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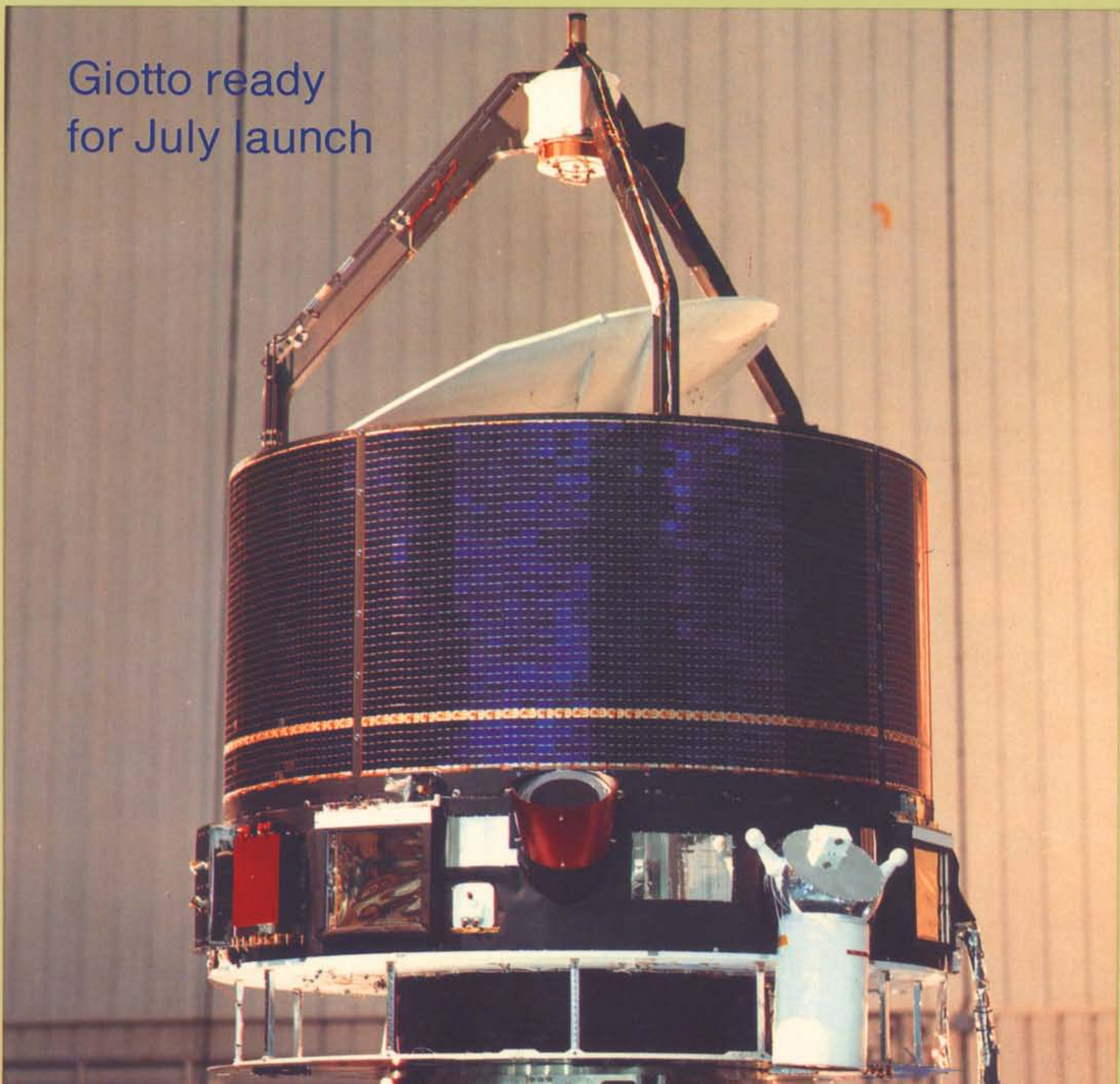

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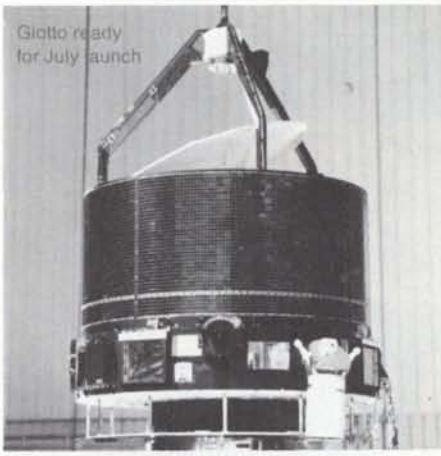

Front cover: The Agency's Giotto spacecraft, which will set out in July for its rendezvous next year with Comet Halley

Back cover: Installation of the Instrument Pointing System (IPS) aboard Spacelab-2 at Kennedy Space Center

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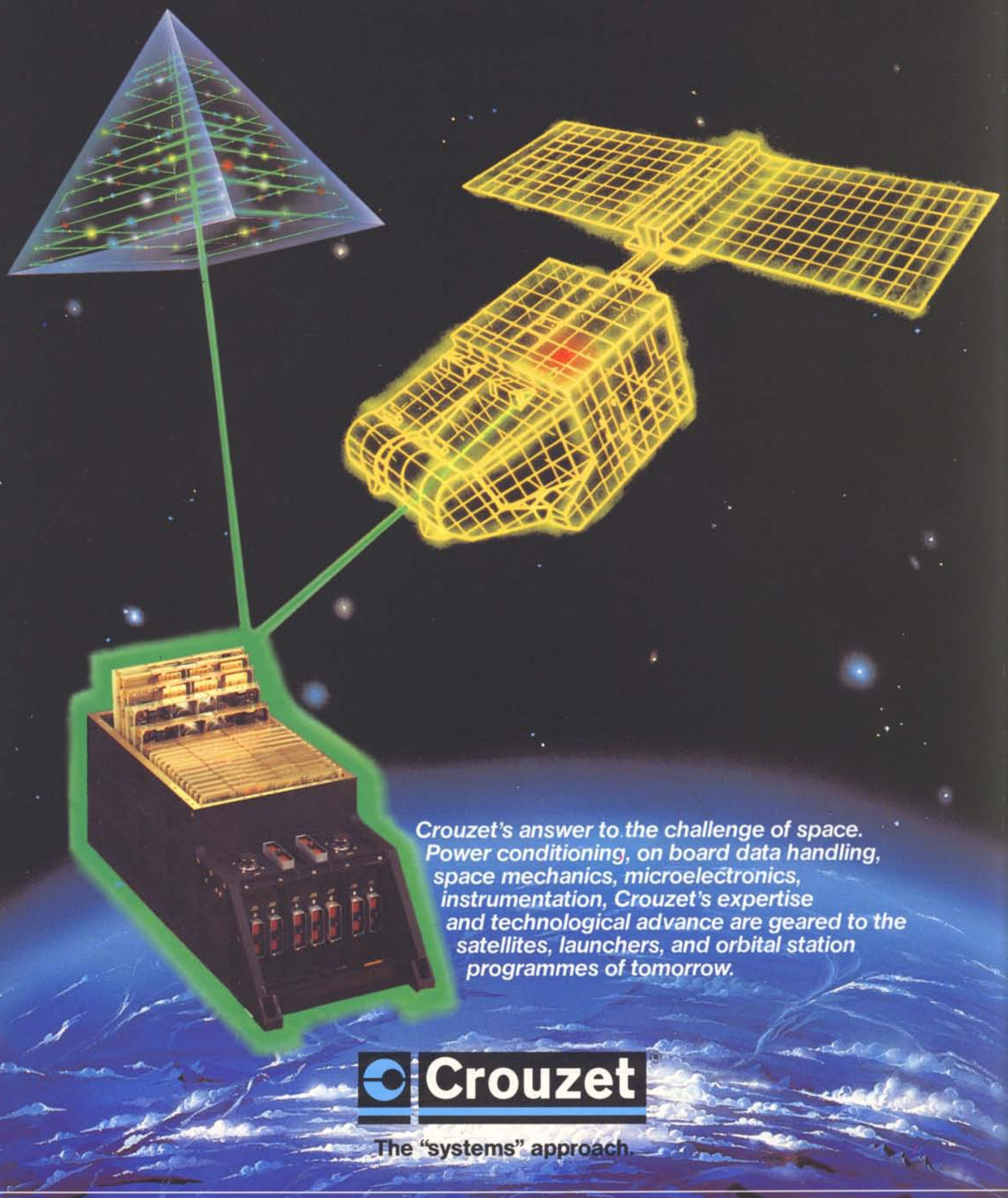
Crouzet, the space challenger



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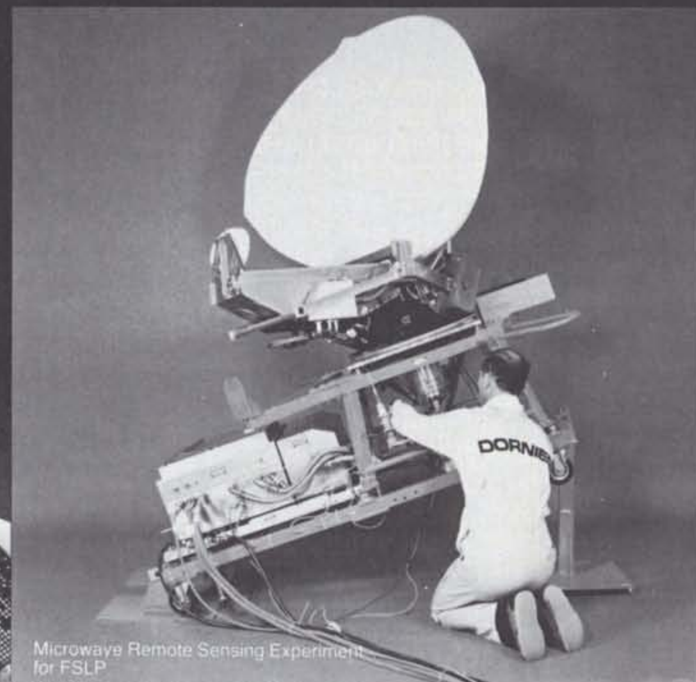
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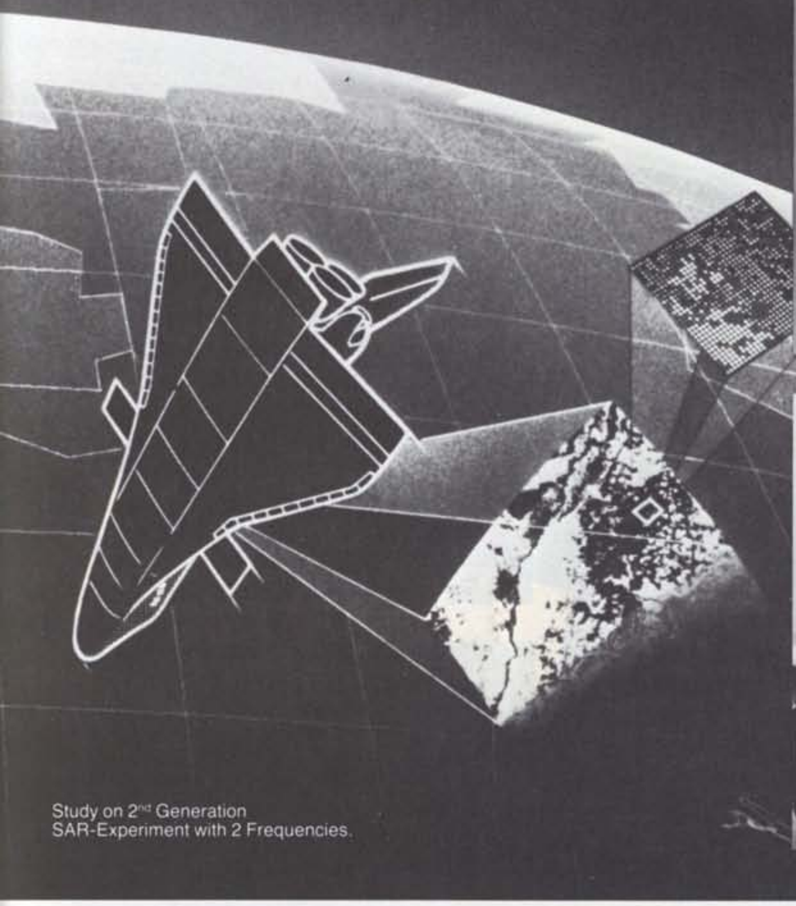
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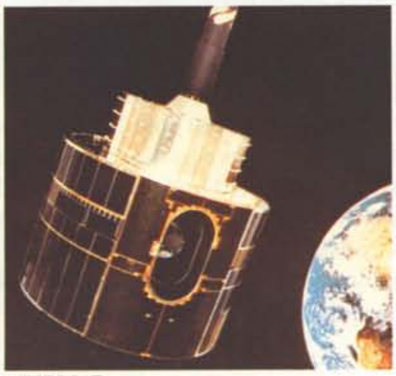

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Gamma-Ray Astronomy and The Spirit of Cos-B

R. Lüst, Director General, European Space Agency, Paris

This article is based on an Invited Lecture presented at a Symposium organised in Leiden in November 1984 in honour of Prof. Henk van de Hulst.

Henk van de Hulst was instrumental in the birth of the European Space Research Organisation (ESRO), ESA's forerunner, serving as Vice Chairman of COPERS, the 'Preparatory Commission to Study the Possibilities of European Collaboration in the Field of Space Research', set up on 1 December 1960. He became Vice Chairman of the ESRO Council in 1964, and served as its Chairman from 1968 until 1970. Between 1964 and 1973 he was the Netherlands' Delegate to ESRO and from June 1972 until 1975 he was Chairman of ESRO's Launching Programmes Advisory Committee. He has been Chairman of the Cos-B Steering Committee (1968–1977) and of the Space Telescope Instrument Science Team (1977–1983) and a Member of the ST Advisory Team (1972–present) and NASA/ESA ST Science Working Group (1977–present).

In 1974 and 1975 Henk van de Hulst was Member and Vice Chairman of the Space Science Committee of the European Science Foundation and from 1975–1979 served on the Foundation's Astronomy Committee.

Henk van de Hulst has been a Member of the Science Programme Committee of ESRO and ESA since its inception. His untiring pursuit and promotion of European space research have played a major role in the birth and growth of both ESRO and ESA.

Introduction

Now it is true that the development of gamma-ray astronomy over the last 25 years has been connected with the European scientific satellite Cos-B. But what one might ask, could the 'spirit of Cos-B' mean? Given my limitations in English, I felt I should consult Webster's Dictionary. There I found quite a number of meanings connected with the word 'spirit', but I wondered how they could be connected with gamma-ray astronomy, with the Cos-B project, or with the reasons for this Symposium. In the dictionary I found:

1. Spirit – strong distilled alcoholic liqueur. I could see almost no connection, since the spark chamber of Cos-B was filled with neon, and not with alcohol, which was only requested during the more depressing phases of the project by certain persons.
2. Spirit – a supernatural being, an angel, a ghost. This too could not be the meaning, although in some circumstances there apparently were angels who helped in the Cos-B project.
3. Spirit – the inspiring principle or dominant influence, soul.

Figure 1 — Prof. Henk van de Hulst (left) in discussion with Prof. Pierre Auger, on the occasion of the 10th Anniversary of ESRO/ESA, in 1974

I concluded that this third definition must be the right one, since it brings together gamma-ray astronomy, the Cos-B project, and the person in whose honour we are holding this Symposium, namely Henk van de Hulst. He was important for the inspiring principle of Cos-B, he strongly influenced it, and he was one of the 'souls' of the Cos-B project.

A European presence in the science of space astronomy, i.e. the observation of celestial objects with instruments above the Earth's atmosphere, would not have been possible but for the endeavours of a few astronomers who, together with their physicist colleagues, had the vision, at the end of the fifties, to make plans for a European Space Research Organisation. Most astronomers were not even willing to contemplate such a step at that time, because they feared competition between the budgets for space astronomy and those earmarked for ground-based observatories.

One of the first European promoters of a Space Research Organisation in Europe was Henk van de Hulst, who at that time was President of COSPAR. At the first COSPAR Symposium in Nice in January 1960, Edouardo Amaldi, Pierre Auger, Sir Harrie Massey and Henk van de Hulst himself discussed with others the first plans, from which initially ESRO and later ESA subsequently developed. He was also responsible for my participation in the preparations for ESRO, and hence in part for my being with the Agency today.

The development of gamma-ray astronomy

New discoveries in physics and new experimental techniques in physics and engineering, as well as new theoretical insights, have opened up more and more new branches and fields in astronomy. As a result, astronomy has been 'invaded' several times by scientific experts from completely different fields, and it has always taken some time for them to be accepted by the traditional astronomy community.

This process could be observed when radio astronomy developed, and a very similar thing happened when space technology opened new perspectives for the observation of astronomical objects. I had first met Henk van de Hulst not at a meeting primarily organised by the astronomers, but at one organised by radio-engineers and experts on the ionosphere, namely the URSI Meeting in The Hague in 1954. It was at that Meeting that the Dutch astronomers presented their impressive results on the observation of the 21 cm line that Henk van de Hulst had predicted back in 1944.

High-energy particle physics had been, in part, the domain of the cosmic-ray physicists and it was they who pointed out the possible importance of gamma-ray astronomy. The scientific potential of this part of the electromagnetic spectrum for astronomy had been recognised from a theoretical viewpoint since the early fifties, by such researchers as P. Morrison, E. Schatzmann, W.I. Ginsburg, S.V. Syrovatskij, S. Hayakawa and G. Hutchinson.

Gamma rays originate wherever a suitable combination of highly relativistic charged particles and matter or electromagnetic fields is present, so that astrophysical processes involving large transfers of energy can occur. In many cases these concentrations of energy are not detectable at other wavelengths, nor can they be traced by studying the particles themselves, since they have lost all directional information upon arrival at the Earth due to their diffuse passages through the magnetic fields of interstellar space. By contrast, gamma rays travel in straight lines from their sites of origin and therefore gamma-ray astronomy has the potential to reveal as yet unseen highly energetic processes. Of the utmost importance is the penetrating power of

Figure 2 — The TD-1A second prototype model undergoing moment-of-inertia measurement

gamma rays, which exceeds that of softer photons. In fact, the attenuation of gamma radiation from any part of the Galaxy or Universe can be neglected due to the very small interaction cross-section of gamma rays in the energy range considered.

However, in spite of what gamma-ray observations could tell us about the Galaxy and the Universe, this branch of astronomy has been very slow in developing, because the intensities are very low, and the background produced locally within the instrumentation or the surroundings by the interacting particles of the cosmic radiation is very high. As a result, it has taken many years and quite a number of unsuccessful missions for the techniques to be developed sufficiently to allow satisfactory observations to be carried out.

Many groups tried to detect celestial gamma rays, first with relatively simple instruments and later with larger, more sophisticated detector systems flown on balloons. Until about 1967, these early attempts were either negative or inconclusive. The first certain detection of galactic high-energy gamma rays was made by W. Kraushaar and his collaborators with the pioneering experiment on board the OSO-3 satellite launched in 1967. They measured gamma rays with energies in excess of 50 MeV from the Galactic Plane. Although the total number of photons collected was only 631, their galactic longitudinal distribution showed a clear peak in intensity towards the Galactic Centre.

A big step forward was made with the launch of the first second-generation satellite experiment onboard the SAS-2 spacecraft, on 15 November 1972. The sensitivity of the SAS-2 gamma-ray telescope was approximately twelve times that of OSO-3 and the angular resolution was improved to a few degrees. Important results could be obtained by this mission – about 8000 gamma photons were received – but, unfortunately, it failed after only seven months. The general picture of our Milky Way improved and three gamma-ray point-like sources, the Crab and Vela pulsars and an unidentified source in the constellation of Gemini, were observed.

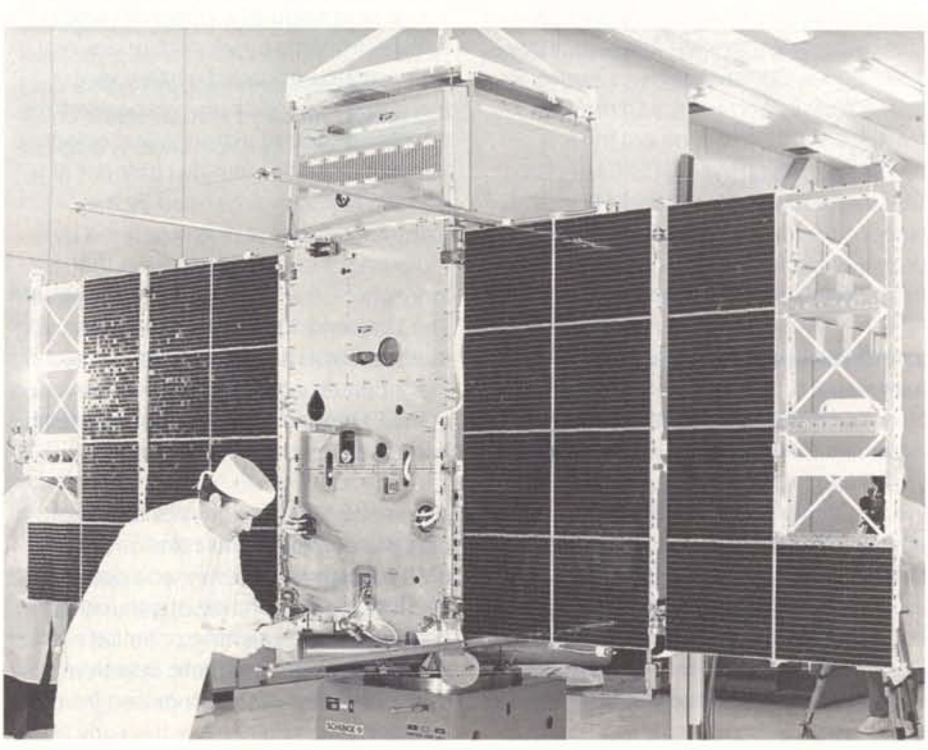
The Cos-B project

It is against the above background that one must judge the Cos-B project, the origins of which go back to the mid-sixties, before the launch of either OSO-3 or SAS-2.

In the early days of ESRO, two proposals had been submitted to measure cosmic gamma rays: one outlined a plan for a large spark chamber of a size incompatible with any of the planned satellites, but the second, submitted somewhat later, was more modest, bearing in mind ESRO's plans at that time. This second one (code named S-133) was finally accepted for flight on the large TD-1 satellite, while the first one (code named S-111) had no chance since no satellite was being planned at that time that was large enough to carry it. The S-133 experiment was finally launched onboard TD-1 in March 1972, but it was not very successful in obtaining good scientific results, suffering severely from particle-induced background.

Both proposals, S-133 and S-111, were presented by three Institutes: Centre d'Etudes Nucleaires de Saclay, France; Laboratorio di Fisica Cosmica e Tecnologie Relative del CNR, Milan, Italy; and Max-Planck-Institut für Extraterrestrische Physik, Garching, Germany. I believe it was G. Occhialini, then Director of the Milan institute, who christened this collaboration the Caravane Collaboration, perhaps because we usually met caravan-style, at airports, to discuss our project.

The S-111 proposal, submitted to ESRO in November 1965, resulted finally in a 'Phase-A' study for a satellite project devoted to X-ray and gamma-ray astronomy. Lively arguments took place about whether both spectral energy ranges could or should be included or only one, and in that case which one.



The idea of a single-experiment satellite was not absolutely new to ESRO, but there were grave misgivings due to the unhappy experience with the Large Astronomical Satellite (LAS), where agreement could not be reached as to which scientific group in Europe should build the payload and the telescope. In addition, the idea of a single-experiment satellite presented the risk that the failure of the experiment implied failure of the whole mission, while all other ESRO satellites at that time carried several experiments. The issue was hotly debated in the various ESRO committees, especially in the Launching Programmes Advisory Committee (LPAC), the forerunner of the present Science Advisory Committee (SAC), which had to make recommendations on the selection of satellites and their payloads to the appropriate bodies of the Organisation.

In the meantime the scope of the cooperation had been enlarged with the entry of a British group, the Physical Laboratory of the University of Southampton, headed by G. Hutchinson and, finally, the Cosmic-Ray Group of the Kamerlingh Onnes Laboratorium, Leiden, headed by Henk van de Hulst.

The collaborators decided to stick to a single-experiment satellite devoted entirely to gamma-ray astronomy. The final 'confrontation' occurred in May 1969 at a Symposium organised by ESRO to decide on its Scientific Programme. As well as Cos-A, a project including X-ray and gamma-ray detectors, and Cos-B, which included only a gamma-ray detector, other projects were also discussed: a satellite for the study of the ionosphere, a geostationary satellite for the joint study of the magnetosphere and ionosphere, a satellite for the study of atmospheric phenomena, a scientific mission towards the planet Mercury and two satellites for the study of ultraviolet radiation. This meeting laid the basis for the final choices: the geostationary magnetospheric satellite Geos, and Cos-B. The reasons for these 'choices'

Figure 3 — An exploded view of the Cos-B satellite

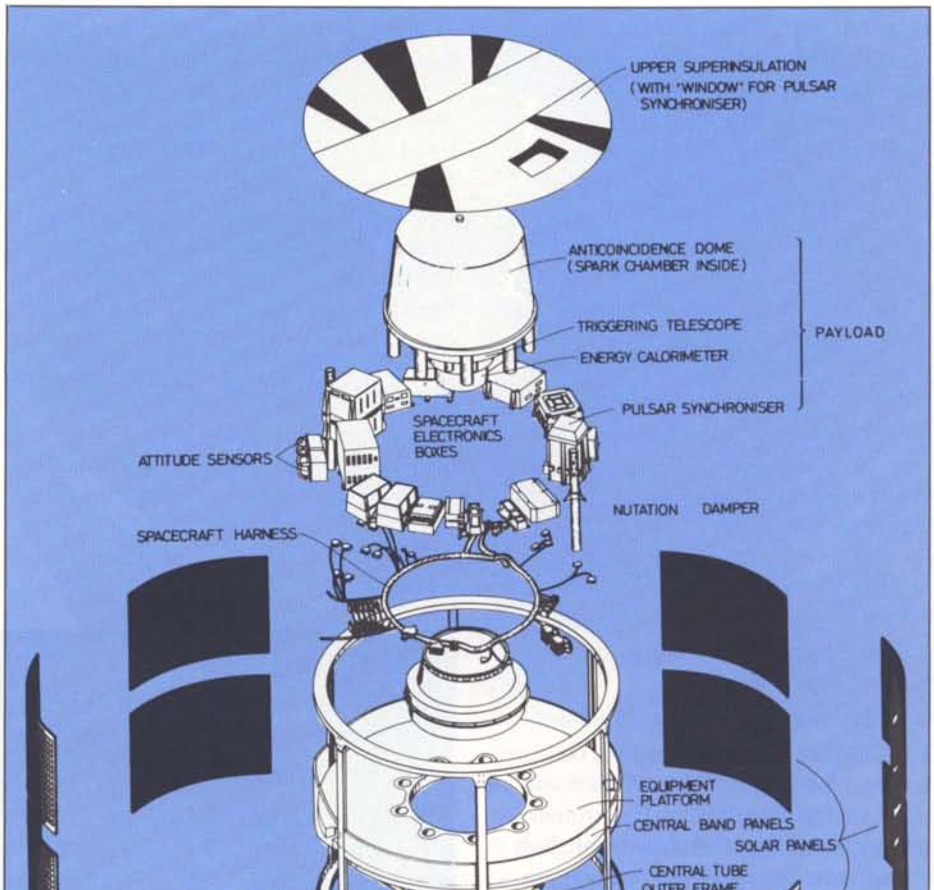


Figure 4 — Integration of the prototype models of the Cos-B payload and spacecraft at MBB in Germany

were that, in the Geos satellite, quite a number of European groups who had already demonstrated first-class work in space could participate; Cos-B was chosen because it gave Europe and its scientists the chance of achieving a scientific 'first' and establishing a lead even over NASA. At the same time, it was felt that in the X-ray field we should wait for the next generation of satellites in order to compete with the United States. This decision led subsequently to the Exosat project and the X-ray observatory now in orbit.

In July 1969, three and a half years after the presentation of S-111, the ESRO Council formally approved the inclusion of Cos-B in the Organisation's Scientific Programme. Now the real work was to start and it involved overcoming quite a number of difficulties.

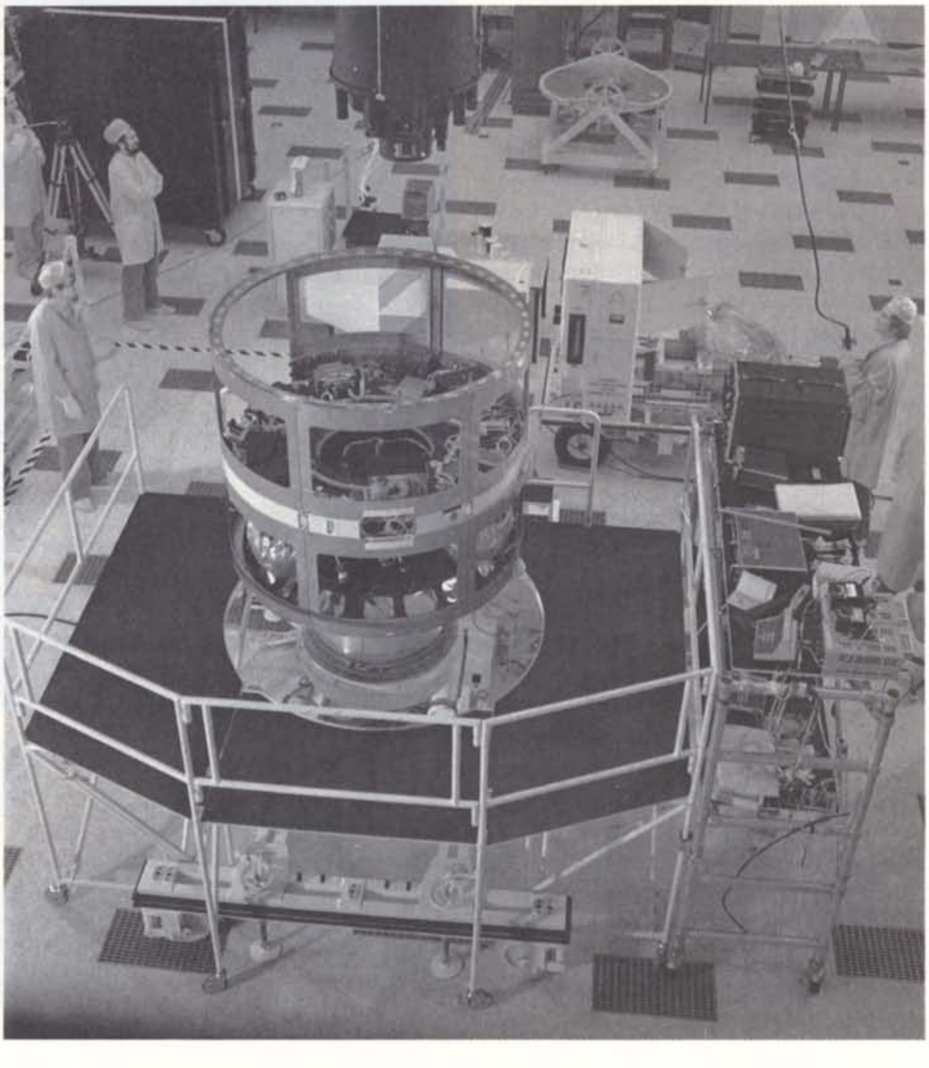
The Collaboration's spirit was to be tested first by a five-page letter from Henk van de Hulst, concerning the Cos-B instrument design. In this letter, he stated that: 'Two main aspects of the present design are open to question. Both of them, in our opinion, are strong enough to conclude that the execution of the present design would not be a wise decision'.

Discussions had resulted in a document called 'Re-evaluation of the Cos-B Gamma-Ray Experiment', produced by J.A.M. Bleeker, Henk van de Hulst and B.N. Swanenburg in September 1969. Alternative designs and accelerator tests were proposed. That document was received by the Collaboration 'with mixed feelings'. The Leiden Group was the 'youngest' member and their criticisms were not easily accepted by the 'older' ones. Even more importantly, the time schedule would become critical and V. Manno, the first Project Scientist (the second was B.G. Taylor and the third R.D. Wills) pressed the Collaboration to draw up specific plans of action, with associated time scales, since the engineers at ESTEC and the firms involved were ready to go ahead.

This led to the formal creation of a Steering Committee, which had its first meeting on 8 October 1969. It agreed to a management scheme, and I was elected Chairman. I was succeeded in 1971 by Henk van de Hulst, who chaired this Committee until 1977, two years after the launch of Cos-B. The Cos-B Project Manager at ESTEC was G. Altmann, the Payload Manager P. Coufleau, and the Spacecraft Manager P. Hill.

The second serious problem occurred very soon after, in spring 1970, when the UK Science Research Council decided not to give funds to the Southampton Group involved in the Caravane. The Collaboration therefore lost one of its member Institutes, which could well have jeopardised the whole project. Thanks to the interventions of ESRO's former Director General Prof. Hermann Bondi, and Dr. Ernst Trendelenburg, at that time Head of the Organisation's Space Science Department, the remaining members were able to invite the Space Science Department to join the Collaboration.

Of course, space experiments had been built before by more than one group, but this undertaking was still rather special because of the numbers collaborating, because of the size of the experiment, and because the experiment would determine the layout of the complete satellite.



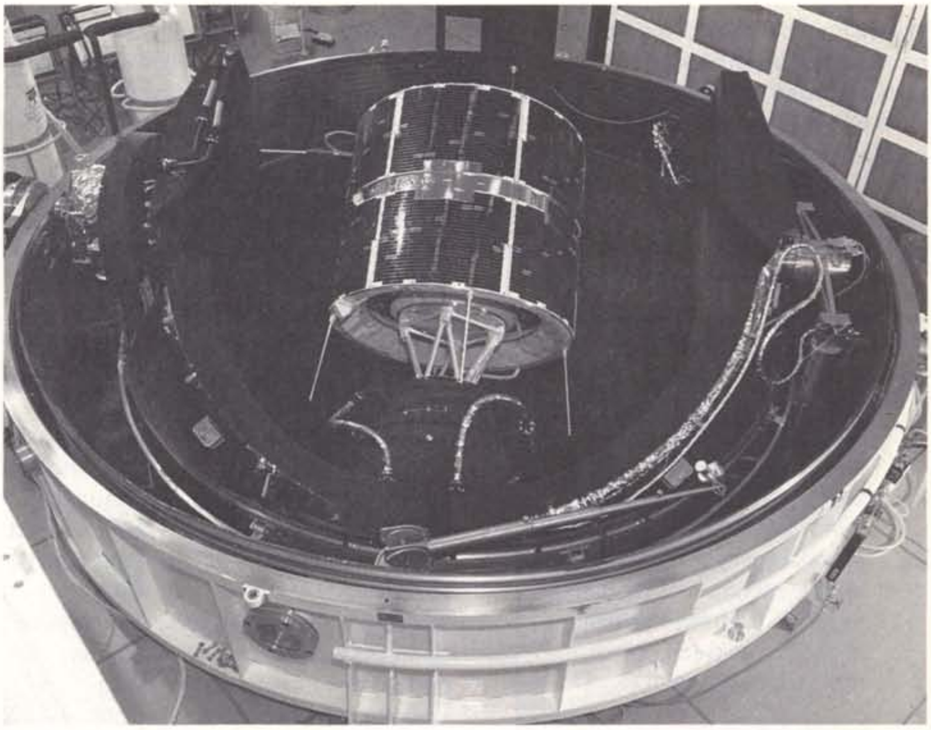


Figure 5 — Cos-B under test in the Heat-Balance Facility at ESTEC

Furthermore, ESRO was not paying for the experiment and each group had to finance the part of the experiment to be built under that Institute's responsibility. The final request for financial support from the national authorities could therefore only be made after the definition of the complete instrument and the division of work between the different institutes. All this had to be discussed and finally decided by consensus in the Steering Committee. The latter had to settle the general rules, to control the work on the experiment, and to provide guidelines for the publication policy, including final approval for publication. It had to act in case of crises and to resolve them. It met 18 times in seven years prior to Cos-B's launch.

The real work, however, was done by the payload group at ESTEC and by the Experiment Officers representing the Institutes. W. Hermsen, a student of Henk van de Hulst, described that work in the following way: 'Especially during the working sessions of this group in the very early stages, the spirit of the Collaboration was successfully tested when significant modifications to the experiment and spacecraft were suggested and the essential role of accelerator verifications was claimed. Reluctance to accept these ideas gradually changed into a discussion and finally into efficient working sessions. Looking back, one may conclude that every change introduced in that first half year provided a crucial contribution to the success of the mission'.

There was another important and rather new Working Group which was set up at an early stage; this was the Data Reduction Group (DRG), which began work in the second half of 1971, four years before the launch. This Group concentrated initially on the programming and analysis of calibration measurements. At the same time, an early start was made with the development of the software package for flight-data analysis. In the early years, the DRG meetings were coordinated and 'pushed' by Dr. J.J. Burger, later succeeded by Dr. R.D. Wills. For the calibration measurements the 'Caravane was marching through Europe' to test the experiment in several accelerator beams, at DESY (Hamburg), CERN (Geneva), Bonn and Saclay. The experiment was even tested by an engineering-model balloon flight from Sioux City in the USA.

This last test brought about a crisis, when it seemed that the production of secondary radiation in the instrument would be too high for a successful mission. There were long discussions and considerable tensions within the Collaboration, leading some researchers to abandon the experiment.

Even before those tests had been agreed upon, the difficult decision to add a small X-ray detector to the main gamma-ray detector had been taken. The aim of this instrument, called the 'pulsar synchroniser', was to detect sources of periodically variable X-radiation and to synchronise at the observed period the possible parallel variation in the gamma radiation from the same source.

R. Buccheri and A. Rosso described the situation which the Steering Committee had to face as follows: 'Also in this case the decision was not very simple to take because of the interlacing of scientific and extra-scientific factors. From the scientific point of view, there was the interest to detect and study the possible gamma-ray emission from pulsars (discovered in 1967 as radio sources). At the same time there were at least two reasons for strong opposition. Firstly, incorporating an X-ray detector brought back to life the ghost of Cos-A, with the unavoidable reactions within ESRO; secondly the 'pulsar synchroniser' would be produced by the Istituto di Fisica of Palermo University, where one of the main collaborators of G. Occhialini, L. Scarsi, had become full professor of Fisica Superiore. This implied a broadening of the Collaboration, and a modification of the equilibrium that had been obtained only with some difficulty. The pulsar synchroniser was finally approved, and the Palermo Group officially became part of the Collaboration'.

Figure 6 – The launch of Cos-B on 9 August 1975

Finally, the objectives of the Cos-B mission were set out as follows:
With the broad aim of studying in detail the sources of extraterrestrial gamma radiation of energy above about 30 MeV, the principal objectives of the Cos-B mission were:

(i) Investigation of the spatial structure and energy spectrum of gamma-ray emission from the Galaxy.
(ii) Examination of known or postulated localised sources of gamma radiation, determination of the energy spectra of sufficiently strong sources and the search for time variations (long- and short-term) in their intensities.
(iii) Measurement of the intensity and energy spectrum of the diffuse radiation from high galactic latitudes, believed to be of extragalactic origin.

The instrumentation to fulfil these objectives consisted of:

- A Spark Chamber, in which gamma rays are converted into electron – positron pairs and their tracks are visualised (Max-Planck-Institut für Extraterrestrische Physik, Garching).
- A Triggering Telescope, which provides a trigger pulse to the spark chamber when it detects the passage of the electrons (Space Science Department, ESA).
- An Energy Calorimeter, which provides a measure of the energy of the detected photon by absorption of the electron energy (at least in part) (Kamerlingh Onnes Laboratorium, Leiden).
- A Charged-Particle Shield, or Guard Counter, which provides a veto signal to inhibit triggering by cosmic-ray particles (Centre d'Etudes Nucléaires, Saclay).
- A complex Data Handling Electronics Package (Istituto di Scienze Fisische, Università di Milano).

In addition, there was the Pulsar Synchroniser, the X-ray detector from the University of Palermo.

The satellite had a mass of 278 kg, 118 kg of which was made up by the experiment units. It was spin-stabilised at about 10 rpm about its axis of symmetry, which coincided with the optical axis of the gamma-ray detector. A simple nitrogen-gas attitude-control system was used to point the experiment in the desired direction. Sun and Earth sensors were used for attitude measurements, from which the pointing direction could be reconstituted with a precision of 0.5°.

Cos-B was launched from Western Test Range, California in the early morning of 9 August 1975 on a Thor Delta launcher, since the planned Europa-II launcher had had to be abandoned. The satellite's orbit was a highly eccentric one, with an apogee of about 100 000 km a perigee of about 350 km initially. This orbit was chosen because it permitted long uninterrupted observation periods.

Three days after launch, the instrumentation was switched on and the first gamma-ray photo was recorded. Its computer image was enthusiastically acclaimed by all those in the Control Room at the European Space Operations Centre (ESOC) in Darmstadt.

The telex announcing the event, and confirming the excellent performance of all the instruments aboard read, in the words of the Project Scientist, Brian Taylor: 'We seem to be in business'.

Indeed, since the start of routine operations on 17 August 1975 Cos-B has provided scientific data for almost 7 years. More than 100 000 gamma photons have been registered. The satellite was actually designed for a nominal lifetime of one year, with consumables (for the spark chamber and attitude-control subsystem) dimensioned for two years of operation. When the development of the Cos-B experiment started, no spark chamber of that type had ever been operated in a space environment before. The gas consumption turned out to be much lower than expected, especially since the chamber stayed cleaner than anticipated and the interval between gas-flushing operations could be extended. The performance of the attitude-control system was also better than had been envisaged. The nominal 4000° of

Figure 7 – High-energy gamma-ray emission from the Milky Way, as mapped by Cos-B

Figure 8 – The first gamma-ray detected by Cos-B, adorned with the signatures of those present in the Control Room when the event was observed

manoeuvring was achieved in November 1980, and everything since then has been a bonus.

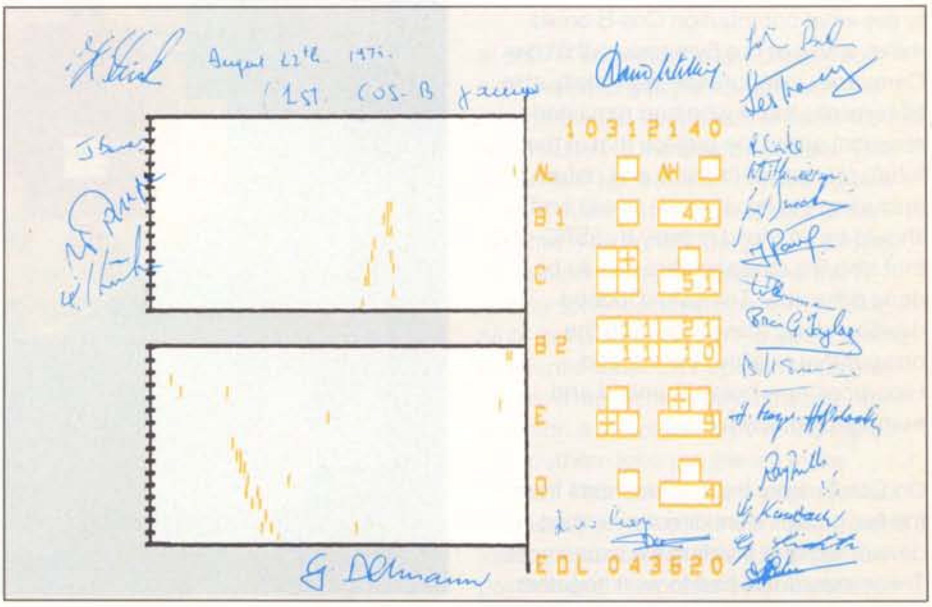
The cost-to-completion of the Cos-B Programme, including the planned two years of orbital operation, charged to the ESA Scientific Programme's budget, amounted to approximately 65 MAU at the time of the launch in 1975. The mission extension has been conducted at a yearly cost of about 2.5 MAU, so that in all about 75 MAU have been expended on the mission.

Highlights of the scientific results

Most of the observations were devoted to the study of the galactic disc, so that the first complete and detailed gamma-ray survey of the Milky Way could be obtained. It resolved the 'line source' of gamma radiation along the galactic equator. About 25 sources have been found concentrated along the galactic disc. Among the earliest celestial objects to be studied by Cos-B was the radio pulsar in the Crab and Vela. A search through the Cos-B data for gamma radiation from a number of extragalactic objects revealed no strong evidence for any positive identification, except for the quasar 3C273. Upper limits for the photon fluxes were evaluated.

