsion is, however, the responsibility of the Director of Space Transportation Systems, located at the Agency's Headquarters in Paris. The execution of the Agency's

Ariane programme, of which launcher propulsion is one facet, is assigned to the French National Space Agency (CNES). Monitoring and review activities for the Launcher Propulsion Programme are performed by an Office of Launcher Technology, set up within the Technical Directorate at ESTEC in June 1983.

The SPT Programme is funded from the Agency's Technological Research Programme (TRP), the funds for which are derived from two sources: from the Agency's General Budget, which consists of mandatory contributions from all of the Agency's Member States, and from the Agency's Supporting Technology Programmes (STPs), which are funded by optional contributions from Member States who, by this means, finance research activities performed by their own industries under ESA management (Fig. 3). So far only the STP of the Directorate of Applications Programmes (ASTP) has been implemented, but activities are in progress to create STPs for the Directorate of Space Transportation Systems and the Directorate of Scientific Programmes. Nevertheless, it can be seen from Figure 3 that Spacecraft Propulsion Technology funding has increased by a factor of four over the period 1981–1985. In addition to the TRP funds, the Agency's spacecraft projects pay directly for technical support for their respective propulsion systems (total ±4 man-years per year).

Formulated within the Spacecraft Technology Department in consultation with the Agency's other (user) Directorates and the Technical Directorate's Systems Engineering Department (Fig. 4), the SPT Programme is revised annually, taking into account inputs from Agency studies for future projects and the propulsion-technology needs identified by European industry. A continuing focus is provided by the Agency's 'In-Orbit Propulsion Working Group', which studies and identifies needs under the TRP theme of 'In-orbit operations', one of seven themes around which the whole TRP programme is formulated.

SPT Programme approval is obtained by submission to and review by the Agency's Industrial Policy Committee (IPC), whose members are drawn from the Delegations of the Member States.

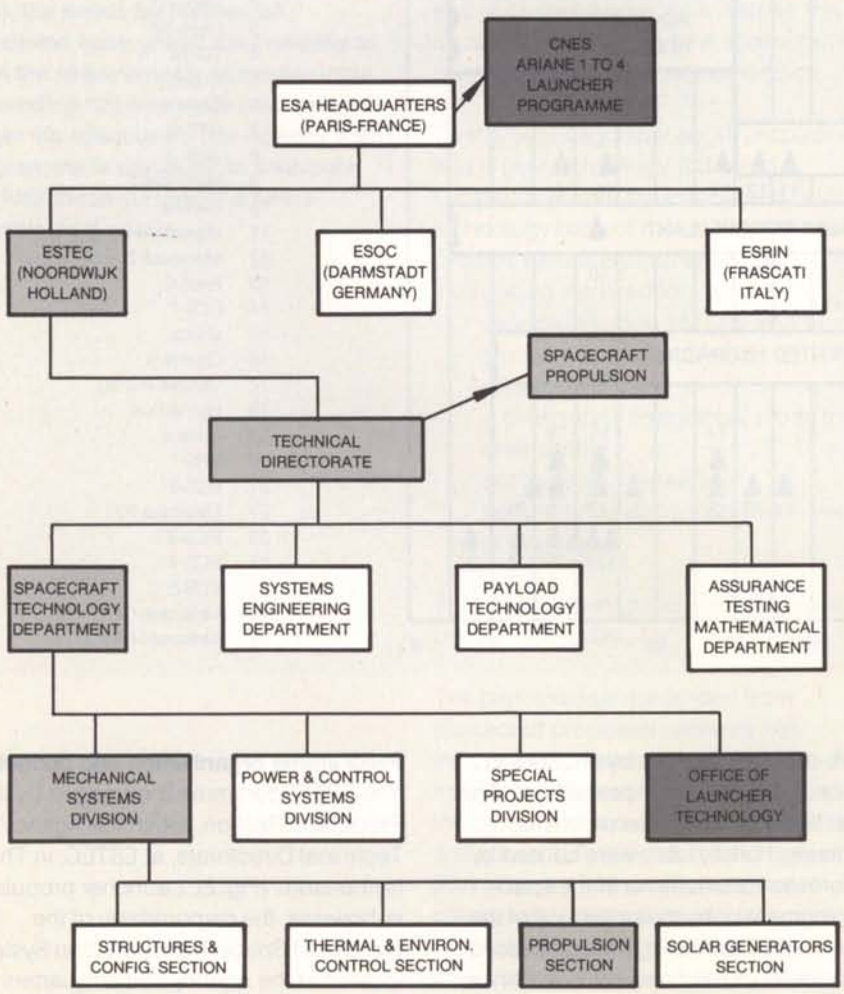
The annually revised and approved Programme is implemented by the Spacecraft Propulsion Section, which performs internal studies to a depth sufficient to identify and specify clearly the detailed technology activities needed. These activities are then formulated into technical specifications and work statements, from which Agency external contracts are prepared. The majority of the contracts are placed via competitive tenders with European Industry and the Section then supervises the technical work of the contractors selected.

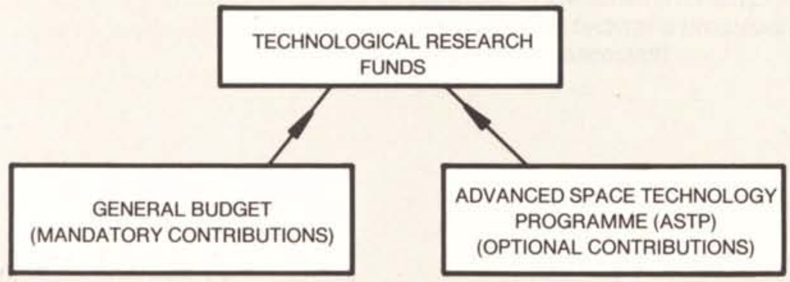
Status of the Programme

Cold-gas propulsion

The SPT Programme has had to grow substantially to keep pace with the demand for propulsion in the last 20 years. At the time of ESRO's birth in 1964, low-thrust or micro propulsion was a completely new technology and spacecraft needs were still quite modest, ESRO-II, for example, requiring only a spin-rate-control capability. It was followed by the Heos-1 and -2, TD-1 and

Figure 2 – ESA organigramme





TECHNOLOGICAL RESEARCH FUNDS (KAU)	1981	1982	1983	1984	1985
GENERAL BUDGET	550	1130	1350	1550	2050*
ASTP BUDGET	400	1050	1900	1300	1500*
TOTAL	950	2180	3250	2850	3550*

* Estimates

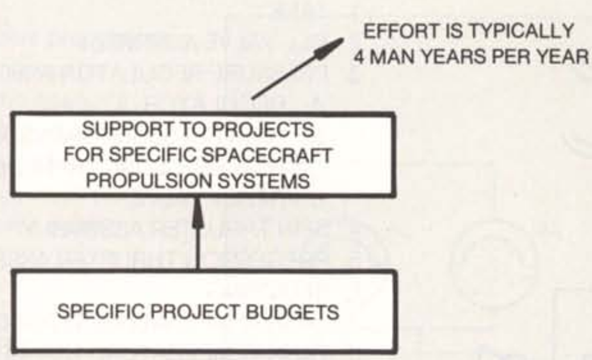


Figure 3 – ESA Spacecraft Propulsion Technology (SPT) budget and sources (1981 –1985)

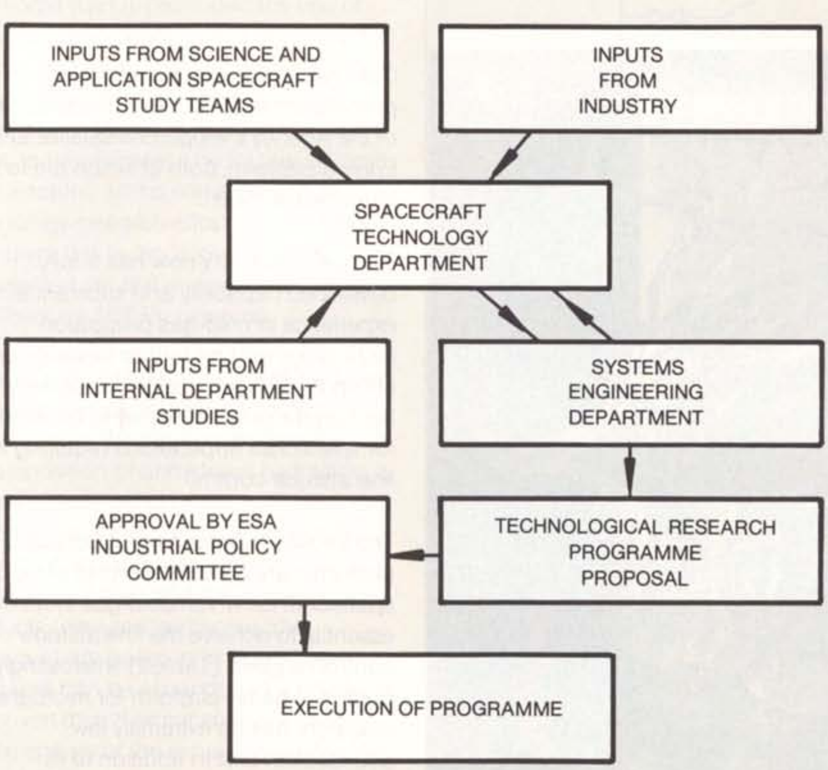


Figure 4 – ESA SPT Programme formulation methodology

Cos-B spacecraft, which needed greater total impulses (thrust × time) and brought a requirement for spin-rate control and spin-axis precession, so that they could be steered to point in any required direction.

These needs were best met by simple cold-gas propulsion systems, in which an inert gas, stored at high pressure, is fed to a series of small engines or 'thrusters' via a pressure reducer (Figs. 5&6). The thruster contains an electrically operated shut-off valve and an expansion nozzle. Gases used as propellants were nitrogen (ESRO-II, Heos-1 & 2; Cos-B), argon (TD-1A), freon-CF_4 (ISEE-2), and propane (stored as a compressed liquid in Exosat). The propellant gas was selected via an optimisation process for high specific impulse (impulse per unit mass of propellant expended), low cost and fundamental compatibility of the propellant with the spacecraft (especially its sensors and instruments, which could be impinged upon by thruster exhaust plumes).

ESRO sponsored the development of cold-gas equipment and systems in European industry during the period 1968 to 1975. Specific equipment developed included:

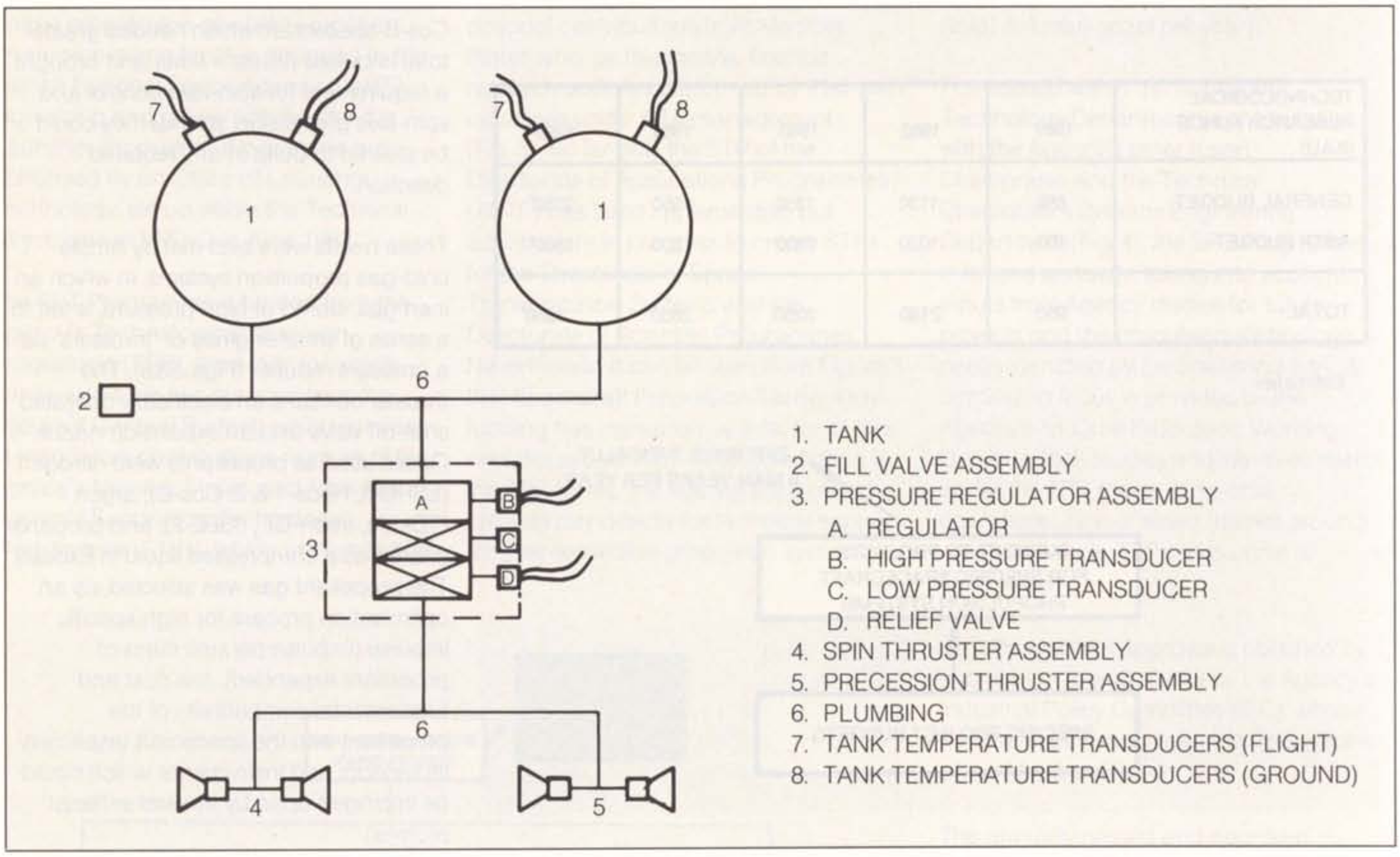
- leakage-redundant pressure regulators, at Aerospatiale (France)
- leakage-redundant isolation 'latching' valves, at Aerospatiale (France) and
- titanium-alloy, high-pressure gas tanks, at SEP (France).

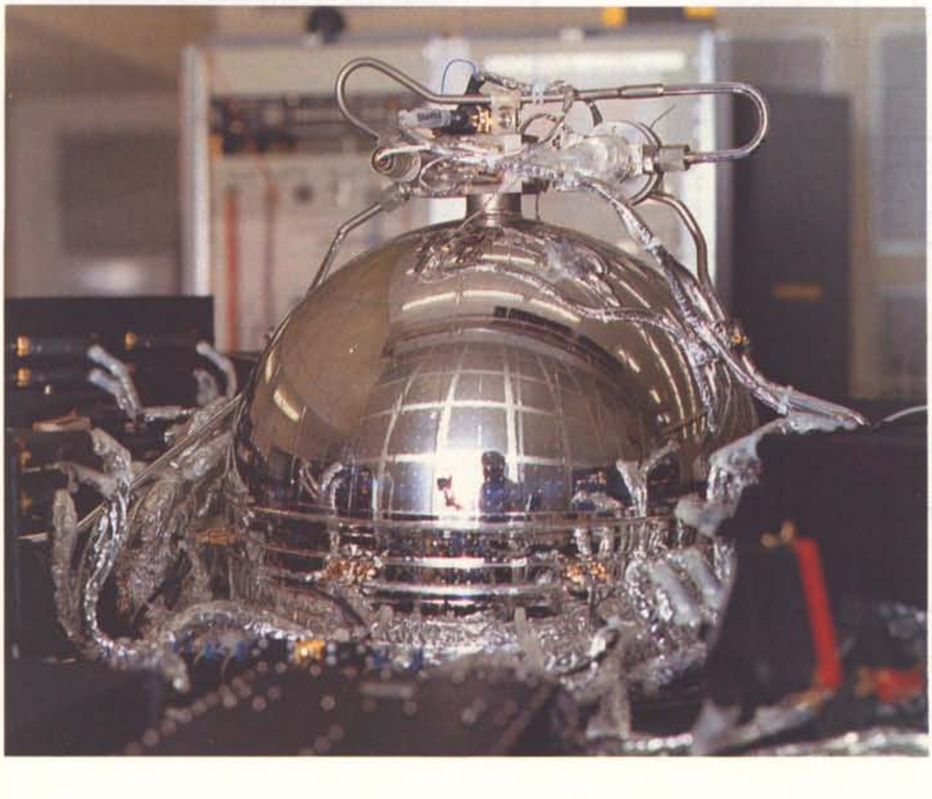
Cold-gas systems developed and flown to date include:

Satellite	Contractor	Year
ESRO-II	ESRO	1968
Heos-A1	Junkers, now MBB (Germany)	1968
Heos-A2	Junkers, now MBB	1972
TD-1A	ERNO, Germany	1972
Cos-B	BAe, United Kingdom	1975
ISEE-2	SEP, France	1977
Exosat (attitude control)	Marconi Space Systems, UK	1984

Figure 5 – Flow scheme for a typical cold-gas propulsion system (Cos-B) spacecraft

Figure 6 – Cold-gas propulsion system tank and pressure-regulator assembly (with thermal protection installed) on the ISEE-2 spacecraft





Cold-gas systems are currently in preparation at ERNO for attitude control of the Agency's Hipparcos satellite and Eureca platform, both of which are to be launched in 1988.

European industry now has a fully developed capability and substantial flight experience in cold-gas propulsion technology and no further development efforts by ESA are deemed necessary. Such systems will continue to be needed for spacecraft applications requiring very fine attitude control.

The Exosat, Hipparcos and Eureca platforms are typical examples of modern spacecraft for which cold-gas systems are essential to achieve the fine attitude control required (Table 2). Interestingly, Eureca, a heavy platform for microgravity research, has an extremely low acceleration limit in addition to its attitude-control requirements.

Table 2 — Cold-gas propulsion system requirements for modern scientific spacecraft

Spacecraft	Launch Date	Life-time (yrs)	Launch mass (kg)	Attitude Control (deg)	Maximum Acceleration (g)	Thrust Level (N)	Minimum Impulse Bit (Ns)	Minimum 'On' Time(s)
Exosat	May 1983	2	510	0.016	No requirement	0.05	1.5×10^{-4}	0.003
Hipparcos	March 1988	2.5	1095	0.16	No requirement	0.020	1×10^{-4}	0.005
Eureca-I	January 1988	0.5	4000	1.0	1×10^{-5}	0.020	2×10^{-4}	0.01

Monopropellant hydrazine propulsion

The addition of heavier, longer life spacecraft missions to the Agency's programme began in 1972 with the inclusion of applications satellites for telecommunications and meteorology in what had previously been a purely scientific programme.

The propulsion needs for the Agency's Orbital Test Satellite (OTS) for telecommunications and the Meteosat satellites for meteorology, in geostationary Earth orbit (GEO), precluded the use of the simple, low-performance (typically 65 s specific impulse), cold-gas propulsion systems used hitherto. To reduce the propulsion system's mass to acceptable levels, monopropellant hydrazine systems were adopted and a corresponding technology research effort was necessary to acquire this technology in Europe. This represented the first major expansion in the Agency's SPT Programme.

Monopropellant hydrazine systems derive their energy (typically 230 s specific impulse) from the catalytic or thermal decomposition of anhydrous hydrazine, a liquid propellant (N_2H_4). It is an endothermic compound, decomposition of which is accompanied by the generation of heat and the decomposed products (nitrogen, ammonia and hydrogen) are gaseous in state. These hot gases can be expanded in a nozzle, to convert their thermal energy into the kinetic energy of the exhaust stream (Figs. 7 & 8).

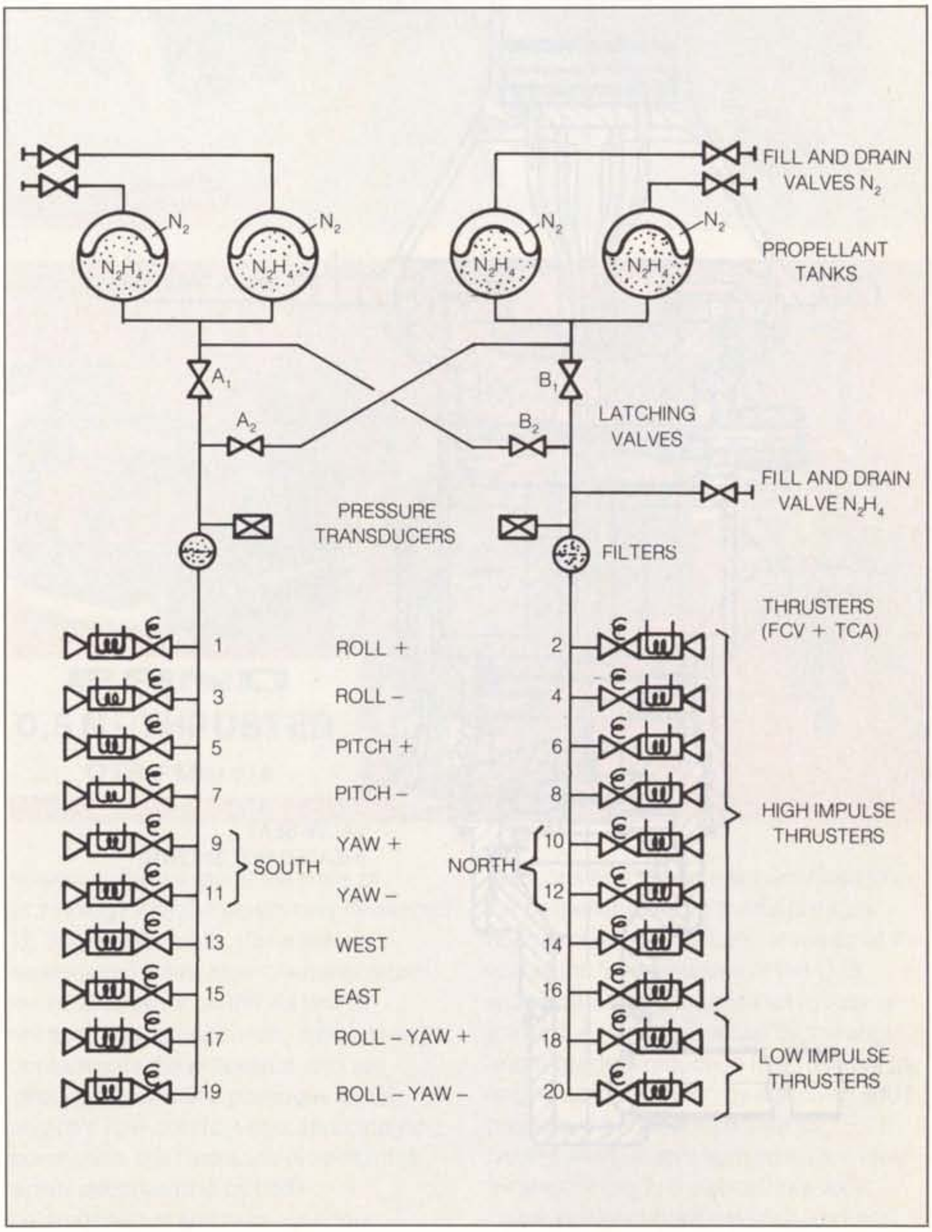
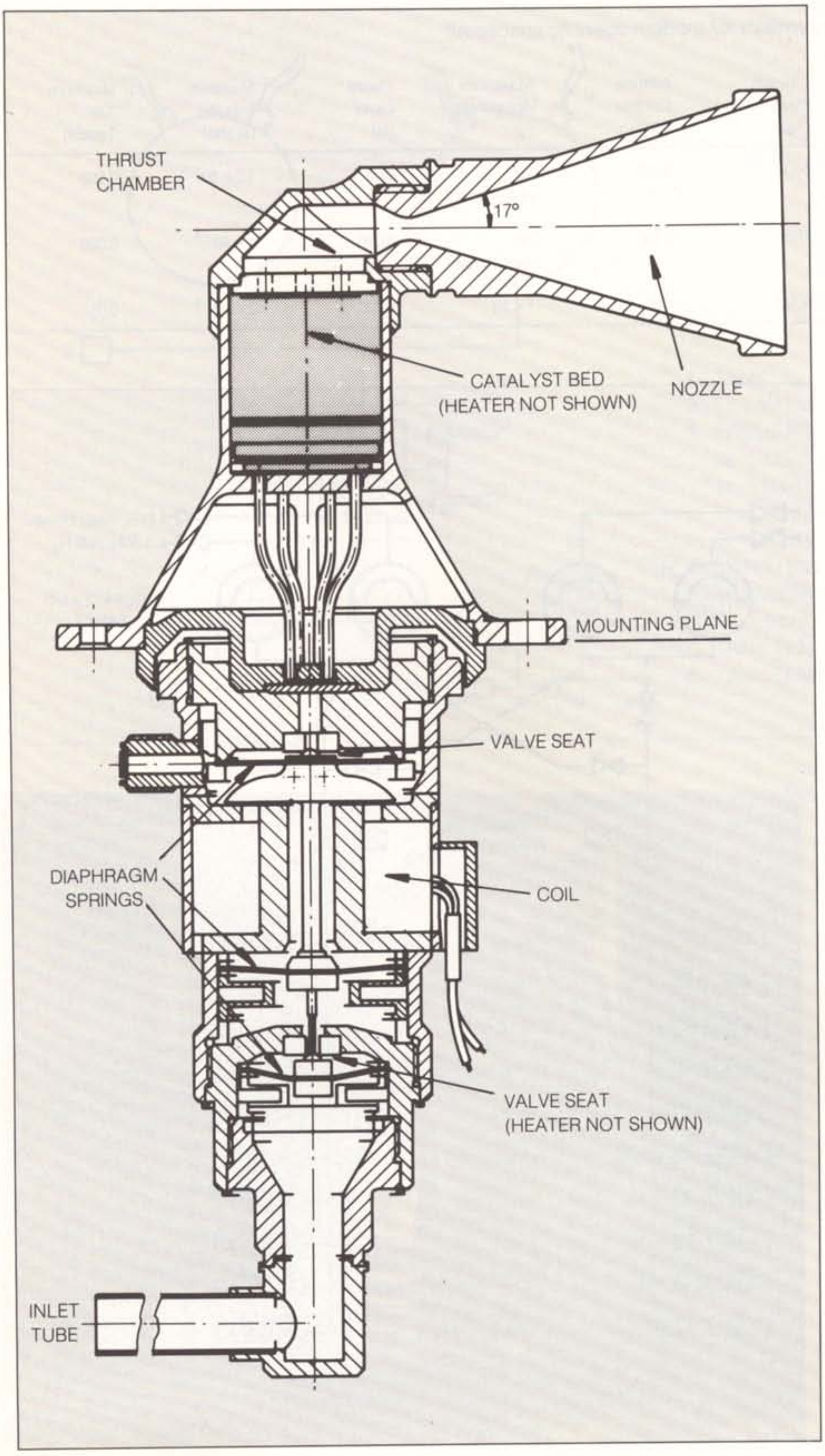


Figure 7 – Flow scheme for a typical monpropellant hydrazine propulsion system (OTS spacecraft)

Figure 8 – Cutaway drawing of a 14 N monopropellant hydrazine engine, used on the Geos-1 and -2 spacecraft (manufacturer SEP, France)



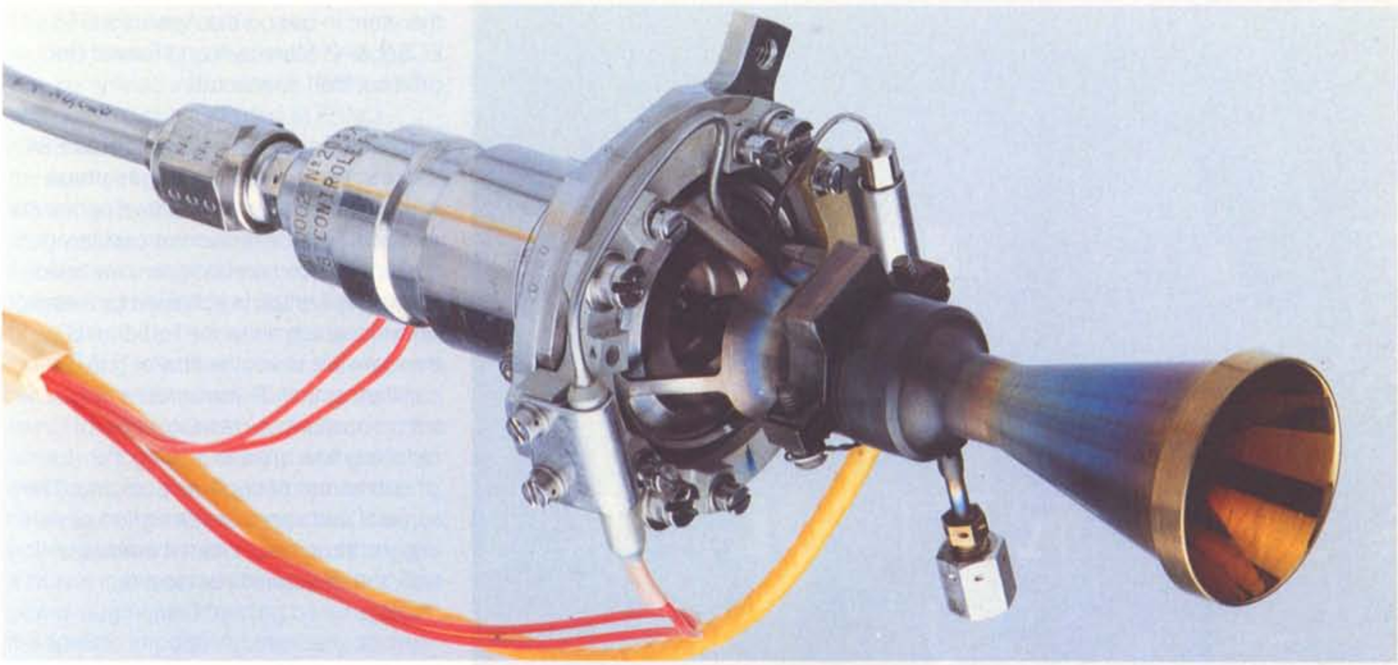
The liquid propellant, contained in tanks under the pressure of an inert gas (nitrogen or helium), is fed to the engines via electrically operated, isolating 'latching' valves. An electrically operated flow-control valve allows the propellant to flow into a decomposition chamber, where it is catalytically or thermally decomposed into hot gases, which are then expanded through a nozzle. The catalyst used exclusively in monopropellant hydrazine systems for space applications is iridium, which is finely dispersed to provide a large surface area by impregnation into a porous aluminium-oxide substrate. The resulting product consists of small irregular pellets or granules of different 'mesh' sizes.

Development of this apparently simple catalyst has needed many years of endeavour and a large investment and scientific effort. Three essentially similar catalysts have been independently developed: Shell 405 developed by the Shell Company in the USA in 1966; CNESRO, developed jointly by CNES and ESRO in 1970 (Fig. 9); and Kaliechemie developed in Germany in 1974.

Figure 9 – The CNESRO decomposition catalyst for monopropellant hydrazine

Figure 10 – The SEP 14 N monopropellant engine used on the Exosat spacecraft

Figure 11 – The ERNO 0.5 N monopropellant hydrazine catalytic thruster used on the OTS, Marecs, ECS and French Telecom spacecraft



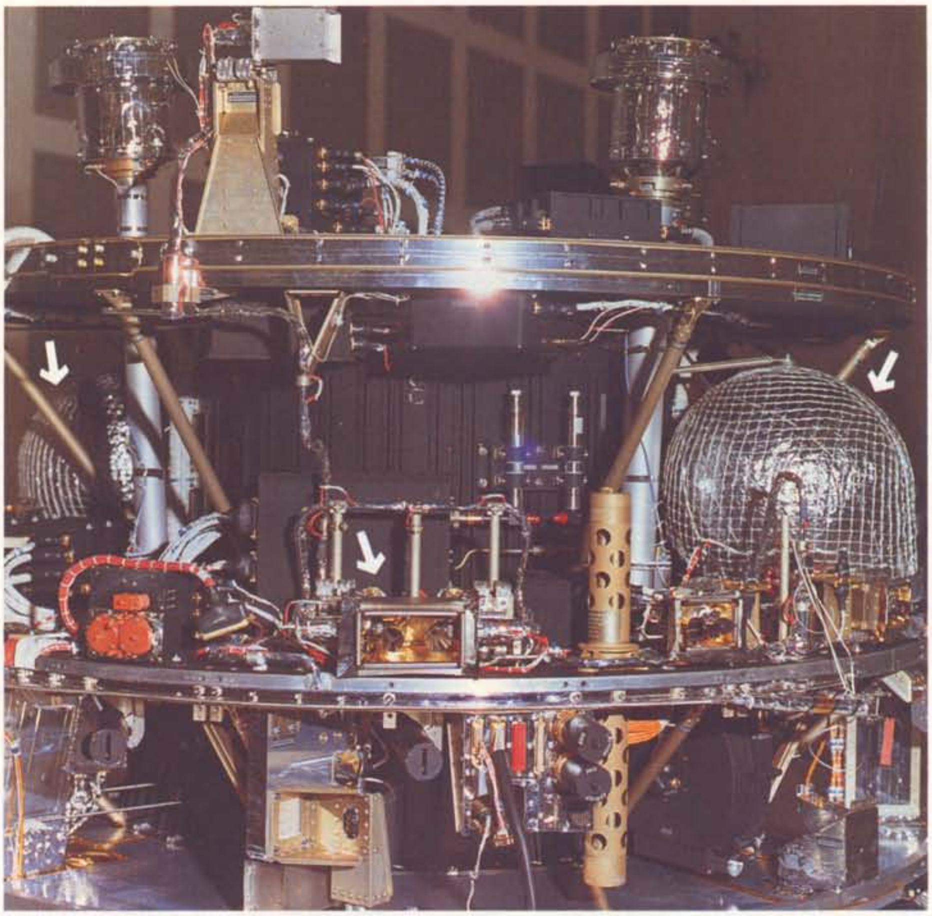
The SEP hydrazine thruster used on the Exosat spacecraft and the ERNO thrusters used on the OTS/ECS spacecraft are shown in Figures 10 and 11, respectively. Figure 12 shows part of Geos' monopropellant hydrazine system.

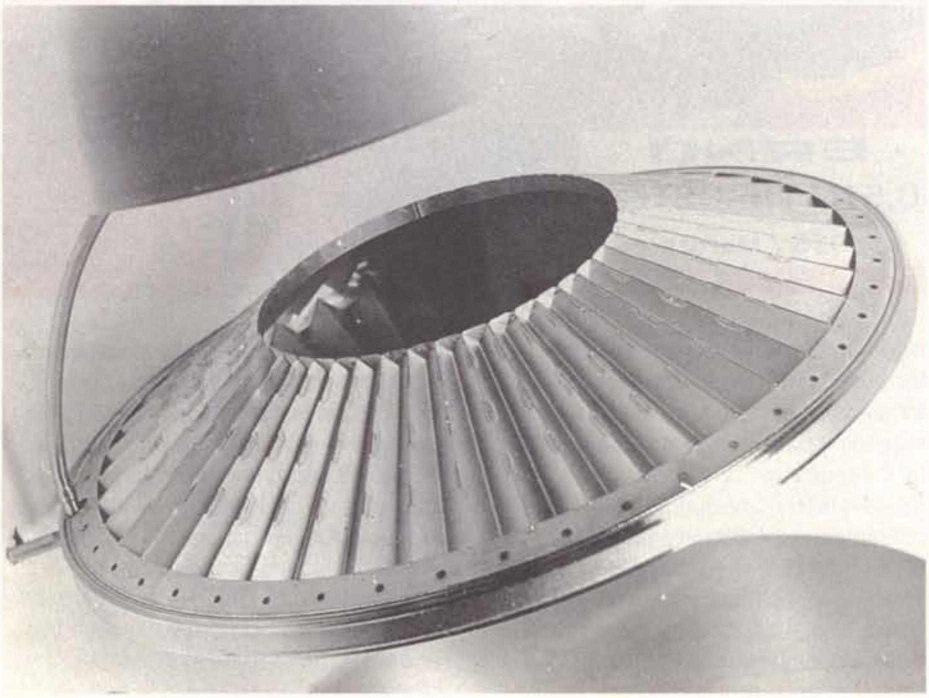
The development of larger spacecraft also heralded the introduction of three-axis stabilisation. For the propulsion engineer, this posed the problem of achieving phase separation between liquid propellant and gaseous pressurant gas in the propellant tanks. This separation is essential to avoid expulsion and therefore loss of the pressurising gas, and to avoid performance irregularities caused by the passage of gas through the engines.

The first solution to this problem was the development of the diaphragm tank, in which an elastomeric diaphragm is used to divide the tank into two compartments. Such tanks have been developed by the Agency to meet the demanding requirements of good chemical compatibility with the propellant, low diaphragm permeability to propellant and pressurant, and a high expulsion efficiency. Experience has shown, however, that we are at the limits of technology with the elastomers developed for diaphragm tanks. For missions exceeding 5 years, slow chemical attack by the propellant on the elastomer releases 'filler compounds', which then contaminate the propellant and are deposited in the fine passages of the engine's flow-control valve and catalyst pores. Also, the hydrazine propellant is slowly decomposed by both heterogeneous and homogeneous reactions and this gas accumulates on the propellant side of the diaphragm. Such problems have been revealed at the end of the 5-year lifetime of the OTS spacecraft, being manifested by loss of thrust due to gas ingestion by the engines and a gradual reduction in thrust due to engine contamination by dissolved propellant-borne contaminants. Nevertheless, diaphragm tanks are ideal for shorter (up to 5 years) three-axis-stabilised spacecraft missions and are

Figure 12 – Hydrazine-propellant tanks and a pair of radial thrusters (with thermal protection) on the Geos spacecraft

Figure 13 – Surface tension device from the SEP RETS-13 hydrazine tank





therefore in use on the Agency's OTS, ECS-1 & -2, Marecs-A and Exosat (for orbit control) spacecraft.

A second approach undertaken by ESA to the solution of the liquid/gas-phase separation problem is the development of all-metal surface-tension or capillary tanks, in which no elastomers are used. Phase separation is achieved by metallic screens, which allow the liquid to flow through, but block the flow of gas by capillary action. These screens can be fed with propellant by metallic vanes of reducing flow area, exploiting the phenomenon of capillary pumping. The screens and vanes are designed as integral structures, located inside the tank's shell before final closure (Fig. 13).

Surface-tension tanks, unfortunately, impose problems of complex design analysis and the need to tailor the design for each specific mission. This necessitates knowledge early in propulsion-system design of the flow rates, acceleration levels and directions throughout the mission life of the spacecraft. Testing of these tanks in the Earth's 1 g acceleration environment is difficult, and only limited testing in 'drop towers' or on parabolic-trajectory aircraft flights is possible. For such short tests (typically 2.5 s in a 30 m drop tower and 30 s in an aircraft), it is necessary to use scale models. This, in turn, invokes complex work in dimensional analysis, with limited possibilities for experimental validation of theories. The ESA proposal now under study for an in-orbit technology demonstration programme would allow space-flight-testing of surface-tension tanks before commitment to operational missions.

The four frames in Figure 14 of a high-speed cine film taken during drop-tower testing at ONERA (France) of a scale-model surface-tension tank show the progressive re-orientation of the liquid from the 1 g case to the almost zero-gravity case.

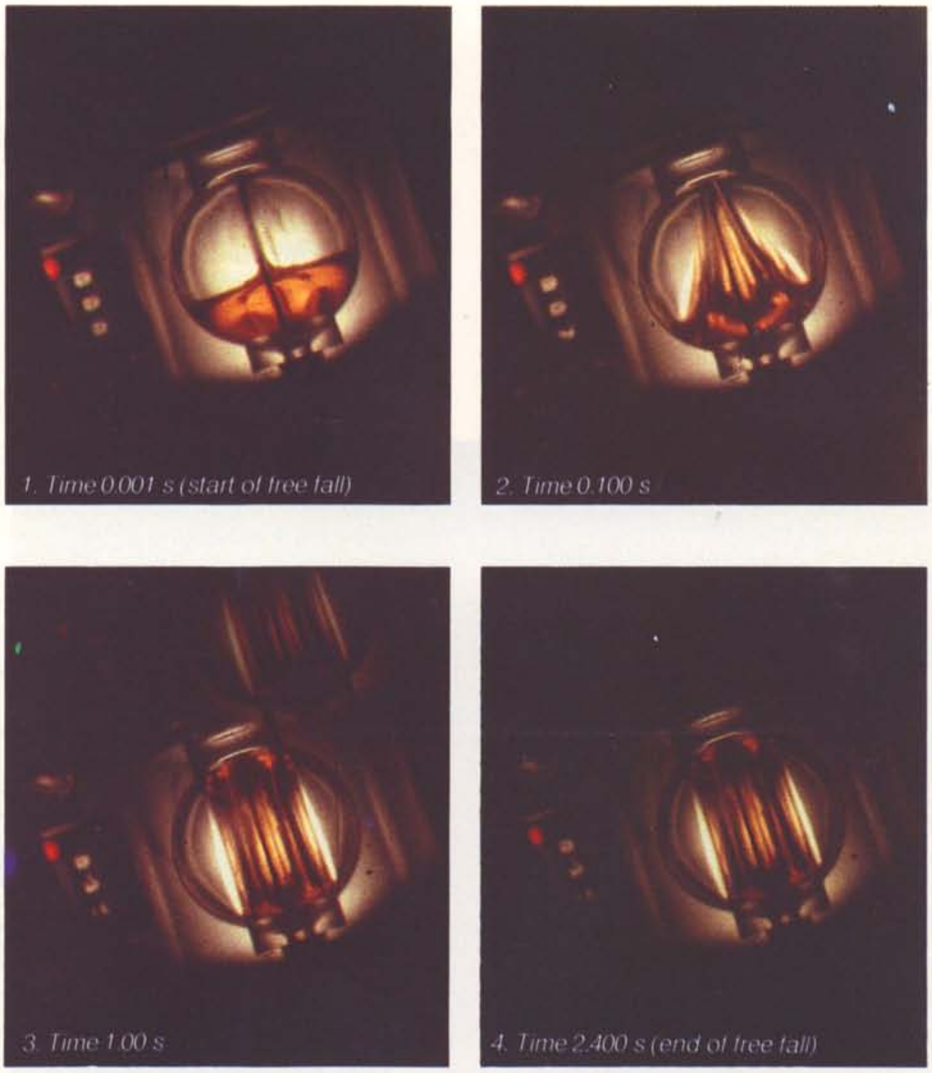


Figure 14 – Four frames from a high-speed cine film (200 frames/s) showing propellant reorientation in a model surface-tension tank during zero-gravity drop-tower testing at ONERA, France

The development of the basic monopropellant hydrazine technology was completed in Europe in 1978, with competence concentrated at ERNO (Germany) and SEP (France). That year, the Agency initiated the development of advanced hydrazine technology and this programme, now nearing completion, involves two major developments: the Power-Augmented Hydrazine Thruster (PAHT) and the hydrazine gas generator. In the PAHT, electrical power derived from the spacecraft's power-supply system is used to resistively heat (Joule heating) the already hot decomposed gases in a heat exchanger located downstream of the catalytic or thermal decomposer. The hotter gases are then expanded through a nozzle in the conventional manner. This power-augmented heating can increase the specific impulse substantially above the 230 s typically achievable from simple hydrazine decomposition, but is limited in practice by the availability of materials able to withstand the corrosive gas environment at temperatures in excess of 1800°C. Specific impulses of 305 s have been achieved and a target value of 320 s seems feasible. Refractory metals, typically rhenium, molybdenum and alloys of these elements, are used in the PAHT.

The hydrazine gas generator is being developed to reduce further the mass of cold-gas propulsion systems, by allowing the propellant to be stored in liquid phase and thus substantially reducing the mass of the high-pressure tank. For cold-gas systems using high-pressure inert gases as propellant, the tank specific mass is typically 1.1 kg per kg of propellant; for the hydrazine gas generator system, this can be reduced to 0.1 kg per kg of propellant.

In the hydrazine gas-generator systems, liquid-phase hydrazine is decomposed conventionally in a catalytic decomposer and the hot gases stored in a tank or plenum, from which the cold-gas thrusters are then fed. Again, this seemingly simple system has proved to be difficult to develop in practice, one major problem being the slow but progressive deposition of propellant-borne contaminants in the fine passages of the thrusters, eventually blocking them completely. A further development problem has been thermal control of the plenum tank. The decomposed hot gases must be cooled from about 1000°C to 100°C and the heat radiated to space in an acceptable manner. These problems have now been solved and a life-test programme is nearing completion, demonstrating problem-free operation over a six-month period (1.5 million cycles accumulated).

