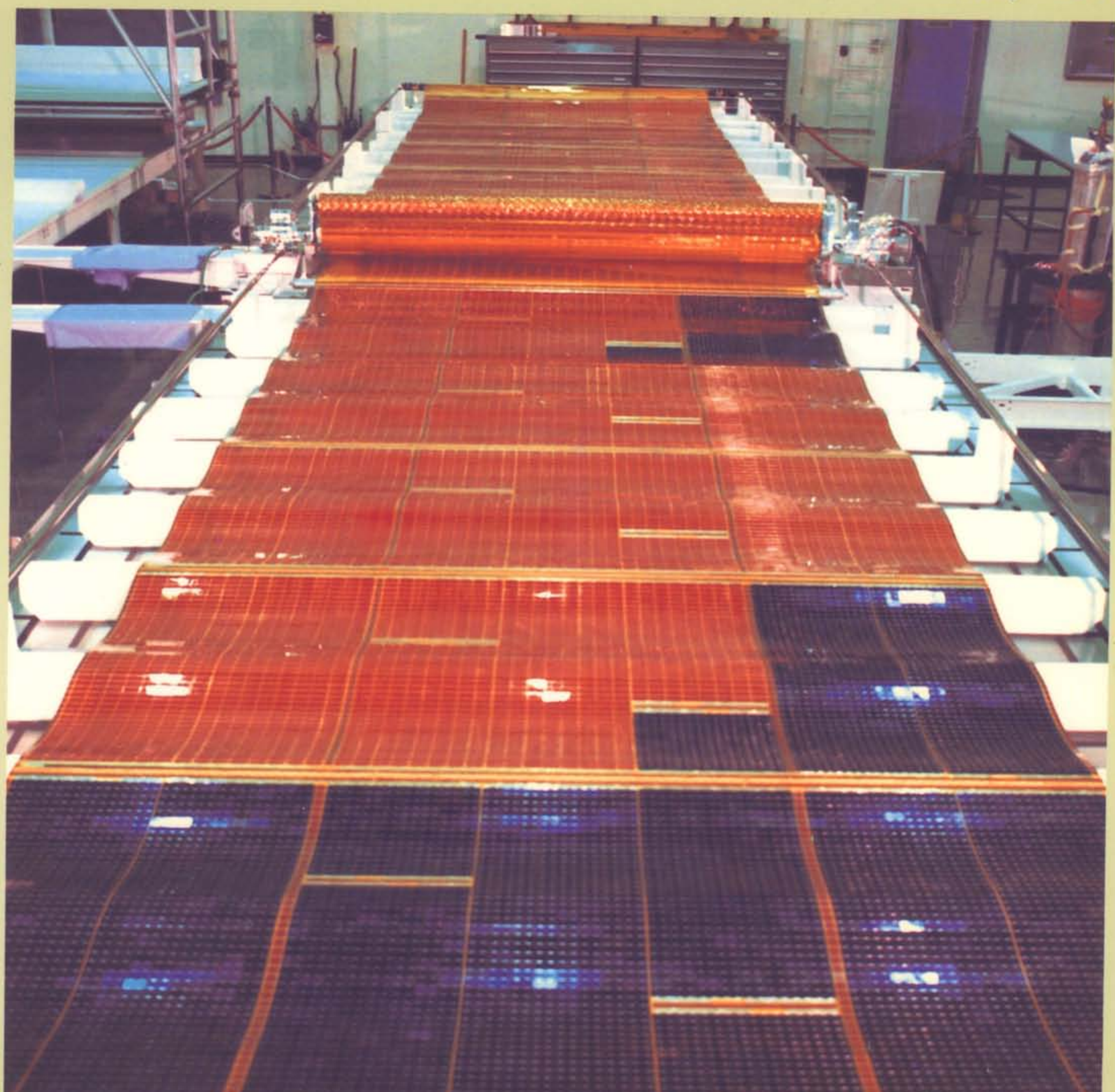
esa bulletin

number 26

may 1981



european space agency

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

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

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

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

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

The ESA HEADQUARTERS are in Paris.

The major establishments of ESA are:

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

ESRIN, Frascati, Italy.

Chairman of the Council: Mr. J. Stiernstedt (Sweden).

Director General: Mr. E. Quistgaard.

agence spatiale européenne

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

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

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

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

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esa bulletin

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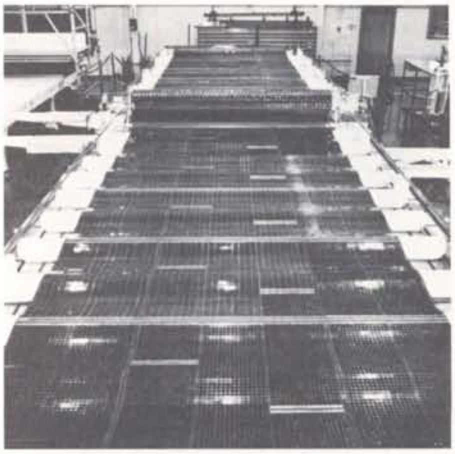

Front cover: Development model of the solar array for the Space Telescope, photographed fully deployed during tests at British Aerospace (UK) in December 1980.

Back cover: One of Ariane's Viking V engines under test at SEP (F) in January 1981 during resolution of the injector problem.

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Printed in The Netherlands by ESTEC Reproduction Services 810713
ISSN 0376-4265

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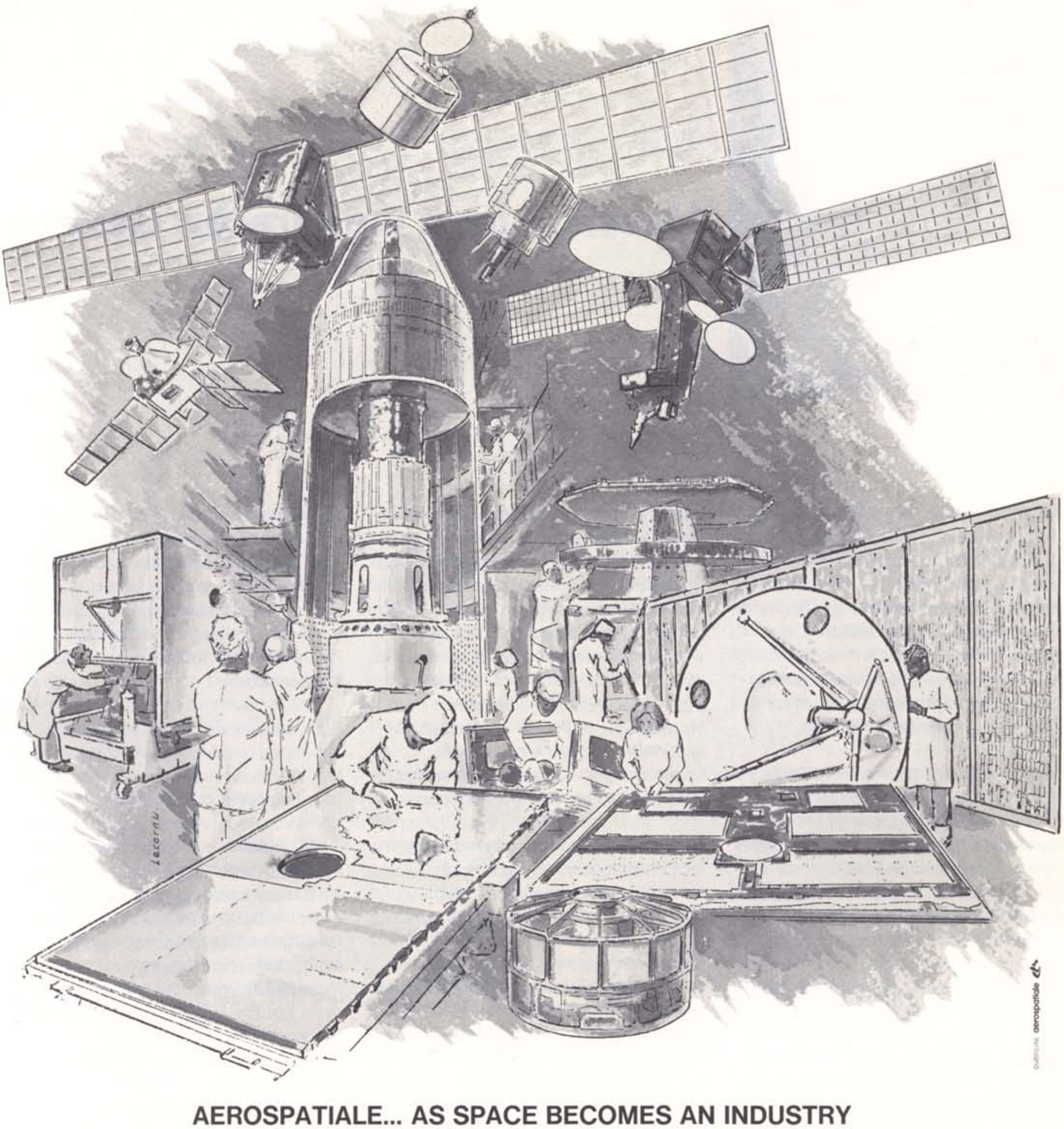
75738 Paris 15, France



Message from the Director General

As I write this message at the end of my first year in office, I still have fresh in my mind's eye the exciting pictures of the Space Shuttle landing; an event which thrilled and lifted the hearts and hopes of all who work in space research. The impact of so successful a mission has generated interest at all levels of public life, and should provide a stimulus for further efforts, not least in Europe.

For Europeans, of course, there will be the added interest that a European-built pallet (one of the components of Spacelab) is due to fly on the next Shuttle flight in September this year. Unfortunately we must wait until 1983 for the first European mission specialist to fly in the full Spacelab module.

Looking back on my first year in office, I have come to realise that ESA, like so many other institutions, suffers from the slow growth of the European concept, and is subject to the pulls of nationalism, even though the advantages of, and need for a collective European endeavour in such a rapidly advancing, expensive, and potentially very rewarding domain as space research are clear. Of course, having said that, one must immediately point to the tremendous support given to me by all Member States at the highest possible level when the International Solar Polar Mission (ISPM) was threatened with cancellation due to the cutback in NASA's budget appropriations. At the time of writing I have every reason to believe that the US Administration is responding positively to this united European representation. This can be seen as due in no small part to the political will engendered in the Member States and the speed with which they gave support.

For some time, however, there has been a lack of strategic planning in space research, and it is therefore extremely difficult to run ESA economically. A settled environment, in the sense that the Member States, the Agency's staff, user communities and industry can see several years ahead, is essential if Europe is to reap the harvest of the good work done in the last decade.

It was for that reason that I placed so much emphasis from my arrival on the need for a plan outlining the Agency's activities in the eighties. It has not been possible for the Member States to agree on a plan for the decade, but there are signs which give rise to optimism that agreement can be reached on a five-year level of resources and that decisions will soon be taken on the future of L-Sat, the Earth Resources Satellite (ERS-1), the follow-on development of Spacelab and Ariane, together with the second launch pad for Kourou.

Looking back on my first year in ESA, I am impressed by the high level of endeavour that continues in the Agency irrespective of the outcome of peak events. The operation of our embarrassment of riches – the scientific satellites that feed back interesting data long after their nominal life is over – seems almost commonplace except to those of us looking with new eyes. It is encouraging that ways are sought to finance the prolongation of these operations rather than abandon them. Equally, one can point to the many successful experiments carried out using OTS, with the user communities learning so much of importance for the generations of commercial telecommunication systems to come. Despite the loss of the imaging channels, the data-collection mission of Meteosat-1 goes on unabated, and the meteorologists are still studying, analysing and learning from the earlier images. The Agency is also applying the lessons learned as it prepares Meteosat-2 for launch. Much good work is done quietly in the background in laboratories, workshops, test centres, offices, and computer rooms, in support of ongoing and future programmes. The advances achieved in technological research are the backbones on which European competence is shaped.

Of course the peak events will always attract most attention, and the loss of Ariane L02 was a disappointment to all. That it did not cause alarm among potential customers can be gauged by the number of enquiries and orders placed in the firm belief that the problem would very soon be overcome. At the time of writing, we wait with optimism for the forthcoming launch of L03.

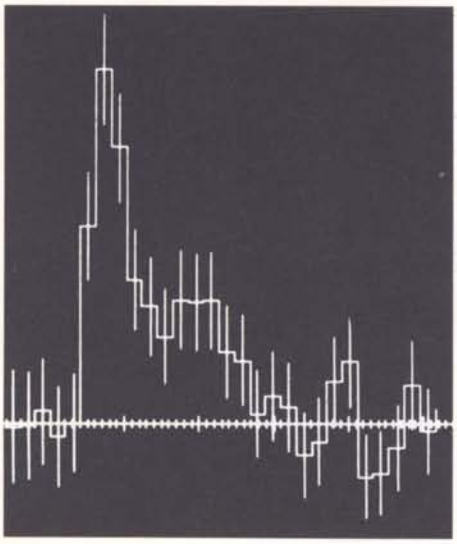
Less publicised, but of particular significance, was the Inmarsat decision to lease Marecs satellites for part of the global maritime satellite system. It too boosted Europe's confidence that it can build applications satellites that can compete with what the rest of the world has to offer.

After the trials and tribulations with Spacelab in previous years it was satisfying to sign a contract with NASA for a second unit and to see the Spacelab engineering model delivered to NASA. Work is proceeding apace on the flight unit, and on follow-on production. The only black clouds on the horizon concerned progress on the Instrument Pointing System (IPS), which ran into design problems, and the uncertainty regarding the utilisation of Spacelab by Europe beyond the First Spacelab Payload (FSLP). This latter point is unlikely to be resolved completely before Europe's scientists and technologists have had an opportunity to study the experience and results from the first flights.

In one area I have not progressed as quickly as I would have liked, namely the reorganisation of ESA's internal structure. It is, of course, very difficult to mould the internal structure of the Agency to make best use of staff, or indeed to know what staff are needed, until we have agreement on the future programmes. I have, in the meantime, grouped the Directors into a Management Board, and set up a Co-ordination and Monitoring Office reporting directly to me. Within the matrix organisation of programme and support directorates, I found a certain amount of confusion as to the roles to be played. Very shortly therefore I shall be clarifying the responsibilities within the matrix and, by a better definition of functions, I hope not only to facilitate the decision-making processes, but also to give greater visibility into our various operations.

I believe that I can finish this end-of-first-year message on a note of cautious optimism. The way in which the Council voted the 1981 budget before the end of 1980 and the decision to go head with two scientific projects – Hipparcos and Giotto – I take as pointers to positive thinking on the part of Member States. I have a firm conviction that, building upon the successes of the past, and with the accumulated expertise, goodwill, and belief in Europe that I find in the Agency's staff, and with a definite set of objectives before us, the Agency can give European scientists, technologists, industry and user communities a real voice in the world's space forums in the eighties and beyond.

E. Quistgaard



The Development of the Gas Scintillation Proportional Counter for X-Ray Astronomy

B.G. Taylor, Head of High-Energy Astrophysics Division, ESA Space Science Department, ESTEC, Noordwijk, Netherlands

Exploratory missions in X-ray astronomy conducted in the 1970s demonstrated the potential richness of this field in opening up new windows on the universe. Latterly, and certainly in the coming years, this potential will be brought to fruition by detailed, in-depth studies of cosmic X-ray sources using new and sophisticated instrumentation. The gas scintillation proportional counter (GSPC) has been specifically developed as a new instrument to reveal emission and absorption features in the spectra of sources between 1 and 10 keV. A technical and scientific proving flight was conducted on an Aries rocket in 1980 as a precursor to embarking such instruments on a number of space missions, including Exosat.

Spectroscopy in X-ray astronomy

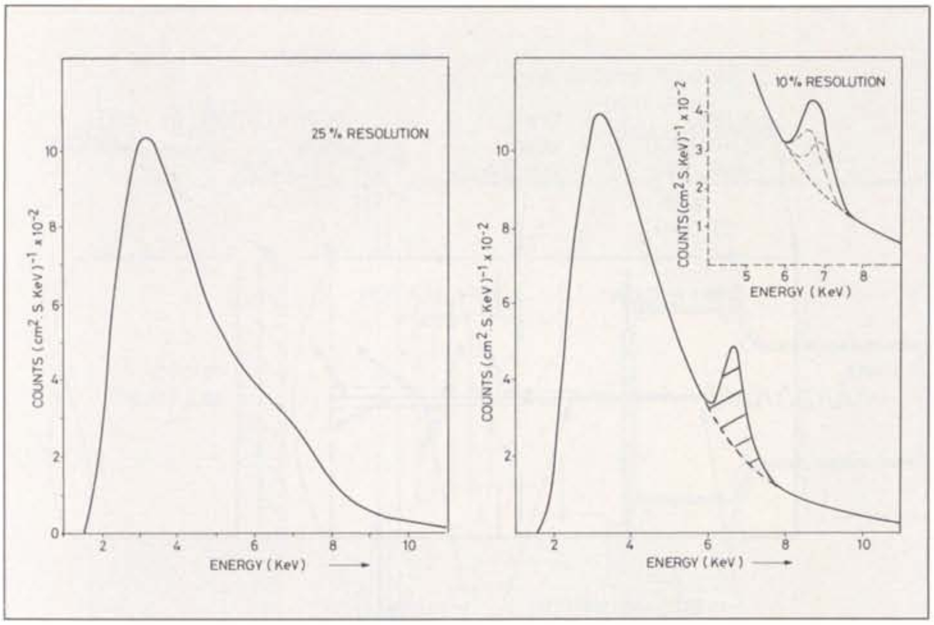
The majority of X-ray astronomy spacecraft missions flown in the 1970s – starting with Uhuru and progressing through Ariel-V, ANS, OSO-8, SAS-3, HEAO-1, the Einstein Observatory (HEAO-2) and Ariel-VI – have tended to concentrate on the detection and identification of X-ray sources to lower limiting sensitivities and the detection and study of the temporal behaviour of the sources. However, largely as a result of the limited performance of the instrumentation employed, data revealing details of spectral features, such as emission lines and absorption edges, are scarce. Thus while much is known about various classes of X-ray sources, e.g. compact objects in binary systems, supernova remnants, Seyferts, quasars and clusters of galaxies, and in particular about their structure, spatial distribution and time-varying characteristics, very little is known of their physics and chemistry as can be revealed by spectroscopic examination.