The spirit of Cos-B

What was the spirit of Cos-B and why was a special spirit needed? The Cos-B experiment represented a turning point for astronomical observations using space techniques. Although the Cos-B satellite was already an observer-type satellite, it was considered more of a multi-experiment satellite. Five different institutes developed their components independently, and supplied them to a



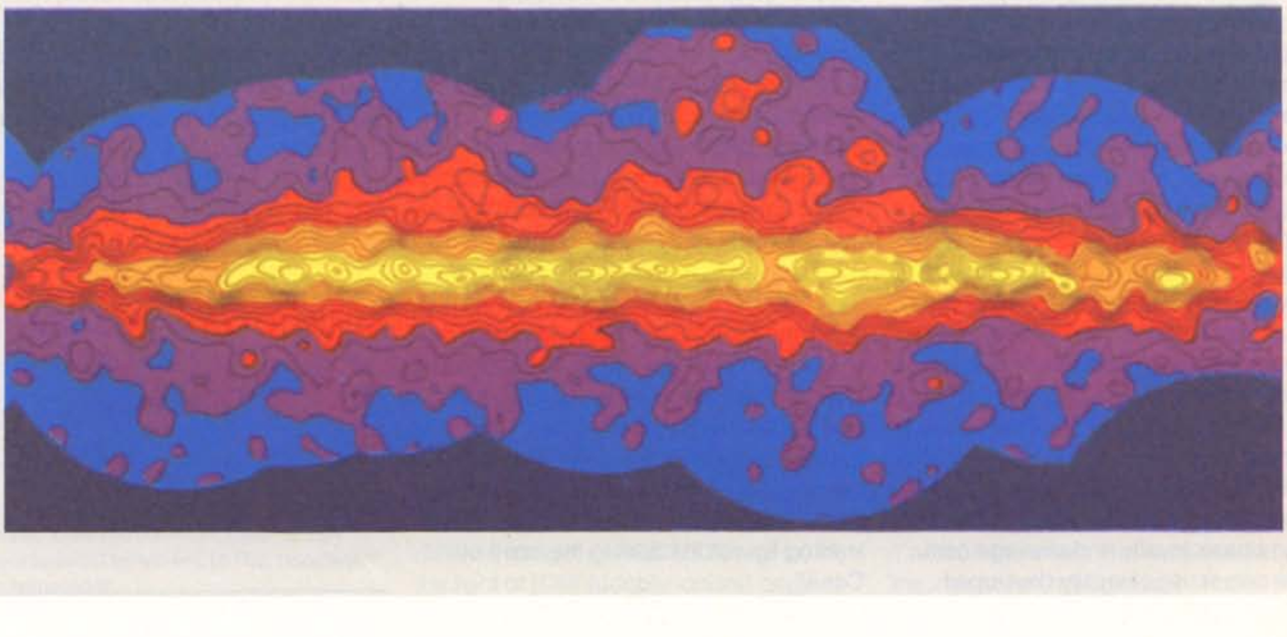


Figure 9 — The Earth as seen by Cos-B's gamma-ray detector

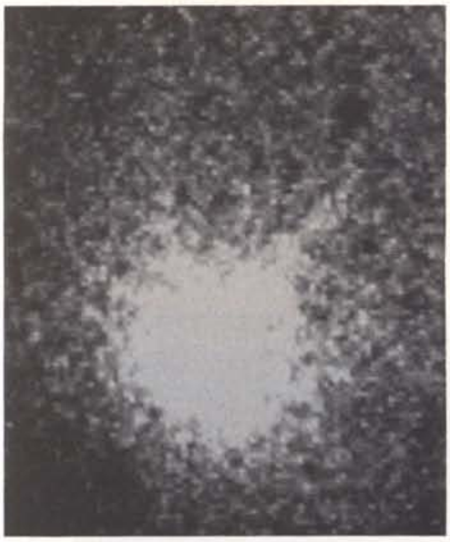
single experiment. How they developed and built their components was left entirely to them, and they were also responsible for their own financing. Sir Harrie Massey discussed this point at the Gamma-Ray Astrophysics Symposium in January 1970 in Noordwijk where, after the decision by the ESRO Council on Cos-B, all aspects of gamma-ray astronomy were discussed afresh in order to see what contribution Cos-B could make. It was at this Symposium that the Caravane Collaboration was finally able to convince those who had remained sceptical about the project, that in the future projects of this size and nature (including the experiment) would and should be financed entirely by ESRO and that also the management should be done differently. Things did indeed develop along these lines, with the observatory satellites Exosat and Hipparcos now being financed and managed entirely by ESA.

On Cos-B, more than 35 scientists from the five groups were directly involved in developing and building the experiment. These individuals had to work together and had to be kept together. After the successful launch, Henk van de Hulst wrote:

'This was a unique daring enterprise, to build a joint experiment with the five groups so widely dispersed. Travel and communication could form real obstacles, as could the different backgrounds and temperaments. While one scientist may be at his optimum in a pragmatic assessment of a well-presented report, another gives of his best in a desperate series of telephone calls. Never a dull moment – not even the industrial disputes were uniformly timed. Fortunately, from the very beginning the concept of a joint experiment, which would be successful only if all parts functioned perfectly, was never questioned.
Two factors led the Collaboration to successful completion of the building and testing phase: loyalty and management. The strong sense of loyalty developed during innumerable week-long sessions, where competent young scientists hammered out the problems together. Most of these sessions were held at ESTEC, but other venues included the several sites where the elaborate accelerator tests were being conducted. Yet loyalty alone would have led to confusion and frustration, while management alone, however competent, would have led to alienation and a lack of real involvement: only the right combination of both factors could work'.

The two Cos-B Project Scientists, B.G. Taylor and R.D. Wills, commenting on on how they saw the spirit, wrote: 'Everybody associated has had the attitude, What can I put in?, not What can I get out?' This is certainly true of Henk van de Hulst, who was so inspiring and who was one of the leading figures in creating the 'spirit of Cos-B'.

Acknowledgement
I would like to take this opportunity to express my thanks to J.J. Burger, R. Buccheri, A. Russo, B.G. Taylor, R.D. Wills, W. Hermsen and H.A. Mayer-Hasselwander for their kind assistance in providing key material for the preparation of the original Symposium presentation.



The Study of Astrophysical Interactions with the ESA Photon Counting Detector

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We have used the ESA Photon Counting Detector, a scientific model of the Faint-Object Camera to be flown on the Space Telescope, to study various aspects of the interactions between astrophysical objects. Examples include the relationship between a planetary nebula and a nearby star, the effects of shock waves in the interstellar medium of a young galaxy, the interaction of the jet in a radio galaxy with the surrounding intergalactic medium, and the perturbation in a quasar gas halo caused by a gravitationally interacting galaxy in the same group.

In many sciences, observation of the mutual interaction between objects under study provides an important tool for the understanding of those objects and of the laws governing them. The interaction process in fact often triggers phenomena not normally observable. This is, of course, also true in astrophysics, the only difference being that in this discipline one can only observe what nature displays and one cannot experiment by provoking the phenomena oneself.

The ESA Photon Counting Detector (PCD) was developed at ESTEC as a scientific model of the Faint-Object Camera for the ESA/NASA Space Telescope. It is a photon-counting imaging detector (Figs. 1 and 2) consisting of a high-gain image intensifier coupled by a lens system to a television camera. In combination with signal-processing electronics and a control computer, it is possible to detect about 20% of the photons arriving on each picture element in a 512 × 512 square matrix. The very low intrinsic noise of the PCD and its quantised operation make it a very sensitive and accurate instrument for the detection of faint astrophysical objects in the ultraviolet and blue wavelength bands.

The planetary nebula NGC 6905

NGC 6905 (the object numbered 6905 in the New General Catalogue) is a 'planetary nebula', which is a star that, in the course of its evolution, has expelled a considerable amount of material, now visible around it. Figures 3a and b are two different images of NGC 6905, one (a) in the light of [OIII] (doubly-ionised oxygen) at 5007 Å showing the low density and highly excited gas particularly well, the other (b) in the continuum around 4000 Å, better suited to the display of stars. The 'Moon-like' appearance of the brightest stars is due to saturation effects in the detector. The continuum picture shows the central star (saturated) and the nearby spherical envelope surrounding it. All of this is saturated in Figure 3b, where two fainter lobes on opposite sides are visible. What immediately attracted our attention is the object right at the top of the southern lobe (on the left in the figures). This object is very bright (in fact saturated) on the continuum picture and the spectrum shows that it is a star. Its position and the presence of a gaseous filament pointing directly to it suggest that it may be in interaction with the nebula and, in this case, associated with the presence of the lobes.

To confirm this hypothesis and exclude the possibility that the 'southern star' is a foreground or a background star, and therefore not associated with NGC 6905, we tried to measure its distance and compare it with that of the nebula. Unfortunately, distances are not easy to measure in astrophysics. The nebula itself is thought to be at a distance varying between 1.3 and 2.3 kiloparsec (1 parsec = 3.25 light years = 3×10^{13} km), with a slight preference among the authors for some 1.4 kiloparsec. From spectroscopic observations, we derived that the 'southern star' is of spectral type-A and therefore, if it is a Main-Sequence star, as is most likely, lies at a distance of between 1 and 5 kiloparsec. This is consistent with the interaction hypothesis, but does not

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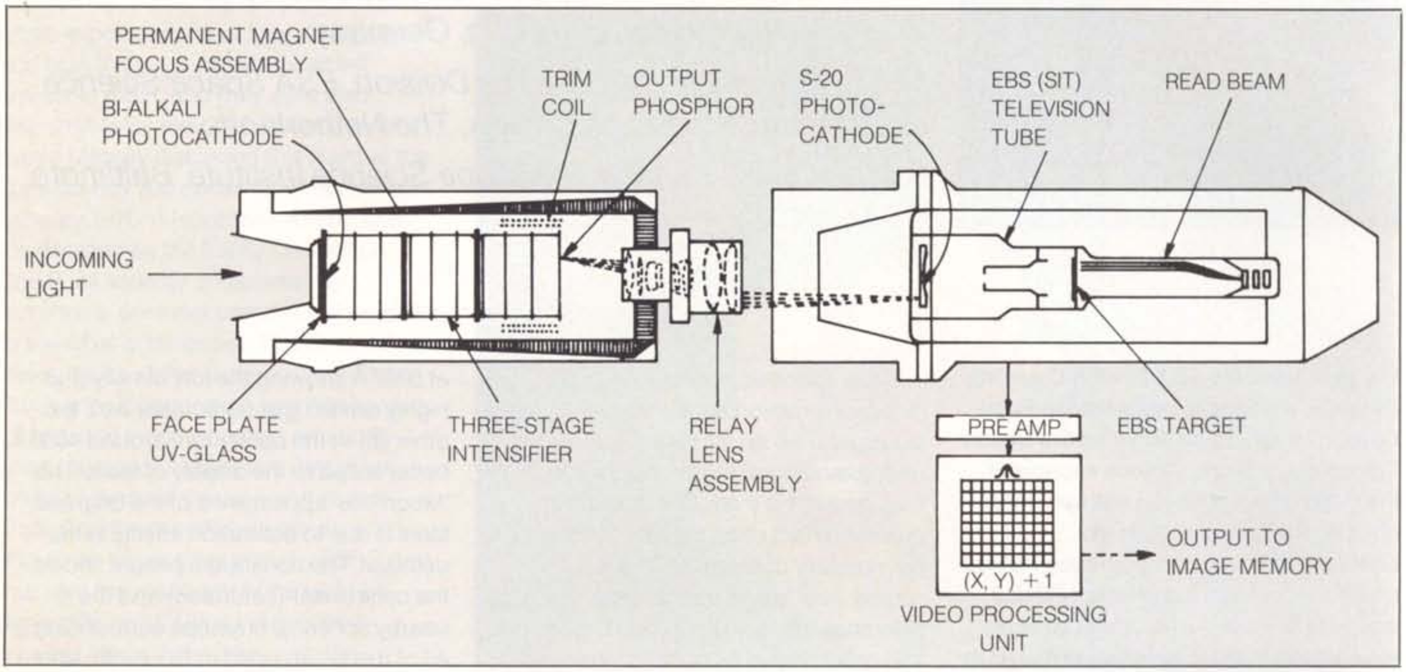


Figure 1 – Schematic of the ESA Photon Counting Detector (PCD)

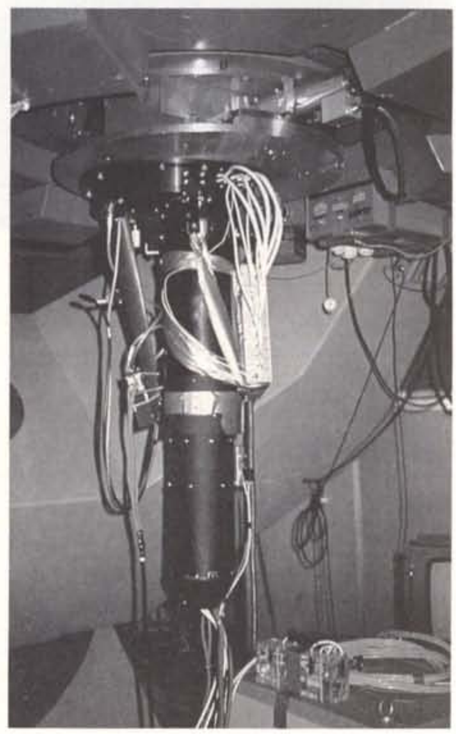


Figure 2 – The ESA Photon Counting Detector (PCD) mounted on the 1.8 m telescope at Asiago Observatory

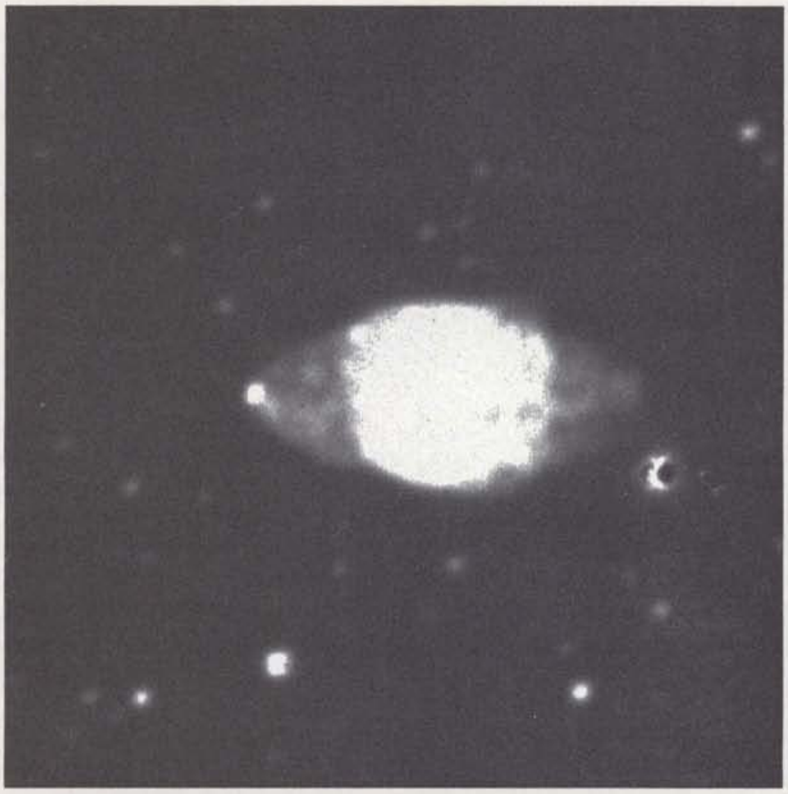
provide convincing proof. We are now trying to measure the velocity of the gas in the southern lobe spectroscopically, to see whether there is any dynamical influence caused by the 'southern star'.

The galaxy NGC 1569
NGC 1569 is a very blue, nearby dwarf galaxy. Its extremely blue colour indicates that it is presently undergoing a very intense burst of star formation, the blue hue resulting from the presence of very hot, very luminous young stars. This object gives us the opportunity to observe interactions of shock waves on galactic scales, and the effects of these shocks on the normally relatively undisturbed interstellar medium that permeates the space between the stars.

The galaxy is interesting not only because we know that bursts of star formation are proceeding in it (many galaxies are known to be in this state), but also because it is one of the few where we have any clear idea about what has led to the star bursts. At the centre of the galaxy, two blue objects can be seen; both are of unusually high luminosity. Although they appear unresolved at the resolution of ground-based optical telescopes and are therefore relatively compact, the brightest of the two central objects has a luminous output comparable to that of some 1600 OB stars (OB stars are the brightest of the many different types of stars found in galaxies). It is possible that this large number of stars exists in a very compact cluster, or it may be that the origin of the intense radiation lies in a single very massive object, or in a much larger number of stars each much less luminous than an OB star. Whatever the nature of these objects, their luminosity can be expressed in another way – the brightest of the two objects has a luminous output one hundred million times greater than that of our own Sun!

When the objects are studied at radio wavelengths, the radio maps give a further clue as to the nature of the galaxy. The objects are then observed to be surrounded by a 'hole' both in the radio continuum and in the radio-emission characteristic of emission from neutral hydrogen. This hole, some 200 parsec in diameter, appears to be caused by a stellar 'wind' originating from the central objects, due simply to radiation pressure driving matter away from them. It is probable that where this stellar wind interacts with the interstellar medium distributed throughout the galaxy, shock fronts are created. At these shocked boundaries, matter is compressed, resulting in conditions suitable for star formation. We can argue that the star formation is actually occurring in a burst

Figure 3 – The planetary nebula NGC 6905 in the light of the [OIII] line at 5007 Å (a) and in the continuum radiation around 4000 Å (b). North is at the top and east to the left in all figures, except where noted otherwise



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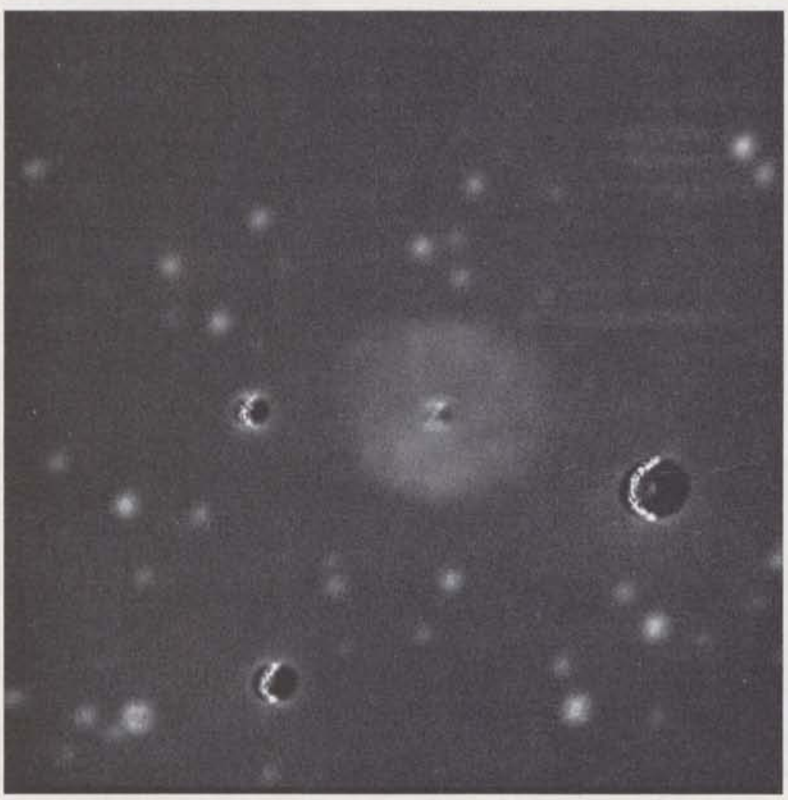

b

and that it cannot be sustained over long time scales, simply because at the present rate of star formation all the neutral hydrogen making up the interstellar medium would be exhausted in only a hundred million years, a rather short period compared with the lifetime of the galaxy as a whole.

Our observations, shown in Figure 4, were made to discover more about the young star population ionising the gas, and in an attempt to determine the precise form of the excitation mechanism observed in the galaxy.

The images were taken in the light of ionised hydrogen ($H\alpha$ upper left and $H\beta$ lower right), singly ionised oxygen (lower left) and doubly ionised oxygen (upper right). Comparison of these images provides information on extinction due to dust within the galaxy and on the degree of ionisation of gas in the galaxy, due to the emission of hot stars, interstellar shock fronts or both.

The jet in the radio galaxy 3C 66B

Astrophysical jets provide evidence for the extremely high energies produced in the nuclei of active galaxies and quasars. Detailed studies of the phenomena have been pursued mostly in the radio band, because at these wavelengths the jet, a collimated plasma of protons and electrons travelling at a large fraction of the speed of light, is very prominent and easily detectable. These studies have shown that the jets, which can extend over distances of hundreds of thousands of parsecs (much larger than the galaxies in which they originate), are the transport mechanism for the energy produced at the centre of radio galaxies and then deposited in the intergalactic medium, resulting in the so-called 'radio lobes' typical of these galaxies.

As part of our research programme, we have undertaken a study of these jets in the optical region, with the aim of identifying and studying in detail the optical properties of the plasma and hopefully shedding light on the energy-production mechanism of the central energy source.

One of the most prominent optical jets we have observed is that of 3C 66B (Fig. 5). This jet emerges from the galaxy's centre and extends for over 10 arcseconds, tracing the well-known radio jet perfectly. In the galaxy itself, the radiation due to stars is seen to be heavily obscured by absorption from dust. The study of the distribution of this dust is an extremely interesting problem in itself.

Detailed analyses of this and other jets are now being pursued, and more observations are planned during three observing campaigns in the course of this year with the European Southern Observatory (ESO) telescopes in Chile.

The halo surrounding the quasar MR 2251-178

MR 2251-178 is a relatively nearby quasar, lying at a distance of about 390 megaparsec. It was discovered because of its strong X-ray emission, and lies within a group of galaxies. Spectroscopic work by other investigators has revealed the presence of ionised gas around the quasar at distances up to 170 kiloparsec and rotating about it, similar to the rotation of many spiral galaxies, including our own. Many nearby quasars have been found to reside at the centres of galaxies, although the nature of these and their relationship with the quasar phenomenon is not clear. The presence of gas so far from the nucleus is related to the question of dark halos around galaxies and of the intergalactic medium in general, and to the problem of the missing mass in the Universe. We therefore decided to study the spatial distribution of the ionised gas surrounding MR 2251-178.

Figure 6a, a continuum-radiation picture, shows the quasar and some of the galaxies in the same group. To reveal the distribution of the ionised gas, we took a picture in the light of [OIII] at 5007 Å and

Figure 4 – Four images of the 'star bursting' extremely blue dwarf galaxy NGC 1569. The images are not corrected for sky background and variations in detector sensitivity. Intensity is colour-coded, blue and white indicating the highest intensities and green the lowest. Here top is west and left is south

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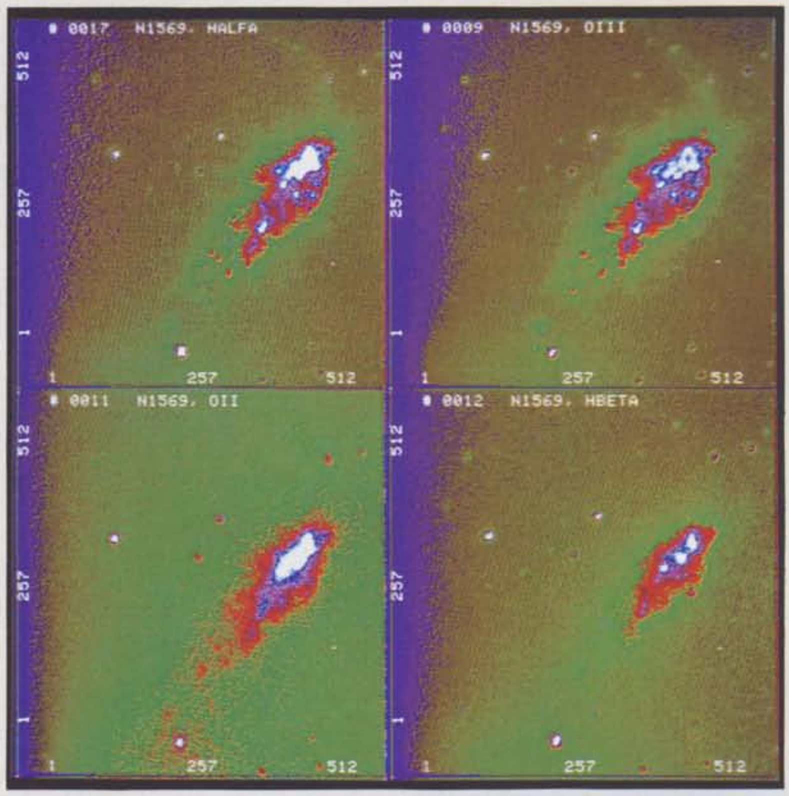

Figure 5 – Four prints of the same exposure of the radio galaxy 3C 66B. Prints (a), (b) and (c) are on a linear intensity scale and show increasingly fainter, and therefore outer, features. Print (d) is on a logarithmic intensity scale and can display the whole intensity range. The optical jet emerges from the nucleus towards the upper left

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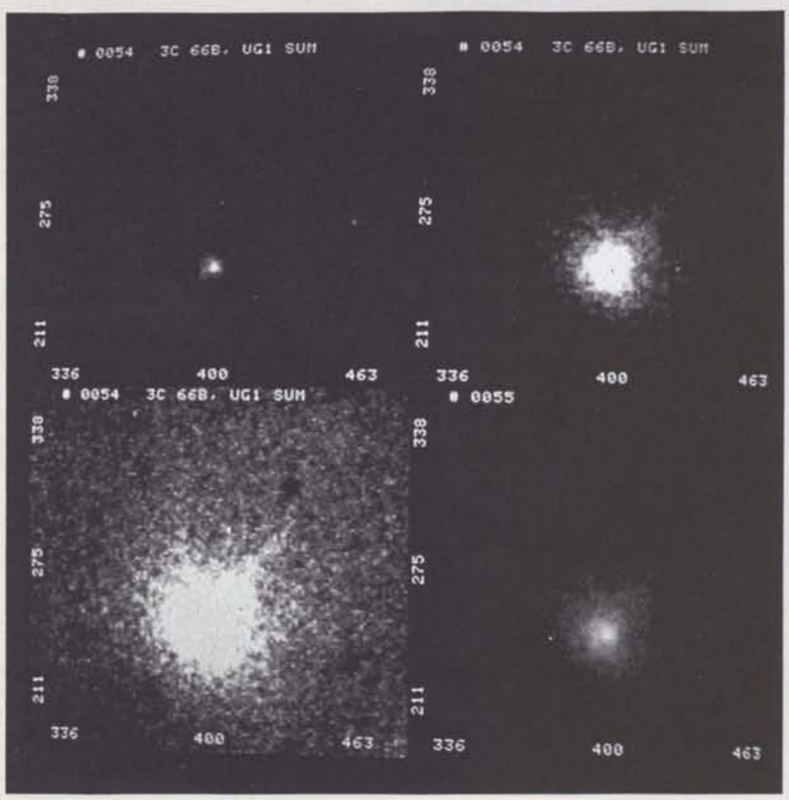


subtracted from it the image in the continuum light (in fact Figure 6a), in order to isolate the light emitted by the gas from that due to stars and to the sky background. The result is shown in Figure 6b, where a spiral structure is visible at a large distance from the centre.

Apart from the nebulosity close to the nucleus, the most prominent features are three condensations (A-C), forming an 'arm' to the east (left on the picture) of the centre, and a more diffuse region (D) on the opposite side. We attribute these regions of enhanced [OIII] emission to density perturbations in the gaseous halo, or disc, which rotates about the quasar. We also suggest that these density enhancements have been caused by tidal effects due to the passage of the galaxy G1 near to the quasar. This hypothesis is consistent with the kinematics of the system, with theoretical models of such encounters, which predict the formation of an arm on the side of the interaction and of a more diffuse counter-arm on the opposite side, and with the fact that galaxy G1 also shows signs of activity, possibly associated with the encounter.

Finally, we can speculate that the kind of interaction observed here could initiate the activity of the quasar itself. To understand how this might occur precisely, we are now studying the region very close to the nucleus of this and other quasars with the best radio and optical ground-based telescopes, trying to prepare ourselves to take optimum advantage of the unprecedented optical resolution soon to be provided by the Space Telescope (due for launch in June 1986).

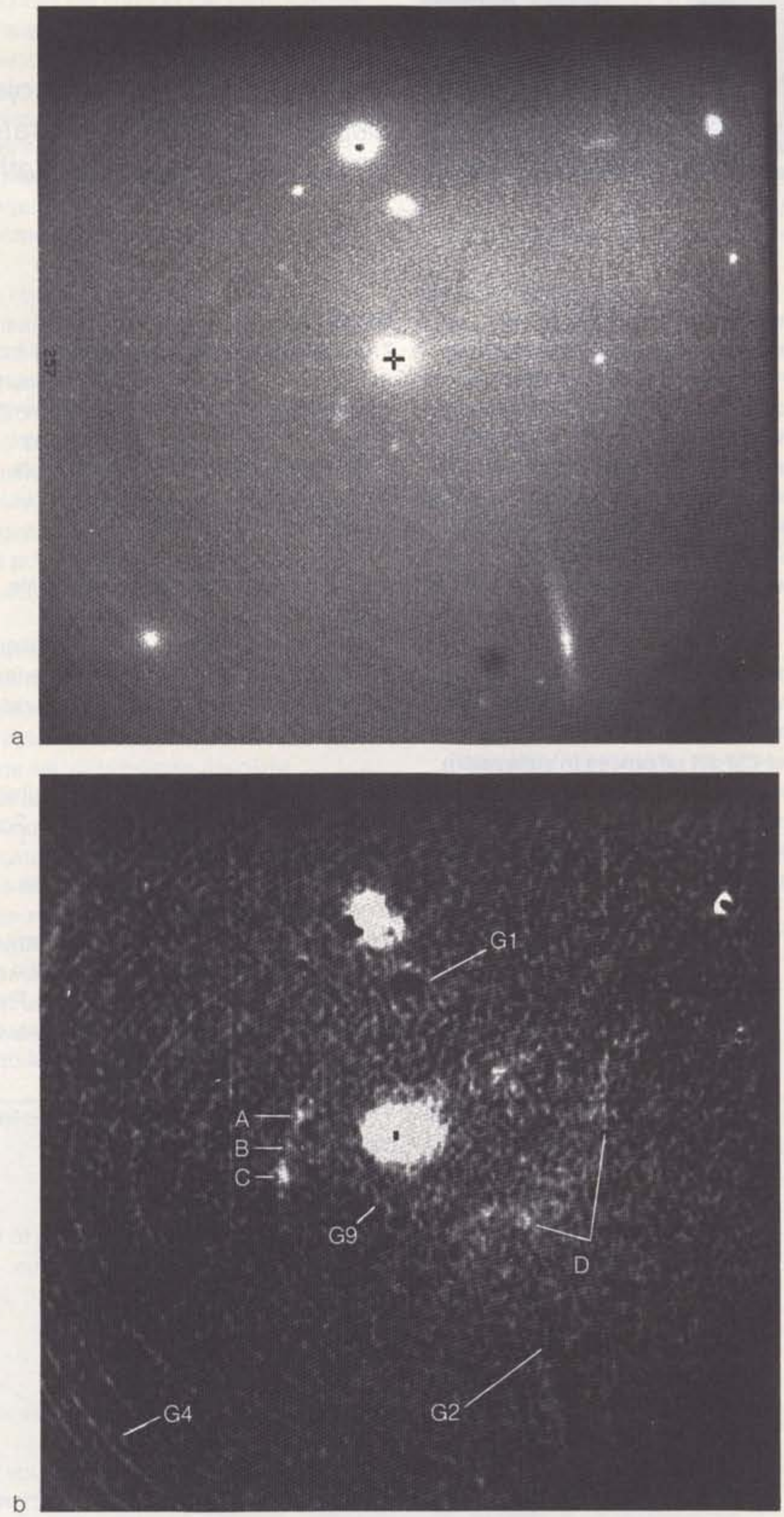
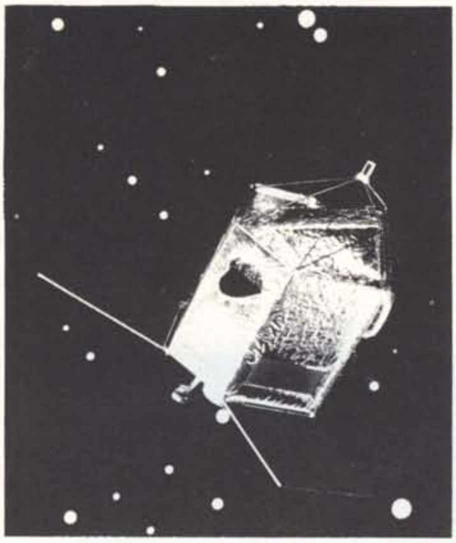


Figure 6 – The field of the quasar MR 2251-178 shown in continuum radiation (a) and in the light of the [OIII] line at 5007 Å with the continuum radiation subtracted from it (b). The positions of galaxies G1, G2, G4 and G9 are marked, as well as the main features in the [OIII] picture (1 arcminute corresponds to about 115 kiloparsec at the distance of the quasar)



The Hipparcos Satellite's Mission: The Objectives and Their Implementation

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The first European satellite to be dedicated to astrometry, Hipparcos, is under development for ESA by the Mesh Consortium led by Matra, with a view to a launch by Ariane in 1988. In parallel, four scientific consortia, drawn from the astronomical community, are preparing for the satellite's scientific operations. Three of these consortia will be responsible for the reduction of the flight data.

The mission combines the now classical features of geostationary satellites with an original scientific payload and some state-of-the-art advances in subsystem design. This joint industrial and scientific effort will culminate in the publication of a large and highly precise stellar catalogue.

Introduction

Like the Space Telescope, which will be launched in 1986, by the time of its launch into geostationary orbit in the course of 1988, Hipparcos will have a very long history behind it; the original concepts having been put forward by Prof. P. Lacroute back in 1966.

In its two and a half years of orbital life, this novel visible-light astronomy observatory will scan the celestial sphere completely five times, a performance far beyond the reach of any single ground-based telescope.

Positional data on 100 000 stars brighter than magnitude 12 will be gathered. Some three years later the results of their processing by two scientific consortia, together with part of the Space Telescope's work, will bring astrometry, a traditional and fundamental discipline of astronomy, truly into the space age. The completeness and very high accuracy of the Hipparcos catalogue of stars will open the door to new discoveries in astrophysics, in cosmology, and also in solar-system and Earth dynamics.

Figure 1 traces the evolution in the accuracy of stellar catalogues back to the lifetime of the astronomer Hipparchus, after whom the acronym Hipparcos (High-Precision Parallax Collecting Satellite) was cast.

The Tycho experiment aboard Hipparcos (named in honour of the famous astronomer Tycho-Brahé), will use one of the satellite's auxiliary sensors to perform a further astrometric and photometric survey, gathering information on more than 400 000 stars. The astrometric accuracy of this data will, however, be about an order of magnitude coarser than that of the primary Hipparcos data.

Scientific objectives of the mission

The results of the Hipparcos mission will be published in the form of a Hipparcos Astrometric Catalogue, to be followed later by those from the Tycho experiment in the form of the Tycho Astrometric and Photometric Catalogue. The Tycho experiment draws only marginally on the satellite's resources, and its impact on satellite design and operations is limited to some optimisation of the star mapper and its detection chain and to tape deliveries to a third separate data-reduction consortium. We will therefore concentrate in this brief résumé on the Hipparcos 'main mission', which is the design driver.

Present astrometric knowledge is contained in very precise stellar catalogues (with accuracies ranging from a few tens to a few hundreds of milliarcseconds) for just a few thousands of relatively bright stars, and in more comprehensive catalogues with far poorer accuracies. Moreover, the uncertainty in stellar apparent motion in the sky due to galactic motion, and to the vicinity of companion objects – the so-called 'proper motions' – causes a secular degradation in the positional accuracy of the stars at any time remote from the central year of a given catalogue. Ground-based astrometry has remained hampered by such factors as the multiple corrections that account for

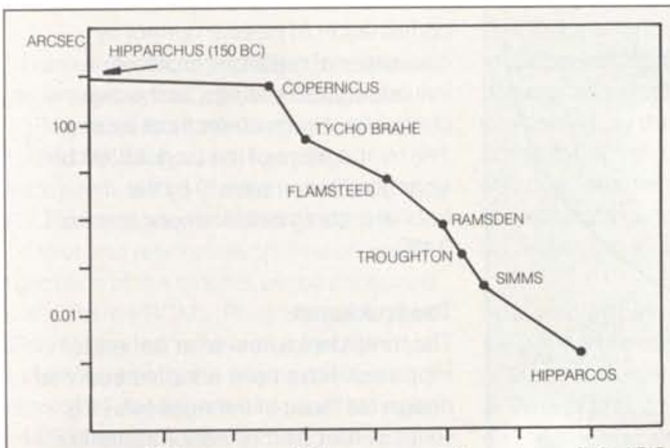


Figure 1 – Evolution in the accuracy of stellar catalogues (courtesy of D. Hughes). Hipparcos will allow the positions of stars some hundreds of parsecs (1000 light years) from our solar system to be measured to accuracies of a few milliarcseconds

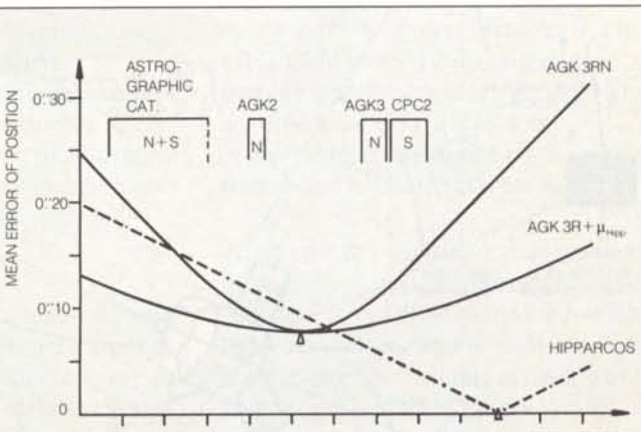


Figure 2 – Improvement of stellar position accuracy (courtesy of Prof. C. de Vegt). The Hipparcos stellar catalogue will help to 'correct' previous catalogues (e.g. AGK3R) by reducing errors induced by poorly known proper motions

telescope deformations due to gravity, atmospheric refraction, the time-consuming measurement of photographic plates, and the limited sky coverage of ground-based observatories. Coupled with the previous difficulties, these factors lead to error-prone correlations between different groups of observations.

All of these problems will be overcome with the Hipparcos observatory in geostationary orbit, continuously recording the transit of stars in its 0.9° × 0.9° field of view. The only interruptions will be due to occultations by the 17°-wide Earth's disc four times per day on average, and far less frequent lunar occultations.

The improvement that Hipparcos will bring to astrometric catalogues with its more accurate 'proper motions' is illustrated by Figure 2. The curve labelled 'AGK3R + μHIPP' results from a combination of the AGK3R catalogue* positions with the Hipparcos positions and proper motions. The stellar-position and proper-motion components must be complemented in stellar catalogues by a fifth parameter, the parallax, which describes the effect of the Earth's yearly translation about the Sun on the *apparent* positions of stars, an effect comparable to the error incurred by a car passenger when leaning over to read the driver's instruments. Parallax, the amplitude of this apparent motion with a one year period, is a measure of the remoteness of stars from our solar system.

The Hipparcos satellite's measurements will lead to a catalogue accuracy of 2 – 2.5 milliarcsec (depending on the star colour) in position and parallax, and 2 – 2.5 milliarcsec/year for proper motions, for about 95 000 of the 'programme stars'. Somewhat higher accuracies will be achieved for stars much brighter than magnitude 9, whilst for stars at the fainter end accuracies of 4 to 5 milliarcsec will result (down to magnitude 12).

A summary of the scientific goals that the enhanced accuracy of the Hipparcos measurements will help to achieve is given in Table 1. The very accurate reference frame will allow precise *absolute* parallaxes to be measured, whereas ground-based measurements call for delicate, and thus unreliable, corrections to be added to *relative* parallaxes measured with respect to those stars surrounding the one of interest. Knowledge of stellar distances, the reciprocals of parallaxes, will lead to knowledge of the absolute magnitudes of stars, a basic parameter in their physical study. The locations of stars in the well-known Hertzsprung-Russell luminosity/colour diagrams will then be known precisely for stars several hundreds of parsecs (1 parsec is equal to about 3.3 light years, or 3.3×10^{13} km) from the solar system. Calibrations of stellar luminosities in nearby galactic clusters such as the Hyades will lead, in turn, to better knowledge of cosmic distance scales.

* One of the currently most comprehensive astrometric catalogues, containing about 20 000 stars of the Northern Hemisphere, known to 0.1 arcsec.

Table 1 – Scientific goals for space astrometry

REFERENCE FRAME
- Comparison at other wavelengths (Very-Long Baseline Interferometry (VLBI); Space Telescope)
- Dynamics of solar system
  - Earth's rotation, continental drift
  - Moon's motion
  - Asteroids, planets

PROPER MOTIONS
- Galaxy rotation and dynamics
- Motions of young stars
- Nearby stars (regions of star formation)

PARALLAXES
- Stellar structure
  - Size
  - Mass
  - Luminosity
- Stellar evolution (Hertzsprung-Russell Diagram for early/giant stars)
- Chemical evolution of galaxy (with photometry/spectroscopy)
- Cosmic distance scale

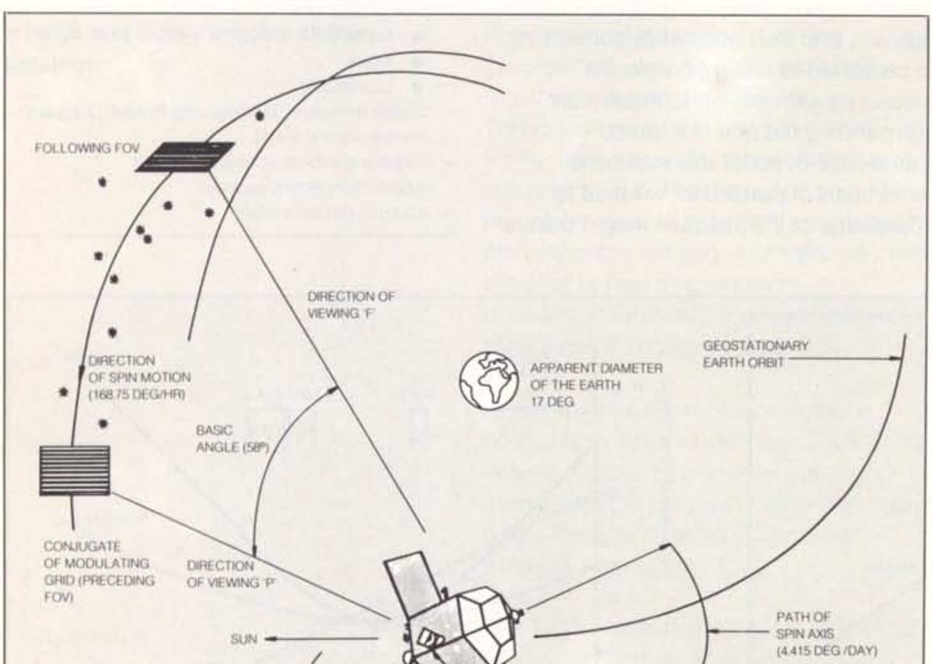


Figure 3 – Hipparcos' revolving scanning motion (courtesy of Dr. A. Peraldi). The spacecraft's two fields of view scan the sky with 11.25 revolutions/day. The spin axis precesses slowly and completes 6.4 revolutions about the Earth – Sun direction in one year. The periodic grid (imaged here on the sky in the two viewing directions) modulates the light from stars crossing the fields of view

For the Tycho Astrometric and Photometric Catalogue the astrometric and photometric accuracies, at magnitude 10, will be 0.015 arcsec and 0.05 magnitude root mean square (r.m.s.), respectively.

Principles of Hipparcos' operation

The Hipparcos astrometric observations will rely on four key principles:

1. The combination in one telescope of two directions of observation separated by 58°.
2. The measurement of the relative positions of stars within the scanning motion via a modulating grid in the telescope's focal plane.
3. The observation of selected stars by the use of an Image Dissector Tube (IDT), the Instantaneous Field of View (IFOV) of which is centred electronically on the transiting star of interest.
4. The revolving scanning law for the celestial sphere.