Monopropellant hydrazine systems will continue to be needed for spacecraft applications with modest total-impulse requirements. The availability of the PAHT and the gas generator will expand their usefulness considerably. The Agency intends to pursue these developments and to solve the many associated problems, most of which are due to subtle effects and unknown phenomena related to materials compatibility and hydrazine chemistry. This phase of the development can be seen as a refinement of Europe's already well-developed hydrazine technology.

To complete this monopropellant hydrazine 'status report', the major items developed by the Agency are shown in the accompanying panel (see overleaf).

Status of the Agency's Monopropellant Hydrazine Technology

Equipment developed
- Decomposition catalyst (CNESRO, SEP)
- Materials compatibility (BAe)
- Diaphragm tank (BAe)
- Low-thrust catalytic engines (ERNO, SEP)
- Surface-tension tanks (SEP)
- Electro-thermal decomposition engines (BAe, ERNO)
- Electro-thermal gas generators (BAe, ERNO)
- Catalytic gas generators (ERNO)
- Augmented electro-thermal engines (SEP, ERNO)
- Engine heaters (ERNO)

Systems developed and flown
- 1976 Geos-1 (BAe, SEP)
- 1977 Geos-2 (BAe, SEP)
- 1977 OTS-2 (ERNO)
- 1977 Meteosat-1 (MSDS)
- 1981 Meteosat-2 (MSDS)
- 1982 Marecs-A (ERNO)
- 1983 Exosat (MSDS, SEP)
- 1983 ECS-1 (ERNO)
- 1984 ECS-2 (ERNO)

Systems under developmeht
- 1984–88 ECS-3, 4 (ERNO)
- 1984–86 Marecs-B
- 1985 Giotto (ERNO)
- 1986 ISPM (ERNO)
- 1988 Hipparcos (ERNO)
- 1988 Eureca-1

Storable-bipropellant technology

The availability of the new family of heavy-lift launchers, Ariane-3 and -4 and NASA's STS, has opened the way for larger spacecraft. ESA's first heavy spacecraft in this category, Olympus-1, is an advanced telecommunications spacecraft to be launched on an Ariane-3 in 1987. The propulsion requirements for Olympus-1, which will weigh 2400 kg at lift-off, of which 1170 kg will be propellants, are very substantial. It is the forerunner of future spacecraft of 4200 kg lift-off mass, which is the Geostationary Transfer Orbit (GTO) capability of the Ariane-44L launcher.

Again, to reduce further the mass of the propulsion system for these heavy spacecraft, a more performant system than monopropellant hydrazine is required. The use of storable-bipropellant systems can meet this requirement, and the Agency initiated development of specific aspects of this technology in 1978. Systems using nitrogen tetroxide (NTO) as the oxidiser and monomethyl-hydrazine (MMH) as the fuel are being developed. The use of anhydrous hydrazine as fuel is also planned. The NTO-MMH combination can deliver specific impulses in the range 290–340 s, depending on thrust level. This increase in performance over monopropellant hydrazine (230 s) gives substantial mass reductions, at the expense of significantly increased system complexity. The highly reactive, hypergolic propellants must be stored and fed to the engines separately, necessitating a virtual doubling of components relative to a comparable monopropellant system (Fig. 15).

The Agency entered the development of storable bipropellant systems rather late, the reasons being twofold. Firstly, the European technology base for low-thrust storable-bipropellant systems had already been developed by MBB (Germany) for the German/French Symphonie-1 and -2 telecommunications satellites, launched in 1974 and 1975, respectively. MBB had been engaged in low-thrust storable-bipropellant system development since the mid-60's for the vernier control system of the Europa-I and -II launchers, and

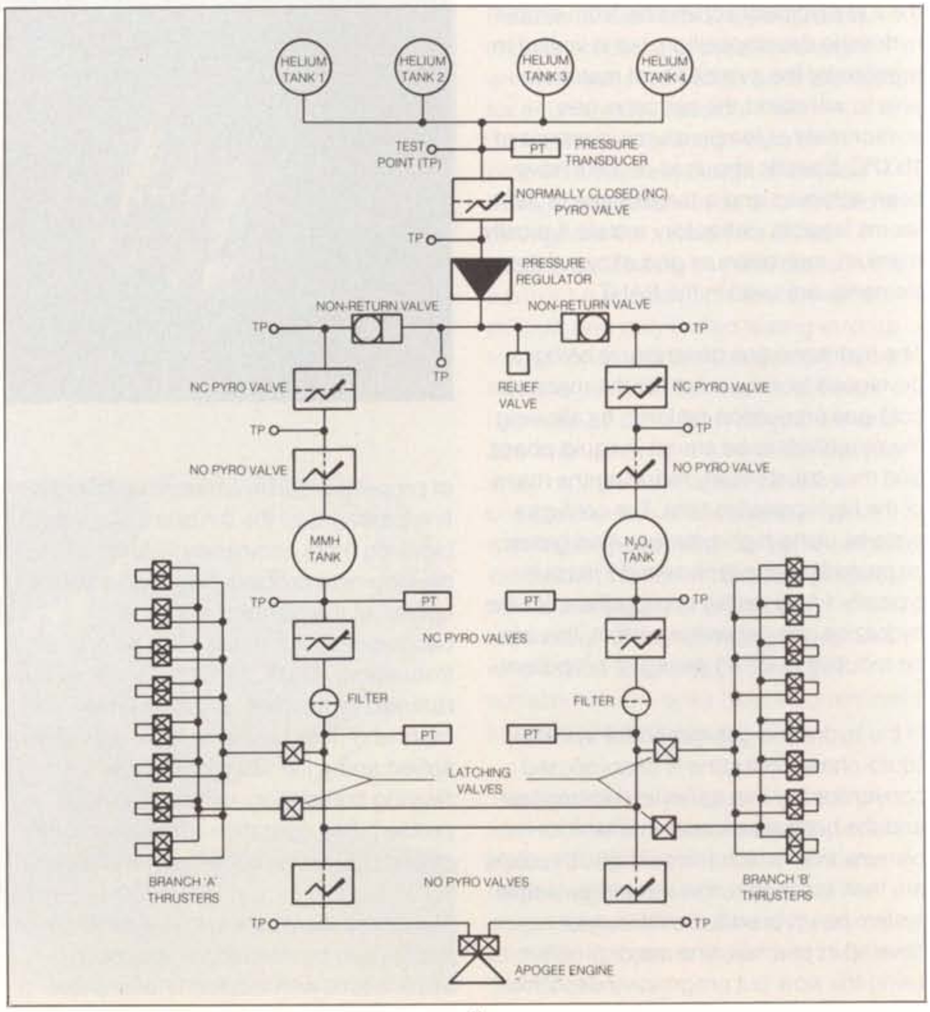


Figure 15 – Flow scheme for a typical storable-bipropellant propulsion system (Olympus-1 spacecraft)

Figure 16 – Rocket-exhaust-plume impingement on the cylindrical outer body of the ISEE-2 spacecraft, showing plume deflection and impingement shock

used this technology as a springboard for Symphonie's propulsion. Secondly, there was the full commitment of the available SPT funds to the then more urgent needs of the monopropellant programme.

One of the most significant developments fostered by the Agency is the investigation at MBB (Germany) of the so-called 'NTO oxidiser flow-decay' phenomenon, manifested by a gradual reduction of oxidiser flow rate caused by the deposition of oxidiser-borne dissolved contaminants in fine flow passages in the system. This work has concentrated on understanding the chemistry, evolving design guidelines to avoid the problem, evolving techniques for recovering blocked systems and the manufacture, handling and storage of low-water-content, high-purity NTO.

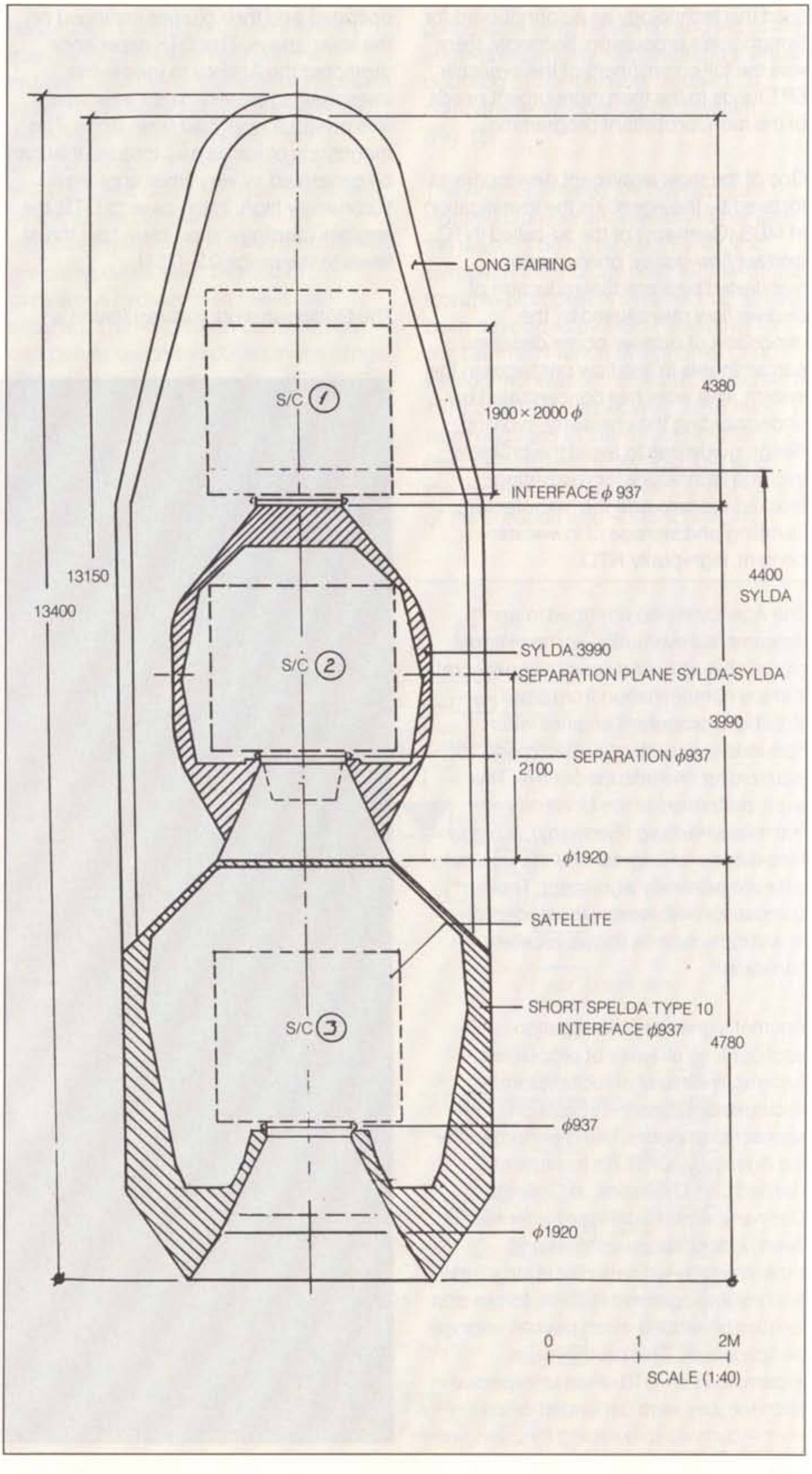
The Agency is also engaged in an experimental evaluation of the exhaust-plume chemistry and sensitive-spacecraft-surface contamination from small storable-bipropellant engines when operated in very short pulsed mode, for example for fine attitude control. This work, performed at the University of Hamburg-Harburg (Germany), is highly innovative and original and the results to date are extremely significant. Their comparison with computer models of analytical solutions shows excellent correlation.

Another significant investigation, applicable to all types of propulsion systems, is a study of rocket-plume-impingement dynamic effects on spacecraft surfaces, being performed for the Agency by DFVLR's Institute of Rarified Gas Dynamics, at Göttingen, Germany. Again significant work has been undertaken to analyse and experimentally validate plume structures and the impingement models, forces and torques generated when plumes impinge on spacecraft. This problem was experienced on OTS when unexpected pitch torques were generated when the north-south stationkeeping thrusters were operated and their plumes impinged on the solar arrays. This OTS experience prompted the Agency to initiate this investigative research in an area where little previous work had been done. The magnitude of forces and torques that can be generated by very small engines is surprisingly high; in the case of OTS, the engines causing the problem had thrust levels in the range 0.2–0.5 N.

The Göttingen work has resulted in a comprehensive computer program which can be used by engineers (not necessarily gas dynamicists) to predict impingement forces and torques in the early spacecraft-design stage. Current work at Göttingen is concentrated on experimental validation of the theories used in the analytical modelling.

Figure 16 is a glow-discharge photograph of plume impingement and deflection on the ISEE-2 spacecraft's body

Figure 17 – Triple launch configuration for the Ariane-44 launcher



So far in this article we have addressed only spacecraft propulsion systems integrated into the spacecraft itself, which has been the traditional way of applying propulsion. A new trend is emerging however – again due to the availability of the new heavy-lift launchers, able to launch several spacecraft, suitably stacked, in a multiple-launch configuration – to use orbital propulsion modules attached externally to a spacecraft or stack of spacecraft. The Agency's Ariane-4 launcher, for example, can launch two spacecraft simultaneously with its SYLDA* and SPELDA* adaptors. It is also conceivable that three spacecraft may be launched simultaneously by Ariane, for example by mounting the first inside SPELDA, the second in SYLDA, and the third on top of SYLDA (Fig. 17).

The use of orbital propulsion modules can permit missions currently precluded by launcher operational constraints, can augment launcher payload capability, and can offer potential cost savings, especially when a versatile standardised module can be used for a wide range of space missions. The module may also be built offline from the spacecraft by a specialist propulsion company, thereby easing the logistics of spacecraft assembly and test.

These concepts, and the increasing need for large-total-impulse space propulsion for its projects, have prompted the Agency to study closely the specific needs for the 1990s. As a result, it has identified a need for a new 3 kN storable-bipropellant engine and large (1 m diameter) surface-tension tanks for use on a wide variety of new spacecraft missions. These key items could be used in integrated propulsion systems or in orbital propulsion modules, which could mature to fully autonomous orbital propulsion stages by adding the required control and guidance, power and telecommand and telemetry systems.

* SYLDA = Système de Lancement Double Ariane
** SPELDA = Structure Porteuse Externe de Lancement Double Ariane.

Development of the 3 kN engine at MBB (Germany) and the large tank at SEP (F) has already been initiated by ESA. The latter has also initiated a study of possible configurations for a versatile orbital propulsion module, utilising the new engine and tanks. This study has shown that a versatile module with a maximum of 2000 kg of propellant could be used in a wide variety of missions, the most important being the GTO to GEO transfer of Ariane-44L-launched spacecraft and the orbital manoeuvring of heavy spacecraft in Low Earth Orbit (LEO). A second larger module is required as a first stage in a two-stage transfer of Ariane-5 or STS-launched payloads from LEO to GEO; the second stage would be the smaller module. This larger module would also use the 3 kN engine and the large tanks. Associated with these developments, the Agency has undertaken several other studies considered essential at an early stage in the development of these new large propulsion systems: they include the problems of fluid sloshing on spacecraft dynamic stability; orbit-transfer strategies for use of low-thrust propulsion; and the control and guidance requirements for LEO to GEO transfer (Fig. 18). The plan is to have the orbital propulsion module available for use after Ariane-4's qualification. Complete funding for the development of the 3 kN engine and the large tank has not yet been established. The hope is that the 3 kN engine will become a harmonised programme with the German Ministry of Technology and the large tank a harmonised programme with CNES, the French Space Agency.

A further development in storable-bipropellant technology that is especially attractive for the GTO to GEO transfer of large spacecraft is an electrically driven pump feed system, being developed for the Agency by Volvo Flygmotor in Sweden. The electrical power would be derived from the deployed spacecraft solar array and/or batteries. Such a system can reduce the propulsion mass of an Ariane-44L-launched spacecraft by about 60 kg, a significant reduction when translated into extended spacecraft lifetime or extra communications capacity for telecommunications spacecraft, thereby significantly improving revenue potential.

Finally, in 1984, the Agency plans to initiate industrial studies on fluid-transfer management in space, to identify the problems, and propose solutions and operating procedures for the in-orbit replenishment of spacecraft propellants. This is seen as a key element of in-orbit infrastructure for the next decade, particularly in relation to the proposed NASA Space Station and ESA Columbus projects.

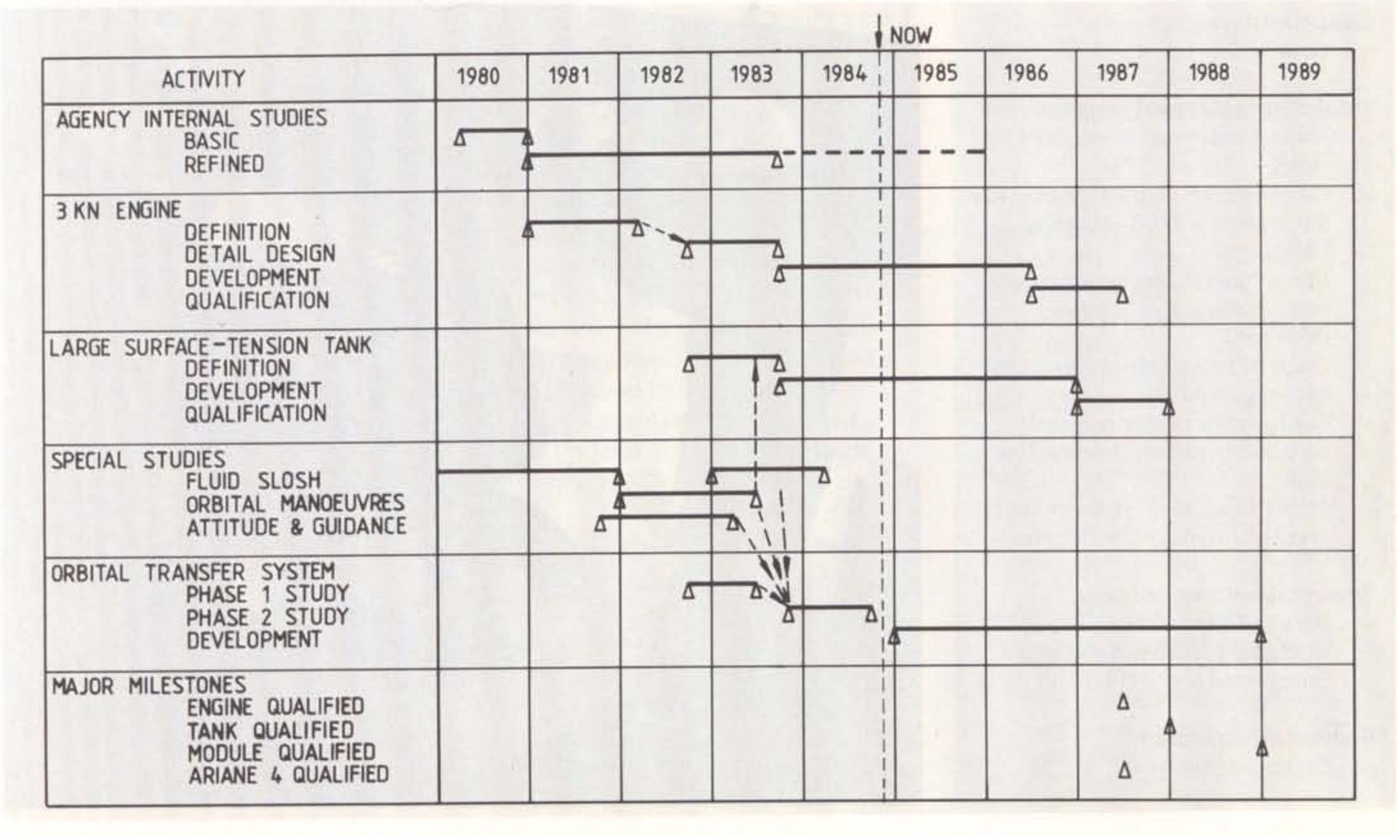


Figure 18 – The ESA development programme for medium-thrust storable-bipropellant technology

Figure 19 – The MAGE-2 solid-propellant Apogee Boost Motor (ABM) used on the ECS and French Telecom spacecraft

In 1986, ESA plans to use its 3 kN engine technology to develop a 12 kN engine, by increasing the chamber pressure by a factor of 4. An associated activity will be development of a turbopump system for this engine. The 3 kN engine has already been designed with this growth in mind, and only minor modifications to injector and cooling system will be needed.

The status of the Agency's storable-bipropellant technology is summarised in the accompanying panel.

Solid-propellant motors
ESRO initiated the development of solid-propellant motors in 1972, the first applications being for apogee insertion of the Geos-1 and -2 spacecraft, launched in 1977 and 1978, respectively. The Geos motors, developed by SNIA-BPD in Italy, were conventional radial-burning designs using a Carboxy-Terminated Poly-Butadiene (CTPB) propellant. Their excellent performance led to development of a larger solid propellant motor in 1974, called the MAGE (Moteur Apogée Géostationaire), with the intention of giving Europe its own solid-propellant apogee motors for geostationary spacecraft.

This programme, completed in 1982 with the successive development of the MAGE-1, 1S and 2 series of motors, was undertaken for the Agency by a consortium led by SEP (F), as the prime contractor responsible for the overall design and nozzles, with SNIA-BDP (I) responsible for the propellant formulation, loading and curing and MAN (D) for the kevlar-epoxy case. MAGE-1 has been used successfully on the Agency's Meteosat-2, launched in 1981, and MAGE-2 on the ECS-1 and -2 and French Telecom-1A spacecraft. The motors are all radial-burning designs using CTPB propellants. The MAGE-2 is an advanced design using a carbon–carbon composite for the nozzle throat and nozzle extension (Fig. 19). Table 3 shows the major design characteristics of the MAGE family of motors.

Status of the Agency's Storable-Bipropellant Technology (NTO/MMH)

Basic technology fully developed by MBB, advanced technology in progress.

Equipment developed
- None

Technology activities in progress
- Oxidiser flow-decay phenomena (MBB)
- Contamination characteristics of low-thrust engines (MBB–University of Hamburg)
- Plume impingement dynamics and heating interactions (DFVLR, Göttingen)
- Large surface-tension tanks (SEP)
- 3 kN engine (MBB)
- Configuration studies on orbital propulsion modules (Aerospatiale, MBB)
- Electric pump feed system for 400 N and 3 kN engines (Volvo Flygmotor)

Systems developed and flown
- None by ESA
- MBB have flown bipropellants on Symphonie-I and -II (1974 and 1975)

Systems in preparation
- Olympus-1 (1987)

Table 3 – Characteristics of the MAGE solid-propellant motors

Motor	Maximum Total Mass (kg)	Maximum Propellant Mass (kg)	Total Mass Fraction	Impulse (Ns)	Specific Impulse (s)	Expansion Ratio	Maximum Vacuum Thrust (kN)
MAGE-1	368.5	335	0.9093	0.767×10^6	287.6	45	28.5
MAGE-1S	447.2	410	0.9168	1.168×10^6	290.7	54	33.4
MAGE-2	528.25	490	0.9276	1.410×10^6	293.8	64	46.7

The Agency is currently engaged in a technology programme for advanced solid-propellant motors. Activities already completed include formulation of a Hydroxy-Terminated Poly-Butadiene (HTPB) propellant, and development of a low-density, asbestos-free liner. Present activities include the development of grain-machining technology for slotted, End-Burning Motors (EBM), and a consumable igniter for the EBMs. In conjunction with SNIA-BPD (Italy), the Agency is about to start a comprehensive co-ordinated programme for the development of an EBM based on the Italian IRIS upper-stage motor, to embody and verify all the EBM and HTPB technologies developed to date.

The status of the Agency's solid-propellant motor programme is summarised in the accompanying panel.

Electric propulsion

ESRO/ESA has been engaged on electric-propulsion development programmes since 1968. Initial efforts devoted to developing a colloid propulsion system were terminated in 1972, due to the problem of dissociation of the colloid propellant in the radiation environment of space. Since 1972, the Agency has been engaged in developing the Field-Emission Electric Propulsion (FEEP) system.

In 1980, the Agency initiated a development programme for Magneto-Plasma-Dynamic (MPD) propulsion with BPD in Italy, funded under the Italian Advanced Space Technology Programme (ASTP).

In April 1984, ESA initiated the basic definition and laboratory investigation of the RITA-35 system, as a primary propulsion system for interplanetary missions, with the proposed Agora asteroid mission (launch 1992) as a baseline.

ESA has also been involved in following progress in the electric-propulsion development efforts in its Member States, including the UK mercury-bombardment system, the CNES caesium-contact system, the SEP caesium-bombardment system, and the German RIT system. These independent developments were evaluated by ESTEC at the Member States' request in 1976 and the recommendation was made that only the German RIT-10 and the UK-T5 systems merited further development, for flight testing on Ariane flight APEX L04. Subsequently, the UK terminated their T5 programme in 1977. Germany continued the ground qualification of its RIT-10 engine, which has now been ground-qualified with mercury propellant and is being prepared for flight testing with xenon propellant on ESA's Eureca-1 mission in 1988. This activity is funded by the German ASTP.

The ESA-sponsored electric-propulsion activities can be summarised as follows:

1. Radio-frequency Ionisation Thruster Assembly (10 cm) – RITA-10: flight-test preparations for the Eureca-1 mission, at MBB, Munich.
2. Field-Emission Electric Propulsion (FEEP): basic development at ESTEC and industrialisation at SEP, France

Status of the Agency's Solid-Propellant Motor Programme

- Radial-burning technology using Carboxy-Terminated Poly-Butadiene (CTPB) propellants fully developed
- Advanced technology development using end-burning technology with Hydroxy-Terminated Poly-Butadiene (HTPB) propellants in progress.

Equipment developed

1972–1975 Geos apogee motor (BPD)
1978–1982 MAGE-1, 1S and 2 (SEP–BPD–MAN)
1980–1982 HTPB propellant formulations
1980–1982 Low-density-liner technology (BPD)

Systems flown

1976 Geos-1 apogee motor
1977 Geos-2 apogee motor
1981 Meteosat-2 apogee motor (MAGE-2)
1983 ECS-1 (MAGE-2)
1984 ECS-2, Telecom-1A (MAGE-2)

Systems in preparation

- ECS-3 to -5 apogee motors (MAGE-2)
- Giotto transfer mode (MAGE-1)
- Hipparcos apogee motor (MAGE-1)

Technology in progress

- End-burning motor igniter technology (BPD)
- EBM grain machining (BPD)
- End-burning motor design (BPD) (imminent)

3. Magneto-Plasma Dynamic (MPD) thrusters: basic development at BPD, Rome
4. RITA-35: definition study for Agora mission and basic development at MBB, Munich.

There are three basic types of electric propulsion:
- *Electrothermal engines*, in which electrical energy is used to heat a propellant gas, which is then expanded in a nozzle. Examples are the Resistojet and Power Augmented Hydrazine Thrusters (PAHTs).
- *Electrostatic engines*, in which electrical energy is used to ionise a propellant gas. The ions are then expelled at high velocity by an electric field (commonly called an 'ion engine').
- *Electromagnetic engines*, in which a neutral plasma propellant gas is expelled at high velocity by a magnetic field [commonly called Magneto-Plasma-Dynamic (MPD) thrusters].

The Agency is currently engaged in the development of all three technologies, as noted above.

In chemical propulsion, the energy released is limited by the energy content of the chemical propellants (heats of formation), implying high thrust and low exhaust velocity. In electric propulsion, electrical energy is used to create or augment the kinetic energy of the exhaust jet, so that the exhaust velocity can be very high. In practice, the limits are set by the availability of electrical power onboard the spacecraft, implying low thrust and high exhaust velocity.

Typical nominal thrusts and specific impulses for electric propulsion systems are shown in Table 4. Comparison with values quoted earlier for chemical systems shows that the specific impulse of electric propulsion systems is one order of magnitude higher, allowing a corresponding decrease in propellant mass.

The inherent characteristics of electric propulsion are presented in the accompanying panel.

RITA-10 is a first-generation system, available now for low-thrust applications. The ions are created by electron bombardment of neutral propellant atoms in a quartz discharge chamber. The electrons derive their energy from a high-frequency electric field. Figure 20 shows the RITA-10 ion engine and its propulsion and power control units, and Figure 21 its operation in a vacuum test facility.

FEEP is a second-generation system currently beginning its industrialisation

Characteristics of Electric Propulsion

Primary characteristics
- High exhaust velocity (typically 30000 m/s for the German RIT-10 system)
- High specific electric power* (typically 35 W/mN for the German RIT-10 system)
- High operating voltages (typically ± 1500 V DC for the German RIT-10 system).

Derived characteristics
- A low propellant mass (typically less than 10% of that required with advanced solid propellants and space-storable bipropellants)
- A low thrust level; to keep the mass of the electric power source acceptably low
- Long operating durations; necessitated by the low thrust characteristic (typically 5000 h of operation are required)
- Electric power conversion and regulation is required, necessitating a power conditioning unit.

System elements
- A power generator (solar array, batteries or nuclear power generator)
- A power conditioning unit
- A set of engines with neutralisers
- Engine-mounting provisions and gimbals (if thrust vector control is required)
- A propellant-storage and feed system
- Propellant

Table 4 – Comparative performances and characteristics of the ESA-sponsored electric-propulsion systems

System	Type	Type Classification	Propellant	Nominal Thrust (mN)	Specific Impulse (s)	Specific* Power (W/mN)
RITA-10	Radio-frequency	Electrostatic ion engine	1. Mercury 2. Xenon	10	1. 3000 2. 3500	1. 35 2. 45
FEEP	Field emission	Ion engine	Caesium	5 per double emitter	6000	65
MPD	Magneto-plasma dynamic	Pulsed-plasma engine	Teflon	10	3000	35
RITA-35	Radio-frequency	Electrostatic ion engine	Mercury	160	3200	30

* Specific power is the ratio of total electrical power consumed (including neutraliser) to the thrust (W/mN)

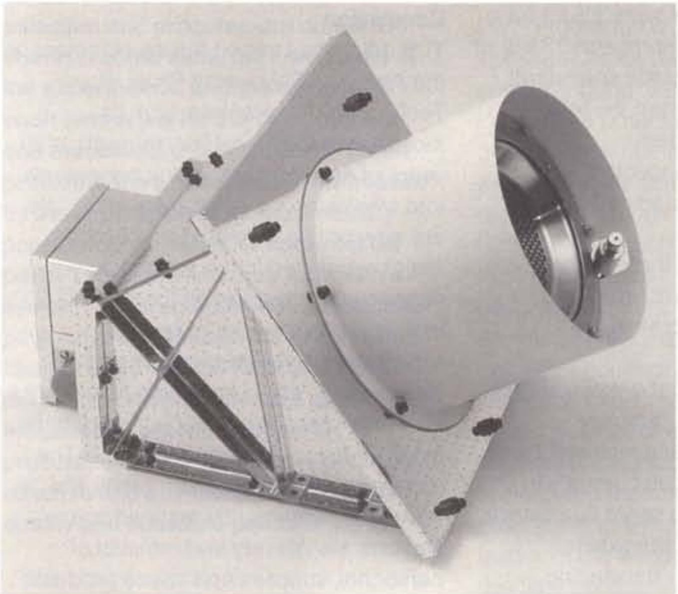
Figure 20 – The RITA-10 electric-propulsion and power-conditioning units, packaged for direct mounting onto a spacecraft

Figure 21 – The RITA-10 ion engine in operation in a vacuum chamber

phase. Here, the ions are created not by electron bombardment of a gas or metallic vapour, but directly from the surface of a liquid metal exposed to vacuum, by applying high electric fields to an emitting unit and shaping the liquid surface into a series of sharp cones.

Development of the FEEP system has centred around a modular unit, called an 'emitter module'. It consists simply of two highly polished metallic plates (Fig. 22), the inside face of one of which is selectively sputter-deposited with a fine layer of nickel. The precision with which the emitter's slit width is determined is important, since it plays a major role in the hydrodynamic impedance presented to the continuous flow of liquid metal during emitter operation. Emitters with lengths of 1, 3, 5 and 8 cm have already been made, initially from stainless steel and more recently from Inconel X 750, and emitters up to 15 cm long are planned. They can be clustered easily to build higher thrust 'units'.

The Agency plans to promote a technology-demonstration test flight of the FEEP system in 1989, and an operational test flight for the north-south stationkeeping of a telecommunications spacecraft in 1992.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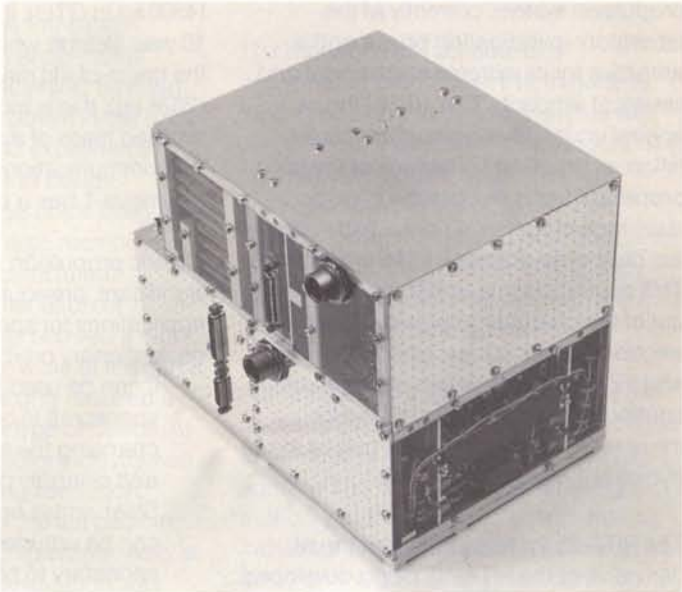
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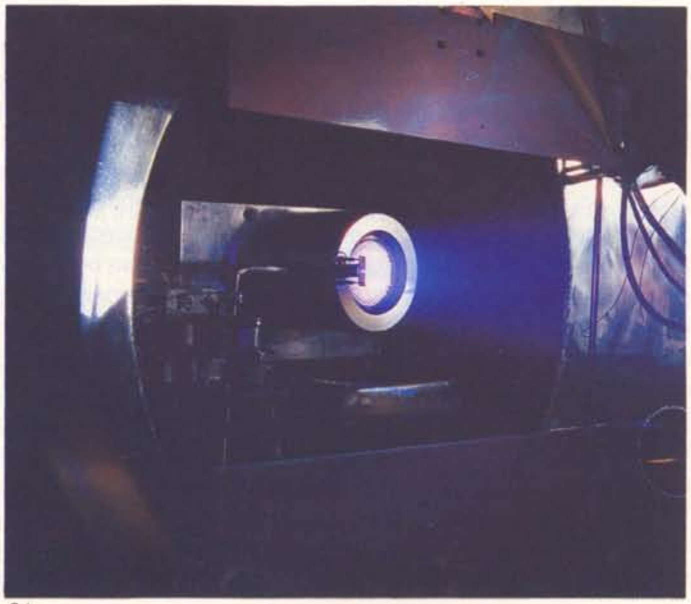
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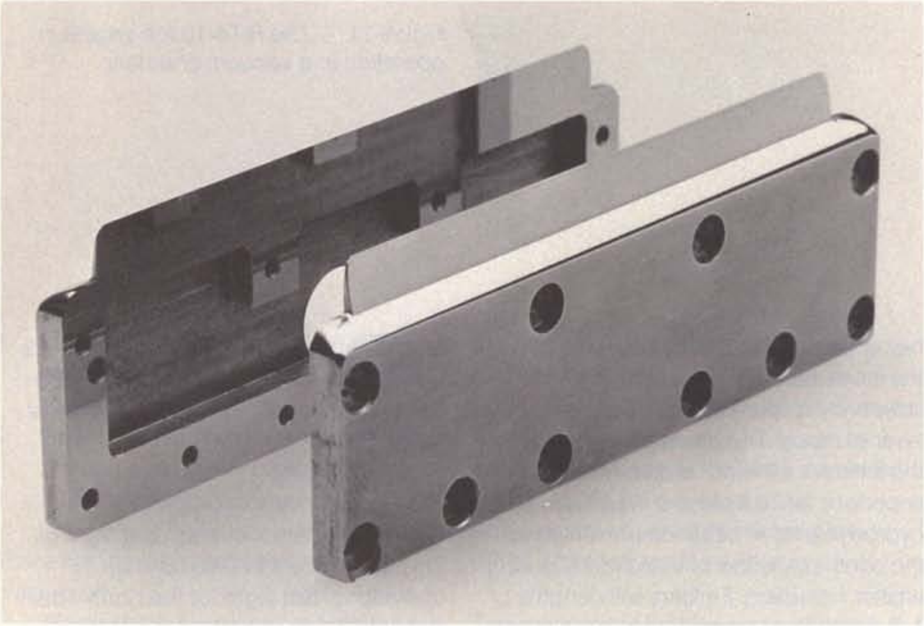


Figure 22 – The FEEP emitter module, dismantled

MPD is a third-generation electric propulsion system, currently at the laboratory-investigation phase and is attractive for its extreme mechanical and electrical simplicity. The 10 mN thrust engine under development uses solid teflon as propellant. The face of the solid propellant bar is fed into the engine discharge chamber, where a high-voltage arc discharge ablates it to form a plasma. This neutral plasma is then accelerated out of the chamber to provide thrust via electromagnetic forces. Unlike the RITA and FEEP systems, which are operated in continuous-thrust modes, the MPD thruster will be operated in a pulsed mode (typically 1 ms on/999 ms off).

The RITA-35 system is a higher thrust derivative of the RITA-10, being developed as a primary propulsion system for high-energy interplanetary space missions. Such missions cannot be achieved with chemical propulsion because of its low specific impulse. Although still at the basic laboratory-investigation phase, the RITA-35 system can draw substantially on RITA-10 technology.

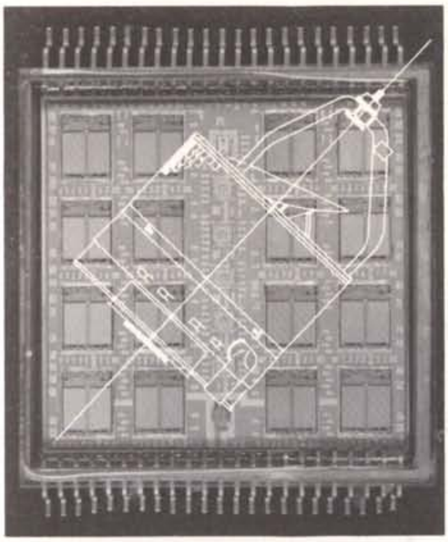
Future applications for electric propulsion
In the near-term (from 1984), electric propulsion can be used ideally for the orbit control (stationkeeping) of geostationary spacecraft. Such spacecraft, most frequently used for telecommunications and meteorology, have solar generators sized for their 'end-of-life' power requirements. Their excess 'begin-of-life' power is therefore conveniently available for electric-propulsion stationkeeping. For an Ariane-4-launched geostationary spacecraft (4300 kg in GTO), it can save 355 kg for a 10 year lifetime, which represents 13.5% of the begin-of-life mass of the spacecraft (2626 kg); this is more than the total payload mass of a modern telecommunications spacecraft (Olympus-1 has a payload of 307 kg).

Electric propulsion has three further significant, previously unconsidered applications for spacecraft in the geostationary orbit:
- It can be used to stationkeep spare spacecraft in orbit, radically changing the satellite replenishment and reliability policies currently in use. Solar arrays on the spare spacecraft can be unfurled to the extent necessary to power the electric propulsion.
- It can be used to remove obsolete spacecraft from the crowded geostationary orbit.
- It can be used to control electrostatic charging of spacecraft (already demonstrated successfully at Giessen University (D) under an ESTEC Contract and on the Sert-II spacecraft by NASA).
- It can be used for atmospheric drag compensation on low-altitude spacecraft, giving precise orbit control at low cost in terms of mass.

In the medium-term (from 1990), electric propulsion may also be used for orbital transfer for high-total-impulse missions, such as the transfer from low-Earth to geostationary orbit of very large structures. Structural-dynamics considerations will necessitate very low thrusts. For the transfer of elements of Solar Power Stations, for example, the electrical power from the solar arrays of each element could be used directly for their electrical propulsion.

In the longer-term (from 2000), electric propulsion will be essential to the viability of high-energy space missions, the electrical power perhaps having to be provided by nuclear generators.

Conclusion
This article has traced the development of the Agency's Spacecraft Propulsion Technology Programme, from its inception in ESRO in 1964, through its 20 years of development and achievements, into what is now a substantial effort. We are now on the threshold of a further major expansion in the needs for spacecraft propulsion as the space industry enters an era of space exploitation, for telecommunications, meteorology, earth-resources surveillance, industrial processing in space and many more ambitious scientific missions. The increasing use of low Earth orbits, the advent of permanently manned space stations, the delivery and retrieval of personnel, supplies and space products, and the in-orbit servicing and refueling of spacecraft are all vital elements of tomorrow's in-orbit infrastructure. Space propulsion will play a key role in making this future possible and the Agency intends to meet the challenge by a continuing investment in its SPT Programme. The basic programme for the future has already been implemented: advanced monopropellant technology, advanced solid-propellant technology, medium-thrust storable-bipropellant technology and high-performance electric propulsion.



The Giotto Payload Parts Procurement and Engineering Programme

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The Giotto scientific payload presented a unique problem in electronic parts selection and procurement due to the financial constraints, the complexity of the experiments, and the extremely short time scale for the development and manufacture of flight units. These problems were successfully addressed by the application of a coordinated procurement system for common US parts. This is the first time that such a system has been applied to a scientific payload and, although the programme has not been without its problems, it is felt that the results achieved so far indicate that coordinated parts procurement for a payload is both cost effective and advantageous from the quality and schedule points of view.

Introduction

In late 1981, Science Working Team (SWT) meetings with the Principal Investigators for the ten experiments comprising the Giotto scientific payload indicated a potential problem in the area of parts procurement. All experiments were extremely complex in design, employing various Large-Scale Integrated Circuits (LSI), such as large memories, microprocessors and associated peripheral circuits. Examination of experiment requirements showed a high degree of commonality, while at the same time each experimenter only required a limited number of each type of device. At this time the semiconductor industry was undergoing a packaging revolution, attempting to terminate the flat pack in favour of the leadless chip carrier. Also at this time the order-book situation was such that semiconductor manufacturers were not accepting 'High-Rel' specifications, except at highly inflated prices and with a minimum order quantity in the region of 100 pieces. Extremely long lead times were also then the norm.

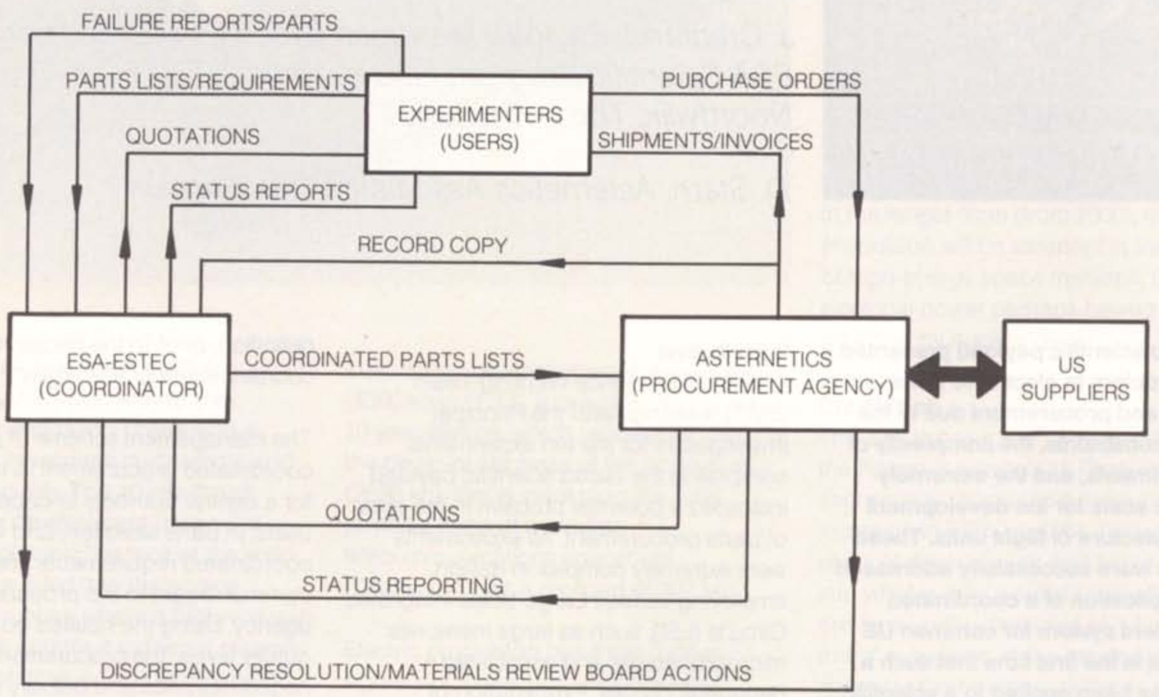
At the Science Working Team meetings, the general consensus was that the only feasible approach to the problems posed was a parts reduction and standardisation exercise, coupled with a coordinated procurement. It was also agreed that the technical aspects of the coordination should be performed by ESTEC and the procurement and shipping by Asternetics Associates (an independent consultancy and procurement agency that had provided valuable technical support to the Giotto payload in the early phases of parts definition, prior to the decision to coordinate the procurement).