X-rays with energies greater than 1 kilo electron volt (keV), corresponding to a wavelength of approximately 10 Å, are emitted as 'thermal' radiation from plasmas at temperatures from 10^6–10^8 °C. At such temperatures the atoms of the lighter elements are completely stripped of all their electrons, but the heavier atoms still retain the inner one or two electrons. The hydrogen- and helium-like electron transitions in these atoms give rise to characteristic emission lines at 1.8–2.4 keV for silicon, 2.4–3.1 keV for sulphur, 3.1–4.0 keV for argon, 3.9–5.9 keV for calcium, 6.7–8.3 keV for iron and 7.8–9.6 keV for nickel; these atomic species likely being the most abundant. Additionally, fluorescent characteristic lines and absorption features may also be expected in the spectra of X-ray sources. The emission lines, while being intrinsically very narrow, may be broadened in reality due to electron scattering and through rotational and gravitational effects in the sources. These discrete spectral features due to the heavy elements will be superimposed on an underlying continuum spectrum from the X-ray source.

The relatively crude instruments on Ariel-V and OSO-8 gave the first evidence of spectral features, attributed to iron at about 7 keV, while silicon, sulphur and argon features have been detected by the high-spectral-resolution instruments of the Einstein Observatory. It might be noted that 'nonthermal' spectral features include cyclotron emission, as observed in HER X-1 at about 60 keV, and perhaps cyclotron absorption, as observed in 4U0115+63, and in X-ray bursts from a number of sources. To measure such broadened emission lines and absorption features and thereby determine line widths, plasma temperatures, ionisation state and elemental abundances, a large-area detector with high efficiency, good energy resolution and broad energy bandwidth is therefore required. Current instrumentation fails on one or more criteria; for example, the gas proportional counter as flown on most earlier X-ray astronomy missions has insufficient energy resolution, the solid-state detector is available only with relatively small areas, and the Bragg crystal spectrometer lacks

Figure 1 — Computer simulation of the spectrum of Cygnus X-3 with a narrow line feature due to an Fe^{+24} resonance line at 6.7 keV as would be observed by a conventional proportional counter (left) and a gas scintillation proportional counter (right). The hatched area is the 'residual' spectrum (see also Fig. 9)

Figure 2 — Development models of the GSPC as produced in ESA's Space Science Department (time runs from left to right)



energy bandwidth and, as presently available, sensitivity.

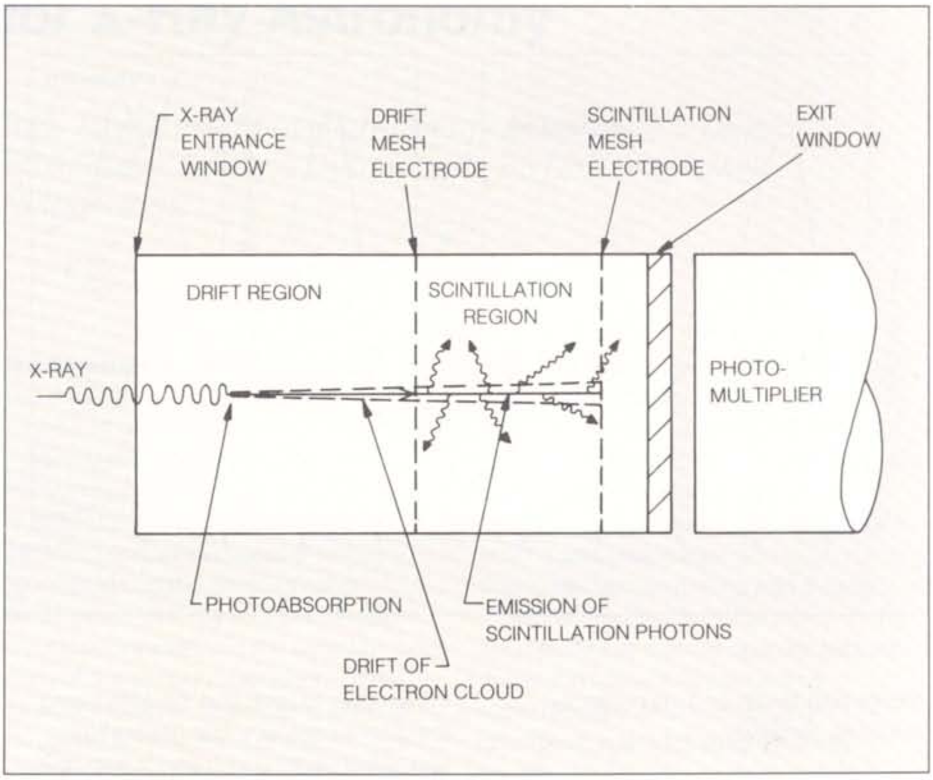
In the early 1970s A.J.L.P. Policarpo and his colleagues at the University of Coimbra, Portugal published a number of papers reporting laboratory measurements of scintillation light generated by electrons accelerated down an electric field and showing that this process could yield the energy of X-rays with a resolution limited only by the statistics of the photo-absorption process. Spurred on by these findings, a number of research groups started work on the development of the Gas Scintillation Proportional Counter (GSPC) for application in X-ray astronomy.

The resolving power of the GSPC compared with the conventional gas proportional counter is amply demonstrated in Figure 1, which shows a computer simulation of an X-ray source spectrum, featuring a narrow emission line superimposed on a thermal Bremsstrahlung spectrum. The energy resolutions (FWHM) at 6 keV have been taken as 25% and 10% for the gas proportional counter and GSPC, respectively, the 25% being typical of those flown to date and the 10% being the goal we set for a first-generation, space-flightworthy instrument. Figure 2 shows a number of GSPCs developed by ESA's Space Science Department (SSD) which led to the realisation of the goal, and the instrument flown on an Aries rocket in September 1980.

The gas scintillation process

The gas scintillation process and operation of a GSPC can be best described with reference to Figure 3, which shows schematically a linear-field, planar-geometry gas scintillation proportional counter. X-rays enter the noble-gas volume through a thin, low-absorbing window and are photo-electrically absorbed in the gas in a region of relatively low electric field. The cloud of electrons thus formed drifts under the influence of this field through the mesh electrode, which defines the field strength in the drift region, into a region of relatively high electric field. The electron cloud is thus accelerated and the electrons gain sufficient kinetic energy to excite the noble-gas atoms, i.e. to raise an atomic electron to a higher energy level. The excited atom then forms an excited molecule through collisions with other atoms. After a short time, the excited molecule returns to the ground state with the production of a photon which is emitted in a random direction. A single electron in the original cloud can thus be responsible for the production of many such photons. It should be noted that the electric field in the scintillation region is kept below that value at which the electrons in the cloud can generate more electrons through ionisation collisions due to their acquiring too much kinetic energy. A photomultiplier observing the scintillation region will deliver a burst of signals, the burst having a length

Figure 3 — Schematic of the gas scintillation process and GSPC operation



corresponding to the transit time of the electron cloud across the scintillation region.

Comparative measurements undertaken in SSD showed that the scintillation light spectrum from xenon was akin to that of the radio-frequency-excited spectrum, i.e. a continuum-type spectrum concentrated between 1500 and 2000 Å in the ultraviolet. Other noble gases would be expected to have their scintillation light spectrum centred on even shorter wavelengths and thereby not readily directly observable with photomultiplier tubes. On the other hand, xenon with its atomic number of 54 has the best stopping power for X-rays, and hence detection efficiency, for a given volume of all the practical noble gases.

The energy resolution of the GSPC for a photon energy of E_x can be expressed as

$$\% \text{ Res} = 236\,(Fe/E_x + 1/KA)^{0.5}$$

where F is the Fano factor, e is the energy to produce an ion pair (0.17 and 21.9 eV, respectively, for xenon), A is the mean amplitude of the integral of the photomultiplier output signal, being proportional to the number of scintillation photons detected, and K a constant associated with the signal-processing electronics. The term $236\,(Fe/E_x)^{0.5}$, referred to as the intrinsic electron resolution, is determined only by the photo-absorption process.

Measurements undertaken in SSD have shown that in the case of a practical GSPC the photo-absorption of an X-ray at 5.9 keV (from an Fe^{55} calibration standard) will result in the liberation of some 10^5 ultraviolet photons with good light collection efficiency. The dominating term in the energy resolution equation is therefore the intrinsic electron resolution, which at 5.9 keV is approximately 6% FWHM.

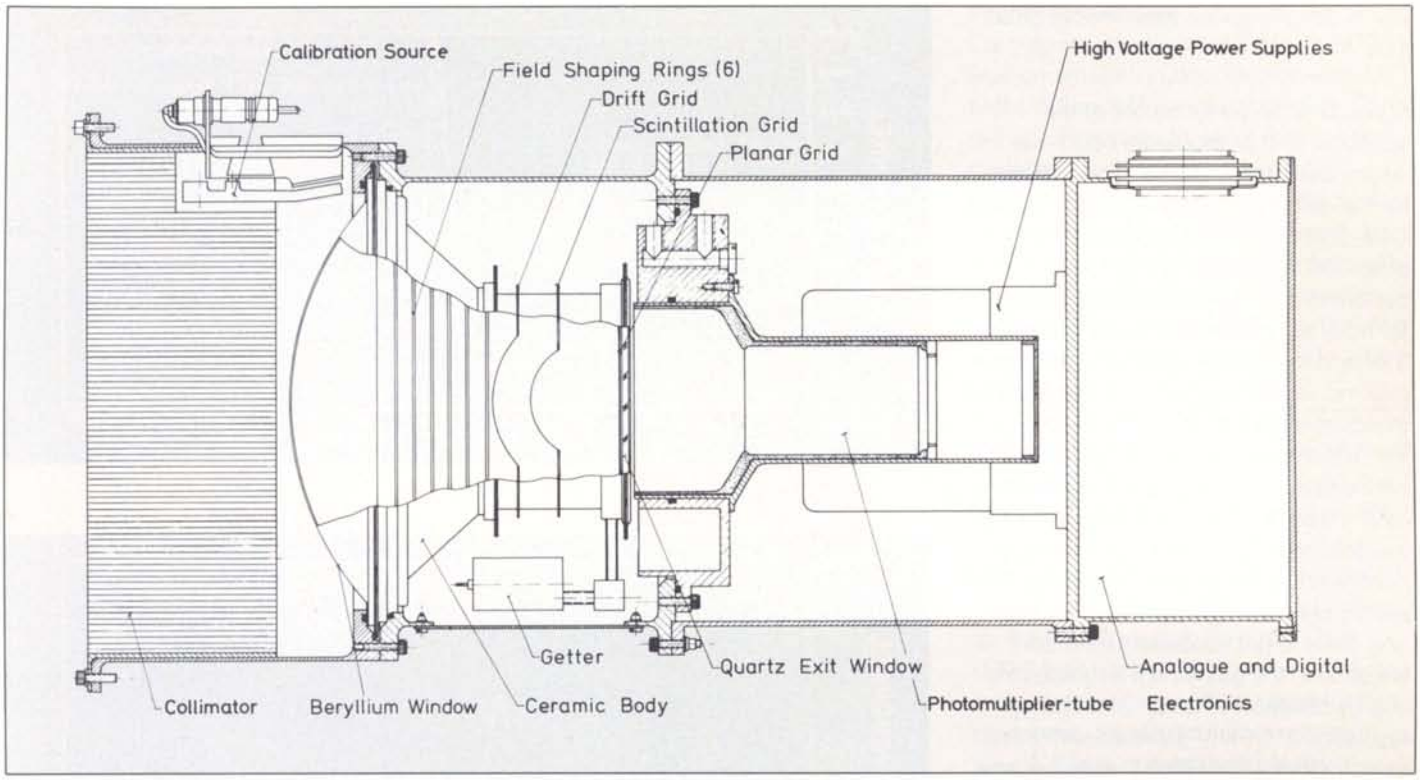
Practical considerations

Because on the one hand it would yield significantly new scientific results through its better energy resolution, yet on the other it was an untried instrument, it was decided that the first-generation flight instrument was to: (i) make only modest demands on mass and power resources, (ii) be of simple design, and (iii) have demonstrated long life.

The simple planar-geometry cell of Figure 1 has two drawbacks; firstly it implies that the effective area for X-ray absorption is equal to the area of the photomultiplier, and secondly, but most importantly, the amount of light collected by the photomultiplier is dependent on the lateral position of the X-ray absorption. The latter results in a poor total energy resolution when the response is integrated over the full area. These drawbacks were overcome in the development of the spherical-geometry detector (Fig. 4) which ensures that the solid angle subtended from any point in the scintillation region to the photomultiplier is largely independent of lateral position. A commercially available, ruggedised, 90 mm diameter, flight-proven photomultiplier was selected and since it had been shown that no electrons in the cloud would be lost when drifted through 10 cm of pure xenon at one atmosphere under moderate field strengths, the other major dimensions of the detector could be determined. In particular a 20 cm diameter, spherical-section, entrance window was defined which yields a useful detector area in excess of 300 cm^2.

As noted earlier, the scintillation light is emitted below 2000 Å. The majority of the work of A.J.P.L. Policarpo and others was done using low-efficiency wavelength shifters and standard phototubes. However, by utilising spectrosil (quartz) both in the exit window of the GSPC and for the photocathode window, little of the ultraviolet light would be lost and possible ageing or contamination effects due to the wavelength shifter could be avoided. The photomultiplier must of course have a photocathode with adequate quantum efficiency in the ultraviolet.

Figure 4 – Schematic of the spherical-field GSPC and associated units as flown on the Aries rocket



To avoid electrons being lost before reaching the scintillation region, the xenon gas must be of the highest purity, free from electro-negative impurities (e.g. oxygen), and must remain pure unless gas-supply systems (violating resource and simplicity constraints) are to be added. Such high purity is maintained by the construction of the GSPC to ultra-high-vacuum standards. Only metals and ceramics are used and only welding or brazing techniques are employed, thus allowing high-temperature (350°C) bake-out prior to filling. As an added precaution, the GSPC may be equipped with a getter pump that can be reactivated using modest power if and when required.

To preserve the spherical field geometry, the X-ray entrance window is a spherical section of beryllium and to improve the definition of the spherical electric field in the drift region and to provide some flexibility for performance optimisation, the conical section of the detector body is equipped with six metallic field-shaping rings. Beryllium is the only viable material at these low X-ray energies which will, due to its low atomic number, transmit the bulk of the X-rays, yet be of sufficient strength in such a thin section (450 μm) for the unsupported window to withstand at least a two-atmosphere differential pressure and be leak-tight to the degree required.

It is natural that this beryllium window and other external metallic structural parts of the gas cell should be maintained at zero (spacecraft) potential and that only the drift and scintillation grids within the cell are raised to high, positive potential. However, it is also conventional practice for there to be no electric field across the window of the photomultiplier tube and to run the photocathode at zero potentials. This then imposes the introduction of a planar grid at zero potential on the exit window of the gas cell and hence the introduction of a 'dead space' between the scintillation grid and exit window. As will be seen, this dead space makes for the largest contribution to the degradation in energy resolution from the intrinsic electron resolution to that finally realised.

Figure 4 also indicates in schematic form the structural arrangement of the GSPC as configured for the Aries rocket flight. Specific points to note are the collimator, which defines the field of view of the instrument mechanically, the in-flight calibration X-ray source, and the arrangement of the high-voltage power supplies and the signal-processing and data-handling electronics.

Performance parameters
Three performance parameters of the instrument have to be optimised to achieve the scientific goals: the energy resolution, so that the spectral features of the cosmic X-ray sources can be revealed; the time resolution of the burst of UV photons, so that background events can be rejected; and the transit time of the electron cloud through the drift region,

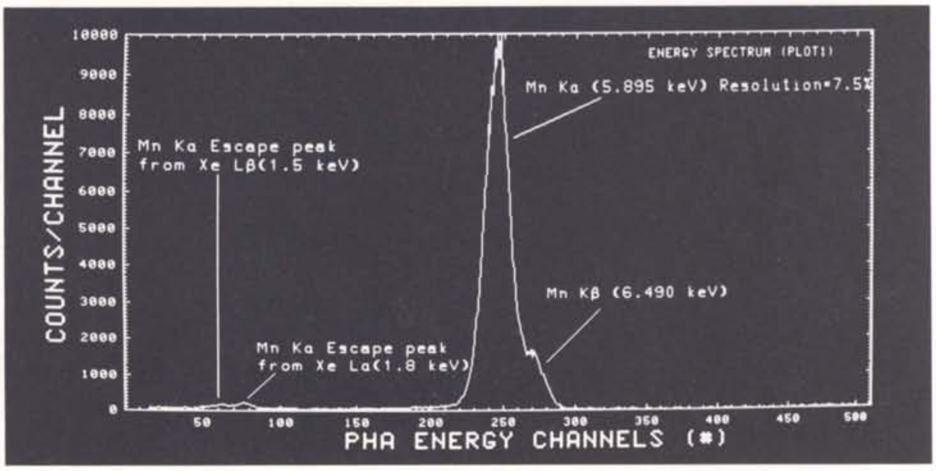


Figure 5 — Energy spectrum of an ^{55}Fe calibration source obtained with the GSPC with the manganese k_α and k_β lines resolved. The energy resolution at Mn k_α is 7.5% FWHM

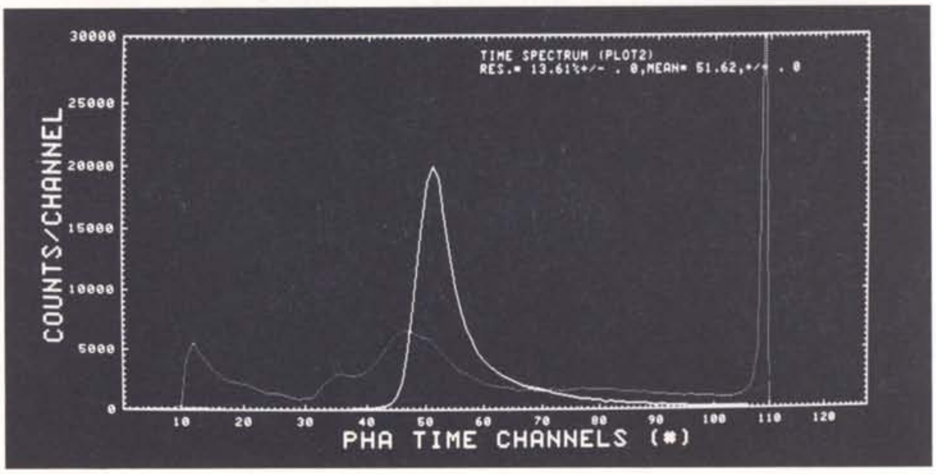


Figure 6 — The UV photon burst-time spectrum (central peak at channel 52) of ^{55}Fe source X-rays at 6 keV superimposed on the time spectrum due to ^{60}Co gamma-ray-induced background events, indicating how time discrimination can be used to suppress background