The first of these key principles, the basis of the project as originally conceived by Prof. Lacroute, eases the reconstitution of the celestial sphere from all of the consecutive measurements, by allowing separate areas of the sky to be correlated, thereby minimising the propagation of errors along a scanned great circle.

With a scan speed of about 170 deg/h and a stellar-light modulating grid period of 1.2 arcsec, the phase and thus position of stars (magnitude 9) in the scanning motion can be detected with an r.m.s. uncertainty of 7 – 8 milliarcsec.

Finally, the axis of Hipparcos' scanning motion will be slowly precessed at a rate of 4.4 deg/day. In a Sun-centred system, its spin-axis motion will therefore be along a cone centred on the Earth – Sun direction, with a semi-aperture of 43° and a period of about 57 days. Thanks to this complex motion, every observed star will be scanned on widely intersecting great circles during the Hipparcos mission, thus providing further accuracy for the reduction of the celestial sphere. The latter is achieved in a manner broadly comparable to geodetic triangulation on Earth (Fig. 3).

The Hipparcos satellite

Hipparcos is divided into two system-level assemblies, the spacecraft and the payload, mutually decoupled to the maximum possible extent (Fig. 4). An interface structure connects the payload mechanically with the spacecraft, with the exception of the two baffles, which are not an integral part of the payload (precautions having been taken to guarantee light-tightness at their interface). Most of the payload electronics are mounted on the upper platform of the spacecraft, together with some other spacecraft equipment. Carbon-Fibre Reinforced Plastic (CFRP) is used extensively in the construction of the payload and solar panels, the spacecraft itself being made of aluminium honeycomb.

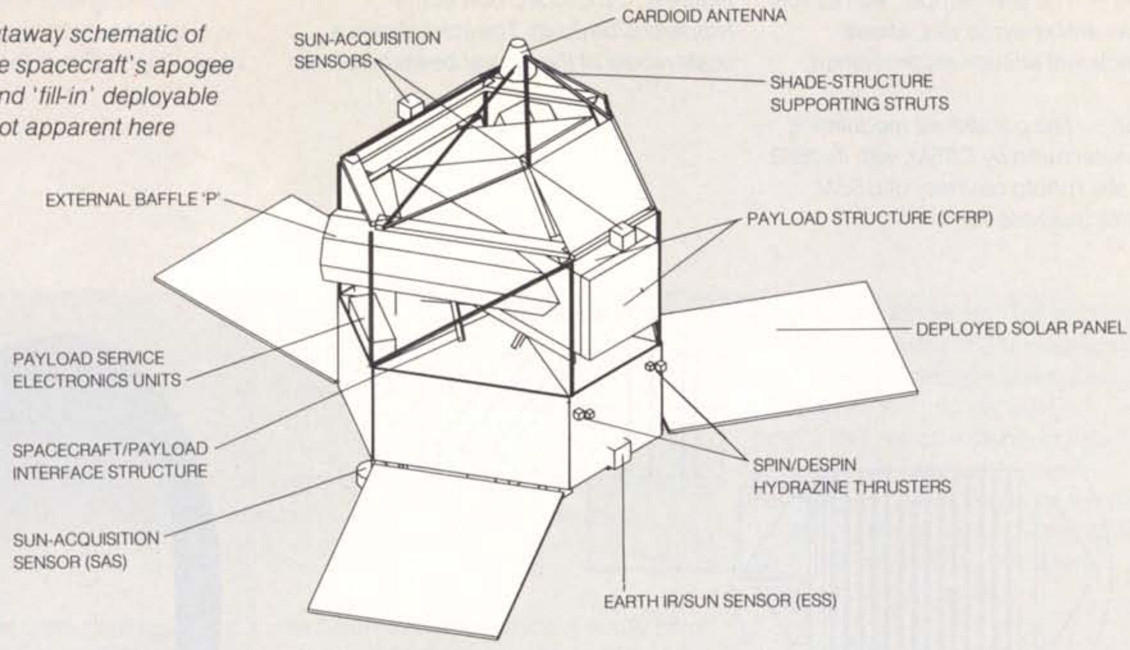
During its revolving scanning motion, Hipparcos will be able to assume any orientation with respect to the Agency's Odenwald receiving antenna in Germany, and omnidirectional RF coverage is achieved by switching several times per day between a cardioid-pattern antenna and a deployable antenna; the latter is located at the bottom of the spacecraft. Its RF coverage overlaps that of the upper cardioid antenna by about 15°.

The satellite's thermal control will be a combination of passive control by conventional radiators, multilayer insulation and coatings, and active control by means of electrical heaters. The temperature of the payload will be controlled automatically by the onboard computer to an accuracy of 0.1°C.

The spacecraft

The three deployable solar panels for Hipparcos have been adapted from the design for those of the Agency's ECS series of telecommunications satellites. At the nominal 43° Sun aspect angle, each

Figure 4 — Cutaway schematic of Hipparcos. The spacecraft's apogee boost motor and 'fill-in' deployable antenna are not apparent here



panel will deliver about 120 W at the end of the $2^1/_2$ year mission. Nickel-cadmium batteries will provide power in eclipse. The primary power-distribution system relies on a regulated DC bus, supplemented by AC secondary distribution to individual equipment items.

To avoid electrostatic discharges of the sort observed on previous geostationary satellites, the outer surface of Hipparcos is electrically conductive, with the exception of the solar-array cover glasses. Great care has also been taken to minimise the effects of any such discharges, each unit having its own signal ground.

Hipparcos will communicate with the ground via an S-band (2000 MHz) RF transponder, the signals being switchable to either spacecraft antenna by ground command. The uplink and downlink data rates will be 2000 and 24 000 bit/s, 9600 bit/s in the downlink being dedicated to the Tycho experiment.

There will be two computers onboard, a general-purpose Onboard Computer (OBC) coupled to the Central Terminal Unit (CTU) of the data-handling subsystem, and a Control Law Electronics (CLE) computer dedicated to attitude control and reconstitution. The essential functions of the satellite will be contained onboard in PROMs (Programmable Read Only Memories). Information on the stars to be followed by the payload will be stored in RAM (Random-Access Memory) (±3000 words capacity) upon receipt from the uplink.

For attitude control, Hipparcos has two reaction-control assemblies, a hydrazine assembly equipped with 5 Newton thrusters, which will operate until station acquisition, and a cold-nitrogen assembly with 0.02 Newton thrusters to be used thereafter for all manoeuvring, including east-west station-keeping. Outside specific station-keeping epochs, typical thruster actuations will last only 0.1 – 0.2 s, and will be separated by an average of 600 s. Analyses have shown that the level of residual attitude jitter on the optical viewing directions will be no more than 4 milliarcsec.

The redundant star mapper (Fig. 5a & b) located next to the modulating grid in the telescope's focal plane has a set of parallel and 'chevron' slits. Through the measurement of stellar transits due to the scanning motion, this allows the satellite's attitude to be measured, in combination with the gyroscope package. Numerous simulations have demonstrated that the specified performance of 1 arcsec r.m.s. for onboard real-time attitude determination can be met. Further ground processing, by the data-reduction consortia, will provide even more accurate star positions, resulting eventually in an attitude-determination accuracy of 0.1 arcsec r.m.s.

Real-time attitude determination is one of the key functions controlling the piloting of the 37 arcsec-wide Instantaneous Field of View (IFOV), so that it remains centred on the selected 'programme star'. The latter is observed during a fraction of its 19 s crossing of the field of view, with the scanning motion of the satellite. The other function, implemented in the Central Onboard Software of the OBC, is a 'Star Observing Strategy', which processes the programme-star file uplinked from the ground to establish observation priorities, switches from one programme star to another, etc.

The payload

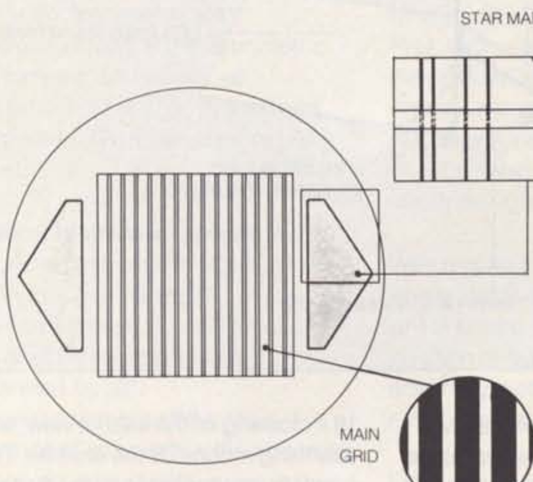
Hipparcos' scientific payload is a 290 mm-aperture, all-reflecting telescope (Fig. 6). The entrance pupil is a beam combiner made of two semi-circular elements shaped (Schmidt-Kerber profile) to combine, on the instrument's optical axis, the visible light coming from two directions in the sky separated by 58°. Due to the curvature at the focus, the modulating grid and the star mapper have been etched on a convex substrate with a radius of curvature equal to the focal length, i.e. 1400 mm. Behind the grid, an optical relay transmits stellar light to the detector, the Image Dissector Tube (IDT). Light coming through the star mapper slits of the grid is then deflected, split into 'blue' and 'visible' light components by a dichroic plate, and transmitted to photomultiplier tubes.

To achieve the required accuracy, the payload must be of the 'diffraction-limited' type in which all aberrations are reduced to an absolute minimum. The tolerance specifications in the table at the top of page 27 provide some insight into the stringency of the payload requirements.

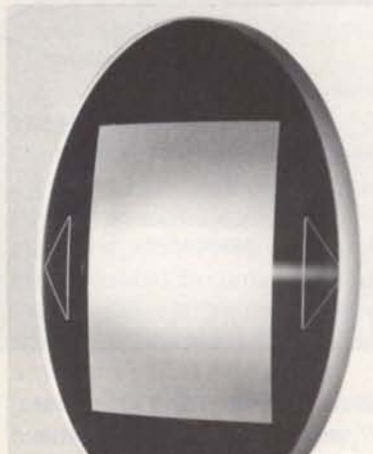
Figure 5a – The star mapper, with its sets of parallel and chevron slits, allows omnidirectional attitude reconstitution

Figure 5b – The parallel-slit modulating grid manufactured by CSEM, with its 2688 parallel slits (photo courtesy of CSEM, Neuchâtel, Switzerland)

Figure 6 – Exploded view of the Hipparcos payload. The inset shows a scale model of the optical beam combiner



5a.



5b.

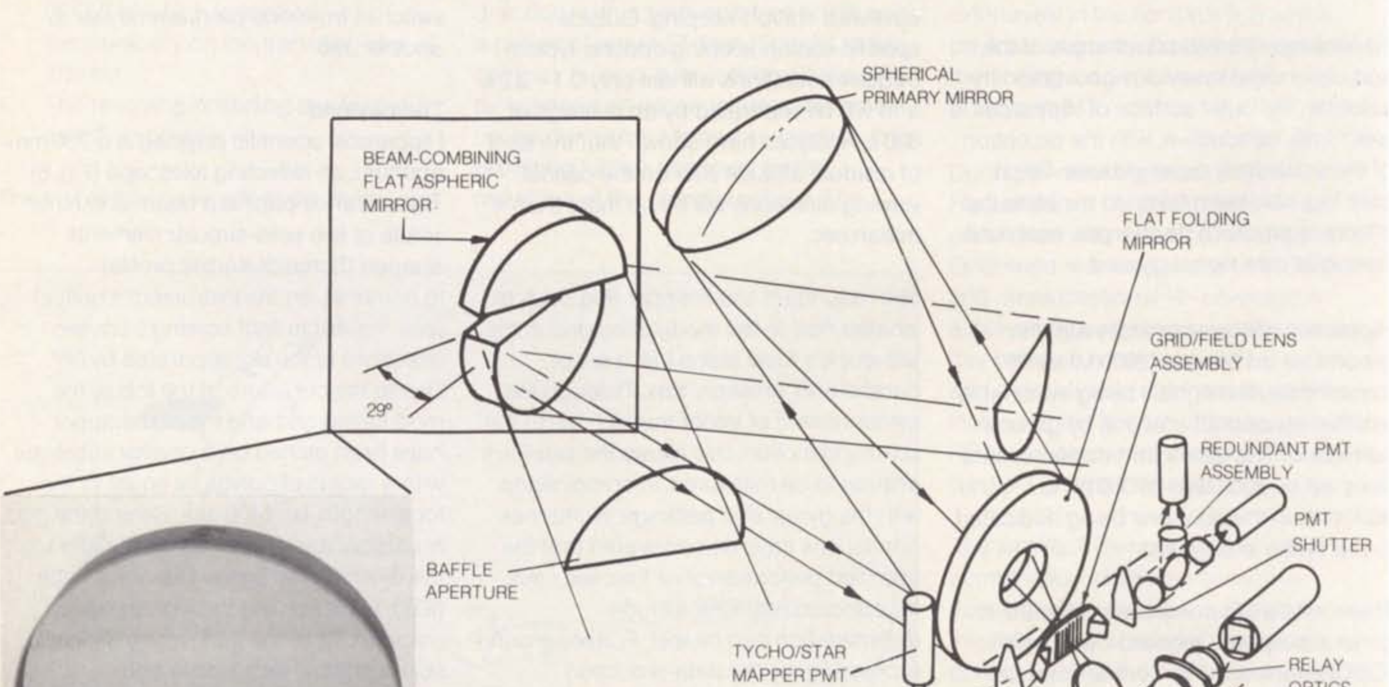


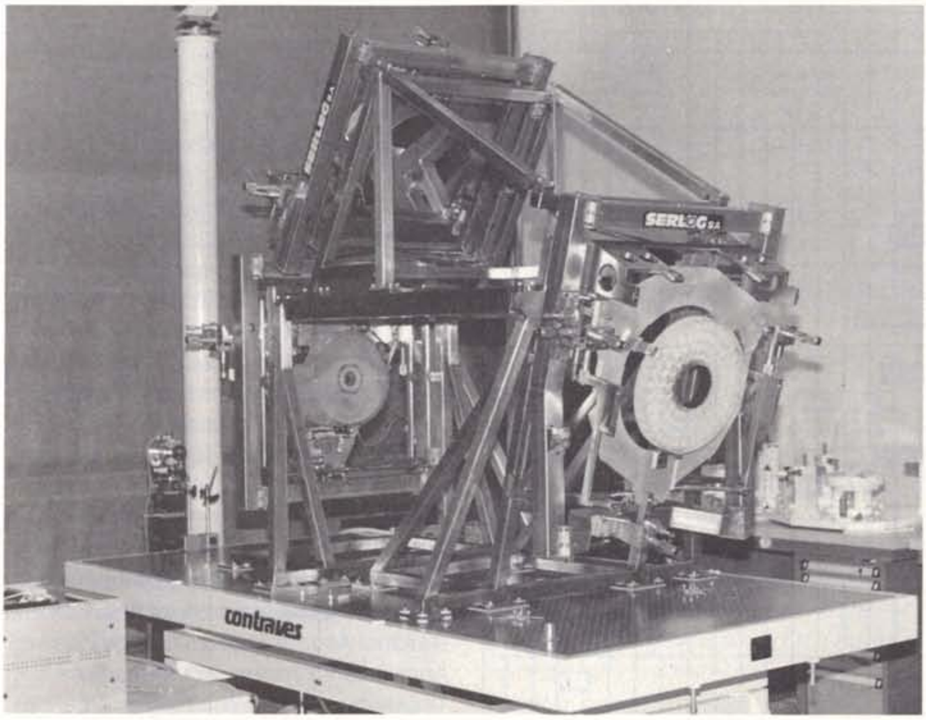
Figure 7 — Alignment testing of the Hipparcos beam combiner, at Matra (Toulouse), as part of the Optical Support Programme

– Optical quality of the mirrors	$\lambda/60$
– Symmetry of the wavefront error along the direction of scan	$\lambda/40$
– Stability of the focus	0.6 μm over 24 h
– Stability of grid rotation w.r.t. IDT optical axis	0.1 arcsec over 24 h
– Stability of beam-combiner temperature	0.05° over 2.6 h

Needless to say, demonstration that such tolerances will be achieved calls for refined optical, structural and thermal analyses of payload structure and mirrors, and verification of structural and thermal behaviour by thermal-vacuum testing at all stages of the project. In addition, a number of payload calibrations will have to be undertaken during the satellite's in-orbit commissioning and some of these will need to be repeated during the course of the mission.

All three mirrors – the beam combiner, a spherical mirror, and a flat inclined mirror to fold the optical path in order to save space – are polished from a Zerodur substrate. A novel feature of Hipparcos is the beam combiner, which is made from one blank cut into two after final polishing, the two halves then being glued together to achieve the 58° 'basic angle' (29° between the two optical surfaces).

To remain compatible with the accuracy expected from a star transit – approximately 7 milliarcsec for a star of magnitude 9 – the profiles of the equidistant lines of the modulating grid must also satisfy extremely stringent tolerances, with irregularities limited to the order of a few tens of nanometres. Such a fine grid could not be produced on a curved substrate by the usual practices of optical-grating production and it has been necessary to resort to micro-circuit production technology. The grid has been made at the Swiss CSEM research centre employing the electron-beam photo-lithography techniques used in fabricating complex semiconductor integrated circuits. Subsequent calibrations have shown that the difficulty of etching the 22 mm × 22 mm grid in 46 × 168 'scan fields' has been successfully overcome.

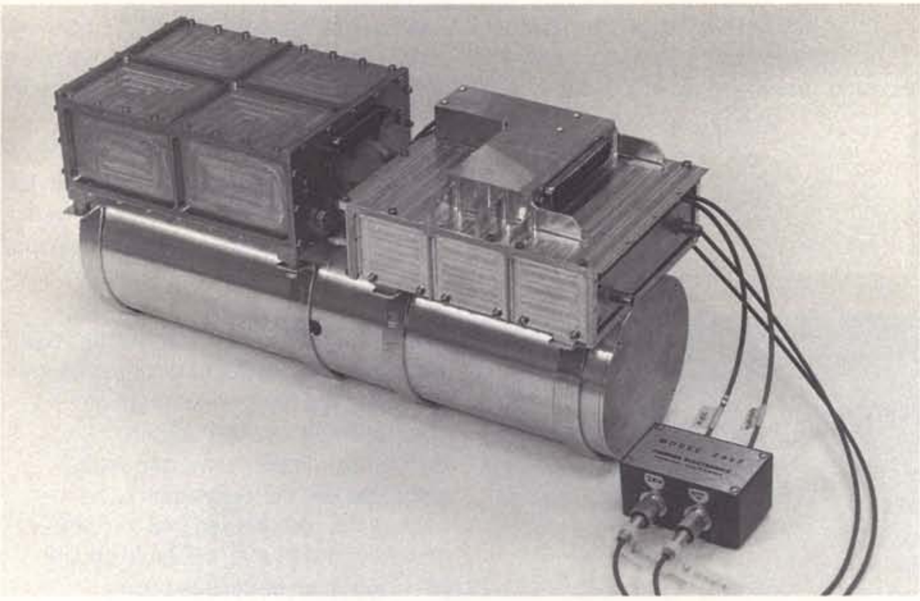


The main detector for Hipparcos, the Image Dissector Tube (Fig. 8a, b), is being made by IT&T in the USA. Engineering models and flight units have already been delivered to The Netherlands Space Research Laboratory in Utrecht, where tests have shown detection characteristics and tolerances commensurate with the detector's critical contribution to the satellite's performance.

A protoflight model philosophy is being employed, with complete qualification of the equipment at engineering-model level. Integration of the complete satellite will be carried out at Aeritalia in Turin. In parallel with the Structural and Thermal Model (STM) activities, an OSTM (Optical STM) programme will help support the payload-performance activities. The overall project schedule is summarised in Figure 9.

Data processing

An Input Catalogue Consortium (INCA), led by Dr. C. Turon (Paris), is charged with the selection of the 100 000 programme stars and assignment of their astrometric and photometric characteristics (to 1.5 arcsec and 0.5 mag, respectively), including a campaign of measurements for those stars that are as yet poorly known. The complex data-reduction scheme is being tackled by two consortia, the Northern Data Analysis Consortium (NDAC) led by Dr. E. Høg (Copenhagen) and the Fundamental Astronomy by Space Techniques (FAST) group led by Prof. J. Kovalevsky (Grasse). Regular seminars are taking place and the drawing up of the data-reduction algorithms is proceeding according to plan.



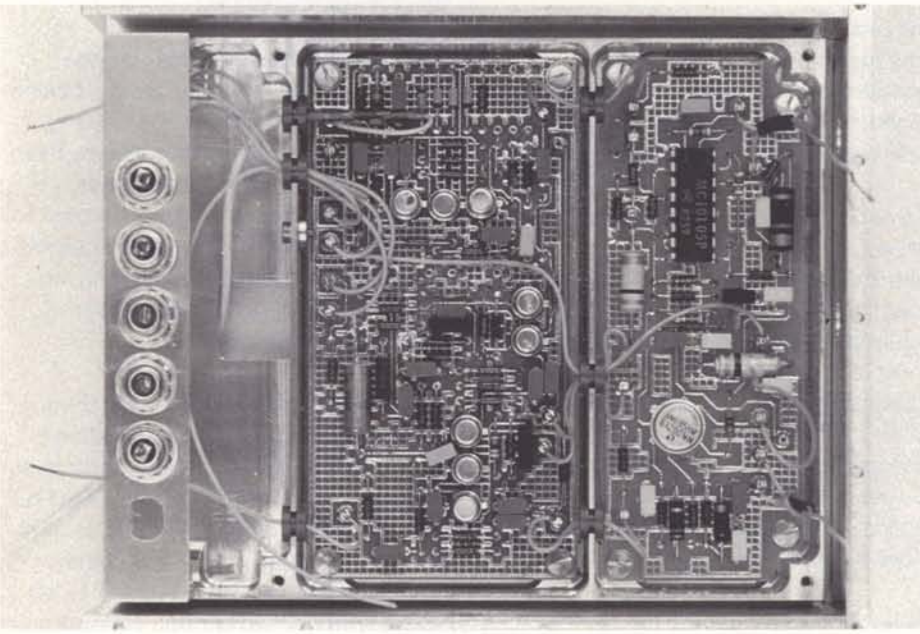


Figure 8a — Development model of Hipparcos' Main Detector Assembly (MDA). The Image Dissector Tube (IDT) focussing and deflection coils and preamplifiers are located in the cylindrical housing. The Pulse Amplifier and Discriminator (PAD) is located in the housing at the rear, the high-voltage power supply (CRI) in that at the front (courtesy of Netherlands Space Research Laboratory)

Figure 8b — The Pulse Amplifier and Discriminator (PAD) payload unit (courtesy of Netherlands Space Research Laboratory)

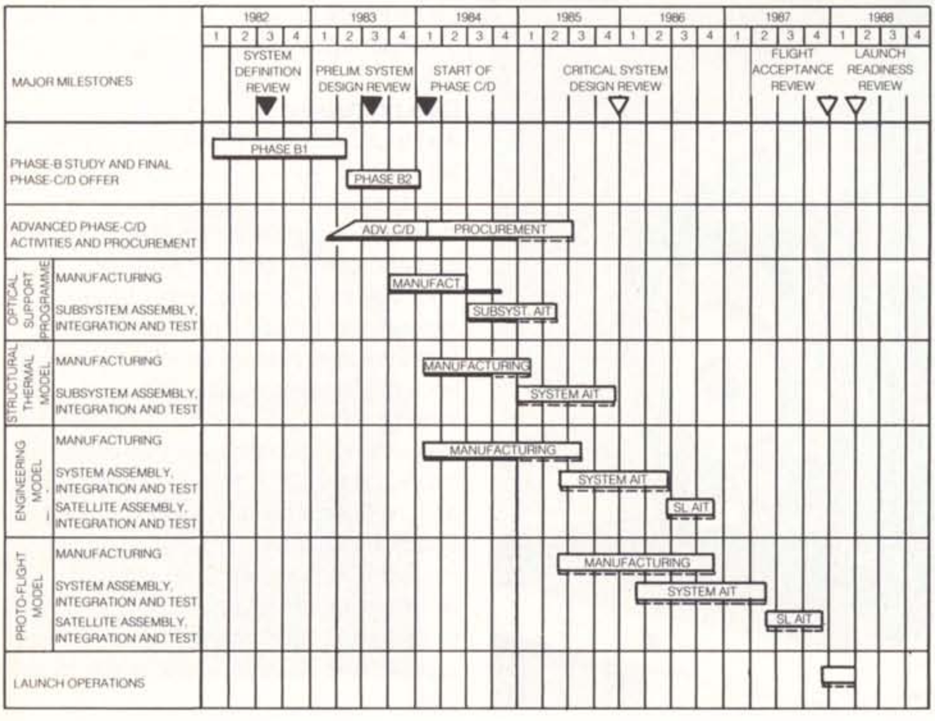


Figure 9 — Summary programme schedule

The data from the Tycho experiment will be processed by a Tycho Data-Analysis Consortium, also led by Dr. Høg.

Early operations

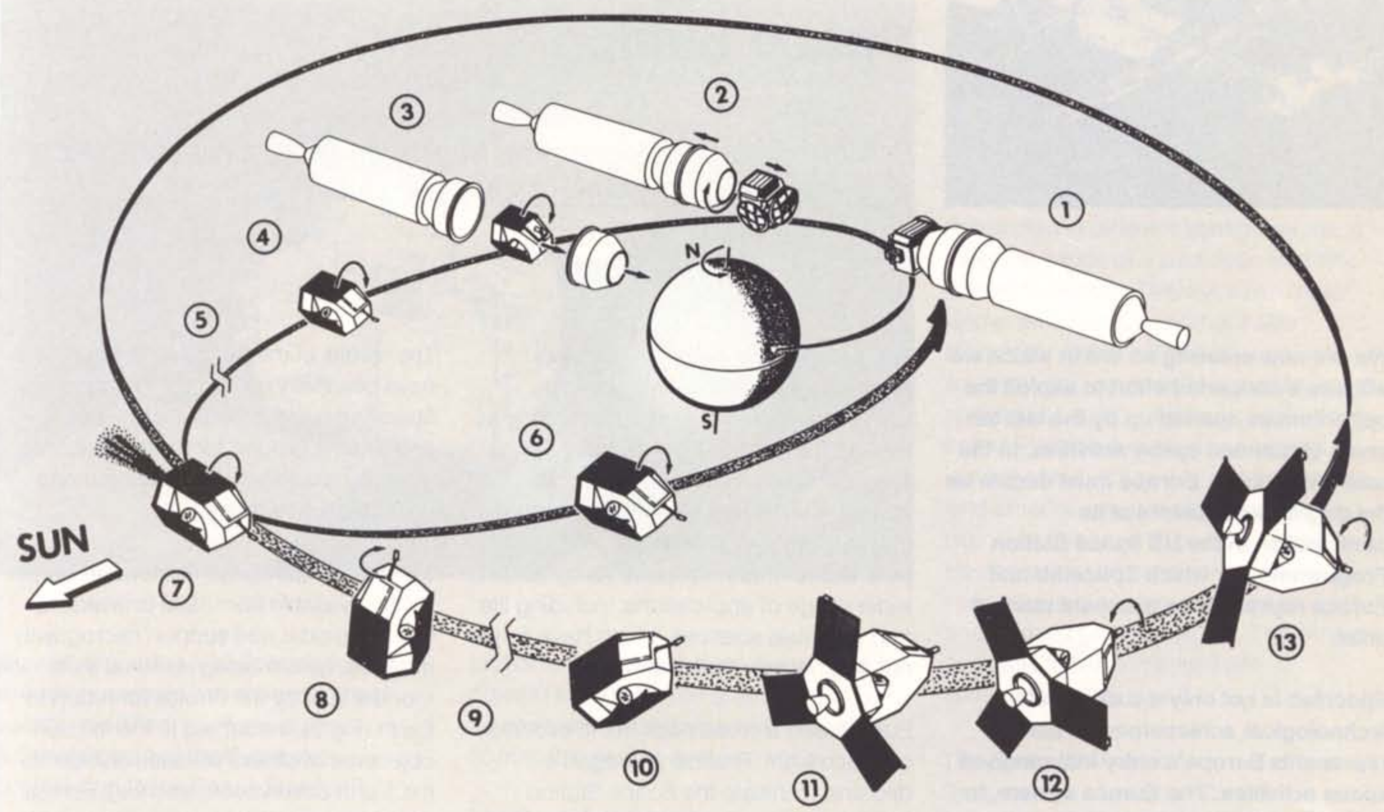
Hipparcos will be launched from ESA's Kourou launch base in French Guiana (Centre Spatial Guyanais) in a dual-launch configuration by an Ariane vehicle into geostationary transfer orbit. Injection into near-synchronous orbit will be achieved with the satellite's own Mage-2 solid-propellant motor. Tracking will be performed by the four-station Launch and Early Orbit Phase (LEOP) network of ground stations operated by ESOC.

Distinctive features of the near-synchronous orbit are an initial inclination of less than 1° to the equator, sufficient to avoid the need for north-south station-keeping manoeuvres during the $2^1/_2$ year mission, and spin-stabilisation of the satellite at 60 rpm about an axis normal to the orbital plane (the result of thermal-control and optical-attitude-sensor design trade-offs). Only after final station acquisition will the satellite be despun, its solar panels deployed, and the nominal attitude-control law put into operation. The sequence of operations from launch to the start of the scientific mission is summarised in Figure 10.

Conclusion

In the words of Dr. Freeman J. Dyson of Princeton University, in a presentation to the US National Academy of Sciences and National Air and Space Museum 25th Anniversary Symposium on Space on 14 October 1982, in Washington DC:

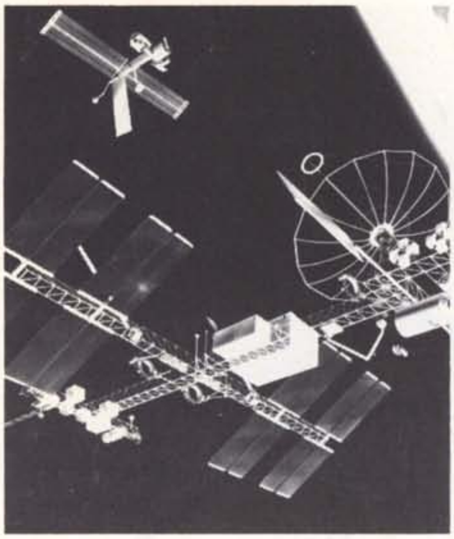
Figure 10 — Sequence of operations for the launch and early operational phases of the Hipparcos mission



1. ARIANE THIRD-STAGE BURNOUT AND INJECTION INTO TRANSFER ORBIT
2. ORIENTATION OF COMPOSITE (THIRD STAGE + PAYLOAD) & SPIN UP (MAX 10 RPM) BY THIRD-STAGE ATTITUDE CONTROL AS REQUIRED BY COMPANION SATELLITE
   SEPARATION OF UPPER SATELLITE
3. ORIENTATION OF COMPOSITE (THIRD STAGE + LOWER PASSENGER + SYLDA) AND SETTING OF SPIN RATE (MAX. 10 RPM) AS REQUIRED BY LOWER PASSENGER (HIPPARCOS)
   SEPARATION OF UPPER PART OF SYLDA AND OF HIPPARCOS
4. SATELLITE ACQUISITION BY LEOP GROUND STATION NETWORK
   FULL SPIN UP
   START OF ORBIT AND ATTITUDE RESTITUTION
   FINE SPIN-AXIS ORIENTATION
5. TRANSFER-ORBIT PHASE (3.5 ORBITS UP TO NOMINAL APOGEE)
6. ORBIT AND ATTITUDE RESTITUTION
   SATELLITE MONITORING
7. APOGEE-MOTOR FIRING
8. REORIENTATION OF THE SPIN AXIS PERPENDICULAR TO THE NEAR-STATIONARY-ORBIT (NSO) PLANE
9. NSO PHASE (~12 ORBITS BEFORE STATION ACQUISITION)
10. SATELLITE DESPIN
    POINTING OF THE Z-AXIS TOWARDS THE SUN
11. DEPLOYMENT OF SOLAR PANELS AND 'FILL IN' ANTENNA
12. SLOW ROTATION ABOUT THE Z-AXIS (~170 DEG/H)
    PAYLOAD CALIBRATION (STAR MAPPER)
    OBTAINING OF A PHASE REFERENCE AROUND THE SUN BY OPERATION OF STAR MAPPER
13. POINTING OF THE Z-AXIS TO THE STARTING POINT
    PAYLOAD CALIBRATION
    NORMAL OPERATION

'Hipparcos is an astrometric satellite, designed to do nothing else than measure very accurately the angular positions of stars in the sky. It will give positions about ten times as accurate as those measured by ground-based telescopes. This sounds like a modest and unrevolutionary objective, but in fact the improvement of positional accuracy is of central importance to astronomy...... In this and other ways, the data from Hipparcos will give us a wealth of new information about the constitution and evolution of stars and about the dynamical behaviour of our galaxy. The Hipparcos mission also includes a completely automated data processing system on the ground, so that star positions will not be measured laboriously one at a time, but will be computed in batches of a hundred thousand. The data-processing system will be a more revolutionary improvement of the state of the art of astrometry than the satellite itself'.

To make the Hipparcos mission possible, quite a number of technical difficulties have had to be tackled, but progress in the development work conducted so far makes us confident that this unprecedented space mission will be successful in meeting the demanding goals that have been set for it.



Spacelab and Eureca as a Basis for European Involvement in The Space Station

R. Mory, Eureca Programme Manager, Directorate of Space Transportation Systems, ESA, Paris

We are now entering an era in which we will see a concerted effort to exploit the opportunities opened up by the last ten years of manned space activities. In the next few months, Europe must decide on the degree and content of its participation in the US Space Station Programme, for which Spacelab and Eureca represent an excellent starting point.

Spacelab is not only a successful technological achievement, it also represents Europe's entry into manned space activities. The Eureca system, to be launched in early 1988, will demonstrate the technology required for the free-flying elements of the Space Station. It will constitute a first European demonstration mission for free-flying, autonomous, unmanned systems, whilst at the same time serving as a test-bed for Space-Station technology.

The combination of the Shuttle and Spacelab represents a milestone in US – European cooperation, providing as they do the World's first re-usable Space Transportation System equipped with a large, shirt-sleeve-environment laboratory (Fig. 1). With their availability, we have the potential for manned space ventures for a wider range of applications, including life and materials sciences, which have as yet not been deeply explored.

Europe is at a crossroads in the evolution of space flight. President Reagan's decision to initiate the Space-Station Programme, taken back in January 1984, was linked with an invitation to 'friends and allies' to participate in the Programme. Preparation for this participation is now fully under way in Europe.

The results of the Spacelab-1 mission have been very encouraging and further Spacelab missions in the late 1980s will prepare the ground for Space-Station operations with selected research and application activities.

Eureca, the European Retrievable Carrier, will be available from 1988 onwards to carry into orbit and support microgravity missions, before being retrieved six to nine months later by the Shuttle for return to Earth (Fig. 2). If adapted to the mission objectives of other interested disciplines (i.e. Earth observation, science), Eureca will be an important operational tool for these other areas also. Furthermore, it provides the basis for the development of free-flying platforms in the framework of the in-orbit infrastructure foreseen for the turn of the century.

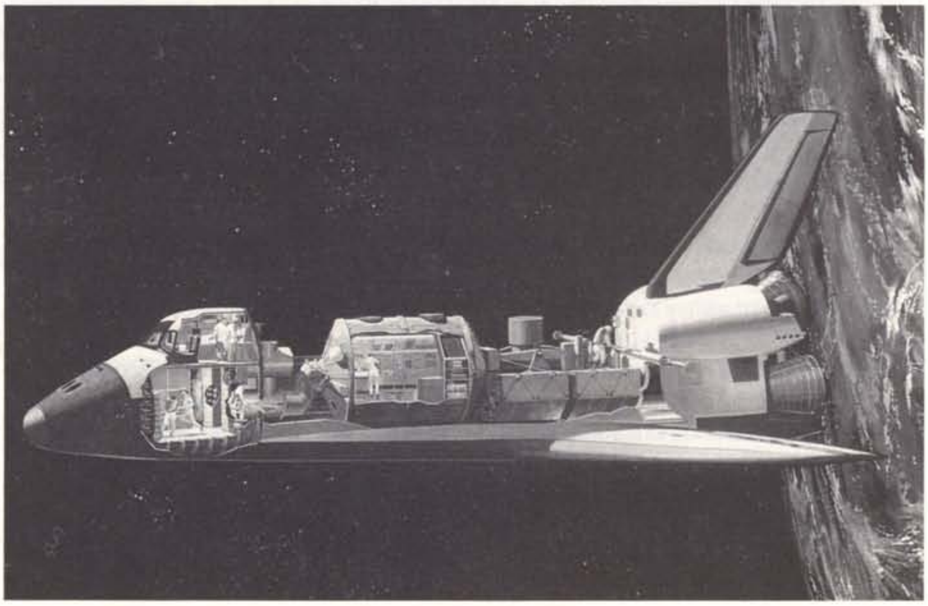


Figure 1 – Spacelab in the Shuttle's payload bay (Spacelab-1 configuration)

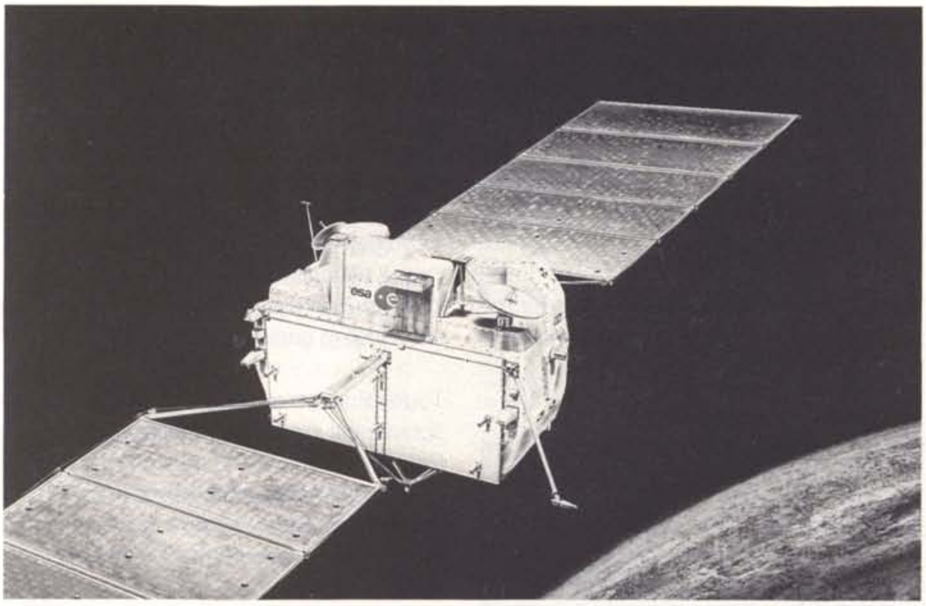


Figure 2 – Artist's impression of the Eureca platform

All in all, in Eureca and Spacelab, Europe already possesses two elements that, suitably modified, can form a very worthwhile part of the European contribution to the Space Station.

Spacelab's development and integration
Spacelab was designed, developed, funded and built by ESA as Europe's contribution to the NASA Space Transportation System. Considered one of ESA's most important programmes of recent years, Spacelab represents a European investment of almost one billion US dollars. An industrial consortium of some 50 firms in ten European countries has participated in the construction of the laboratory's hardware.

NASA monitored Spacelab's development and was responsible for its integration and assembly for flight. Throughout the design and development process, the two Agencies worked closely together to meet the common objectives of the Spacelab Programme, such as the provision of versatile laboratory facilities, rapid user access and minimum interference with Shuttle turn-around activities. Operational concepts also influenced the design and construction of Spacelab elements, ensuring that the experiment, Spacelab and Shuttle cycles of operation would dovetail smoothly. The Shuttle's development process had an impact on Spacelab's design, and vice versa.

The Spacelab system
Figure 3 shows the initial Spacelab configuration of 1973, based on studies by the Spacelab Consortium, with its still retained features of modularity and facilities for the rapid exchange of scientific payloads. When carried in the Space Shuttle's payload bay, it converts the Shuttle into a versatile, in-orbit research centre.

With its modern design and construction, Spacelab consists of several interchangeable components that can be assembled in different configurations to meet the needs of a particular scientific research mission. There are two major elements: a pressurised habitable laboratory called a 'Module', in which scientists can work without cumbersome space suits, and unpressurised platforms called 'Pallets', designed to support instruments such as telescopes, sensors and antennas, which require direct exposure to space (Figs 4, 5). These elements may be used separately or in various combinations, returned to Earth and re-used on other flights. The services available to experimenters are summarised in Figure 6.

The Spacelab mission
Spacelab was first flown on the STS-9/Spacelab-1 mission, in November 1983. This Spacelab-1 mission was a joint ESA/NASA mission and each Agency sponsored approximately half of the scientific payload.

The primary purpose of the first Spacelab

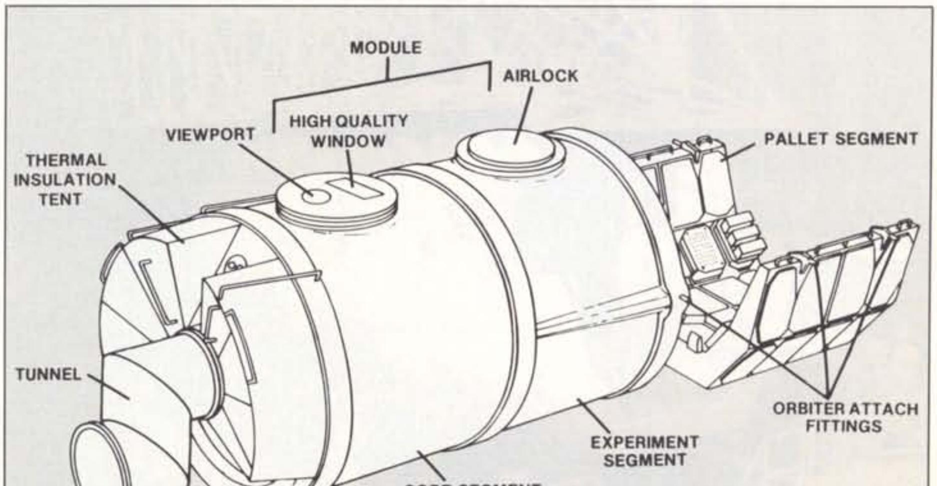


Figure 3 – Principal features of Spacelab

Figure 4 – Typical Spacelab flight configurations

Figure 5 – Spacelab Module and Pallet being hoisted into the Cargo Integration Test Equipment (CITE)

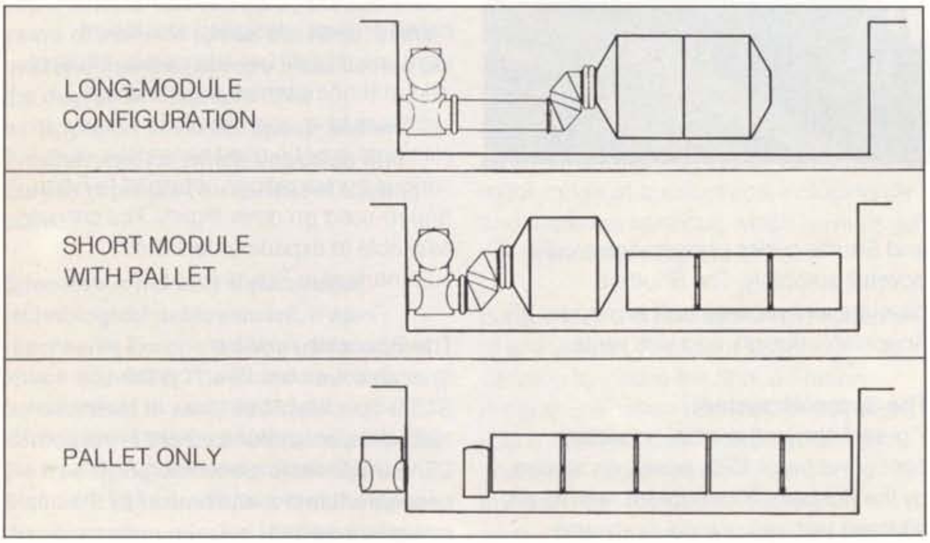
mission was to verify the laboratory's integrity and to test the thousands of structural, mechanical and electronic components that it contains. Special flight instrumentation therefore formed an important element of that payload.