The management scheme of a coordinated procurement is, in general, for a central authority to cooperate with users, in parts selection, and vendors. The coordinated requirements are then communicated to the procurement agency. Using the notified quantities and quality levels, the procurement agency negotiates price and delivery with the chosen vendors and advises the coordinating authority, who in turn notifies the users. On acceptance of the quotation, each user places his purchase order directly with the procurement agency. The role of the coordinating authority at this time is to ensure that all individual orders are placed promptly, as delay on the part of any user can jeopardise the whole procurement scheme. The procurement agency progresses the order, resolves technical problems, performs source inspection, incoming inspection and shipping, as agreed in the Programme Plan.

Procurement aspects

The Giotto payload procurement scheme is shown in Figure 1, together with the responsibilities of the various participants and the information flow. A number of ground rules were established for the procurement activities. These rules were established by mutual agreement between Principal Investigators and ESTEC, following initial surveys by Asternetics concerning realistic quality levels achievable within cost and schedule constraints. These ground rules were subsequently formalised in a

Figure 1 – Giotto payload coordinated parts procurement: management scheme



Programme Plan prepared by Asternetics and approved by the Giotto Project Management.

Initially it was believed that the major portion of the integrated circuit procurement would be based on Leadless-Chip-Carrier (LCC) packaging and that quality levels would exceed those of the MIL system. After a round of negotiations and investigations by Asternetics, the final situation was that the semiconductor industry delayed the introduction of the LCC and adopted an extremely hard line with respect to specifications other than MIL or 'in-house equivalent'. An evaluation of available options by ESTEC and Asternetics led to the establishment of the following ground rules, agreed by all users and Giotto Project Management:

1. It was decided that the simplest set of instructions would effect the cleanest communication of programme rules to all concerned; Coordinating Authority, Procurement Agency, Users and Parts Manufacturers. The most standard and widely practised procedures were thus selected. Where such standard procedures were considered in need of supplementary actions, the latter were to be carried out either by ESTEC, the user, or Asternetics themselves as appropriate.
2. All integrated circuits to be purchased to MIL 883 B or equivalent and discrete semiconductors to JAN TXV or equivalent. Where equivalent specifications were to be used, a stringent specification review was to be performed to ensure adequacy and define any supplementary actions.
3. All passive components to be bought to Established Reliability Specifications.
4. Destructive Physical Analysis (DPA) to be applied to most active components, and additional screening to be performed as necessary.
5. The payload procurement list to be continuously monitored against 'Alerts' from the GIDEP System, and appropriate action to be taken as necessary.
6. Continuous feedback to be maintained on DPA results and user experience, to allow timely corrective action by the Procurement Agency.
7. An agreement to be established with all users to keep ESTEC fully informed on results of incoming inspection and all anomalies from Engineering Models onwards. Failure analysis to be performed by ESTEC as appropriate.

Some indication of the size and complexity of the final coordinated procurement package for the Giotto payload may be gained from the following table:

Category	Quantity	Part types
IC Digital LSI	459	10
IC Digital Logic	13 734	147
IC Linear	493	20
Hybrid Microcircuits	80	2
Transistors	220	3
Diodes	505	4
Capacitors	2 646	240

Figure 2 — One of Giotto's 64 kbit Random Access Memory (RAM) microcircuits, manufactured by Teledyne

A point worth noting is that the amount of digital logic foreseen shortly prior to order placement in March 1983 was only 6000 pieces; other part types showed similar evolutions in numbers in the early stages of the procurement.

Engineering aspects

A unique feature of the Giotto payload parts procurement was the large amount of engineering effort injected in the pre-procurement phase prior to order placement with any major vendors. This generally involved the performance of a 'generic destructive physical analysis', whereby candidate devices from the selected vendor and of the appropriate quality level were subjected to test and analysis to determine if any generic problems existed. In certain critical cases, this was followed up with a visit to the vendor to review fabrication and assembly procedures, to determine the adequacy of final test and quality-assurance procedures and negotiate procurement specifications. These pre-procurement activities not only provided a sound base from which to launch the procurement proper, but also allowed the planning of appropriate order-progressing and source-inspection activities. A preliminary listing of critical items requiring special attention was also generated as a result of the pre-procurement activities. Certain items were found to require special engineering efforts during procurement and these are briefly reviewed in the following paragraphs.

One of the simplest functional electronic elements, a ceramic chip capacitor, proves that procurement difficulty is not always a function of complexity. In this case the high voltage rating of 5 kV was a problem in that the user required the capacitance to be verified at 60% of the working voltage. Surprisingly, it was found that this requirement could not be met by any of the high-voltage-capacitor manufacturers. The solution to the problem was the design and manufacture of a special test jig by Asternetics, which was provided to the manufacturers. This jig was found to be so effective by the manufacturer that he requested to retain it at the end of the Giotto programme!

Early in the programme a significant number (approx 15%) of CMOS logic ICs (integrated circuits) were found to have dented metal lids. An immediate analysis was performed by the ESTEC Components Laboratory and in parallel by an independent US Laboratory. These analyses led to the establishment of visual-inspection criteria, agreed by the supplier, which allowed rejection of items considered to be a risk. Replacement items were provided free of charge by the supplier, but this in turn led to a degree of schedule slippage. Subsequently no payload failures were reported exhibiting this condition and so it would appear that all potentially defective units were diverted by the special inspection. Follow up with the supplier showed the defect to be introduced by excessive spring pressure on a test fixture used at final test.

An early failure of CMOS logic was determined by ESTEC to be probably due to the lead dress on internal wires allowing small clearance to the edge of the chip. One wire appeared to have touched the bare silicon scribe lane, making a short circuit between wire and chip. A major programme of Destructive Physical Analysis was undertaken specifically searching for this defect. A number of devices were classified as marginal in this respect, but no systematic defect was noted and no subsequent failures have been attributable to this problem. Considering the large quantities used, the CMOS logic devices have been remarkably free of failures.

A number of experiments had a requirement for a large Random Access Memory. A number of potential solutions were considered, the final choice being a hermetic hybrid microcircuit of 64 kbit capacity, manufactured by Teledyne Microelectronics of Los Angeles (Fig. 2). This hybrid was similar to the hybrid

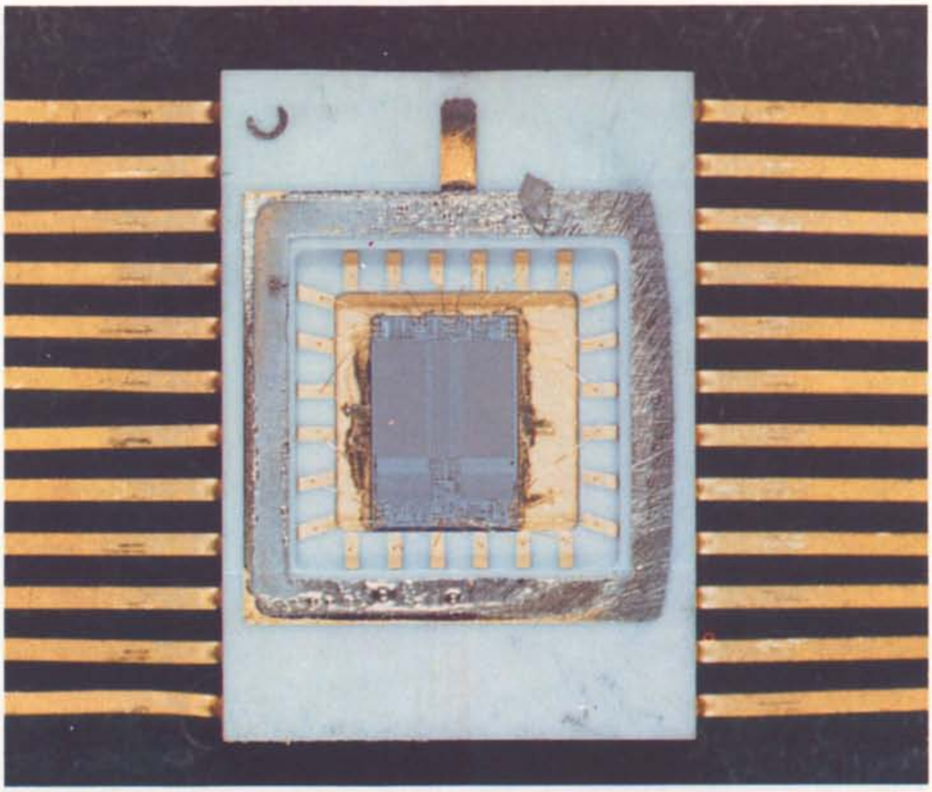


Figure 3 — One of Giotto's 4 kbit CMOS Programmable Read-Only Memories (PROMs)

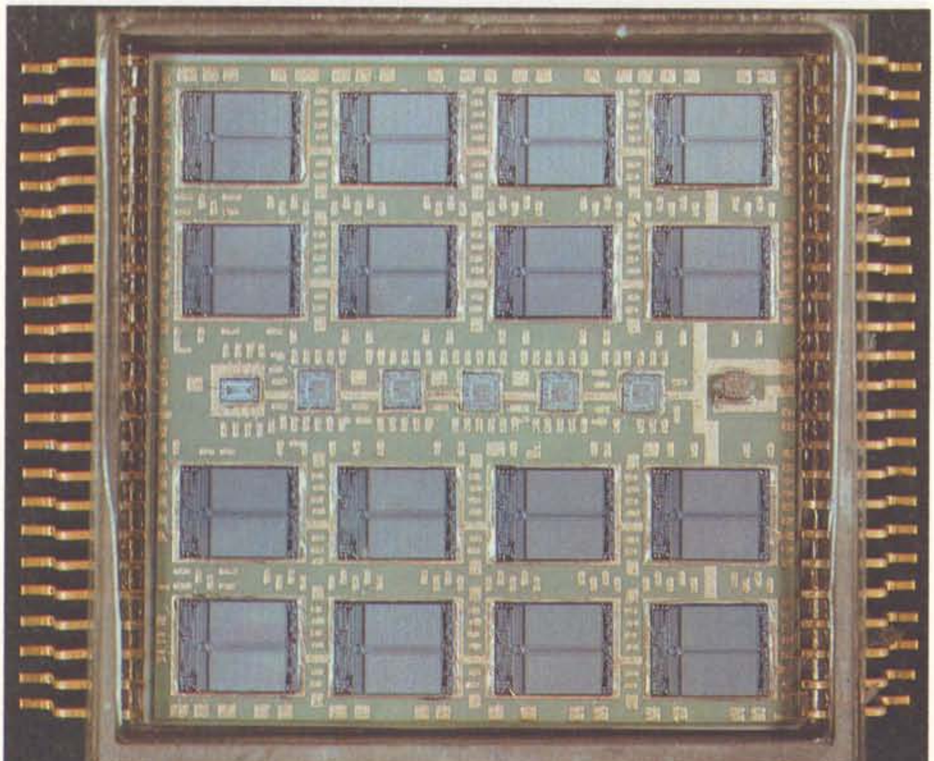
memory to be used in the Scientific Data Store of the Space Telescope's Faint-Object Camera (FOC). Both ESTEC and Asternetics had gained considerable experience of Teledyne during the FOC programme, and were confident with the choice for Giotto. Nevertheless, the Teledyne memory was considered to be a critical item for the following reasons:

a. The memory was a single source item.
b. The memory is a complex device containing 16 memory chips with decoders and buffers.
c. The hybrid memory was an item of intermittent production.
d. Experience in the FOC programme showed that manufacture of the hybrid required extreme attention to detail, with the highest level of quality control.

The Giotto payload required 80 hybrids and, in view of the complexity, criticality and tight schedule, ESTEC participated in the negotiation and manufacturing release meetings as well as a final inspection.

Throughout the programme, Asternetics were in continous contact with Teledyne and performed customer source inspection on all units. Early in the programme, a number of units were found to have damaged leads on receipt in Europe. The cause of the damage was impossible to trace, but was believed to have been due to customs inspection. A number of units were returned to Teledyne for rework and retest and a new form of external package sealing was introduced to provide evidence if the package were opened after leaving Teledyne. Few electrical failures were encountered; a total of 4 units exhibited 'stuck bits', and although outside the guarantee period were satisfactorily reworked by Teledyne free of charge.

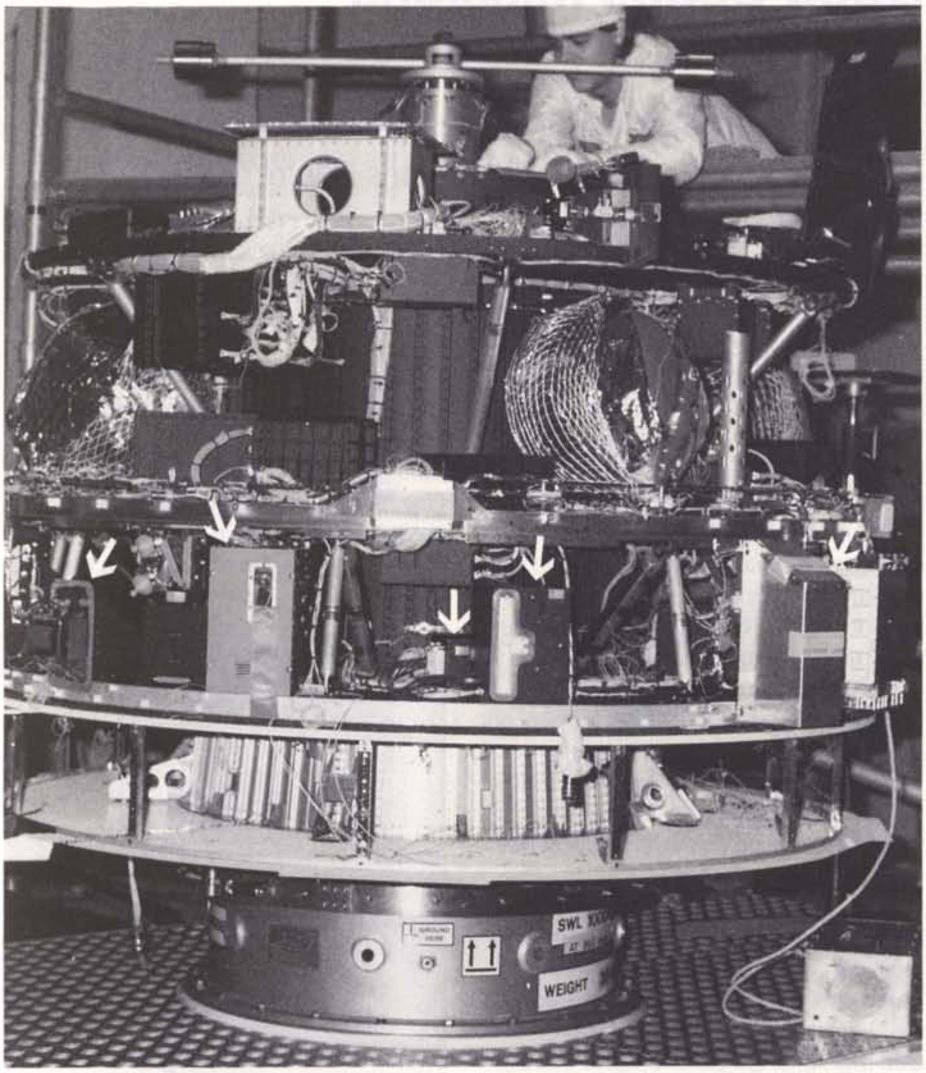
The most critical item in the payload procurement proved to be a 4 kbit



Programmable Read-Only Memory (PROM), type HM 6641 (Fig. 3). This is still considered a critical item requiring vigilance on the part of users as well as ESTEC and Asternetics. Severe schedule problems were experienced during procurement and several weeks prior to promised delivery a routine monitoring enquiry showed a delay of at least two months due to confusion over internal work orders at the manufacturer. Further investigation showed this predicted two-month delay to be highly questionable as the manufacturer had omitted to order the packages, which were known to be a long-lead item. In view of the dubious status of this critical item, Asternetics recommended the placement of a backup order with an alternative supplier, who had a stock of the appropriate chips and access to suitable packages with a fairly short lead time. Immediate agreement was given by Giotto Project Management and users informed accordingly. Finally, both main and backup orders were delivered concurrently at the beginning of 1983. The excess devices have subsequently all been used, due to changes in programme content and technical problems in programming.

A rather specialised aspect of parts engineering was the test programme initiated by ESTEC when information was received indicating that the 6641 was prone to an electrical malfunction known as 'latch-up', under the influence of irradiation by heavy ions from cosmic rays. 'Latch-up' is a permanent malfunction and potentially destructive. Fortunately, an ESTEC-sponsored research programme on cosmic-ray effects was in progress at the UK Atomic Energy Research Establishment (AERE), Harwell. AERE were able to carry out an immediate test programme using a variable-energy cyclotron and a recently developed test technique using a californium radioactive source. The test programme showed the latch-up condition to be far more serious than at first imagined; the electrical latch could be sustained not only through the power

Figure 4 – Giotto flight-model spacecraft during integration. Some of the experiments using 6641 PROMs are arrowed



supply, but also through any of the input/output terminals. Fortunately, the test programme also showed the risk of latch-up to be acceptably small, particularly in view of the short operating time of most of the experiments. For certain experiments with a residual risk, and also for the spacecraft, protection circuitry was incorporated using the results from the AERE test programme.

Conclusions
The application of a coordinated procurement to a scientific payload has proved to be both practicable and effective. Valuable lessons have been learned by all parties involved and this experience will benefit any future payloads for which it is decided to follow the same route.

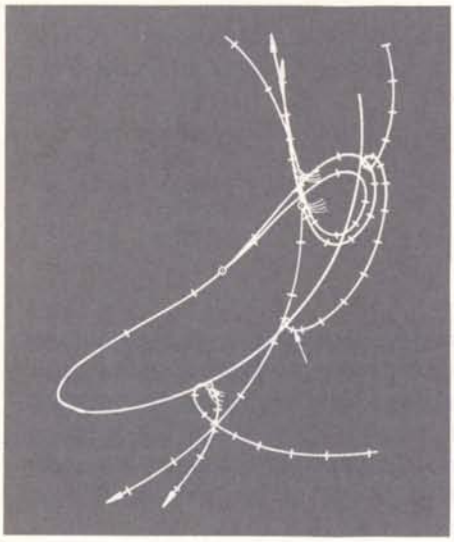
Significant advantages are to be obtained in cost and schedule, due to the greater 'procurement leverage' that can be exerted by virtue of large single ordering with manufacturers. Most 'minimum-buy' problems can be obviated by grouping orders and reducing the multiplicity of parts types through discussion and negotiation with users. Pre-procurement activities in the form of 'generic DPA' and visits to manufacturers play an important role in securing a sound base for the procurement proper and in reducing the number of problems during procurement. Unfortunately, the Giotto schedule did not allow as many pre-procurement activities as we would have wished. One incidental advantage of visiting manfucturers is the establishment of direct contact with key personnel, which can be important in the event of later problems requiring a rapid response.

The centralisation of engineering effort has been effective in ensuring a timely response to potential problems and securing the information flow to and from users and the procurement agency.

The importance of centralising engineering effort is best illustrated by the HM 6641 problems. Individual users experienced problems which, in isolation, appeared insignificant. By grouping together all the individual problems, a pattern emerged that indicated that further action was required.

The Giotto payload procurement has certainly not been problem free. At the same time, this is the first ESA payload with an extremely tight and effective information flow. Consequently, it could be said that virtually all parts problems have been recognised, evaluated and any further action taken as necessary. It is too early yet to claim success, but all indications so far are that the decision to proceed with a coordinated procurement was correct and has resulted in significant gains in quality, cost and schedule.

In closing, we would like to acknowledge the active support of the Giotto Project Management throughout this activity, and above all the cooperation of the experimenters who, despite the pressing problems of instrument development, still made the effort to participate fully in the sometimes tedious details of coordinated procurement.



Trajectory Control for the Agency's Deep-Space Missions

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A software system has been developed at ESOC for trajectory control for deep-space missions. It will be first used for the Agency's Giotto and Ulysses (formerly ISPM) missions, but can be extended to serve future missions without changing the basic design concept.

Giotto and Ulysses are ESA deep-space missions for which ESOC is responsible for trajectory control. To be able to support them, ESOC has developed a new software system to control interplanetary trajectories, a system that can also be used for future deep-space missions. If these future missions should involve nonspinning spacecraft equipped with other types of propulsion systems, certain modifications will be necessary. Extensions to cover additional tasks might also be required, for example to compute burns for insertions into planetary orbits, but the mathematical concepts, the basic structure as well as the bulk of the software, can be reused.

The present capabilities of the system are most easily illustrated by outlining the trajectory control that will be required for the Giotto and Ulysses missions, thereby also highlighting typical features of deep-space missions.

The Giotto mission

The ESA Giotto mission is based on a fast flyby of comet Halley, as illustrated in Figure 1, by a spin-stabilised spacecraft launched initially into Earth orbit by Europe's Ariane launcher in July 1985. After three revolutions of the spacecraft around the Earth, a solid-propellant motor will be fired to increase Giotto's velocity sufficiently for it to leave the Earth in a hyperbolic escape orbit, as shown in Figure 2. The time and direction of the motor firing will be chosen so that the spacecraft follows a heliocentric orbit, displayed in Figure 3, to encounter the comet in mid-March 1986.

To achieve the desired flyby geometry shown in Figure 1, additional orbit-correction manoeuvres will be required during the interplanetary cruise phase. One reason for this is the firing dispersion. Assuming a maximum inaccuracy in motor performance of 1%, and a pointing

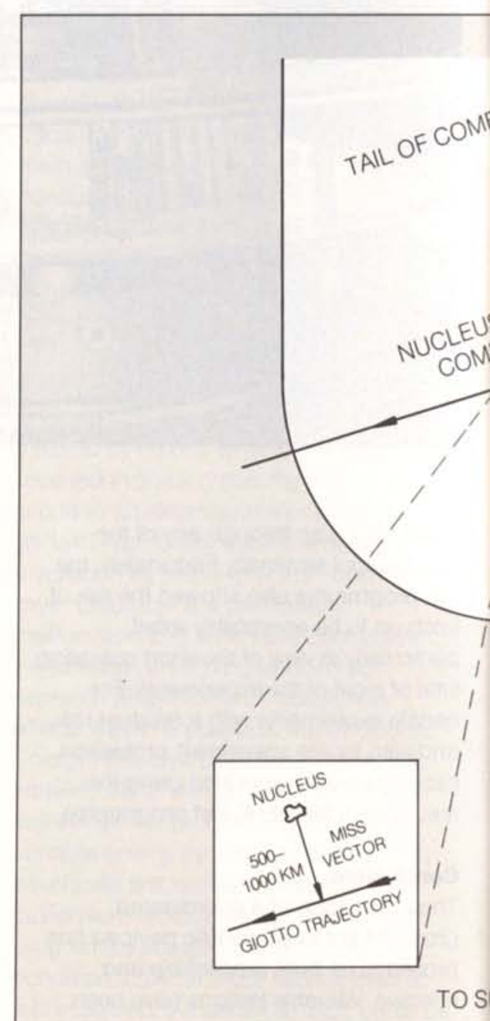


Figure 1 – Giotto flyby geometry relative to the comet

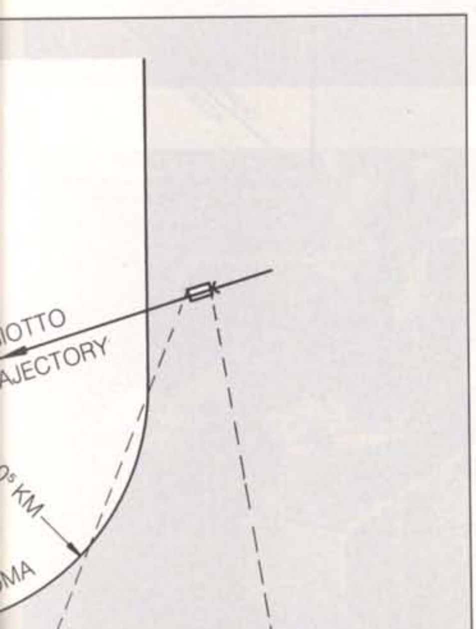
Figure 2 – The initial Earth orbit and the hyperbolic escape orbit after TPS firing

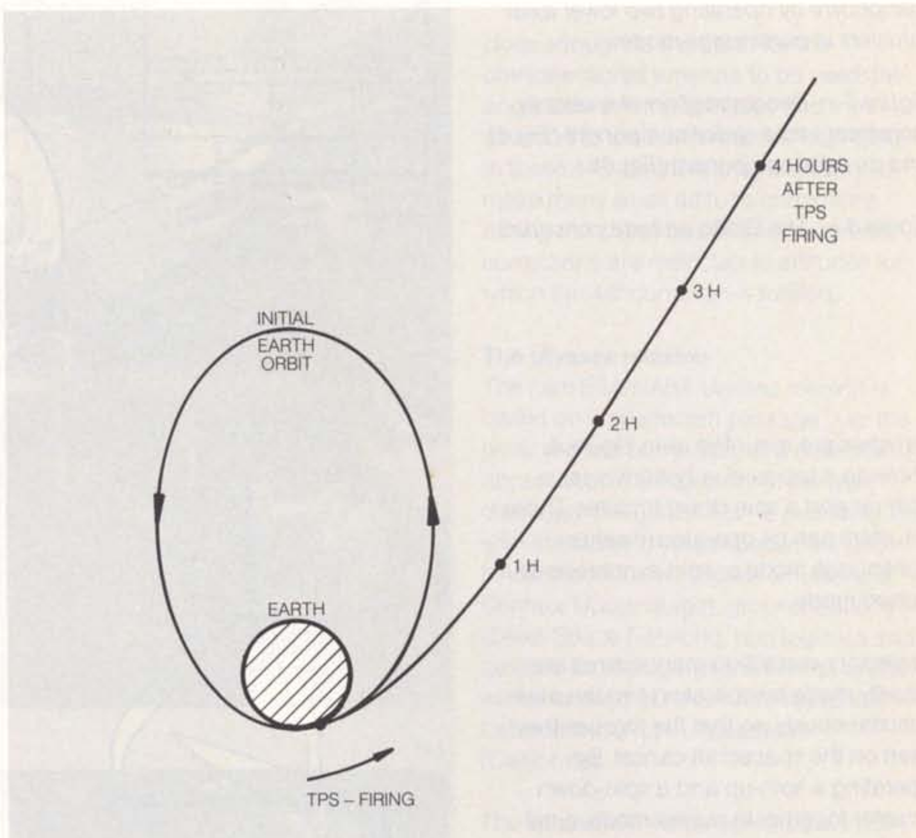
Figure 3 – The interplanetary orbit with the 8.5 month flight shown divided into six equal parts

inaccuracy during firing* of up to 1°, this dispersion could otherwise result in a miss-distance of millions of kilometres. Another reason is that the comet's ephemeris will not be known with total accuracy until later in the mission. The last update will, in fact, utilise data collected by the Soviet Vega spacecraft during their flyby of the comet about one week before the Giotto flyby.

The orbit corrections will be made with a hydrazine reaction control system. The

* The torques impacted by the burn will cause the spin axis to nutate. The offset between the mean spin-axis direction during the firing and the attitude determined before the firing is the total pointing inaccuracy.





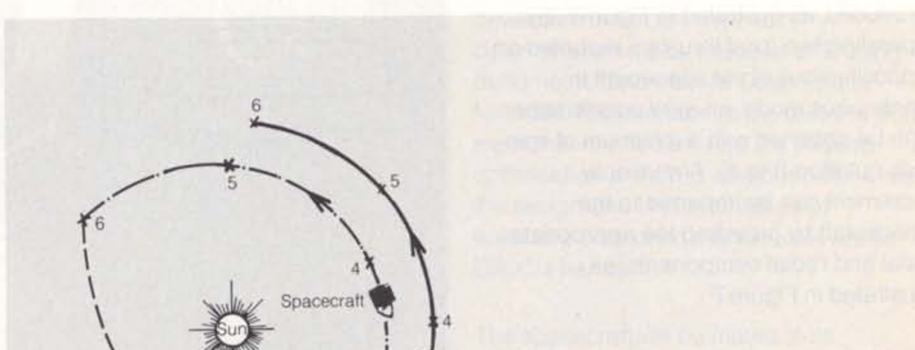


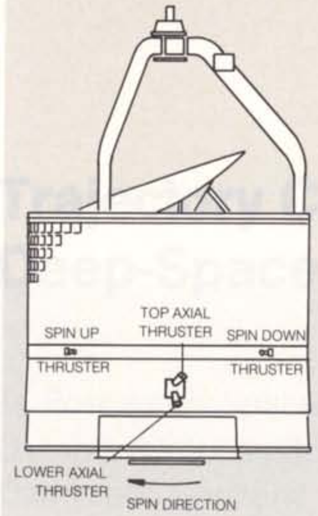
Figure 4 — The Giotto thrusters (similar set on other side of spacecraft)

Figure 5 — Radial orbit-correction manoeuvre by firing a spin-up and a spin-down thruster simultaneously in pulsed mode

Figure 6 — Axial orbit-correction manoeuvre by operating two lower axial thrusters in continuous mode

Figure 7 — Decomposition of a velocity increment into a radial component (Fig. 5) and an axial component (Fig. 6)

Figure 8 — The Giotto attitude constraint



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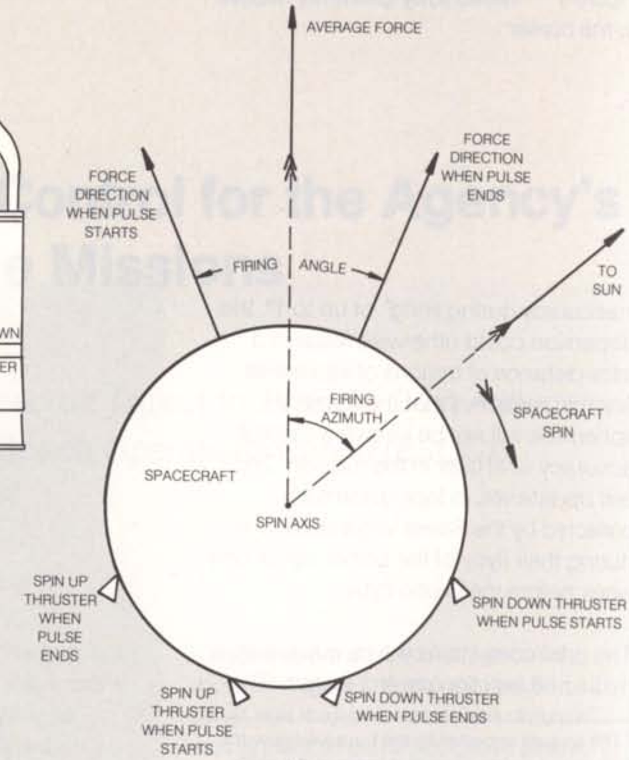

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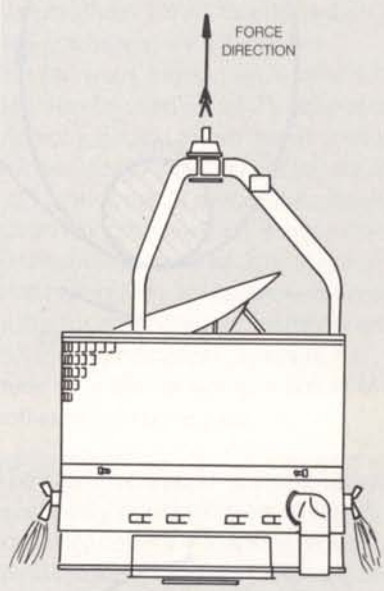

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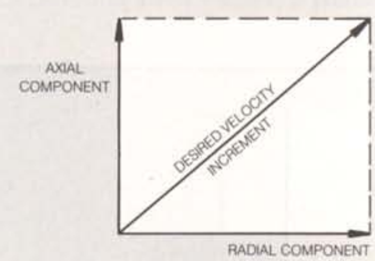

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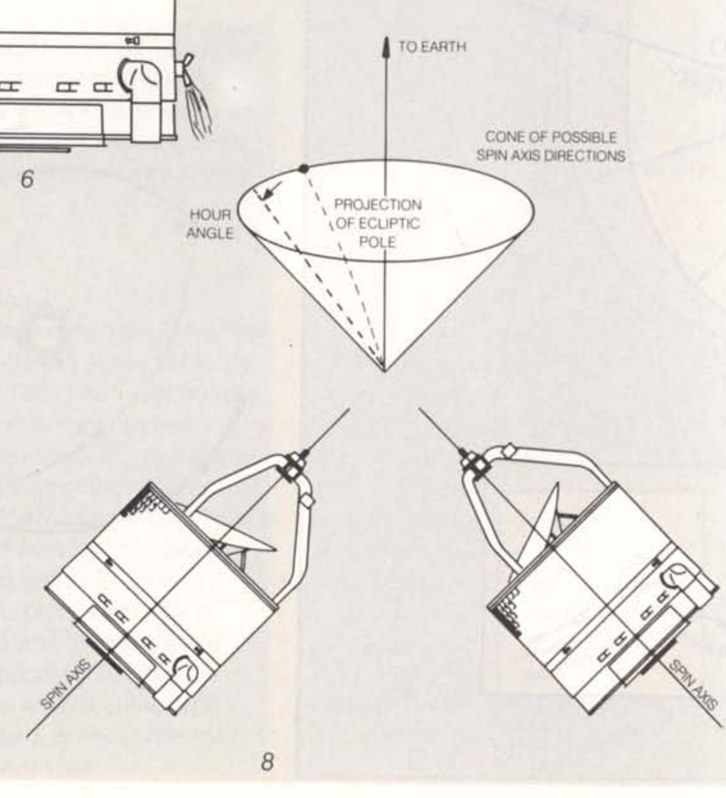

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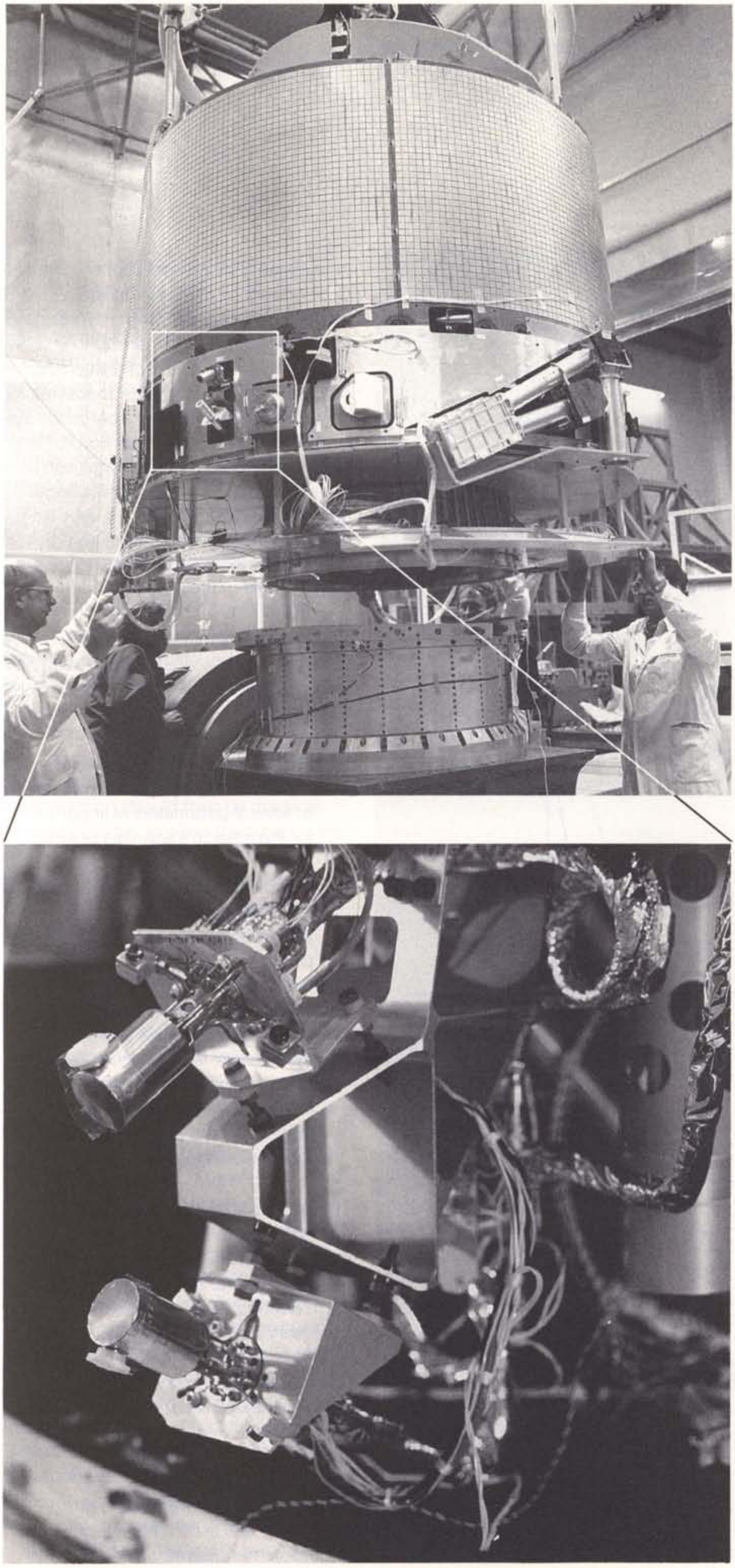
thrusters are mounted as in Figure 4, showing a top axial, a bottom axial, a spin-up and a spin-down thruster. These thrusters can be operated in either continuous mode or spin-synchronous pulsed mode.

Trajectory-correction manoeuvres are usually made by operating two thrusters simultaneously, so that the torques they exert on the spacecraft cancel. By operating a spin-up and a spin-down thruster together in pulsed mode, a net acceleration in any direction orthogonal to the spacecraft spin axis can be produced, as illustrated in Figure 5. By operating two axial thrusters mounted on opposite sides of the spacecraft in continuous mode, an axial acceleration can be obtained with a minimum of spin-axis nutation (Fig. 6). Any velocity increment can be imparted to the spacecraft by providing the appropriate axial and radial components, as illustrated in Figure 7.

Precession manoeuvres are generally made by operating an axial thruster in pulsed mode. Such precession manoeuvres affect the spacecraft's orbit and are therefore also elements in the trajectory-control strategy.

The design of trajectory-correction manoeuvres is affected by the fact that the spacecraft is equipped with a despun, high-gain antenna, the beam of which makes an angle of 44° with the spacecraft's spin axis (Fig. 8). Except for the first few days, when the spacecraft is



Giotto and its thrusters

close enough to the Earth for the omnidirectional antenna to be used, the angle between the spin axis and the direction to the Earth must be kept close to these 44°. It is therefore necessary to make many small attitude corrections during the cruise phase and the orbital corrections are restricted to attitudes for which the 44° condition is fulfilled.

The Ulysses mission

The joint ESA/NASA Ulysses mission is based on a spacecraft passage over the polar regions of the Sun, at a distance of about 2 AU, in a trajectory of the type displayed in Figure 9. ESA is providing the spin-stabilised Ulysses spacecraft, and NASA the launcher (Space Shuttle and Centaur Upper Stage), ground stations (Deep-Space Network), and logistics and facilities for the operations centre, which will be located at NASA Jet Propulsion Laboratory (JPL) in Pasadena (California).

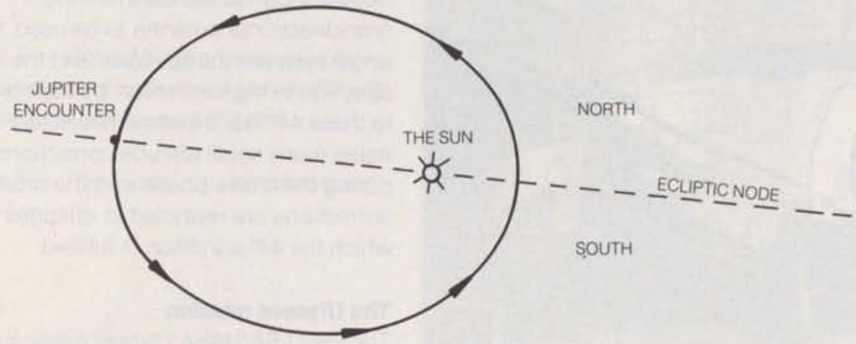
The spacecraft will be operated from JPL by ESOC staff utilising an ESA-owned computer, running flight-control software developed in ESOC. The orbit determination will be made by JPL using radiometric data from its Deep-Space Network. The interface to the scientist with experiments onboard and the mission optimisation are JPL's responsibility, while the design and implementation of trajectory-correction manoeuvres are in ESOC's hands.

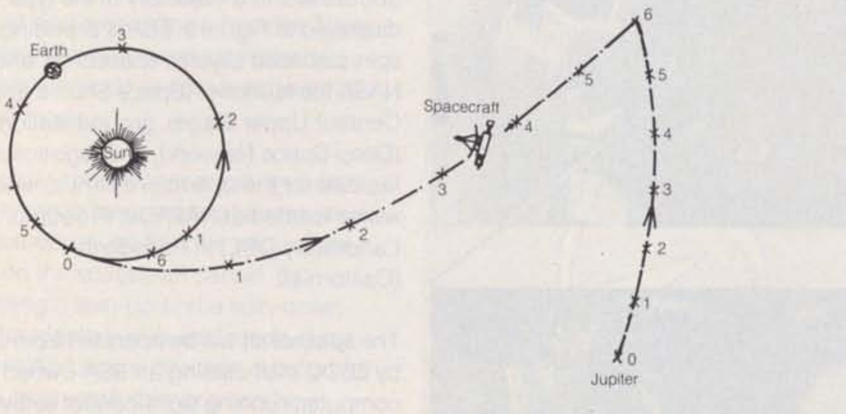
The spacecraft will be mated to its Centaur Upper Stage and launched into Earth orbit by a Space Shuttle in May 1986. After between five and seven revolutions around the Earth, the Centaur Upper Stage will be fired to inject the spacecraft into an interplanetary orbit to encounter Jupiter in July or August 1987. The gravitational field of Jupiter will then deflect the spacecraft into the desired solar-polar orbit. Ulysses' orbit before the Jupiter passage is shown in Figure 10. Small variations in the initial state close to Earth will result in large variations in the size and direction of the deflection, and

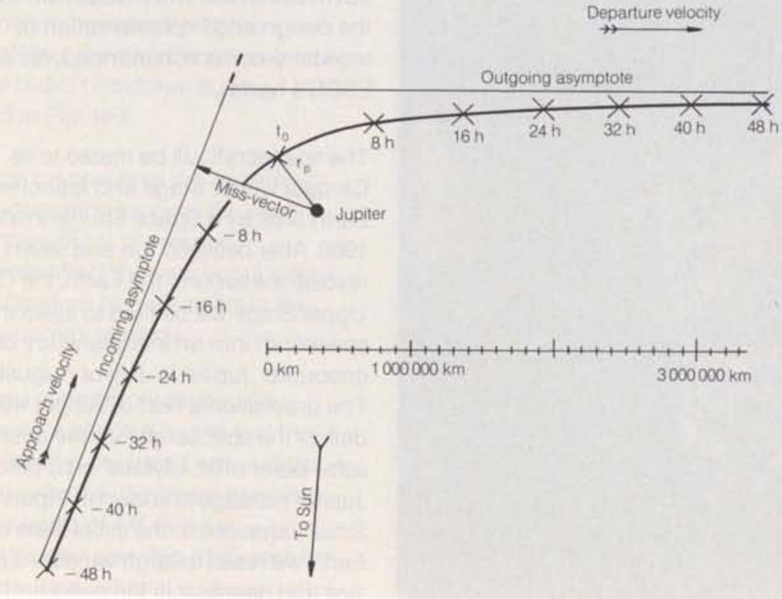
Figure 9 – The Ulysses solar-polar orbit (ecliptic inclination ~78°; perihelion radius ~1.1 AU; orbital period ~5½ yr)

Figure 10 – Interplanetary orbit of Ulysses to Jupiter, with the 13.5 month flight divided into six equal parts

Figure 11 – The Ulysses flyby of Jupiter. The plane of the orbit is inclined 39° to the ecliptic







consequently in the post-Jupiter orbit. Orbit-correction manoeuvres are therefore to be made using a hydrazine reaction-control system, similar to that of Giotto, to compensate for the injection dispersion and to target the spacecraft for an optimal deflection. For a particular day of injection into interplanetary orbit, the elements of the post-Jupiter orbit can be considered functions of the miss vector displayed in Figure 11 and the flyby time, as the approach velocity (size and direction) is, in a first approximation, a function only of the flyby time.