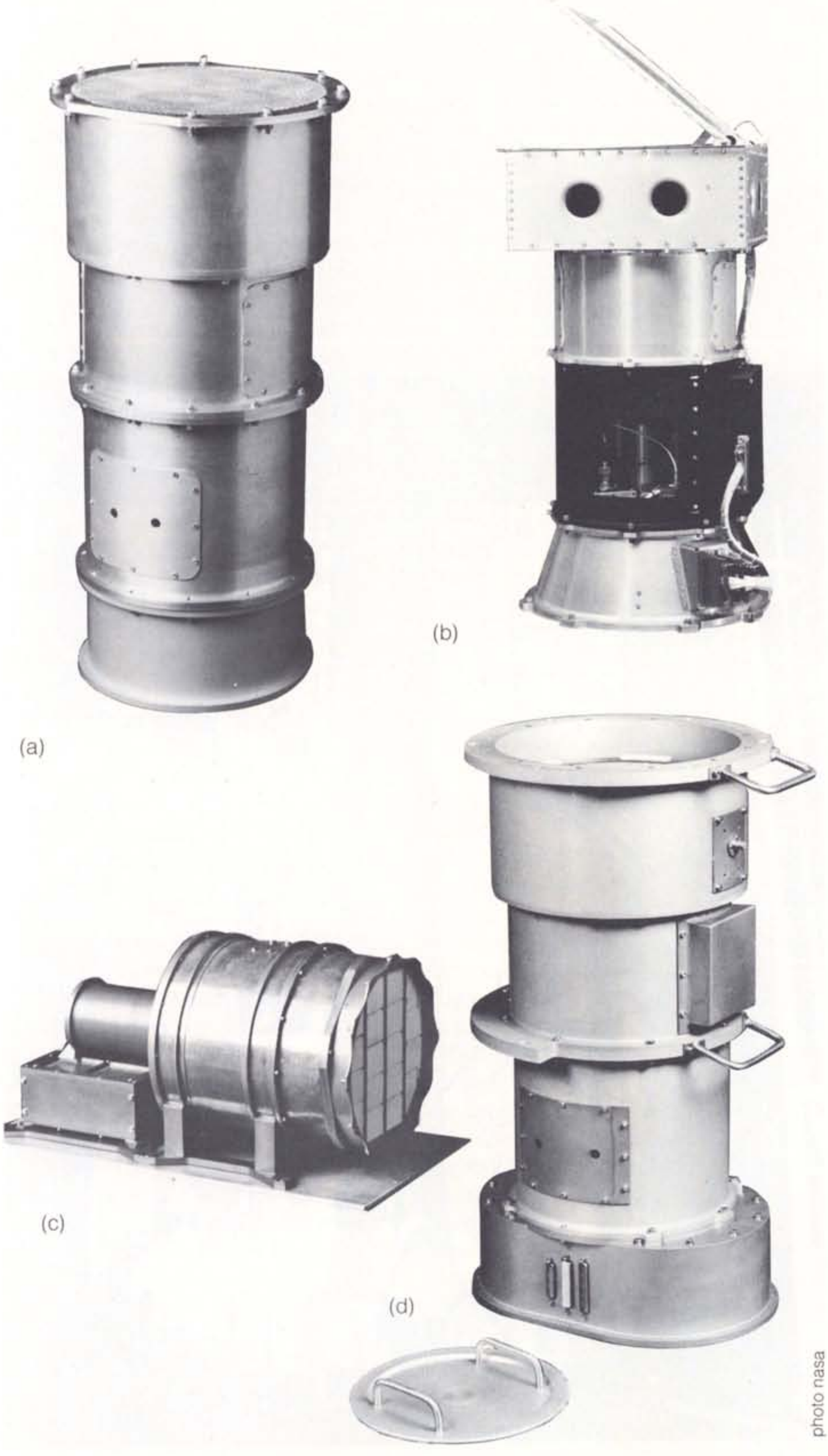
which determines the instrument's dead time.

In practice, the performance of the spherical-field proportional counter is largely determined by the values chosen for the drift and scintillation region electric fields and the field-shaping ring potentials. It was found that the performance parameters are optimised for potential differences of approximately 3 kV and 8 kV for the drift and scintillation regions, respectively. While a drift potential in excess of 3 kV would reduce the electron transit time (about 80 μs) and hence dead time, some scintillation 'early light' will be produced in the back part of the drift region (remember that the field is nonlinear). While a scintillation potential in excess of 8 kV would produce more light, one starts to get secondary electron emission in the gas, which degrades the energy resolution. The on-axis energy resolution at 5.9 keV achieved with this detector was 9.7% FWHM, while the time resolution was 11% FWHM with a mean burst time of 4.6 μs. The integral energy resolution and time resolution achieved over the full aperture were 11% and 14% FWHM, respectively.

The study of weak cosmic X-ray sources is hampered by the general cosmic-ray background which, in interacting with the material of the instrument or satellite, produces gamma radiation. This interacts with the detector walls to produce Compton electrons in the gas with a broad energy distribution. Of course the cosmic rays and locally produced energetic secondaries can also traverse the detector volume, depositing energy through ionisation of the gas. These sources of background can be simulated in the laboratory using a ^{60}Co gamma-ray source and cosmic-ray muons. Background rejection in the spherical-field GSPC described here is achieved firstly by vetoing all events that deposit energy outside the range of interest and secondly by burst-length discrimination. An energetic electron or cosmic ray traversing the drift space will leave an extended track of ionisation compared with the localised cloud of electrons for an X-ray absorption, and thus the duration of the ultraviolet scintillation burst will in general be longer. If the background event occurs in the scintillation region or end-space volume, the burst will generally be shorter. Thus the narrower the burst-length resolution for X-rays, the greater will be the amount of background rejected. On the basis of a ^{60}Co stimulation, 97% of background events in the region of interest from 1 to 10 keV can be rejected.

The best energy-resolution performance of a GSPC achieved with a development model (centre foreground in Fig. 2) is illustrated in Figure 5. A figure of 7.5% FWHM at 5.895 keV was achieved with the k_α and k_β lines of manganese clearly separated. In this model the dead space between scintillation grid and exit window was eliminated and the entrance window run at negative potential. Such a configuration maximises light collection by the photomultiplier and eliminates the concurrent production of scintillation light (and perhaps secondary electrons) in the dead space by photoelectrons ejected from the exit window and surroundings by the flood of primary scintillation light, whose photon energy, typically 8 eV, is well above that required for surface photoemission. An example of the burst-time spectrum for 6 keV X-rays compared with a typical ^{60}Co time spectrum is given in Figure 6.

Figure 7 — GSPC flight hardware for:
(a) Aries
(b) First Spacelab Payload
(c) Exosat
(d) Sirene



(a) (b) (c) (d)

photo nasa

Flight programmes

Early development of the GSPC in SSD was undertaken in cooperation with the Mullard Space Science Laboratory (MSSL), Holmbury St. Mary (UK), and through this cooperation two GSPC detectors of the type shown in Figure 4 were to be flown on an Aries sounding rocket (the NASA version of the second-stage Minuteman ICBM) as a scientific and technical proving flight. The decision to embark on this programme was taken in 1976, but due to the extended development time scale of the cosmic X-ray imaging-telescope main experiment (from MSSL and Lockheed groups), the flight took place only in September 1980.

Proposals, submitted jointly with MSSL and LFCTR groups at Milan and Palermo, for the First Spacelab Payload FSLP (1976) and Exosat (1977) were successful. Instruments for these flight opportunities have been developed in the meantime (Fig. 7). It was anticipated that the Spacelab experiment would be flown before Exosat so that the extended operation of FSLP with its several hours of dedicated GSPC operating time would provide valuable feedback to the Exosat instrument development and orbital operations. It is likely, however, that this flight sequence will be reversed, which makes the Aries rocket-flight data all the more valuable. Nevertheless the virtue of the FSLP flight is that its low orbit, compared with the highly eccentric orbit of Exosat, will provide a lower background environment, making the Spacelab experiment more sensitive for the study of weaker sources. The Sirene experiment, including hardware similar to the Aries version of the GSPC, is being prepared in collaboration with groups at CESR Toulouse and IKI Moscow for flight in 1982. The major scientific differences between the Aries instrument and those that follow are the use of free-standing 175 μm beryllium windows (cf. 450 μm) which will provide sensitivity to spectral features down to 2 keV and the admixture of helium to the xenon to lower the electron-cloud transit time from a maximum of 80 μs to 40 μs, to reduce the instrument dead time by a factor of two.

The Aries flight took place on 20 September 1980 from the White Sands Missile Range in New Mexico (Fig. 8). During the 470 s of flight above 100 km, the payload was pointed to the Crab Nebula (100 s), the supernova remnant Cas-A (210 s) (being the principal target for the GSPC) and the black-hole candidate Cygnus X-1 (50 s). The in-flight radioactive source was used during the slew manoeuvres between targets to provide contemporary calibration data.

Preliminary analysis of the observation of Cas-A has resulted in the production of the count spectrum shown in Figure 9. The energy range of interest has been limited to 5.5–11 keV, the data from the two detectors added, and the continuum spectrum from the source and background subtracted so as to yield the residual spectrum due to the iron emission. The first peak at about 6.7 keV is attributed to the $1s^2$–$1s2p\ ^1P$ transition in Fe^{+24} (helium-like k_α transition) while the second, at about 8.0 keV, is attributed to the $1s^2$–$1s3p\ ^1P$ Fe^{+24} transition (helium-like k_β). The one-sigma error bars indicate the quality of the statistics of the 210 s observation. This signal measurement gives a clear demonstration of the resolving power of the GSPC instrument compared with conventional proportional counters.

Further developments

It has been demonstrated that the spherical-field GSPC shown in Figure 4 can be pressurised safely to 5 atm and thus the effective energy range of the device extended to about 100 keV. A major advantage of working at higher pressure is that the diffusion of the electron cloud in the drift region is reduced, which makes for a narrower burst-length spectrum, which in turn improves the background-rejection efficiency.

At X-ray energies above the k_α absorption edge in xenon at 34.6 keV, photo-absorption of the input X-ray takes place largely with the emission of fluorescent photons having a characteristic energy. At high pressure there is a high probability that this 'escaping' photon can also be photo-absorbed at a different place in the detector volume. The detection of such a double event, one having the characteristic energy, results in a vast improvement in background rejection as the background is hard pressed to simulate such double events. Furthermore since the energy of one of the photo-absorptions is known exactly from the physics, the net energy resolution for the double event is thus significantly better than for a single absorption. At about 60 keV, the energy of the cyclotron emission feature detected in Her X-1, a GSPC employing 'fluorescent gating' should achieve a background rejection efficiency of 99% and an energy resolution of 2.5% FWHM.

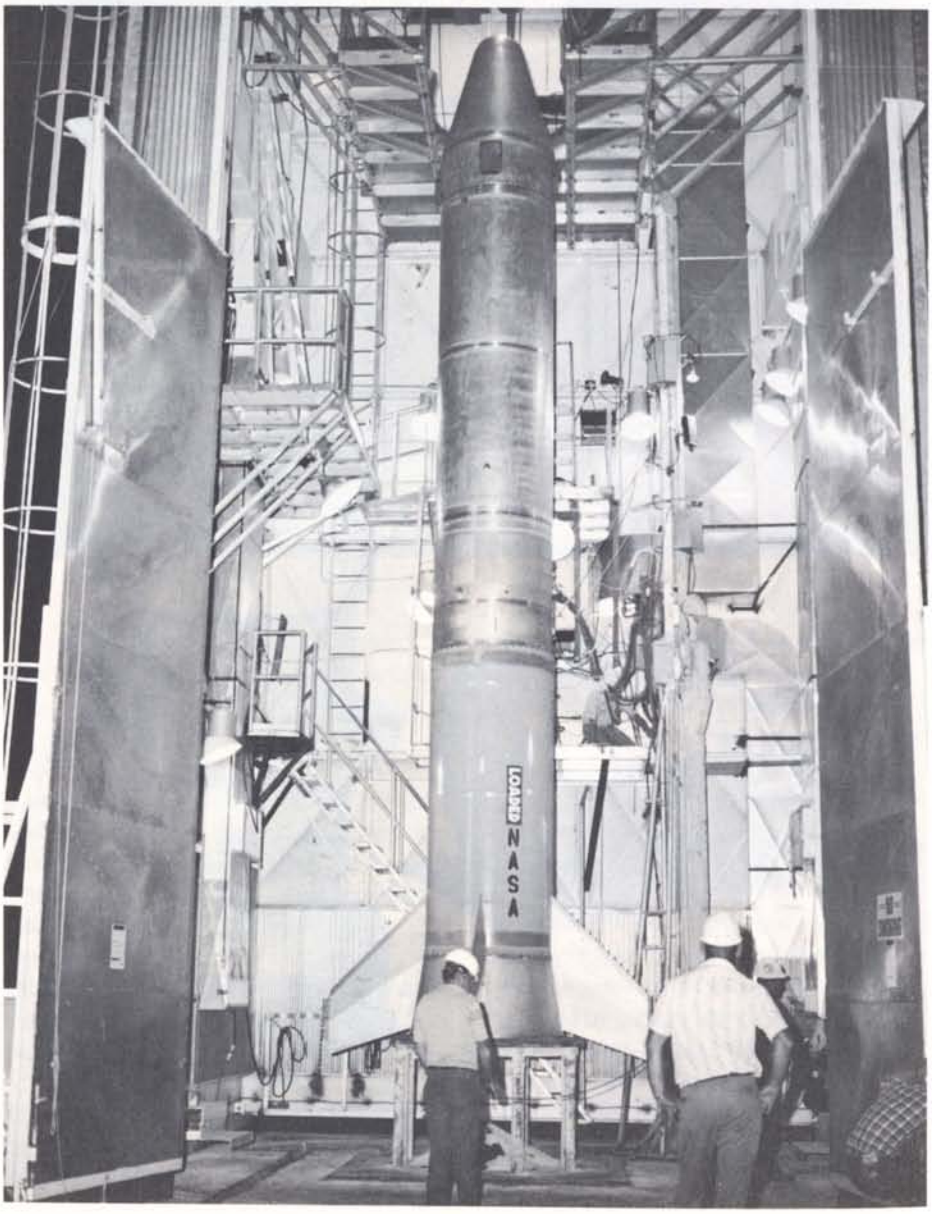
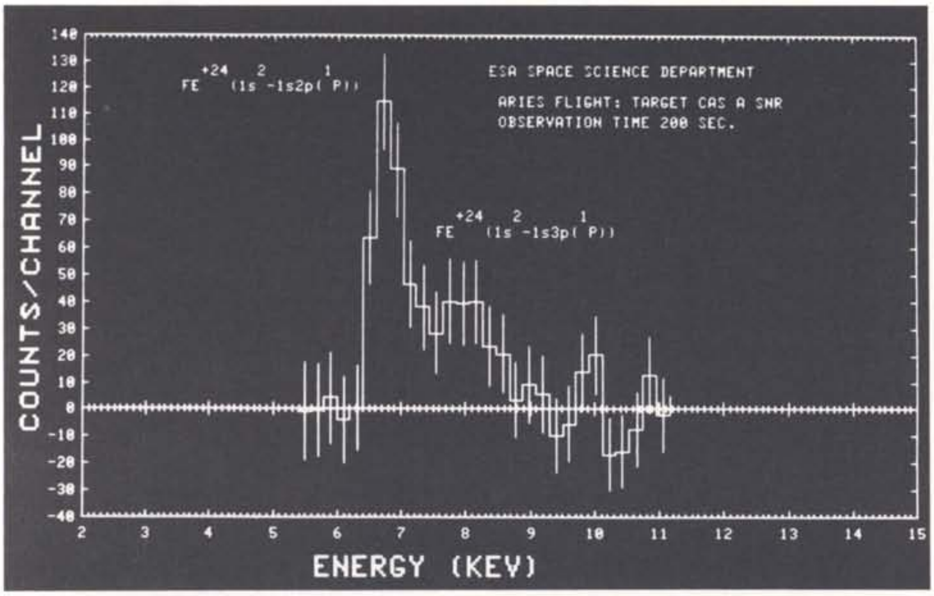


Figure 8 — Preparation for the Aries rocket launch on 20 September 1980 with the vehicle on the launch pad, umbilicals connected, just prior to gantry removal

Figure 9 — Preliminary pulse-height spectrum of Cas-A as seen for 210 s by the two detectors on the Aries rocket flight. Continuum and background have been subtracted to yield the residual spectrum due to iron emission (cf. Fig. 1)

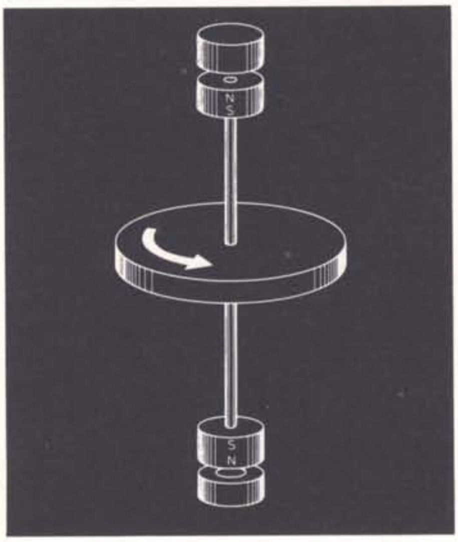


As an instrument for high-energy X-ray astronomy the spherical-field-geometry GSPC provides a diminishing effective area as the energy increases due to the tapering, conical gas volume. This drawback can be overcome by going to a planar geometry with the scintillation region viewed by a number of photomultipliers. From the relative amplitudes of the photomultiplier signals, the lateral position of incident X-rays can be determined, and this knowledge can be used to correct the energy determination derived from the sum of the photomultiplier signals. Determination of the position of the X-ray photo-absorption brings two great advantages: firstly, background events produced by Compton electrons ejected from the detector walls can readily be detected, and secondly, in conjunction with a multiple-pinhole mask situated some distance above the collimator, the detector can produce images of the field under observation to provide high-resolution spectral maps of extended cosmic X-ray sources.

A planar-geometry GSPC is presently under development in SSD which employs nineteen 90 mm photomultipliers and provides for an entrance aperture of 40 cm diameter. Such a device has applications in nuclear medicine as a replacement for the gamma-camera used for taking 'X-rays' in hospitals. The advantage the gas scintillator brings is its high background rejection and high energy resolution, which enable high-contrast, good-definition X-ray images to be obtained with a lower X-ray dose to the patient.