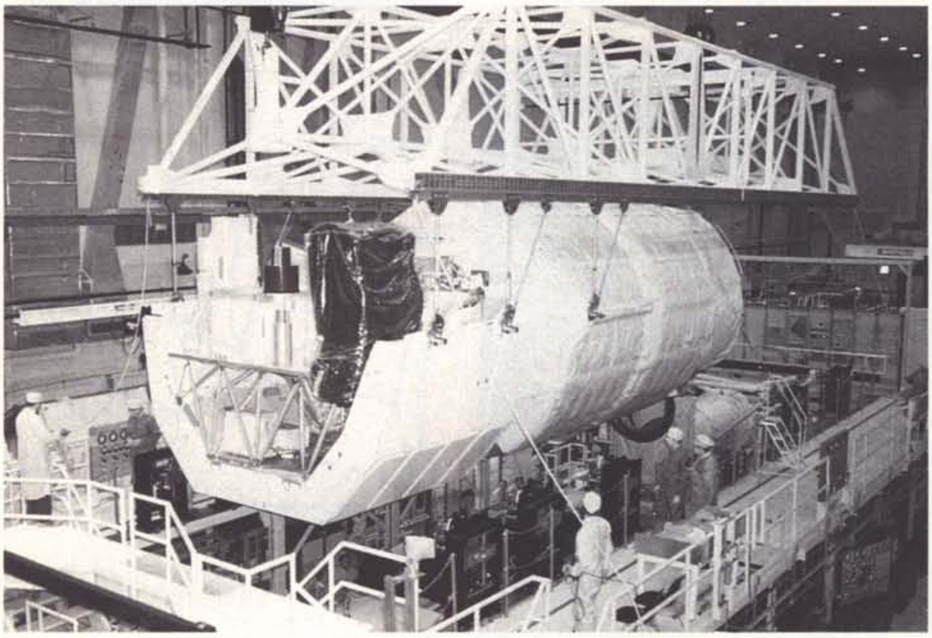
As a second objective, four tons of experiments were carried, representing a total of 70 experiments, the highest number ever flown on a single mission. Of the European instruments, developed under national funding, the material-sciences experiments tested low-gravity techniques for materials processing. These experiments take advantage of the microgravity conditions for studies in such areas as tribology, fluid physics, crystal growth and metallurgy.

The Spacelab-1 mission proved extremely successful and, in both Europe and the USA, the Spacelab Programme is considered to be the largest and most successful example of international space cooperation to date.

With the successful STS-9 flight, Europe has made its entry into the domain of manned spaceflight. The managerial and technical knowhow acquired over more than a decade has reached fruition with the demonstration of Spacelab's outstanding capabilities.

Today Europe, as a result of its substantial investments in the Spacelab Programme, has at its disposal the industrial infrastructure needed to develop, manufacture and qualify several of the essential elements of a manned space system.





Eureca's development

Another important tool in preparing for further cooperation in the framework of the Space Station Programme will be the European Retrievable Carrier, available from 1988 onwards for microgravity missions.

With the Eureca system, the Agency will be providing the user community with the first European retrievable carrier for long-duration missions. By extending the capabilities of the available re-usable systems such as Spacelab, Eureca will bridge the gap until the availability of the Space Station. The system has been designed as a multipurpose carrier, with a dedicated microgravity payload to be carried during the first flight. Studies to define Eureca's utilisation for astronomy missions, Earth observation, solar physics and technology missions are currently being completed.

The Eureca system

The Eureca payload carrier now under development incorporates the more attractive features of Spacelab (high mass and power capability, recovery) and those of conventional expendable satellites (extended operating time, pollution-free environment). Moreover, Eureca is commensurate with the size of payload

Figure 6 – Spacelab services to users

Figure 7 – Eureca flight profile

that can currently be developed economically in Europe (Table 1).

Eureca will be boosted to a height of about 525 km from the Shuttle's low Earth orbit by its own thruster system and this orbital altitude will slowly decrease during the carrier's period of operation. At the end of the mission, Eureca will rendezvous with the Shuttle to be retrieved and returned to Earth, leading to a mission profile of the type shown in Figure 7. The major system requirements are summarised in Table 2.

The framework of the Eureca primary structure is made up of standardised high-strength carbon and titanium struts and elements borrowed directly from the SPAS (Shuttle Pallet Satellite) structure,

Spacelab configuration	Short module +9 m pallet	Long module	15 m pallet	Independently suspended pallet
Payload weight (kg)	~ 4950	~ 4800	~ 7650	~ 8800
Volume for experiment equipment:				
Inside module (m^3)	8	22	–	–
On pallet (m^3)	100	–	167	100
Pallet mounting area (m^2)	51	–	85	54
Electrical power (28 V DC 115/200 V at 400 Hz AC)				
Average (kW)	2.5 - 4.0	2.5 - 4.5	4.5 - 5.5	4.5 - 5.5
Peak (kW)	7	8	9	9
Energy (kWh)	~ 250	~ 300	~ 550	~ 550
Experiment-support computer with central processing unit and data acquisition system	64 K core memory of 16 bit words, 350 000 operations per second, 15 K core available to users			

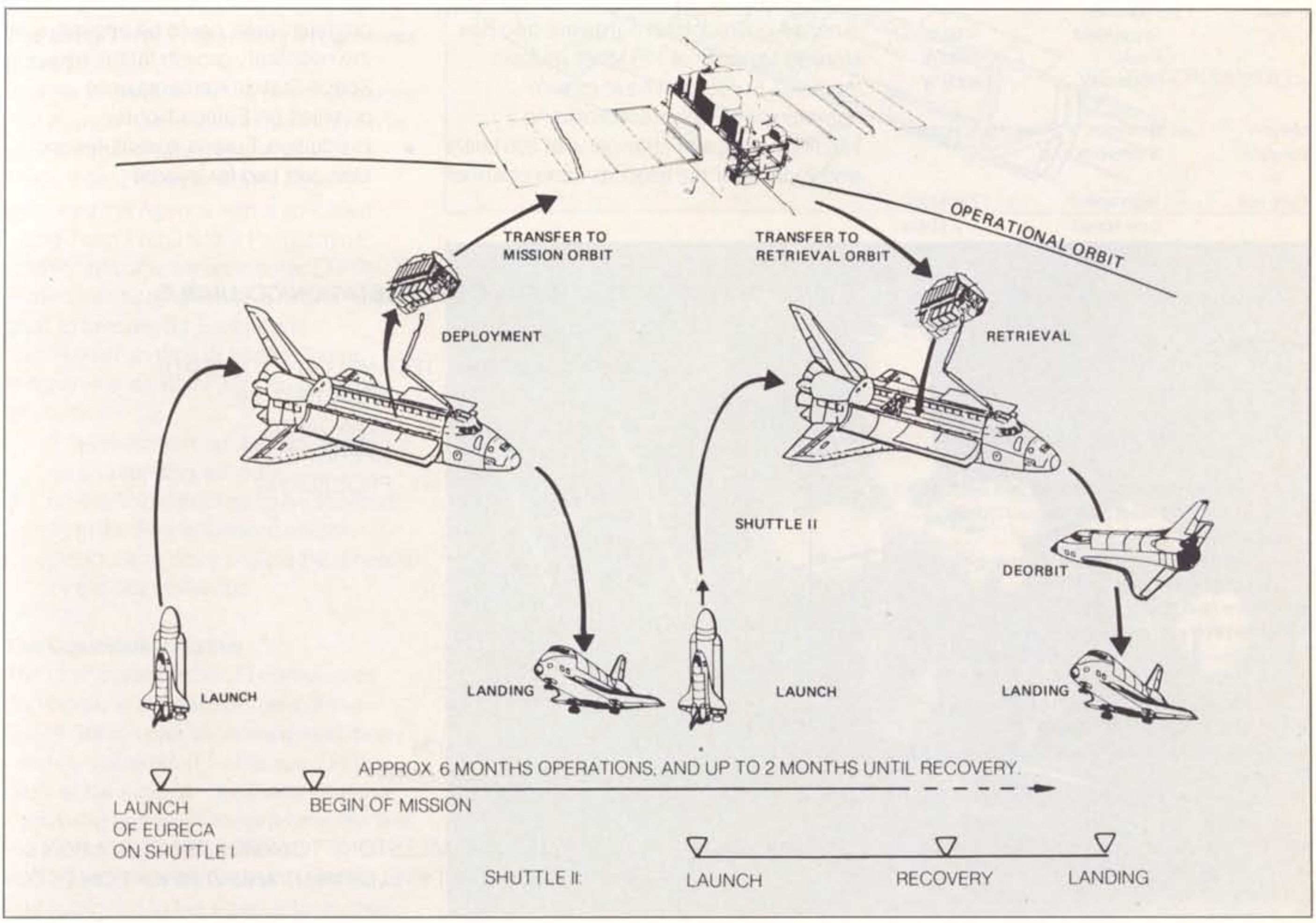


Figure 8 — Design and operational aspects

The carrier will weigh approximately 4000 kg at launch, including 1000 kg of payload. It is presently 2.45 m long and fits comfortably into the 4.6 m diameter cargo bay.

Eureca's thermal-control system uses space-proven passive techniques combined with active heat-rejection by means of a fluid loop dissipating thermal loads into space through two radiator panels. Experiments and equipment will be cooled either with cold plates or with fluid flowing directly to the interiors of the experiments.

An electrical power subsystem generates, stores, conditions and distributes power (5000 W output) to all subsystem units and instruments. Deployable and retractable solar arrays are used to provide 1000 W of continuous power to the payload in both sunlight and eclipse.

Attitude and orbit control is provided by a monopropellant system with eight hydrazine thrusters (20 Newton) for orbit-change manoeuvres, and a cold-gas system combined with reaction wheels with magnetic torquers for fine attitude control. Eureca will be three-axis stabilised and Sun-pointing in its normal operating mode, with an attitude accuracy of ±1°.

The data-handling subsystem for Eureca is based on Spacelab hardware and has storage capacity of 128 Mbits (bubble memory). Eureca will have its own communications system providing a telemetry high-rate channel with 256 kbit/s and 2 kbit/s for the telecommand channel.

The present system, as well as several subsystems, has growth capabilities, either because existing designs and hardware can be re-used or because the design of existing hardware is flexible enough to allow increases in performance without major redesign. Studies to investigate the requirements for various mission applications have led to a final design that facilitates adaptation to other missions, such as technology, Earth observation, solar-physics missions, and astronomy. In addition to serving its primary role as a re-usable payload carrier, therefore, the Eureca system will contribute considerably to the future Space-Station scenario in several respects:

- The capabilities provided by Eureca in terms of power generation, heat rejection, orbit-to-ground communication, attitude control, and orbital transfer could be applied, with the necessary growth factor, to Space-Station elements once qualified on Eureca flights.
- In addition, Eureca constitutes an ideal test bed for in-orbit

Table 1 — Some key data for Eureca (appropriate for the first mission)

Mass:	Total:	4000 kg
	Available to payload:	1000 kg
Power:	Available to payload:	1000 W
	Peak:	1500 W
	Total max.:	5300 W
Mission duration:	6 months + 3 months (dormant) 5 missions total	
Date rate:	High speed:	256 kbit/s
	Low speed:	2 kbit/s
	Data storage:	128 Mbit
Attitude pointing accuracy: ±1° (3 σ)		
Microgravity:	10^{-5} < 1 Hz	
	10^{-3} > 100 Hz	

Table 2 — Major system requirements

- Reference orbit 525 km altitude, 28.5 inclination
- Deployment/retrieval orbit 160 nm/170 nm altitude, 28.5° inclination
- Orbital transfer manoeuvres for change of altitude, orbital plane and phase
- Eureca operational modes:
  - experiment operation 6 months
  - semi-dormant, thereafter until retrieval by Orbiter appr. 3 months later
  - mission contingency up to further 9 months
- Lifetime: 5 missions or 10 years
- Minimise length in launch configuration to minimise STS cost
- Launch mass 4000 kg with a payload mass of 1000 kg
- Flight operations control from ESOC (Darmstadt)
- Transportable with commercial aircraft (Boeing-747)

EURECA SYSTEM - TEST BED FOR SPACE STATION/COLUMBUS

TECHNOLOGY CONCEPTS
- ARCHITECTURE
- STANDARDS
- OPERATIONS
- PROCESSING

ELEMENTS
- HARDWARE
- SOFTWARE
- ON-BOARD
- GROUND

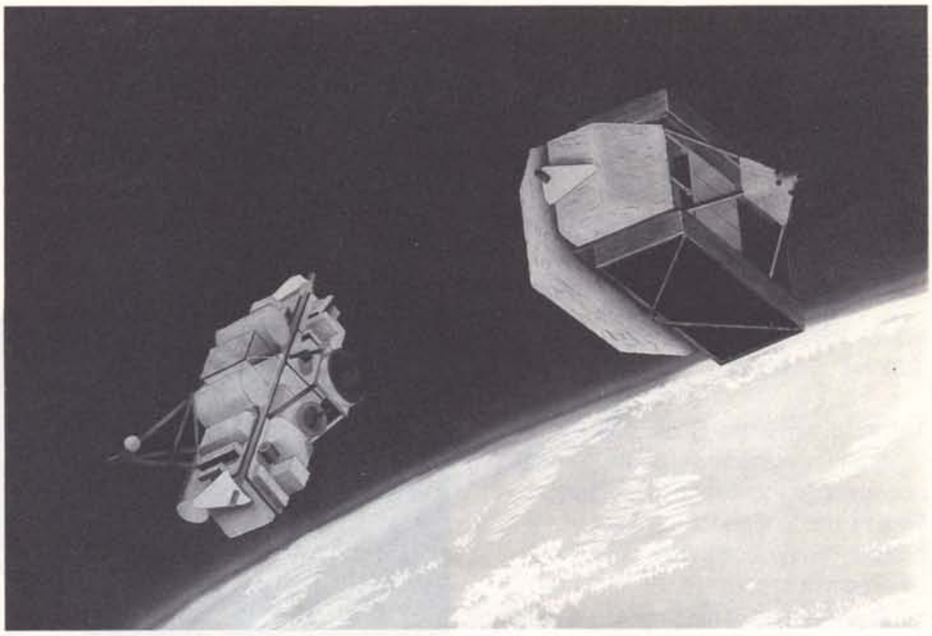
PROGRAMMES
- PROGRAMMATICAL APPROACH
- ASSEMBLY AND TEST PHILOSOPHY
- VERIFICATION & CONTROL

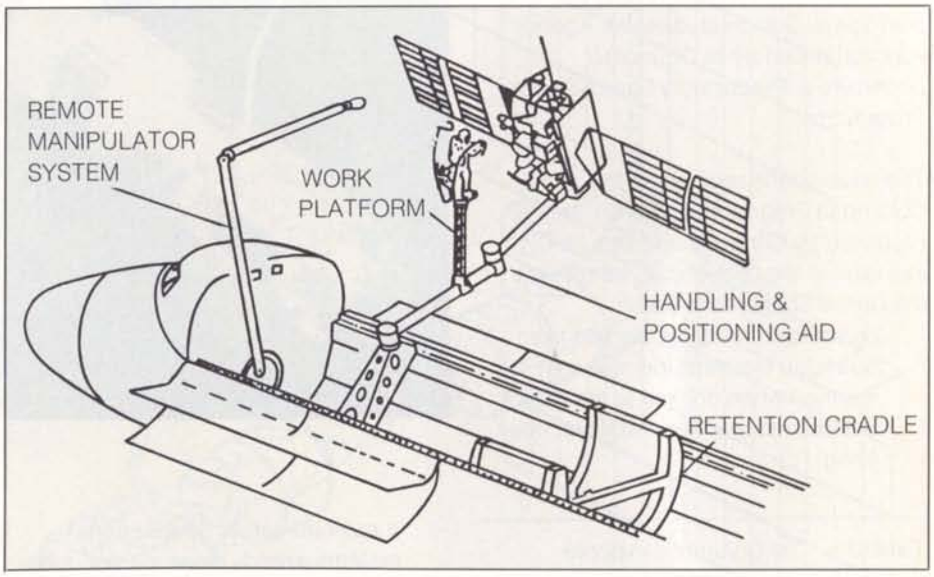
EURECA SYSTEM = PROMOTER AND MILESTONE TOWARDS SPACE STATION & INITIAL TEST-BED, DEVELOPMENT AND VERIFICATION TOOL

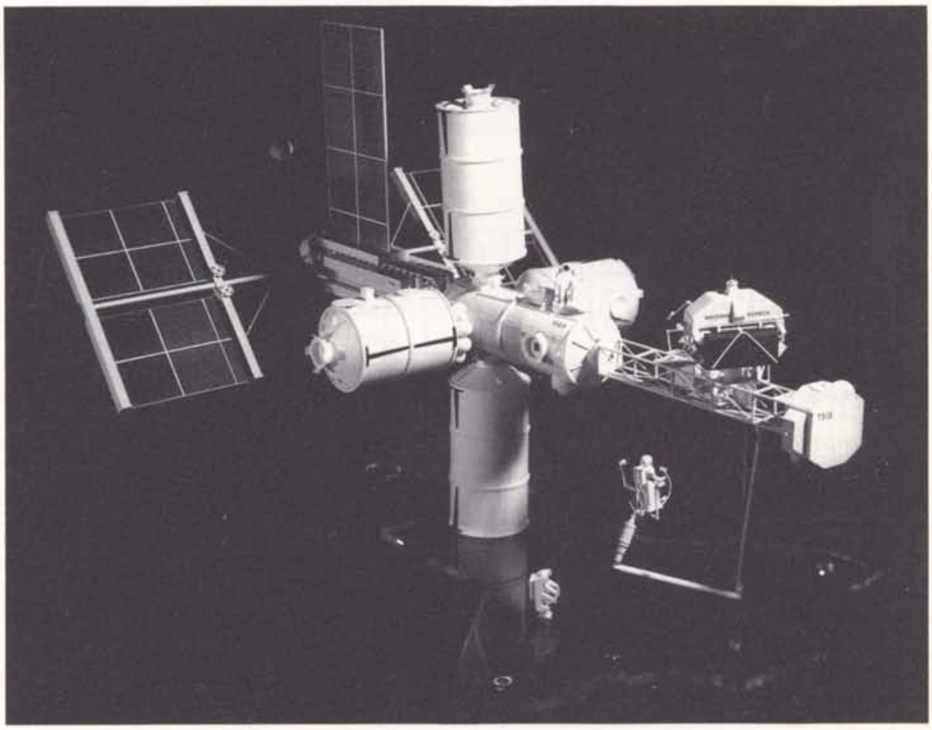
Figure 9 – Rendezvous and docking demonstration

Figure 10 – Eureca in the Columbus scenario. In-orbit-servicing demonstration mission, with Eureca in the Handling/Positioning Aid (HPA)

Figure 11 – Spacelab Modules and Eureca attached to the Space Station







demonstration of such technologies as inter-orbit communication, rendezvous and docking, and in-orbit servicing, all of which are essential to Europe achieving its long-term objectives in space (Figs. 8, 9).

- Eureca constitutes a demonstration mission for Europe in the fields of ground processing, launch, retrieval, in-orbit operations, and payload processing, all of which will be a part of the future Space-Station scenario (Fig. 10).
- Eureca will be a co-orbiting Space-Station element, able to provide the advantages of an unmanned automatic platform. This platform, however, requires improvement and adaptation to be compatible with the Space-Station Programme's overall objectives (Fig. 11).

The Long-Term Preparatory Programme (LTPP)

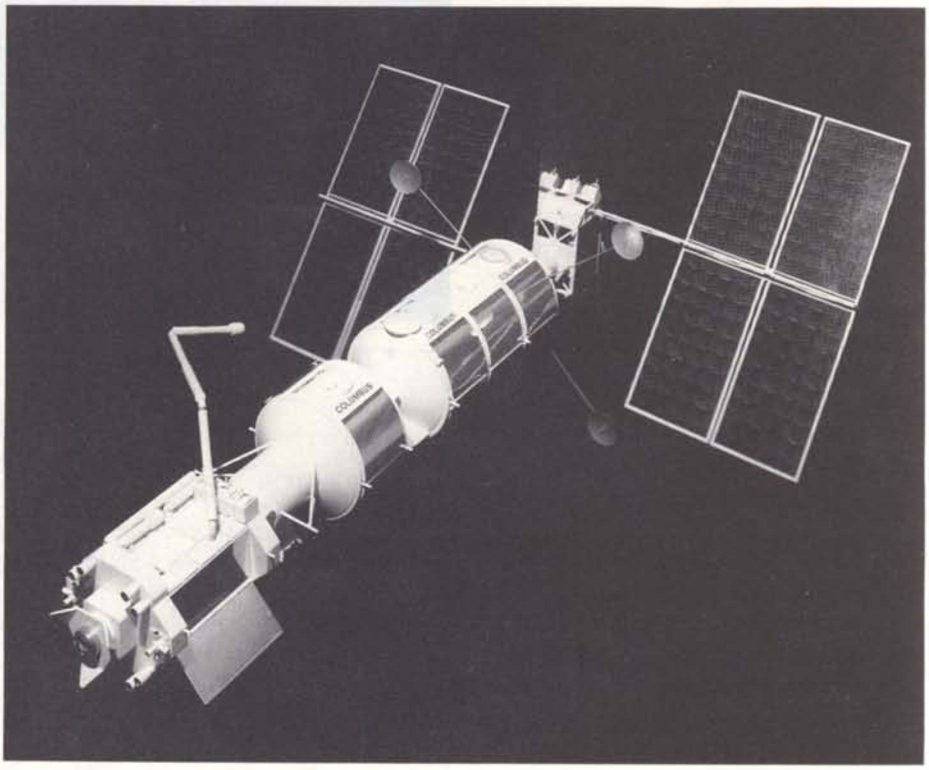
In order to prepare for the major decisions that Europe has to take in deciding on its space-transportation elements for the 1990s, ESA's Member States have entrusted the Agency with a so-called 'Long-Term Preparatory Programme (LTPP)'. Major emphasis in the LTPP studies has been given to a nearer-term goal, to prepare for European participation in the US Space Station Programme, concentrating in particular on:

- a pressurised module, with emphasis on a laboratory module
- co-orbiting platforms to be serviced from the Space Station, and/or platforms in polar orbit to be serviced by the Space Shuttle.

The Columbus initiative

The offer made by the US President to participate in the development of the Space Station has, as already said, been carefully considered by Europe. On the basis of the experience gained from the successful Spacelab Programme, the first technical proposals have been elaborated jointly by Germany and Italy and submitted to the Agency for further

Figure 12 – Columbus elements: Manned service vehicle docked to free-flying pressurised laboratory



action under the programme name 'Columbus' (Table 3).

The initial aim of the Columbus Programme was to investigate Europe's options for participation in the Space Station and to elaborate a first programme proposal. This activity resulted in a proposal to ESA for the Europeanisation of the project. Based on this initiative, and on the results of ESA's own Space-Station studies, the Agency was authorised by its Council to undertake a 'Preparatory Space-Station Programme'.

The basic space segment of the Columbus Programme (Fig. 12), as proposed by Germany and Italy for inclusion in the cooperative venture with the United States, consists of:
- pressurised *modules*, derived from Spacelab elements, permanently manned when docked to the Space Station and man-tended when free-flying
- a *payload carrier* derived from systems already developed or under development in Europe (SPAS, Eureca, etc.) carrying a variety of experiments and serviced from the Space Station or the Space Shuttle when docked or free-flying, respectively
- *resources modules* providing resources to the free-flying pressurised modules or to the payload carrier
- a servicing vehicle to support free-flying modules or platforms is also included as a possible long-term extension to the Columbus Programme.

Table 3 – The Columbus initiative

- German/Italian effort at national level resulted in Columbus Programme
- Columbus presented to ESA for Europeanisation (June 1984)
- Columbus comprises:

  Space segment
  - pressurised module
  - resource module
  - platform
  - service vehicle

  Ground segment
  - payload integration and control
  - ground support equipment
  - crew training/mission simulation

  Demonstration missions
  - pressurised module docked to Station (microgravity)
  - free-flying platform in polar orbit or co-orbiting with Station
- Being studied by ESA as preparatory Space Station Programme and as basis for cooperation with NASA

Two demonstration missions are presently included in the Columbus Programme:
- a pressurised module, docked and serviced by the Space Station (Fig. 13a)
- a free-flying platform, composed of the payload carrier and the resources module, either co-orbiting with the Space Station or in a polar orbit (Fig. 13b).

Figure 14 shows the planning for Eureca in the context of the Columbus scenario.

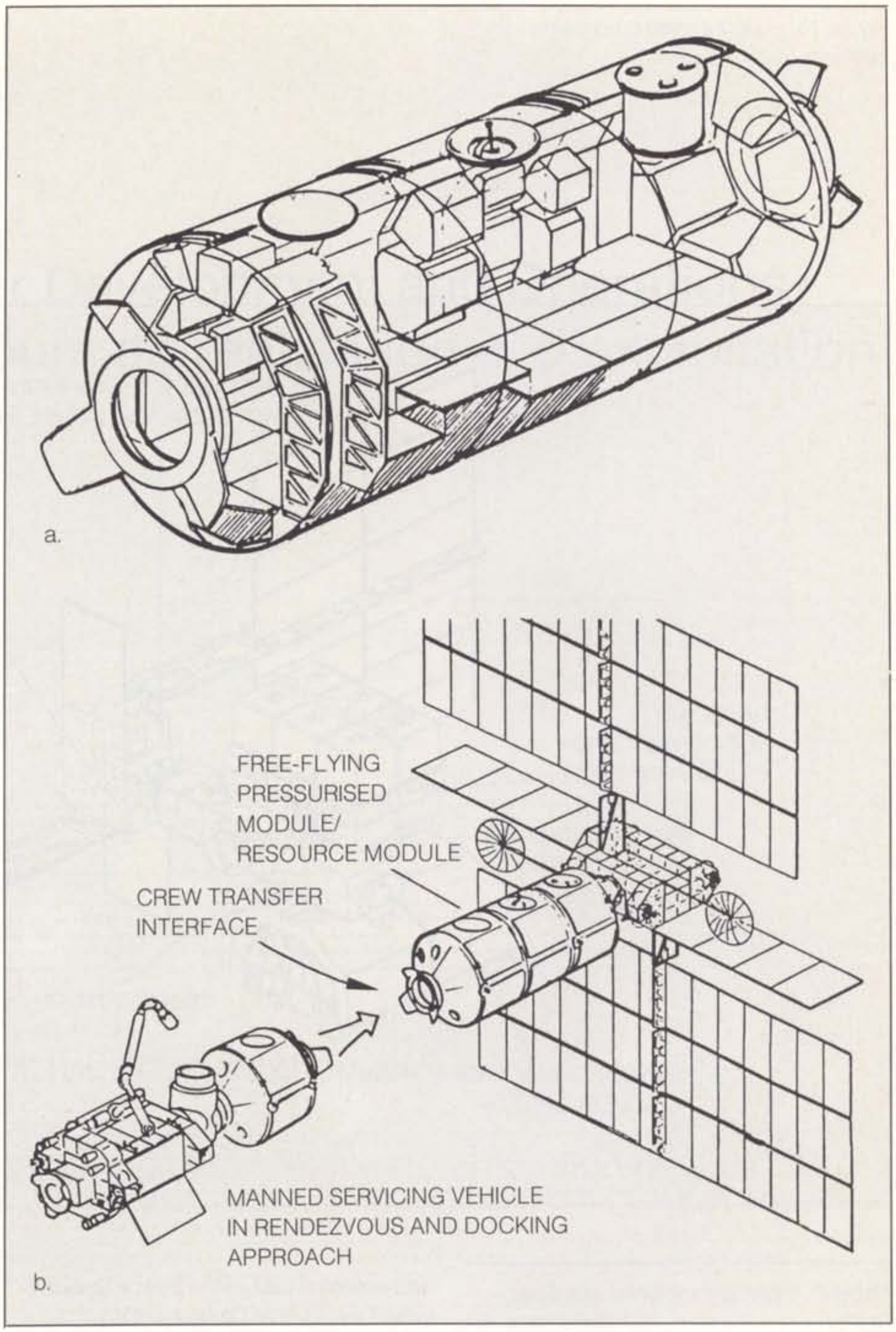
Future activities

The ESA Council, meeting at Ministerial Level in Rome on 30 and 31 January 1985, welcomed and endorsed the Agency's proposal to undertake the Columbus Programme, as a significant part of the International Space Station Programme. It is currently estimated that the Columbus Programme will cost 2600 Million Accounting Units up to 1995, including a three-year period of operation and initial utilisation.

The major tasks during the coming months will be to make a preliminary definition of the European elements and to negotiate with NASA satisfactory conditions for the European participation. Candidate systems for inclusion in the cooperative Space-Station Programme

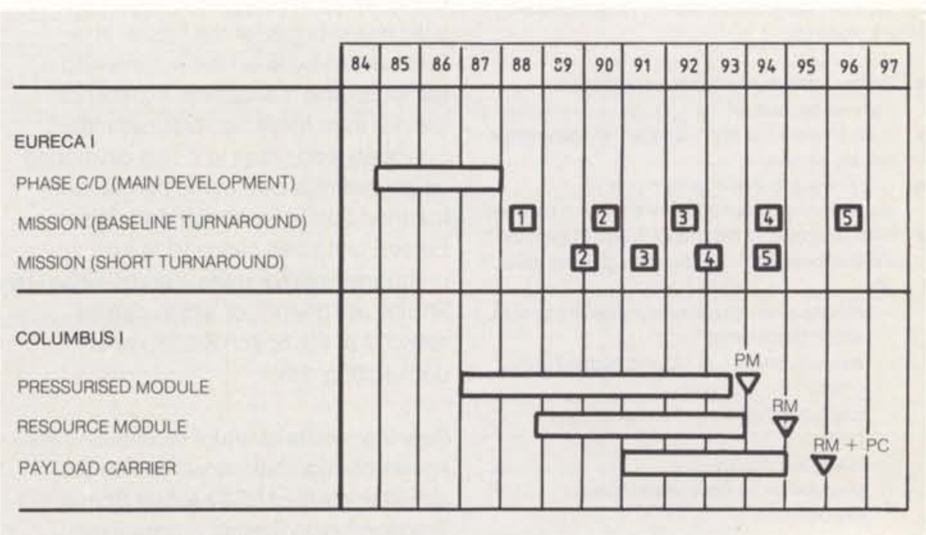
Figure 13. — (a) Pressurised module (internal layout) to be docked to Space Station; (b) Pressurised module in free-flying configuration in conjunction with servicing vehicle

Figure 14 — Time lines for the Eureca and Columbus scenarios



and their utilisation will be studied. The contents of a preliminary definition and design phase (Phase-B) and a related Technology Programme have already been approved earlier this year. The Phase-B programme itself will be conducted in two parts: Phase-B1 will see the study of a number of options for European participation based on the Columbus elements study. The scope and final content of a participation will emerge at the end of 1985. The chosen Space Station will undergo detailed design during Phase-B2 and plans will be prepared at that time for the industrial development phase.

The European Phase-B activities will be conducted in parallel with the NASA Phase-B effort. The conditions for the European participation in Phase-C/D (development) and Phase-E (operations and utilisation) will be negotiated with the United States and will result, at the end of 1986, in an Agreement between the US and the participating European States on the cooperation in the Space Station Programme and its period of validity. A Memorandum of Understanding between NASA and ESA defining the mutual relationships and mechanisms for coordination and exchange of information during Phase-B is currently in preparation.



Conclusions

The major interest of an eventual European participation in the US Space-Station Programme is to continue the trans-Atlantic cooperation in manned space flights and to give the European user community access to the overall Space Station (Table 4). This cooperation must, however, result in scientific, technical and economic benefits. The promise of commercial space processing is, in fact, one of Europe's major motivations for investment in man-tended research laboratories and free-flying platforms. In addition, a fundamental European consideration for the cooperation is the European element(s) that should be considered an important

Figure 15 – Unmanned co-orbiting platform

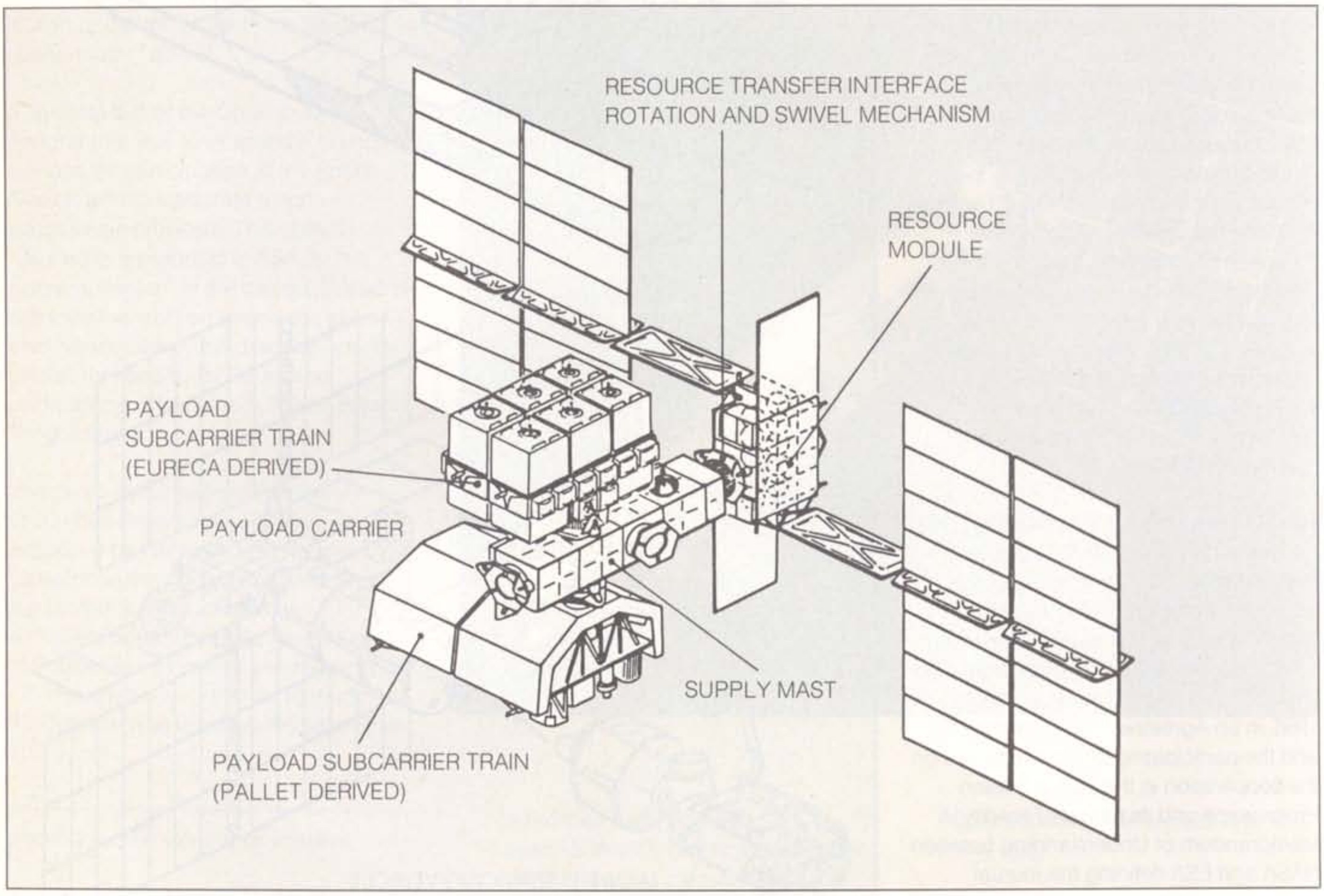


Table 4 – Europe's interest in a Space Station

Participation in the Space Station Programme will allow Europe to:

- Continue the trans-Atlantic cooperation in manned spaceflight
- Build on technical and management experience already gained
- Evolve towards the long-term goal of autonomous European manned space activities
- Provide access to the overall Space Station for the European user community, e.g. in the areas of:
  - microgravity (life sciences, material sciences, space processing)
  - space sciences (in LEO and higher Earth orbits)
  - Earth observation (in particular, polar platform)
  - space technology
  - preparation for commercial space exploitation

and essential part of the Space Station's Initial Operational Capacity (IOC).

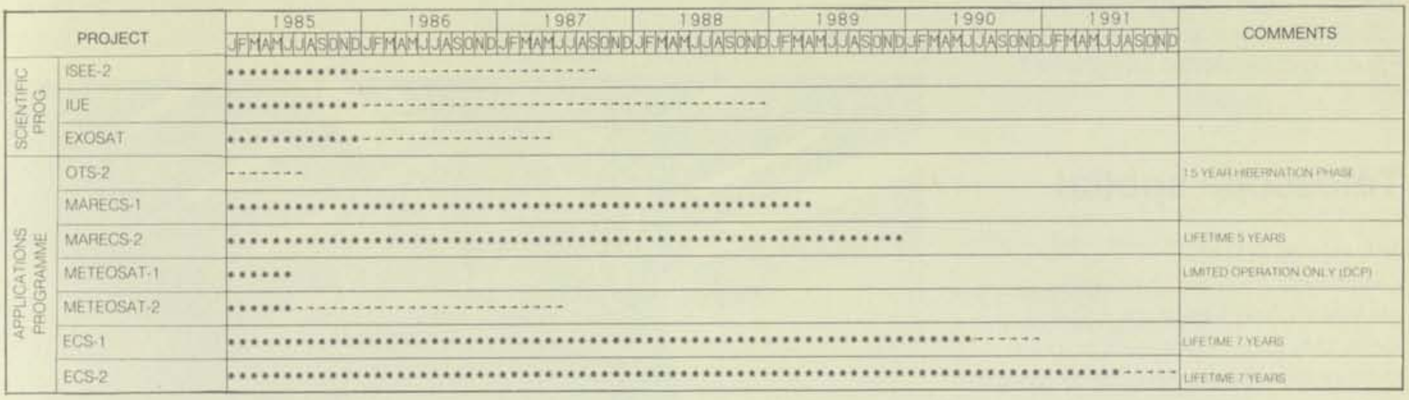
Certainly, Spacelab and Eureca represent solid investments for the future, and Europe can build on the engineering, technical and managerial experience gained from these two programmes. Spacelab lends itself to being developed as an essential part of the permanently manned Space Station and the basic Eureca principles can lead to an unmanned platform that can be visited by Shuttle astronauts, or which can be serviced at the Space Station when docked (Fig. 15).

Only the results of future studies and the imminent negotiations will decide the actual content of ESA's future Space Transportation System programmes.

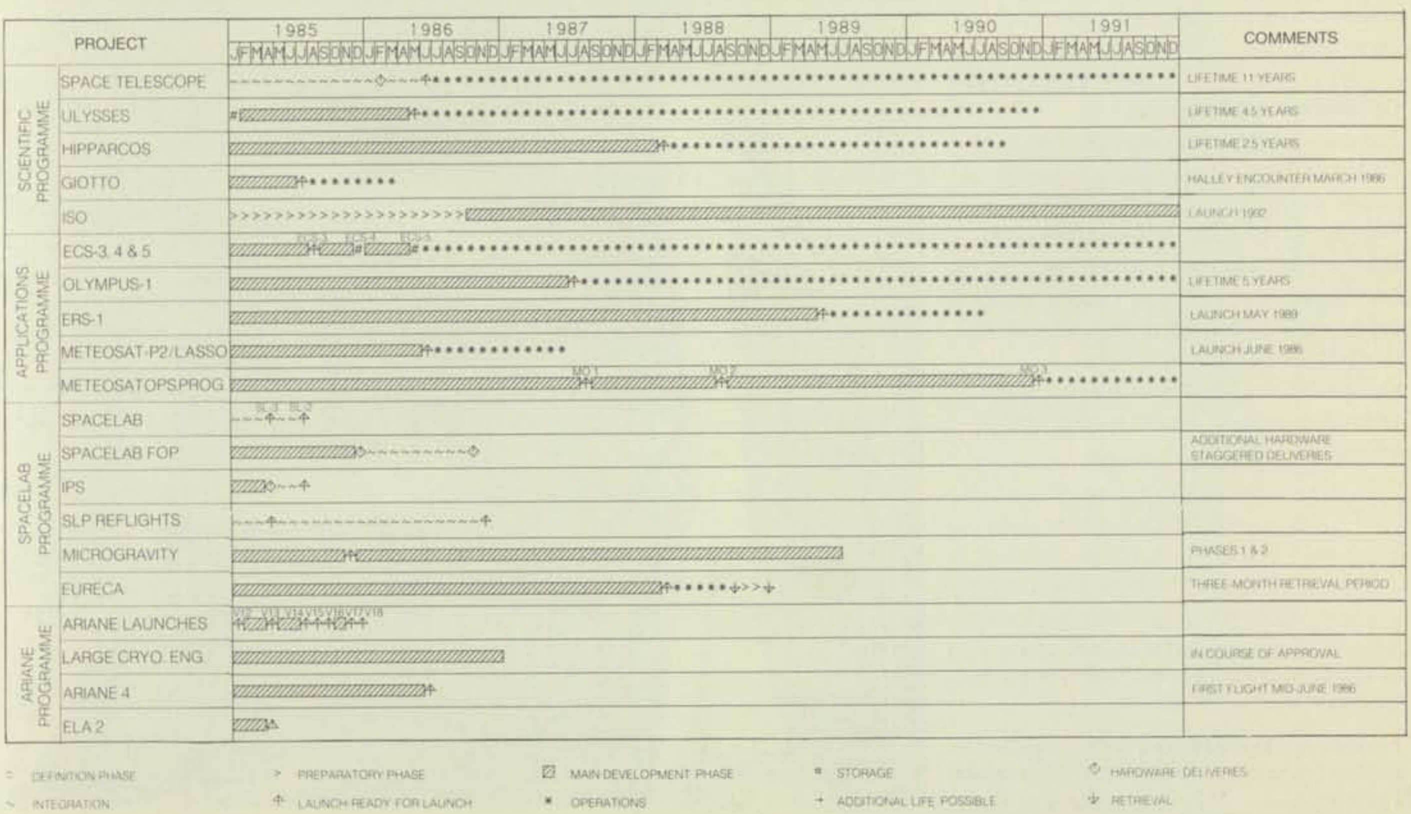
Comprehensive activities are currently under way in Europe to prepare for trans-Atlantic cooperation in the Space-Station Programme and the coming months will be a challenging run up to the final decision.

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

In Orbit / En orbite



Under Development / En cours de réalisation



Marecs

Marecs-A, lancé le 19 décembre 1981, a bouclé avec succès sa troisième année en orbite et continue encore à rendre des services très satisfaisants à INMARSAT.

Après le lancement réussi de Marecs-B2 le 9 novembre 1984, le satellite a atteint sa longitude orbitale définitive de 177,5°E le 20 décembre 1984, la phase de prise en mains et d'essais de recette ayant été menée à bien.

Le contrat de location passé avec INMARSAT pour les services de télécommunications est devenu effectif le 1er janvier 1985; les services opérationnels ont commencé le 8 janvier. Depuis cette dernière date, Marecs-B2 est le satellite opérationnel pour la région de l'Océan Pacifique et fonctionne parfaitement.

Télescope spatial

Activités de la NASA

L'ensemble du télescope optique, ayant été livré à Lockheed Missiles Space Corporation, est maintenant en cours d'intégration dans le Module de servitude. Les essais d'interface électrique avec les cinq instruments se sont déroulés au ralenti du fait de problèmes avec le logiciel d'essais au sol de la NASA. Le projet reste conforme au calendrier pour le lancement d'un télescope spatial d'ici à la mi-1986.

Générateur solaire

Les essais d'homologation des cellules solaires en vue de qualifier la nouvelle nappe de cellules jusqu'à 30 000 cycles thermiques ont rencontré des difficultés. Deux échantillons ont accusé des conditions de circuit ouvert après 12 000 cycles, ce qui équivaut à deux années de fonctionnement. La fabrication de l'ensemble des panneaux solaires a été interrompue jusqu'à ce que ce problème trouve une solution.

Les mécanismes de déploiement secondaires de vol 1 et 2 ont achévé leurs essais de vibration après que des problèmes posés par le dispositif de verrouillage du tambour aient été résolus.

Chambre pour objets faibles

Après l'étalonnage sous vide du détecteur à f/96, le détecteur à f/48 a été enlevé et remplacé par le détecteur de rechange. Il n'a pas été besoin de nouvel étalonnage car ce détecteur de rechange avait déjà été installé dans la chambre pendant l'étalonnage effectué en juillet 1984. Celle-ci a ensuite été transportée du Centre de vols spatiaux Goddard (GFSC) chez Lockheed Missiles Space Corporation, où il subit actuellement un contrôle d'arrivée.

Ulysse

A environ quinze mois du lancement, on a entrepris de recertifier le satellite après sa période de mise en sommeil. Toutes les expériences et tous les sous-systèmes ont été remis en état et réessayés dans la mesure du nécessaire, et la construction du satellite lui-même est maintenant en cours. Dans les mois à venir, celui-ci subira une série d'essais, y compris un essai de vide-température, la date d'achèvement étant prévue pour le début septembre. Cela laisse une marge de trois mois avant expédition jusqu'au lieu de lancement à la fin de l'année.