This is the basis for the midcourse-correction-manoeuvre interface between the experimenters, JPL and ESOC, which has been organised as follows:

- JPL generates so-called 'B-plane contours' displaying the dependence of several parameters of importance for the mission's scientific objectives on the miss vector and flyby time, e.g. number of days above 70° and below –70° heliocentric latitude, maximal and minimal heliocentric latitude, perihelion radius, etc.
- Based on these contours, the experimenters choose the miss-vector and flyby-time values that optimise the scientific value of the mission.
- ESOC defines and implements a sequence of orbit and attitude manoeuvres to achieve the chosen flyby parameters.

The spacecraft is equipped with a high-gain antenna with a beam directed parallel to the spin axis, which must therefore be kept pointing towards the Earth during the cruise phase. This is necessary not only for the satisfactory radio link, but also for the 'CONSCAN'-type attitude-determination system, which relies on the uplink carrier received via the high-gain antenna.

Basic principles

There are always several ways of implementing a certain trajectory-correction manoeuvre, which raises the

Figure 12 – Ulysses' turn and burn manoeuvre using lower axial thrusters in continuous mode

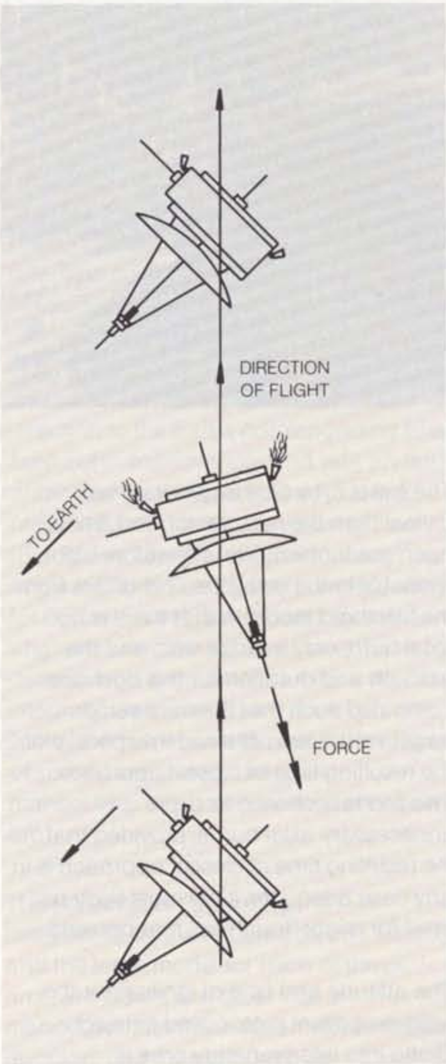
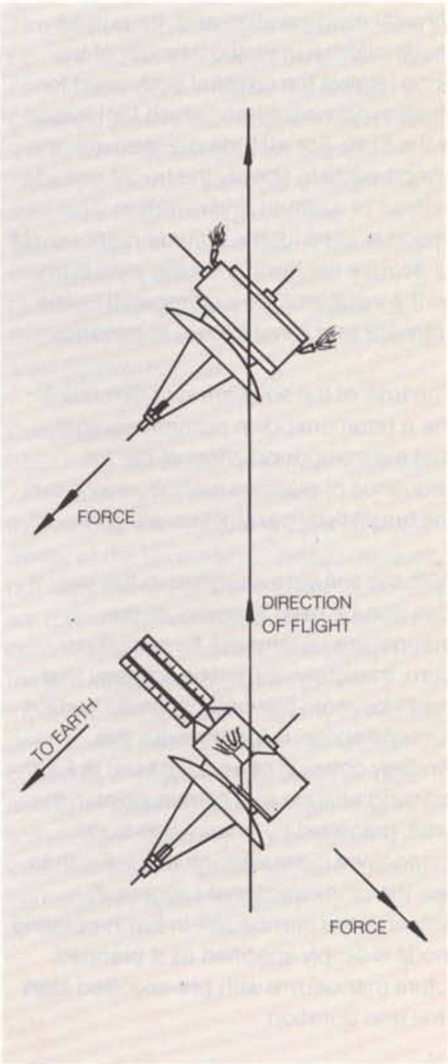


Figure 13 – Ulysses' 'vectored' manoeuvre with one radial burn and one axial burn



question of optimisation, i.e. which of the many possible ways is the most advantageous. In general, one tries to make the corrections so that a minimal amount of fuel is used, thereby maximising fuel reserves for future orbit and attitude control. However, if the fuel budget is in any case adequate for the mission, other factors might be more important.

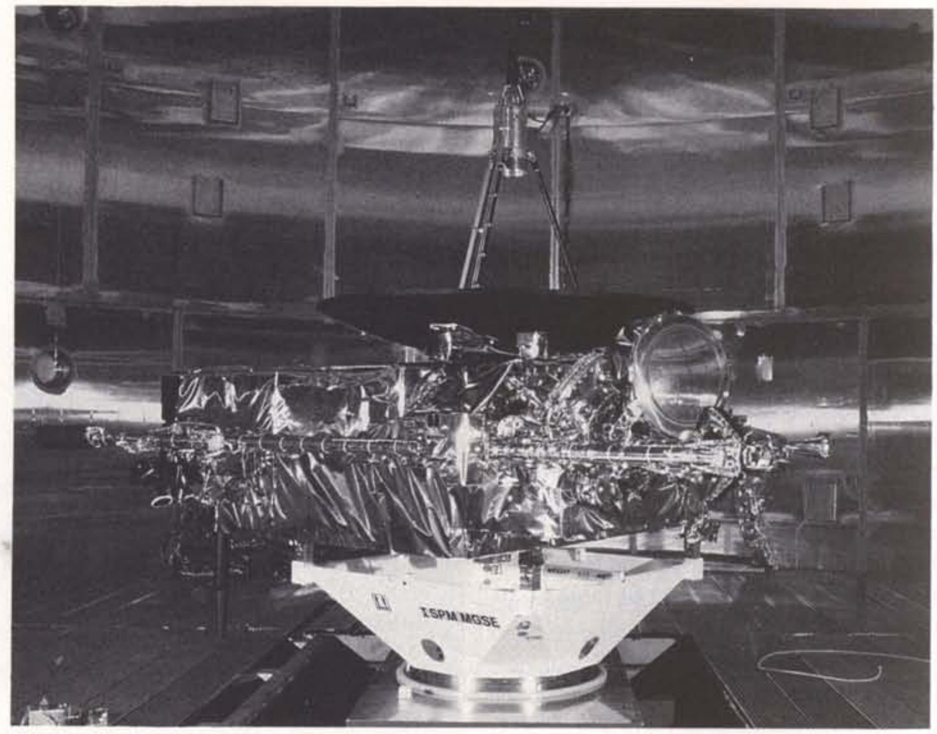
An example is the first trajectory-correction manoeuvre for Ulysses, which it has been agreed should be made about a week after the spacecraft's injection into interplanetary orbit. The reason is essentially the orbit-determination accuracy attainable, rather than the fuel efficiency. One week of tracking measurements is adequate for the required orbit-determination accuracy prior to the first trajectory manoeuvre, and this correction should then be made as soon as possible, to allow tracking for the next orbit determination to start. The trajectory correction should be made either in a 'turn-and-burn' mode, or in a 'vectored' mode.

In 'turn-and-burn' mode, which in general is more fuel-efficient, the spin axis is precessed to an attitude from which the required miss-vector and flyby-time values can be achieved by a continuous axial burn (Fig. 12). However, this mode has a certain disadvantage in terms of operational security. Ulysses' 'CONSCAN' attitude-determination system only functions when a transmitting ground station is close to the spacecraft's spin axis. The target attitude must therefore be obtained with a 'blind' precession manoeuvre, with only the Sun-aspect-angle readings and the Doppler shift in the downlink carrier as feedback. Except when a large injection dispersion makes the fuel budget marginal, the preferred mode is therefore the less fuel optimal 'vectored' mode in which the corrections are made, with the spin axis pointing to the Earth, via a continuous-mode axial thrust *and* a pulsed-mode radial thrust (Fig. 13). The term 'vectored' comes from the fact that, provided the time separation between the two manoeuvres is short, their compound orbital effect depends only on the vector sum of the two velocity increments (Fig. 7).

These types of operational strategies and spacecraft-hardware-dependent features are not suitable for coding into the basic software for manoeuvre computation. The result would be a suite of software insufficiently flexible for adaption to new strategies and/or nonnominal situations and inadequate for multiple-project use.

The underlying principle of the software that has been developed at ESOC is therefore that the user defines so many parameters for the manoeuvres that the remaining parameters to be determined by the software are uniquely defined by the required target.

To compute the Ulysses 'turn-and-burn' maneouvres using this software, one defines a sequence of manoeuvres, including a single precession manoeuvre, to obtain an a priori unknown, midcourse correction attitude to be determined by the software and a subsequent axial burn with unknown duration also to be determined by the software. The other planned manoeuvres are completely defined by specifying start time, duration,



thruster configuration and, for pulsed-mode manoeuvres, the azimuth of the firing relative the celestial body used for pulse synchronisation (which for Ulysses is the Sun). For attitude manoeuvres, the option exists to specify the target attitude instead of azimuth and duration. This option is used for the attitude manoeuvres to acquire the Earth after the axial burn, as the initial attitude is computed by the software and is not known in advance.

The task of the software is to determine the a priori unknown parameters such that the compound effect of the full sequence of planned manoeuvres is that the target flyby parameters are achieved.

With the software designed in this way, it can also be used to compute the manoeuvre parameters for a multiple-burn, trajectory-correction strategy that might be more fuel optimal under certain circumstances. If, for example, this strategy consists of an axial burn in Earth-pointing attitude at a certain point in the orbit, preceded by a 'turn-and-burn' manoeuvre close enough to the Earth to use the omnidirectional spacecraft antenna, the manoeuvre in Earth-pointing mode is simply specified as a planned future manoeuvre with pre-specified start time and duration.

The unspecified manoeuvre parameters will then be computed such that this multiple-burn strategy results in the desired flyby parameters. For such applications, it is then necessary to have other software tools available to define fuel-optimal strategies; only the final step with full-precision computation of the manoeuvre parameters is made with the basic manoeuvre-computation software.

The computation for the 'vectored-mode' trajectory-correction manoeuvre is very similar, the only difference being that the precession manoeuvre to obtain the attitude for the axial burn is replaced by a so-called 'pulsed-mode radial Δv manoeuvre' with duration and firing azimuth to be determined by the software.

The exact flyby time is generally less critical than the miss vector and a time-open guidance mode is therefore also available in the software. This differs from the 'vectored mode' in that there is no axial burn, only a radial one, and the azimuth and duration for this burn are computed such that the miss-vector target values are obtained irrespective of the resulting time of closest approach. This mode is chosen to avoid unnecessary axial burns, provided that the resulting time of closest approach is in any case adequate. It will most likely be used for minor 'touch-up' manoeuvres.

The attitude and time of ignition for the solid-propellant motor used to inject Giotto into interplanetary orbit is computed in a similar manner. Any set of manoeuvres subsequent to the burn using the hydrazine reaction control system can be specified and the firing parameters computed such that, for nominal motor and reaction-control-system performances, the compound effect of all manoeuvres is that the target celestial body is encountered at the desired time.

Mathematical algorithms used

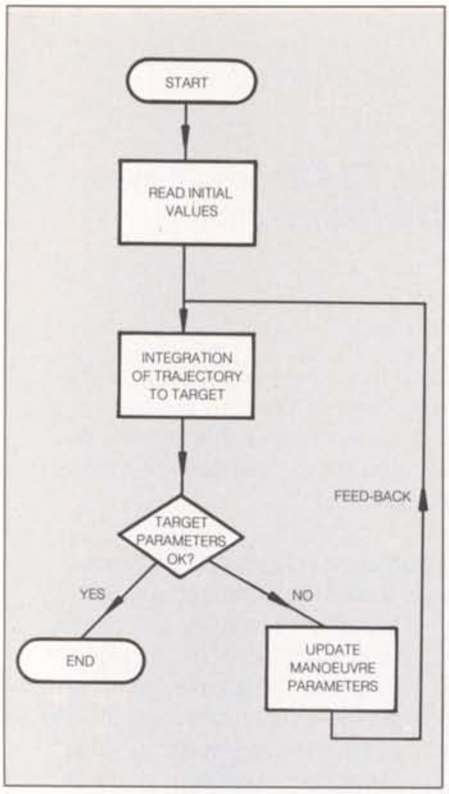
The manoeuvre parameters are computed using an iterative algorithm based on a full-precision numerical integration of the equations of motion for the spacecraft, as illustrated in Figure 14. The forces that can be taken into account for the numerical integration are the first- and second-order terms of the gravitational potential of the celestial bodies, the solar radiation pressure and the manoeuvre forces.

The spin of a spacecraft causes a variation in the thruster force direction unless the thrusters are operated in continuous mode and the forces are completely parallel to the spin axis (Fig. 6). For the orbit integration, these rapidly varying forces can be replaced by their time averages over one spin period without causing any loss in accuracy, thereby allowing a longer integration step.

Provided a thruster combination is used that exerts a torque with a nonzero radial component relative to the centre of gravity, the spacecraft will not be in a pure spin around its principal axis during the manoeuvre, but will nutate. In the case of a pulsed-mode manoeuvre, there will also be a spin-axis precession. In reality, the amplitude of the nutation will not be so large that it influences the orbital effects of the manoeuvre and the average force over a spin period can be computed as if the spacecraft was in a pure spin motion about its principal axis. The precession, on the other hand, must be modelled in the software, as the direction of average thruster force over one spin revolution depends on the spin-axis direction, as well as on the direction to the reference body and the delay angle.

Having replaced the true thruster forces

Figure 14 — Flowchart for the manoeuvre-computation software



by their average over one spin period, the time variations in these 'fictitious' forces are caused by blow-down effects*, and for pulsed-mode manoeuvres also by the spin-axis precession.

For the numerical integration, the trajectory is divided into several arcs, for each of which a certain force model is used. Some of these are manoeuvre arcs over which manoeuvre forces are present; some are ballistic arcs over which there are only forces caused by gravitation and solar radiation pressure. Over a ballistic arc, the step length is typically one day or more, while for manoeuvre arcs it is one order of magnitude smaller.

For both Giotto and Ulysses, a large number of small precession manoeuvres have to be made to maintain the high-gain antenna Earth-pointing. To avoid splitting up the trajectory into too many different integration arcs, there is the option to replace these manoeuvre forces with an equivalent continuous force proportional to the average precession rate. This does not result in any loss in precision, particularly as the exact timing of these manoeuvres is not known in advance. For this, the spin axis is assumed to be on a cone around the direction to the Earth, corresponding to a fixed Earth aspect angle and with an hour angle relative the ecliptic pole that is a prescribed continuous function of time (Fig. 8). For Ulysses, this Earth aspect angle is 0° (spin axis Earth-pointing), while for Giotto it is 44°, corresponding to the angle between the spin axis and the despun high-gain antenna beam. An integration arc over which such a fictitious force is used to model the effect of several small 'daily precession manoeuvres' is also considered a ballistic arc.

The parameters controlling the integration, i.e. the subdivision into arcs and the force model for each of these arcs, are stored in a table. For a manoeuvre arc, these parameters include duration, and for pulsed-mode manoeuvres also the firing azimuth. After each iteration, the parameters to be computed are updated until the flyby parameters predicted by the numerical integration are sufficiently close to the target values. Normally the durations for the manoeuvres to be computed are initially set to zero, so that for the first integration corresponding integration arcs are dummies.

The above description is also valid for the computation of the TPS (Fig. 2) firing parameters. The difference is that instead of manoeuvre duration, the start time is computed by the software. There are also no blowdown effects; the thrust force is modelled as constant during the burn, which lasts for about 1 min.

The iterative updates of the parameters to be determined are based on a 'patched conics approach', in which a linear equation system with coefficients formed by partial derivatives for an elliptic heliocentric orbit relating the position at flyby time to the velocities at the manoeuvre times is solved. The order of this equation system is equal to the number of target flyby parameters, i.e. three for time-fixed guidance and two for time-open guidance.

Conclusion

ESOC has developed a software system for the control of interplanetary trajectories. This system is tailored to the needs of the Giotto and Ulysses missions, both spacecraft being spin-stabilised and equipped with hydrazine blowdown orbit-control systems. However, the design of the software is such that it can be modified for the support of any future ESA deep-space mission. Many of the new concepts and design principles would also be suitable for the next generation of software for the control of geocentric trajectories, for example for 'rendezvous' manoeuvres and similar tasks.

* The hydrazine tanks use helium gas as a pressurant. As the quantity of fuel in the tanks decreases, the gas pressure also decreases, resulting in a lower fuel flow rate to the thrusters and a lower thruster force.

Neutron Stars, Black Holes and Exosat

A. Peacock, Exosat Project Scientist, ESA Space Science Department, ESTEC, Noordwijk, The Netherlands

Some of the most exciting Exosat results to date have come from the study of neutron stars and black holes. Through these observations, Exosat is making a major contribution to our understanding of objects in which matter is in an incredibly condensed form.

The satellite has now been in orbit for more than a year (see ESA Bulletin No. 39, page 101) and it has become apparent that a major research area in which astronomers have made significant strides directly as a result of Exosat observations is the field of classical galactic X-ray sources. These sources generally involve such exotic objects as neutron stars or black holes.

In the sky as seen at X-ray wavelengths (Fig. 1), the majority of the bright (green dots) X-ray sources are clustered along the galactic plane. These X-ray sources are all within our own galaxy and are generally thought to consist of either a neutron star or black hole locked in a binary system with a normal optical companion star. Exosat has now observed practically all of these sources to determine their temporal and spectral characteristics. It is from this data that the physics involved in the X-ray emission mechanism and the physical and dynamic properties of the stars can be understood.

What actually are neutron stars and black holes? To understand such objects, we must look at stellar evolution, how stars 'live', and how they eventually die.

Briefly, a star produces vast amounts of energy in the form of electromagnetic radiation through a nuclear-fusion process. The thermal pressure produced by this energy opposes the gravitational force, which is attempting to collapse the outer layers of the star onto the interior stellar core. The star consumes its hydrogen fusion fuel and eventually uses up such fuel at its centre, at which time the core contracts and heats up. The star has now reached the 'red-giant' stage of its life, when its surface is much cooler than a normal star like our Sun, but its diameter is about 10–100 times greater.

Figure 2 relates the size of a typical red giant such as the star Betelgeuse in the Orion constellation, to that of our own solar system. Our Sun will eventually become such a red-giant star, in about 5 billion years. During the red-giant phase, the star eventually exhausts its nuclear fuel and collapses to become a 'stellar corpse'.

There are four types of stellar corpse:

(i) The star can undergo a violent disruption, producing a supernova (see ESA Bulletin No. 38, page 17). This supernova explosion will leave behind a supernova remnant, and sometimes also the compressed stellar core in the form of a neutron star.

(ii) The star can undergo a controlled collapse, to form a white dwarf.

(iii) The star's mass may be such that the core collapse continues until it stabilises in the form of a neutron star.

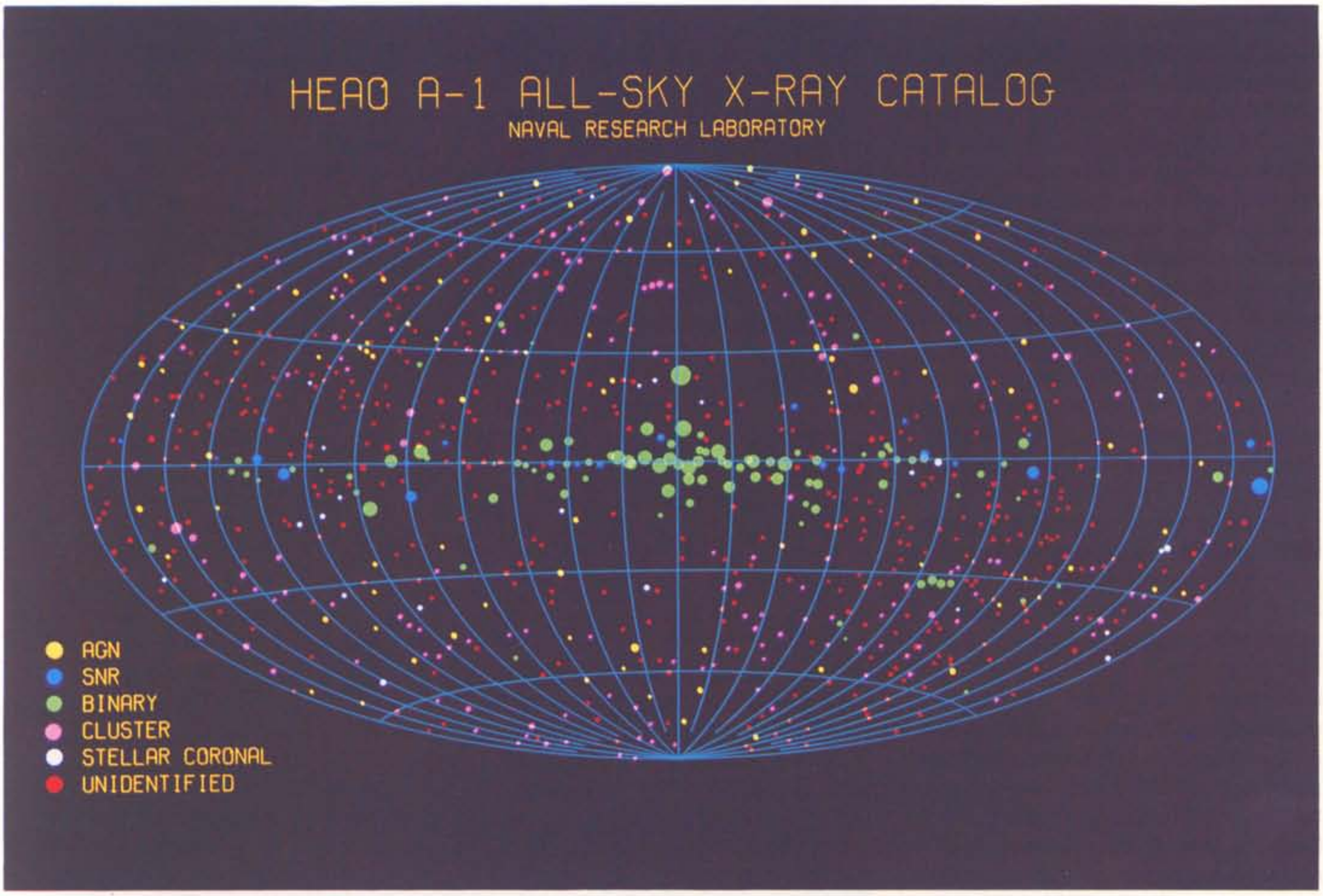
(iv) The star cannot oppose the gravitational pressure and continues to collapse to a singularity, forming a black hole.

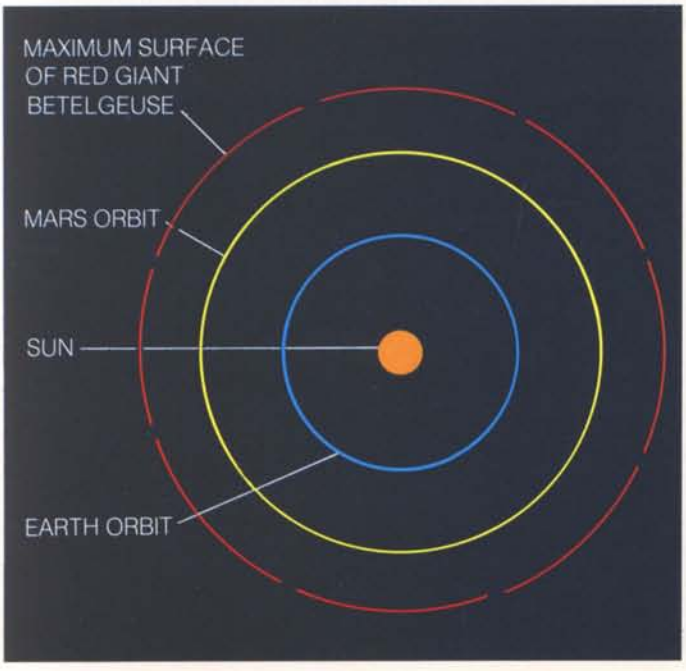
As the star reaches the end of its lifetime, therefore, the thermal pressure cannot oppose the collapse. If, however, the core of the star is small enough, the star can become a white dwarf. Here the gravitational pressure is now opposed in the core not by thermal pressure, but by the degeneracy pressure of the free electrons, i.e. the electrons oppose being packed closer together. The first white dwarf ever discovered was also the brightest, the nearby star Sirius-B. This star is part of a binary system, its companion being Sirius-A, the Dog star. The size of Sirius-B compared with our own Sun and Earth is illustrated in Figure 3

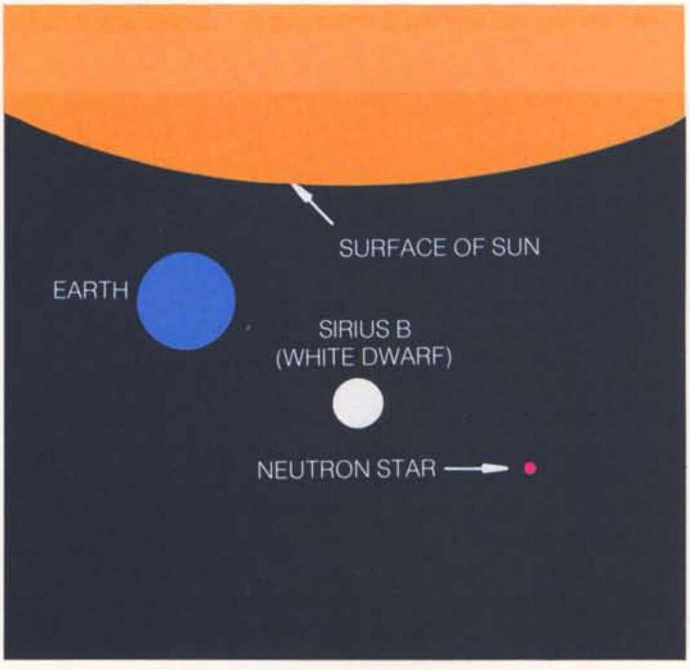
Figure 1 – The X-ray sky observed by the satellite HEAO-A, with about 1000 sources detected. The green dots indicate sources associated with neutron stars or black holes in binary systems

Figure 2 – Size of a typical red-giant star, such as Betelgeuse, in the context of our solar system

Figure 3 – Sizes of a neutron star and white dwarf compared with our own Earth and Sun







Not all stars, however, need to end their lives as white dwarfs. If a star is more massive, the electron degeneracy pressure can itself be overcome and the stellar collapse will continue, eventually to form a neutron star. Then the electrons and nucleons in the core fuse to produce neutrons. The stellar collapse is now arrested and stabilised as a result of the neutron degeneracy pressure. Neutron stars are now known to exist from both radio astronomy (the study of pulsars is the study of neutron stars) and X-ray astronomy. Neutrons stars are therefore extremely dense objects, less than 20 km in diameter. Their central densities are more than 10^{15} times that of water, and their masses sometimes twice that of our Sun. Both white dwarfs and neutron stars have finally managed to defeat the forces of gravity and keep themselves from further collapsing to form black holes.

Black holes form from the collapse of very massive stars. The black hole is thus that area of space surrounding an object that has collapsed to such small dimensions that its gravity becomes overwhelming. Even electromagnetic radiation cannot escape this gravitational force and leave the black hole. The central feature of a black hole is its event horizon beyond which nothing, not even light, can escape. All physical phenomena we observe therefore occur outside this horizon.

X-ray astronomy offers us a unique tool with which to study black holes and neutron stars. Such objects, when formed in binary systems, interact with the companion star. The degenerate object produces tidal effects on its companion. Huge amounts of gas flow from the surface of the companion, forming an accretion disc around the degenerate object. Gas from this disc spirals in towards the collapsed object, heating itself up and emitting copious quantities of X-rays. If the collapsed object is a neutron star with a magnetic field, the falling gas can be channelled by the magnetic field lines to the star's magnetic poles. If the neutron star rotates, as is the case for pulsars, then the X-rays will be modulated in part by the rotation, producing X-ray pulsations. In addition, since the neutron star is part of a binary system, the motion of the neutron star about the system's centre of gravity should be detectable in many cases. In fact, the pulsations will exhibit a doppler effect, and an X-ray eclipse by the neutron star of the companion should be observable. In the case of a black hole, the spiralling hot-gas stream will radiate X-rays until it passes beyond the black hole's event horizon. In this situation, the X-rays will flicker very rapidly, but no pulsations are to be expected. The best-known and most favoured black-hole candidate is found in a binary system in the constellation Cygnus, and is called Cygnus X-1. Here a B-type supergiant star has a hidden companion, thought to be a black hole with a mass at least five times that of our Sun. The model for this X-ray source is shown in Figure 4.

Cygnus X-1 is rather bright in X-rays and was therefore observed by Exosat during the early orbit-calibration phase to determine the low-energy imaging telescope's point-source response function. Figure 5 shows the colour-coded telescope image of this source.

The source indeed showed the well-known chaotic flickering of the X-ray flux thought to be characteristic of a black hole (Fig. 6). Study of the variability of this flux and the associated spectrum is currently under way and should provide insight into the physical conditions of the hot gas near the black hole's event horizon.

Exosat observed the classical X-ray binary source Cygnus X-3 early in the mission. Previous observations have shown this to

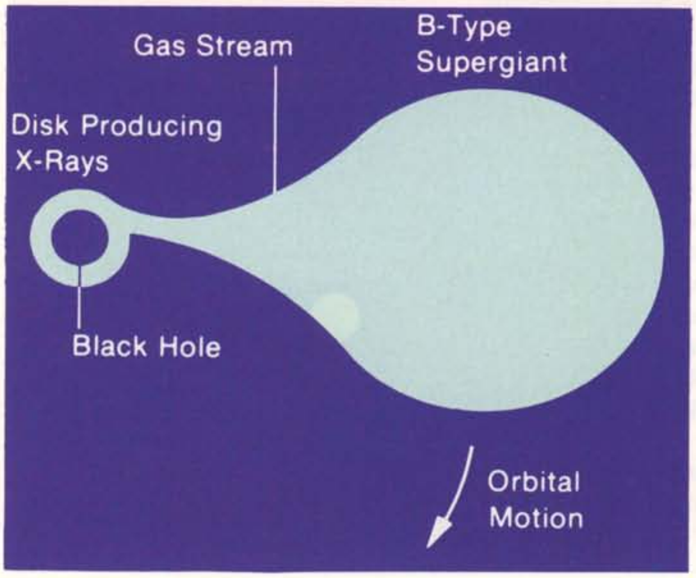


Figure 4 – Model of the black-hole candidate Cygnus X-1

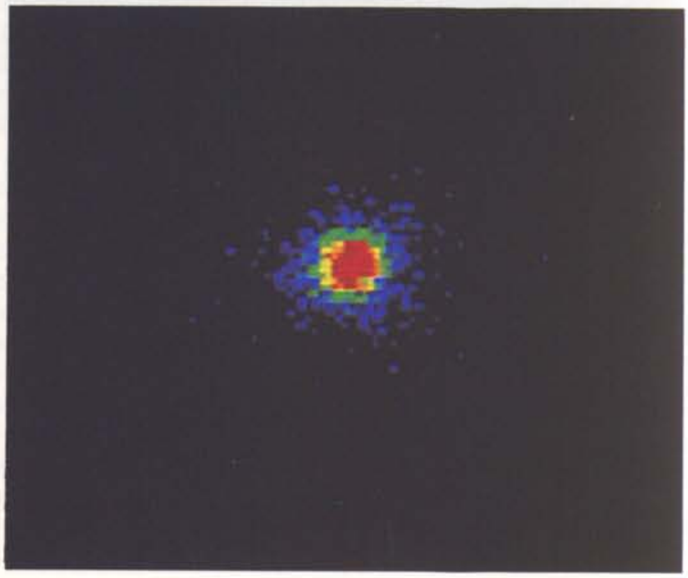


Figure 5 – Exosat low-energy telescope image of the black hole Cygnus X-1

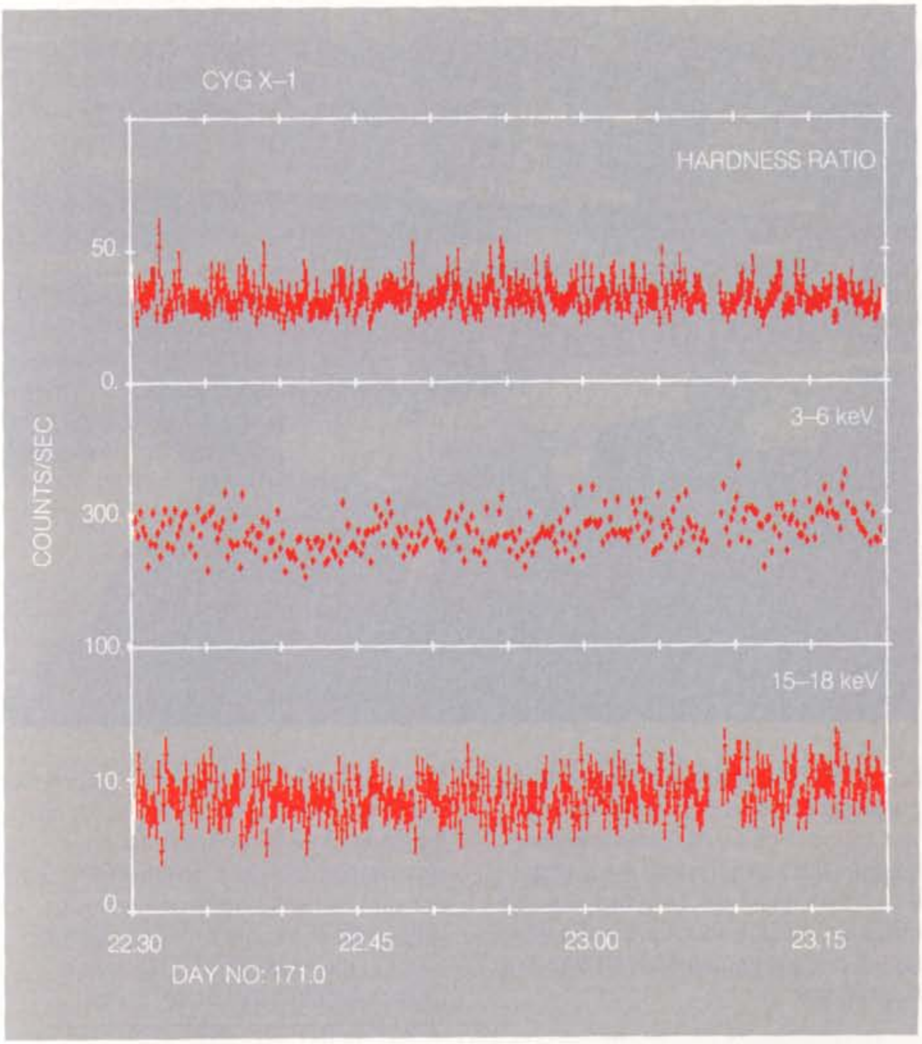


Figure 6 – Chaotic variability of the X-ray flux from Cygnus X-1 as observed by the Exosat medium-energy experiment

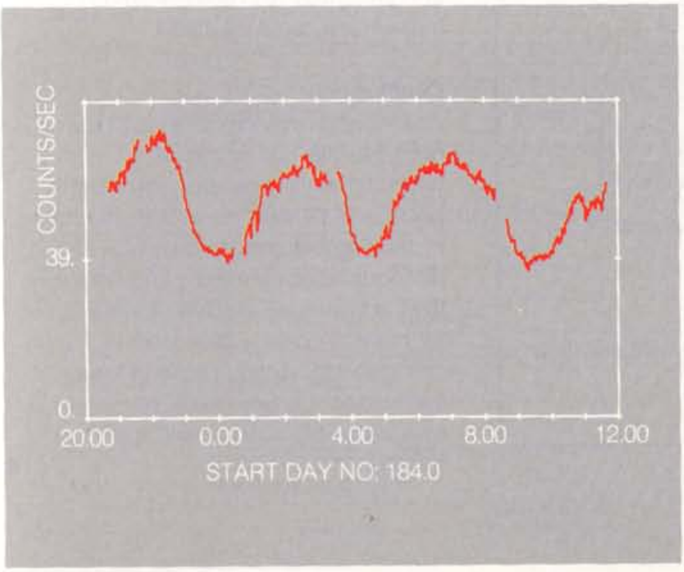


Figure 7 – Light curve of the binary X-ray source Cygnus X-3 as observed by the Exosat gas-scintillation spectrometer. Three binary cycles, each of 4.8 h, are shown

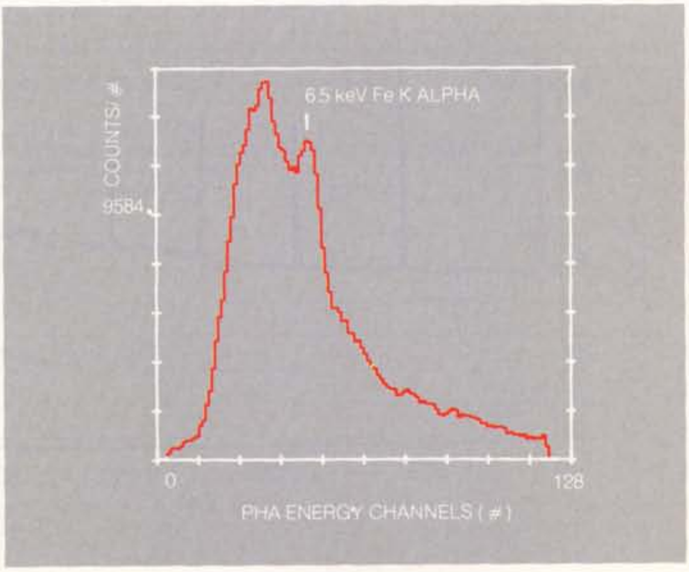


Figure 8 – Raw energy spectrum of the binary X-ray source Cygnus X-3 as observed by the Exosat gas-scintillation spectrometer

be a binary system, with a period of about 5 h, which probably contains a neutron star. The eccentric orbit of Exosat, with a period of about 90 h, and the sensitivity of the instruments is such that a continuous high-precision observation of the star over many binary cycles could be performed. Figure 7 shows the light curve for three binary cycles of the source. The system was observed continuously for a total of 30 h and the observations reveal a complex, highly structured light curve and spectra. The raw spectrum of the source at a particular binary phase, as observed by Exosat's gas-scintillation spectrometer, is shown in Figure 8. The strong emission feature around 6.5 keV results from the presence of iron. Detailed study of this emission feature at different binary phases is currently being undertaken to determine the conditions on the surface of the companion star, as well as in the region near the neutron star.

A number of X-ray sources also exhibit X-ray bursts, superimposed on a quasi-steady X-ray flux, which are believed to arise from a thermonuclear explosion on or near to the surface of the neutron star. Exosat has observed a number of these X-ray 'bursters' and studied their temporal and spectral characteristics in detail. One such burster, 2S1636-536, observed for

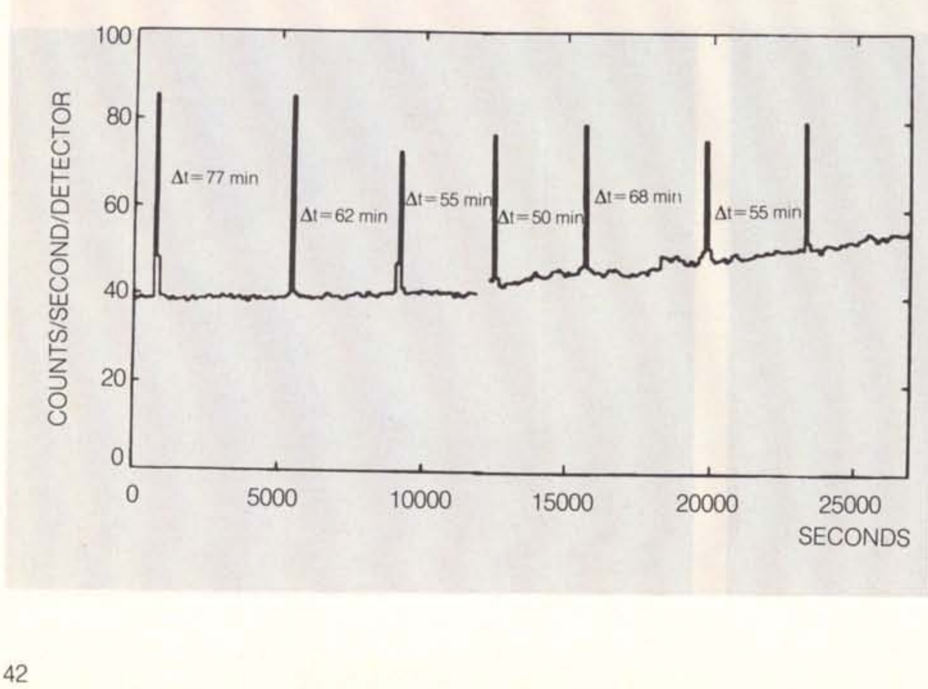


Figure 9 – X-ray bursts from 2S1636-536 as seen by Exosat's medium-energy experiment. Each burst represents a thermonuclear explosion close to the surface of the neutron star

Figure 10 – The Exosat Observatory at ESOC, in Darmstadt, Germany

about 7 h, is particularly intriguing. A dip in the X-ray spectrum observed during the evolution of the bursts may well be due to absorption due to iron in the overlying atmosphere of the neutron star, but now red-shifted from 8 keV to 4.5 keV by the neutron star's intense gravitational field. If this is so, the red shift enables the mass-to-radius ratio of the neutron star to be determined. The apparent red shift gives a radius of about 6 km for a neutron star about 1.4 times as massive as our own Sun. Figure 9 illustrates the time history of the bursts observed by Exosat's medium-energy experiment, the interval between thermonuclear explosions (Δt) being about 1 h.

A particularly important observation of a black hole candidate, V0332+53, was made by Exosat in November 1983. This source is a supposedly transient X-ray source that exhibits rapid black-hole-like flickering of the X-ray flux. However, the Exosat observations discovered stable pulsations with a period of about 4 s. Doppler variation in the pulse period was also observed and a binary orbital period of about 34 d discovered. This binary orbit is not circular, but elliptical, with the transient X-rays occurring when the compact object is closest to the companion. At other times, no X-rays are observed. The spectrum of the source was found to be typical of an accreting neutron star, rather than a black hole. Whilst the rapid X-ray flickering was also observed, the pulsations prove that the nature of the compact object is that of a neutron star.

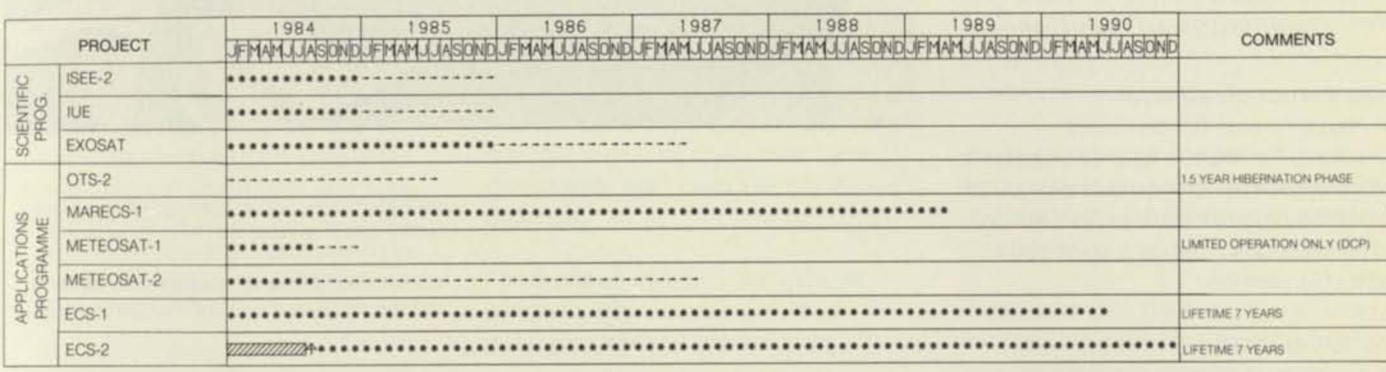
The major conclusion that can be drawn from the Exosat observations is that rapid flickering of the X-ray flux is not an exclusive property of black holes, but can occur in neutron stars, possibly due to instabilities in the star's magnetosphere. Proof of the existence of a black hole cannot therefore rest simply on the observed temporal characteristics of the X-ray flux, but must involve the spectrum, and preferably also determination of the mass of the compact object.