The position-sensitive gas scintillator has a further application in X-ray astronomy in connection with X-ray imaging telescopes, such as are found on the Einstein Observatory and Exosat for the spectral mapping of extended objects like supernova remnants and clusters of galaxies. The upper energy cut-off of the telescope of NASA's planned Advanced X-ray Astrophysics Facility (AXAF) will be at about 10 keV, which means that the emission and absorption features due to heavy elements in high-temperature plasmas described in the first section will be observable through the telescope. A prototype position-sensitive GSPC incorporating seven 2.5 cm diameter photomultipliers and to a scale appropriate to the AXAF optics is under development in SSD. Initial results indicate that the relative improvement in energy resolution over conventional proportional counters of a factor 2 to 3 can be maintained while position resolutions better than 500 μm should be achievable at 6 keV. This position resolution is equivalent to better than 10 arcs angular resolution through the AXAF optics.

Acknowledgements
The achievements described above have resulted from an extensive team effort involving SSD/ESA staff, industrial contractors who supplied various hardware items, and staff from collaborating institutes. As the single author of this paper (unlike most of the subjects emanating from SSD), I am therefore able to record due thanks to my colleagues A. Peacock, A. van Dordrecht, E.-A. Leimann, G. Manzo, J. Davelaar, R.D. Andresen and W. Vleeshhouwer, all of whom have made invaluable contributions to instrument development and the realisation and publication of scientific results. It might be noted that AP, JD, and GM were, or presently are, in receipt of ESA Research Fellowships.



Magnetic Bearings – The Ultimate Means of Support for Moving Parts in Space

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Contactless magnetic bearings rotate without friction, have virtually unlimited life and require no lubrication. These and other unique properties make them ideal for use in spacecraft mechanisms where high precision and reliable operation in vacuum over very long periods of time are prime requirements. This article discusses the types and operating principles of magnetic bearings as used in space. It also gives an idea of some of the hardware developments that are presently underway in this promising new area of technology.

Introduction

Developments in magnetic materials and microelectronics during the past decade have allowed some spectacular advances to be made in the technology of contactless, electromagnetic suspension systems. So-called 'magnetic bearings', which not so long ago were regarded as laboratory curiosities, have now reached the stage of becoming practical and attractive alternatives to conventional bearings for a wide variety of uses. The advantages of magnetic bearings are especially relevant for space applications. They can be summarised as follows:

- total freedom from any kind of lubrication; hence vacuum compatibility
- unlimited lifetime due to the absence of abrasion and wear
- very high reliability through electronic redundancy alone
- no stiction
- very low rotational losses, virtually independent of temperature
- low rotational noise and transmissibility of vibrations
- stiffness properties adjustable electronically
- the supported member can be micropositioned electrically.

These and other features are of particular significance for devices such as momentum and reaction wheels, optical scanning heads, high-speed energy-storage rotors and other spacecraft components.

The rapid evolution in magnetic bearings is due very largely to development work within the European space industry. The intention here is to illustrate some of these developments and, at the same time, to review the basic techniques involved in the practical realisation of magnetic bearings.

Magnetic-bearing types and classification

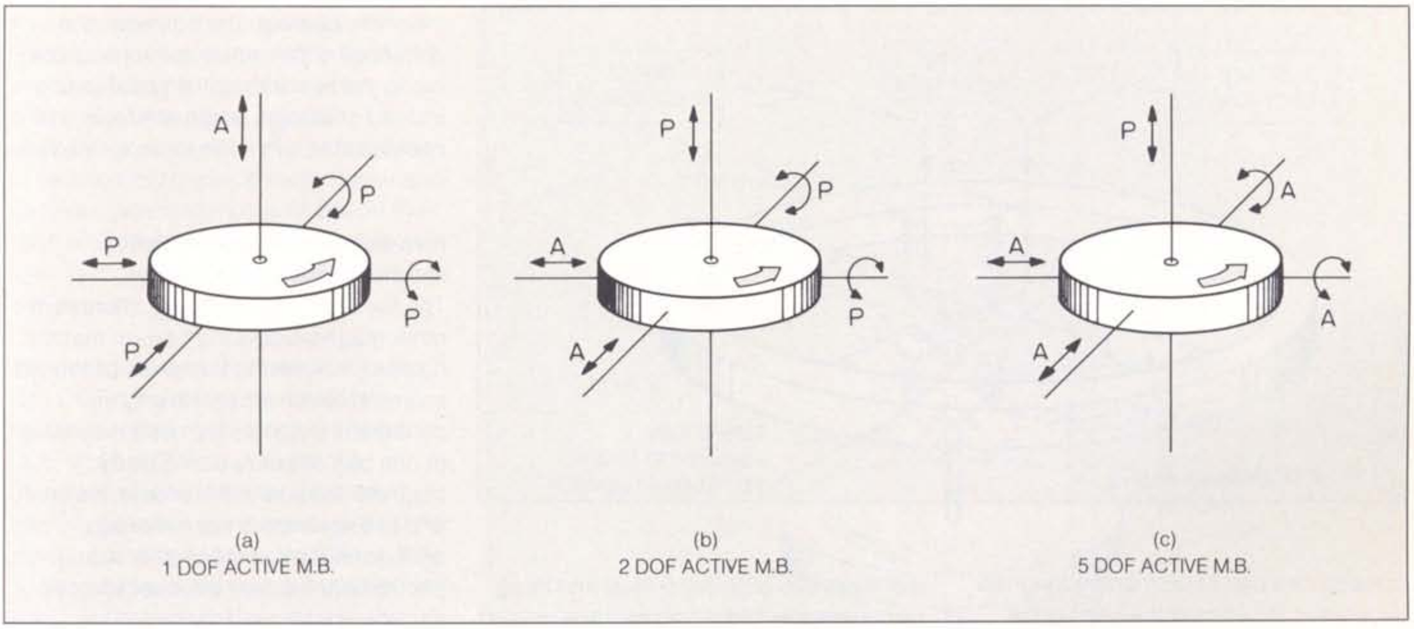
A magnetic bearing is defined as a system of mechanical, electronic and electromechanical elements arranged to produce levitation and positioning of a body by magnetic forces in an entirely contactless manner. The terms 'magnetic bearing' and 'magnetic suspension' are used synonymously.

In the majority of space applications magnetic bearings are used to position a rotor with respect to a stator. Complete positional and orientational control of a body in space requires the control of six degrees of freedom (DOF), i.e. three translations and three rotations. In the case of rotating mechanisms such as momentum wheels, gimbal mounts, optical scanners, etc., one degree of rotational motion is generally controlled by a motor and is not part of the controlling task of the bearing. Any suspension of a rotor and in particular a magnetic-bearing suspension must therefore provide control of five degrees of freedom.

Magnetic bearings are generally classified according to the elements they employ for controlling these five degrees of freedom. A distinction is made between active elements such as electromagnets, the excitations of which are varied electronically as a function of rotor

Figure 1 – Active and passive constraint directions for magnetic suspensions of the one, two and five DOF active types
A = ACTIVE CONSTRAINT
P = PASSIVE CONSTRAINT

Figure 2 – Practical realisation of a one DOF active magnetic bearing



position and velocity, and passive elements such as permanent magnets or electromagnets with fixed excitations. A fundamental theorem governing the design of magnetic bearings states that it is physically impossible to constrain all five degrees of freedom by passive magnetic means alone and active control of at least one degree of freedom is necessary.

It is therefore possible to define the following realisable bearing types:

one DOF active (four DOF passive)
two DOF active (three DOF passive)
three DOF active (two DOF passive)
four DOF active (one DOF passive)
five DOF active (no DOF passive)

Of these, the following three have emerged as the preferred types for space applications from various studies and development work performed to date:
- *the one DOF active magnetic bearing* (Fig. 1a), in which the translational position of the rotor along its rotational axis is the only actively controlled DOF
- *the two DOF active magnetic bearing* (Fig. 1b), in which the two translational degrees of freedom of the rotor orthogonal to the rotation axis are actively controlled
- *the five DOF active magnetic bearing* (Fig. 1c), in which all translational and rotational degrees of freedom (excluding rotor spin) are actively controlled.

These three bearing types, in various geometrical and detailed implementations, have been studied extensively in Europe and several items of space hardware incorporating them have now reached an advanced stage of development.

Bearing constructions and characteristics
The aforementioned classification scheme, although essential for distinguishing purposes, affords little insight into the constructional features of magnetic bearings. The hardware elements involved and how they are combined to form practical units can best be illustrated by some examples.

One-degree-of-freedom active magnetic bearing (Fig. 2)
This type of bearing, in its simplest form,

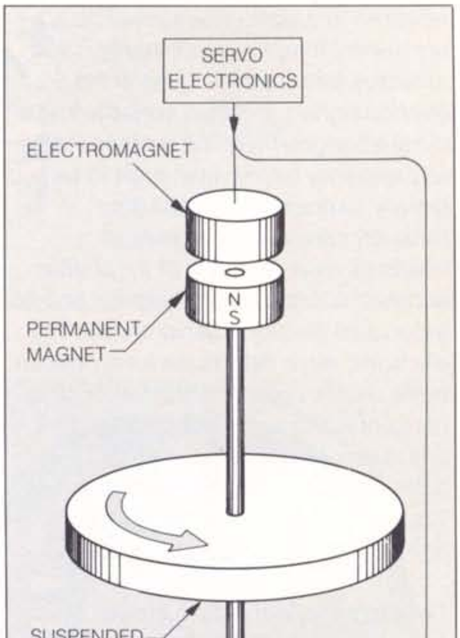
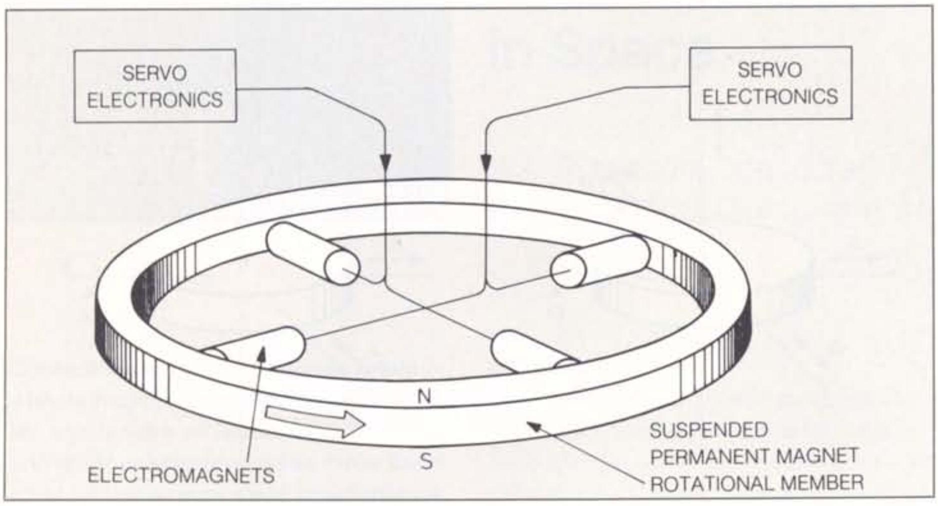


Figure 3 – Practical realisation of a two DOF active magnetic bearing



consists of a pair of permanent magnets situated at the ends of the shaft to be supported, and a pair of adjacently situated iron-cored electromagnets attached to a stationary frame. The permanent magnets exert steady attractive forces on the cores of the electromagnets and thus keep the axis of the shaft aligned with the latter so that any tendency for the shaft ends to be radially displaced is resisted (four passively constrained degrees of freedom). Axial centering of the shaft is achieved with the electromagnets and an associated electronic servo system. The electronic servo detects the axial position of the shaft by optical, inductive or other noncontacting means, and corrects for any displacement from centre by differentially exciting the electromagnets in such a way that the requisite axial restoring force is produced.

Two-degrees-of-freedom active magnetic bearing (Fig. 3)

This type of bearing consists typically of an axially magnetised permanent-magnet ring forming the suspended member, and an assembly of four radially acting electromagnets attached to a frame comprising the fixed member. The steady attractive forces exerted by the permanent-magnet ring on the electromagnet cores tend to bring the planes of the fixed and suspended members into alignment. Axial and tilting displacements of the ring are thus resisted by permanent-magnet forces (three passively constrained degrees of freedom). The ring is centred radially by the electromagnets and associated electronic servos in a way similar to that already described for the one DOF active magnetic bearing. The only essential difference is that active control is applied along the two orthogonal radial axes instead of along a single axial axis, this necessitating two servo loops instead of one.

Five-degrees-of-freedom active magnetic bearing (Fig. 4)

The five DOF active bearing differs from other magnetic-bearing types in that the necessary centering forces are produced entirely by electromagnets and no permanent magnets are used. It consists of one pair of axially acting electro-magnets situated at the ends of the shaft, and two assemblies each with two orthogonally mounted radially acting electromagnets near the shaft ends. All electromagnets are attached to the stationary, nonsuspended part of the bearing and act on ferrous members attached to the suspended shaft. An electronic servo loop is associated with each electromagnet pair. Each servo includes means of detecting

Table 1 – Typical properties of magnetic-bearing types of similar dimensions

		one DOF active magnetic bearing	two DOF active magnetic bearing	five DOF active magnetic bearing
Dimensions (mm):	Length	100	25	100
	Diameter	25	100	25
Load capacity (N):	Axial	150	75	150
	Radial	30	100	100
Compliance (mm/N):	Axial	-4×10^{-3}	8×10^{-3}	4×10^{-3}
	Radial	20×10^{-3}	-6×10^{-3}	5×10^{-3}
Runout (μm):	Axial	5	10	5
	Radial	25	5	5
Rotational drag torque (Nm/1000 rpm)		$\simeq10^{-4}$	$\simeq10^{-3}$	$\simeq5\times10^{-4}$
Mass (kg) (excluding electronics)		$\simeq$0.25	$\simeq$0.60	$\simeq$0.40
Suspension power (W)		0.5	1.0	2.5–12.5 depending on load
Reliability (10 yr)				
– No redundancy		0.970	0.950	0.880
– With single redundant electronics		0.999	0.997	0.985

displacements of the suspended member from its centred position in one degree of freedom. Corrections are made by differentially energising opposite electromagnets of each pair in response to the detected displacements, causing an imbalance in attractive forces on the shaft-mounted ferrous parts in a direction such that centering of the suspended part is restored.

The configurations for three DOF and four DOF active bearings are rather similar, respectively, to those of the two DOF and five DOF active versions discussed above. However, as these bearing types have undergone almost no development for space applications, their constructional details will not be dealt with here.

Practical versions of the three 'preferred' bearing types described generally include a number of components in addition to those already discussed. For example, means of damping unwanted vibrational motions must normally be provided and electromechanical elements such as eddy-current dampers are sometimes built into the bearing for this purpose. Also, where the supported load is required to rotate at high speeds it is normal practice to include a system of emergency bearings (e.g. ball bearings) to provide a 'smooth landing' in the event of the suspension electronics being inadvertently disengaged. Drive motors, monitoring devices and other elements may also be incorporated.

Typical physical properties of one DOF, two DOF and five DOF active magnetic bearings of similar basic dimensions and with sizes representative of space applications, are given in Table 1.

Magnetic-bearing developments in Europe

The development of magnetic bearings for space applications is presently being pursued in three of the Agency's Member States (Germany, France and the United Kingdom).