Une étude brève, mais très intensive, a été effectuée au cours de ces derniers mois

Photo: perkin-elmer

Space Telescope's Optical Telescope Assembly being integrated with the Focal Plane Assembly at Lockheed's premises in California

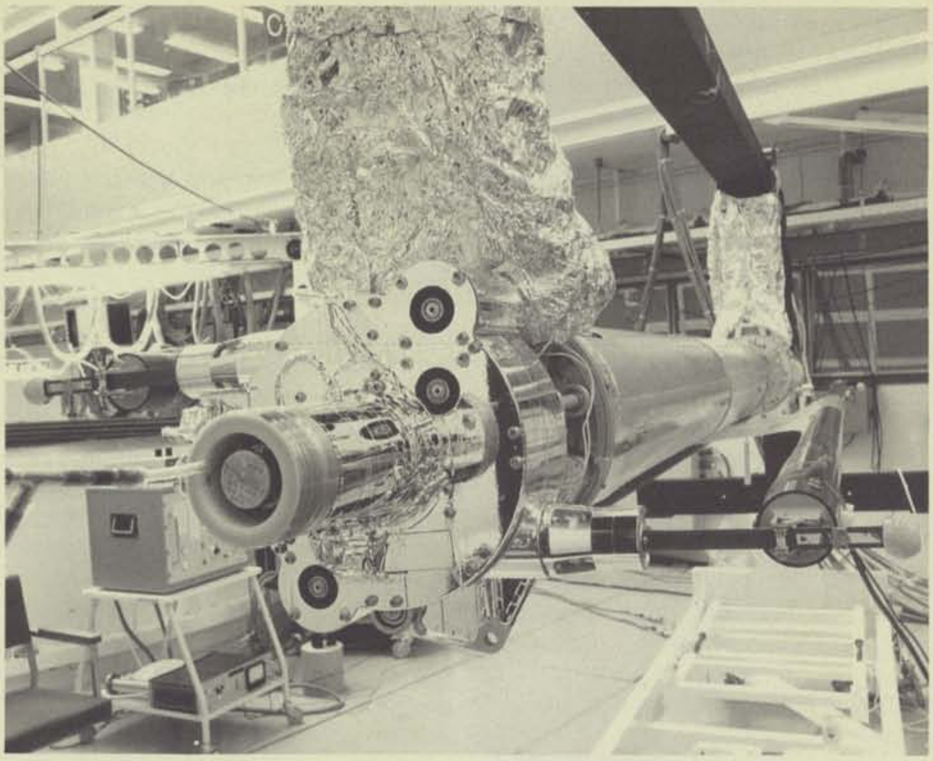
Intégration de l'ensemble optique du Télescope spatial à l'ensemble du plan focal chez Lockheed en Californie

Marecs

Marecs-A, launched on 19 December 1981, has successfully completed its third year in orbit and still continues to give very satisfactory services to INMARSAT.

After the successful launch of Marecs-B2 on 9 November 1984, the spacecraft arrived at its final orbital longitude of 177.5°E on 20 December 1984, with the commissioning and acceptance-test phase successfully completed.

The lease contract with INMARSAT for communication services started on 1 January 1985, while operational services commenced on 8 January. Since this last date, Marecs-B2 has been the operational spacecraft for the Pacific Ocean Region and has been performing flawlessly.



Essai du mécanisme de déploiement du générateur solaire du Télescope spatial à l'ESTEC

Space Telescope solar-array deployment mechanism under test at ESTEC

Space Telescope

NASA activities

The optical-telescope assembly, having been delivered to Lockheed Missiles Space Corporation (MSC), is now being integrated with the Support System Module (SSM). Electrical-interface testing with the five instruments has proceeded slowly due to problems with the NASA ground test software. The project remains on schedule for a Space Telescope launch by mid-1986.

Solar array

Cell type-approval tests to qualify the new blanket to 30 000 thermal cycles have run into trouble. Two samples showed open-circuit conditions after 12 000 cycles, equivalent to two years of operation. Solar-panel-assembly manufacture has been halted until this problem can be resolved.

The flight-1 and -2 secondary deployment mechanisms have completed vibration testing after problems on the drum lock device had been resolved.

Faint Object Camera

Following the vacuum calibration of the FOC's f/96 detector, the f/48 detector was removed and replaced by the spare. No repeat calibration was needed as the spare had previously been in the FOC during the July 1984 calibration. The FOC was then transported from Goddard Space Flight Center (GSFC) to Lockheed MSC, where it is now going through incoming inspection.

Ulysses

With the launch of Ulysses some fifteen months away, activity has now started on the recertification of the spacecraft after its storage period. All of the experiments and subsystems have been refurbished and retested where necessary and the build-up of the spacecraft itself is now under way. During the coming months it will undergo a series of tests, including a thermal-vacuum test, with an estimated completion date of early September. This allows a three-month buffer period before shipment to the launch range at the end of the year.

A brief, but very intensive, study was carried out during the last few months when analysis and test appeared to indicate that a minute possibility existed that, in the event of certain launch-pad explosions, an escape could take place of the radioactive material from the Radioisotope Thermoelectric Generator (RTG) used to power the spacecraft. Designs were prepared of a blast shield to protect the RTG from the explosion. However, more recent work has shown that the risk is less than earlier predicted and this work has been stopped.

The major activity over the last months has been the build-up of the operations activity, both in planning the launch and in the preparation of software and procedures for post-launch operation of the spacecraft. All of these activities, in Europe (ESOC) and in the USA (JPL), are proceeding on schedule.

Hipparcos

The autumn of 1984 was a period of intense contractual activity. Meetings between ESA, the industrial prime contractor, and the subcontractors were held, at which the first details of the future subcontracts were established as well as the terms of the prime contract. The prime contract was subsequently finalised and signed just before Christmas.

Industrial problems and technological difficulties associated with some optical elements for the satellite development programme will have some schedule impact, particularly in the near term. A detailed analysis is currently taking place to assess the overall extent of the problem.

After some delays in the delivery of payload optical hardware, it has been possible, after recovery actions by the *lorsque l'analyse et les essais ont semblé indiquer qu'il existait un tout petit risque de voir se produire, en cas d'explosion d'un certain type sur l'aire de lancement, une fuite de matières radio-actives du générateur thermo-électrique à radio-isotopes servant à alimenter le satellite en énergie. Il a été établi des formules de conception d'un bouclier antisouffle destiné à protéger le générateur contre de telles explosions. Cependant, des travaux plus récents ont montré que le risque était moins grand qu'on ne s'y attendait, et ces études ont été interrompues.*

L'effort majeur de ces derniers mois a été consacré à la mise sur pied des activités relatives aux opérations, aussi bien pour planifier le lancement que pour préparer le logiciel et les procédures d'exploitation du satellite après son lancement. Toutes ces activités, en Europe (ESOC) et aux Etats-Unis (JPL), se déroulent suivant les prévisions.

Hipparcos

L'automne de 1984 a été une période d'activité contractuelle intense. Des réunions entre l'Agence, le maître d'oeuvre industriel et ses sous-traitants ont permis de fixer les premiers détails des futurs contrats de sous-traitance, ainsi que les dispositions du contrat de maîtrise d'oeuvre. Ce dernier a été ensuite mis dans sa forme définitive et signé juste avant Noël.

Des difficultés industrielles et technologiques liées à certains éléments optiques prévus pour le programme de réalisation du satellite auront une certaine incidence sur le calendrier, en particulier à court terme. Une analyse détaillée a lieu actuellement pour apprécier l'ampleur de ce problème.

Après quelques retards dans la livraison du matériel optique de la charge utile, il a été possible, après que des mesures de rattrapage aient été prises par le maître d'oeuvre, de mettre en route le programme de soutien relatif à la partie optique. Ce programme a déjà apporté une expérience utile pour l'intégration et l'alignement du modèle technologique du matériel de la charge utile.

La structure principale de la charge utile, qui est faite de matière plastique armée de fibres de carbone, a été livrée au maître d'oeuvre pour le début des activités relatives à la partie optique, à la structure et à la régulation thermique de la charge utile.

Un modèle mécanique du combinateur de faisceaux a été assemblé et a subi des essais thermiques sous vide. Les résultats, qui sont en cours d'évaluation, sont encourageants. Des tubes dissecteurs d'images et multiplicateurs de photons ont été livrés, certains avec des performances nettement supérieures à celles du cahier des charges.

Des membres de l'équipe de projet ont participé à la seconde 'foire aux idées' FAST qui s'est tenue à Marseille du 21 au 25 janvier 1985. Les contributions des membres du consortium FAST y ont fait ressortir des progrès incessants dans la mise au point d'algorithmes et de logiciels pour la réduction des données d'Hipparcos.

Giotto

Les essais au niveau du système se sont achevés courant 1984 sur les installations d'Intespace au CNES, à Toulouse. Le programme d'essais a donné généralement satisfaction en ce sens que l'on n'a pas observé d'anomalies notables dans des conditions de vibrations mécaniques sinusoïdales-aléatoires et de vide thermique. Cependant on a constaté que, lorsqu'on faisait subir au satellite des essais de simulation solaire, les températures semblaient supérieures de quelques

Giotto being prepared for final electrical testing at the Intespace facility in Toulouse

Préparation de Giotto aux essais électriques finals à Intespace à Toulouse prime contractor, to initiate the Optical Support Programme. This Programme has already provided useful experience for the integration and alignment of the engineering-model payload equipment.

The payload primary structure, made of carbon-fibre-reinforced plastic, has been delivered to the prime contractor for the start of optical/structural/thermal payload activities.

A mechanical model of the beam combiner has been bonded and subjected to thermal-vacuum tests. The results, which are at present under evaluation, are encouraging. Image-dissector and photon-multiplier tubes have been delivered, and some have performances well above specification.

Members of the project team participated in the Second FAST Thinkshop, in Marseille, on 21 – 25 January 1985. The contributions of the members of the FAST Consortium reflected continuing progress in the development of algorithms and software for the reduction of Hipparcos data.

Giotto

System-level testing was completed during 1984 at the Intespace facilities at CNES, Toulouse. The test programme was generally satisfactory in that no significant anomalies were observed under mechanical sine/random vibration and thermal vacuum. However, it was found that when subjected to solar-simulation testing, the spacecraft's temperatures appeared to be a few degrees higher than predicted by the thermal computer model. Diagnosis activities led to the conclusion that adjustments could be made by trimming of thermal radiators, and that in the context of the total programme it would not be appropriate to subject the spacecraft to a second solar-simulation test.

Spacecraft-level activities continued with the exchanging of experiment units for calibrated flight models, and preparation for the demagnetisation and magnetic testing activities. These will be conducted at IABG (Munich) during March 1985.

Progress on the Experiment Payload has generally proceeded well, although some schedule difficulties have been experienced with the Halley Multicolour Camera (HMC). These schedule difficulties have stemmed from the inherent complexity of the HMC software development, but will not affect the overall programme schedule.

Pathfinder navigation planning, using imaging data from the Soviet Vega spacecraft, was given impetus with the successful launch of Vegas-1 and -2 in December 1984. Concerning the baseline navigation concept using Halley ephemerides derived from ground-based observations, work is continuing in collaboration with the International Halley Watch (IHW), and ESA is also intending to secure the services of some additional observatories to provide direct support to Giotto.

The focus of the project will move to Kourou at the end of April with the spacecraft's arrival at the launch site to start the launch campaign. All basic campaign planning and equipment schedule work has been completed, with the intention of making the first launch attempt on 2 July 1985.

ISO

The ISO Project took a significant step forward in January when submissions were formally made by the scientific community for the focal-plane instruments. In the event, there were four proposals, which were broadly complementary in terms of satisfying the established scientific goals of the mission and which absorbed in total somewhat more than the foreseen satellite resources. The task ahead is therefore not so much one of selection of instruments, as of refining the payload so as to optimise the scientific return of the mission within the available resources. To this end, scientific and technical evaluation panels have been set up by the Astronomy Working Group and ESTEC, respectively, and the intention is to submit a finalised payload for approval by the Science Programme Committee (SPC) in June 1985.

Concurrently with the experiment proposals, members of the scientific community were invited to apply for positions as Mission Scientists for ISO. Their task will be to assist in structuring the mission so as to provide the greatest overall scientific benefit, as well as to advise on specific areas of interest. A total of 15 applications were received and, following advice from the Astronomy Working Group and the Space Science Advisory Group, five have been appointed by the Director of Science to serve for the next three years.

On the technical front, a number of studies are under way. In particular, the Phase-A study was performed on the assumption that the launch vehicle would be an Ariane-2. However, Arianespace have now announced that in 1992 Ariane-2 will no longer be available and consequently it will be necessary to use Ariane-4. This vehicle is more powerful, but also more expensive, which raises the possibility of alternatives that could not be considered in earlier studies due to launcher constraints.

Olympus

The payload Development Baseline Review (DBR) was held at the end of December 1984 and the second part of the system-level DBR between the Prime Contractor and ESA has now been scheduled for 6 March 1985.

The propulsion module for the structural-model spacecraft was delivered to British Aerospace at the end of December and integrated with the service and communications modules in the new integration facility during January 1985. The completed spacecraft was then prepared for its modal-survey test and installed in the excitation test rig on the seismic block in Stevenage. The first multipoint excitation test with the spacecraft loaded with simulated propellants was completed in February and the whole test series is expected to be finished in March. The spacecraft will then be transported to Canada for the series of dynamic tests.

After reconfiguration, the thermal-model spacecraft completed its second series of system-level solar-simulation tests satisfactorily at JPL during December 1984. The spacecraft has now been transported to David Florida Laboratories (Ottawa) for the appendage release tests to be conducted under thermal-vacuum conditions later in the year.

Final preparations have been made to start the main integration activities on the *degrés à celles qui étaient prévues par le modèle thermique sur ordinateur. Des activités de diagnostic ont amené à la conclusion qu'il était possible de procéder à des corrections en ajustant les radiateurs thermiques, et que dans le contexte du programme d'ensemble il ne serait pas approprié de faire subir au satellite un second essai de simulation solaire.*

Les travaux au niveau du satellite se sont poursuivis avec l'échange d'appareillages pour expériences contre des modèles de vol étalonnés, et avec des préparatifs en vue des activités de démagnétisation et d'essais magnétiques. Celles-ci auront lieu à l'IABG (Munich) au cours du mois de mars 1985.

Les travaux sur la charge utile scientifique se sont généralement bien déroulés, encore que certaines difficultés de calendrier aient été éprouvées avec la caméra multichrome. Ces difficultés tenaient à la complexité intrinsèque de la mise au point du logiciel correspondant, mais seront sans influence sur le calendrier global du programme.

Les projets de navigation au 'mouchard' à l'aide des données d'image fournies par les sondes soviétiques Vega 1 et Vega 2 ont reçu un nouvel élan avec le lancement réussi de ces deux sondes en décembre 1984. En ce qui concerne le concept de navigation de base utilisant les éphémérides établies à partir des observations au sol, les travaux se poursuivent en conjonction avec le programme de veille internationale mis sur pied pour surveiller l'approche de la comète, et l'Agence compte également s'assurer les services de quelques observatoires supplémentaires pour fournir un soutien direct à Giotto.

Le centre de gravité du projet se déplacera à Kourou à la fin du mois d'avril avec l'arrivée du satellite sur le lieu de lancement. Tous les travaux fondamentaux de planification de la campagne et d'établissement du calendrier du matériel ont pris fin, l'intention étant de procéder à une première tentative de lancement le 2 juillet 1985.

ISO

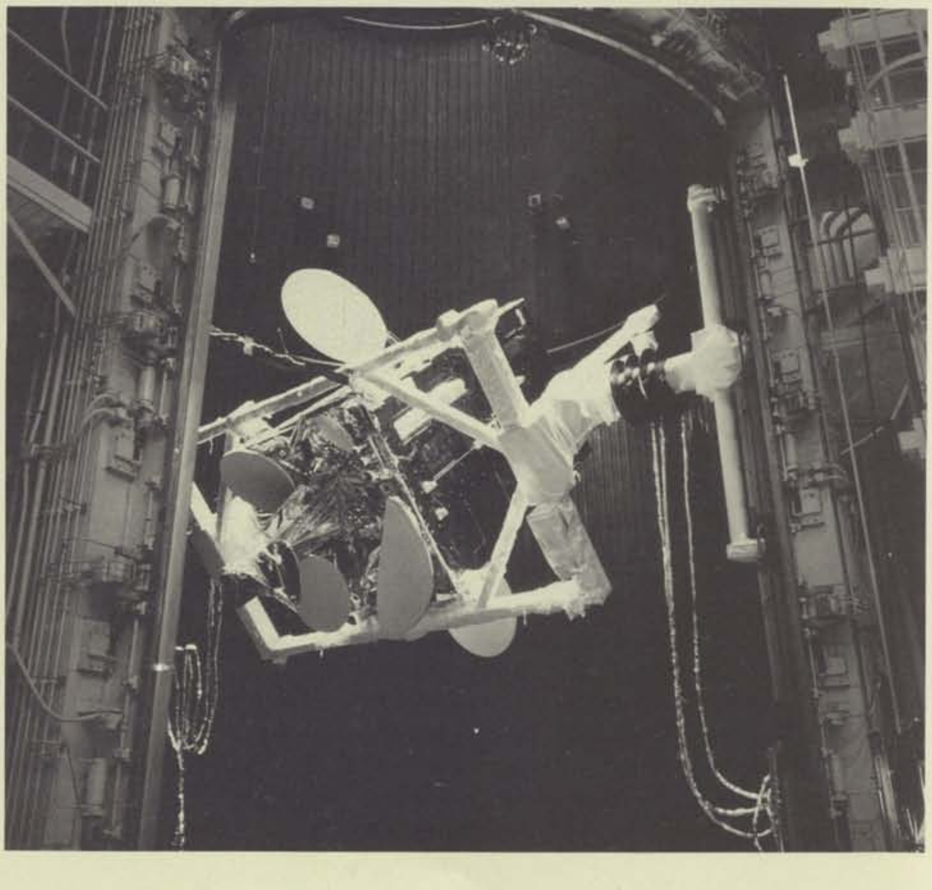
Le projet ISO a fait un important pas en avant au mois de janvier lorsque des propositions en bonne et due forme ont été faites par les milieux scientifiques pour les instruments au plan focal. En l'occurrence il y a eu quatre propositions, qui étaient plus ou moins complémentaires quant à la satisfaction des objectifs scientifiques de la mission, et qui absorbaient au total un peu plus que les ressources prévues pour le satellite. La tâche restant à accomplir n'est donc pas tant une tâche de sélection des instruments qu'une tâche d'affinage de la charge utile de façon à optimaliser les retombées scientifiques de la mission dans la limite des ressources disponibles. A cette fin, des comités d'évaluation scientifique et technique ont été institués respectivement par le Groupe de travail chargé des questions d'astronomie et par l'ESTEC, l'intention étant de soumettre une charge utile définitive à l'approbation du Comité des programmes scientifiques (SPC) en juin 1985.

Concurremment aux propositions d'expériences, des membres de la communauté scientifique ont été invités à solliciter des postes de 'responsable scientifique de mission' pour ISO. Leur tâche sera d'aider à mieux structurer la mission de façon qu'elle procure le plus grand bénéfice scientifique global possible, et d'autre part d'agir en qualité de conseillers sur des domaines d'intérêt spécifiques. Un total de 15 candidatures a été reçu et, suite à l'avis donné par le Groupe de travail chargé des questions d'astronomie et par le Groupe consultatif de science spatiale, cinq personnes ont été nommées par le directeur scientifique pour les trois prochaines années.

Sur le plan technique, un certain nombre d'études sont en cours. En particulier, l'étude de phase A a été exécutée dans l'hypothèse d'un lancement par Ariane-2. Or, Arianespace a maintenant annoncé qu'en 1992 ce lanceur ne sera plus disponible, et par conséquent il sera nécessaire d'utiliser Ariane-4. Ce dernier est certes plus coûteux, mais aussi plus puissant, ce qui rend possibles des solutions de rechange qui n'avaient pu être envisagées dans les études antérieures du fait des contraintes de lanceur.

Olympus

La Revue d'ensemble des bases de référence pour le développement de la charge utile a eu lieu à la fin décembre

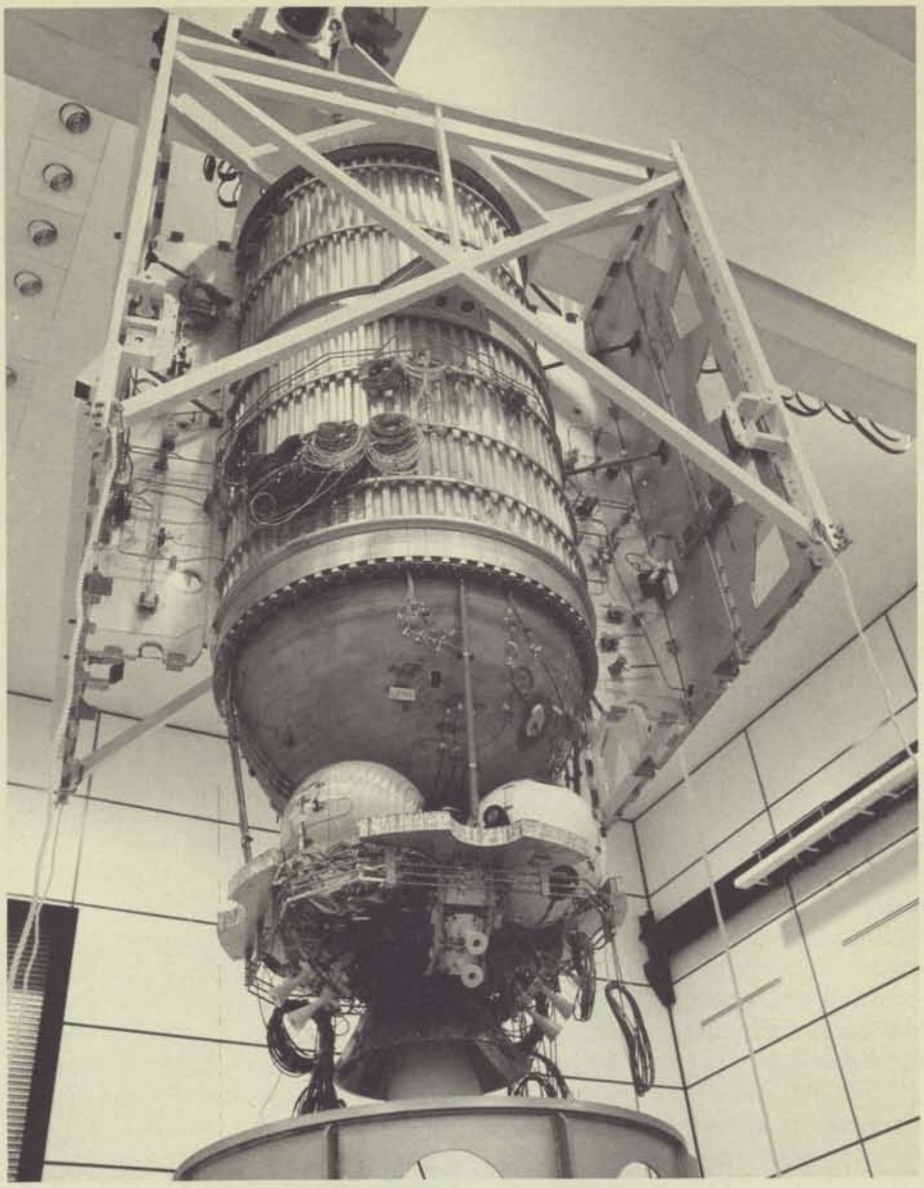


Thermal model of Olympus undergoing solar-simulation testing at JPL, California

Essai de simulation solaire du modèle thermique d'Olympus au JPL en Californie

Intégration du module de propulsion de modèle mécanique d'Olympus chez BAe à Stevenage

Olympus structural-model propulsion module at British Aerospace in Stevenage



service module of the electrical integration-model spacecraft (EIM) early in March 1985. In the meantime, integration of the EIM repeaters onto their respective communications-module panels has continued at the payload contractor.

Flight-model spacecraft manufacture is progressing and the structure has been delivered in readiness for thermal equipping.

The issue and subsequent evaluation of Invitations to Tender (ITT) for ground-station equipment is continuing.

ERS-1

At the end of November, the Industrial Policy Committee (IPC) approved the award of the main development (Phase-C/D) contract to Dornier System. The kick-off meeting was held on 14 December, and a schedule was established for the detailed negotiations with members of the industrial consortium.

A number of technical progress meetings have been held with Dornier and major co-contractors, to cover the current status of designs. Special emphasis has been placed on power, thermal aspects and the payload-mass situation. Work is continuing on the preparation and review of major project documents, such as the Satellite Systems Requirements. The procurement of some time-critical components has been initiated.

Meteosat

Pre-operational programme

The preparation of Meteosat-P2 for launch with the first Ariane-4 flight in June 1986 is progressing on schedule. Electrical testing of the spacecraft is being performed at SNIAS's Cannes premises, using the new set of checkout equipment. Most of the subsystems and spares have been checked and no problems have occurred.

The Laser Synchronisation from Synchronous Orbit (Lasso) experiment, originally scheduled to fly on the Sirio satellite, is being adapted to fly on P2. The objective of this experiment is to carry out time-comparison measurements employing laser techniques with an accuracy of 1 ns or better. The testing of mechanical parts is presently being performed, and preliminary results are under evaluation. Preparatory activities by the project, ESOC and Telespazio (Lasso coordination centre) for Lasso operations have been re-started.

Meteosat operational programme

For the first three months, the Programme is financed on the basis of the 1984 budget, which was much lower than the budget proposed for 1985.

The Legal Adviser to the Eumetsat Interim Unit took up his duties in early January, and preparation of the legal texts necessary for the setting up of Eumetsat has commenced.

Space segment

Most of the subsystem reviews have been performed, and the System Design Review will take place in early March. The respective data packages are under review by the various review panel members, in Toulouse, ESTEC, and ESOC. The objective of the Review is the release of the engineering model for integration.

The project is progressing on schedule, and the launch period (August/September 1987) remains unchanged.

1984, et la seconde partie de la revue correspondante au niveau du système entre le maître d'oeuvre et l'Agence est maintenant programmée pour le 6 mars 1985.

Le module de propulsion destiné au modèle mécanique du satellite a été livré à British Aerospace à la fin décembre et intégré aux modules de servitude et de télécommunications dans les nouvelles installations d'intégration en janvier 1985. Le satellite complet a ensuite été préparé pour son essai d'analyse modale et a été placé sur le dispositif d'excitation surmontant le bloc sismique à Stevenage. Le premier essai d'excitation multipoint avec le satellite chargé de propergols factices a pris fin en février, et il est prévu que toute la série des essais sera terminée en mars. Le satellite sera alors transporté au Canada pour les essais dynamiques.

Après reconfiguration, le modèle thermique du satellite a subi avec succès au JPL, en décembre 1984, sa seconde série d'essais de simulation solaire au niveau du système. Le satellite a maintenant été transporté aux David Florida Laboratories (Ottawa) pour les essais de libération des organes annexes qui doivent être conduits dans des conditions de vide-température plus tard dans l'année.

Les derniers préparatifs ont été menés à bien pour commencer les activités d'intégration principales sur le module de servitude du modèle d'intégration électrique de satellite au début du mois de mars 1985. Dans l'intervalle, l'intégration des répéteurs dudit modèle sur leurs panneaux respectifs à l'intérieur du module de télécommunications s'est poursuivie chez le contractant responsable de la charge utile.

La construction du modèle de vol du satellite progresse et la structure a été livrée, prête à recevoir son équipement thermique.

Le lancement des appels d'offres relatifs au matériel de la station sol, ainsi que l'évaluation des réponses, se poursuivent.

ERS-1

A la fin novembre, le Comité de la politique industrielle (IPC) a approuvé l'adjudication du contrat pour la phase de réalisation principale (Phase-C/D) à Dornier System. La réunion de mise en route a eu lieu le 14 décembre, et un calendrier a été établi pour les négociations détaillées avec les membres du consortium industriel.

Un certain nombre de réunions techniques d'avancement se sont tenues avec Dornier et les principaux co-contractants, pour examiner l'état actuel des conceptions. Une attention spéciale a été prêtée aux aspects énergétiques et thermiques et au bilan de masse de la charge utile. Les travaux se poursuivent pour l'établissement et le passage en revue des documents majeurs du projet, tels que le cahier des charges des systèmes du satellite. L'acquisition de certains composants critiques pour le calendrier a été entreprise.

Météosat

Programme préopérationnel

La préparation de Météosat P2 en vue de son lancement dans le cadre du premier vol d'Ariane 4 en juin 1986 se déroule conformément au calendrier. Des essais électriques du satellite sont en cours d'exécution dans les locaux de la SNIAS à Cannes avec l'aide du nouvel ensemble d'équipements de vérification. La plupart des sous-systèmes et des pièces de rechange ont été vérifiés, et aucun problème n'est apparu.

L'expérience Lasso de synchronisation par laser à partir de l'orbite des satellites géostationnaires, qui devait à l'origine prendre place sur le satellite Sirio, est en cours d'adaptation pour voler sur Météosat-P2. L'objectif de cette expérience est de procéder à des mesures de comparaison entre horloges en utilisant des techniques laser avec une précision d'une nanoseconde ou mieux. Les essais de la partie mécanique sont en cours d'exécution, et les résultats préliminaires sont en cours d'évaluation. L'équipe de projet, l'ESOC et Telespazio (centre de coordination de Lasso) ont repris leurs préparatifs d'opérations.

Programme opérationnel

Ce programme est, pour les trois premiers mois, financé sur la base du budget 1984, qui était nettement inférieur au budget proposé pour 1985.

Le conseiller juridique du groupe assurant l'intérim d'Eumetsat a pris ses fonctions début janvier, et l'établissement des textes juridiques nécessaires à la constitution d'Eumetsat a commencé.

Secteur spatial

La plupart des revues de sous-systèmes ont été effectuées, et la 'revue de conception du système' aura lieu début mars. Les dossiers respectifs sont en cours d'examen par les différents membres de la commission de revue, à Toulouse, à l'ESTEC et à l'ESOC. Il s'agit de donner le feu vert au modèle technologique en vue de l'intégration.

Le projet progresse conformément au calendrier, et la période de lancement (août-septembre 1987) reste inchangée.

Secteur terrien

Depuis le dernier rapport de situation, le rendement des trois missions fondamentales est nettement supérieur à 95%.

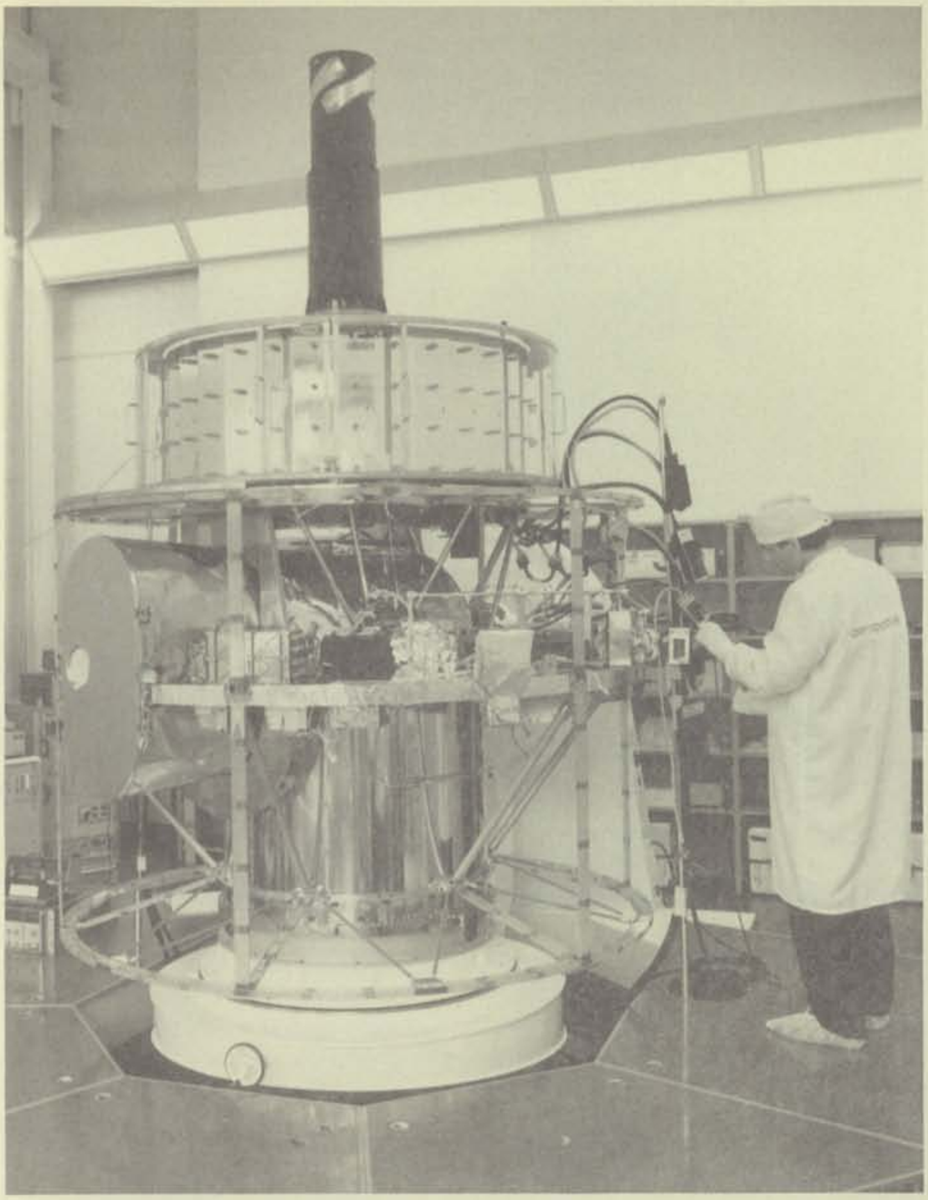
Les activités de réaménagement du secteur terrien se poursuivent conformément au calendrier. L'équipe météorologique est maintenant complète.

Pour le système de collecte de données, GOES-4 remplacera en juillet 1985 Météosat-F1, qui a épuisé ses réserves d'hydrazine. Cet échange n'aura aucune conséquence pour les utilisateurs de Météosat.

Spacelab

La préparation de Spacelab-3 se poursuit, avec une date de lancement fixée au 30 avril 1985.

Le vol Spacelab-2 n'aura pas lieu avant le 9 juillet 1985, du fait du problème posé par les tuiles protectrices de la navette Challenger. Un défaut de conception ayant été découvert dans l'ordinateur du Spacelab lors des opérations de vérification de Spacelab-2 (en décembre et janvier), une modification a été mise au point pour y remédier et est en cours de vérification. Un programme de 'rattrapage' est en préparation pour tous les ordinateurs de vol du Spacelab. A l'heure actuelle, les efforts se concentrent sur les essais relatifs au logiciel, aux interfaces entre le système de pointage d'instruments et les expériences et aux séquences de mission.



Météosat-P2 en chambre d'essais à l'Aérospatiale à Cannes

Meteosat-P2 in the test chamber at Aerospatiale in Cannes

Ground segment
Since the last status report, the performance of the three basic missions has been well above 95%.

The ground-segment refurbishment activities are continuing according to schedule. The meteorological team is now complete.

In July 1985 GOES-4 will replace Meteosat-F1 for the data-collection system since the F1 spacecraft's hydrazine supply has now been exhausted. This exchange will have no impact on Meteosat users.

Spacelab

Preparation of Spacelab-3 continues, with a launch date of 30 April 1985.

The Spacelab-2 flight will not take place before 9 July 1985, due to the Shuttle Challenger's tile problem. A design deficiency was discovered in the Spacelab computer during Spacelab-2 checkout (in December and January) and a design change has been developed and is in the process of being verified. A schedule to retrofit all Spacelab flight computers is in preparation. Presently, efforts are concentrated on testing in the areas of software, IPS/experiment interface and mission sequence tests.

IPS
The Spacelab Instrument Pointing System (IPS) has been mated onto the Spacelab-2 pallet and fit checks involving the IPS payload have been performed successfully, as have a number of functional tests. It was discovered that some springs used in the IPS are made from stress-corrosion-susceptible material and have to be replaced. Replacements are being procured, with the retrofit expected to take place in March 1985 without impacting the schedule. The remaining activities at Kennedy Space Center are IPS payload and Optical Sensor Package (OSP) installation and checkout.

The IPS mechanisms' remaining qualification tests have been delayed from December 1984 until February 1985, with the tests now in progress. The final test is expected to be completed by the end of March 1985.

Follow-On Production (FOP)
The FOP hardware is presently being integrated at Kennedy Space Center for the German Spacelab-D1 mission.

NASA has continued to procure additional hardware for both Spacelab and its Instrument Pointing System (IPS), to a value of approximately 3.3 MAU, consisting of a ground multiplexer and spares to support the two IPS systems.

The FOP IPS delivery has slipped one month, until the end of May 1985, due to additional problems with the Spacelab gyro package needed for FOP testing and delays in life-cycle testing, which uses FOP actuators.

ESA/NASA and the Prime Contractor have developed a consolidated development-phase and FOP schedule for the repair/refurbishment of the computers and input/output units, but contractual issues still have to be resolved.

Microgravity

Biorack
The interface testing of the Biorack flight model with Spacelab-D1 has been completed without problems. The cooler/freezer unit was exchanged in the last week of January, as planned.

IPS

Le système de pointage d'instruments (IPS) a été adapté sur la palette de Spacelab-2 et des contrôles d'ajustage faisant intervenir la charge utile de l'IPS ont été effectués avec succès, de même qu'un certain nombre d'essais de fonctionnement. On s'est aperçu que certains ressorts utilisés dans l'IPS étaient faits d'un matériau sujet à la corrosion sous contrainte et devaient être remplacés. On est en train de se procurer les rechanges nécessaires, le rattrapage étant prévu pour le mois de mars 1985 sans modification du calendrier. Les autres activités au Centre Spatial Kennedy sont l'installation et la vérification de la charge utile et du bloc de détection optique de l'IPS.

Les autres essais de qualification des mécanismes de l'IPS ont été retardés de décembre 1984 à février 1985, et sont maintenant en cours. On s'attend à ce que le dernier essai soit achevé d'ici à la fin mars 1985.

Production ultérieure

Le matériel destiné à la production ultérieure est actuellement en cours d'intégration au Centre Spatial Kennedy en vue de la mission allemande Spacelab-D1.

La NASA a continué à acquérir du matériel supplémentaire aussi bien pour le Spacelab que pour son système de pointage d'instruments, pour une valeur d'environ 3,3 millions d'unités de compte, ce matériel se composant d'un multiplexeur au sol et de rechanges destinées aux deux systèmes de pointage d'instruments.

La livraison du système de pointage d'instruments a été décalée d'un mois, jusqu'à la fin mai 1985, en raison de problèmes supplémentaires posés par la centrale gyroscopique du Spacelab nécessaire aux essais dudit système, et par suite de retards dans les essais d'endurance qui font appel à des éléments relevant de la production ultérieure.

L'ESA, la NASA et la maître d'oeuvre ont mis au point une phase de développement unifié et un calendrier de production pour la réparation et la mise à niveau des ordinateurs et des unités d'entrée-sortie, mais des questions contractuelles restent encore à résoudre.

Spacelab crew members in the course of the Biorack training session at ESTEC

Equipage de Spacelab en entraînement à l'ESTEC pour le projet Biorack

Microgravité

Biorack

Les essais d'interface du modèle de vol du Biorack avec Spacelab-D1 se sont terminés sans problèmes. Le bloc réfrigérateur-congélateur a été changé dans la dernière semaine de janvier, comme prévu.

Le modèle de familiarisation du Biorack a terminé ses essais et a été livré à l'ESTEC. L'essai de déroulement des expériences, destiné à tester toute la série d'expériences du programme avec le système Biorack intégré (arrimage de l'installation, unités passives, etc.) a été mené à bien à l'ESTEC dans la seconde moitié de février.

Les préparatifs d'une séance d'entraînement de l'équipage qui doit avoir lieu début mars ont été achevés.

Les problèmes posés par les 'Unités passives de conditionnement thermique' ont été résolus; il a été démontré que la capacité de maintien en température était compatible avec la durée de la mission Spacelab-D1.

Module de physique des fluides

Deux vols sur avion KC135, représentant un total de 44 paraboles, ont parfaitement réussi. Une réunion de travail a eu lieu en janvier pour revoir les films et les données obtenus. La préparation du module en vue de son embarquement sur Spacelab-D1 se déroule selon les prévisions.

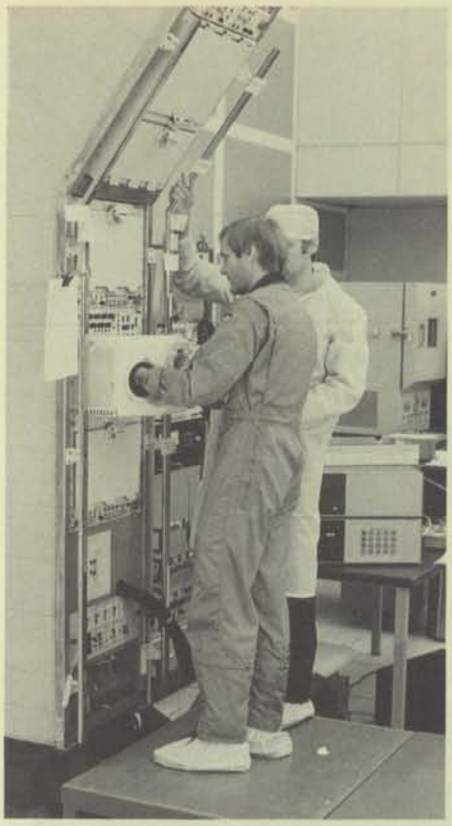
Module autonome de physique des fluides

La réunion de mise en route a eu lieu à la fin novembre 1984, le contrat démarrant en janvier 1985. Les aspects relatifs à l'assurance qualité ont été passés en revue en janvier.

La phase 2 du programme de microgravité a été approuvée par le Conseil directeur du programme Spacelab en février, et des propositions de fourniture ont été soumises au Comité de la politique industrielle.

Fusées-sondes

La préparation des modules de charge utile pour les vols des fusées Texus 11 et



Equipage de Spacelab en entraînement à l'ESTEC pour le projet Biorack

Spacelab crew members in the course of the Biorack training session at ESTEC

The Biorack training model has completed testing and has been delivered to ESTEC. The Experiment Sequence Test, to exercise the total Biorack experiment complement with the integrated Biorack system (Biorack facility stowage, passive units, etc.) was performed satisfactorily at ESTEC during the second half of February.

A Biorack crew-training session took place in ESTEC in early March.

The problems with the Passive Thermal Conditioning Units (PTCUs) have been resolved; the temperature-holding capability has been demonstrated to be compatible with the duration of the Spacelab-D1 mission.

Fluid Physics Module (FPM)

Two flights with the KC135 aircraft, giving a total of 44 parabolas, were very successful (see page 58 of this issue). A Workshop was held in January to review the films and data obtained. Preparation of the FPM for flight on Spacelab-D1 is proceeding according to plan.

Autonomous Fluid Physics Module (AFPM/CUSP)

The kick-off meeting took place at the end of November 1984, with the contract starting in January 1985. Quality-assurance aspects were reviewed in January.

Phase-2 of the Microgravity Programme was approved by the Agency's Spacelab Programme Board (PB-SL) in February, and procurement proposals have been submitted to the Industrial Policy Committee (IPC).

Sounding rockets

Preparation of the payload modules for the Texus-11/12 rocket flights have continued and the module and experiment complements have been established for the two flights. Testing and integration of experiment cells/samples is continuing without major problems. Some experiments for re-flight have been modified in terms of parameters only, while others have been modified to obviate failures that occurred previously.

As regards module development, a contract has been placed with Saab of Sweden for the preliminary design of an isothermal furnace module and a fluid-science/critical-point module, both intended for the Swedish Maser-1 flight in 1986. Discussions with the Swedish authorities to define ESA's participation in the Maser-1 Sounding-Rocket Project have been progressing well.

A new call for experiment proposals for sounding rockets is in preparation and will be distributed to potential experimenters in early 1985, including flight possibilities on either Texus or Maser launches.

Eureca

The Agency's Industrial Policy Committee (IPC) authorised the main development (Phase-C/D) contract for Eureca at the end of November 1984. By mid-December, a Preliminary Authorisation To Proceed (PATP) had been agreed with industry, with a view to the launching of Eureca by March 1988.