Conclusion

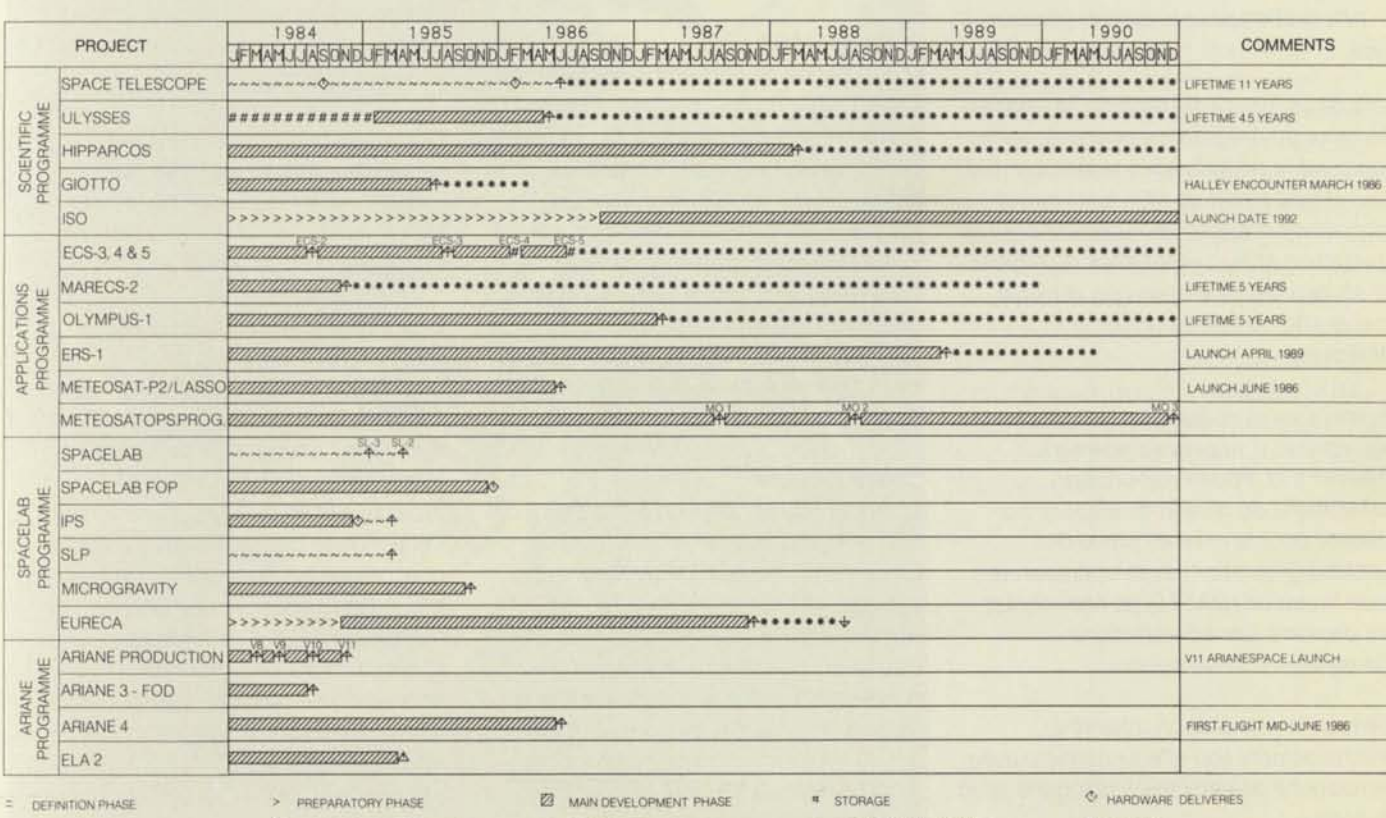
As Exosat moves into its second year of observations, further detailed measurements of neutron stars and black-hole candidates will be undertaken in an attempt to understand how to distinguish between them and determine their individual characteristics. In this way, we hope to come a little closer to comprehending the physics involved in such objects, where matter has been compressed to such an extraordinary degree.

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

In Orbit / En orbite



Under Development / En cours de réalisation



Météosat

Programme préopérationnel
Les missions ont été accomplies normalement par les satellites F1 et F2 dans les trois derniers mois. Il convient cependant de signaler une anomalie lors d'une opération de maintien à poste de F1. Les investigations sont en cours mais il semble d'ores et déjà que le problème soit dû à l'épuisement des réservoirs d'hydrazine, ce qui semble normal à l'issue de près de sept ans en orbite.

Le satellite P2, passager du premier vol Ariane-4/APEX, sera lancé en juin 1986 (date prévisionnelle) – l'expérience Lasso-B, qui sera installée sur P3, fait l'objet d'une proposition, dont les premiers éléments sont en cours d'évaluation.

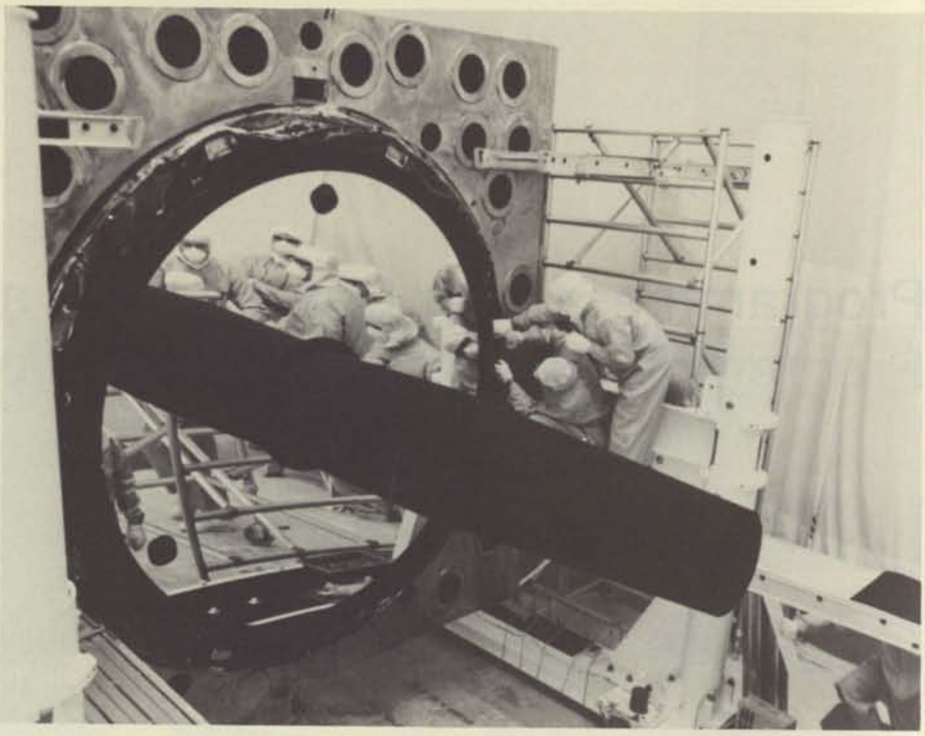
Programme opérationnel
Le deuxième membre de l'Unité Intérimaire Eumetsat a rejoint son poste le 1er juillet 1984. A noter qu'à la date du 31 août, trois pays ont ratifié la Convention Eumetsat et que l'Irlande a signé cette même Convention.

Segment spatial
Le programme se déroule suivant le calendrier avec notamment la tenue des dernières revues des sous-systèmes et les premières livraisons de composants aux utilisateurs. En conclusion de toutes les revues précédentes, une revue satellite est en préparation pour le dernier trimestre 1984.

Lors de sa quatrième réunion, le Conseil directeur du programme opérationnel a approuvé la période août-septembre 1987 pour le lancement de M01 ainsi que la proposition d'approvisionnement pour la production et la maintenance du logiciel de soutien des opérations du véhicule spatial pour la partie concernant Météosat.

Segment sol et opérations
Les activités d'approvisionnement relatives à la modernisation des installations du réseau de stations sol utilisées pour la mise en orbite des satellites géostationnaires opérationnels et de la station (DATTS) de Michelstadt ont demarré. Les consultations industrielles sont en cours.

L'équipe d'exploitation atteindra prochainement son effectif nominal avec l'embauche de deux météorologues et un ingénieur.



Installation of the Space Telescope primary mirror's central optical baffle, at the Perkin Elmer facility

Mise en place de l'écran optique central du miroir principal du Télescope spatial chez Perkin Elmer

Télescope spatial

Activités NASA
L'intégration de l'ensemble du Télescope optique est pratiquement terminée chez Perkin-Elmer et sa livraison à Lockheed, contractant chargé de l'intégration principale du Télescope spatial, est prévue pour novembre 1984. Par ailleurs, le matériel du Module des systèmes de soutien est en phase d'intégration et les essais de systèmes électriques ont commencé. Les activités se poursuivent conformément au calendrier qui prévoit un lancement à la mi-1986.

Réseau solaire
L'examen de conception préliminaire des nouvelles nappes de cellules à grand rendement s'est terminé de façon satisfaisante. On procède actuellement aux 'essais d'approbation de type' des photocellules et à la qualification d'échantillons des nouvelles nappes de cellules en faisant subir à ces derniers 30 000 cycles de fonctionnement entre −100°C et +100°C pour simuler cinq années d'opérations en orbite.

L'examen de recette pour le vol de l'électronique de commande du générateur solaire et des ensembles de diodes du modèle de vol s'est achevé de manière satisfaisante.

Chez BAe, contractant principal du générateur solaire, les travaux sur le mécanisme de déploiement secondaire sont ralentis, par suite de conflits du travail depuis la fin juillet.

Chambre à objets faibles (FOC)
L'étalonnage sous vide de la FOC a commencé au Centre spatial Goddard le 13 juillet. Après étalonnage de la chaîne à f/96 dans l'ultraviolet et de la chaîne à f/48 dans l'ultraviolet et le visible, on est repassé à la chaîne f/96 pour terminer l'étalonnage dans le visible. Peu après, la consommation de courant trop élevée a provoqué la coupure de l'alimentation haute tension de l'intensificateur. La raison n'en est pas encore connue. On envisage de remplacer le détecteur f/96 par l'unité de rechange disponible chez BAe. Les activités sont également ralenties par les conflits sociaux déjà mentionnés.

Meteosat

Preoperational programme

Over the past three months missions have been carried out according to plan by the F1 and F2 satellites, though mention must be made of a malfunction that occurred during a station-keeping operation on F1. Investigations are underway, though it already seems that the problem was due to depletion of the hydrazine stocks; this would be normal after nearly seven years in orbit.

The P2 satellite, as the passenger on the first Ariane-4 APEX flight, is planned to be launched in June 1986. The Lasso-B experiment, which will be placed on P2, is the subject of a proposal, the first elements of which are now being evaluated.

Operational programme

The second member of the Eumetsat Interim Unit took up his duties on 1 July 1984. It should be noted that, as of 31 August, three countries have ratified the Eumetsat Convention and that Ireland has signed it.

Space segment

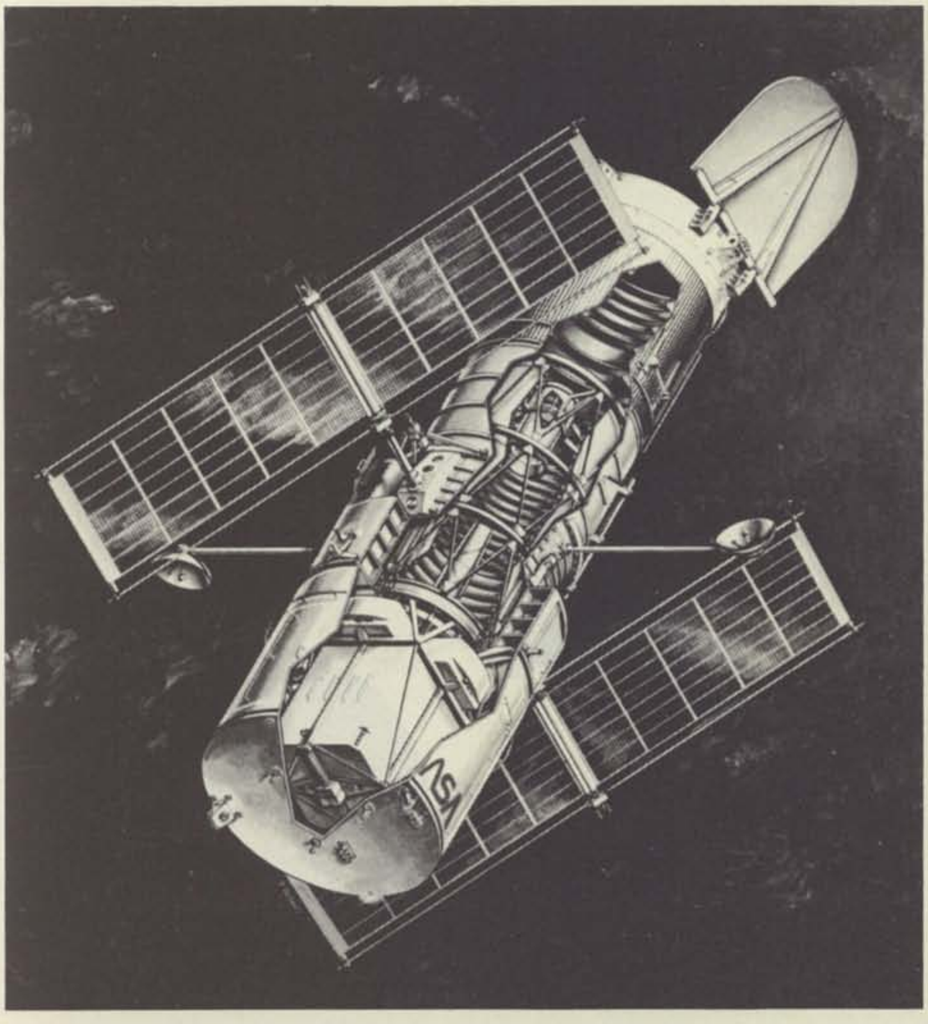
The programme is running on schedule, in particular as regards the holding of the final subsystem reviews and the first deliveries of components to users. A satellite review is being prepared for the last quarter of 1984, as a conclusion to all the previous reviews.

At its fourth meeting, the Operational Meteosat Programme Board approved the period of August-September 1987 for the launch of M01, together with the relevant part of the procurement proposal for production and maintenance of the software for supporting the spacecraft operations.

Ground segment and operations

The procurement activities relating to the updating of both the Michelstadt station (DATTS) and the ground station network facilities, used for placing the operational satellites in geostationary orbit, have started. Discussion with industry is underway.

The exploitation team will shortly be complete, with the addition of two meteorologists and one engineer.



Space Telescope

NASA activities

The integration of the optical telescope assembly has nearly been finalised at Perkin-Elmer and delivery to Lockheed, the Space Telescope main integration contractor, is foreseen for November 1984. Also the Support System Module hardware is in integration and electrical systems testing has started. Activities are proceeding on schedule for launching of the Space Telescope by mid-1986.

Solar array

The Preliminary Design Review for the new high-power blankets has been completed satisfactorily and cell type-approval testing and qualification of new blanket samples over 30 000 cycles (−100°C to +100°C) to simulate five years in orbit are under way.

The Flight Acceptance Reviews for the flight-model solar-array drive electronics and diode boxes have been completed satisfactorily.

Progress at BAe, the Prime Contractor for the solar array, on the secondary deployment mechanism, has been hindered by industrial disputes since the end of July.

Faint Object Camera

The calibration of the Faint Object Camera in vacuum was started at Goddard Space Flight Center on 13 July. After finalisation of the calibration of the f/96 chain in the ultraviolet and the f/48 chain in the ultraviolet and visible, the switchover to the f/96 chain for finalisation of the calibration in the visible was made. Shortly thereafter, the high-voltage supply of the intensifier section switched itself off because too high a current was drawn. The cause is not yet understood. It is planned to exchange the f/96 detector with the spare detector available at BAe. Again, however, progress has been hindered by the industrial disputes since the end of July.

Vue conceptuelle du Télescope spatial

Artist's impression of the Space Telescope

Ulysses

Les activités s'intensifient dans plusieurs domaines à moins de deux ans de la période prévue pour le lancement. En juin a eu lieu un examen officiel du planning des opérations, examen jugé satisfaisant par la Commission mixte ESA-NASA. Une réunion de l'équipe scientifique s'est également tenue, mettant désormais l'accent sur les opérations après lancement plutôt que sur la préparation du véhicule spatial. Cette réunion a été elle aussi couronnée de succès.

De l'autre côté de l'Atlantique, les choses ne traînent pas non plus, en particulier en ce qui concerne la conception et la construction de l'étage supérieur Centaur, destiné à placer la sonde sur sa trajectoire interplanétaire à partir de l'orbite de la Navette spatiale. Des réunions ont eu lieu au Centre spatial Kennedy dans le cadre des préparatifs de la campagne de lancement qui doit démarrer en janvier 1986.

Hipparcos

La mise au point définitive du contrat industriel de phase C/D est en bonne voie. Les questions en suspens ayant pour la plupart été résolues, il est prévu que l'Agence et le contractant principal seront en mesure de signer le contrat avant la fin de l'année.

A quelques exceptions près, tous les examens préliminaires de conception des équipements sont terminés et les travaux se poursuivent avec la fabrication du matériel destiné au modèle d'identification.

Les difficultés rencontrées par certains fournisseurs de la charge utile retardent la mise en route du 'Programme de soutien optique' qui a pour objet de vérifier le plus tôt possible si l'équipement de soutien optique au sol est adéquat, de contrôler les techniques d'essai et de mettre au point les procédures correspondantes. Des mesures sont prises pour éviter que le calendrier d'ensemble ne soit bouleversé.

Un 'essai de ballottement' effectué sur un modèle du satellite pour mesurer la constante de temps du mouvement divergent de nutation de l'axe de rotation dû à la dissipation d'énergie a confirmé le principe du système de commande d'orientation développé au cours de la phase B.

ISO

Vers fin juillet, l'Agence a lancé, auprès des milieux scientifiques des deux côtés de l'Atlantique, un appel aux propositions d'expériences à embarquer sur l'Observatoire spatial dans l'infrarouge (ISO). Les réponses sont attendues entre septembre 1984 et janvier 1985. Après évaluation de leur faisabilité et de leur valeur scientifique, on procèdera ensuite à la sélection de la charge utile complète avant de la faire approuver en juin 1985. Ceci permettra d'examiner en détail les incidences de la charge utile sur la conception du satellite avant d'entamer la phase B, qui interviendra environ un an plus tard.

Bien que les grands travaux industriels ne doivent pas commencer avant deux ans, un certain nombre d'actions sont déjà en cours. Suite au choix d'Aérospatiale (France) comme maître d'ouvre du projet, des négociations ont eu lieu en vue de former l'équipe de développement industriel. Ces négociations vont probablement se poursuivre jusqu'au début de l'année prochaine, époque où la majorité des sous-contractants auront été choisis. On sera ainsi en mesure d'établir les spécifications et autres documents nécessaires en prévision de la phase B. Un certain nombre d'études sur des domaines particuliers où l'aspect technologique entre en jeu sont également en train de démarrer ou en cours de préparation.

Nul doute que le satellite ISO — premier observatoire infrarouge de ce genre à être mis à la disposition de la communauté scientifique et successeur naturel du satellite IRAS dont on connaît le grand succès — suscite un vif intérêt chez les scientifiques aussi bien que chez les industriels.

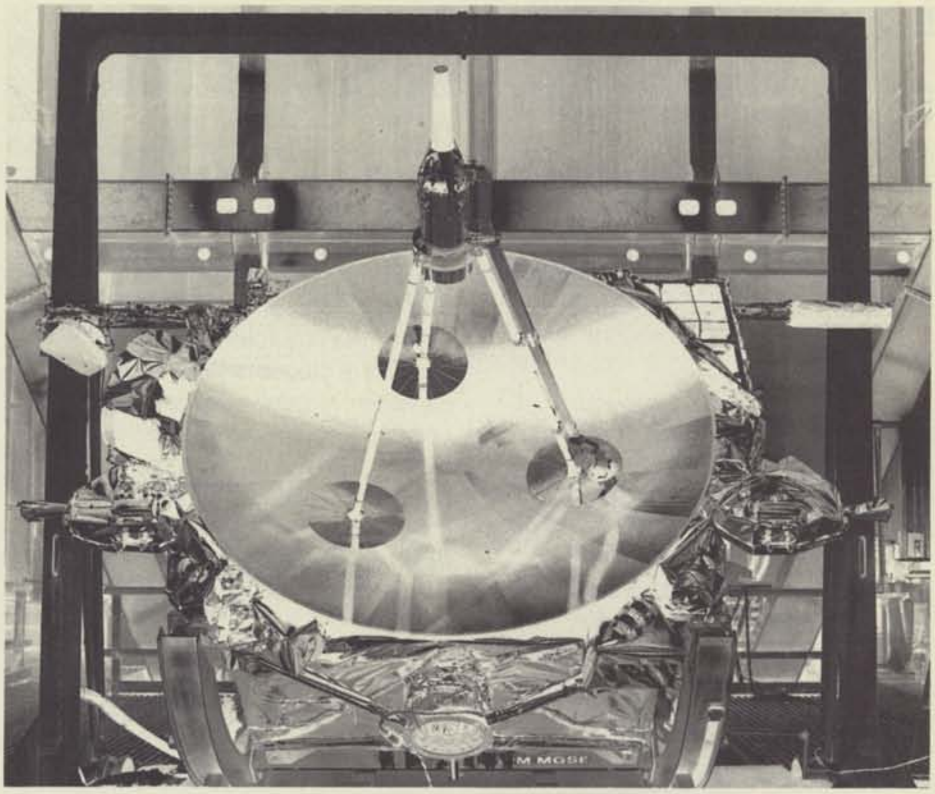
Artist's impression of the Infrared Space Observatory (ISO)

Vue conceptuelle de l'Observatoire spatial dans l'infrarouge (ISO)

Ulysses

Activity in several areas is increasing now that the launch period is less than two years away. During the month of June there was a formal Review of Mission Operations planning, which was determined by the joint ESA/NASA Board to be satisfactory. A meeting of the Science Working Team was also held, with the emphasis now turning to post-launch operations, rather than spacecraft preparations. This meeting was also very successful.

On the other side of the Atlantic, things are also moving rapidly, particularly with the design and building of the Centaur Upper Stage, which will inject the spacecraft onto its interplanetary trajectory from the Space Shuttle's orbit. Meetings have been held at Kennedy Space Center (KSC) as a part of the preparations for the launch campaign, scheduled to start in January 1986.



Modèle de vol d'Ulysses à l'ESTEC

Flight model of the 'Ulysses' spacecraft (formerly ISPM) at ESTEC

Hipparcos

Progress has been made towards finalisation of the industrial contract for Phase-C/D. The great majority of the relevant open points have now been settled and it is foreseen that the Agency and the Prime Contractor will be in a position to sign the contract before the end of the year.

With a few exceptions, all Preliminary Design Reviews at equipment level have now been concluded, and work is proceeding with the manufacturing of the engineering-model hardware.

Difficulties experienced by some of the payload suppliers are causing a delay in the start of the 'Optical Support Programme' intended to verify, at an early stage, the adequacy of the optical ground-support equipment and the relevant test methods, and to develop the related procedures. Recovery actions are in hand to prevent perturbations to the overall schedule.

A 'sloshing test' carried out on a model of the spacecraft to measure the time constant of the spin-axis-nutation divergent motion due to energy dissipation has confirmed the validity of the attitude-control-system baseline developed during Phase-B.

ISO

Towards the end of July, the Infrared Space Observatory (ISO) project issued the 'Call for Experiment Proposals', inviting the scientific communities of both Europe and the USA to submit ideas for the experimental payload for this satellite. The initial responses are due by mid-September and the final submissions by January of next year. They will then be scrutinised for feasibility and for scientific merit with the objective of having the complete payload selected and approved by June of the same year. This will permit a thorough examination of its impact upon the satellite design prior to the start of Phase-B, about one year later.

Although the major industrial activity does not start until two years from now, a number of actions are already under way. Following the decision that Aerospatiale (France) should be the Prime Contractor for this project, there have been a number of discussions aimed at forming the industrial development team. These discussions will, it is estimated, continue into the early part of next year, by which time the majority of the subcontractors will have been selected. Again, this will permit adequate preparation of specifications, etc. before Phase-B. A number of studies on selected topics where new technology is involved are also being started or are in preparation at the present time.

ISO, the first infrared observatory to be made generally available to the scientific community, and the natural successor to the highly successful IRAS satellite, is creating much interest in both the scientific and industrial communities.

ECS

ECS-2, launched from Kourou, French Guiana, by Ariane 3 on 4 August 1984, was injected into a circular drift orbit by its MAGE-2 Apogee Boost Motor on 6 August, and has now achieved its prescribed geostationary test location (10°E) in a stable three-axes controlled, Earth-pointing configuration.

Spacecraft control, handled by ESOC in the early phases, was handed over on 24 August to the dedicated ECS Control Station at Redu, Belgium.

All operations were nominal, and the whole sequence of events – launch

ECS

ECS-2, lancé de Kourou par Ariane 3 le 4 août 1984, a été placé le 6 août sur orbite de dérive circulaire par son moteur d'apogée MAGE-2; le satellite, en configuration de pointage géocentrique et stabilisée selon 3 axes, a maintenant atteint la position qu'il doit occuper sur l'orbite des satellites géostationnaires (10°E) pour les essais.

La commande du véhicule spatial, assurée dans les premières phases par l'ESOC, a été transférée le 24 août à la station de contrôle de Redu (Belgique) spécialement affectée à ECS.

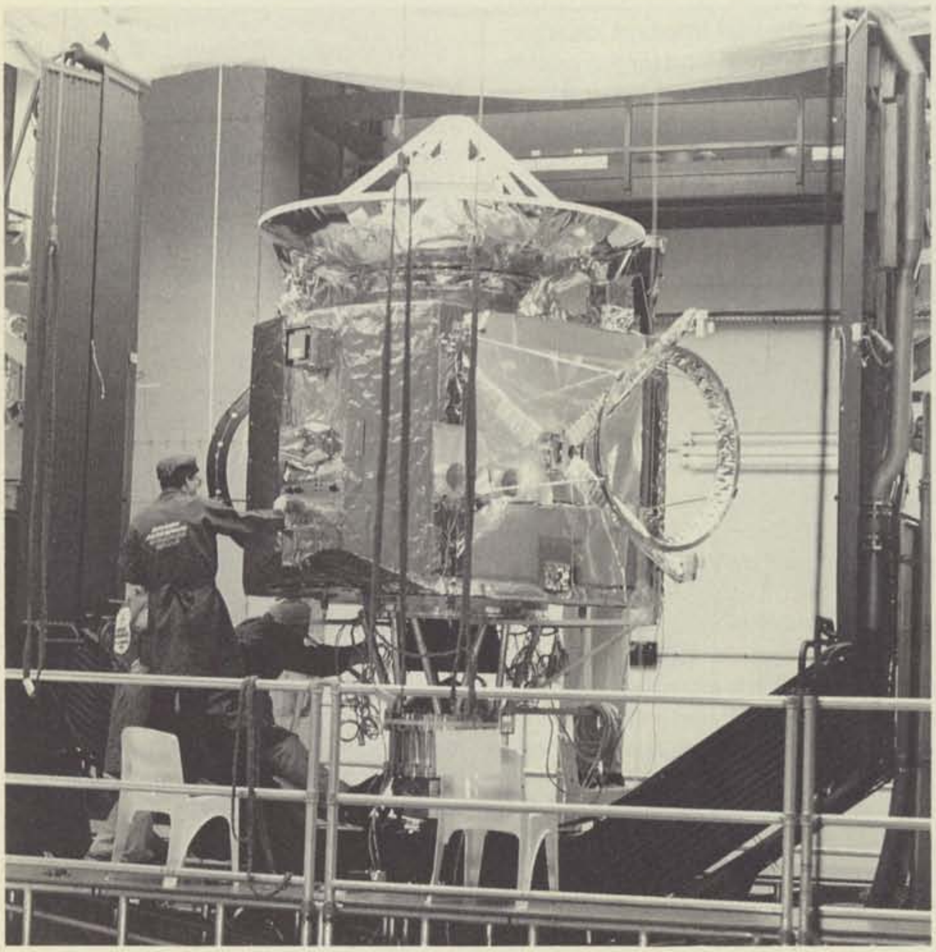
Toutes les opérations se sont déroulées de façon nominale et la séquence complète d'événements — préparatifs de lancement, lancement, mise sur orbite circulaire, acquisition solaire et terrestre et dérive jusqu'au poste prévu — se sont parfaitement déroulées.

Au cours de la mise en service qui a occupé les cinq premiers jours après l'arrivée à poste, les quatorze chaînes de répéteurs, unités redondantes comprises, ont été commutées pour de courtes périodes, leurs caractéristiques essentielles ont été vérifiées et se sont avérées conformes aux prévisions. La phase d'essais de recette a commencé le 30 août et doit se terminer fin septembre. Au cours de cette phase, le satellite est soumis à une série de mesures précises destinées à vérifier que ses performances sont conformes aux spécifications. Toutes les mesures effectuées à ce jour confirment que les performances dépassent largement les spécifications. Lorsque cette phase aura été menée à bien, le satellite sera remis officiellement aux mains d'Eutelsat le 12 octobre. Il sera ensuite amené à sa position opérationnelle définitive, à 7°E sur l'orbite des satellites géostationnaires.

ECS-1 continue à bien fonctionner et est essentiellement utilisé pour la diffusion de programmes télévisés. Avec deux véhicules spatiaux en orbite, le système, tel qu'il a été initialement conçu, est complet. Toutefois, la demande de canaux est telle qu'il est très probable qu'un troisième ECS soit lancé courant 1985.

Ariane-3 ready for lift-off from ESA's Kourou launch base

Ariane-3 prêt au décollage sur l'aire de lancement de l'Agence à Kourou



Marecs

Marecs-A continue d'assurer à Inmarsat un service d'excellente qualité au-dessus de la région de l'océan Atlantique et, selon cette organisation, il a contribué de façon non négligeable à la croissance de 40% du trafic télex et de 70% du trafic téléphonique entre 1983 et 1984.

Marecs-B2 a été expédié à Kourou pour la campagne qui doit aboutir à son lancement par Ariane le 9 novembre 1984. Le satellite, qui sera placé au-dessus de l'océan Pacifique (à 177,5° de longitude Est), améliorera de façon notable les services d'Inmarsat dans cette région.

Marecs-2 at Intesat in Toulouse during pre-launch testing

Marecs-2 chez Intesat à Toulouse lors des essais précédant le lancement preparation, launch, injection into circular orbit, Sun and Earth acquisition and drift to the prescribed station – went notably smoothly.

During the commissioning phase, which extended over the first five days following arrival on station, all fourteen repeater chains, including redundant units, were briefly switched on, and their most important characteristics checked and found to meet expectations. The acceptance test phase started on 30 August and is scheduled for completion by the end of September. During this period, the satellite is being submitted to a series of accurate measurements aimed at verifying that performance conforms to specifications. All measurements so far confirm that performances exceed specifications by comfortable margins.

Upon successful completion of this phase, the satellite will be available for official take-over by Eutelsat, scheduled for 12 October. It will subsequently be shifted to its final operational position at 7°E on the geostationary orbit (see page 76 of this issue for latest information).

ECS-1 continues to work well and is used principally for TV distribution. With two spacecraft in orbit, the system as originally envisaged is complete. There is, however, such a demand for channels that there is a very high probability that a third ECS will be launched during 1985.

Marecs

Marecs-A has continued to give Inmarsat excellent service over the Atlantic Ocean Region and has contributed in no small part to the growth reported by Inmarsat of 40% for telex traffic and 70% for telephone traffic between 1983 and 1984.

Marecs-B2 has been shipped to the Ariane launch site in Kourou, French Guiana for the campaign leading up to its scheduled launch on 9 November 1984. It will be placed above the Pacific Ocean Region (177.5°E) and will considerably enhance Inmarsat's services in this region.

Phase-1 of the Prosat programme, involving the initial development of small mobile terminals for land, maritime and aeronautical applications and an experimental programme of tests using the excess capacity of Marecs-A, has been progressing satisfactorily and is now nearing completion. Phase-2 has now been approved. This involves building on the experience gained during Phase-1, further development and procurement of a significant number of small mobile terminals, which will then be used in trial systems for evaluation of performance and demonstration of capabilities to potential users and system providers.

Olympus

Following the completion of equipment- and subsystem-level Development Baseline Reviews (DBRs), the first part of the system level DBR has been held between the Prime Contractor and ESA. This review concentrated mainly on the platform subsystems, and the contractors involved are acting upon the Review Board's recommendations. A special working group has been addressing the payload analysis area since July and, subject to the completion of their work, the Review is expected to be concluded in early November.

Following successful completion of the static testing of the structural model, the spacecraft has been dismantled into its constituent modules. These are being fitted with equipment mass dummies, prior to reassembly for modal-survey and dynamic testing early next year.

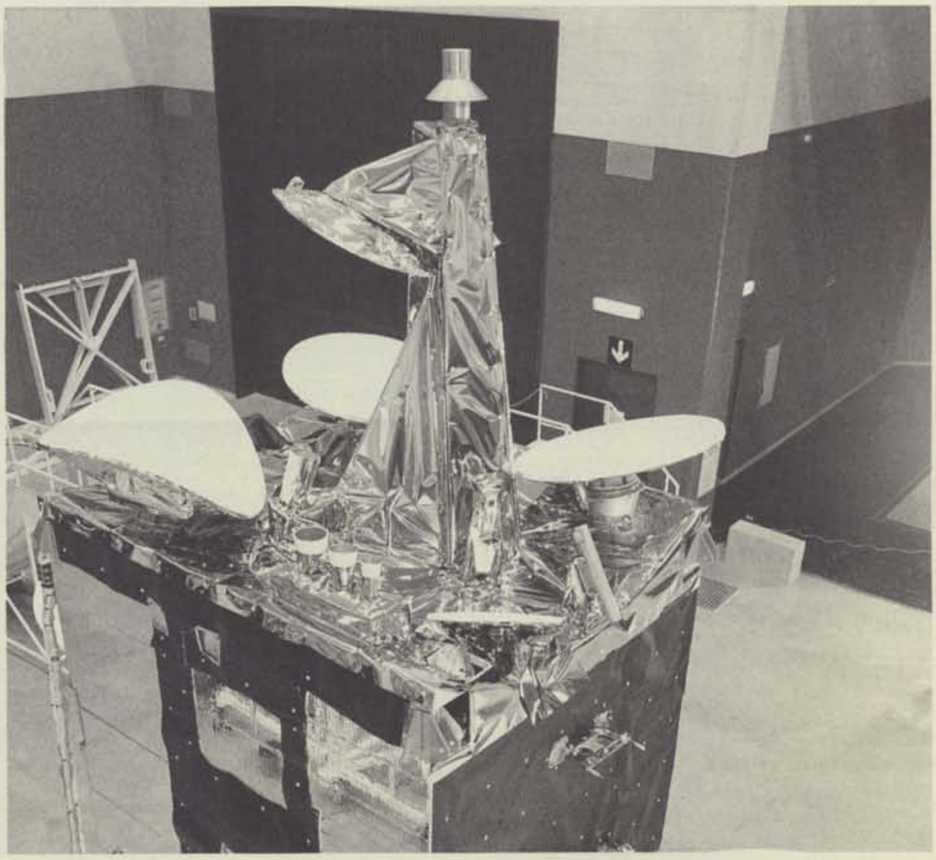
The thermal model-spacecraft is progressing well and integration is nearing completion, with only a few blankets remaining to be fitted. Solar-simulation testing will commence in mid-October and continue for about two months.

Integration of the payload engineering-model equipment onto the communications-module panels is proceeding. Some subsystem-level testing of the platform subsystems has also been completed, but progress on most subsystems is constrained by the absence of key equipment.

Requests for Procurement (RFPs) for ground-station equipment are being issued, and more will be issued between now and early next year.

Module d'antenne du modèle mécanique d'Olympus en cours d'intégration chez Aeritalia à Turin

Antenna module of the structural model of Olympus during integration at Aeritalia in Turin



La phase 1 du programme Prosat, qui comprend les premières phases du développement de petits terminaux mobiles pour les applications terrestres, maritimes et aéronautiques, et un programme expérimental d'essais pour lequel la capacité excédentaire de Marecs-A est utilisée, avance de façon satisfaisante et est près d'être achevée. La phase 2 est maintenant approuvée. Elle prévoit, sur la base de l'expérience acquise au cours de la phase 1, la suite des activités de développement et l'achat d'un nombre important de petits terminaux mobiles qui seront par la suite utilisés dans des systèmes expérimentaux pour évaluer les performances des terminaux et en démontrer les possibilités aux utilisateurs potentiels et aux fournisseurs des systèmes.

Olympus

Après l'achèvement des examens consacrés aux bases de référence du développement (DBR) au niveau équipement et sous-système, le contractant principal et l'ESA ont procédé à la première partie du DBR au niveau système. L'examen a essentiellement porté sur les sous-systèmes de la plate-forme et les contractants intéressés donnent actuellement suite aux recommandations de la commission d'examen. Un groupe de travail spécial procède à l'analyse de la charge utile depuis juillet et, sous réserve de l'achèvement de ces travaux, l'examen devrait être clos début novembre.

Les essais statiques du modèle mécanique ayant été menés à bien, le véhicule spatial a été démonté en ses modules constitutifs. Des masses fictives correspondant aux équipements sont en cours d'installation sur ces modules, avant que ceux-ci ne soient remontés pour les essais de recherche des modes propres et les essais dynamiques au début de l'an prochain.

Les travaux progressent de façon satisfaisante sur le modèle thermique du véhicule spatial dont l'intégration approche de son terme: il ne reste plus que quelques revêtements à mettre en place. Les essais de simulation solaire commenceront à la mi-octobre pour se poursuivre pendant environ deux mois.

Les équipements du modèle d'identification de la charge utile sont en cours d'intégration sur les panneaux du module de télécommunications. Certains essais au niveau des sous-systèmes de la plate-forme ont également été achevés mais l'absence d'équipements clés empêche d'avancer pour la plupart des sous-systèmes.

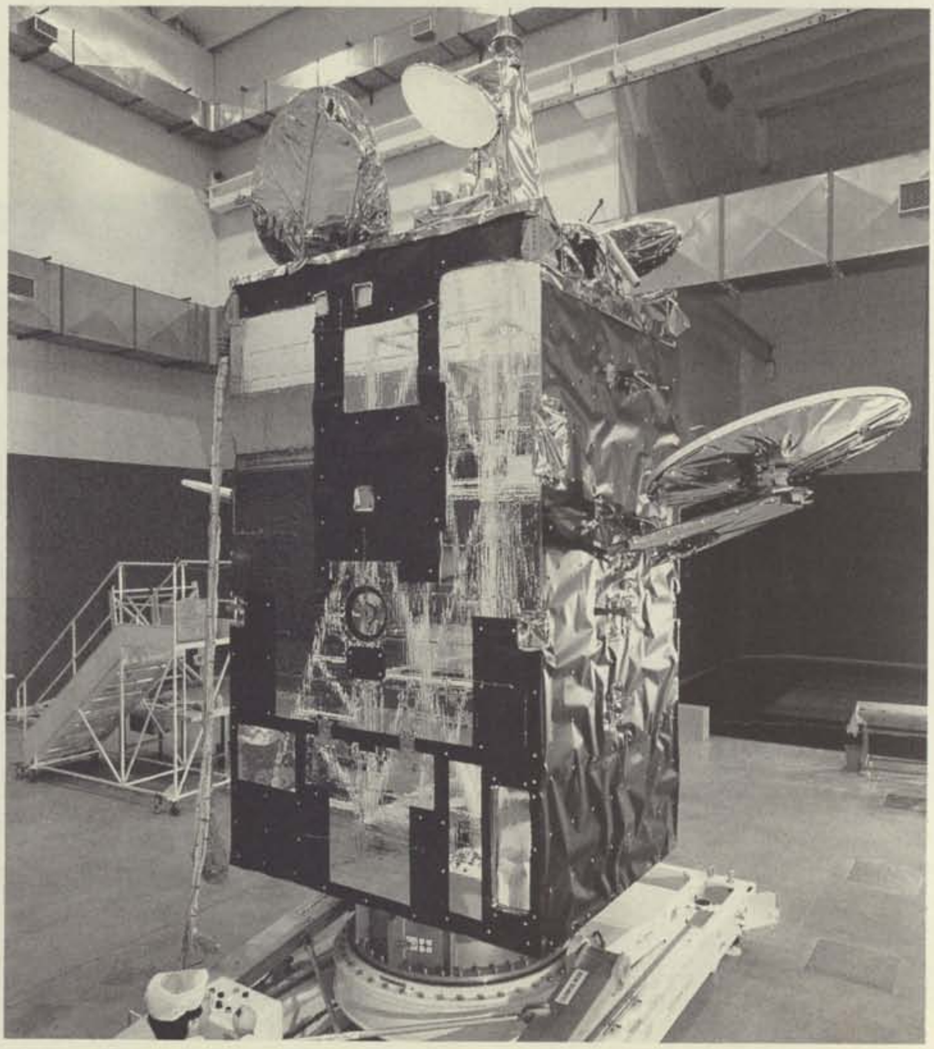
Des demandes d'approvisionnement sont lancées pour des équipements de stations sol, d'autres le seront d'ici au début de l'an prochain.

Spacelab

Les lancements de Spacelab-3 et Spacelab-2 sont maintenant prévus respectivement pour janvier et avril 1985. En août, les essais portant sur le déroulement de la mission ont été effectués avec satisfaction sur la configuration complète de Spacelab-3. Ce dernier va maintenant être mis en sommeil pendant deux mois, en attendant la mise en condition des organes propulsifs pour les essais de dégazage des produits toxiques et l'aménagement du matériel d'expérience; après quoi il sera prêt à quitter l'Ensemble de préparation de l'Etage orbital.

L'intégration de Spacelab-2 (sans le système de pointage d'instruments) progresse à grands pas. Les essais au niveau sous-systèmes sont terminés et les appareillages de vérification sont installés. La configuration de vol devrait quitter le niveau IV pour le niveau III/II en septembre 1984.

Les calendriers d'integration et de vérification au Centre spatial Kennedy visent toujours un lancement en avril 1985.



Structural model of Olympus during integration at Aeritalia in Turin

Modèle mécanique d'Olympus en cours d'intégration chez Aeritalia à Turin

Spacelab

The present flight dates for Spacelab-3 and Spacelab-2 are January 1985 and April 1985, respectively. The Mission Sequence Test was satisfactorily performed on the completed Spacelab-3 configuration in August. It will now go into a 'dwell' period for two months prior to powering up for the toxic outgassing test and experiment preparations in readiness for the roll-out from the Orbiter Processing Facility in November 1984.

The integration of Spacelab-2 (without IPS) is progressing very well. The subsystem testing has been completed and the Verification Flight Instrumentation (VFI) installed. It is anticipated that the flight configuration will be moved from the Level-IV to the Level-III/II stands in September 1984.

The integration and checkout schedules at Kennedy Space Flight Center (KSC) still have a launch-date goal of April 1985.

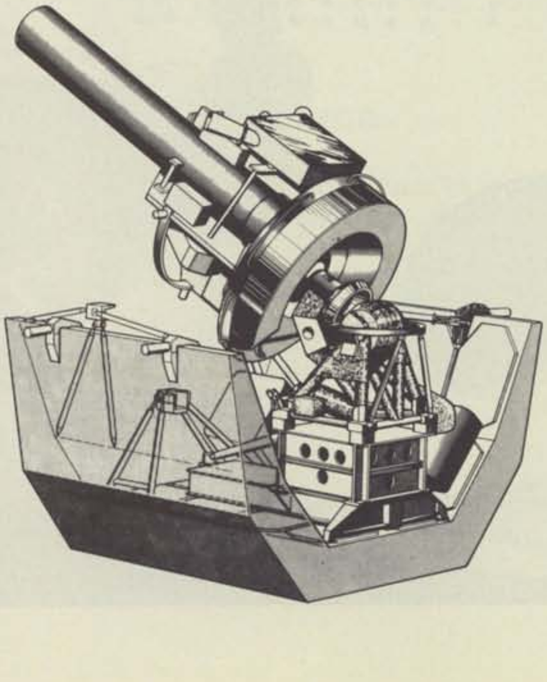
Follow-on Production (FOP)
System-level testing has been completed successfully on both the Igloo/1-Pallet and the Short-Core-Module configurations. Some failures were experienced which slightly affected the completion date of the tests. Technical solutions have been found in all cases except one, which relates to performance verification of the computer I/O unit interface, where nonconformances had been noted that could not be reproduced at unit level. Further failure investigations are in progress utilising the engineering-model Igloo and the Electrical Ground-Support Equipment (EGSE) station.