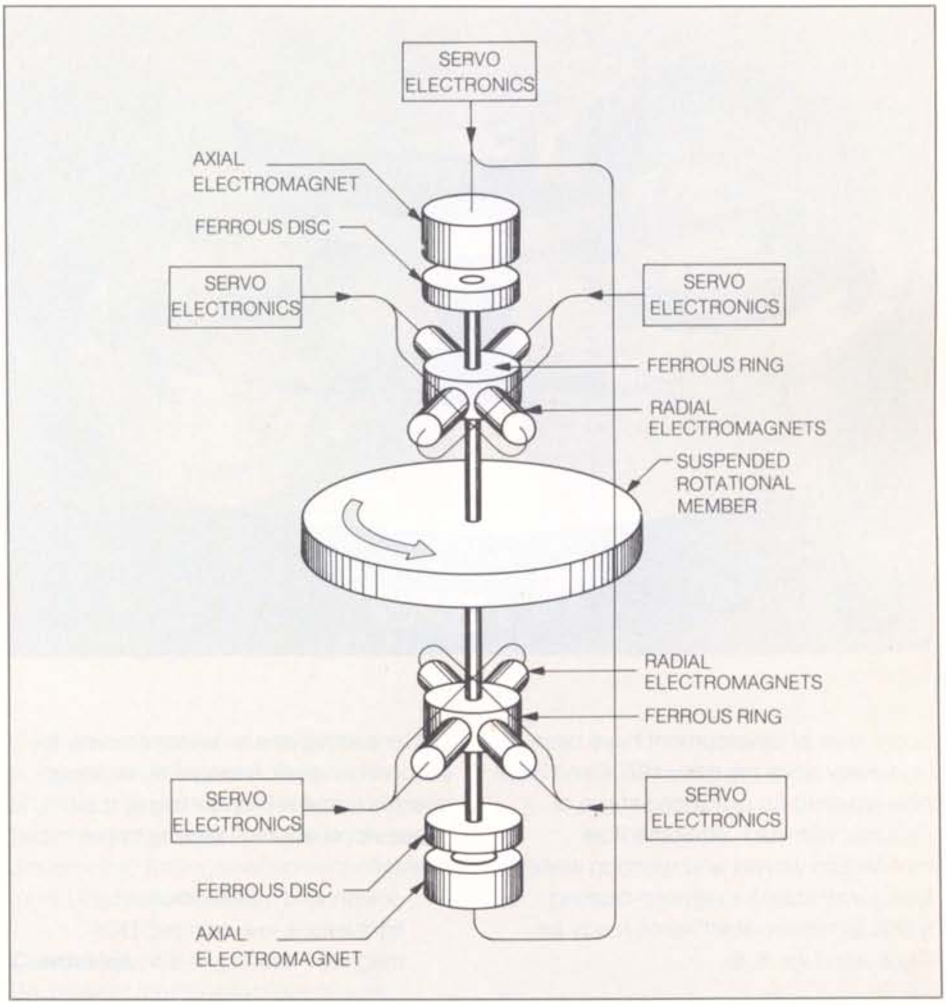


Figure 4 – Practical realisation of a five DOF active magnetic bearing

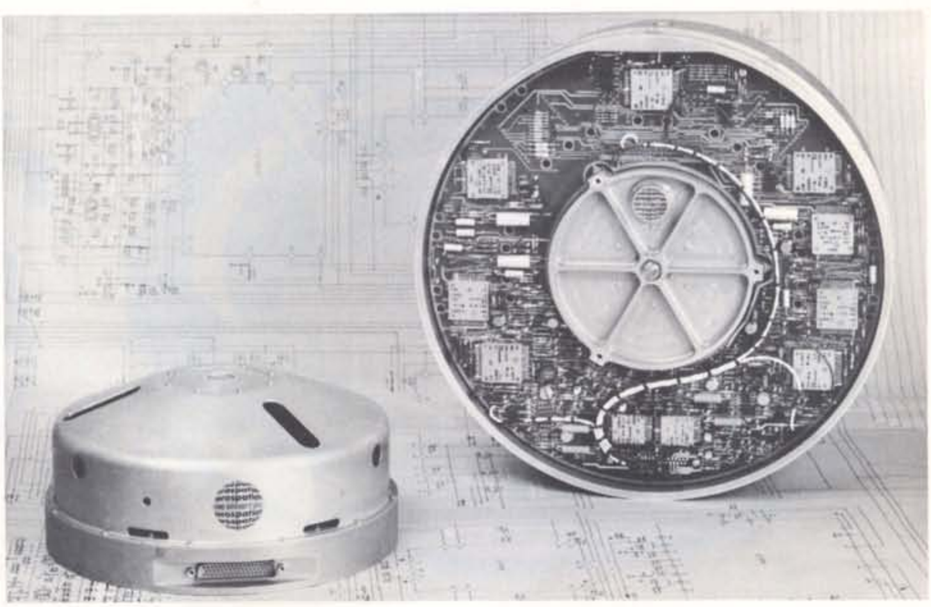
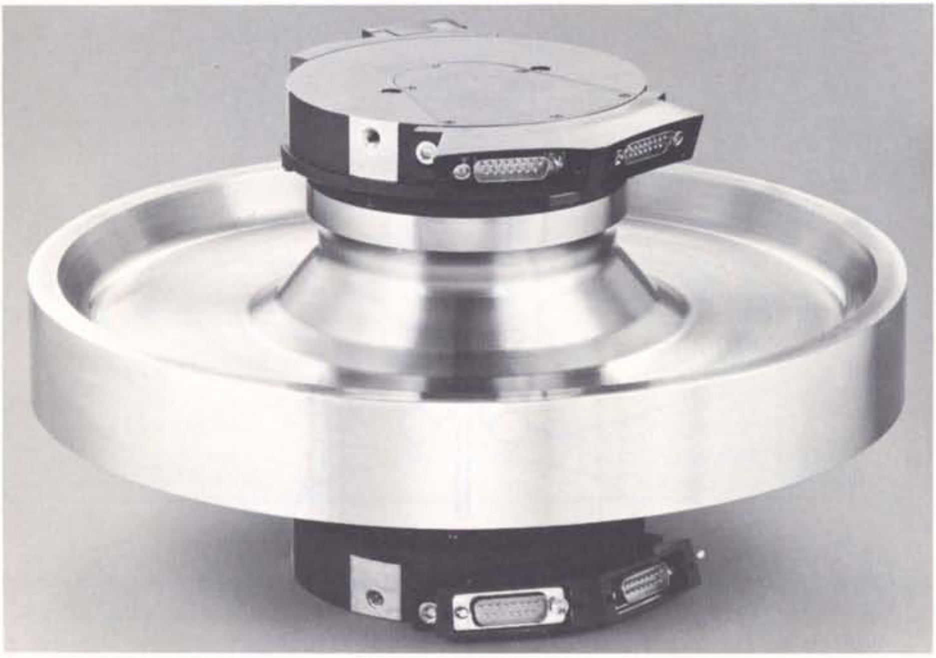


Figure 5 – One DOF active magnetic-bearing reaction and momentum wheels developed by SNIAS (F). Wheels of similar design will be used for stabilisation of the French SPOT satellite

Figure 6 – Momentum wheel with magnetic bearing of the five DOF active type developed jointly by Teldix (D) and SEP (F)

Figure 7 – Prototype annular magnetic bearing of the two DOF active type developed at ESTEC. Further development is being carried out by British Aerospace (UK)



Some lines of development have been underway since the early 1970s and have now reached an advanced stage of maturity, with such equipment as momentum wheels and reaction wheels being available in magnetic-bearing forms as 'off-the-shelf' items ready for flight use (Figs. 5, 6).

Current activities are devoted mainly to second-generation magnetic-bearing designs and the broadening of their space applications. These activities include:

- design and manufacture of a lightweight, low-cost two DOF magnetic bearing of annular form. Applications include momentum and reaction rings, kinetic-energy storage devices and large-bore bearing systems (British Aerospace, UK) (Fig. 7)
- development of a modular family of five DOF magnetic-bearing momentum wheels (Teldix, Germany)
- demonstration of a miniature two DOF magnetic bearing of advanced design for general-purpose space and terrestrial applications (ESTEC activity) (Fig. 8)
- development of a two DOF magnetic-bearing-supported scanning head for use with infrared attitude sensors and small optical instruments (British Aerospace, UK)
- design of a magnetic-bearing-supported scan mechanism for the Ocean-Colour Monitor (OCM) radiometer instrument to be used on the Coastal-Ocean-Monitoring Satellite System (COMSS) (British Aerospace, UK)
- development of high-speed flywheels with one DOF magnetic bearings for kinetic-energy-storage applications (SNIAS, France)
- development of a five DOF magnetic-bearing-supported turbomolecular

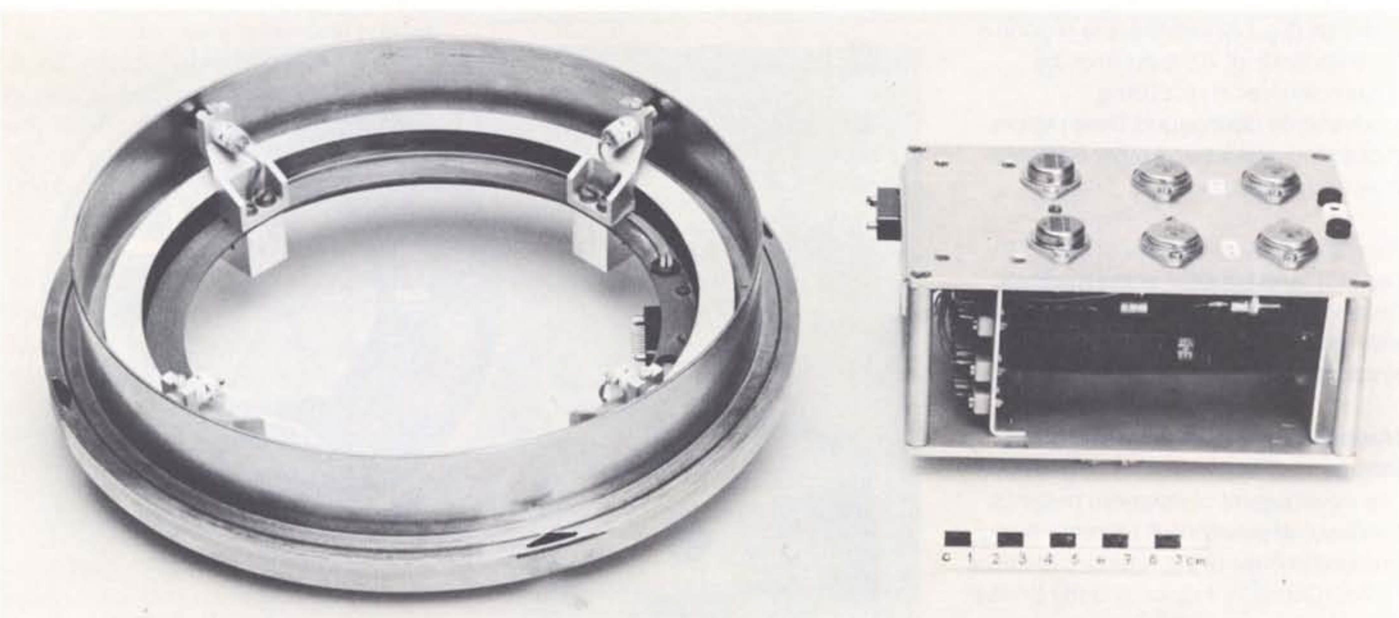
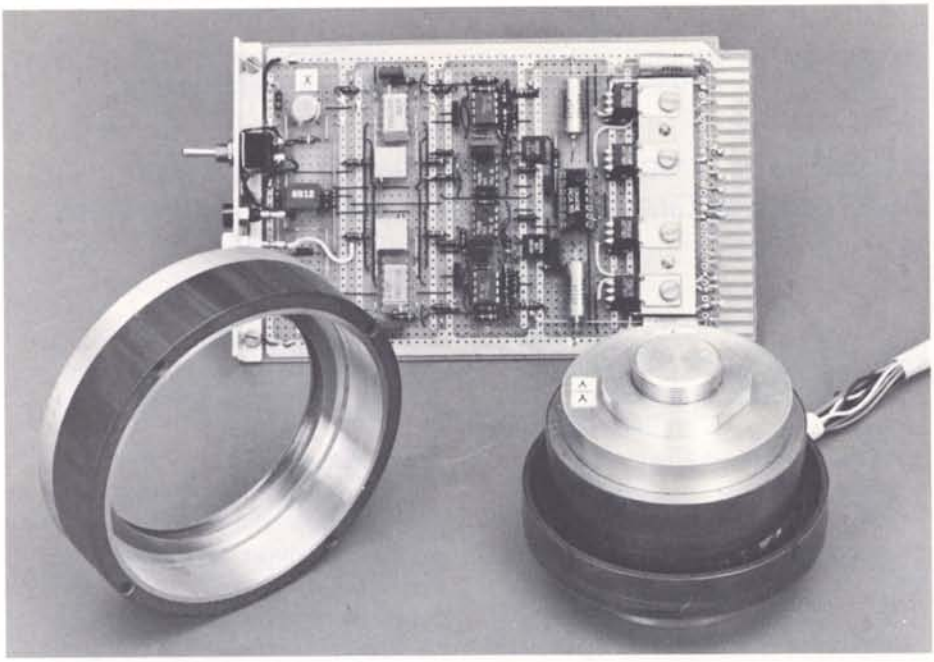


Figure 8 – Small two DOF active magnetic bearing developed at ESTEC for general-purpose space and terrestrial applications

Figure 9 – High-speed turbomolecular pump with magnetic bearings of the five DOF active type, developed by Leybold (D) and SEP (F) for use in the materials-science experiment on Spacelab



pump for use in materials-science experiments on Spacelab (Leybold, Germany and SEP, France) (Fig. 9).

The future

Magnetic bearings can be expected to play an increasingly important role in space applications in the future. They will never, of course, be employed to the same extent as conventional mechanical bearings, but their more widespread use in mechanisms with special performance requirements and/or where higher reliability/confidence levels are sought is only a matter of time.

Typical future application possibilities include such areas as cryogenic cooling systems, inertial instruments, frictionless gimbal supports, materials centrifuges, micropositioning manipulators, kinetic-energy-storage devices, and many others.

So far, most development efforts on magnetic bearings have been carried out in connection with specific components and equipment. As the number of applications tends to grow, it is probable, and indeed essential, that magnetic bearings will become available as 'off-the-shelf' items for more or less general-purpose use. Advanced designs that promise to make this possible are already beginning to emerge and it is on these designs that future development efforts must be concentrated.

Conclusion

Because of their contactless nature, magnetic bearings provide an ideal means of support for moving parts in space. With the trend in technology towards spacecraft with longer mission durations and more ambitious payloads, it is likely that there will be an increasing need for magnetic bearings in space in the future.

Spacecraft Structural Acoustics

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High-frequency mechanical vibrations are induced in spacecraft and their equipment during launch due to the effects of the launch vehicle rocket motor noise and aerodynamic noise transmitted into the payload bay. Acoustic fatigue in the primary spacecraft structure is unlikely even in the case of multi-mission spacecraft of the sort that could be envisaged for use with the Space Shuttle, but the induced vibrations can create problems in service and payload equipment. The acoustic energy accepted by large spacecraft surfaces such as antennas and solar arrays can augment these levels of vibration. The research into structural acoustics being conducted for ESTEC (mainly by British Aerospace Aircraft Group, Bristol, in conjunction with the Institute of Sound and Vibration Research at Southampton University) as part of ESA's Technological Research Programme is aimed at a better understanding of the structural behaviour of spacecraft when subjected to the noise and high-frequency vibrations of the launch environment.

The means for predicting the vibration levels to which spacecraft will be subjected during launch, at an early stage in the design process and for defining subsystem vibration test levels and test requirements, have yet to be fully developed into a readily available design aid.

Zoning of the spacecraft into regions in which vibration levels are likely to be similar is a technique that has already been used in aerospace investigations. Acoustic-fatigue investigations such as those conducted for the Concord programme have demonstrated that it is possible to confine oneself to structural segments rather than the complete structure when conducting experimental investigations or making theoretical predictions.

In the current ESA spacecraft research activities these concepts are being further investigated. The ultimate goals are to provide a better understanding of response behaviour, to reduce the complexity of theoretical models and test configurations, and to evolve improved structural configurations for housing payloads and equipment from the high-frequency vibration viewpoint. This should also lead to more realistic test levels when mechanical vibration tests are used to simulate acoustic-environment effects in the qualification of spacecraft structures and spacecraft equipment*.

Typical noise levels encountered in the Ariane launcher payload bay are presented in Figure 1, while Figure 2 shows examples of typical vibrations induced in spacecraft panels during acoustic qualification testing.

Spacecraft zoning

To explore experimentally the feasibility of zoning a spacecraft, a simplified satellite configuration has been evolved which can be readily broken down into its constituent parts or partial assemblies constructed (Figs. 3, 4). The complete assembly or subassemblies can be examined under acoustic excitation to study the contributions of individual components and their structural-acoustic couplings. The dynamic behaviour of such components can also be investigated. Corresponding theoretical estimations are being made in order to assess the scope and accuracy of the prediction methods currently available.

A reverberant sound field is assumed in both the acoustic testing and theoretical predictions. However, the near-field sound characteristics within a shroud can modify the local structural response and this effect is the subject of additional studies using a simulated shroud enclosure containing the satellite structures. This combination is subjected to reverberant excitation in the acoustic chamber (Fig. 5). The testing is being conducted in the acoustic facility at IABG, Munich.

In order to assess more complex configurations, a similar programme of work is being undertaken using a Marots prototype flight model (Fig. 6), and investigations will shortly begin using a development version of a Spacelab pallet.

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* A more detailed account of aspects of this work will be contained in an article to be published in the June 1981 issue of the ESA Journal.

** A description of the indirect method for establishing modal density and loss factor characteristics is to be published shortly in the Journal of Sound and Vibration (co-authors B.L. Clarkson & R.J. Pope).

Figure 1 – Ariane payload-bay internal noise levels during flight

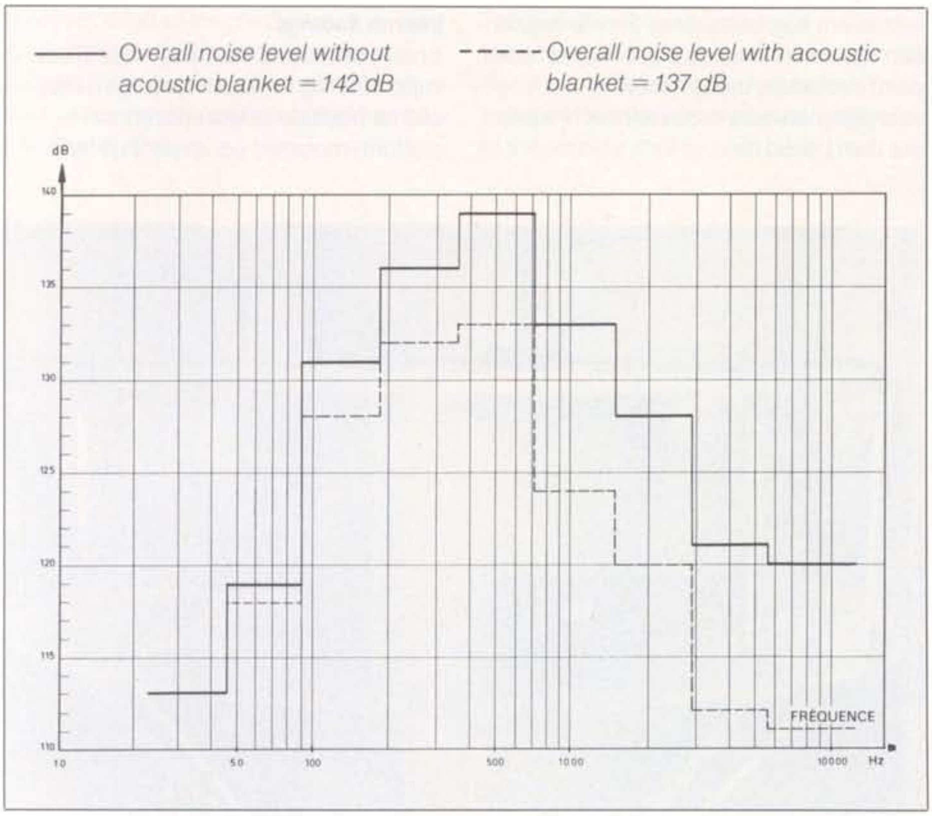
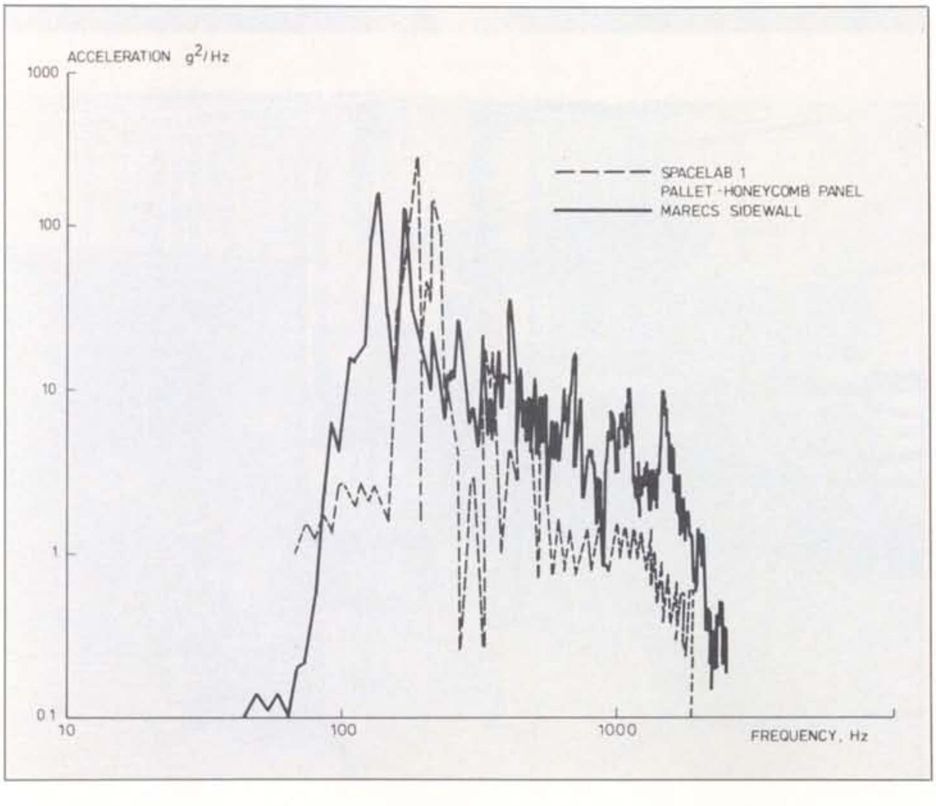


Figure 2 – Typical structural vibrations induced in panels during acoustic qualification testing (narrowband spectral analyses)



Statistical energy analysis

Earlier investigations of high-frequency-vibration predictions, particularly structural resonances at specific frequencies, have used normal-mode vibration analyses or similar techniques. However, over much of the frequency range of interest the number of such modes becomes too high in quite narrow frequency bands (high modal density) for the use of these classical techniques.