PATPs have also been given for four of the Eureca core payloads, while the PATP for the Solution Growth Facility is expected in March 1985.

Negotiations with NASA for the Shuttle launch have been conducted satisfactorily, and a legal Launch Service Agreement is expected in April 1985.

Space-Station/ Columbus

The Space-Station Preparatory Programme/Columbus may now proceed based on the decisions taken at the ESA Council Meeting at Ministerial level held in Rome on 30/31 January 1985 and at the Spacelab Programme Board (SP-PB)* in February.

The Invitation to Tender (ITT) for the study phase (B1) has been released in mid-February. Response from industry is due in early April, commensurate with contract initiation in May 1985.

* The Spacelab Programme Board has now been renamed the Columbus Programme Board

Ariane

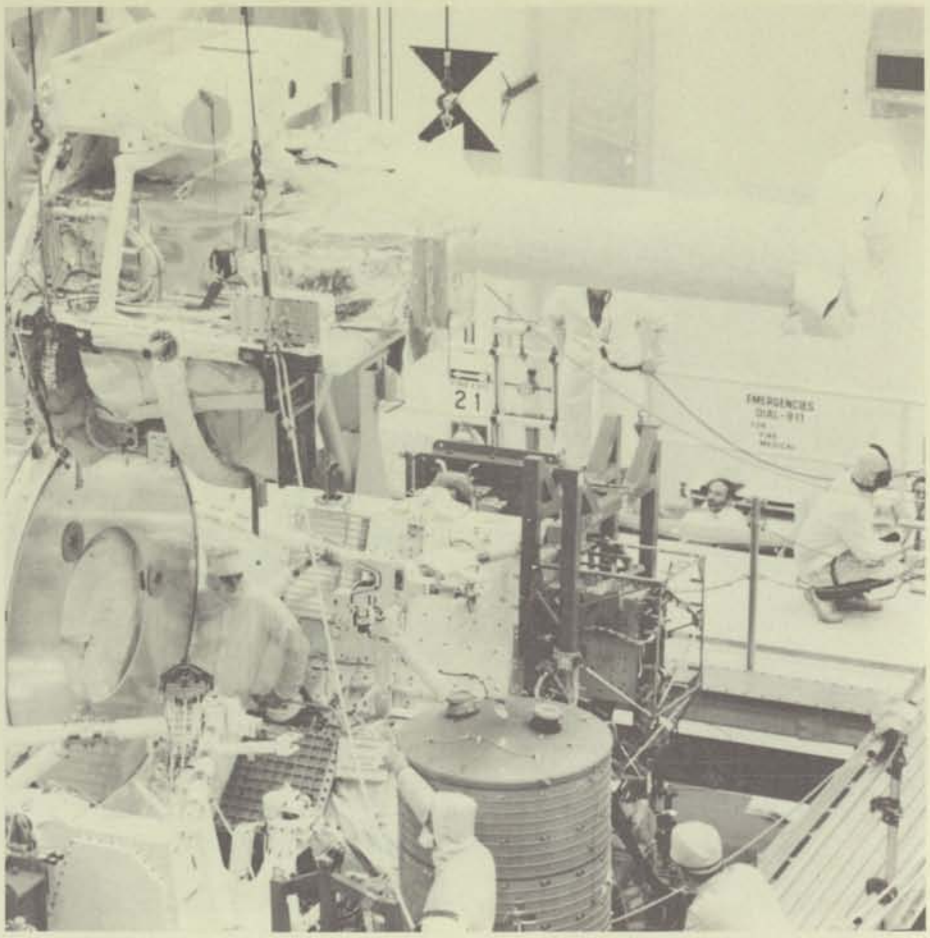
Ariane-4 development

The Ariane-4 development plan for 1985 provides for ground qualification of the structure and of the propulsion systems.

The propulsion test phase started at the end of 1984 with two test firings of the first stage propulsion bay (15 s and nominal thrust of 208 s) at Vernon in France, and one test firing of a solid booster at Colleferro in Italy (nominal thrust time of 42 s). The results of these tests were completely satisfactory. They will be followed by four tests on liquid boosters, due to start in March at Hardthausen, Germany, a development test, and two qualification tests on the solid boosters.

The fairing separation tests successfully carried out at ESTEC also provided an opportunity to test the operation of a system designed to minimise shock loads when the fairing is jettisoned. The environmental qualification of this soft release system and testing of the fairing's rainproofing are under way.

The overall programme planning remains in line with a demonstration flight due to take place in June 1986.



The Spacelab Instrument Pointing System (IPS) in the course of integration at Kennedy Space Center, in readiness for the Spacelab-2 flight

Intégration du Système de pointage d'instrument au Centre spatial Kennedy en vue du vol Spacelab-2

12 s'est poursuivie; les modules et l'ensemble des expériences à embarquer ont été établis pour les deux vols. Les essais et l'intégration de cellules et échantillons destinés aux expériences se poursuivent sans problèmes majeurs. Des expériences faisant l'objet d'une réédition ont été modifiées soit en ce qui concerne leurs paramètres, soit dans le souci d'éviter les défaillances qui se sont produites précédemment.

En ce qui concerne la mise au point des modules, un contrat a été adjugé à la firme suédoise Saab pour la conception préliminaire d'un module de four isotherme et d'un module de science des fluides et d'études des points critiques, tous deux destinés au vol suédois Maser-1 qui doit avoir lieu en 1986. Des discussions avec les autorités suédoises pour définir la participation de l'Agence à ce dernier projet de fusée-sonde ont progressé de manière satisfaisante.

Un nouvel appel aux propositions d'expériences sur fusée-sonde est en préparation et sera lancé au début de 1985; il prévoit des possibilités de vol sur l'un ou l'autre des lanceurs Texus ou Maser.

Eureca

Le Comité de la politique industrielle de l'Agence a donné son autorisation pour le contrat de réalisation principale (Phase C/D) d'Eureca à la fin novembre 1984. A la mi-décembre, une 'Autorisation préliminaire de mise à exécution' avait été convenue avec l'industrie, en vue du lancement d'Eureca d'ici au mois de mars 1988.

De semblables autorisations ont également été données pour quatre des cinq charges utiles centrales d'Eureca, tandis que celle concernant l''Installation de croissance en solution' est prévue pour mars 1985.

Des négociations ont été menées de manière satisfaisante avec la NASA pour le lancement de la Navette, et un accord en bonne et due forme sur les services de lancement est prévu pour avril 1985.

Station spatiale/ Columbus

Le programme de préparation de la Station spatiale/Columbus peut maintenant se dérouler à partir des décisions prises à la réunion du Conseil de l'ESA qui s'est tenue au niveau ministériel à Rome les 30 et 31 janvier 1985, et à la réunion du Conseil directeur du programme Spacelab en février.

L'appel d'offres relatif à l'étude de phase B1 a été lancé à la mi-février. La réponse de l'industrie est fixée au début d'avril, date compatible avec un démarrage du contrat en mai 1985.

Ariane

Développement Ariane-4

Le plan de développement Ariane-4 prévoit pour 1985 la qualification au sol des structures et ensembles propulsifs.

La phase des essais de propulsion a été abordée en fin 1984 avec la réalisation à Vernon en France, de deux tirs de baie de propulsion du 1er étage (15 s et durée nominale de 208 s) et à Colleferro en Italie, d'un tir de propulseur d'appoint à poudre (durée nominale de 42 s). Les résultats de ces essais sont tout à fait satisfaisants.

Ils seront suivis par quatre essais de propulseurs d'appoints à liquides qui débuteront au mois de mars à Hardthausen en Allemagne et un essai de développement et deux essais de qualification des propulseurs d'appoint à poudre.

La coiffe a subi avec succès ses essais de séparation dans les installations ESTEC à Noordwijk aux Pays-Bas, qui ont également permis d'effectuer un essai de fonctionnement d'un système qui diminue le choc au largage. La qualification en environnement de ce système de désanglage 'doux' ainsi que le test d'étanchéité à la pluie de la coiffe sont en cours.

Le planning général du programme permet toujours de prévoir le vol de démonstration en juin 1986.

Artificial Intelligence – A Space Tool of the Future?

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The increasing complexity of the Agency's spacecraft and space platforms, the greater sophistication of the new missions, and the larger volumes of data to be processed onboard the spacecraft or on the ground, are requiring more and more computing power, with more and more complex software to control hardware and to assist operators and crews during the critical phases of a mission. The traditional methods of software system control will eventually no longer be adequate, due to the very large number of potential courses of action to be considered simultaneously.

Artificial intelligence promises practical solutions for these types of problems in the space domain, where decisions have to be made by manipulating complex information structures sometimes involving incomplete or unreliable data.

Artificial Intelligence (AI) theories and techniques have evolved slowly during the last fifteen years. Their most spectacular applications are to be found in the so-called 'Expert Systems', 'Rules-Based Systems', and 'Knowledge-Based Systems' proposed by some as the ultimate solution for a wide variety of technical, scientific, medical, and administrative problems. One of the best known medical-related examples is the 'boat without a doctor', where medical advice would be provided by an Expert System in the case of an emergency.

Any attempt to arrive at a formal definition of an Expert System triggers a long and passionate discussion between specialists, since there are as many definitions as there are specialists. To make matters even more confusing, what is designated by some under the general heading of an Expert System, is split by others into Expert Systems (ES), Rules-Based Systems (RBS), Knowledge-Based Systems (KBS) and Blackboard-Systems (BS), etc. depending on the level of complexity of the rules, the internal mechanisms, the user interface, the connections to the outside world, and a few more emotional criteria.

In very broad terms, an Expert System is a combination of computer hardware and software that mimics human expertise within a well-defined field of knowledge. The system processes facts describing a particular situation, supplied by a human operator or by such external sensors as cameras, Sun sensors, star mappers, etc. The facts are stored as data structures in the base of knowledge, together with rules describing the human expertise. From the rules and the known facts ('causes'), it is possible to infer new facts ('consequences') using forward chaining. Inversely, backtracking is the action of confirming or refuting a hypothesis by searching to determine whether the potential causes (facts) are known to the system.

Artificial Intelligence is today one of the most actively pursued disciplines in the world of computer hardware and software, forming one of the major elements of Japan's fifth-generation computer programme, part of the Alvey programme in the UK, and one of the avenues of research of the Esprit programme being undertaken by the EEC. Within the framework of the ESA Technological Research Programme, the Simulation Section of ESTEC's Mathematical Support Division started activities on Artificial Intelligence in 1984, paying special attention to those Expert Systems (or KBS or RBS) that seem the most eligible for short-term application in ESA's field.

The prime objectives of these activities in AI are threefold:
- to become familiar with the AI tools and techniques in order to achieve a sound level of knowhow and expertise within the Agency. The AI programming languages differ greatly from traditional computer languages and require a significant investment in terms of manpower for the training of future users;
- to analyse the potential benefits of these tools and techniques, when

applied to some carefully selected ESA fields of interest.
- to be able to evaluate correctly and objectively proposals from industry that involve expert systems. Examples could be systems (ground or onboard) providing crews with assistance for experiment management, results interpretation, or failure assessment.

Activities to date
The Agency's activities so far have progressed in parallel along two paths, theoretical and practical. The theoretical work has involved the study of academic papers, theses, articles, tutorial books, attendance of Conferences or Workshops and the letting of study contracts to industry. The practical work has included the implementation of a prototype Expert System using different AI languages, techniques and hardware environments.

External studies
Two AI study contracts were awarded to industry by ESA in 1984, by ESTEC's Mathematical Support Division and the Data Handling & Signal Processing Division. The first, titled 'Study of Expert Systems Applied to Space Projects' is being executed in parallel by two aerospace/AI consortia, BAe and SPL and ESD and Cognitech. Its purposes are to issue a primer on ES, review the existing ES applications, list possible applications for ESA, select a particular one, and finally produce the Software Requirements Document (SRD) for later implementation. The contract deliberately restricts itself to ground applications, since a practical and convincing application is envisaged in the short term. The contract should be followed by the development of an ES prototype.

The second contract, titled 'Study of Expert Systems for Spacecraft Management', has been awarded to a consortium that includes Laben, CRI and MBB/ERNO. Its purposes are to assess the feasibility with state-of-the-art technology of an onboard ES for the management of an autonomous spacecraft, to specify the requirements for the design, development and testing of the ES, to assess the resulting onboard complexity, and finally to indicate areas of future research and investigation in the field. A breadboard ES is to be produced at the end of this contract.

The two contracts started at the beginning of 1985 and will run for approximately one year.

Software
The first major step was to acquire an appropriate software environment by installing the two most popular AI languages, Lisp and Prolog, on the simulation laboratory's computers. Lisp is no newcomer to today's large family of programming languages, since it was created some 25 years ago! By contrast, Prolog can indeed be considered a newcomer, and a promising one, having been adopted by the Japanese as the language for their fifth-generation computer development. Both languages differ from the traditional ones such as Fortran, Pascal and Ada, in that they are designed to manipulate symbolic expressions, as well as lists, complex structures and numerical expressions.

Hands-on experience
Anyone entering the field of AI is faced with a situation similar to that confronting the potential buyer of a camera, hi-fi system, home computer or car: Where does one start? How does one select the best one? What is really needed? Of all the products on the market, which are meaningful and useful?

We have opted to start with a particular application and to develop a prototype for training and evaluation. As some of the people involved were already working on the Attitude and Orbit Control Measurement Subsystem (AOCMS) and Data-Handling Sub-System (DHSS) simulations for the Agency's Giotto spacecraft, a natural candidate for the prototype was one related to one of these systems, a good understanding of which was already available.

The first prototype was subsequently developed, using the Giotto User Manual (GUM) as a guide, with the following capabilities in mind:

- Assess any problem in the AOCMS with the information derived from the telemetry and the initial conditions. Since the ES is not connected to the telemetry, the parameter statuses are obtained from the user, during the reasoning, via a man-machine dialogue.
- Once found, cure the problem by proposing to the operator the appropriate telecommands to be sent to the spacecraft (in our case the simulator!).
- Explain, when requested, why such a question is posed to the operator, by displaying the logic tree.
- Explain, on request, how a conclusion has been reached.
- Show, on request, all the known facts and the rules used to infer them.

Example of an application
Figure 1 shows an example of how 'expert knowledge' is integrated into a KBS. The system shown represents a typical architecture for a satellite subsystem. Four units are shown: AOCE1, AOCE2, PDE1 and PDE2. (AOCE = Attitude and Orbit Control Electronics; PDE = Power Distribution Electronics). In our example, the PDE controls the power of the AOCE. The ground will receive telemetry from both PDE units and from both AOCE units. The two branches are redundant, i.e. in order to function correctly, the subsystem must have either PDE1, AOCE1 or PDE2, AOCE2 switched on. Thus the first drawing in the figure shows a working configuration, whereas the second shows a configuration where telemetry apparently indicates AOCE1 to be on when it should be off. A rule derived from this knowledge of the system is shown and the KBS will use that rule to detect the error.

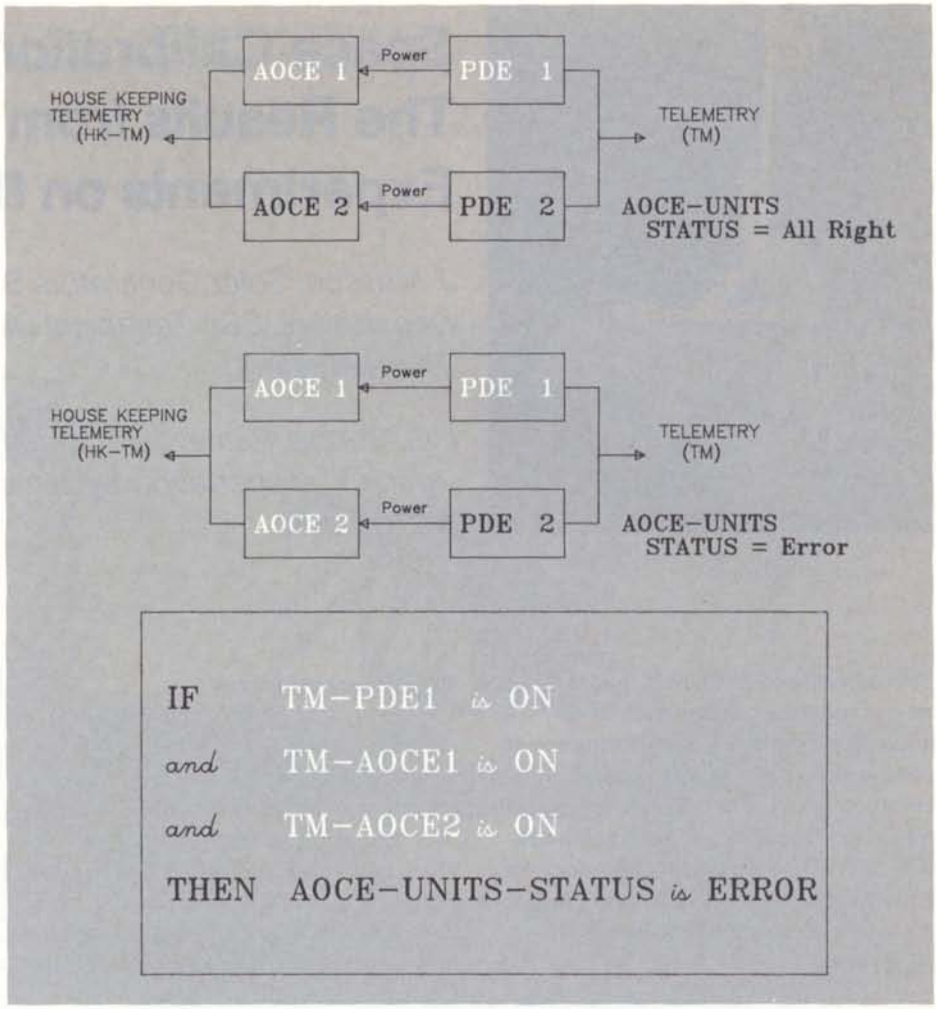

Figure 1 – Example of integration of 'expert knowledge' into a Knowledge-Based System (KBS)

For backup-mode operation of such a system, in Giotto's case about 200 rules describe the knowledge needed to conduct a failure diagnosis, make an analysis and correct the problem.

Future plans

The future activities that are currently planned can be summarised as follows:

Software: Evaluate and eventually acquire an expert system shell with good performance for knowledge representation, flexibility, connection to the outside world, internal visibility and speed. The SAGE expert system shell, commercially available on both personal and mainframe computers, is a typical example of such a product.

Evaluate a software environment to develop AI applications, offering the possibility to use a combination of languages (Lisp, Prolog, Pascal, C, Fortran, etc.) for different parts of the program. Poplog, also commercially available, is a typical example.

Hardware: Evaluate an AI machine to assess the benefits of this approach for a complex problem.

Training: Train a larger number of people in AI languages and tools.

Organise seminars to inform people from other disciplines and projects of the potential benefits of AI.

Studies: Complete the first round of studies with the specification of an ES for a carefully selected Agency application, and possibly the delivery of a prototype by the contractor. Continue the study with a second contract to develop the ES specified.

Investigate the language interfaces available to ease the man/machine dialogue.

Internal effort: Extend the internally developed ES in such a way that it can diagnose and cure problems for both the Giotto AOCMS and DHSS subsystems. The ES will then be connected to the telemetry and telecommand streams of the Giotto software simulator to evaluate its performance in a real-time or faster than real-time environment.

Other branches of AI: Investigate the natural language interfaces to ease the man/machine dialogue. Survey other applications of AI languages.

Conclusion

AI may greatly influence the way in which software is designed, coded and tested in the future, whether this software is intended for AI, scientific, technical, administrative or other applications. More specifically, AI will influence the field of discrete-event simulations, which are usually used to answer 'what if'-type questions for the analysis of large, complex discrete systems. For instance, the back-tracking technique would be of great help for quickly spotting all possible causes of an abnormal state in a simulated system.

To quote one of the world's pioneers in AI, E.A. Feigenbaum of Stanford University: 'The AI field tends to reward scientifically irresponsible pseudo-innovation. That is, it tends to reward individuals for reinventing and renaming concepts and methods that are well explored'.

It is therefore in ESA's interest to build up the expertise needed to distinguish genuine improvements from pseudo-innovations, particularly as AI does not come cheap in the sense that it requires a substantial investment for the training of both designers and users.

Space Calibration of Solar Cells: The Results from Two European Experiments on the Space Shuttle

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The accurate calibration of solar cells is an essential task in the process of analysing the electrical performance of photovoltaic generators in space. It is common practice to calibrate so-called 'primary standards' for each solar-cell type and to use these as a reference for accurate solar-cell module and panel measurements under laboratory conditions.

Several primary calibration methods had been developed in the past, including direct and global sunlight ground calibration and high-altitude aircraft- and balloon-flight methods. The Solar-Cell Calibration Experiment (SCCE) has been developed for direct calibration of solar cells in extraterrestrial sunlight onboard free-flying, retrievable, low-Earth-orbit platforms.

This article discusses the main aspects of the SCCE's design and the flight results to date.

Experiment objectives

The Solar-Cell Calibration Experiment (SCCE) is a facility for calibrating solar cells in space. Designed to fly at regular intervals on the Space Shuttle, this facility was developed at Kayser Threde, in Munich, under ESA contract. The first two flights of the SCCE were on the Shuttle Pallet Satellite (SPAS-01), developed by Messerschmitt-Bölkow-Blohm (MBB), in Germany. SPAS-01 was deployed and retrieved for MBB on each of Shuttle flights nos. 7 and 11, in June 1983 and February 1984, respectively.

The main objective of the experiment was to generate primary solar-cell standards for solar-simulation measurements on the ground and to compare the accuracy of and effort required for space calibration with those of conventional calibration methods, such as balloon flights and high-mountain or sea-level measurements, with subsequent corrections.

Another objective, of a more general nature, was to explore to what extent indirect participation in unmanned spaceflight opportunities can be made attractive to small scientific communities. Significant interest on the part of these groups can be stimulated in space experiments of short duration, involving only limited paperwork and low hardware and flight costs.

Calibration principles

The purpose of a primary calibration is to determine the short-circuit current (I_{sc}) of the standard solar cell under standard conditions, i.e. at 25°C under sunlight illumination at 1 Astronomical Unit (1 AU). This standard is commonly called 'Air Mass zero' (AMO).

During the flight calibration, the Sun's intensity and the cell's temperature, both of which affect the I_{sc} measurement, usually have different values from those used under the defined standard conditions on the ground. Results obtained during flight must therefore be adequately corrected to the standard reference conditions.

The sunlight's intensity has a linear effect on the cell's short-circuit current. Since the Sun-Earth distance, and hence the sunlight's intensity, is known with very high accuracy, this I_{sc} correction is straightforward.

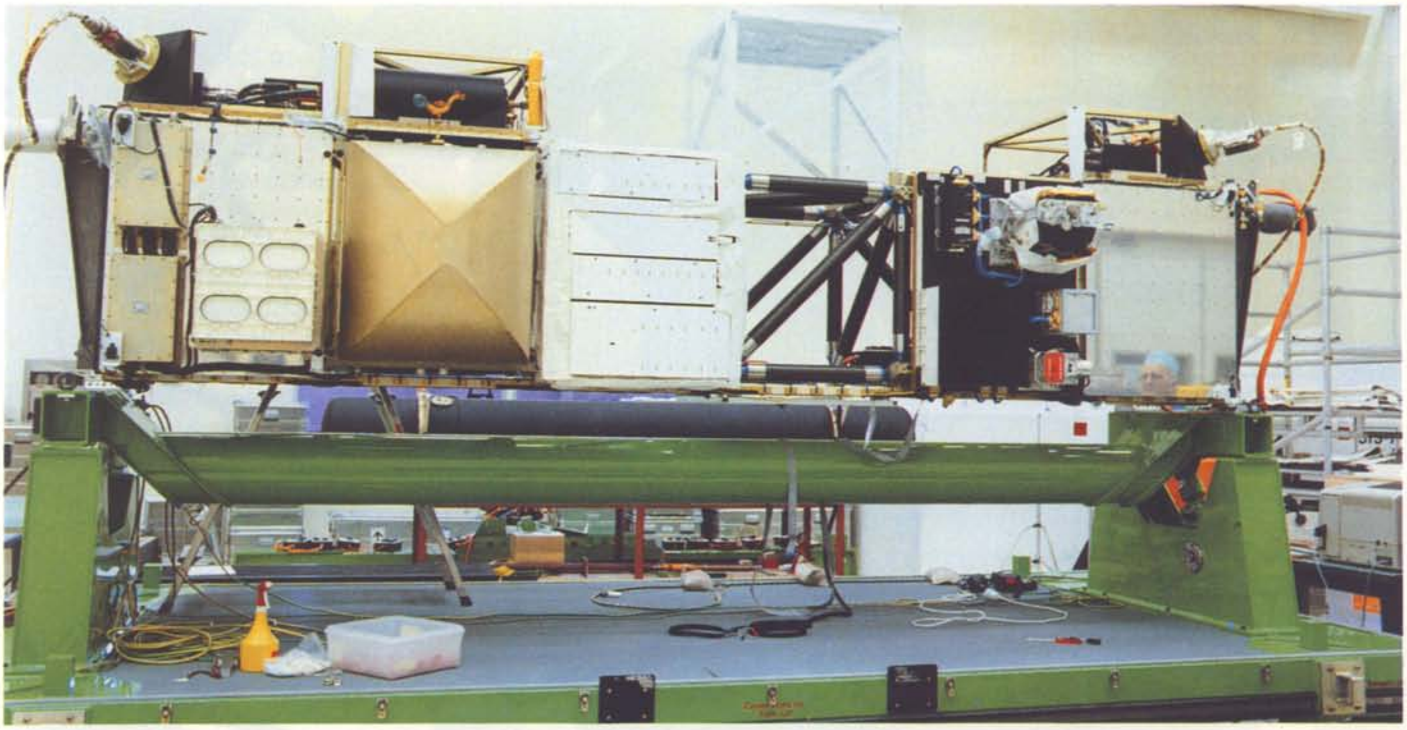
Though the temperature-dependence of the cell's short-circuit current is generally very small (typically around 0.01%/°C), measurements carried out over a wide temperature range may show variations. Corrections are performed without recourse to dedicated thermal sensors for each SCCE specimen, by measuring on the ground the cell's open-circuit voltage (V_{oc}) and its dependence on temperature, which is very pronounced (typically around 2 mV/°C). This dependence is highly reproducible, and largely independent of small variations in the Sun's radiation level. It is therefore possible to use the open-circuit voltage measured during flight as a temperature monitor.

Major SCCE design features

The SCCE was designed to measure the electrical performance of a maximum of

Figure 1 – The Shuttle Pallet Satellite (SPAS-01)

Figure 2 – The Solar-Cell Calibration Experiment in place on SPAS-01



32 solar cells, in terms of both short-circuit current and open-circuit voltage, as well as SCCE housekeeping data. For the reasons explained, the resulting calibration accuracy is acceptable, though final calibration results could be jeopardised if the correlation between cell open-circuit voltage and cell temperature is not determined during preflight testing with sufficient precision.

In order to reduce costs, the SCCE's electronics had no autonomous data-recording system. The measurements were transmitted on line to the SPAS-01 Data Handling System while orbit history and Orbiter vector data were provided by the Shuttle. Reference signals to identify and assign the relevant variable parameters to the measured specimen were provided by the SPAS-01.

The mechanical design of the SCCE is extremely simple. One opto-electronics box was mounted on the top surface of the SPAS support panel no. 8, and one avionics box was mounted on the opposite surface of the same panel. The two boxes weigh a total of 12 kg.

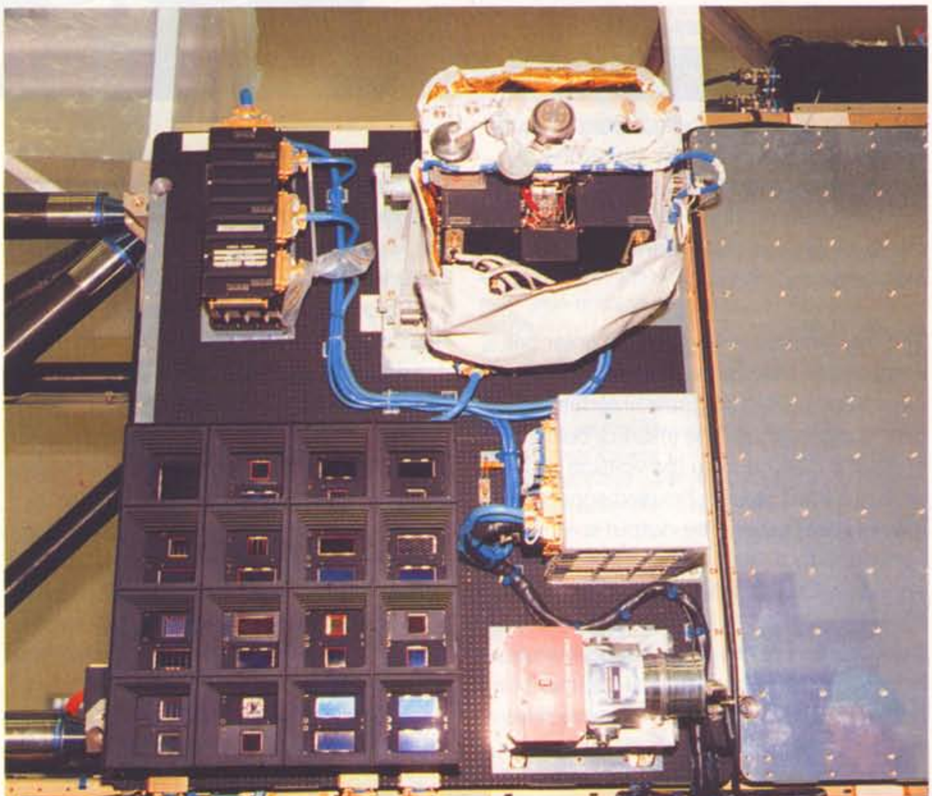
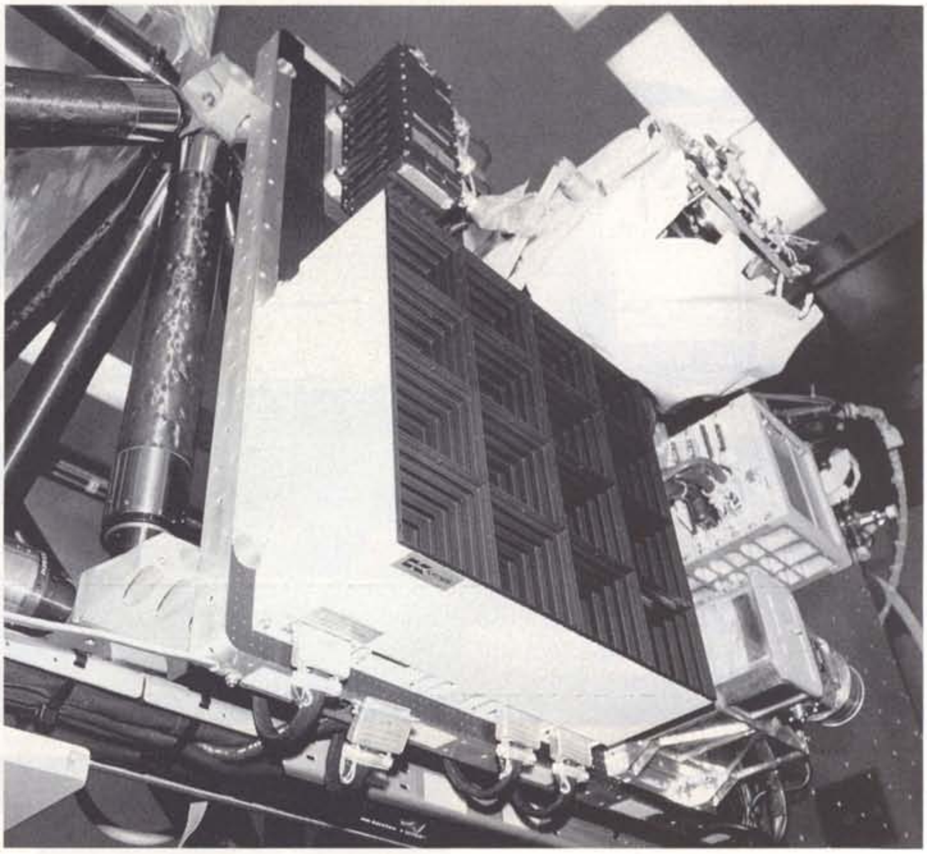


Figure 3 – The SCCE mounted on the experiment support plate on the SPAS, with the baffle subassembly in place



Functionally, the SCCE consists of two subsystems: an optical assembly and an electronics assembly. The optical assembly, holding a maximum of 32 solar cells, is designed as a passive system, relying completely on the accuracy of the Shuttle's orientation and station-keeping systems for suitable Sun exposure.

The solar cells are fixed in four geometrically identical rows, protected against parasitic and stray-light effects by a subassembly of 16 individual light baffles. This somewhat complex optical design was preferred to a more straightforward concept with a single baffle of larger dimensions because of clearance requirements for the Shuttle's remote-manipulator system. Moreover, the longer single baffle design would have occupied a larger volume of the Shuttle's cargo bay, thereby considerably increasing launch costs.

The electronics assembly is modular. All functional blocks are located in the electronics assembly box, with the exception of the four cell-row electronics units, which are located in the opto-electronics assembly. The functional blocks are on modular printed-circuit cards for ease of testing and maintenance.

The open-circuit voltage of the solar cell is amplified to reduce measurement errors caused by electromagnetic interference on the signal lines. The short-circuit current is derived from the voltage drop across a load resistor housed separately in each cell holder. The output is converted to digital form in the central encoder (12 bit resolution).

Composition of the payloads
Because of the experimental natures of both the SCCE and the SPAS carrier, as well as of the STS services (at that time not considered an established routine), ESA called for a complimentary flight opportunity at no charge for preflight testing, mission operations and results evaluation.

Invited governmental institutes and industries in Europe and elsewhere provided more than 70 cell samples for the two flights (Table 1). The contributors included American and European firms and organisations, as well as recent newcomers to the photovoltaic field, from Japan, India and from the People's Republic of China.

All cell suppliers documented their own flight hardware, which was prepared according to a detailed procedure provided by ESA.

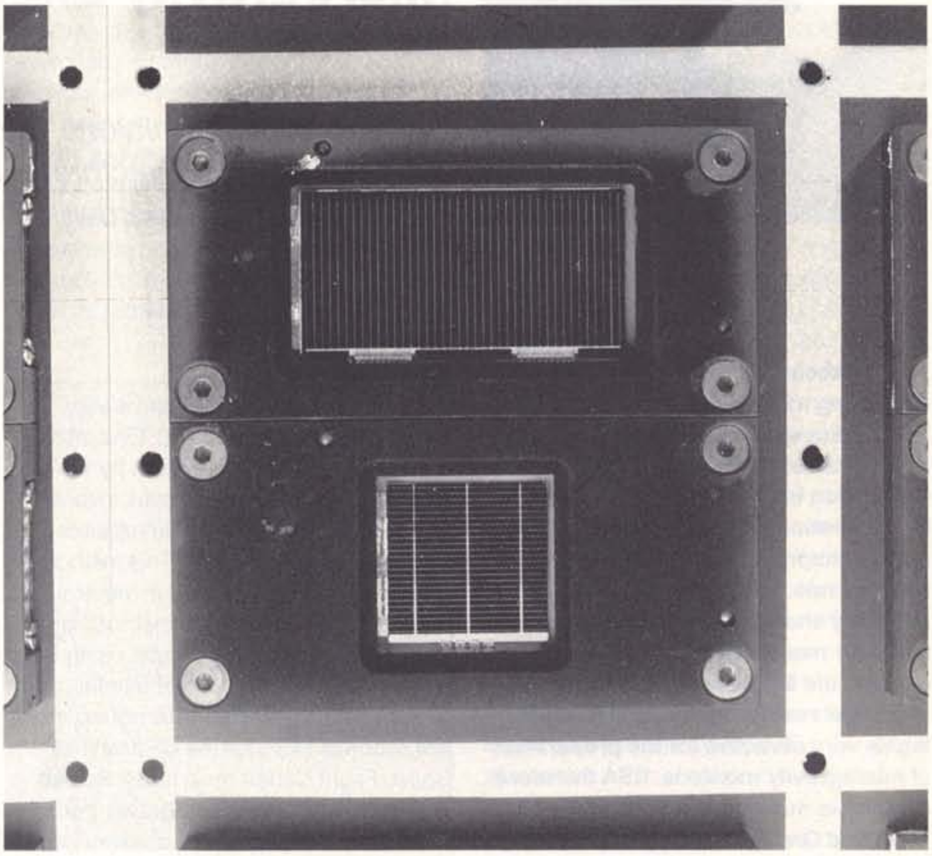
ESA's pre-flight testing was limited mainly to checking the mechanical and electrical integrity of the flight specimens provided.

The STS-7 and STS-11 flights
The first SCCE mission was flown on 18 June 1983 on Shuttle mission STS-7. Before the Shuttle Orbiter's orientation to the Sun, the temperature of the SPAS carrier was extremely low. Fifteen minutes after the Sun-acquisition manoeuvre, the temperature of the SCCE opto-electronics increased from 3.4°C to 7.7°C. During the subsequent 15 min of the Sun-pointing and cell-measurement phase, the temperature increased to only 20°C.

Table 1 – Companies/organisations that supplied solar cells for the Solar-Cell Calibration Experiment (SCCE)

Organisation	Country
AEG-Telefunken	Germany
Chinese Academy of Sciences	China
CISE SpA	Italy
CNES	France
Comsat Laboratories	USA
ESA	
ISRO	India
Lockheed	USA
MBB	Germany
NASA/Lewis Research Center	USA
Royal Aircraft Establishment	UK
Sharp Corporation	Japan
Solarex Corporation	USA
University of Surrey	UK

Figure 4 — Discoloration of the cell mounting plates after the STS-11 flight



Because of this unexpectedly cool SCCE operational environment, accurate cell ground calibration for temperatures below 25°C became essential. Unfortunately, such data were not available for the majority of the specimens.

After the first day of the SPAS-01 mission some intermittent malfunctions in the Data-Handling System (DHS) became more pronounced. Subsequent severe overheating of the SPAS's DHS led to deactivation of the carrier, followed by its reorientation to deep space. Consequently, a scheduled second SCCE measurement cycle with a 15 min Sun-acquisition manoeuvre and 15 min of measurements in sunlight had to be cancelled.

Several problems with the decoding of the flight data tapes delayed the final evaluation of the measurement data, which could only be completed about six months after the flight. Consequently, at the time of SCCE refurbishment for the second flight on STS-11, the results of the first flight were not yet known and no potential improvements could be attempted.

The second SCCE mission was flown on 3 February 1984. On the fourth day of that mission, the SPAS DHS problems that had plagued the earlier flight recurred. The SCCE was commanded 'on', but failed to respond. Consequently, the complete SPAS carrier was switched 'off'. Following the resulting unscheduled cooling period, the carrier was reactivated on the fifth mission day and the SCCE was successfully commanded 'on' for a single measurement cycle.

The SCCE flight hardware has since been returned to ESA and the cell specimens returned to their originators for post-flight inspection and analysis.

Results
About 50% of the cells flown showed deviations of less than 1% between flight and ground data. Three cells showed deviations of more than 10%, indicating erroneous ground calibration, improper sample integration or malfunctioning of the specific measurement channel.

The reproducibility of the flight data between flight STS-7 and STS-11 was excellent (Table 2). Eight cells were reflown in different positions within the SCCE facility and all gave reproducible calibration results within a 1% range.

Conclusions
The SCCE objective of generating space-calibrated primary solar-cell standards has been achieved for the majority of the flight samples.

Our experience indicates that it is necessary to simplify the interfaces between the experiment and the carrier and Orbiter, by providing an autonomous data-handling and storage system, preferably together with an independent measurement of the experiment's attitude.

Table 2 — Grouping of calibration results

	STS-7	STS-11
Good correlation between space calibration and ground calibration	16	16
Possible ground calibration inaccuracy	7	8
Possible wrong sample integration and/or reference-standard inaccuracy	5	4
Voltage-saturated during flight	1	1
Electronics assembly malfunction	2	2

Acknowledgement
The assistance and cooperation of all experimenters in providing cells for this successful experiment is gratefully acknowledged. The contributions of the representatives of MBB and Kayser-Threde are much appreciated.

Parabolic Aircraft Flights – An Effective Tool in Preparing Microgravity Experiments

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The parabolic flight is a useful tool for simulating microgravity and for performing short-duration experiments. Its real value, however, is in the verification tests that can be conducted in preparation for space experiments in order to improve their quality and success rate. The low cost and the relatively short turnaround time (less than four months between decision to perform the flights and the presentation of the first results) make such aircraft flights very attractive for the preparation of microgravity missions. ESA therefore decided to make use of the NASA 'Reduced Gravity Facility', a specially modified aircraft used for astronaut training, to verify some fluid-physics experiments that will be carried on the German Spacelab D-1 Mission.

Introduction

The microgravity environment is very difficult to simulate on Earth. One method applicable to fluids, developed by the Belgian scientist J.A.F. Plateau, involves studying the interaction of immiscible fluids of the same density. This method is used for astronaut training in 'neutral buoyancy facilities'. Other methods are based on the free-fall principle using drop towers. However, the time of free fall, and hence reduced gravity, does not exceed a few seconds (4.3 s for the US Marshall Space Flight Center drop tube). Rocket flights, for which the microgravity period can be of several minutes, are very useful for performing experiments with unmanned instruments. Aircraft flights, however, provide an effective means of simulating microgravity conditions for short periods, with the added advantage of allowing human intervention in the progress of the experiment when necessary.

During a parabolic flight periods of about 25 seconds of greatly reduced gravity can be obtained, sufficient to investigate a number of fundamental phenomena. The NASA Reduced Gravity Facility uses a specially modified KC-135 aircraft, flown over a parabolic arc. Figure 1 shows the trajectory of the aircraft, the duration of each period of less than 1 g and the altitude at which the parabola is performed.

The ESA Fluid Physics Module (FPM), flown as part of the Material Sciences Double Rack (MSDR) on Spacelab-1 in November 1983, can be briefly described as a precision instrument for studying the basic properties of fluids in microgravity (Fig. 2). It consists of an experiment chamber in which the fluid behaviour is observed with two cine cameras. Different stimuli (mechanical, electrical or thermal) can be applied to the liquid under study. Many of the investigations for which it is used are related to the properties of fluid columns, which are formed between two discs.

During the first Spacelab mission, the instrument itself performed nominally, but several unexpected phenomena occurred. In particular the liquids were observed to wet the disc's periphery as well as its surface. After the flight several suggestions for eliminating these difficulties were proposed. Another anomaly involved the appearance of bubbles within the liquid column, which are difficult to remove in the absence of gravity.

During the preparation of the scientific experiments for Spacelab D-1 and the related crew training, it became clear that even a few seconds of reduced-gravity experimentation would allow verification of these proposed improvements, prior to the Spacelab reflight. In collaboration with the DFVLR D-1 Project Team, ESA therefore made plans for two parabolic flights aboard NASA's KC-135 aircraft.