Final customer acceptances were performed, by joint teams from ESA and NASA, for the Igloo/1-Pallet hardware during the first week of June 1984 and for the Short Core Module in the last week of July. These acceptances went very smoothly due to thorough preparation by the Prime Contractor MBB/ERNO.

A NASA-chartered C5A aircraft took the Igloo, one Pallet, the Short Core Module, the Experiment Segment and some smaller hardware items from Hannover Airport to Kennedy Space Center on 9/10 August 1984. This shipment constituted a major milestone in the Follow-on Production Contract, in that it completes, in essence, the delivery of the 'second Spacelab', the contracts for which were concluded between NASA, ESA and the Spacelab Consortium in January 1980.

As further hardware procurements and other services have been added to the existing contract, deliveries are presently scheduled through 1985. Recent contract change negotiations added approximately 4 Million Accounting Units (1979 price basis) worth of hardware and services to the Spacelab FOP Contract.

The progress of the FOP Instrument Pointing System (IPS) is not satisfactory, two delays in delivery date having been announced within two months. Compared with the contractual date of 31 December 1984, delivery was initially slipped by 5 weeks, followed by a further delay of 12 weeks. The projected delivery is now 30 April 1985. Detailed schedule analysis performed by ESA has shown that 70% of the delay is attributable to failure experienced on either Phase-C/D or FOP hardware, and 30% to the utilisation of FOP hardware in support of the Phase-C/D programme test schedule. Schedule recovery actions have been attempted, but have little consequence whilst the Phase-C/D IPS delivery is not complete.



Le Système de pointage d'instruments du Spacelab

The Spacelab Instrument Pointing System

IPS

In the period from June to August 1984, ESA/NASA have conducted the final design qualification review and final acceptance review at Dornier for the IPS main delivery in support of the Spacelab-2 mission. A number of design problems and some areas of design verification were, however, found unacceptable for the issue of a formal certification or a consent to ship. The major problems are as follows:

- The optical sensors are not adequately protected in the event of power loss and generate false counting and tracking information for certain star configurations.
- The gyro package could not be qualified and a flight model made ready in time for system acceptance testing because of several EEE-parts failures and a marginal design in the telemetry system. The gyro package requires model-specific adaptation of system software.
- The software for flight and operational checkout had not yet been made fully compatible with the hardware.

With respect to design verification, the tasks of:

- evaluation of IPS control loop stability and pointing performance
- demonstration of thermal-control adequacy for the drive units
- repetition of software qualification tests for coverage of design changes as a result of earlier failures,

could not be completed until August 1984.

Production ultérieure du Spacelab (FOP)
Les essais au niveau système ont été menés à bonne fin sur les deux configurations 'igloo/1 porte-instruments' et 'module de base court'. Les quelques défaillances enregistrées ont eu peu d'incidences sur la date d'achèvement des essais. Des solutions techniques ont été trouvées dans tous les cas, à la seule exception de la vérification des caractéristiques de fonctionnement de l'interface de l'unité d'entrée-sortie et du calculateur, pour laquelle les non-conformités observées n'ont pu être reproduites au niveau unité. L'étude de cette défaillance se poursuit sur le modèle d'identification de l'igloo et avec la station EGSE (Equipement électrique de soutien au sol).

Les représentants de l'ESA et de la NASA ont procédé conjointement à la recette définitive de l'ensemble igloo/1 porte-instruments durant la première semaine de juillet et du module de base court pendant la dernière semaine de juillet. Ces opérations de recette se sont déroulées sans aucun problème grâce à la qualité de leur préparation par le contractant principal MBB/ERNO.

Un C5A affrété par la NASA a chargé à l'aéroport de Hanovre (RFA) l'igloo, le porte-instruments, le module de base court, la section 'expériences' et quelques matériels de moindre volume pour les transporter au Centre spatial Kennedy les 9 et 10 août 1984. Ce transport représente une étape majeure du contrat de production ultérieure dans la mesure où il termine pour l'essentiel la livraison du 'deuxième Spacelab' dont les contrats avaient été signés entre la NASA, l'ESA et le Consortium Spacelab en janvier 1980.

Des approvisionnements en matériels supplémentaires et d'autres services ayant été ajoutés au contrat existant, des livraisons restent prévues jusqu'en 1985 compris. Les modifications du contrat récemment négociées représentent environ 4 MUC (au niveau des prix de 1979) de matériels et de services qui viennent s'ajouter au contrat Spacelab FOP.

La progression des travaux sur le sous-système de pointage d'instruments (IPS) ne donne pas satisfaction, deux reports de la date de livraison ayant été annoncés en moins de deux mois. Par rapport à la date contractuelle du 31 décembre 1984, la date de livraison a glissé une première fois de 5 semaines, puis à nouveau de 12 semaines. La livraison est désormais prévue pour le 30 avril 1985. L'analyse détaillée du calendrier faite par l'ESA a montré que ce retard devait être attribué pour 70% à des défaillances présentées par des matériels de la phase C/D du FOP, et pour 30% à l'utilisation de matériels FOP en soutien du programme des essais de la phase C/D. Des tentatives de rattrapage du calendrier ont bien été faites mais restent pratiquement sans effet tant que la livraison de l'IPS de phase C/D n'est pas achevée.

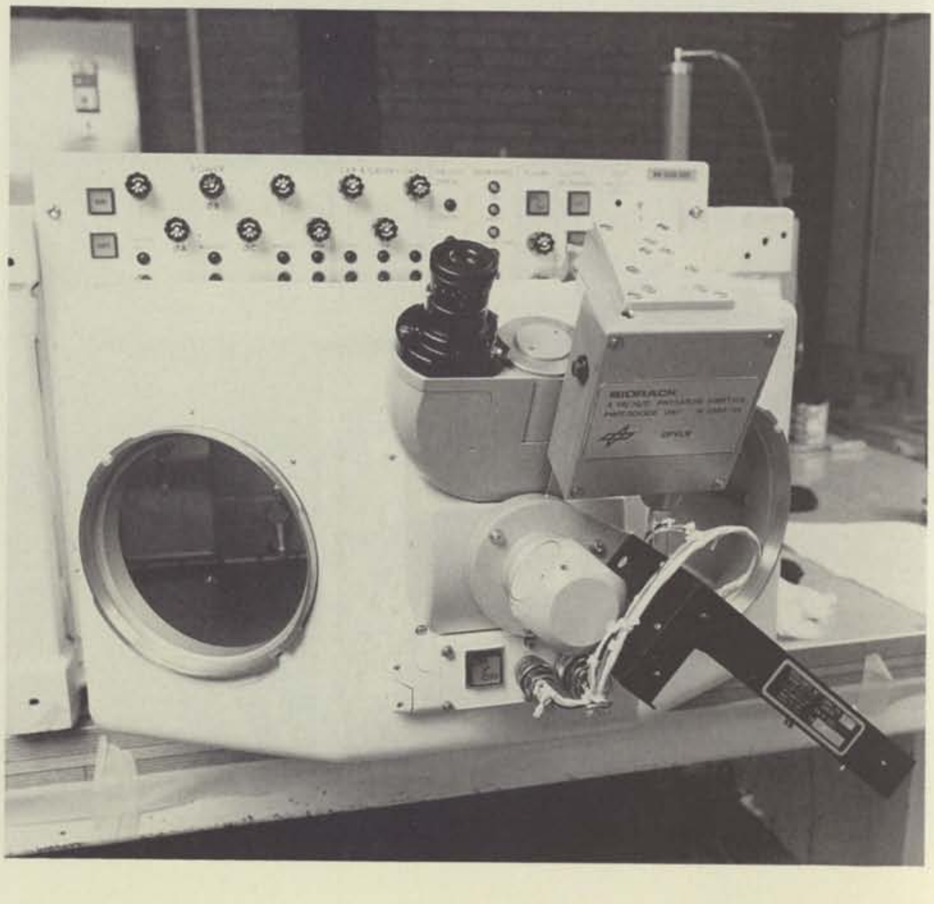
Microgravité

Biorack
Les principales activités de la période écoulée ont porté sur les points suivants:
- *avancement de la fabrication et du montage des équipements thermiques (incubateurs, réfrigérateur/congélateur et enceintes thermiques passives);*
- *livraison de la boîte à gants en vue de son intégration dans le Biorack;*
- *pré-intégration mécanique des unités thermiques;*
- *présentation de l'installation et des expériences à l'équipage du Spacelab D-1;*
- *actualisation des impératifs et du plan de soutien de la mission.*

L'intégration et les essais des équipements thermiques du Biorack (incubateurs, réfrigérateur/congélateur et enceintes thermiques passives) progressent. Les difficultés rencontrées pour l'électronique de commande des unités actives et la fabrication des enceintes thermiques passives ont été réglées, non sans avoir retardé l'achèvement des essais au niveau unité. En vue de rattraper une partie au moins de ce retard, deux équipes d'intégration ont été mises sur pied chez le contractant, l'une pour faire avancer les essais de recette des unités, l'autre pour mettre en route les activités d'assemblage, d'intégration et d'essais (établissement des procédures, pré-intégration mécanique etc...). La boîte à gants et le câblage ont été livrés et sont en cours d'intégration.

Front view of the Biorack Glovebox Training Model with the gloves removed (from the circular holes) and the microscope cine-camera assembly installed

Vue avant du modèle de familiarisation de la boîte à gants du Biorack, ensemble microcinématographique en place, avec les ronds prévus pour les gants



For the acceptance review of the deliverable articles, some Acceptance Data Packages and some deliverable documents (typically operations manuals for hardware and software) were not complete.

The Spacelab/IPS managements of ESA/NASA/DS therefore decided to reschedule a final review period and the Board sessions for formal qualification, certification and acceptance in November and December 1984. The delay in IPS delivery to December will probably not permit NASA to conduct the Spacelab-2/IPS mission in April 1985 as scheduled. The main reason is the lateness of mature IPS software, because NASA requires a fixed time for incorporating this IPS software into the mission software of the complete configuration. Software delivery by the end of July 1984 would have been satisfactory, but at that time the software was still untested at Dornier. NASA is presently replanning the Spacelab-2 launch, but a revised date is not yet agreed.

Microgravity

Biorack

The main activities during the reporting period were:
- progress in the manufacture and assembly of the thermal units (incubators, cooler/freezer and passive cannisters)
- delivery of the glovebox for integration into the Biorack facility
- mechanical pre-integration of the thermal units
- demonstration of the facility and experiments to the Spacelab D-1 crew
- updating of the mission-support requirements and plan.

The integration and testing of the Biorack thermal units (Incubators, Cooler/Freezer and Passive Canisters) is in progress. The problems encountered with the control electronics of the active units and the manufacture of the Passive Canisters have been resolved, but they have delayed the completion of unit-level testing.

To recover this delay, at least partially, two integration teams were set up at the contractor, one to progress the acceptance testing of the units, the other to initiate the integrated Biorack AIT activities (i.e. preparation of procedures, mechanical pre-integration, etc.). The glovebox and the harness have been delivered and their integration into the Biorack facility is in progress.

A demonstration of the Biorack facility and Biorack experiments to the Spacelab D-1 crew has been conducted at DFVLR-Porz Wahn (Simulation and Training Area) and at the experimenters' laboratories, respectively.

Coordination meetings have been held with the D-1 mission authorities to investigate possible means for accommodating the late delivery date of the Biorack.

Eureca

The final payload composition for the first Eureca flight, as recommended to the Programme Board by the Payload Working Group, is summarised in the accompanying table. A total of 90 experiments will be conducted by the 25 Principal Investigators.

The Botany Facility has been deferred to a future Eureca flight, for cost reasons, but the Cosmic Dust Collector experiment (UK) may still be added to the payload complement.

The offer from Industry for the development of the Eureca system has been evaluated by ESA and final negotiations are in progress. Subject to formal authorisation by the Spacelab Programme Board (PB-SL) and ESA's Industrial Policy Committee (IPC) Phase C/D is scheduled to start this November.

The launch readiness date for the integrated Eureca system has been brought forward by two months and is now 38 months from the start of Phase C/D.

Table 1 — Major characteristics of the payload complement for the first Eureca mission

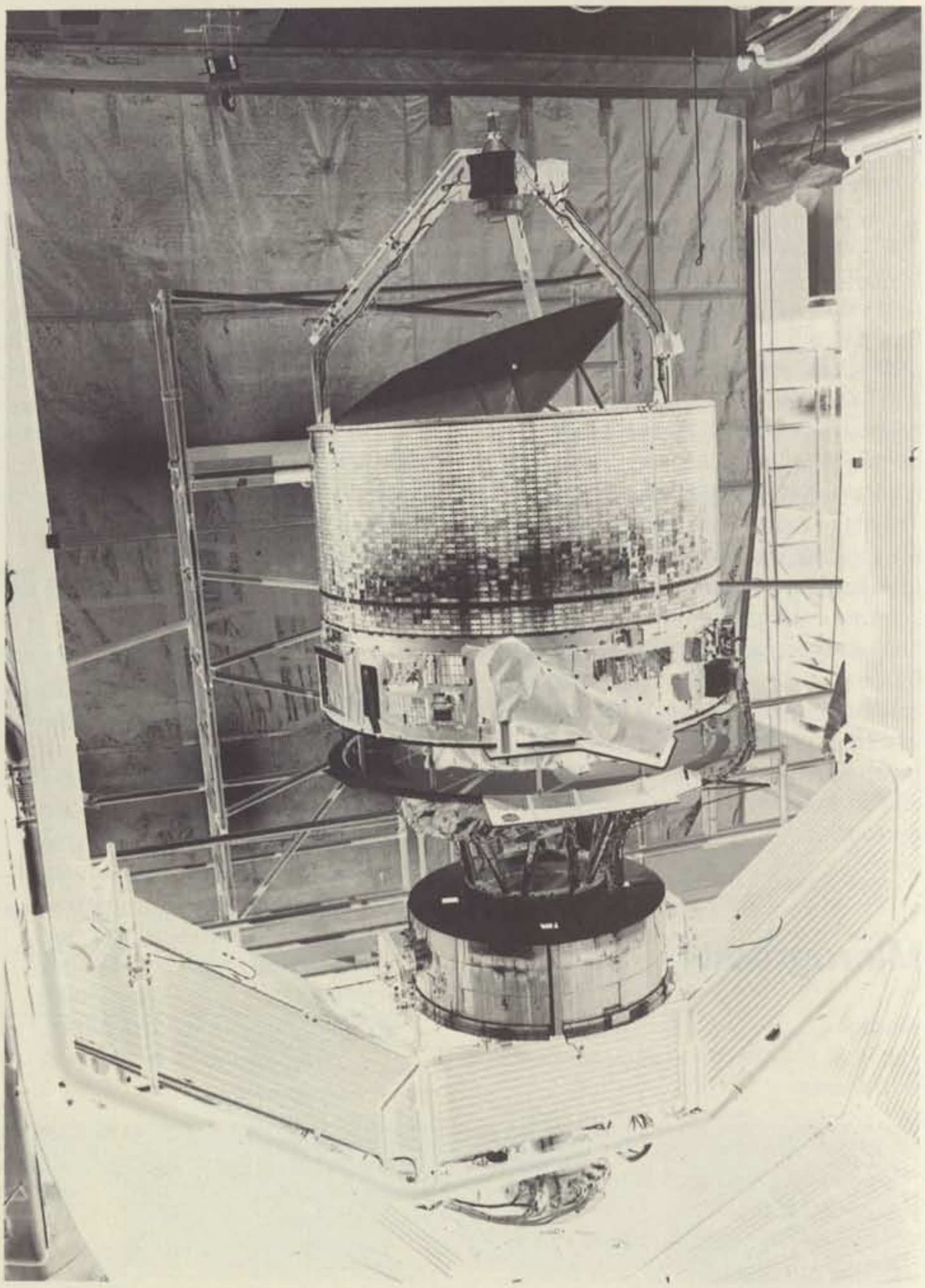
Payload designation	No. PIs/ samples	Origin of experiments
Automatic Mirror Furnace	7/23	D, F
Solution Growth Facility	3/4	DK, D, B
Protein Crystallisation Facility	5/12	D, CH, NL, UK
Multi-Furnace Assembly	5/12	F, D, I
Exobiological Radiation Assembly	5/30	D
High Precision Thermostat	2	D
Surface Furnace Adhesion	1	I
Solar Spectrum Experiment	1	F
Solar Variation Experiment	1	B
Occultation Radiometer	1	B/UK
Wide Angle Telescope for Cosmic and Hard X-rays	1	DK
Radio Frequency Ion Thruster Assembly	1	D
Inter-Orbit Communication	1	F, UK, SP
Gallium Arsenite Solar Cell Calibration	1	I

Ariane

See pages 72 and 76 for further details of the ECS-2 and Telecom-1 launch.

The Giotto spacecraft (flight model), photographed at Intesat in Toulouse

Modèle de vol de la sonde spatiale Giotto (photo prise chez Intesat à Toulouse)



Le fonctionnement du Biorack et des expériences qui lui sont associées a été présenté à l'équipage du Spacelab D-1, à la DFVLR-Porz Wahn (Zone de simulation et de formation) pour le premier et dans les laboratoires des expérimentateurs pour les secondes.

Des réunions de coordination ont été organisées avec les autorités responsables de la mission D-1 pour rechercher les moyens de remédier à la date de livraison tardive du Biorack.

Eureca

La composition finale de la première charge utile de vol d'Eureca – telle que recommandée par le Groupe de travail mis sur pied par le Conseil directeur de programme – est résumée dans le tableau (page 53). Un total de 90 expériences seront menées par 25 chercheurs principaux.

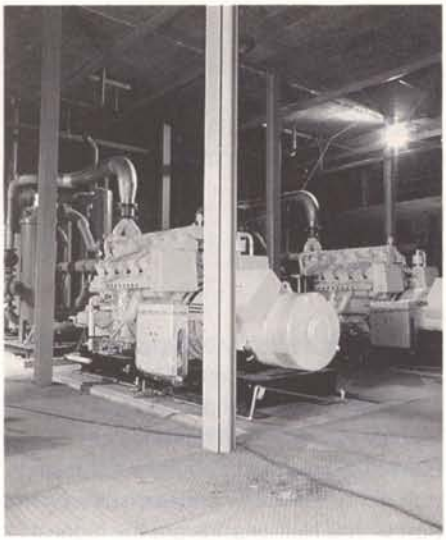
Pour raison de coût, l'installation expérimentale de botanique a été reportée à un vol futur; mais il reste toujours la possibilité d'ajouter à la charge utile le collecteur de poussière cosmique mis au point par le Royaume-Uni.

L'Agence a procédé à l'évaluation de l'offre de développement du système Eureca faite par l'industrie et les négociations finales sont en cours. On n'attend plus que l'autorisation officielle du Conseil directeur du programme Spacelab et du Comité de Politique industrielle de l'Agence pour faire démarrer la phase C/D en novembre.

La revue d'aptitude au vol du système Eureca intégré a été avancée de deux mois et aura donc lieu 38 mois après le démarrage de la phase C/D.

Ariane

Voir pages 72 et 76 pour plus de détails sur le lancement d'ECS-2 et Télécom-1.



Highly Efficient Power Generation at ESTEC

J. Bouman, Test Services Division, ESA Technical Directorate, ESTEC, Noordwijk, The Netherlands

The extensions to the ESTEC Test and Integration Facilities, particularly the Large Space Simulator (LSS) and the extended spacecraft integration area, will increase considerably the on-site demands for electricity and for heating and cooling power. To ensure continuity of supply for these facilities, particularly in the case of a breakdown in the public power grid, a 'power generation system' for the combined generation of electricity and heat is planned for the ESTEC site. This new power system has a considerable advantage over a conventional extension in that its overall efficiency will be approximately 80%, leading to substantial annual savings in energy costs. The new installation will also increase the availability and reliability of the existing energy supply system for the whole of the ESTEC establishment.

After completion of the ESA Capital Investment Plan [ESA/IPC(82)10] for ESTEC, and particularly the completion of the Large Space Simulator, the demand for electrical, heating and cooling power will be considerably higher than at present. Current needs are met by conventional techniques, with three boilers, three chillers and a grid connection to the local power-supply network. Emergency power backup is provided by diesel generators. With the extension of the ESTEC Test and Integration Facilities, substantial additional capacity will be needed (Table 1).

If the increased energy demand were to be realised in the conventional manner, with additional boilers, coolers and emergency generators, estimated energy costs would increase by approximately 30%, up to approximately Dfl 4 000 000 per year. A financial trade-off was therefore made between a conventional extension and alternative, more novel systems aimed at lowering overall energy costs. In this context, it was felt worthwhile to reconsider the principles underlying the existing system. It was concluded that use of a gas-engine system for the simultaneous production of heat and electrical power would have a substantially higher efficiency, leading to a net saving of 15% in annual energy costs.

The new system will run continuously, day and night, to supply the ESTEC electrical baseload of 1000 kW. It will supply approximately 60% of the total electricity, 90% of the heat and 30% of the cooling needs. The local power grid will supply the peaks during daytime and when the LSS is running.

The central heating for the whole of ESTEC can be operated almost year round with the rejected heat from the gas engines. During the summer the engines' exhaust heat will be converted into cooling power.

Compared with a conventional system extension, the new system requires an additional investment of 30%, but this is almost entirely covered by an energy-

Table 1

	Existing capacity, kW	Additional capacity, kW	% extra capacity
Heating	10 000	1000	10
Cooling	3000	1500 (incl. 1000 kW LSS)	50
Electrical power	2400	1800 (incl. 1500 kW LSS)	75
Emergency power	1000 (incl. 500 kW for emergency lights)	1300 (for LSS) (incl. 1000 kW LSS)	130

Figure 1 — An overall view of the ESTEC power generation system

saving subsidy granted by the Dutch Government.

The entire system will be accommodated in a recently completed new building (covering about 500 m²) located adjacent to the existing boiler house, to keep the complex interfacing pipework as short as possible. Apart from the two generator sets, this building will also accommodate the absorption cooler, the various pumps, the high-voltage switchgear, transformers, water-treatment equipment, and the central control room (Fig. 1). The building has room for a third generator set and a second cooler.

The contract for the power-generation system was placed in November 1983. Installation work started in August 1984, after a design phase of eight months, and will be completed in January 1985. The testing and commissioning phase will then last approximately two months.

The co-generation power system
A co-generation system for electricity and heat relies on a prime-mover – an engine – to drive a generator set. The electrical power from the generator is fed into the local power-distribution system, whilst the heat from the exhaust gases, jacket-cooling water and lubricating oil of the engine are recovered and fed into the central-heating system.

The economics of any co-generation power system are affected by two main parameters:
- the plant utilisation factor
- the relationship between fuel costs and the cost of externally purchased energy (electricity).

The plant utilisation factor is the ratio of the power generated per year (in kWh), divided by the installed capacity (kW) × 8700 (h). The ideal would be simultaneously high utilisation factors for both the electrical power and the rejected heat. In practice, the factors depend strongly on the seasonal variations in the demands for the various types of energy.

As can be seen from Figure 2, the electrical load at ESTEC has a distinct 24 h cycle. The relatively high and constant load during the night and over the weekend is a result of the continuous operation of test- and computer-room air conditioning and the loads of the various computer power supplies. In ESTEC's case the utilisation factor is almost ideal when a generation capacity of ± 1000 kW is chosen. The electrical curve shows little seasonal variation, but the heating and cooling demands are both strongly season-dependent (Fig. 3).

One of the main objectives in the design of the new system was to achieve as optimal a match as possible between the availabilities of the various types of energy and the different demands.

The cost of electricity has grown rapidly during recent years, mainly due to the rapid increase in fuel prices. Most power companies in The Netherlands are municipality-owned and have full pricing autonomy. Electricity prices in the western part of The Netherlands are the highest in the country. Although this alone is not a sufficient reason for instituting a private power generation system, it is a very influential factor.

A design criterion of major importance was the backup power required for the LSS, which by coincidence is the same as the ESTEC base load of 1000 kW.

Selection of the prime mover
Internal combustion engines, rather than turbines, have been chosen as the 'prime

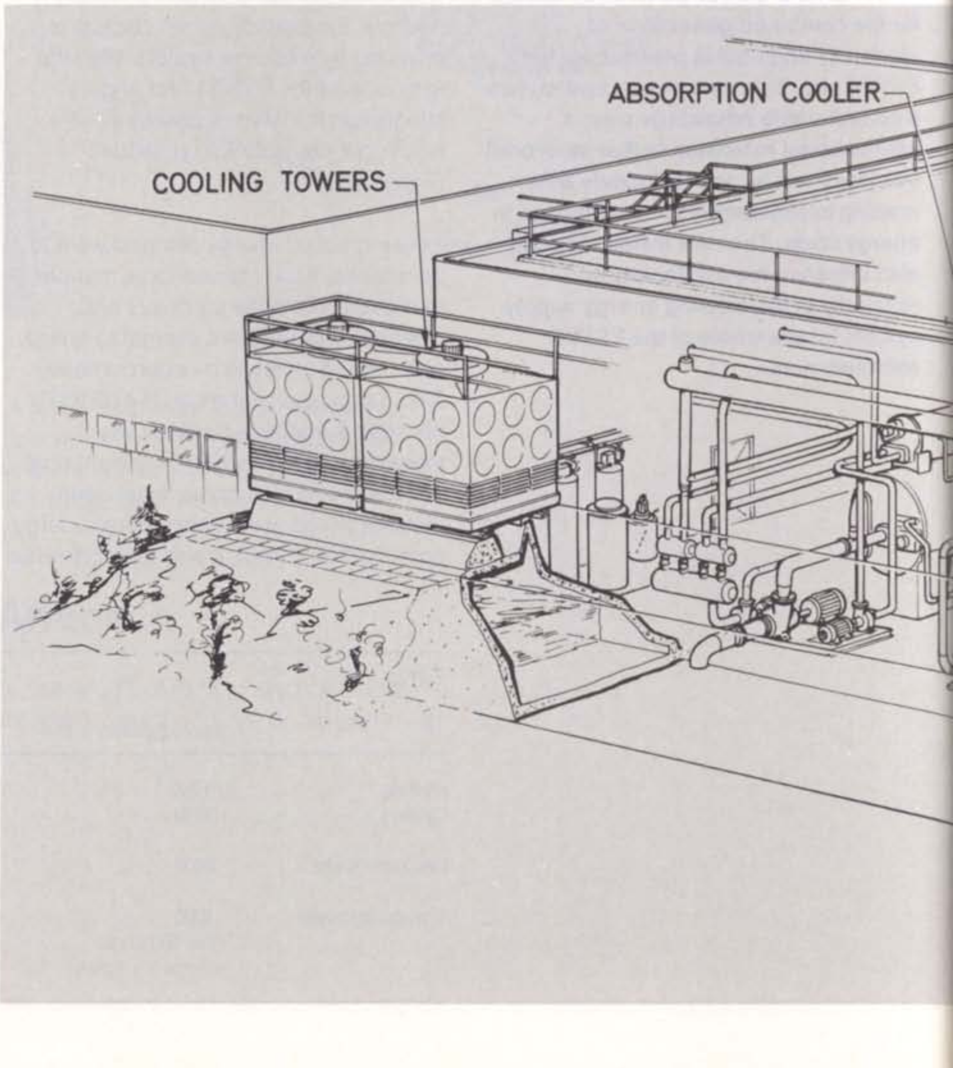
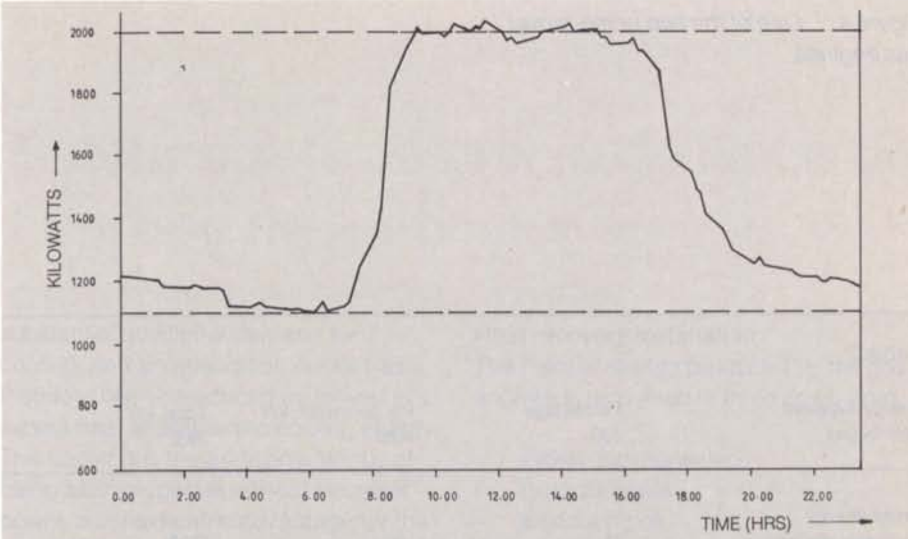
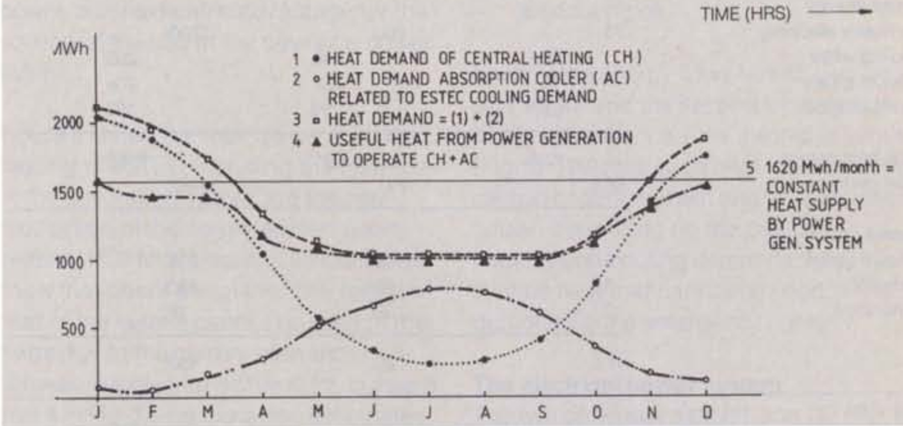


Figure 2 – Daily electrical power consumption at ESTEC

Figure 3 – Annual power consumption, for both heating and cooling, at ESTEC





mover', because their shaft horsepower is approximately 33% of the input heat energy, against some 20% with turbines, and the need at ESTEC is primarily for cheap electrical energy (equivalent to shaft horsepower).

With combustion engines, about 33% of the heat energy in the fuel is converted into shaft horsepower when operating at or near rated load and the remaining energy rejected as heat. The overall thermal efficiency of these systems can be brought up to approximately 88% by recovering the waste heat from the engine's cooling water, exhaust and lubricating oil (Table 2).

Preference was given to gas engines rather than diesels because natural gas is

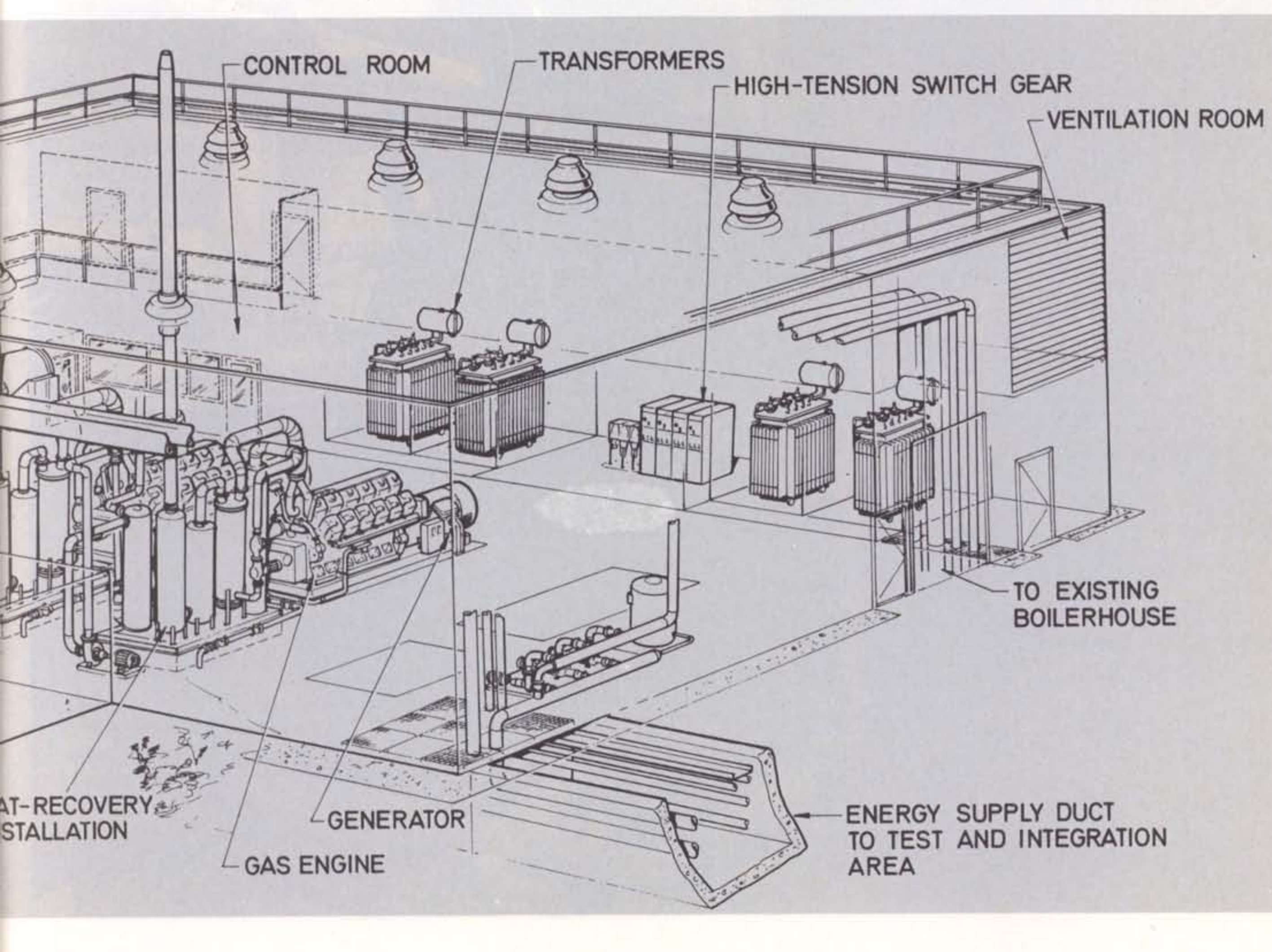


Table 2

Energy supplied	Percentage	Per generator, kW	Total, kW
Natural gas	100	1966	3932
Useful energy			
Generator electricity	33	650	1300
Cooling water	32.5	640	1280
Exhaust gases	18	352	704
Lubricating oil	5	99	198
Total heat energy	55.5	1091	2182
Total useful energy	88.5	1741	3482
Losses			
Exhaust gases	6	118	236
Radiation	3.5	69	130
Generation	2	38	76
	11.5	225	450

cheaper than diesel oil in The Netherlands and it is readily and reliably available.

Another advantage of gas engines is their higher cooling-water and exhaust-gas temperatures, which allow more efficient heat recovery.

The main characteristics of the two gas engines (Fig. 4) are:
- four stroke, 12 cylinder (V-12), overhead valve
- compression ratio 10:1
- water cooling
- continuous output 687 kW at 1000 rpm (922 bhp)
- displacement 115.4 l
- natural-gas consumption at max. power rating 223 m³/h.

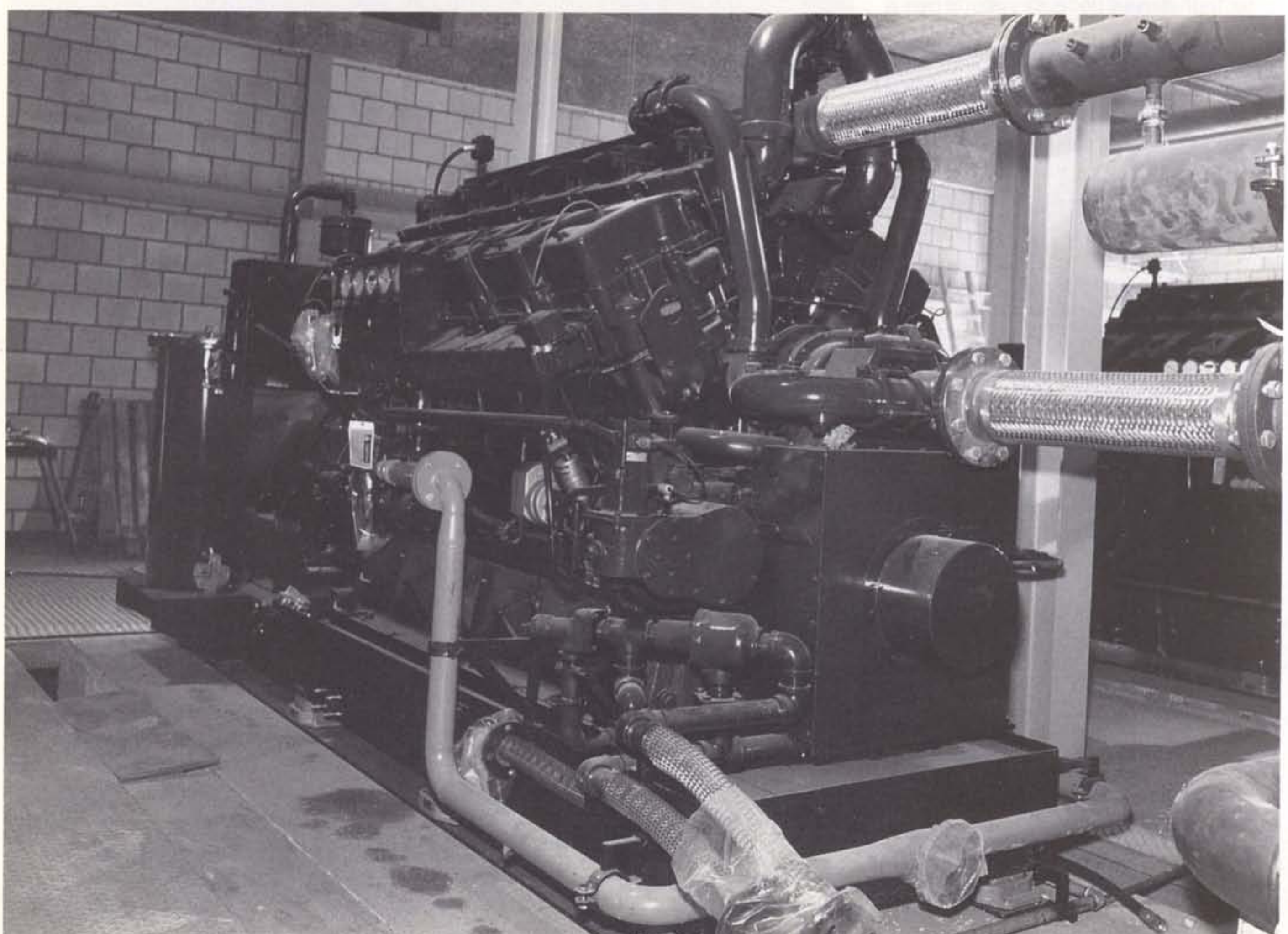


Figure 4 — One of the two prime-mover gas engines

The power requirement for the Large Space Simulator in emergency mode in the case of a breakdown in the public service grid is approximately 1000 kW. To meet this requirement and simultaneously achieve a high utilisation factor, two generator sets have been selected, each with a capacity of 650 kW. The total capacity of 1300 kW is justified because it is anticipated that the basic electrical load at ESTEC will grow in the near future by approximately 300 kW, with future building extensions.

Use of rejected heat
Since the typical power/heat ratio of each gas engine is 1:1.7, the rejected heat available for recovery is 2182 kW (1620 MWh/month) when both engines are running at maximum capacity. This heat can only be used fully by the central-heating system in winter time and considerable quantities of energy would be wasted during the rest of the year. However, the new building extension and the Large Space Simulator also involve a substantial additional demand for cooling, and an absorption cooler has therefore been introduced to convert any excess heat available into cooling energy. This cooler has the additional bonus of being able to operate without electrical power, a considerable advantage for the cooling of the LSS in the case of a power failure.

Figure 3 shows the total demand for the heating of ESTEC, including the operation of the absorption cooler and the heat production of the co-generation power system (1620 MWh/month). Calculations show that about 8% of the 55% rejected heat of the system cannot be used at this stage due to the current mismatch between supply and demand (cf. curves 5 and 4 in Fig. 3). It is, however, anticipated that a few years hence almost all rejected heat can be used, all the year round.

The total useful energy that can be recovered is at most 88.5%, broken down as shown in Table 2.

Heat recovery installation
The thermal energy produced by the gas engines is recovered in three flows, from:

- jacket cooling water
- exhaust gases
- lubricating oil.

Each of the energy flows has its own heat exchanger and the secondary water flows of all exchangers are connected in series (Fig. 5). The recovered heat is fed into the central-heating system and/or absorption cooler, depending on the prevailing heating and cooling demands. Any surplus heat that cannot be used is dumped via the emergency cooler.