This led to the formulation by R.H. Lyon and others of a method known as statistical energy analysis (SEA), which can provide information on average vibration levels in such frequency bandwidths for structural subsystems.

SEA considers the vibratory power flow that occurs between subsystems, such as the random noise field inside a rocket payload shroud and the vibrating spacecraft structure and between the various components of the structure (such as sidewalls and a platform). It is possible to consider a 'power balance' between different subsystems, in the sense that the power received by one subsystem from the others will be equal to the power given to the other subsystems plus that dissipated within the subsystem in question by damping. From such assessments it is possible to obtain a statistical assessment of the typical average response behaviours of the various subsystems.

Initial investigations for ESA, conducted by British Aerospace Dynamics Group (Stevenage), explored the potential of the SEA approach, while the Office National d'Etudes et de Recherches Aérospatiales explored a related statistical approach. It became clear that the analysis could be formalised, and as a result British Aerospace (Aircraft Group, Bristol) have developed a suite of computer programs called GENSTEP which allows the SEA technique to be applied to a wide range of spacecraft structural components, including such items as plain and stiffened thin-walled cylinders, plain and stiffened flat and curved panels, honeycomb panels, beams, and hoops subjected to acoustic excitation.

The GENSTEP computer programs
The program has been developed on a modular basis, which facilitates trouble shooting and the introduction of new features. In a first step, the basic properties of the noise field and the structure under test are introduced. This information is then checked and some basic subsystem properties are calculated. In subsequent steps matrices of modal density, loss factor and coupling loss factor for the subsystems are constructed. Further steps permit the assessment of the power distribution discussed above and calculation of the energies in the individual subsystems.

The final steps allow the responses and sound-transmission characteristics of the various units to be calculated.

The GENSTEP suite of programs is capable of handling twenty linked subsystems.

Work in progress
Much of the current effort is devoted to producing a data bank of information for use with the GENSTEP programs, such as damping values (loss factors) and modal density characteristics, because during the related initial experimental work carried out at ESTEC difficulties were experienced in establishing such parameters.

Means of establishing both the loss factor and modal density indirectly have been developed as a result of theoretical and experimental studies conducted at Southampton University's Institute of Sound and Vibration Research**. Using SEA power-flow concepts, it is possible to demonstrate that both parameters can be derived by measuring the input forces generated by point excitations and considering spatial average response velocity characteristics (Fig. 7). In most of the work, a fast sine sweep (transient excitation) has been used. Similar results can be obtained using stationary random point excitation, though more sophisticated data-reduction techniques are then called for.

Interim findings
It has been found that over most of the important high-frequency range it may well be possible to test spacecraft-platform-mounted equipment using a

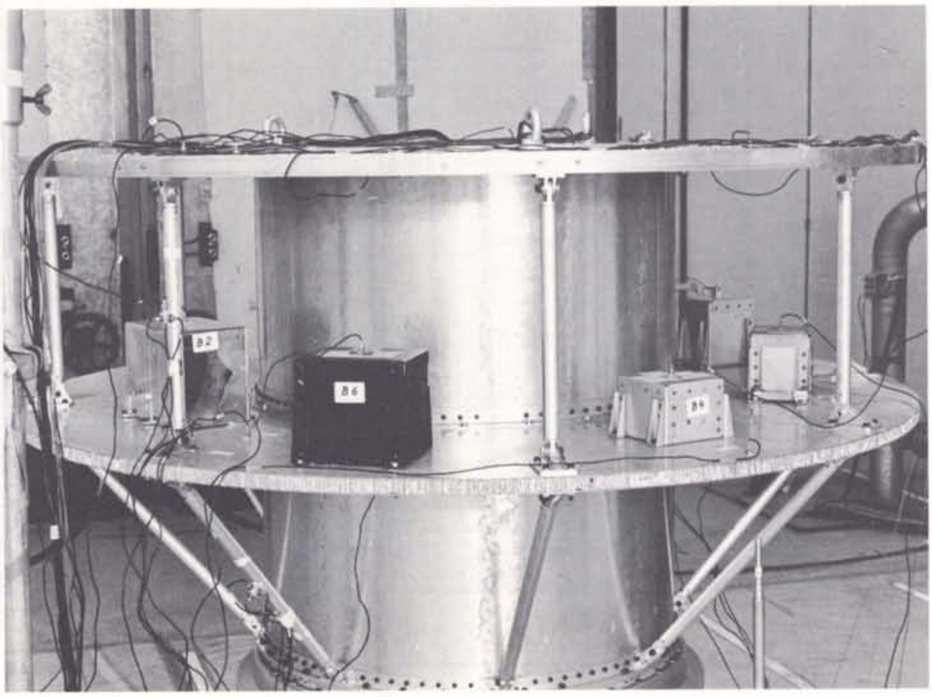


Figure 3 – Simplified satellite structure with equipment boxes

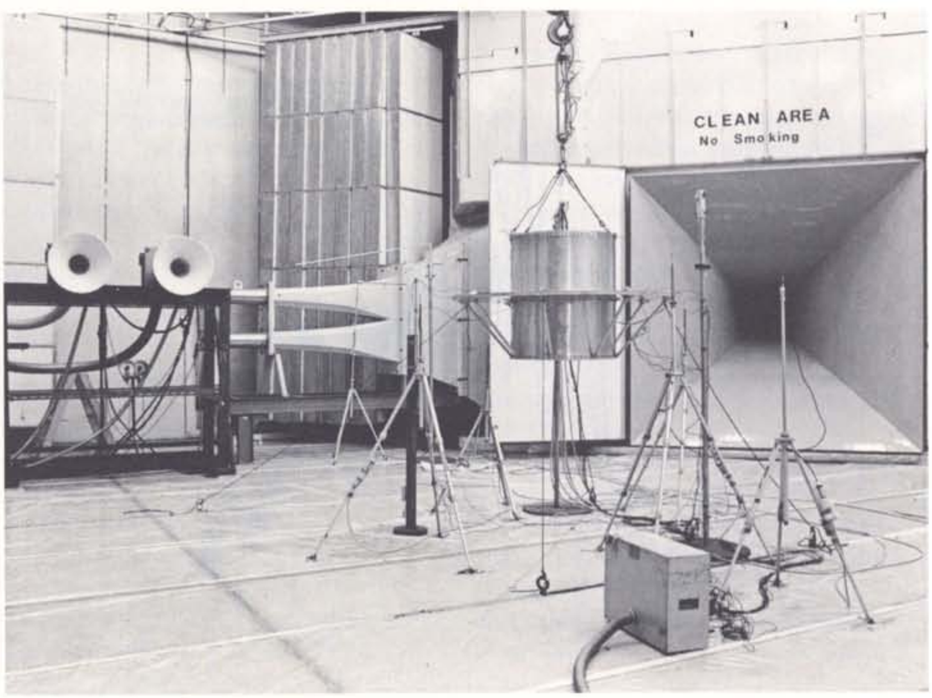


Figure 4 – Selected spacecraft subsystems assembled for acoustic tests at IABG (Munich)

representation of the platform alone. This could simplify development testing and provide more representative conditions than are presently realised in mechanical vibration testing.

The presence of a large central mass on the spacecraft, which could be an apogee boost motor or fuel tank, has been shown to have little effect on the response levels of the satellite structure. Struts in the structure only noticeably modify the responses of adjacent structures in the frequency bands where fundamental flexural strut resonances occur. Cable harnesses have some effect on local frequency response characteristics but little impact on average behaviour.

The method of mounting the simplified satellite specimen in the acoustic chamber, whether with a low-frequency sling or by supporting it at its base, has little effect on its high-frequency response characteristics.

Comparison of the effects of the shroud enclosure configuration with the results of basic reverberant room tests indicate that platform responses may be enhanced at frequencies greater than 1 kHz, but that the central cylinder levels are reduced in the lower frequency regime. The responses of spacecraft appendages that lie relatively close to the shroud wall are, of course, likely to be significantly increased.

An example of a check on the accuracy of the indirectly measured modal density

Figure 5 – Enclosure simulating a launch-vehicle shroud, as used in acoustic tests at IABG

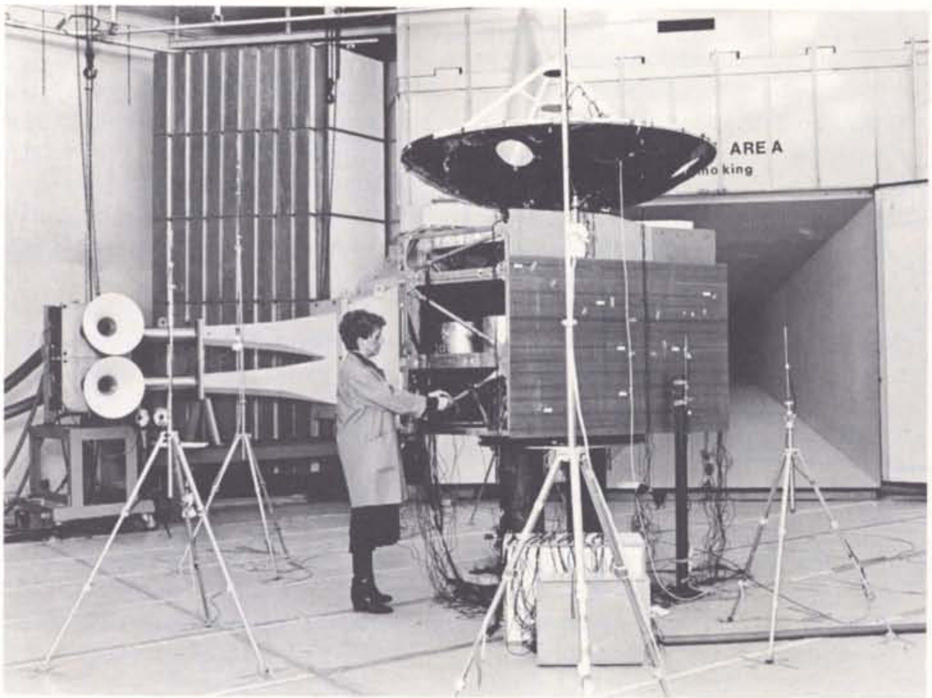


Figure 6 – Marots spacecraft structure and selected equipment in the acoustic facility at IABG

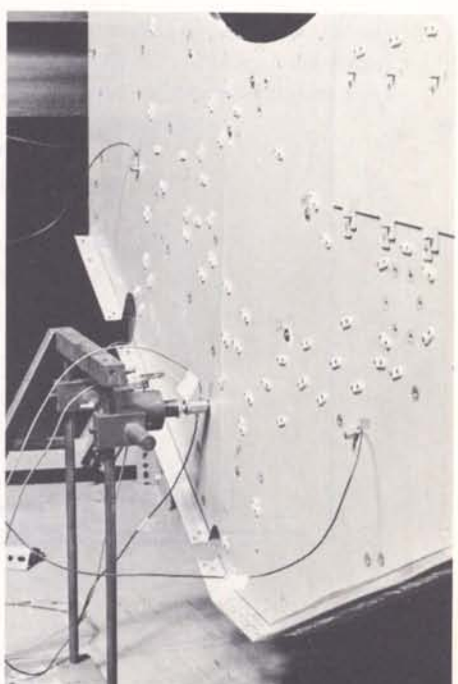
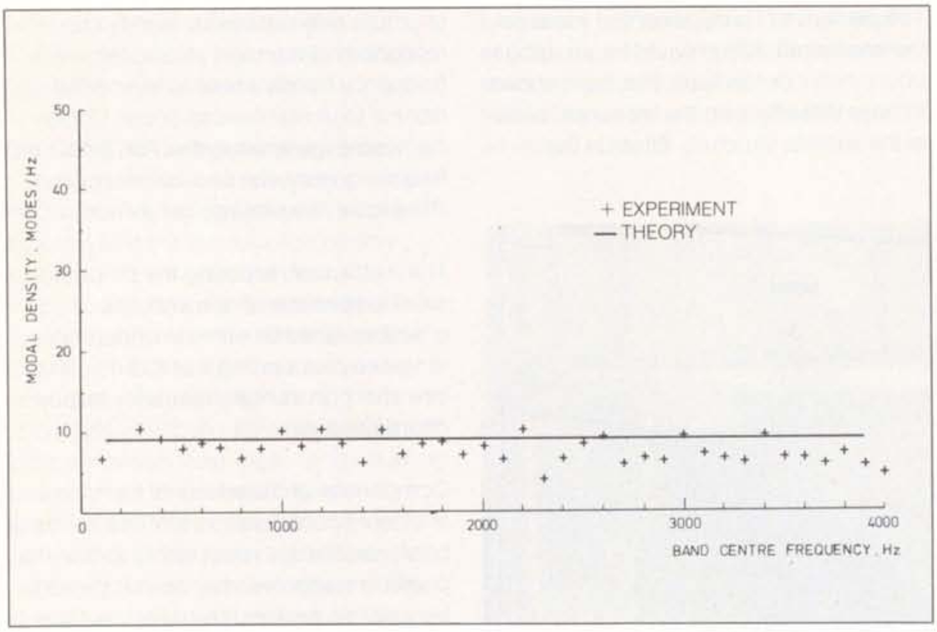


Figure 7 – Proximity exciter and accelerometers located for spatial average assessments (modal-density determination for honeycomb platform), at Southampton University

Figure 8 – Modal density of a flat plate (average value from three-point impedance measurements)

Figure 9 – Average response of stiffened cylinder coupled to stiffened plate platform



compared with the theoretical value is shown in Figure 8. A similar standard of correlation has been found for a cylinder, except that a greater deviation occurs in the vicinity of its ring frequency.

Examples of measured and SEA-predicted response values for a skin-stiffened platform attached to the stiffened central cylinder of a simplified satellite specimen are shown in Figures 9 and 10. The correlation is generally very good, the greatest error occurring mainly below about 200 Hz, probably due to the low modal densities in this region. Large errors are also incurred at the cylinder ring frequency and at the critical coincidence frequency, discrepancies that are always observed and have yet to be fully explained.