Pre-flight preparations

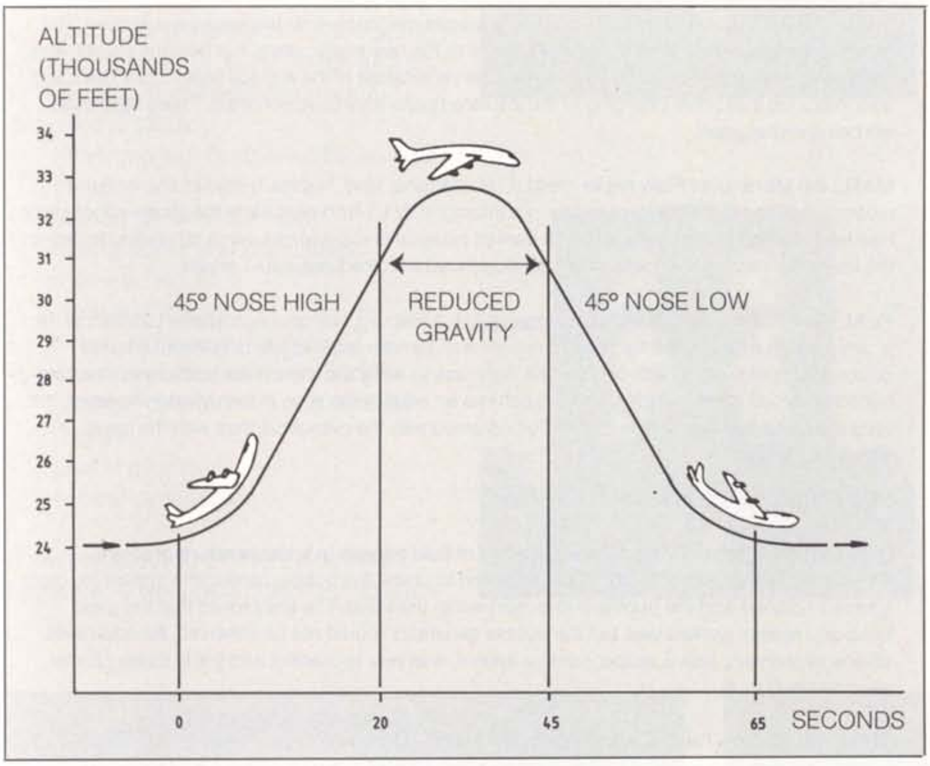
The tests would be performed using the Engineering Model of the FPM, an exact replica of the Flight Model, normally used for crew training and experiment preparation on the ground. This use of available hardware would minimise time,

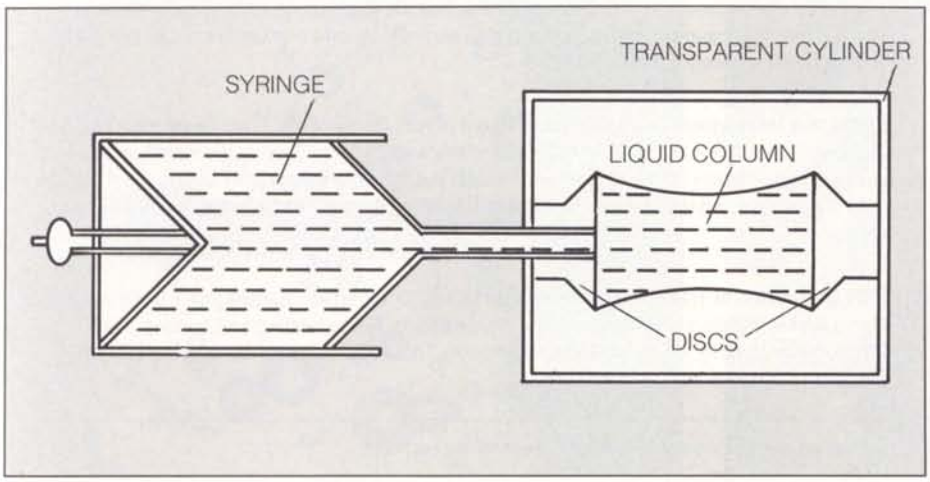
Figure 1 – The KC-135 aircraft trajectory

Figure 2 – ESA's Fluid Physics Module (FPM) concept

effort and cost, and would also allow actual spaceflight conditions to be closely approximated.

Because of the mass of the FPM, two possible configurations had to be considered. One option was to attach the FPM to the floor of the aircraft. This would simulate spaceflight conditions in terms of crew operations, but would have the disadvantage of transmitting aircraft-generated vibrations through the structure. Alternatively the FPM could have been left to float free inside the aircraft, assuring a better low-g level, but for shorter periods (5–15 s instead of 25 s). Crew operations during the microgravity period would have been extremely difficult. The fixed solution was therefore preferred.





ESTEC's Design Office and Workshop manufactured a structure that would support not only the FPM, but also the power supply, the FPM data unit, a video recorder and a monitor. The structure also had a platform with foot-straps to assist crew operations. A set of three accelerometers was fixed to the structure to measure the prevailing gravitational force throughout the flight. A small video camera installed next to the cine camera recorded events inside the experiment chamber. All experiment equipment to be used inside the FPM was stowed in a set of specially constructed drawers.

Except for the FPM itself, Spacelab D-1 flight hardware was used for the majority of experiments. For the fluid column experiments, however, closed containers had to be built to avoid spillage of the liquid (silicon oil) inside the FPM. The attachment discs were therefore mounted inside transparent cylinders (Fig. 2), which allowed visual verification of the liquid's attachment to the discs.

In addition to the driver FPM investigations, a number of other experiments were to be performed under the responsibility of the Principal Investigators (PIs). For these the PIs were required to provide the hardware, its stowage and the safety documentation. Where the astronauts would be called upon to take part themselves in the life-sciences investigations, approval by the D-1 Medical Board and NASA's Human Use Committee was needed. The complete set of experiments then had to be formally approved by a NASA safety committee.

The number of operations that can be performed in a 25 s period is obviously limited. To make maximum use of this low-gravity period, special procedures were written, dividing operations into three phases – set-up, microgravity and shut down – dictated by the requirements of the FPM experiments. One FPM experiment was scheduled per parabolic trajectory to be flown, each parabola commencing in response to a signal from the astronaut performing the experiment. The life-sciences and off-line experiments were scheduled to be performed in parallel.

Since all the experiments required intervention or participation by the crew, much detailed planning was necessary. It involved rotation of the crew members so that each could perform a number of FPM experiments and all could participate in the life-sciences experiments.

The duration of a flight on board the KC-135 is limited to about two hours. A normal flight consists of series of consecutive parabolas, which allows about 40 parabolic trajectories to be flown each flight. However, because of the need to set up a new experiment before each parabola, it was planned to limit the number of parabolas to about 20.

The flights

During the first flight, on 13 December 1984, 21 parabolas were flown, with an average interval of 6 min 20 s. During the second flight, on 14 December, 23 parabolas were flown with an average interval of 5 min 20 s.

Operationally, both flights were a complete success. The nominal timeline for the experiments was followed almost exactly. In the course of the first flight, however, it became clear that it was impossible to create long, stable columns in the containers. For the second flight, therefore, the distances between the end plates was reduced to about 1 cm and better results were obtained.

The campaign also provided an excellent flight-rehearsal opportunity for the complete science team of the D-1 mission, and the Payload and Mission Specialists.

The experiments and their results

The FPM experiments

Specific verification tests were performed during the parabolic flights for each of the scientific investigations to be conducted

Table 1

FPM EXPERIMENTS FOR REFLIGHT ON SPACELAB D-1

CAPS, Capillary Forces in a low gravity environment (J.F. Padday, Kodak Ltd, UK) aims to identify and measure the strength of long-range intermolecular forces between a liquid and a solid. The new design uses attachment discs with extremely sharp edges. The purpose of the parabolic flight test was to verify this new configuration and results indicated that better attachment was achieved (Fig. 3).

FLIZ, Floating Liquid Zone experiment (I. Da Riva, Univ. Madrid, E), studies the outer shapes and the inner motion of a liquid bridge when precise mechanical disturbances are applied. The flights were again used to verify the attachment to the new plastic discs, but here the results were not quite so clear. However, the test showed the importance of the surface finish of the discs and also indicated that some charging of the insulated parts may have occurred. These results are still being investigated.

MAFL, the Marangoni Flow experiment (L. Napolitano, Univ. Naples, I) studies convection motions induced by Marangoni forces in a microgravity environment. Here the sharp-edged discs had been treated on the back with anti-spread material and equipped with a teflon ring to restrict the liquid. An improvement was observed compared with the Spacelab-1 results.

FLIM, the Forced Liquid Motion experiment (J.P. Vreeburg, National Aerospace Laboratory, NL) is designed to evaluate the liquid/solid momentum transfer making use of different shaped containers partially filled with liquids. The flight was to verify the use of new containers. The zero-g period obtained is normally too short to achieve an equilibrium state in the cylinder; however, the tests indicated that better results could be obtained with the cylindrical than with the torus-shaped container.

NEW FPM EXPERIMENTS FOR D-1 MISSION*

BUDY, Bubble Dynamics and the separation of fluid phases in a temperature gradient (R. Naehle, DFVLR, Koln, D). The flight was used to check the bubble production system (by glass covered nozzles) and the bubble distribution within the liquid. The test proved that the glass breakage system worked well, but the bubble generation could not be observed. An equivalent off-line experiment, with a proper camera system, was very successful and the bubbles can be seen clearly (Fig. 4).

STEM, the Surface Tension Minimum experiment (J.C. Legros, Free University of Brussels, B) is to study the convection motion originated by surface-tension forces due to temperature inhomogeneities. The aim of the parabolic flight test was to verify the filling of the cell and the creation of an interface. The interface created during the test had the form of a meniscus, but spurious wetting occurred in the corners of the cell. A similar off-line experiment, using a partially teflonised cell, was very successful (Fig. 5).

MACO, the Marangoni Convection experiment (A.A.H. Drinkenburg, Univ. Groningen, NL) is to measure the coefficient of mass transfer due to Marangoni convection at the interface between liquid and gas phases. The intention was to verify the interface topography during the parabolic flight. It was observed that the interface created by filling the cell from a corner is smooth but is not plane.

STIF, Separation of Transparent Immiscible Fluids (D. Langbein, Battelle Inst. e.V., D) is to study mixing and separation of transparent immiscible liquids during heating and cooling. The intention was to verify the basic column formation. This could be observed effectively, but the column created was slightly asymmetric.

* These experiments are all performed in closed containers.

on the Spacelab D-1 mission. Four of these experiments will be reflights of experiments already flown on the Spacelab-1 mission in November 1983; four are completely new experiments. The results of the parabolic aircraft flights for all eight are summarised in Table 1.

The off-line fluid-physics experiments
The off-line fluid physics experiments were proposed and designed by twelve Principal Investigators, four of whom were on board during the flights: Dr. J. Padday, Prof. J.C. Legros, Dr. D. Neuhaus and Mr. H. Kleingeld. These experiments are designed to study:

- attachment of fluids on different end plates
- stability of liquid surfaces
- mixing of hot and cold liquids
- fluid jets (Fig. 6)
- stability of zones
- critical-point experiments
- creation of an air zone in a liquid
- creation of structures with dipoles (Fig. 7)
- crystal growth
- bubble dynamics.

A total of about 50 off-line fluid-physics experiments were performed during each

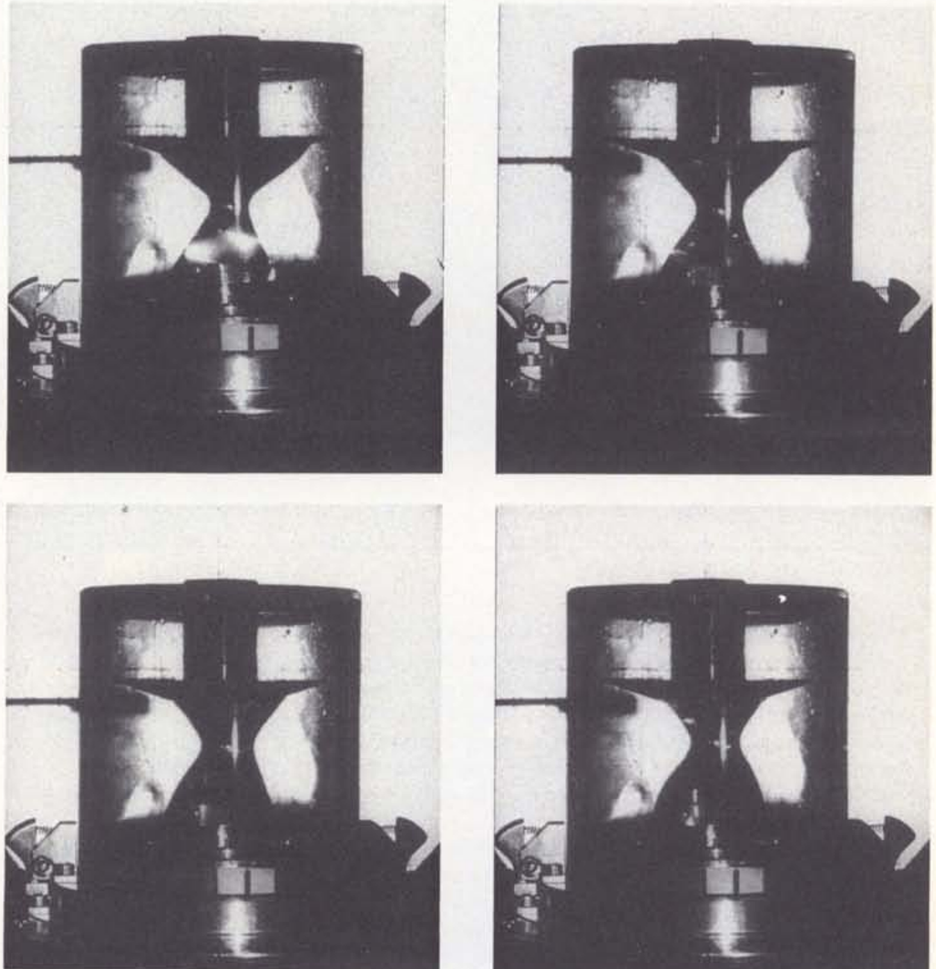


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Figure 3 — The CAPS experiment: formation of a fluid column in microgravity (Courtesy: Dr. J. Padday)

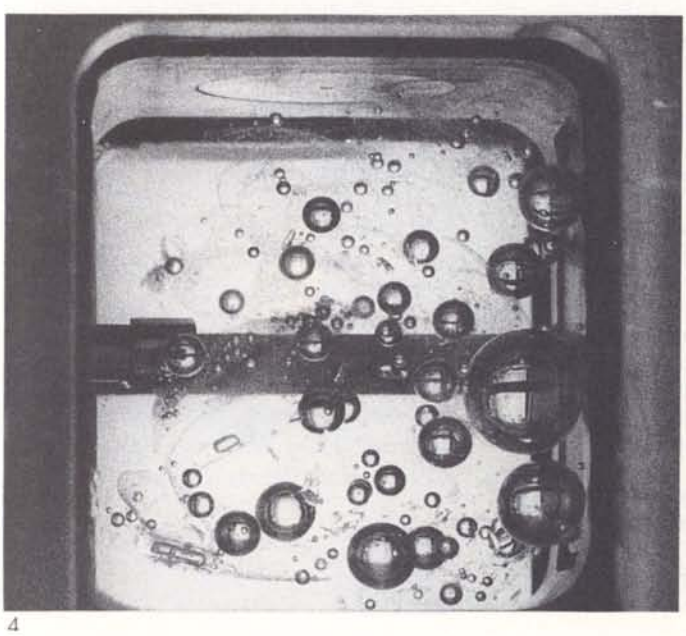

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Figure 4 — Bubble dynamics and the separation of fluid phases in a temperature gradient (Courtesy: Dr. D. Neuhaus)

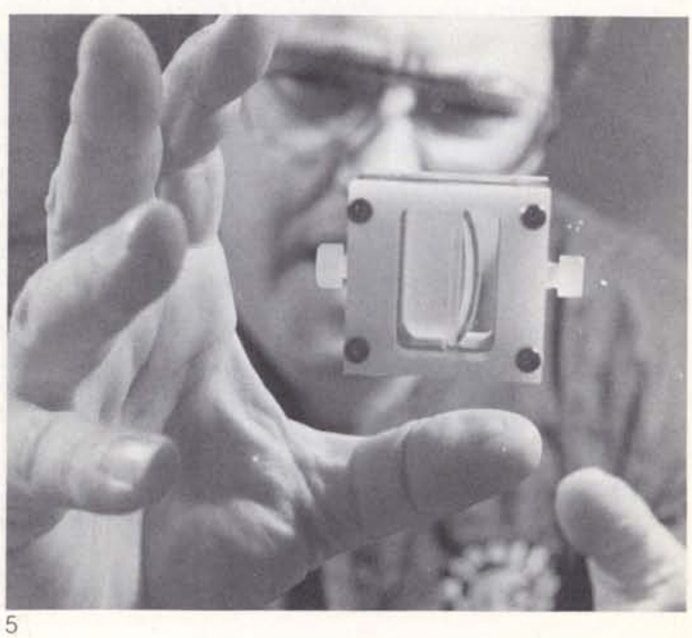

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Figure 5 — The STEM experiment: in microgravity capillary forces have a greater effect on fluid behaviour (Courtesy: Dr. J.C. Legros)

Figure 6 – An off-line experiment studying fluid jets in microgravity

Figure 7 – An attempt to create a three-dimensional atomic structure with small magnetic dipoles (Courtesy: Dr. J.P. Vreeburg)

Table 2

The Neck Receptor experiment (R. von Baumgarten,Univ. Mainz, D) is designed to examine the influence of the neck receptors on the eye motor system and on subjective orientation in man. This experiment made use of the Sled helmet and needed two crew members. The subject had his head fixed in the helmet; the operator had to oscillate the body over 30 degrees in both lateral directions with the head staying fixed. The subject indicated his sensations by means of a joy-stick (Fig. 8). The purpose of the flight was for operational training and baseline data taking. Each crew member performed the experiment seven times as operator and seven times as test subject over the two days.
Preliminary analysis of the data shows evidence that the subjects are aware of their orientation. The main benefit, however, lay in the operational training opportunity.

The Tomex experiment (S. Draeger, Univ. Hamburg, D) is to measure the intra-ocular pressure of the human eye under microgravity conditions. The experiment is performed manually by one crew member on another. The objective of the KC-135 test was to evaluate the D-1 flight procedures for test-subject and operator interaction.
NASA's Human Use Committee considered direct measurement on the subject's eye too dangerous during a parabolic flight because of possible sudden movement, and the experiment had to be performed on a dummy. The crew were still able, however, to practice the procedures (Fig. 9).

The Gravity Perception experiment (D. Volkman, Univ. Bonn, D) is to evaluate the effects of gravity on the growth of the plant, cress. For germination and chemical fixation of culture samples, different chemicals are used. They are located in fluid-tight containers and are transferred to the samples manually via quick disconnects and syringes. The purpose of the test with the KC-135 flight was to analyse the filling procedures, to verify continuous fluid transport with no generation of bubbles, and to demonstrate the exchange of fluids. The experiment was performed successfully by several crew members during the flights (Fig. 10).

Roots (G. Perbal, Univ. P. et M. Curie, Paris, F) is an equivalent experiment on lentils and forms part of Biorack. The purpose of the test was to verify the automatic injection of chemicals into the containers. A special set up was made using two sets of flight containers mounted on a base-plate together with a camera. The test revealed a potential problem in that the different compartments of the container did not fill equally and the results are now being analysed.

The Respiration Belt test (R. von Baumgarten) consisted of a subject breathing into a respiration-measurement device. The purpose was to measure inspiration and expiration under high-g, low-g and during the change.

flight, most of which were of the 'look and see' type.

The life-sciences investigations

Five life-sciences experiments were performed during the two flights. Details of the experiments themselves and the results obtained from the parabolic flights are summarised in Table 2.

Acknowledgement
The success of the KC-135 aircraft flights is due in large part to the professionalism and dedication of the D-1 science astronauts and the Principal Investigators, and of a number of persons at ESTEC (in particular Mr. C. Connor, and also the Workshop, Design Office and Test Facility staff) and the help received from DFVLR Porz-Wahn (H. Dodeck and P. Kuklinski), the various investigator teams, and especially Mr. R. Williams (Flight Coordinator) and his NASA team.

Figure 8 – The Neck Receptor experiment

Figure 9 – Astronauts practice the procedures for eye-pressure measurements

Figure 10 – The Gravity Perception experiment, performed by Mission Specialist B. Dunbar

Courtesy: NASA

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Courtesy: NASA

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Courtesy: NASA

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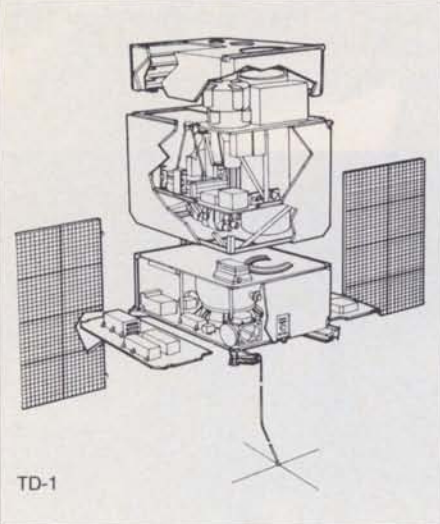


TD-1

Uniform Power Distribution Interfaces for Future Spacecraft

J.J. Capart & D.M. O'Sullivan, Power & Control Systems Division, ESA Technical Directorate, ESTEC, Noordwijk, The Netherlands

The problem of power-distribution interfaces is a long-standing one. Voltages and other important parameters frequently change from one spacecraft to another. The result is often that existing hardware cannot be used and designers have to cope with new, sometimes unexpected, problems.

As in all interface issues there are two main partners involved. The first is the spacecraft designer and industry who have to select the power-distribution interface taking into account all the constraints of the mission. The second, and in the author's view the most important, is the user of the power, namely the payload for an application satellite or the experimenter on a scientific mission.

The role of power distribution in a satellite

The distribution of electricity within a country takes place in two stages. The first is the transport of electricity between a power station and local transformer stations or between several interconnected power plants. There, the distribution interfaces are tailored to such technical considerations as available technology, ohmic losses in high-voltage lines, etc.

In the second step, from the local transformer station to individual houses, the design aims at providing the user with the widely accepted 220 V AC interface, which is simple, efficient, safe, easy to modify by using transformers, and compatible with a variety of applications ranging from crude (e.g. heating) to the sophisticated (e.g. electronic applications).

Unfortunately, the satellite world is far from mirroring this situation. Designers still try to merge these two steps into one, looking for the impossible compromise between cheap and efficient power generation and stable interfaces to the users. This situation could have been justified in the old days, when the ESRO-II power system, for instance, was made from about 1000 components. It can hardly be defended for today's sophisticated satellites, where the power systems may have as many as 20 000 components, not counting all the functions of the numerous integrated circuits.

Before addressing design issues, it is perhaps worthwhile to list, albeit in a somewhat subjective order of priority, the main characteristics for an 'ideal' power interface:

a. The interface *must be safe;* i.e. it must protect the users against malfunctions of the power system, which could give rise to an overvoltage. It must also minimise interferences from other users. Conversely, the power system and the essential users (e.g. telecommand) must be protected against any fault occurring downstream.

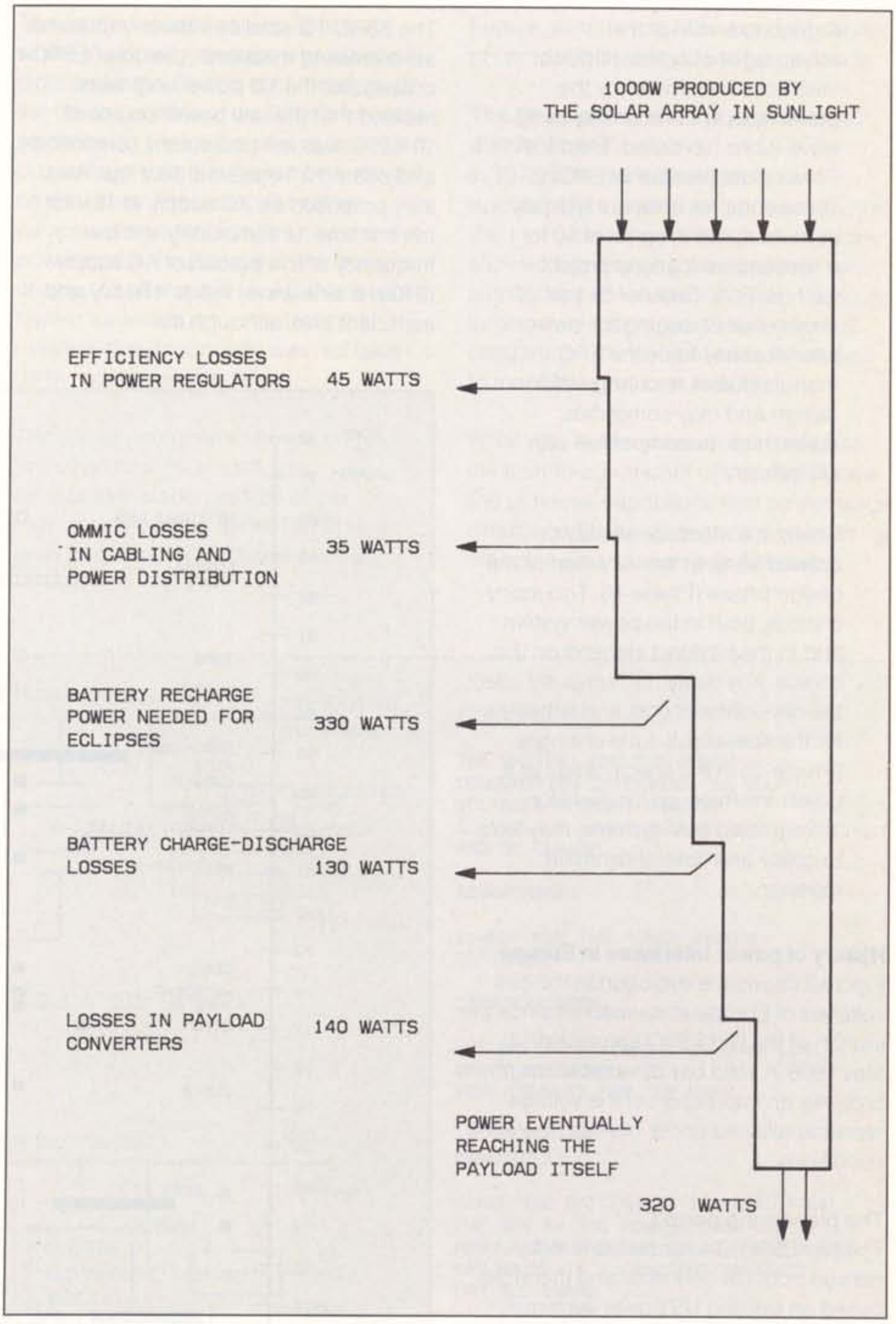
b. The interface must be *power-efficient.* This means that the switching and conversion losses must be minimised on both sides, and ohmic losses in the wiring kept to an acceptable level.

   This requirement may lead to a double system: one of rough power directly tapped from the power sources for very large users, and one more 'user friendly' for small electronic circuits.

   The importance of efficiency stems from the fact that the power system is actually its own best customer! This is illustrated in Figure 1, which shows that two thirds of the energy produced by the array on a low-orbit satellite will never reach the user circuits!

   Two more aspects must also be taken into account:
   - The direct impact on the weight of the power subsystem. For

Figure 1 – Typical drains on the power produced by the solar array of a low-orbit satellite



instance a 5% improvement in the efficiency of the power distribution on a 2.2 kW platform such as Eureca could save 18 kg on the array, the battery, and the electronics.

– The indirect impact of the heat generated by inefficient systems, when translated into radiator mass, spacecraft configuration changes or, even worse, active cooling power consumption. The same 5% losses on a 10 kW Space Station module could result in a 25% increase in power-supply heat-rejection requirements.

c. The interface must be *specified and described in a well-structured manner.*

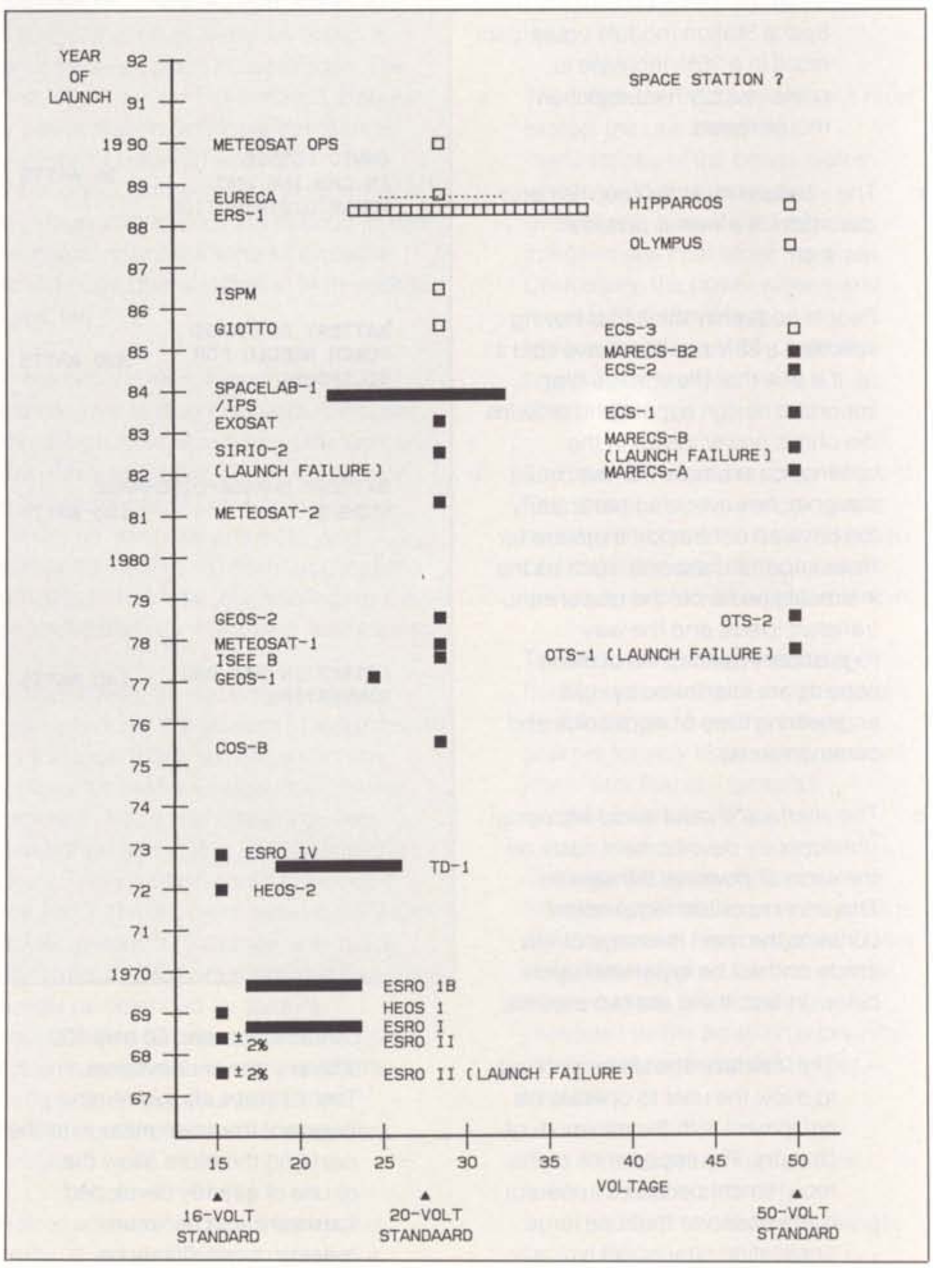
People frequently think that having specified a 28 V bus they have said it all. It is true that the voltage is an important design aspect and dictates the ohmic power losses in the cabling, for example. For the circuit designer, however, and particularly the payload contractor, there are far more important aspects, such as the internal impedance, the response to transient loads, and the way regulation is defined. All of these aspects are interlinked by rigid engineering laws of electronics and common sense.

d. The interface should *avoid imposing unnecessary development costs on the users* of power in the satellite. This very important requirement contains the main message of this article and will be expanded upon below. In fact, there are two aspects:

– The interface should be such as to allow the user to operate his equipment with the minimum of circuitry. The importance of this requirement becomes apparent if one observes that one large application spacecraft typically contains between 50 and 100 different power converters.

– The interface *should remain constant from one mission to the next* and therefore allow the re-use of already developed hardware with minimum redesign costs. It may be necessary, for example, in order to save millions of accounting units on future satellites, to convince a project to accept an interface that would not be optimum, and perhaps not the cheapest, for that particular mission.

Figure 2 – The bus voltages of past and future European satellites



A good example of the advantages of constant power interfaces is provided by the power-supply units for travelling-wave tubes (so-called 'Electrical Power Conditioners' or EPCs). These complex units are typically manufactured in series of 50 for a telecommunications project such as ECS. Experience has shown that changing the power interface may force the EPC manufacturers to change their design and may sometimes make them uncompetitive with US industry.

e. Finally, the *interface should be defined early*, at the very start of the design phase (Phase-B). Too many choices, both in the power system and in the payload, depend on this choice. Any delay can seriously affect the development cost and schedule for the spacecraft. Late changes (Phase-C) in the specification of a power interface, particularly for 'unregulated bus' systems, may lead to costly and time-consuming redesign.

History of power interfaces in Europe

Figure 2 shows the evolution in the bus voltages of European spacecraft since the launch of the first ESRO spacecraft in May 1968. A solid bar of variable length provides an impression of the voltage variation allowed under normal operating conditions.

The pioneering period

The first ESRO satellites were directly derived from US concepts and therefore based on existing US power-system concepts. The voltage was low, which was reasonable considering the low power demands. The main distribution bus was either unregulated (ESRO-I) or regulated (ESRO-II, Heos). The basic configuration of the units, which has changed little since then (although the design of the units themselves has made very impressive progress), is illustrated in Figure 3.

The ESRO TD satellite mission represents an interesting milestone. Like their ESRO-I colleagues, the TD power engineers realised that the raw power source of 19–25 V was not particularly user friendly, and offered a 'regulated' 16 V line. Also, they proposed an AC supply at 18 V for the first time. Unfortunately, the low frequency of this precursor AC supply (2400 Hz sine wave) made it heavy and inefficient and, although the experimenters were very satisfied, the idea of distributing AC current was subsequently shelved for about ten years.

The evolution to the 28 V standard

With Cos-B, the time had come to abandon the 16 V standard for a higher voltage, more in keeping with the continuously increasing power levels. By now, the tendency to supply the experimenters with a reasonably clean

Figure 3 – Essential features of the two concepts for spacecraft power distribution

regulated source was well established. The 28 V system became an accepted interface for most scientific satellites, meeting the objectives described above reasonably well.

At that time it also became clear that a different pattern was emerging in Europe from that prevailing in the USA, where the great majority of missions were still using unregulated power sources.

Like all 'rules', the 28 V regulated standard has exceptions: one of them was Geos, where the solar-array dimensions imposed a reduction in voltage to 25 V. This exception was perfectly acceptable in view of the very stringent electromagnetic-cleanliness requirements of this mission.

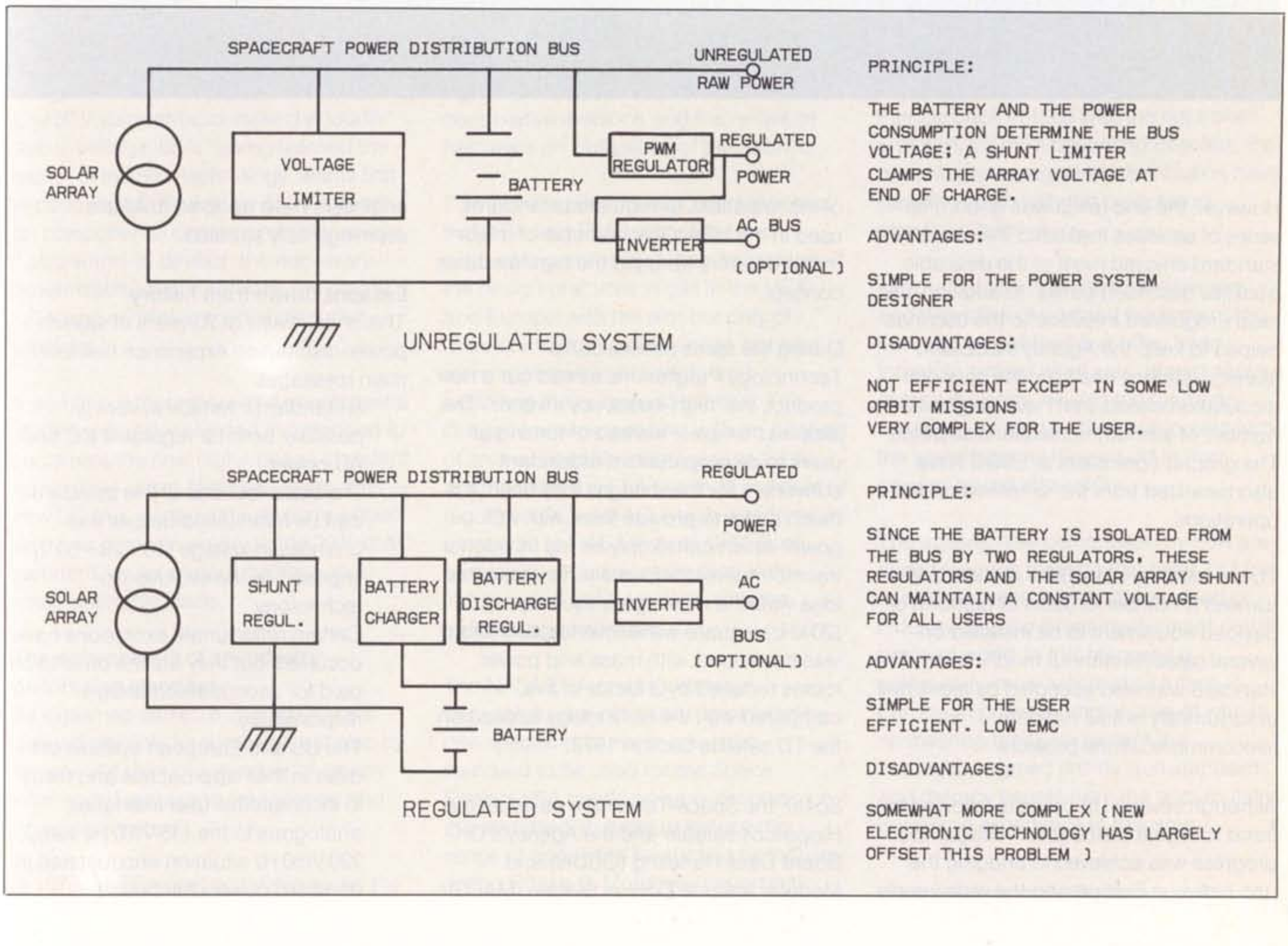
The second exception was Spacelab, where the power interface was obviously dictated by the Shuttle, and therefore by the characteristics of the latter's fuel cells. As shown in Figure 2, a very wide range of bus voltage variation had to be imposed on the users. The result was rather complex converter circuits and excessive power losses. Realising this, the designers decided to offer a 400 Hz AC distribution system as well, but, for nontechnical reasons, this opportunity was not taken up by most experimenters.

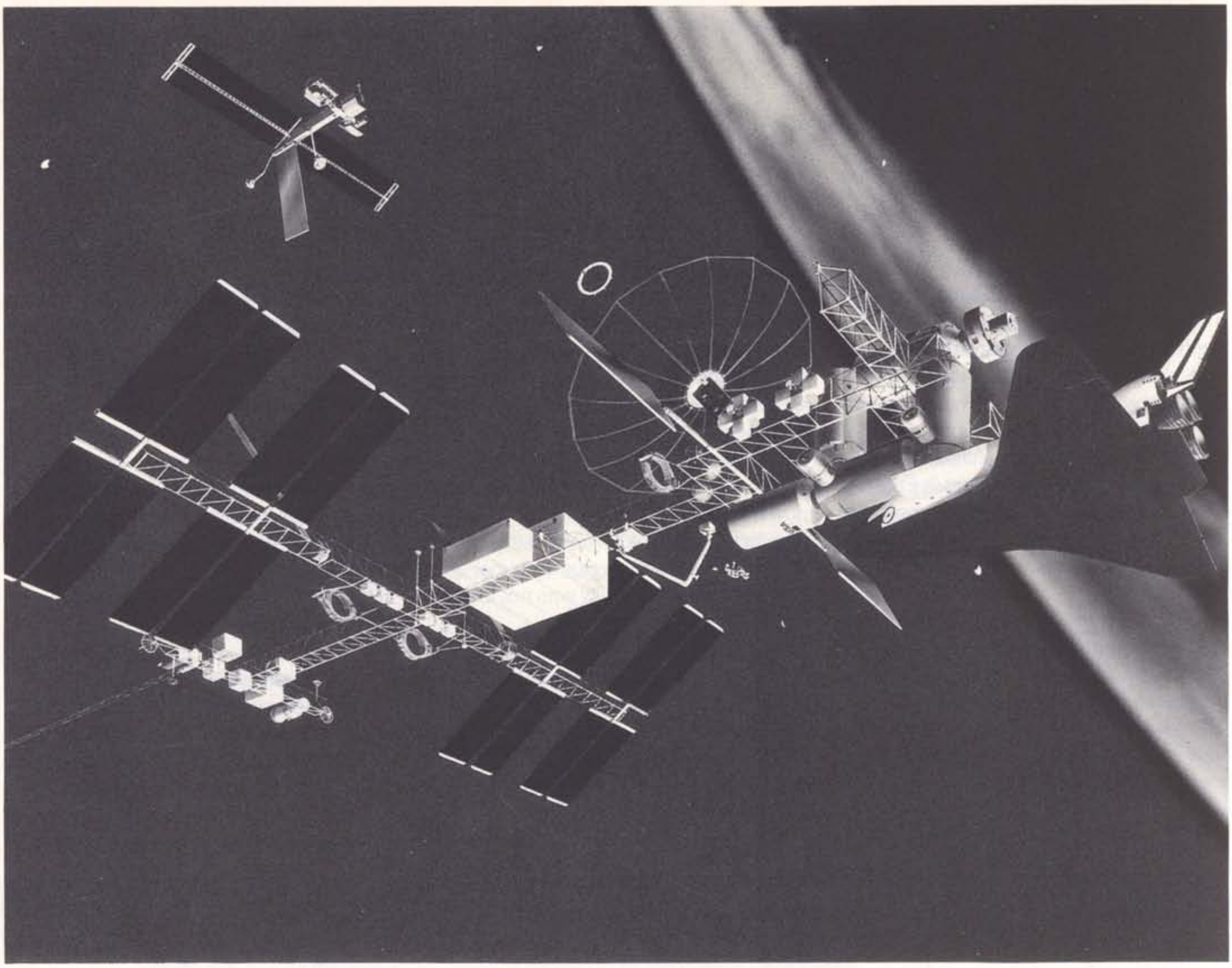
The use of unregulated power on Spacelab has influenced later developments such as that of the Instrument Pointing System (IPS) and even multimission platforms such as Eureca, which must offer a certain degree of compatibility with Spacelab payloads.

The 50 V system and the revival of AC distribution

In 1975, ESA started preparing applications satellites with power needs in the 1 – 10 kW range. Calculations quickly showed that keeping the otherwise very satisfactory 28 V system would entail fairly large power losses, and hence thermal dissipation. The decision was thus taken to make the next step, to 50 V.

What was not foreseen at that time was the technology impact of this step: a new line of relays, capacitors, and power-stage circuits had to be developed, and even the solar-array design was affected.





However, the end result was good. The series of satellites that used the new 50 V standard enjoyed most of the desirable qualities described earlier. In addition, the clean, regulated interface to the user has helped to keep the Agency's ECS and Marecs satellites free from the spurious modulation effects that have plagued a number of telecommunications satellites. The ground controllers at ESOC have also benefited from the simplified orbital operations.

The re-usability of the 50 V standard also allowed a number of items of platform or payload equipment to be installed on several satellites without modification. The standard was also accepted by most, but unfortunately not all national telecommunications projects.

Although several US projects followed the trend to higher distribution voltage, little progress was achieved in bridging the gap between Europe and the wide variety of incompatible, unregulated standards used in the USA. Only a couple of major manufacturers adopted the regulated-bus concept.

During the same period, ESA's Technology Programme turned out a new product, the 'high-frequency inverter'. The idea was simple – instead of forcing all users to develop custom redundant converters for the voltages they need, it is much better to provide them with AC power which can simply be fed through a transformer rectifier system. To make this idea viable, a new high-frequency (20 kHz), square-wave inverter technology was developed, with mass and power losses reduced by a factor of five, compared with the technology applied on the TD satellite back in 1972.

So far, the Space-Telescope payload, the Hipparcos satellite and the Agency's On-Board Data-Handling (OBDH) and Modular Attitude Control System (MACS) engineers have adopted it. All are seemingly fully satisfied.

Lessons drawn from history

This short review of 20 years of satellite power-distribution experience has four main messages:

- A standard interface system is possible, both for regulated DC and AC power.
- The basic features of this standard can be maintained despite the changes in voltage (16 – 28 – 50 V) imposed by the evolution in technology.
- Certain unfortunate exceptions have occurred, but they are the price to be paid for decentralised design responsibility.
- The US and European systems still differ in their approaches and result in incompatible user interfaces, analogous to the 115 V/60 Hz versus 220 V/50 Hz situation encountered in domestic power distribution.

Figure 4 – The 'Power Tower' baseline concept for the Space Station. One of the proposed co-orbiting platforms is also shown

The future

The previous sections have hopefully given a good impression of the reasons for and consequences of the present situation. The actions undertaken by ESA address the problem from three main standpoints:

Preparing the next technology step

Future ESA platforms in low Earth orbit (LEO) and geostationary orbit (GEO) will require power levels well in excess of 10 kW. They will also reach a further level in the variety, number and interchangeability of payloads. More than ever, the simplicity and quality of power interfaces will become a dominating consideration.