The electrical power system
The two generator sets G1 and G2 (Fig. 6) of the 10 kV/380 V power system are designed to deliver their full load of 1300 kW continuously, day and night, in mutual parallel operation and in parallel operation with the public grid (switches A, B and C closed). The system can run fully

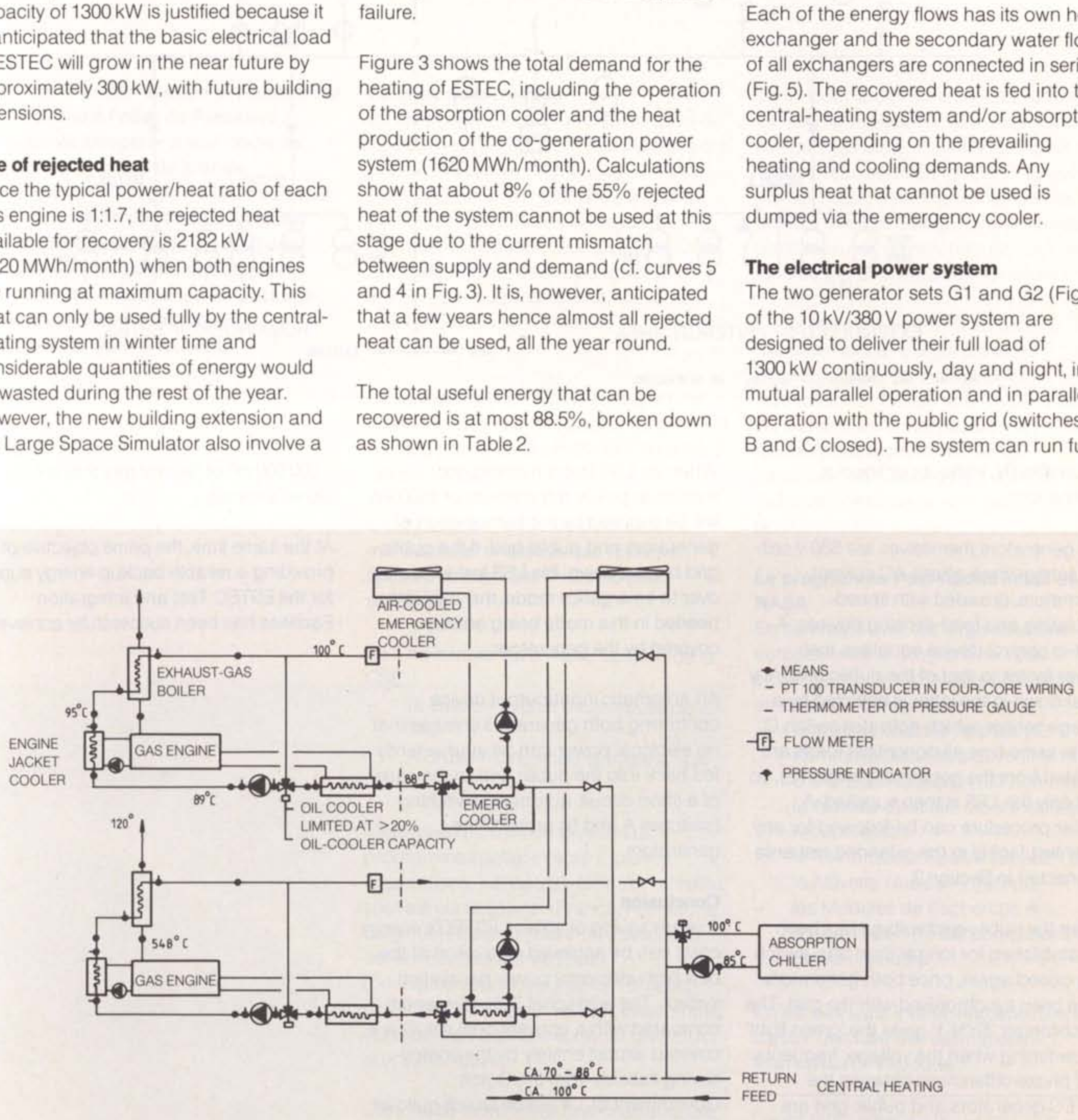


Figure 5 — Schematic of the heat-recovery system

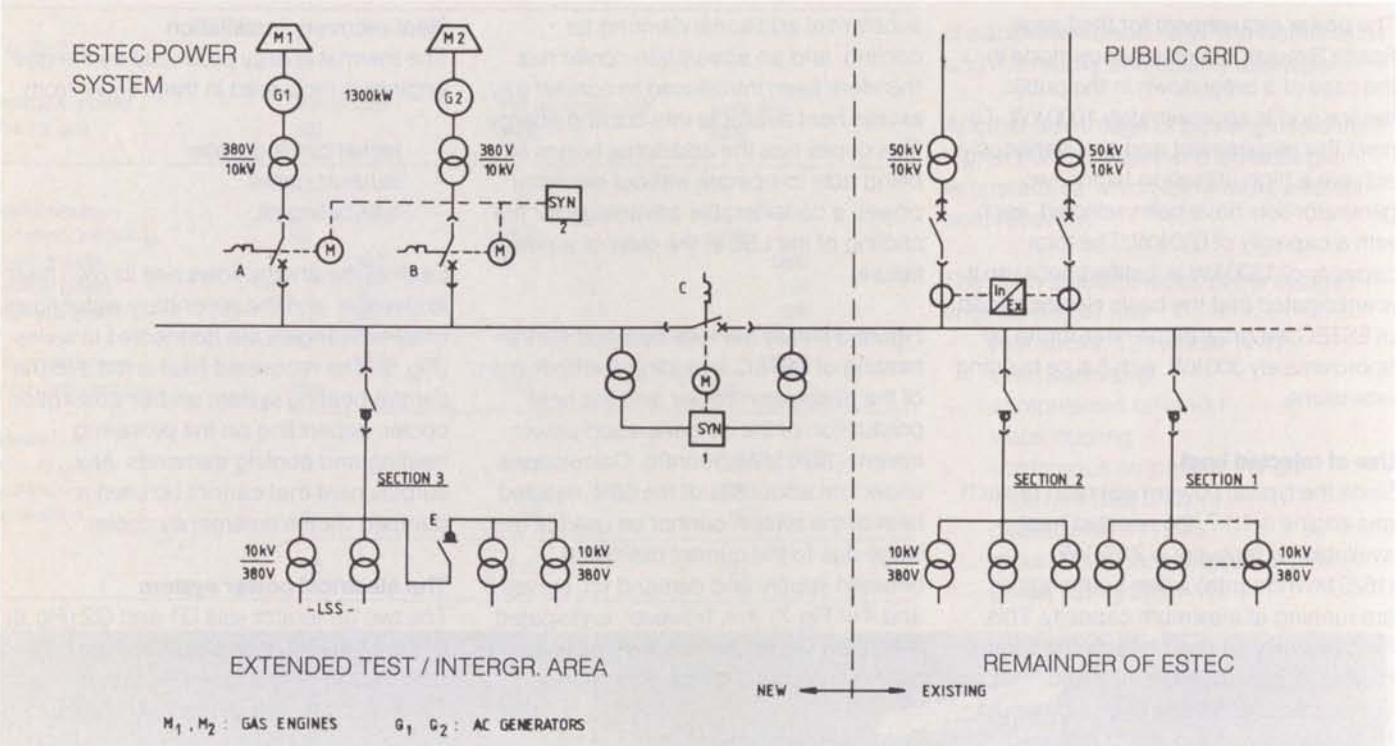


Figure 6 – Simplified electrical diagram for the ESTEC power system/public-grid interface

automatically, without continuous supervision.

The generators themselves are 380 V self-regulating, three-phase AC current alternators, provided with speed-regulating and load-sensing devices. A built-in control device equalises their power factor to that of the public grid. Any breakdown in the latter is detected by a voltage sensor, which activates switch C. At the same time all noncritical loads are isolated from the generators (switch E), so that only the LSS is then supplied. A similar procedure can be followed for any other test facility in the extended test area connected to Section 3.

When the public-grid voltage has been re-established for longer than 30 s, switch C is closed again, once both generators have been synchronised with the grid. The synchroniser 'SYN-1' gives the 'green light' for switching when the voltage, frequency and phase differences between the ESTEC generators and public grid are within narrow preset limits.

When an LSS test is running, the maximum power requirement of 1500 kW will be supplied by the combination of generators and public grid. If the public grid breaks down, the LSS test will switch over to emergency mode, the 1000 kW needed in this mode being entirely covered by the generators.

An automatic input/output device controlling both generators ensures that no electrical power can be inadvertently fed back into the public grid. In the case of a short circuit, automatic switching (switches A and B) protects the generators.

Conclusion

A yearly saving of 15% in ESTEC's energy costs can be achieved as a result of the new high-efficiency power generation system. The additional 30% investment compared with a conventional solution is covered almost entirely by the energy-saving subsidy from the Dutch Government of 1.4 million Dutch guilders, granted on the basis of the approximately 1 000 000 m^3 of natural gas that will be saved annually.

At the same time, the prime objective of providing a reliable backup energy supply for the ESTEC Test and Integration Facilities has been successfully achieved.

Retour sur le passé: la décision de l'Europe de participer au programme Post-Apollo

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A un moment où l'Europe est confrontée de nouveau à l'offre du Président Reagan de coopérer à une nouvelle entreprise spatiale de grande envergure, il n'est pas inutile d'essayer de tirer la leçon du passé. Le lecteur pourra aisément, de ce résumé des tergiversations qui ont marqué les décisions de l'Europe sur le 'package deal no. 2', tirer lui-même les conclusions qui s'imposent.

Le contexte européen
La proposition initiale de participation de l'Europe au programme Post-Apollo a été faite le 14 octobre 1969 par le Dr. Paine (Administrateur de la NASA) au Comité des Hauts Fonctionnaires de la CSE (Conférence Spatiale Européenne). Cette proposition intervenait peu après la culmination du programme Apollo, en juillet 1969, avec le vol Apollo 11: 'l'homme sur la Lune'.

La décision de démarrer le programme américain de Navette Spatiale a fait l'objet d'une déclaration du Président Nixon le 5 janvier 1972.

C'est justement entre les deux dates mentionnées ci-dessus que l'Europe spatiale va subir ses crises les plus sérieuses.

Le 4 novembre 1970, 4ème Session de la CSE:
- 'la Session la plus désastreuse de la CSE'
- 'A Bruxelles, l'Europe spatiale a volé en éclats'.

Trois pays qui sont en faveur d'un programme spatial intégré (Science, Applications, Lanceurs), formant la 'troïka spatiale européenne' (France, Allemagne, Belgique) décident, devant l'absence de consensus des autres Etats (principalement Royaume-Uni et Italie), d'aller de l'avant pour leur propre compte, et lancent en quelque sorte un ultimatum aux autres pays.

L'année se termine sur une crise majeure à l'ESRO, où la France et le Danemark dénoncent la Convention. Le Président du Conseil, le Professeur Van de Hulst, écrivait plus tard: '.... le CERS/ESRO, en 1970, a vécu sous un toit (la CSE) qui prenait l'eau... Vers la fin de l'année, le personnel et les Délégations se tenaient prêts à sauver les meubles dès qu'une fuite au plafond aurait été localisée'.

Si l'année 1971 permet d'amorcer le redressement à l'ESRO, grâce au 'package deal' no. 1, résultat des efforts du Professeur Puppi, nouveau Président du Conseil, il n'en va pas de même pour l'ELDO pour laquelle l'échec du lancement d'Europa-II (le 5 novembre 1971) va constituer le commencement de la fin.

Le programme Post-Apollo initial de la NASA
En contraste avec les tergiversations européennes, le programme initial envisagé par la NASA est extrêmement ambitieux. Il comporte en effet:
- la Station Spatiale habitée (12 hommes) destinée à devenir le noyau d'une Base spatiale (100 hommes)
- la Navette Spatiale, alors totalement récupérable
- le Remorqueur Spatial (Space Tug) et la Navette Nucléaire (Nerva)
- les Modules de Recherche et d'Application (RAM) complétant la Station spatiale.

Il n'est pas sans intérêt, rétrospectivement, d'avoir une idée des estimations financières de l'époque*:

* Avant 1972, 1 dollar = 1 UC; en 1972, 1 UC = 1,08 dollar.

- Navette initiale (totalement réutilisable): coût du développement de l'ordre de 10 000 M dollars, le coût d'une mission étant estimé à 4,5 M dollars (à noter qu'au début 1972, pour la configuration Navette finalement retenue, ces coûts sont devenus respectivement 5150 M dollars et 10,5 M dollars).
- Remorqueur: 500 M dollars.
- Systèmes orbitaux: 5760 M dollars pour l'ensemble du système MSS (Station Spatiale Modulaire), coûts de développement et coûts de production et d'opérations (96 vols de Navette?) sur 10 ans.

Pour ce qui concerne les coûts unitaires de lancement, l'objectif était de réduire par un facteur 10 les coûts en dollar/kg pour l'orbite basse!

Quant au calendrier visé, il était également ambitieux:
- premier vol de la Navette en 1978
- RAM en 1979
- Station Spatiale en 1980!

Quand on compare les prévisions ci-dessus avec la réalité, on peut se dire qu'il y a au moins un domaine – celui des estimations de coûts – où l'Europe n'a pas à avoir de complexe d'infériorité vis-à-vis des Etats-Unis...

1970 et 1971
Dans le contexte européen de crise et en l'absence d'une décision américaine sur le démarrage du programme Post-Apollo, les activités européennes restent de nature exploratoire.

La Conférence Ministérielle de juillet 1970, sur la base du Rapport du Comité des Hauts Fonctionnaires [CSE/HF(70)25], reconnaît (Résolution no. 3) l'intérêt d'une participation au programme Post-Apollo et décide (Résolution no. 2) la création d'un Sous-Comité du Comité des Suppléants 'Coopération au programme Post-Apollo'.

Pour ce qui concerne les systèmes orbitaux intéressant plus particulièrement l'ESRO, un rapport est publié en août 1971: 'Rapport sur les possibilités d'une participation européenne au programme Post-Apollo'. Il permet de noter:
- l'évolution du concept de Station Spatiale vers un système modulaire (modules de 4,5 m de diamètre, au lieu du système initial de 10 m)
- la possibilité pour les Modules de Recherche et d'Applications d'être 'servis' soit par la Navette, soit par la Station Spatiale
- et le concept de missions de sortie de la Navette (7 jours) '*exécutées au moyen d'un équipement expérimental simple fixé sur la Navette*' (c'est de cet équipement 'simple' que sera dérivé Spacelab...).

En décembre 1971, a lieu une réunion du Groupe Commun d'Experts CSE-NASA dont les points notables sont:
- l'évolution du concept de la Navette, le premier étage volant et habité ('fly-back') évoluant vers un premier étage non habité et récupérable (moteurs)
- une très grande variété de possibilités de coopération européenne au programme: 14 lots possibles pour l'Orbiteur de la Navette; le remorqueur spatial; les systèmes orbitaux ('Sortie Can', 'Sortie Pallet', RAM, charges utiles); ou des travaux technologiques (aérodynamique, structure, etc.).

1972
C'est en 1972, après la décision du Président Nixon, qu'une intense activité se déploie (l'avenir de l'ESRO s'est alors éclairci à la suite du 'package deal' no. 1) et qu'on constate une constante évolution des possibilités de participation européenne.

En février 1972, réunion du Groupe commun d'experts CSE – NASA. Les travaux possibles sur la Navette sont réduits à 6 (100 M dollars au total). Le développement de la Station Spatiale est ajourné. La participation européenne dans les systèmes orbitaux s'oriente vers les missions de sortie: caisson de sortie (sortie can), porte-instruments (pallet), expériences et systèmes

En mars 1972, le 'Rapport sur la participation européenne au programme Post-Apollo' fait le point de la situation. Compte tenu du fait que la configuration finale de la Navette a été figée (Orbiteur + 3 moteurs hydrogène-oxygène + 2 fusées à poudre récupérables + 1 réservoir largable) et que les travaux sont prêts à démarrer, une décision de

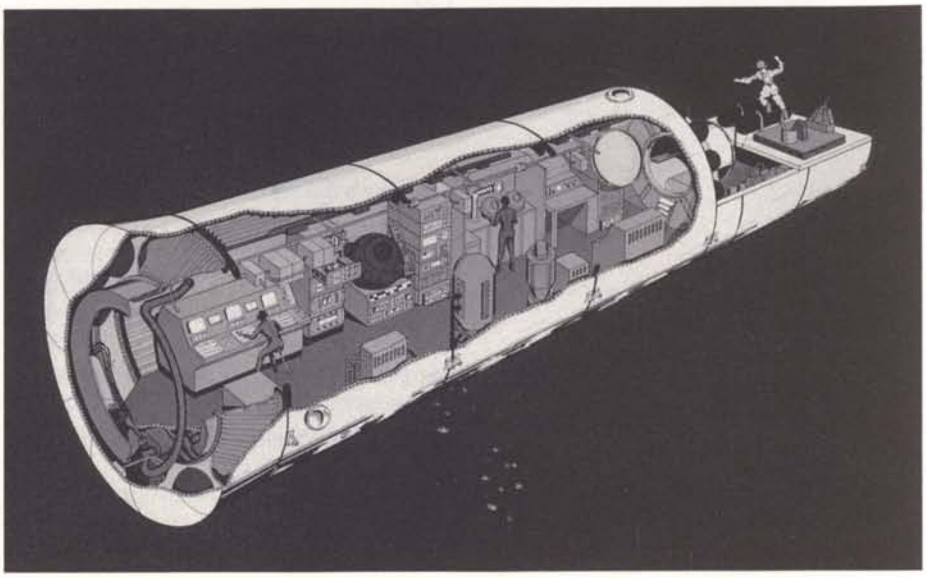

Figure 1 — Vue conceptuelle du spacelab en 1973

participation européenne est à prendre très rapidement. Le remorqueur qui fait appel à des technologies avancées (propulsion, RVD, etc.) serait très intéressant pour l'Europe qui pourrait en avoir la responsabilité de gestion. Dans le domaine des systèmes orbitaux, la station spatiale et les RAM étant retardés, il ne reste plus que le module de sortie et le porte-instruments. Pour justifier cette dernière participation européenne le Rapport fait état d'une réduction d'un facteur 2000(?) sur les coûts des expériences. Le coût d'une mission de sortie est estimé à 25 M dollars: 10,5 M pour le vol Navette; 9,5 M pour l'amortissement du développement et les opérations au sol et en vol; 5 M pour les expériences. Au niveau de la gestion, deux schémas sont envisagés (par la CSE):

(a) pas d'échanges de fonds: la NASA finance les sous-traitants américains du maître d'oeuvre européen; l'Europe finance les sous-traitants européens du maître d'oeuvre américain;
(b) financement réciproque: chaque Agence finance la totalité de son programme y compris les sous-traitances en Europe pour le programme NASA (Navette) et les sous-traitances aux Etats-Unis pour le programme européen, et on essaie d'équilibrer en volume les sous-traitances respectives.

Finalement, le Rapport propose le choix entre trois possibilités:

- l'Europe participe à la Navette: financement de 100 MUC sous-traités par la NASA à l'industrie européenne
- l'Europe réalise le remorqueur (500 MUC), avec compensation entre les sous-traitances nécessaires aux Etats-Unis et les fournitures européennes pour la Navette
- l'Europe réalise le module de sortie (200 MUC) avec le même schéma de compensation que ci-dessus.

Mais toutes ces propositions devaient être en grande partie invalidées à la réunion de juin 1972 à Washington entre les Délégations CSE et Etats-Unis qui fait apparaître des limitations sérieuses à la coopération Europe–Etats-Unis. L'attitude américaine peut alors se résumer comme suit:

- la politique américaine en matière de fourniture de lanceurs est indépendante de la participation de l'Europe au programme Post-Apollo
- la participation européenne à la Navette soulève des difficultés...; en tout état de cause, elle ne serait acceptable que si l'Europe développait aussi le module de sortie
- la définition du remorqueur étant encore incertaine, il n'est pas prudent de poursuivre les discussions sur ce point
- le prix d'utilisation de la Navette ne dépendra pas de la participation européenne au programme; ce sera le même que celui pour les organisations non gouvernementales américaines ou entreprises privées
- le schéma des engagements réciproques en matière de financement est exclu (pas de transfert de fonds des Etats-Unis en Europe)
- aucun engagement ferme ne peut être pris par les Etats-Unis quant à la quantité de matériels (cas du module de sortie) qu'ils achèteront en Europe
- la participation européenne n'entraînera un droit de priorité pour les missions de l'Europe que vis-à-vis des pays non participants.

En résumé, les Etats-Unis a alors 'encouragé' fortement l'Europe à développer le module de sortie, ce qui signifiait en clair que les autres possibilités n'étaient plus d'actualité. Cette attitude était confirmée lors des discussions CSE-NASA tenues à Washington en août 1972, qui se sont pratiquement limitées au module de sortie.

La décision finale de l'Europe

La phase de décision finale a commencé sous de mauvais auspices par la Réunion Ministérielle de la CSE en novembre 1972, qui n'a permis que de clarifier les désaccords majeurs des principaux Etats membres. Rappelons ces positions à travers des extraits des déclarations des Ministres:

– *Le Président Théo Lefèvre* (Belgique): 'Je persiste à croire que la réalisation d'une capacité européenne de lancement est nécessaire'. Pour ce qui concerne le programme Post-Apollo: '... considéré, non comme le substitut d'une politique de lancement autonome, mais comme un complément de celle-ci, il (l'effort financier) reste justifiable'.

– *Le Ministre britannique, M. Heseltine:* 'Je voudrais suggérer que nous créions en Europe une Organisation spatiale unique... dans laquelle nous introduisions progressivement les engagements et programmes nationaux des divers pays européens... Notre proposition serait que, dans l'Organisation européenne, il y ait un certain nombre de programmes spécialisés auxquels les divers pays seraient libres de contribuer individuellement sur la base d'un 'menu à la carte''.

– *Le Ministre français, M. Charbonnel:* '... aucun des besoins économiques de la prochaine décennie ne sera satisfait par la réalisation, en Europe, d'un 'laboratoire de sortie' qui ne peut donc en aucun cas être considéré comme un substitut à un programme de lanceurs'.

– *Le Ministre allemand, M. Von Dohnanyi:* 'Nous ne devrions pas laisser le troisième wagon du train Post-Apollo passer en gare sans y monter'.

– *Le Ministre italien, M. Romita:* 'Ce programme (Post-Apollo) apportera une véritable révolution dans la façon d'exercer une activité se rapportant non seulement à l'exploration de l'espace mais également à l'utilisation de l'espace'.

'Le programme Europa-III ... risque d'absorber une part trop élevée des

Figure 2 — La Conférence spatiale européenne de Bruxelles (20 décembre 1972). De gauche à droite: Dr. A. Hocker, Directeur général de l'ESRO; M. Th. Lefèvre, Président de la CSE; et M. A. Stenmans, Secrétaire général du Département de la Planification de la Politique scientifique de Belgique.

ressources européennes et de pénaliser en conséquence de façon déterminante d'autres activités'.

Une décision 'positive' était toutefois prise, celle de convoquer une Conférence Spatiale Européenne en décembre 1972. Ce n'est que l'après-midi du 20 décembre qu'une proposition nouvelle de la France allait permettre de débloquer l'Europe spatiale. M. Charbonnel déclarait alors: '... La France propose à ses partenaires d'assurer la part principale du financement et d'assumer les risques du développement d'un lanceur de capacité équivalente à celle d'Europa-III (60% de 550 MUC) ... Si la proposition française était acceptée, les autorités françaises seraient prêtes à contribuer au programme Post-Apollo'.

Il semble que cette proposition ait vraiment été faite en temps réel, et il est donc à la fois heureux et surprenant qu'une Résolution ait pu être adoptée dans la même après-midi, résolution qui posait le principe du 'package deal' no. 2:

- création de l'Agence Spatiale Européenne
- accord de principe sur:
  - le laboratoire de sortie
  - le lanceur 'français' (avec abandon d'Europa-III),
  - la rationalisation des programmes de satellites (en clair, un choix à faire sur le programme de satellites maritimes, entre Marots et le projet GTS proposé par le Royaume-Uni).

Cette Conférence sonnait donc le glas de l'ELDO (dont l'existence s'arrêtait peu après, le 27 avril 1973), mais relançait sur de nouvelles bases la coopération spatiale européenne, au moins au niveau des principes, car ce n'est pas sans mal que ses mêmes principes allaient finir par se concrétiser en un 'package deal' final.

Sur la base d'un Rapport du Secrétaire Général de la CSE, une réunion était prévue pour le 12 juillet 1973. Elle devait être ajournée faute d'une position claire de tous les pays quant à leur participation aux différents programmes proposés.

Il fallut attendre le 31 juillet 1973 (reprise de la session ajournée de la CSE) pour qu'un accord général soit obtenu sur la participation des Etats membres aux différents programmes proposés. Et encore il s'en était fallu de peu que la réunion achoppe à cause de l'impossibilité pour le Gouvernement italien de préciser ses contributions. Une astuce formelle permit toutefois à la fin d'attribuer les contributions manquantes pour les différents programmes, sans obliger le Gouvernement italien à s'engager formellement sur ces chiffres: il a simplement suffi d'attribuer les déficits de contributions à 'Italie et autres pays'.

Finalement la Conférence approuvait:
- le programme L III S*
- le programme Spacelab
- le programme Marots
- la création de l'ESA,

étant entendu que toutes ces décisions étaient interdépendantes.

Pour ce qui concerne Spacelab, ces décisions se concrétisaient dans la signature, le 14 août 1973:
- de l'Accord entre le Gouvernement des Etats-Unis et les Gouvernements européens
- du Mémorandum d'Accord entre la NASA et l'ESRO,

et par l'entrée en vigueur, le 10 août 1973, de l'Arrangement entre les Etats membres de l'ESRO sur le programme Spacelab.

Les accords Europe — USA pour Spacelab

La description ci-après des droits et obligations des deux parties est simplifiée à l'extrême et peut paraître caricaturale. Elle est néanmoins révélatrice:

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* Rebaptisé Ariane, dès le lendemain 1er août 1973, par le Conseil de l'ESRO.

Figure 3 – Rencontre ESA/NASA à l'occasion de la signature à Washington du Protocole d'Accord Spacelab. (Assis à gauche: Dr. A. Hocker, Directeur général de l'ESRO; à droite: Dr. J.C. Fletcher, Administrateur de la NASA)

Les obligations
- L'Europe s'engage à financer le développement du Spacelab (et donc toutes les modifications nécessaires, les essais de recette devant être conformes aux spécifications de la NASA) et à le mettre à la disposition de la NASA.
- La NASA s'engage à acheter à l'Europe un deuxième Spacelab, et à faire voler un Européen.

Les droits
- La NASA dispose de la pleine et entière utilisation du Spacelab-1.
- L'Europe a le droit d'utiliser le Spacelab (qu'elle a financé) en remboursant les coûts d'utilisation; cette utilisation peut toutefois être gratuite dans le cadre d'un programme de coopération avec la NASA.

On doit toutefois noter que tout autre pays non européen a la même possibilité d'utilisation du Spacelab ci-dessus, l'avantage des pays européens résidant presque uniquement dans une question de priorité:

- pour les utilisations 'en coopération': 'les propositions des Gouvernements participant au programme Spacelab bénéficient d'une priorité sur celles des pays tiers à condition que leur qualité soit au moins égale à celles des propositions desdits pays'
- pour les utilisations 'en remboursement de frais': priorité de l'Europe vis-à-vis des pays tiers.

L'épilogue du 'package deal no. 2'
- L'Agence Spatiale Européenne était créée en avril 1975.
- Le premier lancement Ariane était effectué le 24 décembre 1979.
- Le premier vol de la Navette avait lieu le 12 avril 1981.
- Marecs-A (Marots) était lancé le 20 décembre 1981 (Ariane devenait opérationnel).
- Spacelab effectuait son premier vol le 28 novembre 1983.

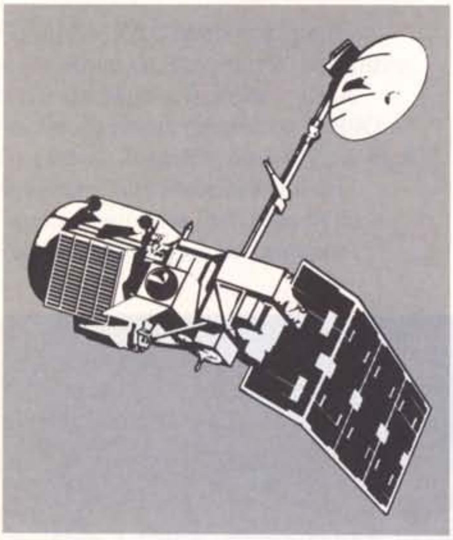
Dix ans après, le pari de quelques Ministres courageux était donc tenu.

Conclusion en forme de questions
Rappelons-nous la déclaration du Ministre allemand M. Von Dohnanyi à Bruxelles. L'Europe est effectivement montée en 1973, à la gare de Bruxelles, dans le troisième wagon du train Post-Apollo. N'était-ce pas le wagon de queue, sans confort, malgré le prix du billet? Ce wagon sera-t-il abandonné sur une voie de garage, ou sera-t-il utilisé pour un nouveau voyage avec les USA?

Mais, d'un autre côté, l'Europe aurait-elle pris le train Ariane, il y a dix ans, si elle avait manqué le train Post-Apollo?

Ne sommes-nous pas aujourd'hui placés devant le même problème de trains, mais peut-être pouvons-nous au moins les aiguiller sur la même voie?

L'histoire recommence, et les Ministres de l'Europe spatiale vont devoir bientôt prendre des décisions lourdes de conséquences pour l'horizon 2000.



Earthnet MSS Data Supports CEC Hunger-Relief Projects in the Sahel

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ESA's Earthnet ground station at Maspalomas, Canary Islands, started collecting and recording Multi-Spectral Scanner (MSS) data from NOAA's Landsat-4 and 5 satellites early in July 1984. This activity is one element of on-going cooperation between ESA and the Commission of the European Communities (CEC) for the use of space technology in support of the Commission's development-aid projects. It is financed under a special CEC programme instituted to combat World hunger.

The Agency's Earthnet Programme is responsible for processing the data acquired at Maspalomas, which is subsequently made available to interested users including, in particular, CEC-sponsored investigators, who perform research and applications work within the satellite-coverage area, and especially in the Sahel, in West Africa.

The project is expected to contribute significantly to Commission-financed studies in agricultural production estimation, water-resources management, pasture-area monitoring, desertification control and forest inventory, since it provides remote-sensing coverage at regular intervals over twelve West-African countries.

The Agency's Maspalomas ground station has been operating since 1980 within the framework of the Earthnet Programme, for the acquisition, preprocessing and dissemination of data from the experimental NASA satellite Nimbus-7, used for research into coastal-water phenomena, fishery and other related fields.

Historical development

The CEC's Commissioner for Development and ESA's Director General met in Paris on 21 January 1983. Together, they sought to identify areas within their respective fields of activity in which their experience and expertise might be mutually beneficial for enhancing the value of the activities for which they are responsible in Europe. They agreed that space technology could make a useful contribution to the socio-economic advancement of the developing countries, as was recognised at the Unispace '82 Conference (see ESA Bulletin No. 33, pp. 55-57).

They instructed their organisations to draw up a report (Report by an EEC/ESA Working Group to the European Commission for Development Cooperation and to the Director General of ESA on the Prospects for the Use of Space Techniques by certain Developing Countries) showing the needs of the African countries, the resources available or to be procured to meet those needs, and the steps that might be taken (particularly with the Agency's support), to consolidate or, in certain cases, start a process of cooperation with the African countries in the field of space technology.

In the area of Earth-observation by satellite, the report identifies and recommends the following actions:

a. The processing and interpretation of meteorological and remote-sensing data to meet specific African needs – identification of pilot schemes.
b. Access to past data and the acquisition of current and future meteorological and remote-sensing data on Africa.
c. Familiarisation and training.

The report also proposes principles under which the Commission and ESA should cooperate to make space technology available to the developing countries:

1. With the Agency's assistance in the areas of its competence, the Commission will define the activities

that would be beneficial and which, in keeping with its rules, could be financed by the Community.
2. The Agency will make its technical and institutional resources available to the Commission in accordance with its rules.
3. The services of the two organisations will do their utmost to develop working relations and make effective use of their complementarity.
4. The actions already taken by the Agency to promote its programmes in the developing countries will, as far as possible, be coordinated with the actions decided by the Commission. The Commission and the Agency will provide each other with information in order to ensure that their actions in this area are mutually consistent.

Following publication of this Report, Earthnet was asked in September 1983 to evaluate the financial resources required to upgrade and operate the Maspalomas station to handle other Earth-observation missions, including the Tiros and Landsat series of spacecraft, in addition to the acquisition and processing of Nimbus-7 Coastal-Zone Colour Scanner (CZCS) data, which has been in operation at Maspalomas since 1980.

In parallel, the Commission, with administrative responsibility assigned to DG VIII (Aid to Development) and technical responsibility to the Remote Sensing Unit of the Joint Research Centre of the European Communities (JRC, Ispra, Varese), has prepared an application programme for remote-sensing-data utilisation in the framework of the special programme 'War Against Hunger in the World'.

Given the dramatic problems facing the African countries situated at the southern edge of the Sahara (Sahelian countries), the monitoring of their fragile, semi-arid environment was considered a priority task. In a first approach, remote sensing should make a valuable contribution for characterising the dynamics of desertification processes (all the factors affecting the environment and causing its degradation, excluding long-term forecasting of meteorological parameters considered elsewhere) and for the study of water resources.

Seven remote-sensing projects have been defined, corresponding to seven important themes of application. They must be considered as pilot R&D actions, performed on limited test-sites selected as representative of Sahelian conditions and aimed at the setting up of adequate methodologies for monitoring and study with a view to later operational use. These projects will be executed by European institutes and laboratories in cooperation with competent African services in the countries involved.

Finalisation of Maspalomas' upgrading

The report prepared by the Earthnet Programme Office contained the technical and financial solution for the upgrading of the Maspalomas station to acquire and process Landsat Multi-Spectral Scanner (MSS) and Thematic Mapper (TM) instrument data and NOAA Tiros AVHRR instrument data.

Owing to financial constraints, the CEC retained only the option relating to the acquisition of the Landsat-4/5 MSS data, with the agreement that the data-system-correction processing should be performed at an Earthnet Landsat ground station.

The following tasks were therefore required:

a. Changes to the existing equipment and new procurements/installations at Maspalomas, including:
- addition of a downconverter to the Nimbus-7 CZCS S-band antenna receiving chain
- procurement of MSS receivers, and bit conditioner (Scientific Atlanta, USA)
- procurement of High-Density Digital Recorders (HDDRs) and frame synchroniser (Schlumberger, France)
- reconfiguration of the station layout to accommodate the new equipment
- installation of relevant software for Landsat spacecraft tracking.

b. The organisation of the processing system for Maspalomas acquisition at Earthnet, including:
- shipment of HDDR tapes from Maspalomas to Fucino
- modification of quick-look and product-generation programs to include Maspalomas acquisitions
- upgrading of the Landsat Catalogue system (LEDA-2*) to include Maspalomas coverage and acquisitions.

c. The expansion of browse activities to include:
- liaison with NOAA for Landsat MSS scheduling during the campaign periods
- archiving of quick-look data and the availability of Maspalomas-related information (coverage maps, sample products, etc.)
- the setting up of adequate support to the pilot projects organised by the CEC.

The critical path faced during the implementation and setting up of the above-mentioned activities was due to the short period available between the formal agreement between the CEC and ESA (April 1984) and the starting of data collection for the CEC pilot projects (July 1984). In fact, most manufacturers were quoting 6–8 month delivery times for the station equipment required. Station readiness for the acquisition campaigns was therefore achieved by moving redundant equipment from the Kiruna (Sweden) and Fucino (Italy) Landsat stations to Maspalomas (Figs. 1 & 2).

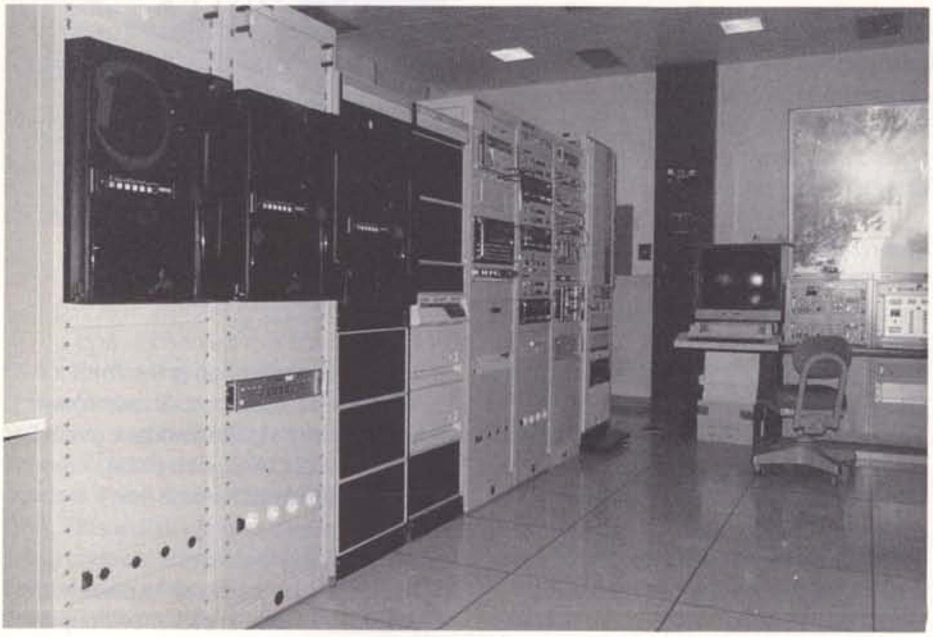
The first attempt to acquire image data was made at Maspalomas on 30 June

* See ESA Bulletin No. 33 pp. 67–72.

Figure 1 – Maspalomas MSS receiving equipment

Figure 2 – The Maspalomas reception antenna

Figure 3 – Landsat-4/5 coverage for the Maspalomas and Fucino stations



1984 and good-quality data have been acquired from both Landsat-4 and 5 since 3 July (Fig. 3).

Finalisation of the application projects
An expert Working Group was set up and the following seven projects were finalised and financially supported (partially) by the CEC:

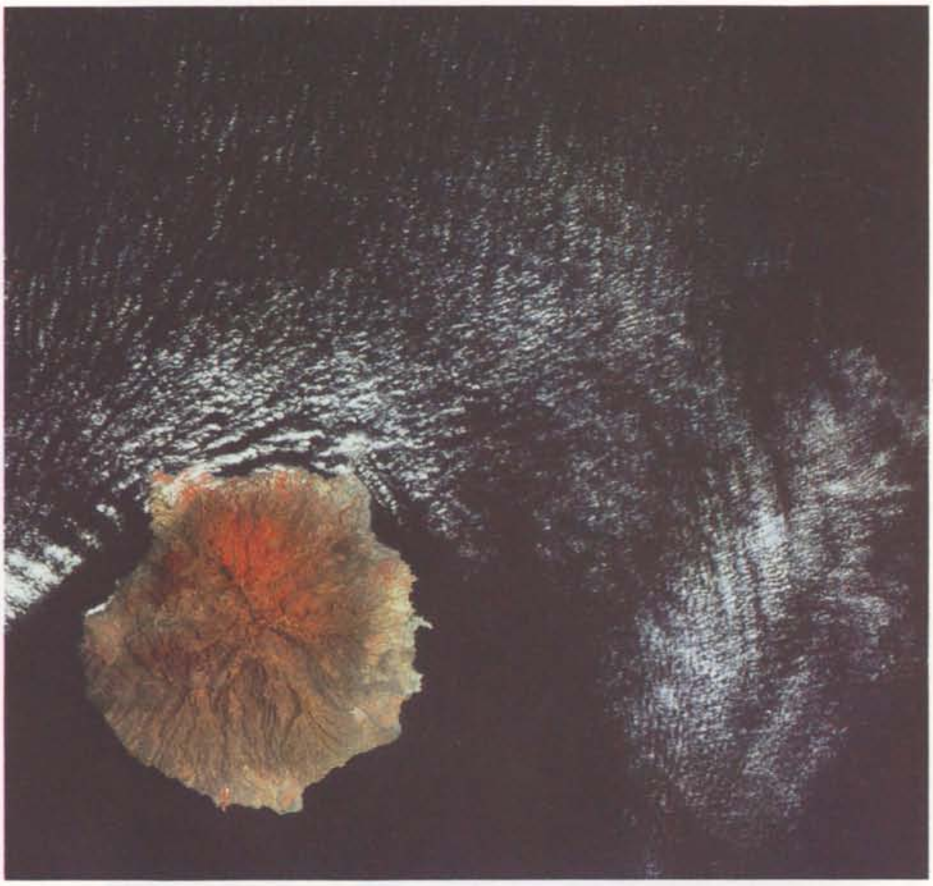
Theme No. 1 – Monitoring of Pasture Land Ecosystems in the Sahel and Mapping of Cloud Cover and Rainfall

Objectives and content

- To develop and test remote-sensing methods for the inventory and monitoring of range-land vegetation.
- To develop and test remote-sensing methods for mapping cloud cover to predict precipitation levels and the carrying capacity of pasture lands.
- To suggest guidelines for an operational system for the monitoring and management of pasture land.

The project will profit from the experience gained previously by British laboratories in the fields of rainfall- and soil-moisture monitoring in Niger.

Figure 4 – False-colour (B1 = blue, B2 = green, B4 = red) composite from Landsat track 206/frame 40 on 4 July 1984, acquired at Maspalomas. The image shows Gran Canaria, where the Maspalomas station is located



Responsible organisation
National Environmental Research Council (NERC, UK), comprising a number of institutions concerned with environmental problems.

Cooperation is foreseen with the Agrhyment Centre in Niamey (Niger) and international organisations such as FAO, WMO and UNEP.

African countries involved
Niger: already covered in previous years by NERC investigation. Mali: an attempt will be made to identify sites to be shared with the other projects (Themes 2 & 3).

Theme No. 2 – Inventory and Monitoring of Timber Vegetation and its Evolution; Identification of Zones of Wind-Erosion Impact

Objectives and content
Wood clearing for the extension of cultivated areas, bush fires provoked by man, and wind erosion are seriously endangering the Sahelian environment. The adequacy of remote-sensing techniques for the recognition, inventory and monitoring of these desertification processes will be investigated in a latitudinal range (between about 13° and 15° latitude) where all these processes are acting, considering the period of vegetation growth and the dry season.

The trends in recent evolution will be assessed by comparing satellite data available for 1976 and 1984–1985.

Responsible organisation
Institute for Applied Geology and Remote Sensing of Berlin University, with the participation of Munich University (Germany).

Cooperation with Reims University (France) for wind-erosion studies and with the French GERDAT remote-sensing laboratory for ecological studies.

Ground-survey assistance from Mali's PIRT (Programme d'Inventaire des Ressources Terrestres, Bamako) team would be highly profitable.

African country involved
Mali: from Dioila-Ségou in the south to Niono-Sokolo in the north, in an attempt to cooperate with the JRC-Ispra project under Theme No. 3.

Theme No. 3 – Evolution of the Urban and Peri-Urban Environment of Large Sahelian Cities

Objectives and content

- Mapping of urban growth.
- Mapping of the degradation of the peri-urban environment as a consequence of cultural extension and wood cutting.
- To suggest guidelines for an operational system for urban management and for a policy for the protection of the peri-urban environment.

The setting up of adequate remote-sensing techniques is necessary to attain these objectives, based on accurate ground-truth data.

The project will profit from the experience gained by the responsible Laboratory (see below) when working on the same subject in Central Africa (Zaire).

Responsible organisation
Remote Sensing Laboratory of Louvain University (Belgium), with cooperation for the ground survey from the Malian PIRT team.

African country involved
Mali: City of Bamako and the peri-urban zone extending east along the Bamako-Ségou road, in an attempt to cooperate with the JRC-Ispra project under Theme 2.

Figure 5 — Landsat track 205/frame 49 on 5 July 1984, acquired at Maspalomas. The image shows northern Dakar (Senegal), the River Senegal and the town of St. Louis

Theme No. 4 – Assessment and Monitoring of Regional Water Balance

Objectives and content

- Determination, at a regional level, of water-balance parameters in superficial soil layers, with special reference to the real evapo-transpiration.
- Monitoring of soil humidity with a view to assisting agricultural management in semi-arid countries

The study will profit from thermal remote-sensing data from Meteosat and Tiros-N. Owing to the resolutions (5 and 1 km, respectively) of these satellites, the impact of the study is intended to be at a regional level.

The study includes the collection of accurate agro-climatological data on African test fields.

Responsible organisation
Institut National de la Recherche Agronomique (INRA, Avignon, France), with the participation of CNES (Toulouse), IRAT (Institut de Recherche en Agronomie Tropicale) and ISRA (Institut Sénégalais de Recherche Agronomique).

African country involved
Senegal: Peanut-growing zone with Sahelian climatic conditions around the city of Linguère.

Theme No. 5 – Detection of Hydrological Indicators in the Basins of the Rivers Nigel and Senegal, with a view to Forecasting of their Flooding Regime

Objectives and content
The hydrological regime of the Niger and Senegal rivers is conditioned by rainfall occurring in the upper basins (in the mountainous ranges of Guinea) and by the gradual replenishment of natural reservoirs (depressions) situated upstream.

The project will set up remote-sensing methods aimed at:

- mapping, in an automatic manner, the areas saturated with water
- monitoring the seasonal evolution of their replenishment
- identifying those saturated areas that act as hydrological reservoirs and establishing the correlation with water flow in the main river downstream
- suggesting guidelines for an operational system of forecasting of river flow and flood regime.

The project will profit from previous experience gained on the Niger river in Mali, in collaboration with JRC-Ispra.

Responsible organisation
Laboratorio per la Geofisica della Litosfera (Laboratory for the Geophysics of the Lithosphere), Consiglio Nazionale della Ricerca (CNR), Milan (Italy), with the cooperation of JRC-Ispra, studying the same subject in the southern affluents of the Niger river.

African countries involved
Guinea: region of the Fouta-Djalon mountains, from which the Senegal river and the Tinkisso affluent of the Niger river originate.

Secondarily, southwest Mali for the Senegal river.

Theme No. 6 – Detection of Geomorphological Structures Favouring Ground-Water Resources along the Mountainous Ranges of the Sahara

Objectives and content

- Setting up of methods integrating conventional and remote-sensing data with a view to mapping aquifers in complex geological terrains.