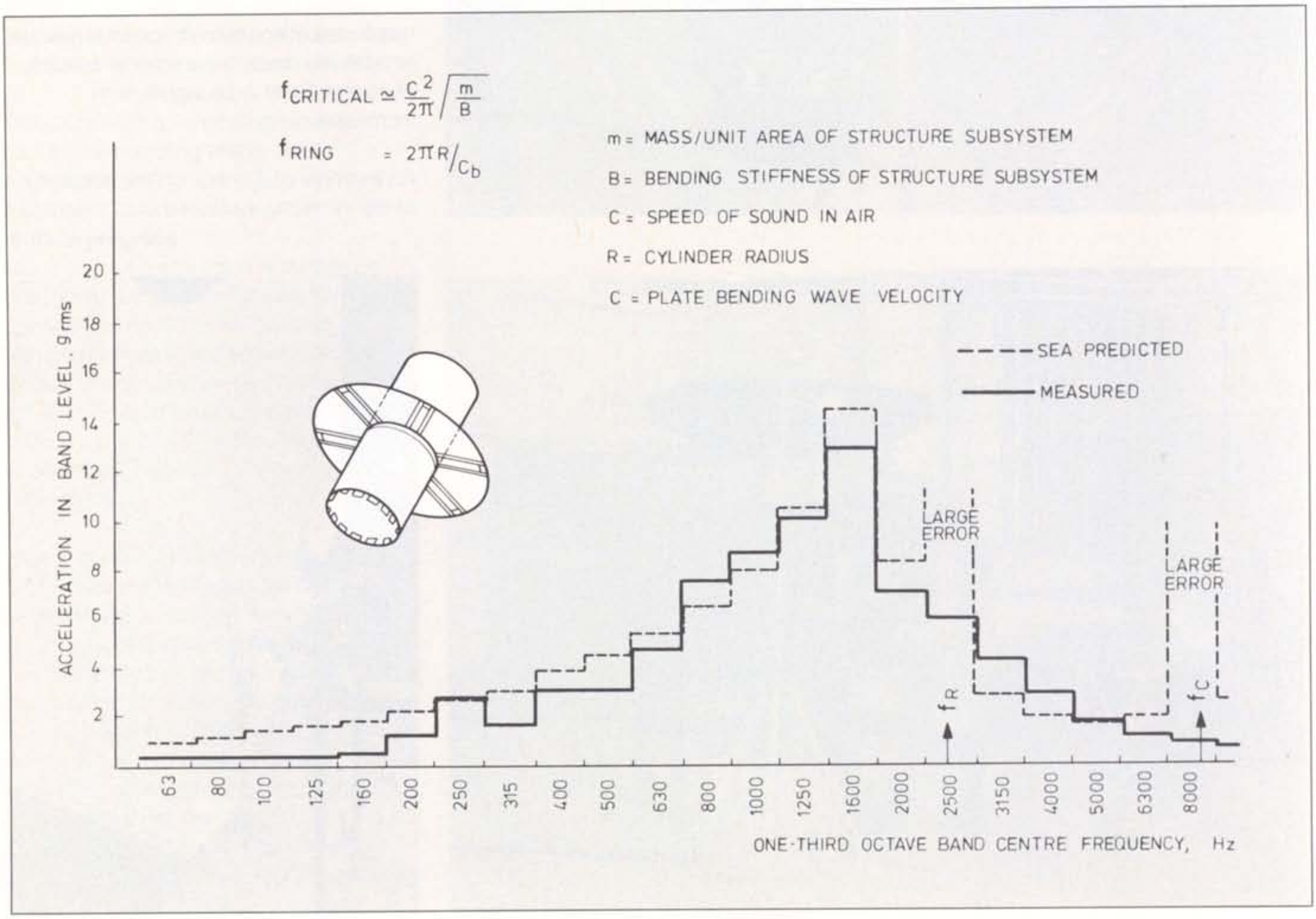
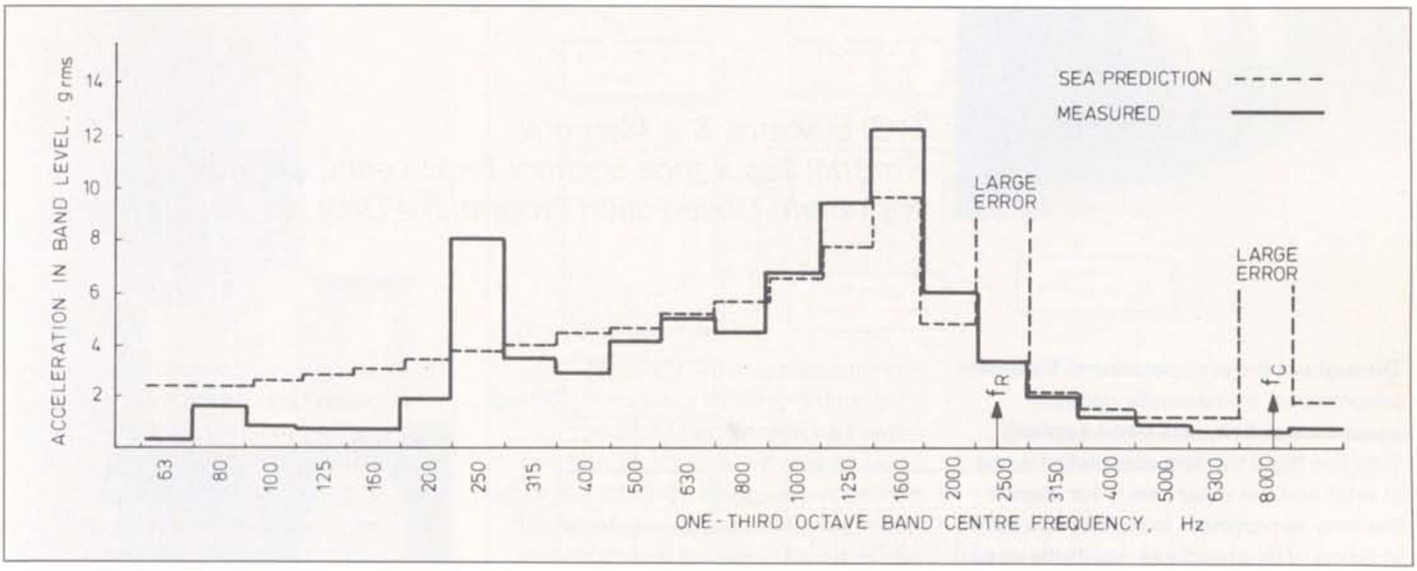


Figure 10 – Average response of stiffened plate platform coupled to stiffened cylinder



Some difficulties have been encountered in the past in predicting responses for honeycomb structures, and on occasions for certain classes of honeycomb structure it has been necessary to resort to a simplified normal mode analysis to establish low-frequency response with sufficient accuracy. A better understanding of the structural parameters that are important in the response behaviour is now leading to improved assessments.

Other work being undertaken using the test structures and simulated spacecraft experiments, appendages and equipment is examining the effects of mechanically induced high-frequency vibrations at the base of the spacecraft structure.

As a result of the directional nature of such vibrations and their localised input, substantially different response behaviours in different structural zones are observed when compared with those set up by the loadings induced by a diffuse acoustic field. This serves to demonstrate that it is often impractical to simulate acoustic excitation by mechanical testing, at least for complex configurations. Mechanical testing is suitable for many classes of equipment when it can be demonstrated that the vibratory energy is mainly transmitted by the local structure, but this is not the case if large flexible equipment surfaces likely to accept acoustic energy are involved.

Current activities will culminate in the first issue of a 'Structural Acoustics Design Guide' later this year, containing:

- A guide to modelling techniques and how they should be used.
- Guidance on the choice of SEA parameters.
- A glossary of loss factors.
- Recommended test methods, including guidance on the simulation of structure vibrations in equipment testing.
- Recommendations on means of scaling past test data for use in confirming vibration levels.
- General observations from surveys of various acoustic and high frequency mechanical vibration tests.
- Examples of applications of prediction and scaling methods.

Future work

Future work will consider the application of SEA to mechanically induced vibrations and explore the practical boundaries of such techniques. The establishment of greater understanding of response behaviours should lead to improved scaling laws, which in turn should permit the extrapolation of test data to a wide range of launch configurations.

Further work is required in order to design against high-frequency vibration problems and the use of artificial damping treatments to reduce vibration levels is but one aspect of such work. Further studies of coupling loss factor have also to be undertaken and the modal densities of advanced materials such as carbon-fibre light alloy honeycomb platforms have yet to be properly investigated.

The Meteosat Product-Assurance Programme – Experience Gained

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Throughout the preoperational Meteosat programme, a systematic product-assurance activity has been applied. With two flight models completed – one in orbit and the other ready for launch – it is now appropriate to review this effort, in terms of its objectives, methods used and experience gained, within the framework of forthcoming programmes and in particular that of operational Meteosat.

From the outset of the Meteosat Programme, product assurance (PA) has formed an integral part of project activities, with the aim of ensuring that defined system goals would be met in the realisation of the spacecraft. Meteosat was required to survive launch and in-orbit environments with an overall mission-reliability target of 0.50 at the end of the three-year nominal lifetime. The two essential parts of the payload, the radiometer and the telecommunications subsystem, posed problems from the beginning in areas such as image quality, cleanliness, detector and cooler design, technology aspects and link budgets. The development programme was based on four prototypes (thermal, structural, electrical and qualification) and two flight models. The PA requirements were those of the just issued ESTEC PA baseline, with particular emphasis on such aspects as contamination control.

Product-assurance programme definition

During the definition phase of the Meteosat Programme, the contractors (COSMOS Consortium led by SNIAS as prime contractor, with Matra as prime contractor for the radiometer), prepared PA plans and procedures to meet the ESA requirements and provided programme-specific instructions. At this stage, particular difficulties were found with obtaining the contractors' full understanding of the requirements and, later, transmission of these to their co- and subcontractors. Additionally, the implementation of some requirements proved difficult where established national or intra-company quality systems diverged or were lacking. The promotion of a unified component-procurement policy, with mandatory preference for European-qualified sources/products, proved logistically and technically arduous. Eventually, however, after lengthy discussions with the prime contractor, systematic specification reviews, and an extensive company audits campaign, a definitive Meteosat PA structure was produced.

PA manning levels within the Agency and prime-contractor project teams reflected the varying needs at different project stages; initially most effort was expended on specification and design review, component activities and quality audits. Emphasis shifted, as prototype manufacture started, to the final editions of parts, materials and processes lists, and then, as such manufacture got under way, to manufacturing audits in preparation for flight-model production. Subsystems manufacturing and test follow-up preceded the start of system assembly, integration and test activities (AIT). Environmental tests, final performance testing and qualification or flight-readiness reviews preceded acceptance of the satellite.

Launch-campaign activities for Meteosat-1 marked the end of this initial phase of the pre-operational programme. The adaptation of Meteosat-2 for Ariane followed, with the repetition of certain qualification tests and AIT activities on the second flight model (F2).

The last stages of the pre-operational programme have consisted of the

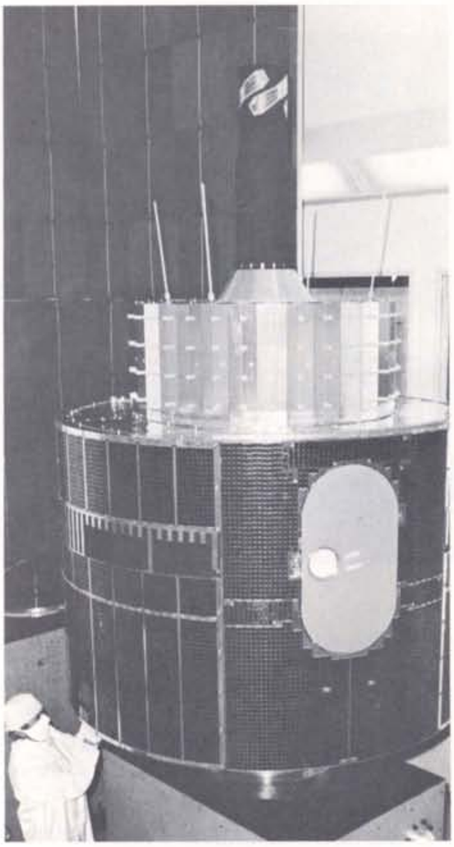


Figure 1 – The Meteosat flight model spacecraft (F1)

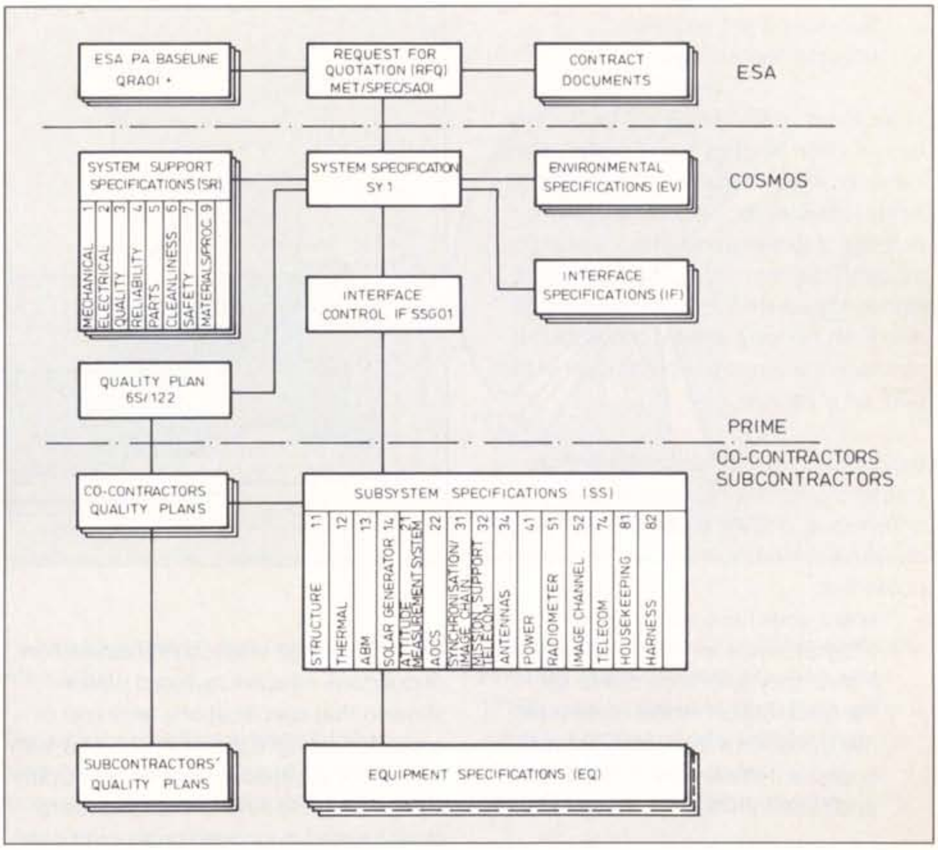


Figure 2 – Specification tree

modifications to the F2 model resulting from the F1 in-orbit experience; although relatively minor in nature, they have nonetheless required repetition of system-level testing.

The first phase of the operational programme also formed part of the product-assurance tasks.

On-ground results – nonconformance records

A global statistical representation shows the distribution, per spacecraft model, of reported nonconformances before launch. They can be categorised as being due to:

- design errors, representing 45% of the total
- workmanship problems representing 35% of the total
- miscellaneous, representing 20% of the total.

Analysis of each category by satellite model has led to a number of interesting observations.

Design errors

1 A major percentage (60%) are discovered during qualification and resolved for flight units by build-standard modifications.

2 A considerable percentage (30%) are repeated and equally distributed on all models. These incidents usually involve out-of-specification performances or interface characteristics (electrical and/or mechanical), but have no or an insignificant impact on the system itself. Only a limited number affect system performance and these are processed at a contractual level (deviations).

3 The remaining 10% are common to qualification and first flight model spacecraft. Due to the overlapping between these two models, some design problems are solved by acceptable repair actions on both; corresponding design changes are implemented on the subsequent model and spares only.

Workmanship problems

This category is composed of all kinds of operators' mistakes, the majority of part failures, manufacturing-process errors, etc. It is responsible for 35% of nonconformances for each model. Examination shows, however, that whereas workmanship problems on the qualification model resulted in major repair actions, on flight models they rarely did, being cured by a simple rework to drawing operations. Here corrective actions, following the early incidents, improved workmanship, processes or controls for the later production.

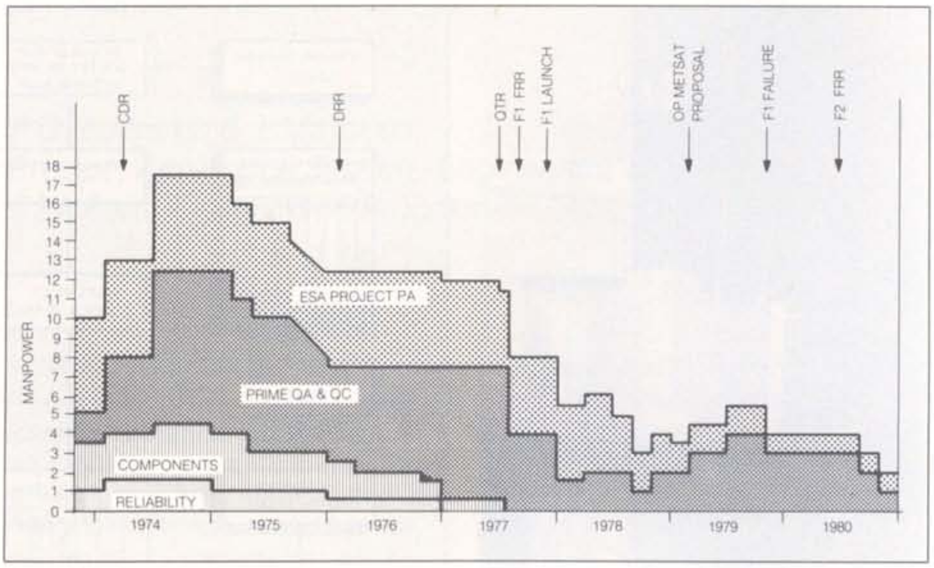
Miscellaneous

This category consists of:

- software problems such as procedural errors

Figure 3 – Product-assurance manning levels (ESA project plus prime contractor PA team complement)

CDR Critical Design Review
DRR Development Results Review
QTR Qualification Tests Review
FRR Flight-Readiness Review



– test-equipment problems
– unexplained anomalies.

The causes of and remedies for the first two problem sources being progressively identified, their frequency of occurrence tends to decrease naturally with the number of similar items of equipment or models built (learning curve). The third item is often a measure of the efficacity and even honesty of the contractor but represents a very small proportion of the total on Meteosat.

Examination of the nonconformance statistics gives the impression of a continuous 'quality' improvement through the various models. It should, however, be noted that:

– spare units have been neither integrated nor tested at system level, nor do they form a complete set
– the qualification model evidences more problems than other models because it carries the most stressed and tested units.

A large number of nonconformances are detected at incoming inspection/acceptance level, which shows that this control stage represents an effective screen. More than 70% of reported nonconformances are electrical rather than mechanical, at subsystem/equipment level. During system activities, such as integration, testing, transportation, storage and launch operations, electrical and mechanical nonconformances are almost equally common.

In-orbit results

Performance

Following its launch on 23 November 1977, Meteosat-1 was successfully commissioned and produced its first (official) image on 9 December 1977. Launch, transfer orbit and apogee boost motor (ABM) firing were achieved without significant difficulty.

Verification of the commissioned spacecraft's principal functions through extensive image analysis and estimation of downlink effective radiated power showed that specifications were met or exceeded. In-flight telemetry showed, with very minor exceptions, that the principal chains (and the 70% of the redundant chains tested during the spacecraft's life) functioned correctly and within specification.

Anomalies

Some problems were, however, experienced from the early days in orbit, though all but one of these proved to be of minor significance. An anomaly reporting and control procedure was set up by the Programme PA authority to collate, analyse and correct anomalies as they occurred.

In-orbit decontamination

An early anomaly was a degradation in cooler performance during the initial offgassing period, in which water adsorbed on spacecraft surfaces (especially the multilayer insulation surrounding the radiator) vaporised and subsequently condensed on the cold (90 K) optics. This effect had been foreseen and a nominal decontamination procedure cleared the pollution. Subsequently two other decontaminations (involving heating of the radiator to ~300 K) proved necessary; following each such operation, the performance of the cooler returned to nominal. This demonstrates the adequacy of the contamination-control measures applied prior to launch – as, also, does a comparison of operational experience with similar spacecraft.