Finally, new components such as the power FET (Field Effect Transistor) and circuit concepts such as ESA's patented LC^3 (Limit Cycling Conductance Control) and 'smart' regulators are available to the designer. It is now time, after the 16, 28 and 50 V standards, to make the fourth step in voltage. ESA, having learned the lesson of the 50 V technology, wants first to perform a careful study of the impact on components, circuits and solar arrays. It also wants to develop the necessary power-distribution hardware, principally a full range of reliable solid-state circuit breakers.

A number of theoretical and experimental studies are underway and it is planned to implement the new high-voltage standard within three years. Needless to say, this new DC bus will remain fully compatible with and complementary to the 20 kHz AC standard for secondary distribution to small electronic loads.

The enforcement of an industry distribution standard

As explained earlier, a user interface is defined not only by a voltage, but also by the specification of a number of closely interrelated regulation, impedance and noise parameters.

In 1978, an ESA contractor examined the relationship between these parameters and their implications for hardware. This exhaustive analysis led to the issue in 1982, under ESA's authority, of two documents that specify and justify, in an unambiguous manner, the best way to define a power interface. For three years, ESA has kept this document as a guideline, in order to collect the comments of industry. It is now the intention to gradually enforce it formally, thereby offering future payload designers an additional guarantee of protection against interface changes. The gradual implementation of this system will also avoid the first user projects having to support any significant extra costs.

The stepping-up of interface negotiations with the USA

In June 1981, a joint NASA/ESA Working Group on power interfaces was appointed with a mandate to issue recommendations applicable to both Agencies, in order to facilitate future cooperative missions and the re-use of hardware on both sides of the Atlantic.

This Working Group, which is supported by NASA and ESA technology and engineering authorities, has first analysed the design practices in use in the USA and Europe, with the aim not only of understanding the differences, but also, more importantly, of finding and exploiting their common aspects. The Group is now proceeding with an analysis of several possible interface standards, among them the ESA two-level concept of regulated DC and AC, which was formally presented to NASA in April 1984. Both parties are regularly consulting with industry and, in ESA's case, with the national agencies also.

The NASA/ESA power-interface discussions are obviously dominated by one specific and major issue: the standard to be used for the Space Station. ESA needs an early definition of this standard, in order to reduce the range of options to be studied by industry during Phase-B. Moreover, important technology developments, such as that of solid-state circuit breakers, cannot start in earnest before an interface is defined.

Whatever interface is chosen, it will be a dominating factor for most space hardware developments on both sides of the Atlantic. With the advent of multimission platforms, payload interchangeability and in-orbit servicing, a high degree of commonality between European and US hardware will have to be achieved. These concerns have been well understood by NASA, who have recognised that the Spacelab 28 V interface is not suitable and are actively studying, among other options, the DC and AC standards proposed by ESA.

Conclusions

Power interfaces have been shown to be an important factor in the cost and performance of spacecraft. History has confirmed that the direction chosen by Europe back in 1965 was the right one and that, far from becoming obsolete, the advantages of regulated distribution have steadily grown with the progress in electronic technology.

Although up to now the experimenters on and providers of payload equipment for European satellites have often been forced to accept what was offered, these users will clearly insist in the future on their right to 'plug in' their equipment with the same ease as they would in their ground-based laboratory.

The actions now being taken by ESA are aimed towards meeting this need, but they cannot succeed without the support of industry and the direct involvement of the payload world. In this respect it is particularly important that all future European projects, irrespective of who is sponsoring them, implement the commonly agreed distribution standards and thereby benefit from the accumulated European experience in this area.

Le deuxième Ensemble de Lancement Ariane (ELA-2)

C. Dana, Direction des Systèmes de Transport spatial, ESA, Paris

Construit à proximité de l'actuel Complexe de Lancement à Kourou en Guyane française, le deuxième Ensemble de Lancement Ariane (ELA-2) tranche par les dimensions importantes de ses ouvrages.

La réalisation de ce nouvel Ensemble, entreprise depuis la mi-81 dans le cadre d'un programme de l'Agence spatiale européenne auquel participent sept Etats membres, était quasiment terminée fin 1984: seules restent à exécuter en 1985 les dernières opérations de validation en vue d'un premier lancement dans le deuxième semestre 1985.

L'ELA-2 est destiné à devenir, à compter de 1986, le complexe de lancement européen normalement utilisé pour les lanceurs Ariane, l'ancien Ensemble de Lancement Ariane (ELA-1) étant conservé comme moyen redondant de secours.

Deux raisons principales ont imposé la réalisation de l'ELA-2:
- disposer d'un complexe de lancement permettant d'accroître la disponibilité des moyens de lancement pour le lanceur Ariane-3, condition importante de la crédibilité commerciale du lanceur,
- permettre le lancement d'Ariane-4 qui représente une évolution significative d'Ariane et qui n'est plus compatible avec l'ELA-1.

La conception de l'ELA-2 a pour objectifs essentiels de:
- augmenter la cadence de lancement grâce à la séparation de la zone de lancement, de la zone de préparation des lanceurs,
- optimiser les coûts opérationnels par réduction des contraintes en exploitation.

L'ELA-2 est constitué essentiellement de deux zones distinctes: la Zone de Préparation des lanceurs et la Zone de Lancement.

La Zone de Préparation des lanceurs est indépendante et située à une distance de sécurité (950 m) de la Zone de Lancement. Les deux zones sont reliées entre elles par un chemin de roulement sur lequel se déplacent les tables de lancement mobiles.

La séparation géographique de la Zone de Préparation des lanceurs et de la Zone de Lancement est la caractéristique principale de l'ELA-2. Cette configuration permet de bénéficier d'une grande souplesse d'utilisation des moyens de lancement puisqu'un lanceur peut être érigé, assemblé et contrôlé en Zone de Préparation, alors que le lanceur précédent, amené érigé sur sa table de lancement mobile en Zone de Lancement, y subit les dernières opérations de contrôle en vue de son lancement imminent.

L'utilisation en parallèle des Zones de Préparation et de Lancement de l'ELA-2 permet donc l'exécution simultanée de deux campagnes de lancement et réduit l'intervalle entre deux lancements à un mois, alors que la conception classique d'ELA-1, qui prévoit l'exécution en série des opérations d'érection, d'assemblage et de contrôle du lanceur sur un même site, conduit à des intervalles d'environ deux mois entre les lancements.

Zone de Préparation

Dans la Zone de Préparation de l'ELA-2 sont effectuées les opérations suivantes sur le lanceur:
- destockage et contrôle d'aspect des éléments du lanceur
- érection des étages et raccordements
- contrôles d'étanchéité
- contrôles moteurs
- préparation et montage des propulseurs d'appoint liquides ou solides
- contrôles électriques.

Le temps de présence du lanceur dans cette zone est d'environ un mois.

Figure 1 — Au premier plan l'ELA-1 avec le lanceur Ariane-3 prêt au lancement; à gauche la Zone de Lancement ELA-2, au fond la Zone de Préparation ELA-2

Les principales installations de la Zone de Préparation des lanceurs sont:

- *le Hall de déstockage* est un bâtiment métallique partiellement bardé destiné à recevoir les étages d'Ariane dans leurs conteneurs à leur arrivée en Guyane; il permet le stockage de deux lanceurs. L'inspection visuelle et la préparation à l'érection des éléments du lanceur sont effectuées dans ce Hall muni de ponts roulants pour la manutention de ces éléments en position horizontale;
- *le Hall d'érection* est un bâtiment métallique de dimensions 15 × 30 × 34 m; bardé, climatisé, muni d'un pont roulant de 30 t, il permet la mise à la verticale des conteneurs des trois étages et des propulseurs d'appoint ainsi que la manutention de la case à équipements en vue de leur érection dans le Dock d'assemblage;
- *le Dock d'assemblage* est un bâtiment métallique bardé, climatisé, accolé au Hall d'érection, de dimension 20 × 20 × 67 m; il est muni de plateformes fixes, escamotables, permettant l'accès aux différents niveaux du lanceur et équipé d'un pont roulant de 20 t et d'un palan rapide de 3,2 t et de deux potences de 16 t. Ce bâtiment permet la mise en place et les raccordements électriques et fluides de la table de lancement, l'érection des étages, de la case à équipements, des propulseurs d'appoint et leur raccordement au Banc de Contrôle Dock;
- *les moyens de Contrôle Lanceur et Systèmes Sol*
  Dans un bâtiment contigu au Dock d'assemblage est installé le Banc de Contrôle Dock d'où sont conduites les opérations de contrôle du lanceur en Zone de Préparation.

Les principales servitudes du complexe de lancement sont regroupées en Zone de Préparation:

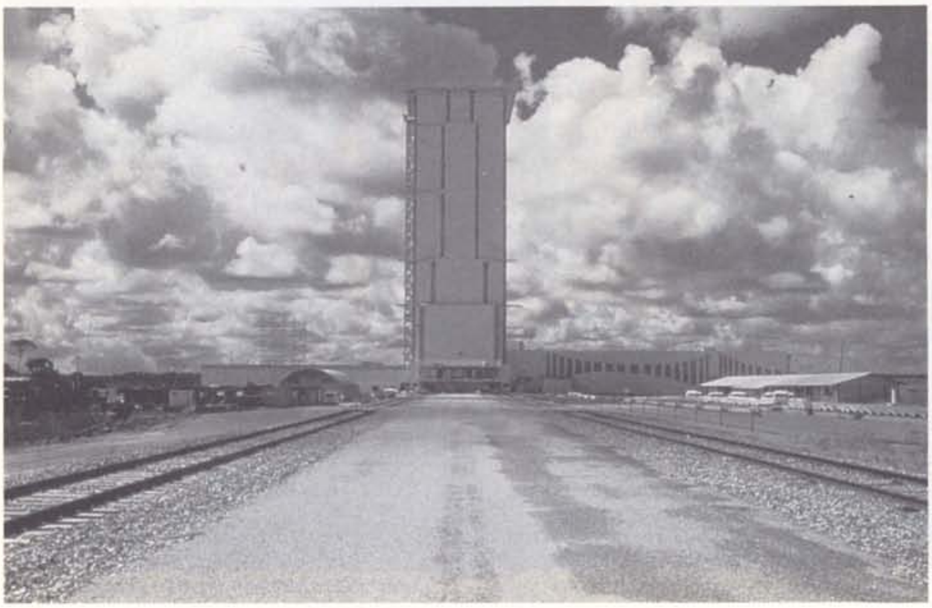
- *Energie:* 4 000 kVA installés; deux groupes électrogènes de secours de 440 kVA, et deux onduleurs de 100 kVA.
- *Climatisation:* 11 groupes assurent une production de 1800 kfrigories/heure et 600 kcalories/heure sous forme d'eau glacée et d'eau chaude. 1660 m³ de stockage en 3 cuves, deux d'eau glacée et une d'eau chaude, permettent 4 heures d'autonomie en cas de coupure d'énergie. Ces fluides servent à la climatisation des locaux et au refroidissement des équipements électroniques (sol et bord) et des ergols stockables.
- *Les Installations fluides:* les installations de production et stockage des fluides conventionnels (air, azote, hélium) communes à l'ELA-1 et l'ELA-2 ont une capacité de stockage de:
  - pour l'air: 4,5 m³ à 200 bars
  - pour l'azote liquide: 275 m³
  - pour l'azote gazeux: 40 m³ à 250 bars
  - pour l'hélium gazeux: 53 m³ répartis selon les besoins opérationnels en stockages spécifiques de 200 à 350 bars.

  Les stockages d'ergols UDMH et N_2O_4 (de capacité unitaire 200 m³), sont communs et reliés aux Zones de Lancement de l'ELA-1 et de l'ELA-2, permettent une utilisation commune au profit des deux Ensembles. Environ 5000 composants (vannes, clapets, soupapes...) et 20 km de liaisons, permettent la distribution de ces fluides.
- *Bureaux, ateliers, magasins*
  Un bâtiment Bureaux d'une surface utile de 1650 m² répartie sur 3 étages, accolé au Centre de Lancement abrite les équipes chargées de l'exploitation de l'ELA-2 et les équipes de lancement.

Le Centre de Lancement est un bâtiment en béton armé, à deux niveaux, recouvert d'une dalle de béton de 2 m d'épaisseur et

Figure 2 — ELA-2: Zone de Préparation des lanceurs: le Dock d'assemblage et à gauche le Centre de Lancement

Figure 3 — Vue intérieure du Centre de lancement avec ses équipements de contrôle: depuis ce Centre sont exécutées les opérations de mise en oeuvre finale du lanceur



d'une couche de terre de 4 m protégeant les personnels et équipements lors du lancement. Sa surface, de 2 × 900 m^2, se répartit en salles techniques, salles d'opération et d'observation, salle de repli. Entièrement climatisé, il constitue la zone de repli du personnel lors du lancement avec une capacité de 200 personnes.

Depuis le Centre de Lancement, où sont installés les équipements de contrôle et commande, sont assurées la mise en oeuvre opérationnelle des équipements de surveillance à distance du lanceur, le déroulement des opérations de mise en oeuvre finale et la chronologie de lancement. Deux systèmes, le Contrôle Commande Electrique (CCE) et le Contrôle Commande Fluides (CCF) constituent les principaux éléments des équipements de contrôle.

Le CCF assure la mise en oeuvre et le contrôle à distance des moyens de l'ensemble des installations de lancement, plus particulièrement la pressurisation des réservoirs et capacités, les remplissages en ergols, les assainissements, le déroulement de la séquence synchronisée, la conduite des automatismes de sécurité.

Le CCE assure la mise en oeuvre et le contrôle des chaînes électriques du lanceur, la mise en oeuvre de la phase de largage et le stockage, l'exploitation et la visualisation des données en provenance du lanceur.

La Zone de Préparation des lanceurs est reliée à la Zone de Lancement par un *chemin de roulement* constitué d'une double voie ferrée de 950 m de longueur allant du Dock d'assemblage jusqu'au Massif de lancement. Une plate-forme tournante (sur coussins d'air) et une voie de dégagement permettent le croisement des tables de lancement.

Pour son transfert depuis la Zone de Préparation à la Zone de Lancement, le lanceur, assemblé jusqu'au niveau de la case à équipements inclus, est posé à la verticale sur sa table de lancement mobile se déplaçant à l'aide de boggies sur la double voie ferrée: le déplacement contrôlé des tables de lancement entre les deux Zones est assuré par un tracteur de 350 CV en moins d'une heure.

La table de lancement roulante, structure métallique en forme de caissons de dimensions 13 × 13 × 4 m et d'une masse d'environ 500 t supporte le système de largage du lanceur, identique pour les versions Ariane-3 et Ariane-4. Deux tables de lancement sont réalisées: une pour les

Figure 4 — Vue intérieure du Dock d'assemblage

Figure 5 — Le chemin de roulement reliant la Zone de Préparation à la Zone de Lancement ELA-2

lanceurs Ariane-3 et une pour les lanceurs Ariane-4.

La table de lancement Ariane-3 est rehaussée d'environ 7 m par rapport à la table Ariane-4 afin de conserver la même altitude au niveau des bras cryogéniques de la tour ombilicale qui assurent les liaisons ergols, fluides et électriques avec le 3ème étage du lanceur. La table Ariane-3 peut être transformée en table Ariane-4 et vice versa.

Zone de Lancement
Dans la Zone de Lancement sont exécutées les opérations suivantes:

- phase finale de contrôle du lanceur
- érection et contrôle de la charge utile
- assemblage de la coiffe
- raccordement des moyens sol, alimentation en ergols et fluides et contrôles/commandes
- préparation au lancement: chronologie et lancement
- éventuellement érection et desérection des propulseurs d'appoint.

Le temps de présence du lanceur dans cette zone est de deux semaines environ.

Les principales installations de la Zone de Lancement sont:
- *Le Massif de lancement* sur lequel vient s'ancrer la table mobile supportant le lanceur. Entouré de plates-formes de manoeuvre, le massif (12 000 t de béton) supporte la table de lancement, le portique de servitude en position avancée, et se prolonge par le chemin de retrait permettant le recul du portique. Un déflecteur de jet, du type sec à deux versants revêtu de béton réfractaire, intégré au massif assure le détournement des jets des moteurs du 1er étage et des propulseurs d'appoint au décollage dans deux carneaux semi-enterrés de forme incurvée. La récupération et l'évacuation des ergols vers une cuve de rétention, en cas de fuite, est prévue à partir des carneaux.
- *La Tour ombilicale*, de dimension 8 × 15 × 74 m, assure les liaisons électriques et fluides entre le lanceur et les installations sol; constituée d'une partie en béton à 13 niveaux et d'une partie en charpente métallique à 10 niveaux, partiellement bardée et protégée côté lanceur, elle est accolée au Massif et située à environ 12 m du lanceur, elle supporte notamment les bras cryogéniques de liaison avec le lanceur.
- *Le Portique de servitude* assure la protection du lanceur sur le Massif et permet l'accès aux différents niveaux.

Mobile, de dimensions 20 × 20 × 80 m, structure métallique bardée en partie supérieure, d'une masse de 3000 t, il est accolé, lorsque le lanceur est transféré en Zone de Lancement, à la Tour ombilicale avec laquelle il forme une enceinte fermée et climatisée dans sa moitié supérieure. Il permet la mise en place sur le lanceur de la charge utile, de la coiffe ou du composite charge utile + coiffe. La partie du Portique située au-dessus du niveau 62 m est une zone propre climatisée, pressurisée, permettant les opérations finales sur la case, la charge utile et la coiffe avant le lancement.

Le Portique est équipé d'un pont roulant de 32 t avec palan rapide de 3,2 t et de deux potences de 16 t. La

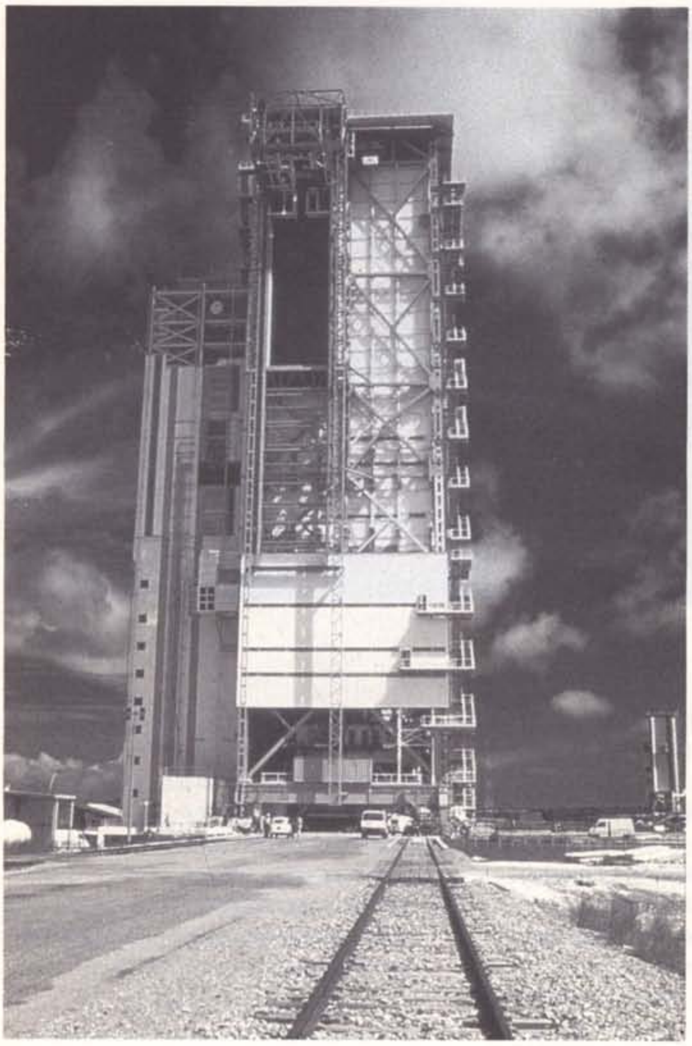


Figure 6 – Zone de Lancement ELA-2: le Portique de servitude accolé à la Tour ombilicale

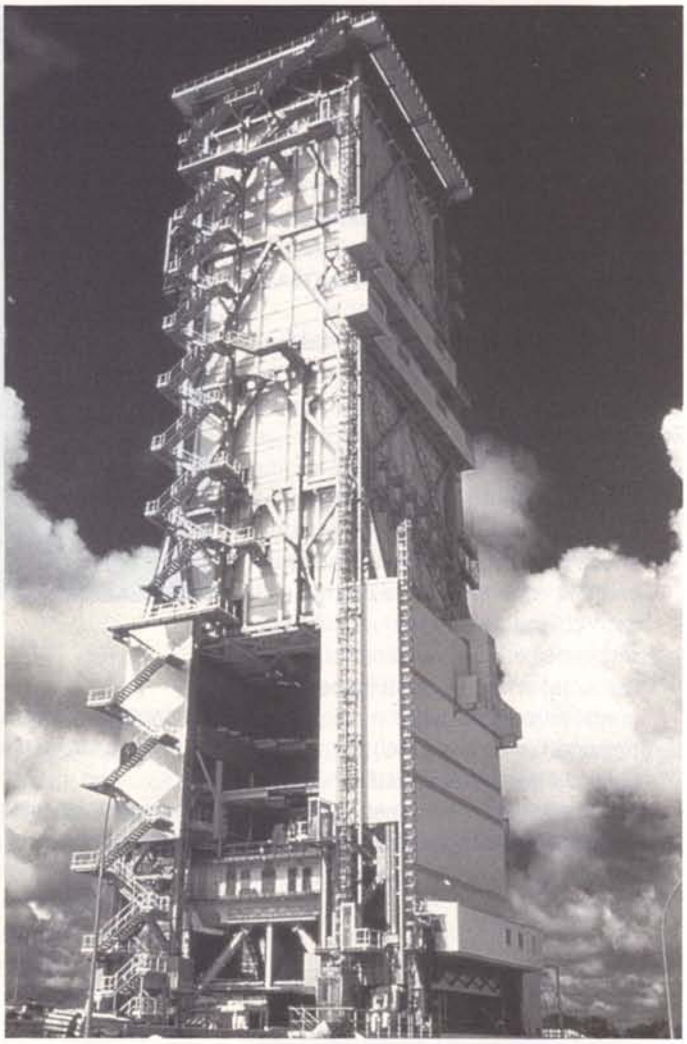


Figure 7 – Le Portique de servitude: abritée par le Portique on aperçoit la table de lancement Ariane-3

zone propre est équipée d'un pont de 12,5 t. Un ascenseur extérieur dessert les niveaux table de lancement et zone propre. Le Portique est reculé sur rails de roulement à une distance d'environ 80 m du lanceur lors du lancement.

- Un stockage d'oxygène liquide (L02) ainsi qu'un stockage d'azote liquide (LN_2) et une piscine de brûlage de l'hydrogène résiduel sont également installée en Zone de Lancement.

La réalisation de l'ELA-2, menée à bien grâce à l'excellente coopération des industriels européens participants, s'est étalée sur environ quatre ans:

2ème semestre 1981	Fin des études et début gros oeuvre
1982–1983	Gros-oeuvre (chantier jusqu'à 450 personnes) et installation des équipements opérationnels
1984	Fin d'installation et essais de mise en service et validation
1er semestre 1985	Fin des essais de validation et recette globale de l'ELA-2.

Le premier lancement Ariane-3 depuis l'ELA-2 est prévu dans le troisième trimestre 1985, et le premier lancement Ariane-4 à la mi-1986.

In Brief

Recent Visitors to ESTEC

Canadian Minister of Science and Technology

The Honourable Thomas E. Siddon, Canada's Minister of State for Science and Technology, visited ESTEC on 28 January. In Mr. Siddon's party were: His Excellency Mr. L.A.H. Smith, Canadian Ambassador to The Netherlands, Dr. Louis Berlinguet, Special Advisor to the Minister of State for Science and Technology, Mr. Kevin Macleod, Chief of the Minister's Staff, Dr. Jocelyn Ghent, Counsellor (European Space Affairs), Canadian Embassy, Paris, Dr. Hendrik Weiler, Counsellor (Scientific) Canadian Embassy, The Hague, Mr. R. Seaborn, Counsellor and Consul (Political Affairs), Canadian Embassy, The Hague and Mr. J. Leng, Counsellor (Commercial), Canadian Embassy, The Hague.

After being welcomed by Prof. M. Trella, ESA's Technical Director and Director of ESTEC, and Mr. E. Mallett, ESA's Director of Applications Programmes, the party spent the morning touring the ESTEC facilities, including the spacecraft environmental test facilities and the materials laboratory. In the afternoon they were given presentations on the Agency's Earth-Observation and Telecommunications Programmes, both of which are of particular interest to Canada. Mr. Siddon and his colleagues were also briefed on ESA's Future Scientific Programme and the Agency's Long-Term Plan.

Delegation from the Ministry of Astronautics, People's Republic of China

The Chinese Delegation, headed by Mr. Li Xu'e, First Vice Minister of the Ministry of Astronautics, visited ESTEC on 21 February. His party included: Sun Jiadong, Chief Engineer, Ministry of Astronautics and President of the Chinese Academy of Space Technology; Zhang Jiqing, Director of Foreign Affairs Bureau, Ministry of Astronautics (Deputy Head of the Delegation); Li Boyong, Chief Engineer, Ministry of Astronautics; Shi Jinmiao, Deputy Director, Astronautics Office of Shanghai; Cheng Lusheng, Deputy Director of Foreign Affairs Bureau, Commission of Science, Technology and Industry for National Defence; U Keli, Deputy Director General of the Great Wall Corporation; Mrs. Liu Fengqin, Director of International Relations Department, Chinese Academy of Space Technology; Zhang Hongxian, Deputy Head of the Planification Department, Ministry of Astronautics; Cao Xisheng, Interpreter, Chinese Academy of Space Technology; and Wang Zhongguo, Responsible for French Affairs, Foreign Affairs Office of the Ministry of Astronautics (Secretary to the Delegation).

During the course of the morning, after a brief introduction to the ESTEC Establishment, presentations were given on the ESA Technology Research Programme, the Remote-Sensing Programme and the Microgravity Programme.

In the afternoon the visitors inspected the ESTEC environmental test facilities and check-out laboratory, before attending a further presentation on the Agency's Spacelab, Eureca and Space Station Programmes.

Marecs-B2 Officially Handed Over to Inmarsat for Commercial Use

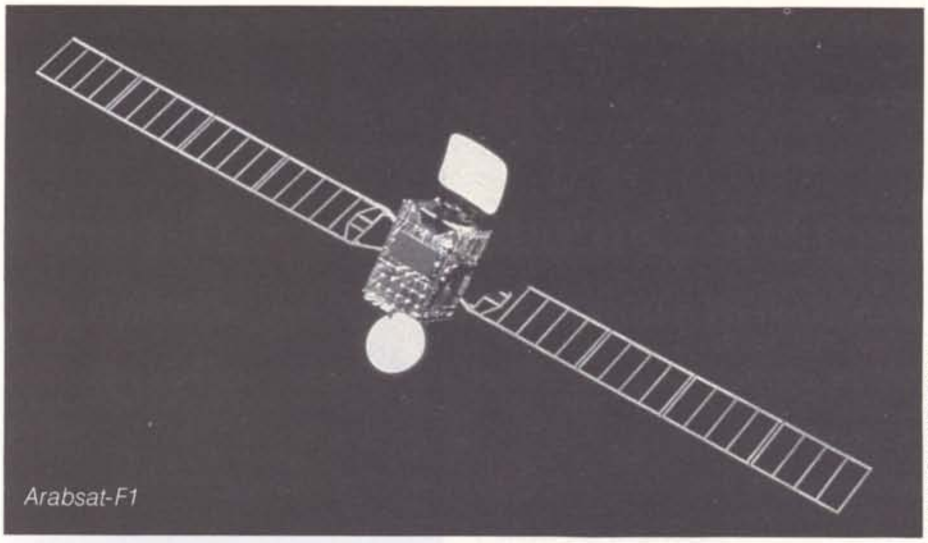
On 5 February, ESA officially handed over its second maritime communications satellite, Marecs-B2, to INMARSAT for the beginning of the satellite's commercial use in orbit. As part of the ceremony, which took place at INMARSAT Headquarters in London, INMARSAT's Director General, Mr. Olof Lundberg, and the Director General of ESA, Prof. Reimar Lüst, held real-time conversations with ships at sea and with a research station on the Antarctic continent.

The spacecraft, which has been in operational service since 8 January 1985, completes INMARSAT's first-generation satellite system, offering a worldwide service and covering three ocean regions: the Atlantic region, with Marecs-A positioned at 26°W, the Indian Ocean, with Intelsat MCS-A at 63°E, and the Pacific Ocean with Marecs B-2 at 176.5°E.

Arabsat and Brasilsat Launched by Ariane

The Ariane-V12 launch took place on 8 February 1985 at 23:22:00 h UT, putting both the Arabsat and Brasilsat communications satellites into geostationary transfer orbit.

Arabsat-F1, with a mass of 1215 kg at launch, is the first of a series of three satellites built under the prime contractorship of Aerospatiale (Cannes) for the Arab Satellite Communication Organisation (ASCO).



Bernard Paris/Arianespace

Bernard Paris/Arianespace

Brasilsat-1

Brasilsat-1 (SBTS-1) is the first of two satellites to be built by the Canadian firm SPAR Aerospace Ltd. for Embratel (Empresa Brasileira de Telecomunicaçoes), a Brazilian firm. At launch this satellite had a mass of 1140 kg.

This was the third Ariane-3 launch and Arianespace's fourth operational launch. The launcher campaign started on 4 January 1985, and that for the satellites on 29 November 1984. No major difficulties occurred.

Countdown took place in two phases; it started on Thursday 7 February from 05.00 to 24.00 h local time with the filling of the first and second stages with propellant, and resumed on Friday 8 February at about 09.00 h local time. The countdown as a whole went without a hitch and resulted in ignition of the first-stage engines at 20:22:00 h (23:22:00 h UT) at the opening of the launch window.

Data received by the Ascension Island radar stations showed that the resulting orbit parameters were as follows (target values in brackets):

- Apogee altitude 36 042 km (35 956)
- Perigee altitude 197.6 km (200.0)
- Inclination 7.10 deg (7.00).

The measurements received from the Akakro station gave values even closer to the target values.

The smooth progress of the campaign, the countdown and the V12 flight with the third Ariane-3 launcher confirmed once again the effectiveness of the launcher, the ground facilities, the procedures, and the teams that implement them.

Last Pre-Launch Meeting of the Giotto Science Working Team

The accompanying photographs show the Members of the Giotto Science Working Team (SWT), who met at ESTEC in Noordwijk on 19 and 20 February 1985.

Among the topics discussed by the Team at this meeting, the last in a regular series of SWT Meetings that have been held throughout Giotto's design and development, were the final details of the now imminent launch campaign.

The Giotto spacecraft is due to be launched by Ariane from the Agency's Kourou launch base, in French Guiana, on 2 July 1985.

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. 9, No. 1:

RENDEZVOUS AND DOCKING TECHNOLOGY DEVELOPMENT FOR FUTURE EUROPEAN MISSIONS
FEHSE W

AN EVALUATION OF 685 NM FLUORESCENCE IMAGERY OF COASTAL WATERS
KIM H H ET AL

ON-BOARD PROCESSOR FOR A TST/SS-TDMA TELECOMMUNICATIONS SYSTEM
ALARIA G B ET AL

LAUNCH AND RETRIEVAL MANOEUVRES FOR THE AGENCY'S FREE-FLYING SPACE PLATFORM 'EURECA'
MUGELLESI R

ORBIT MANOEUVRES WITH FINITE THRUST
WEISS J

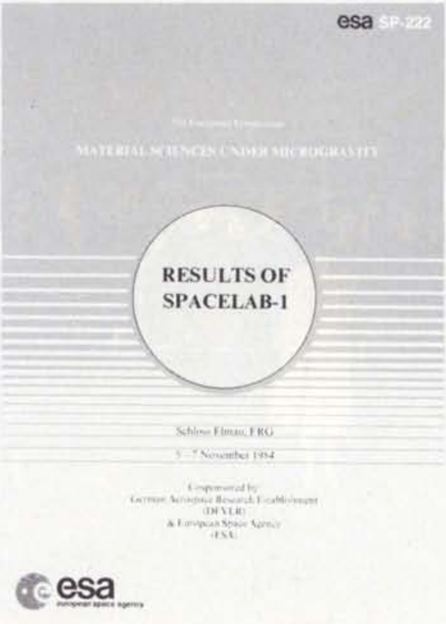
GEOSTATIONARY ORBIT INCLINATION STRATEGY
SOOP E M

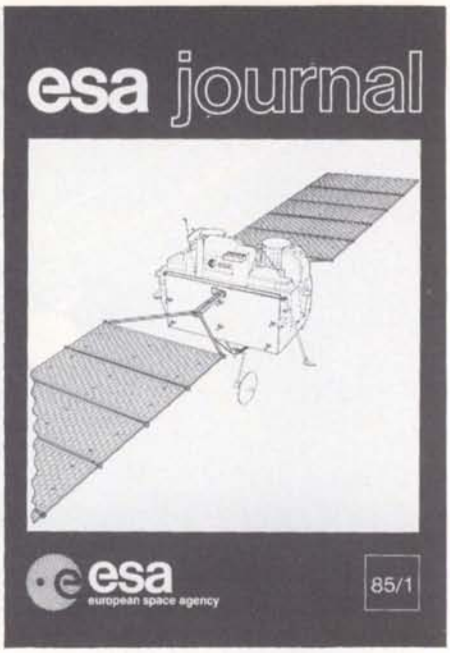
A DISTRIBUTED-ELEMENT METHOD FOR VIBRATION ANALYSIS OF FLEXIBLE SPACECRAFT BASED ON TRANSFER MATRICES
DAVIES M & DAWSON B

Special Publications

ESA SP-222 // 470 PAGES
5TH EUROPEAN SYMPOSIUM ON MATERIAL SCIENCES UNDER MICROGRAVITY – RESULTS OF SPACELAB-1, HELD AT SCHLOSS ELMAU, GERMANY, 5-7 NOVEMBER 1984 (DECEMBER 1984)
GUYENNE T D & HUNT J J (EDS)

ESA SP-227 // 158 PAGES
MICROWAVE REMOTE SENSING APPLIED TO VEGETATION – PROC EARSEL WORKSHOP OEGANISED BY WORKING GROUP 4 HELD AT NLR, AMSTERDAM, THE NETHERLANDS, 10-12 DECEMBER 1984 (JAN 1985)
BURKE W R (ED)





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Scientific & Technical Memoranda

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PRODUCT ASSURANCE DIVISION, ESTEC

Contractor Reports

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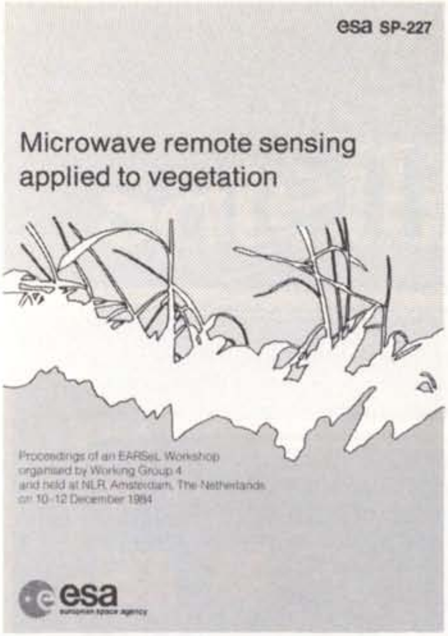

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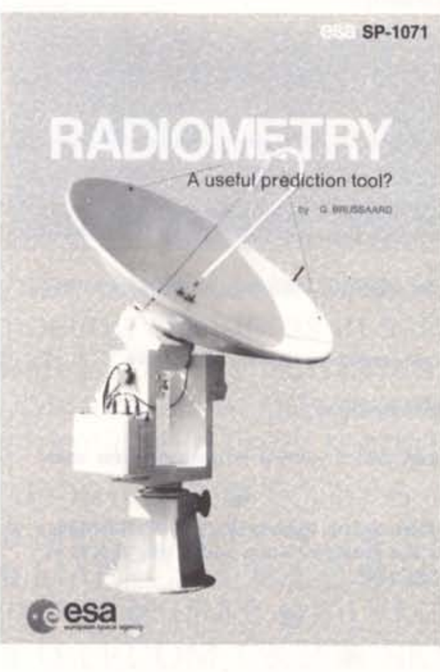

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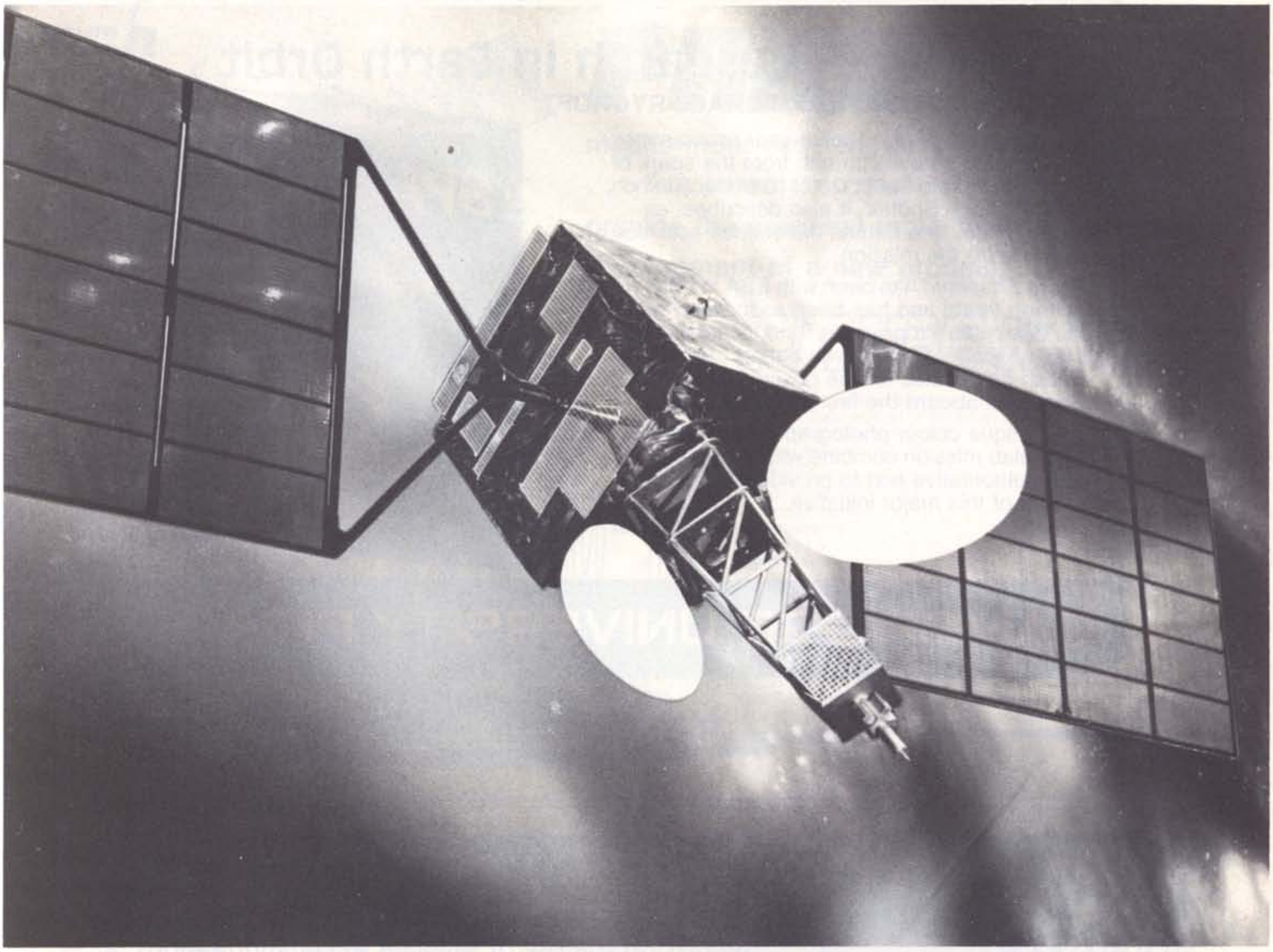


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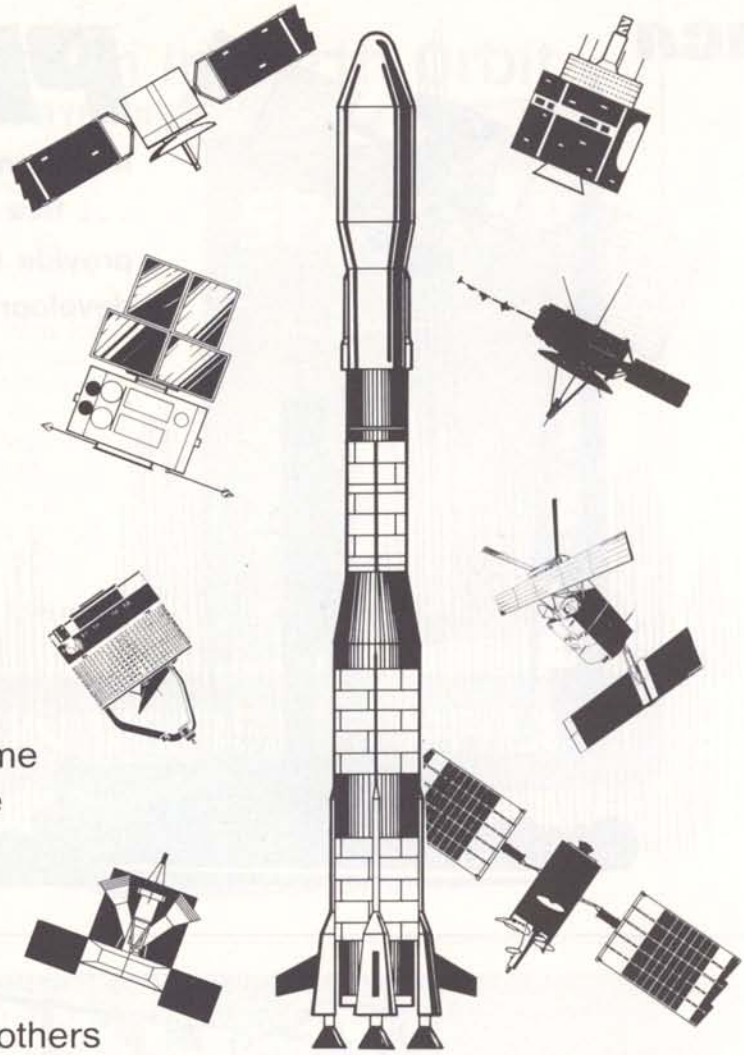

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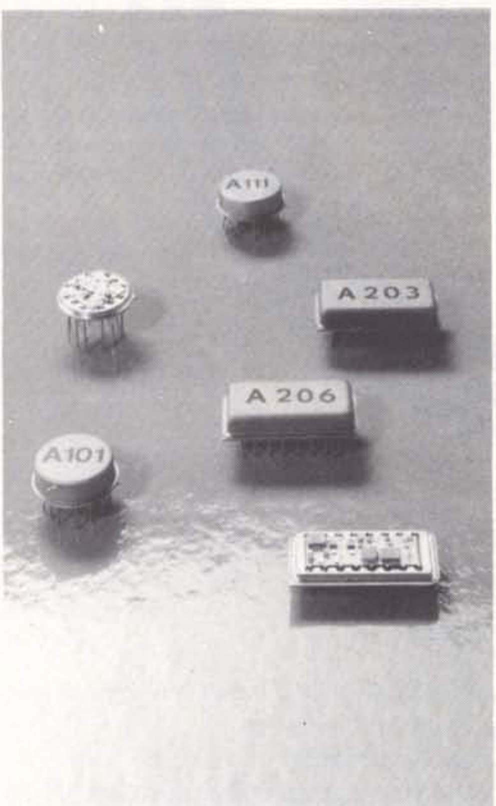

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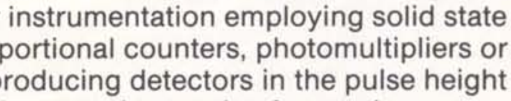

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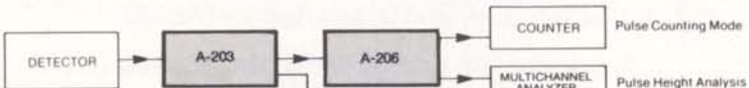

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