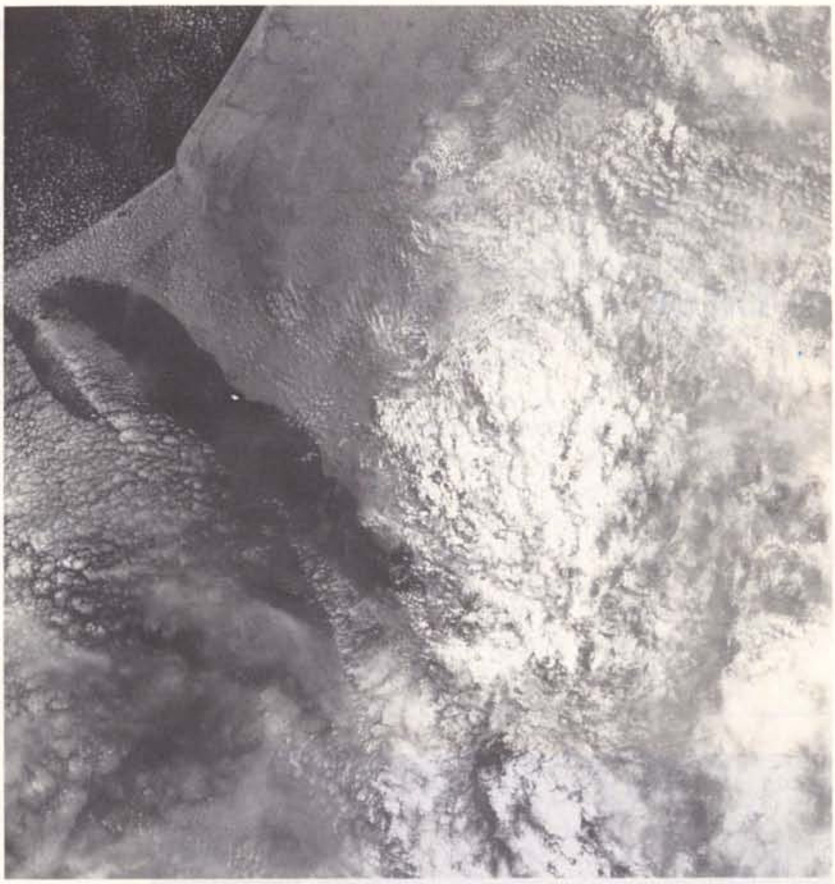


Figure 6 – Landsat track 205/frame 50 (Dakar), acquired at Maspalomas on 5 July 1984 (Band 4)

Figure 7 – Landsat track 195/frame 51 (North of Ouagadougou, Upper Volta), acquired at Maspalomas on 7 July 1984 (Band 3)

- Establishment of guidelines for an operational system aimed at providing ground water to the populations of the Sahara.

The analysis of satellite data will involve the structure of the terrain (lineaments, rock fractures) and the vegetation anomalies and ground-water seepages. It will result, in combination with ground data, in relative-probability maps for ground-water occurrence.

Responsible organisation
Environmental Resources Analysis Ltd., Committee on Business and Industry of Trinity College, Dublin (Ireland), in cooperation with Servizio Geologico d'Italia, Roma, Italy.

African country involved
Mali: Mountainous range 'Adrar des Iforas', in the northeastern part of the country, with pure Saharian conditions.

Theme No. 7 – Establishment of an Information Bank for the Storage and Retrieval of Remote-Sensing Imagery of the Sahelian Areas. Organisation of a Seminar for Final Evaluation of the Various EEC Projects on Desertification

Objectives and content
- To cooperate with the CRTO (Centre Régional de Télédétection de Ouagadougou, Upper Volta) in the setting up of an information bank for the selection and acquisition of significant satellite imagery (including 'unconventional' SIR imagery, MOMS, Metric Camera imagery) on Sahelian countries and for training in the use of the new imagery.
- To train CRTO staff and selected users in information management.
- To organise a final evaluation Seminar for the various EEC projects on desertification.

Responsible organisation
International Institute for Aerial Survey and Earth Sciences (ITC), Enschede (The Netherlands), in cooperation with CRTO (responsible for archiving and training in West Africa).

African countries involved
All Sahelian countries covered by the Maspalomas ground station.

In Brief

First Ariane-3 Launch a Total Success

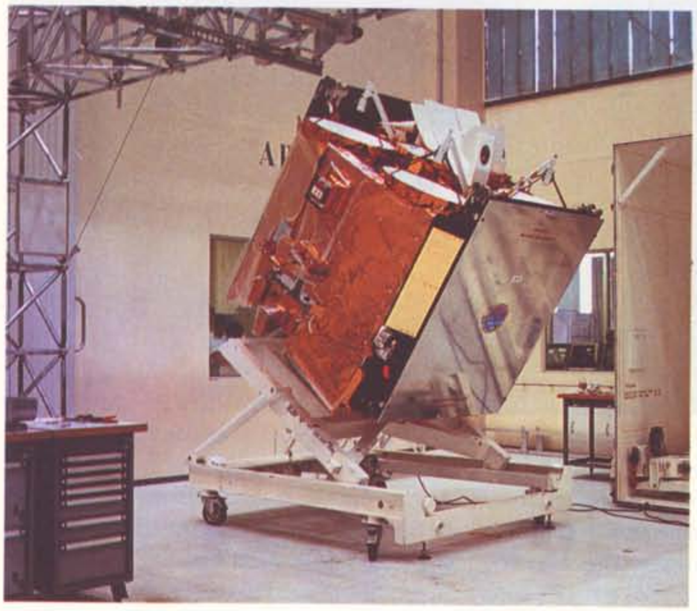
The first Ariane-3 vehicle was launched by Arianespace from Kourou, French Guiana, on 4 August 1984 at 13 h 32 m 54 s GMT (10 h 32 m 54 s Kourou time). The two customer spacecraft, ECS-2 (the second unit in ESA's European Communications Satellite Programme) and Telecom-1A (the first unit of the French communications satellite programme), were injected into a near-nominal transfer orbit:

Perigee:	199.2 km (Target: 200 km)
Apogee:	36 091 km (Target: 36 050 km)
Inclination:	6.98° (Target: 7.00°)

The first evaluation of radar and telemetry data showed that all launcher systems, including the new and modified elements (see below), functioned perfectly. Spacecraft environmental conditions during boosted flight were as expected, and spacecraft separation was completely nominal (orientation, spin rate, etc.). All Guiana Space Center range facilities, including the down-range stations, functioned correctly, the telemetry reception station at Akakro, Ivory Coast, actively participating for the first time.

The apogee boost motors of both satellites were fired as planned at their fourth apogee. The planned orbits were achieved as expected, both spacecraft hydrazine budgets being very favourably conserved because of the precise

The ECS-2 spacecraft



Mating of ECS-2 and apogee boost motor

launcher trajectory. Both satellites' telecommunications payloads were switched on at the end of August 1984, when in-orbit testing started (see below).

The launch campaign had started on 22 June for the launcher, and on 21 June and 20 June for ECS-2 and Telecom-1A, respectively.

Ariane-3 is an upgraded version of the Ariane-1 launcher, able to deliver 2585 kg into geostationary transfer orbit, compared with 1845 kg for Ariane-1. It differs from Ariane-1 in the following respects:

First stage
- The addition of two solid boosters, each delivering 70 kN of thrust.
- An increase in thrust resulting from an increased combustion pressure (up from 53.5 to 58.5 bar).
- Adaptation of the thrust frame and interstage structure to permit attachment and separation of boosters.

Second stage
- An increase in thrust resulting from an increase in combustion pressure (up from 53.5 to 58.5 bar).

Third stage
- A stretched structure, allowing the mass of cryogenic propellants to be raised from 8 to 10.5 tons.
- An increase in thrust resulting from an increase in engine combustion pressure from 30 to 35 bar and lengthening of the expansion nozzle.

Fairing
- Use of a biconical fairing to allow the accommodation of two Delta PAM-D class satellites.

The Ariane-2 version, which differs from Ariane-3 by the absence of the solid boosters, can lift at least 2200 kg into GTO.

The next Ariane launch is scheduled for early November 1984, when another Ariane-3 will launch Marecs-B2, the third unit of ESA's Maritime Satellite Programme and Spacenet-II, the second satellite belonging to the American firm GTE/Spacenet.

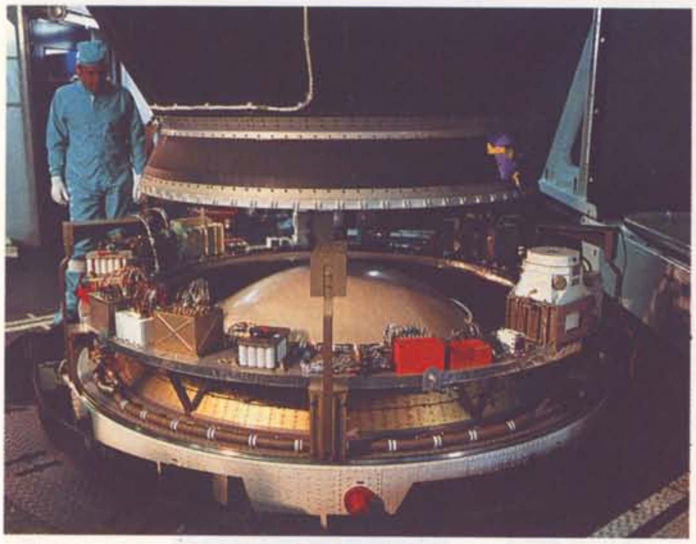
The accompanying photographs, taken at the Kourou Launch Base, show the final stages of integration of ECS-2 and Telecom-1A, prior to launch on Ariane-3's inaugural flight.

Mating of ECS-2 and the SYLDA

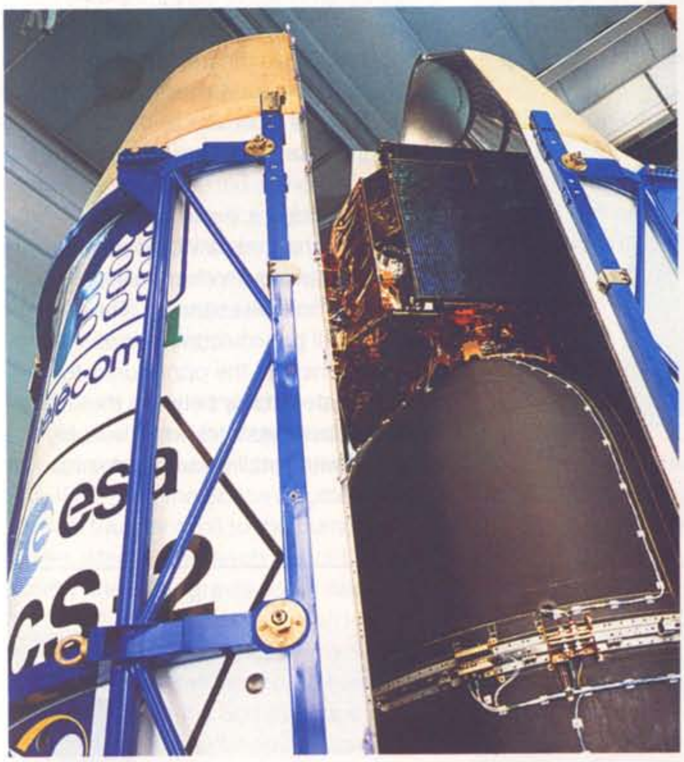
Closure of the SYLDA

Telecom-1A inside the SYLDA

Transportation of the SYLDA to the launch tower



Mating of the SYLDA and Ariane-3 third stage



Closure of the fairing

ECS-2 On-Station

The first spin-up manoeuvre, bringing the ECS-2 spacecraft's rotation rate up to 56 rpm, was successfully performed from the Agency's European Space Operations Centre (ESOC) in Darmstadt, Germany, less than 3 h after launch. The final spin-up prior to apogee-boost-motor firing was performed at 20.15 h GMT on 4 August.

On 23 August, ESOC carried out the final manoeuvre required to halt ECS-2 at its test location in geostationary orbit at 10°E and terminate the drift phase that began with the successful firing of the boost motor on 6 August.

Signature of the ECS-2 hand-over documents by Dr. A. Caruso (left), Secretary General of EUTELSAT, and Prof. R. Lüst (right), ESA's Director General, on 12 October at ESOC, in Darmstadt

The commissioning and acceptance testing of the spacecraft and its payload took place over a period of several weeks. Only thereafter was ECS-2 moved to its final position at 7°E, prior to its handover, on 12 October, to the European telecommunications organisation EUTELSAT, for operational communications service.

With this handover, the existing 12 EUTELSAT channels will be doubled and there will be two extra channels for specialised business services. These extra channels will provide commercial organisations with the opportunity to communicate directly between their dispersed business sites when suitably equipped with small ground terminals.

Launch Contract for Giotto Signed

The contract for the launch of the Agency's Giotto spacecraft was signed at ESA's Paris Headquarters by Prof. R. Bonnet, ESA's Director of Scientific Programmes, and Mr. C. Bigot, Arianespace's Director General, on 12 July 1984.

Giotto will be launched into its heliocentric transfer trajectory aboard an Ariane-1 launcher, procured by ESA within the framework of the Ariane promotion series, in July 1985.

During its subsequent eight-month journey to rendezvous with Halley, Giotto will be controlled from the Agency's European Space Operations Centre (ESOC) in Darmstadt, Germany (see page 30 of this issue).

ESA Acquires Landsat-4/5 Data at Maspalomas

The Agency's Earthnet ground station at Maspalomas, Canary Islands, began collecting and recording Multi-Spectral Scanner (MSS) data from NOAA's Landsat-4 and -5 satellites early in July. This activity forms one element of a cooperative venture between ESA and the Commission of the European Communities to exploit space technology in support of the Commission's development-aid projects to combat World hunger.

The data acquired at Maspalomas are processed by Earthnet and made available to interested users, including Commission-sponsored investigators who perform research and applications work within the areas of satellite coverage, particularly in the Sahel, in Africa (see page 66 of this issue).

The project is expected to contribute significantly to Commission-financed studies in agricultural production estimation, water-resources and pasture-area management and desert and forestry monitoring and control, since it provides remote-sensing data at regular intervals over twelve West-African countries.

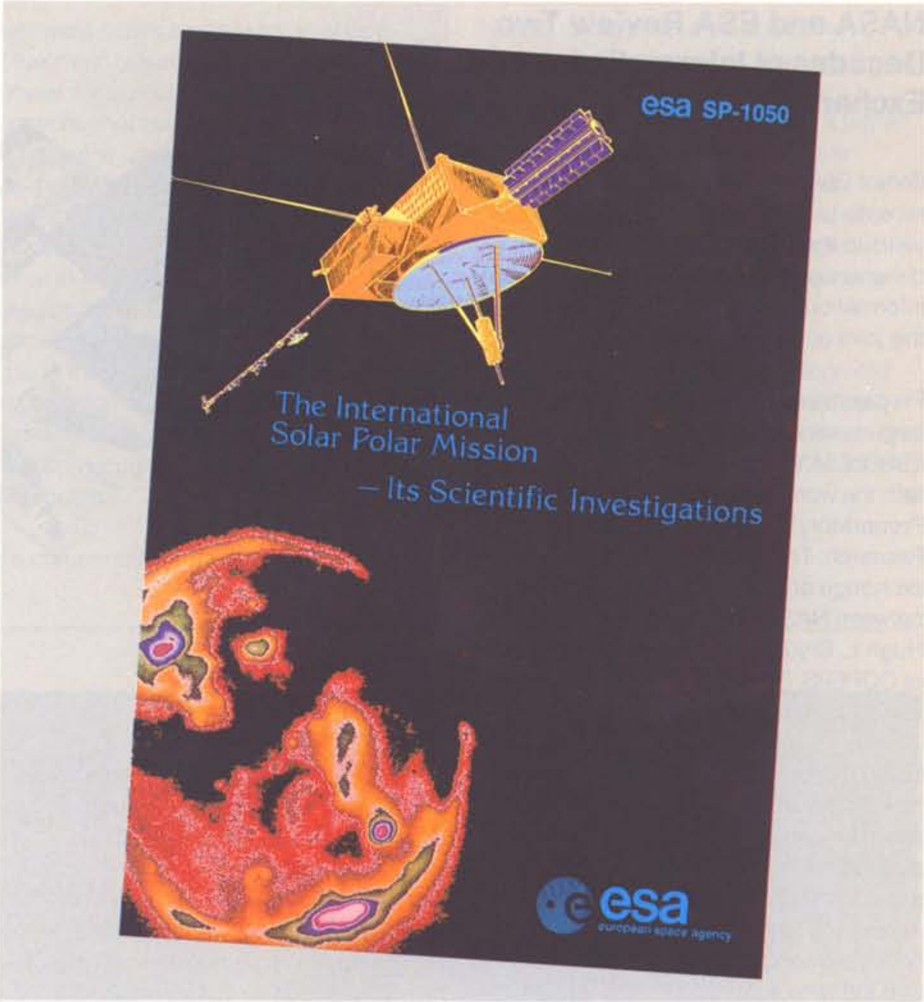
Further information can be obtained from the ESA Earthnet Programme Office, ESRIN, PO Box 64, 00044 Frascati, Italy (Tel. 39/6-940 12 16).

ISPM – 'Ulysses'

The joint ESA/NASA International Solar Polar Mission (ISPM) is being renamed 'Ulysses'. This name has been chosen in reference not only to Homer's mythological hero, but also the Italian poet Dante's description, in the 26th Canto of his Inferno, of Ulysses' urge to explore 'an uninhabited world behind the Sun'. The latter reference is particularly appropriate for a mission that will permit in-situ measurements to be made for the first time over the poles of the Sun away from the ecliptic plane.

To reach its unique trajectory, taking it into the uncharted third dimension of the heliosphere, Ulysses will be launched, in May 1986, from the Space Shuttle into an elliptical transfer orbit to the planet Jupiter, which it will reach about fourteen months later. The gravitational field of Jupiter will deflect the spacecraft into a high-inclination orbit out of the ecliptic plane to pass, some two and a half years later, over one of the Sun's poles. It will then recross the ecliptic plane, reaching the other pole about eight months later. The complete mission will last five years.

The goals of the Ulysses mission and the experiments to be carried are described in detail in ESA Special Publication SP-1050, 'The International Solar Polar Mission – Its Scientific Investigations', available from ESA Scientific & Technical Publications Branch (317 pages, price 175 French francs, or equivalent).



ESA Staff Receive Spacelab Honours Awards

On 10 July, ESA's Director of Space Transportation Systems, Mr. Michel Bignier, received the NASA Distinguished Public Service Medal at the 'Spacelab Honor Awards' ceremony in Washington. The medal, presented by NASA's Administrator Mr. James M. Beggs, was awarded in recognition of his exemplary contributions to the development of the Spacelab system and its successful first mission.

Public Service Medals, granted for exceptional contributions to engineering design and development/programme management coordination, were awarded to seven ESA staff at the Washington ceremony: Gordon R. Bolton, Karl Knott, Frank A. Longhurst, Wubbo Ockels, Burkhard Pfeiffer, Lars G. Tedeman and Alan Thirkettle.

On 17 July, the United States Ambassador to France, Evan G. Galbraith, presented Mr. Erik Quistgaard, then Director General of ESA, with the NASA Distinguished Public Service Medal in recognition of his 'many exceptional contributions to the peaceful exploration of space and his strong commitments to international cooperation, particularly between Europe and America, during the period of his distinguished leadership as ESA's Director General'.

NASA and ESA Review Two Decades of Information Exchange

Senior ESA and NASA officials met recently to review progress over the last 20 years in their collaboration in the dissemination of scientific and technical information and to chart future steps in this joint endeavour.

Preparations for this cooperation were begun even before the formal creation of ESRO, ESA's predecessor organisation, with the work of COPERS, the European Preparatory Commission for Space Research. This effort was initiated by an exchange of letters in the spring of 1964 between NASA's Deputy Administrator, Dr. Hugh L. Dryden, and the Director General of COPERS, Professor Pierre Auger (see ESA Bulletin No. 39, page 27).

Early cooperation involved the provision by ESRO of abstracts of European scientific and technical reports for publication in NASA's semi-monthly journal Scientific and Technical Aerospace Reports (STAR). In return, NASA provided copies of STAR to ESRO, and the two organisations exchanged reports both in microfiche and hard-copy.

In 1969, NASA and ESRO implemented the next phase of this cooperation, making the computer-based STAR Catalogue and the International Aerospace Abstracts (IAA) database available online in Europe to ESRO Member-State organisations capable of providing suitable input for the NASA Information System. In addition, ESRO undertook to process (catalogue, index, abstract, microfiche, and prepare magnetic tapes in accordance with NASA's standards and procedures) European input for the NASA System and to provide English translations of certain space-related technical report series issued by German and French organisations.

First Meeting of Association of European Astronauts

Following discussions at the annual Meribel meeting of July 1984, the astronauts of Western Europe have formed an Association of European Astronauts (AEA). The aims of the AEA are to encourage get-togethers for the exchange of views on their training experience and the projects concerned. All European astronauts who have flown or have been selected to train for a specific mission are eligible to join the AEA.

The AEA presently has seven members: three ESA astronauts, Claude Nicollier, Ulf Merbold and Wubbo Ockels; two French astronauts, Patrick Baudry and Jean-Loup Chrétien; and two German astronauts, Reinhard Furrer and Ernst Messerschmid. Ulf Merbold has already flown on the US Space Shuttle during the first flight of Spacelab, and Jean-Loup Chrétien has flown on the USSR Soyuz T-6/Salyut 7 mission. The other astronauts have been assigned to flights that will take place during 1985.

It is hoped that this pooling of the astronauts' expertise and knowledge will be of mutual benefit and will contribute to the general public's 'awareness' regarding manned-spaceflight activities involving the various countries of western Europe.

Further information can be obtained from Dr. Wubbo Ockels, DFVLR, Linder Höhe, (Postfach 906058), D-5000 Porz-Wahn, Germany (Tel. 19 49/2203 601 2824).

ESA's First 'Get Away Special' Payload

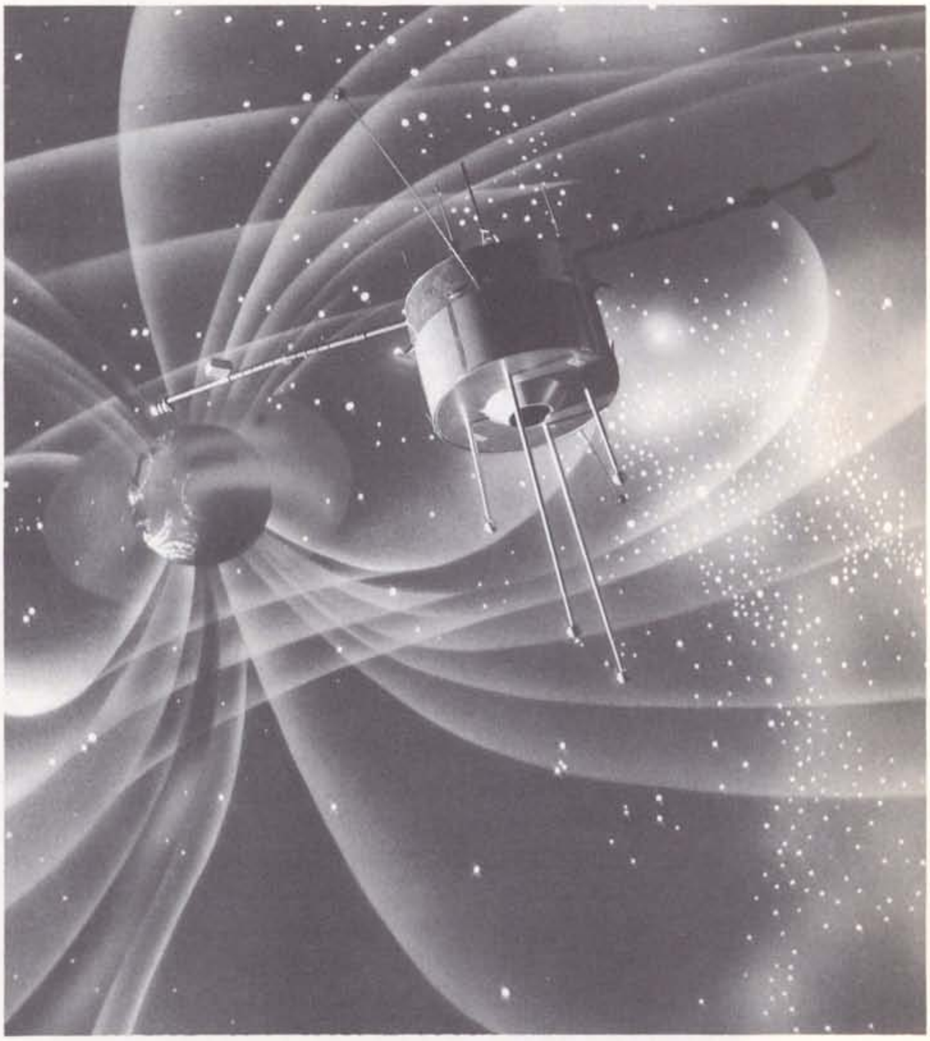
The Space Shuttle launched on 5 October 1984 carried an ESA-funded Halogen Lamp Experiment – 'Halex' – as a 'Get Away Special' payload (a small, self-contained payload which can be flown in the Shuttle's cargo bay when not fully occupied by the primary payload, each experimenter being responsible for providing his own electrical power, heating, data handling facilities, etc.).

Halogen lamps will be used as heat sources for the optical radiation furnaces now under development for future materials-sciences research in space. Their main advantage lies in their low power consumption compared with conventional heating elements, but there is still some uncertainty as to whether they will perform reliably during extended periods of microgravity. The Halex experiment is intended to determine to what extent the absence of convection reduces the effectiveness of the 'halogen cycle', in which the molecules of halogen gas in the lamp react chemically with the evaporated tungsten and draw it back to the filament, where the reverse chemical reaction occurs and the tungsten redeposits.

To compensate for the much shorter mission duration time on board the Shuttle – 8-10 days as opposed to six months or so for retrievable carriers such as Eureca – the lamp was run at a higher power level than normal to simulate several hundred hours of operation. During flight, the radiation behaviour of the lamp was measured and recorded and the results obtained are now being analysed.

The Halex payload was built, integrated and tested by the German firm Kayser-Threde, while the mirror compartment and halogen lamp were supplied by another German firm, Dornier System.

Agency's Geos-2 Satellite Reactivated



At the request of Switzerland and Germany, ESA has reactivated Geos-2, which was launched into geostationary orbit on 14 July 1978 and completed its planned scientific mission in July 1980. In response to the continued interest of the scientific community, Geos-2 operations were resumed in 1981 and continued until the end of 1983. The last year of this extension was carried out as a special project financed bilaterally by Germany and Switzerland.

Last January, to vacate a slot in the densely occupied geostationary orbit, Geos-2 was moved into a higher and slightly asynchronous orbit (see ESA Bulletin No. 38, page 86) where it now drifts about 3.5° in longitude per day, becoming visible to ESOC's Michelstadt ground station for 4 weeks every 3.5 months.

Given the good health of both spacecraft and payload, in view of the scientific community's wish to obtain data over a complete 11-year solar cycle, and to support the current Active Magnetospheric Particle Tracer Experiment (AMPTE – being undertaken jointly by Germany, the United Kingdom and the USA), Switzerland and Germany have agreed to finance this further year of Geos-2 operations.

Geos-2 data have already been widely used in correlations with ground-based data and also with data from other satellites and the satellite has made a significant contribution towards identifying the composition and movements of plasma around the Earth's magnetosphere. Geos-2, which served as a reference spacecraft for the International Magnetospheric Study (IMS), has therefore substantially increased our understanding of our near-Earth environment.

and twenty years ago . . .

EUROPEAN SPACE RESEARCH ORGANISATION (ESRO) N° 6

36, Rue La Pérouse, Paris 16 - Tel. 225.24.02 November 1964

NEWS IN BRIEF

I. ESRO NEWS

MEETING

- 22 October : At an EXTRAORDINARY MEETING OF THE COUNCIL, under the chairmanship of Dr. HOCKER, (Fed. Rep. of Germany), it was agreed to accept the site at Noordwijk (Netherlands) offered by the Netherlands Government for the European Space Technology Centre - ESTEC - which is provisionally working in buildings belonging to the Technological University in Delft.

  The first slice of the Noordwijk construction programme will be the building concerned with environmental testing. Construction will begin in January 1965 and the building, covering an area of 3 600 sq. m., is due to be completed by the end of 1965.

- 10-11 September : 1st meeting of the SCIENTIFIC AND TECHNICAL COMMITTEE (STC); election of the Chairman : Dr. LUST (Fed. Rep. of Germany). Approval of some of the payloads for the first sounding-rocket launching programme (1964-1965); preliminary approval of the experiments to be carried by the first stabilised satellite, due to be launched towards the end of 1968 or beginning of 1969; drawing up of a list of negative priorities for the experiments to be mounted in the satellite ESRO I (to be launched towards the end of 1967); for reasons of weight, withdrawal of two experiments from the payload of the ESRO II satellite, due to be launched at the beginning of 1967.

  (Since a Council decision on these matters is still pending the scientific programme proposed by the STC and the list of the national groups concerned will be given in the next issue of News in Brief).

  The Committee adopted its Rules of Procedure and agreed to maintain the scientific ad hoc groups which functioned during the interim period:

  ATM "Atmospheric Structure" (Chairman: Dr. R. Frith, Fed. Rep. of Germany),

Page 2

ION "Ionosphere and Auroral Phenomena" (Chairman: Dr. B. Hultqvist, Sweden; Deputy Chairman: Prof. R. L. F. Boyd, U.K.),

SUN "Sun" (Chairman: Prof. C. de Jager, Netherlands),

PLA "Moon, Planets, Comets and Interplanetary Medium" (Chairman: Prof. L. Biermann, Fed. Rep. of Germany),

STAR "Stars and stellar systems" (Chairman: Prof. P. Swings, Belgium),

Subgroup LAS "Large Astronomical Satellite" (Chairman: Dr. Butler, U.K.),

COS "Cosmic Rays and Trapped Radiation" (Chairman: Prof. G. Occhialini, Italy),

- From 1 to 9 October : meetings of the Scientific ad hoc Groups LAS, ION, ATM, SUN, PLA and COS as well as the CFSG (Group set up in February 1964 for the purpose of studying a possible cometary mission).

- 6 November : The Launching Programmes Advisory Committee (LPAC) considered the present status of the launching programme, recommending modifications to the composition of the payloads and the addition of new payloads to the 1965 programme; discussed the question of stabilised rockets and payloads recovery, and other matters concerning the Organisation's future policy.

- A brief report on the second meeting of the STC (17-18 November) will be given in the next issue of this bulletin.

- 24-26 September, Paris: SECOND MEETING OF THE ADMINISTRATIVE AND FINANCE COMMITTEE (AFC), under the chairmanship of M. SASSOT (Spain):
Approval of the placing of contracts. Study contracts relating to the stability of highly eccentric orbits (Société SEREB, France) and to the location of a tracking and telemetry station in Belgium (Sonectro, France). Purchase contracts for two thermal vacuum test facilities (High Vacuum Equipment, USA ; European Consortium of Hereaus, Germany - Associated Electrical Industries, USA - Sogev, France) ; Magnetometers (Schonstedt Instrument Company, USA) ; Payload Components (Sud-Aviation, France). Contract for technical aid for the

Page 3

operation and on-the-spot checking of payload VI, to be launched from the Ile du Levant (Sud-Aviation, France). The Secretariat was authorised to continue negotiations with the British Aircraft Corporation (U.K.) with a view to purchasing Skylark rockets and payload components.

The Director General was authorised to conclude an agreement with CNES and Sud-Aviation for the purpose of using Sud-Aviation's launching team, at present in the Ile du Levant, for the forthcoming launching of two Centaure rockets.

Personnel Matters

The AFC agreed that tenders should be invited from insurance firms with a view to setting up an independent Social Security Scheme.

- 7, 8 and 9 October : The Group of Finance Experts met in Delft, under the chairmanship of M. DOUXCHAMP (Belgium). This group was set up at the second meeting of the AFC to study the draft amendments submitted by the Secretariat concerning the rate and amount of expenditure in 1965. Dr. Lüst, Chairman of the Scientific and Technical Committee, attended the meeting.

- 4-6 November 1964, Madrid: At its third meeting the ADMINISTRATIVE AND FINANCE COMMITTEE (Chairman: M. Sassot) recommended that the Council adopt the revised draft budget for 1965, amounting to:

F. 173 499 million for contract authorisations

and F. 85 799 million for payment appropriations.

The Committee determined the rate at which contracts should be placed and staff recruited (staff ceiling : numerical strength by the end of 1965: 827).

Subject to certain conditions, the Committee accepted the proposal to place a joint contract with the Automation Center International of Berne, and Documentation Incorporated of Bethesda, Maryland, for providing a documentation service to be available to European space organisations and Member States.

The Committee approved lease contracts for the Headquarters accommodation in Paris and building contracts for temporary accommodation for ESRANGE AND ESTEC.

Page 4

MISSION

Professor Lüst, Chairman of the Scientific and Technical Committee, Dr. Lines, Technical Director of ESRO and Mr. L. A. Husain, Head of the Large Satellite Division at ESTEC, visited the United States from 19 to 23 October 1964 in order to examine the NASA management of the OAO (Orbiting Astronomical Observatory) Project with special reference to the Spacecraft/Experimental Package relationship.

DISTINCTION

Professor Van de Hulst, Vice-Chairman of the ESRO Council, has received from the Royal Society the Rumford Prize for his scientific work.

HEADQUARTERS

Staff members having joined since 1 September 1964 : Mr. G. Dondi (Italy), Engineer in the Technical Programmes Directorate; Mr. H. Neschke (Fed. Rep. of Germany) Assistant to the Head of the Contracts Section; Mr. N. Isotta (U.K.) Assistant to the Head of the Documentation Service.

NEWS OF THE ESTABLISHMENTS

See next issue of News in Brief for this item.

LAUNCHINGS

A Centaure rocket was launched from the Ile du Levant (France) at midnight, 30th October, with payload No. 6 (airglow photometers). For reasons which are being investigated, the scientific equipment did not function satisfactorily. The second launching was withdrawn pending the results of this investigation.

Publications

The documents listed have been issued since the last publications announcement in the Bulletin. Requests for copies should be made in accordance with the Table and using the Order Form inside the back cover of this issue.

ESA Journal

The following papers have been published in ESA Journal Vol. 8, No. 3:

THE GIOTTO SPACECRAFT SYSTEM AND SUBSYSTEM DESIGN
LO GALBO P

IRAS THERMAL MISALIGNMENT – A LESSON FOR THE FUTURE
KARSTEN L & TEULE F

MODELLING ICE-SHEET SURFACES FOR ERS-1'S RADAR ALTIMETER
MCINTYRE N F & DREWRY D J

A DISTRIBUTED CIRCUIT-DESIGN TECHNIQUE FOR THE DESIGN OF BROADBAND, LOW-NOISE MULTISTAGE AMPLIFIERS
GIBSON M H

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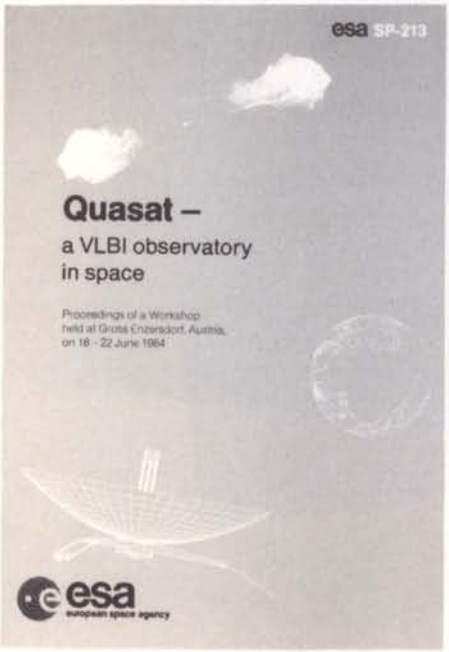

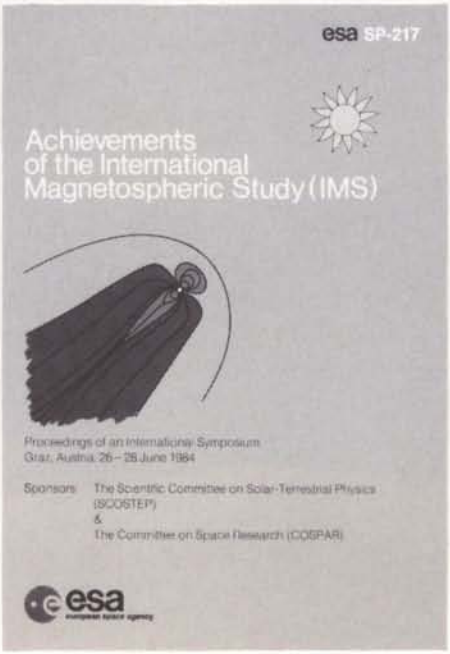

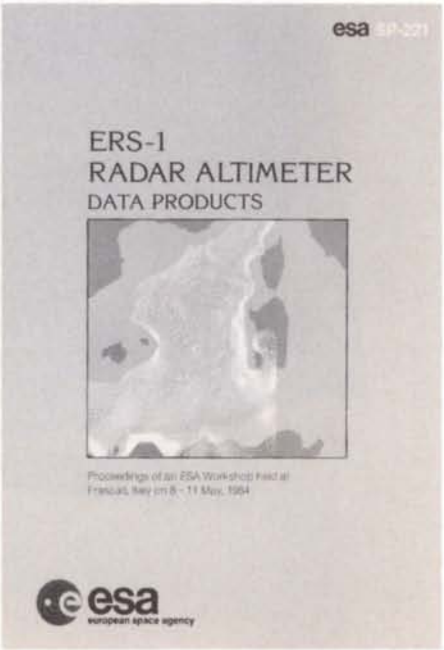

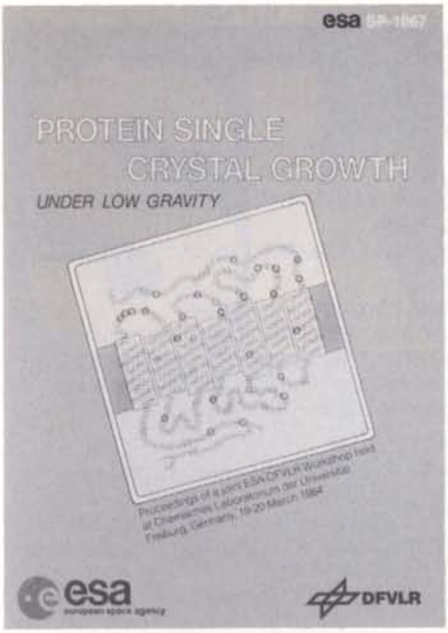

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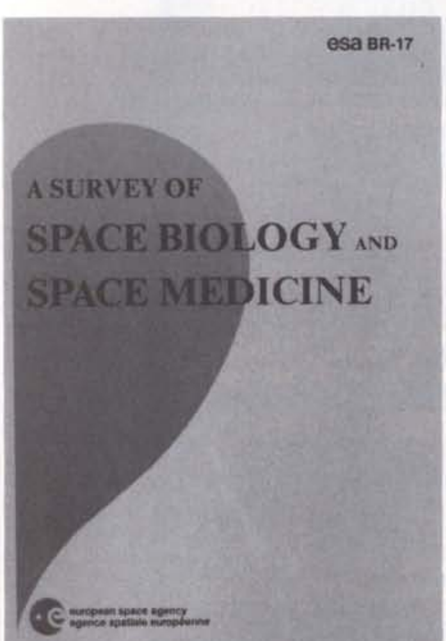

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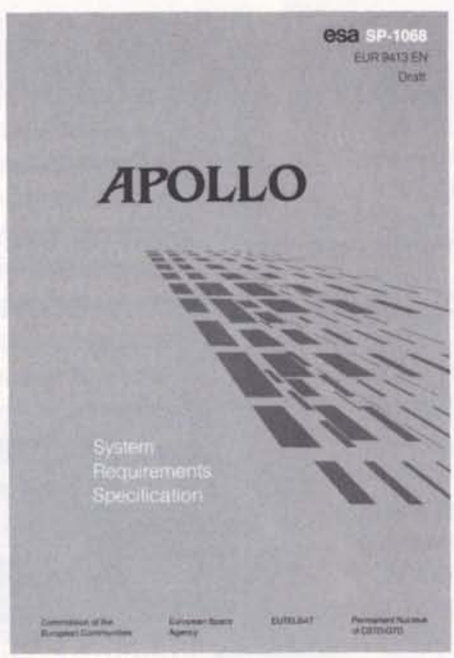

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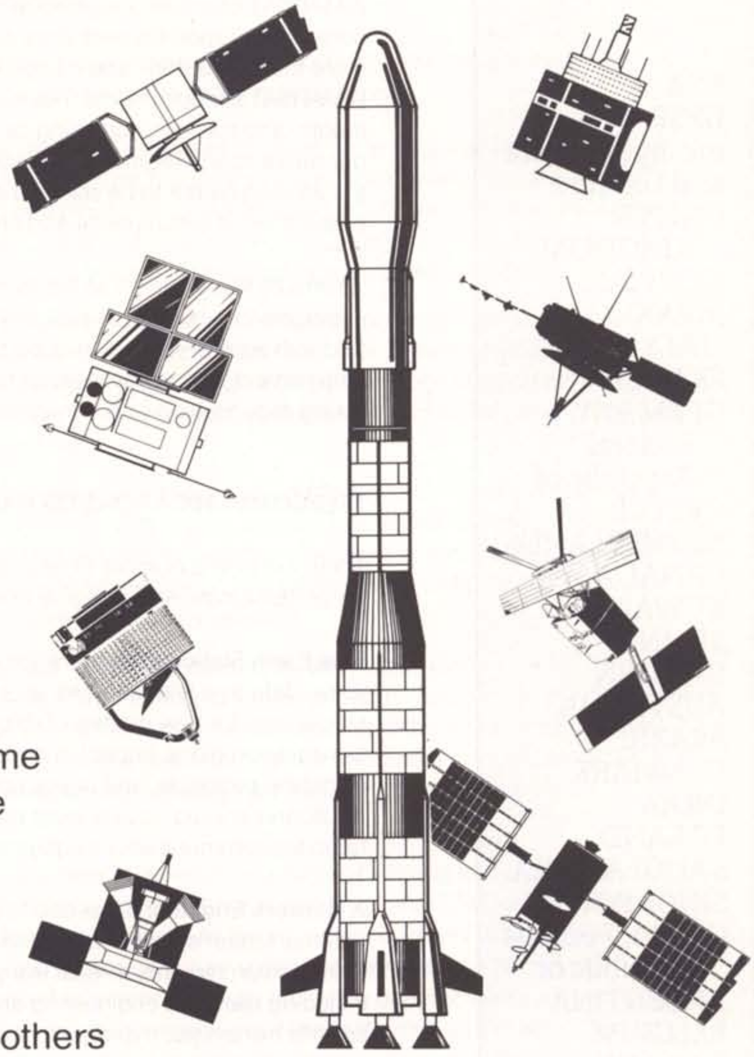

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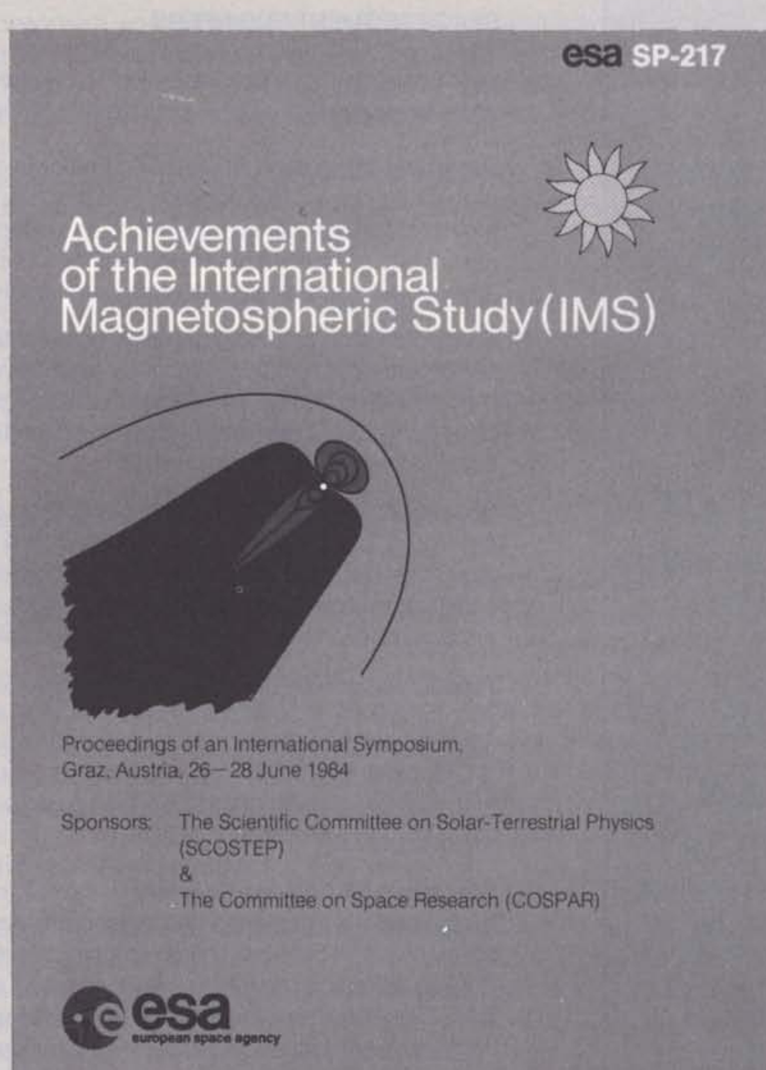

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