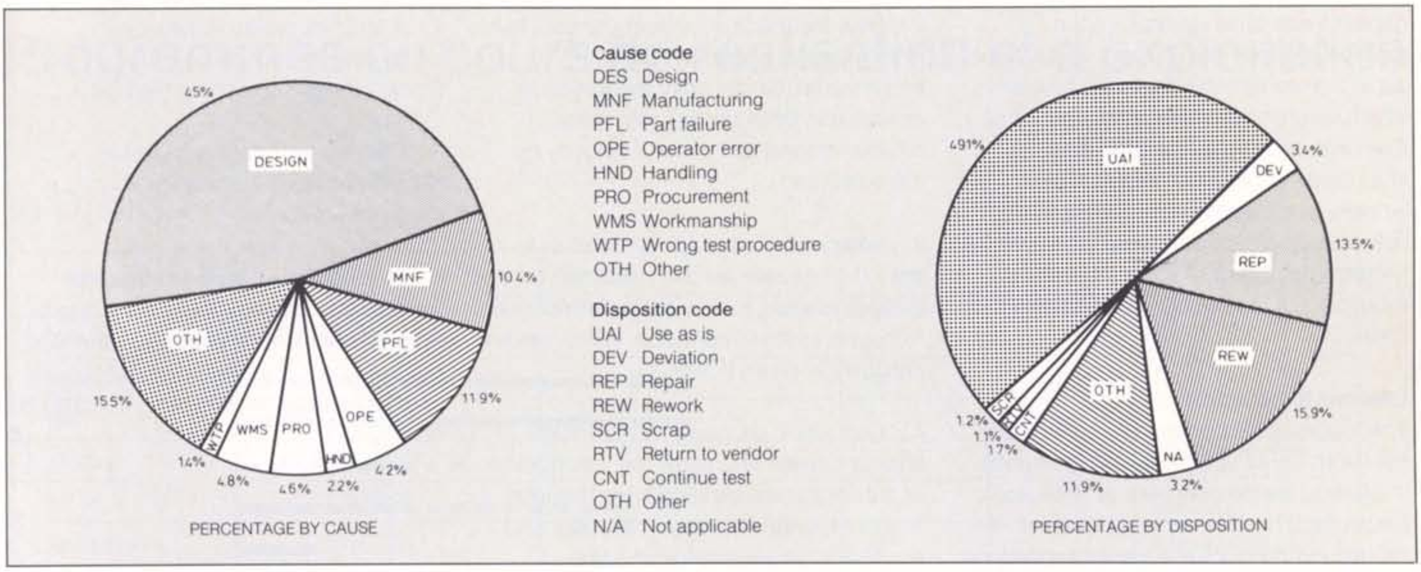
Switching phenomena

A second, more troublesome anomaly (or series of anomalies) was the discovery of spurious switching phenomena. Numbering some 135 events in two years, these are thought to be due to differential charging on spacecraft surfaces from the geostationary-orbit particle environment and subsequent discharge-induced spurious voltages on sensitive switching lines causing status changes. No damage has been caused by these changes of state, but they have been the main cause of loss of image production, though this loss remained very small (1% of the total number of images transmitted to the ground).

Other anomalies included the loss of two temperature telemetry values, a high leakage current in a battery discharger, and some unanticipated design 'peculiarities' such as the '13.50 hours anomaly', whereby a Sun pulse coincided

Figure 4 – Nonconformance statistics

Figure 5 – Distribution of reported nonconformances per satellite model and type

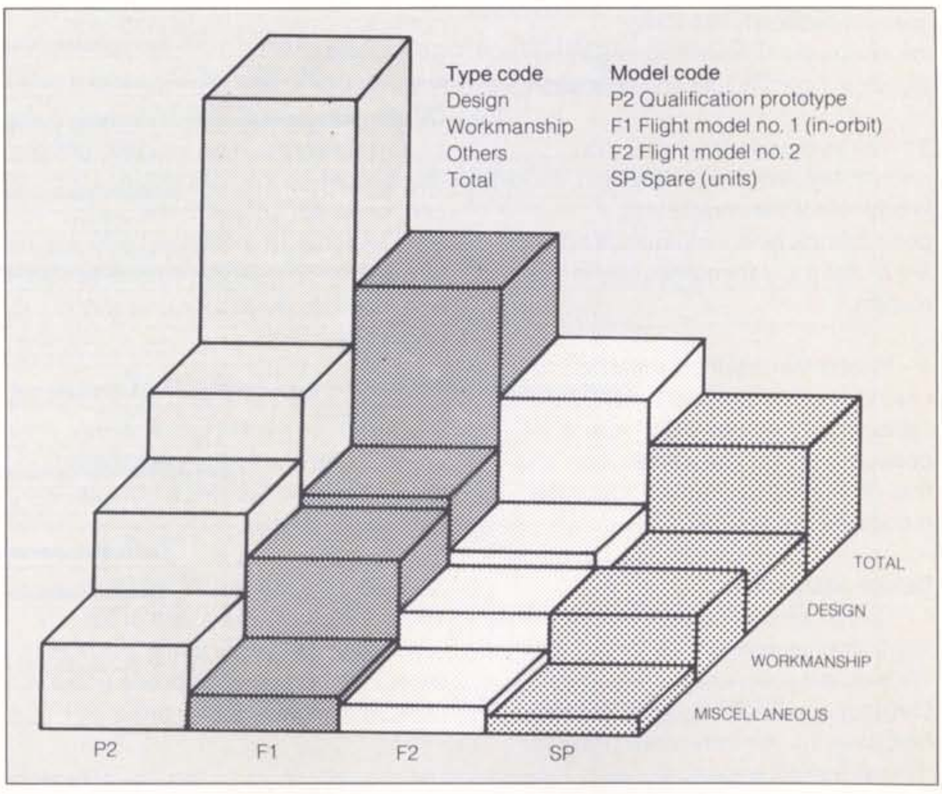


with a scanning-order pulse at a certain time of day and resulted in unforeseen interference. This problem was resolved by changing on-board programmable correction registers.

F1 mission interruption
After almost exactly two years in orbit, a failure in the power subsystem caused a termination of the principal missions. The bus undervoltage protection circuit gave spurious switch-off commands to the principal power distribution relays. This protection unit had been designed to be fail safe with a capacitively coupled output such that failure would imply only one spurious switch-off command. However, the protection circuit and the reference bridge had separately decoupled supplies, with the result that relaxation oscillation was possible, the protection circuit thus sending out a string of 'off' pulses and resulting in the impossibility of switching loads 'on'. The cause of failure has been postulated as a short circuit in a metal-oxide resistor in the reference bridge.

Frequent and varied attempts have been made to recover the spacecraft, but without success. Meteosat-1 is still supporting the data-collection mission for the data-collection platforms (DCPs), but the imaging mission has been completely interrupted.

The resistor type that is postulated to have caused the failure had already received a great deal of attention, having suffered failures previously after assembly. However these resistors, of which some 12 600 were in use in Meteosat equipment, exhibited problems only with two specific assembly techniques at two manufacturers. Consequently, the



decision was taken to replace the resistors in these two suspect areas, but to leave the remaining equipment boxes in which failures had never occurred alone. Even with hindsight, it is difficult to imagine an alternative decision, as wholesale replacement of the resistors (still in use on many other projects without problem) would have meant the virtual rebuilding of the majority of spacecraft units.

Lessons to be learnt

The following 'pot pourri' of observations relates to future spacecraft programmes in general and to operational Meteosat in particular. They are derived both from the on-ground product-assurance experience and Meteosat-1's in-orbit performance.

PA system

1 The full understanding of ESA PA baseline requirements by contractors from the outset is essential to the smooth and efficient development of a project PA programme.

2 Prime and co-contractors need to pay special attention to the timely transmission of compatible requirements to their subcontractors and suppliers.

3 The level and nature of ESA's involvement, which is initially fixed, should in part reflect the contractor's performance. Nonconformance statistics are a useful tool for assessment in this respect.

4 Project management must be reminded – with 'propaganda' if necessary – that the quality-assurance position is usually the safe solution and that other solutions can introduce real reductions in reliability.

Design assurance

1 Design assurance, review activity and reliability engineering must be better involved in the design process. They presently tend to be regarded as 'add-on' functions, though they should have a more direct influence.

2 Real feedback at system-concept level from reliability analysis must be emphasised. Single-point failures must continue to be accepted with great reluctance and very careful scrutiny by the customer.

3 Where real redundancy or fail-safe operation cannot be demonstrated by design analysis, tests must be introduced to support the failure-mode, effects and criticality analysis (FMECA).

4 Long-term programme planning should foresee and allow the introduction of modifications resulting from previous model experience: design, reliability and configuration expertise should be allocated for this task.

5 Specifications should not be regarded with absolute inflexibility, and changes should be made as real system performances and interface characteristics become better known.

6 Maintainability and repairability are becoming increasingly important design constraints, particularly in long-term programmes.

Quality assurance

1 Contractors can be assigned greater responsibility in the nonconformance control system, subject to the demonstrated correctness of dispositions. ESA involvement should thus be flexible and more adjusted to the criticality of nonconformance.

2 Improvements – speed, accuracy and completeness – in PA information/ communications are needed. Modern data-link-based systems should be considered for this.

3 Systematic PA audits are effective and should be continued. Audits in the production phase are as important as those in the preparation phase (more company PA system oriented).

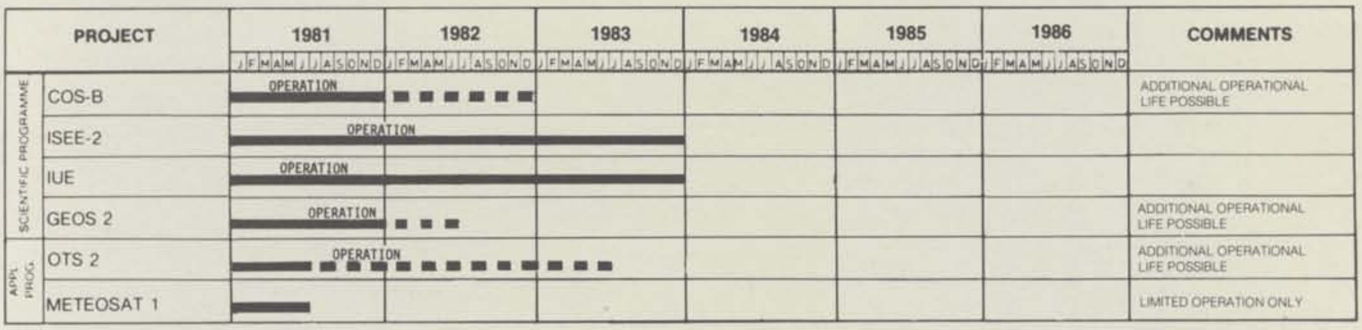
4 A strict incoming subsystem/ equipment inspection policy is a cost-effective screening method.

5 Cleanliness controls must be maintained for the operational programme.

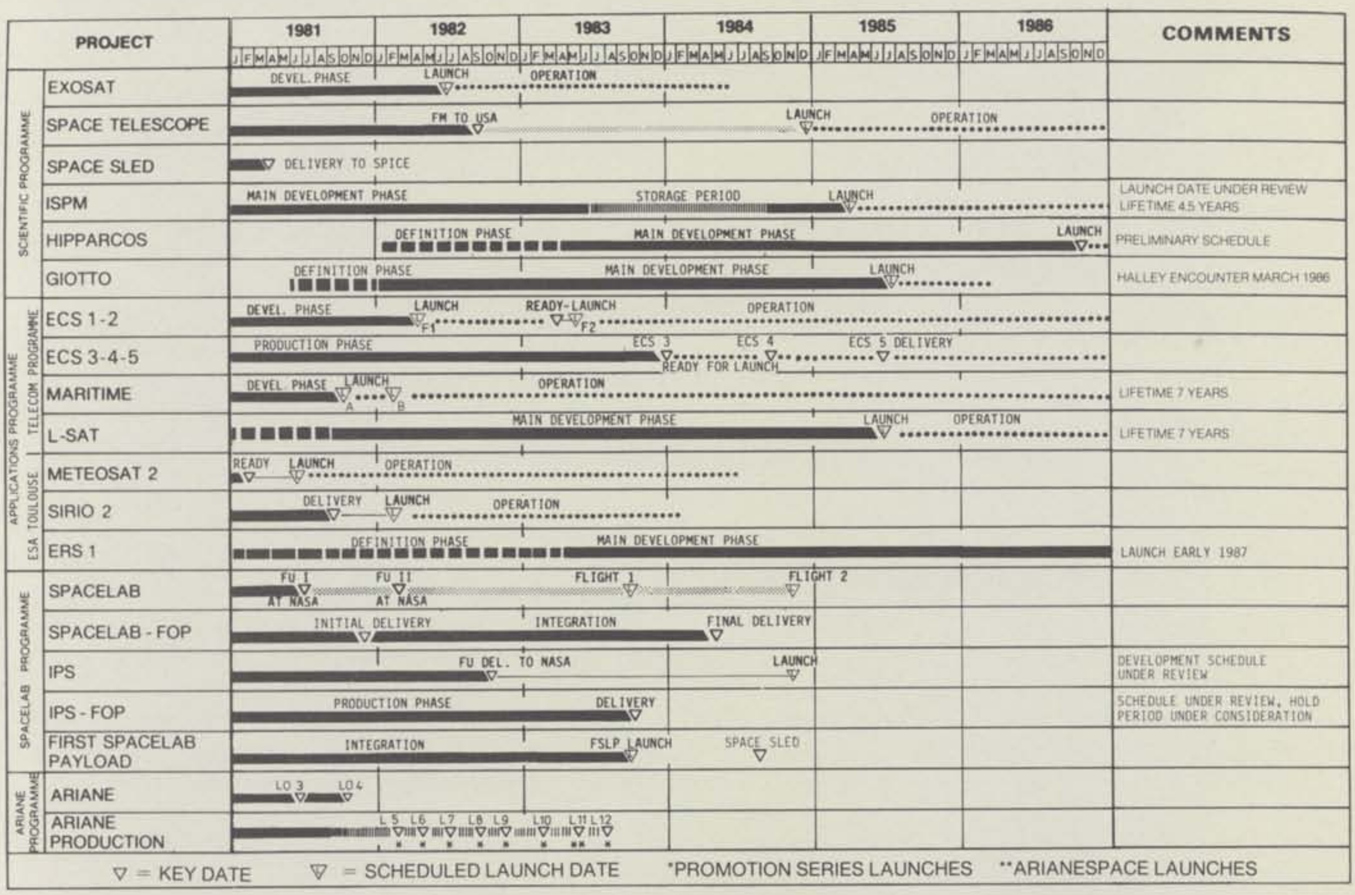
6 More effort is needed to evaluate storage and ageing effects in long-term programmes. Trend analysis is one tool, but technological sample evaluation, life-testing and overstress-testing can also be considered.

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

In Orbit / *En orbite*



Under Development / *En cours de réalisation*



* Reporting status per end February 1981/Bar chart valid per end March 1981

Situation des projets décrits fin février 1981/Planning fin mars 1981

Cos-B

Le plein de gaz de la chambre à étincelles de Cos-B a été refait pour la dernière fois en janvier, ce qui s'est traduit par un rétablissement spectaculaire du rendement de la chambre, qui était depuis quelques mois inférieur au niveau fixé (bien que généralement suffisant pour les besoins de l'astronomie gamma). Il reste dans les réservoirs un peu de gaz qui pourrait être utilisé en cas de nouvelle diminution des performances. On prévoit que Cos-B fonctionnera au moins jusqu'au mois d'octobre mais, si le fonctionnement de l'expérience reste alors nominal, les sous-systèmes du satellite devraient pouvoir assurer la poursuite des opérations pendant encore six mois environ.

Les principaux objectifs du programme pour 1981 consistent en un approfondissement de divers points découlant d'études précédentes. On se propose de modifier désormais moins souvent la direction du pointage pour avoir l'assurance que les mesures effectuées ont une valeur statistique suffisante pour permettre de déterminer véritablement s'il y a ou non variabilité des sources de rayons gamma.

La première observation de l'année visait la source 2CG135+01, qui pourrait être identifiée comme étant la radiosource périodique GT0236+610. Cette observation est actuellement suivie d'une étude, qui porte sur plusieurs sources situées dans une région de rayonnement intense dans la direction générale du centre galactique. Par la suite des études seront consacrées à des émissions gamma de forte intensité découvertes récemment aux latitudes moyennes, émissions qui semblent être liées à la distribution de gaz dans le milieu interstellaire local.

ISEE

La mission en est maitenant à la troisième année de fonctionnement simultané des trois satellites. L'état des sous-systèmes des satellites est bon sauf en ce qui concerne le sous-système de batterie d'ISEE-1 qui ne fournit plus le niveau requis de puissance lorsque le satellite est éclipsé par la Terre. Il reste suffisamment de gaz à bord des trois satellites pour permettre leur exploitation pendant encore une dizaine d'années au moins.

En ce qui concerne la poursuite, la couverture est toujours très bonne puisqu'elle permet de disposer simultanément des données des trois satellites pendant plus de 60% du temps. La NASA assure la poursuite des satellites ISEE jusqu'en octobre 1982 au moins et probablement jusqu'à fin 1985 et l'ASE dresse actuellement le planning de ces opérations après août 1981.

En ce qui concerne les expériences la situation n'a pas changé depuis le compte rendu paru dans le dernier Bulletin.

IUE

IUE a continué à fournir des spectres UV d'étoiles, de galaxies et d'autres objets célestes. L'intérêt reste vif parmi les astronomes européens et 165 propositions d'utilisation du satellite ont été reçues pour la quatrième année d'exploitation qui commencera en avril 1981. Sur ce nombre, 115 propositions ont récemment été acceptées par le Comité ASE de sélection du programme d'observation d'IUE.

Un noùveau logiciel de traitement des images pour les spectres à faible dispersion a été mis en oeuvre à Vilspa. Les améliorations du logiciel de réduction des données qui ont été étudiées à Vilspa seront mises en oeuvre dans le logiciel des routines (signalisation par spot lumineux, signalisation microphonique, etc.).

Parmi les faits récents, il convient particulièrement de signaler:

(a) la découverte de bandes de dissociation du C_2 moléculaire dans une étoile naine blanche dégénérée;

(b) l'observation, juste après une chute d'éclat spectaculaire et inattendue, de l'étoile T-Tauri de type nova, dont le spectre est à présent analogue à celui d'une nova naine;

(c) la preuve renouvelée de la capacité d'IUE à réagir rapidement à des événements inattendus, démontrée lors de l'apparition de deux supernovae: Wild dans NGC 4946 et très récemment Wischnjewsky-Naza dans NGC 1316.

Geos

Le véhicule spatial Geos-2 est resté inactif entre le 1er août 1980 et le 31 janvier 1981. Aucune dégradation n'a été décelée lors de sa remise en activité, le 1er février dernier. Six des sept expériences continuent de fonctionner.

L'analyse des données a atteint à présent le stade où l'on peut s'attaquer à la question des phénomènes à grande échelle et à celle des variations à long terme dans la magnétosphère. Les premières études de ce type ont porté sur la répartition moyenne et sur les variations à court terme de la densité et de la température du plasma au niveau de l'orbite géostationnaire. Des analyses conjointes des données de Geos-2 et d'ISEE – concernant notamment les particules énergiques, les champs électriques et la composition du plasma – permettent désormais d'établir une représentation détaillée à grande échelle de la magnétosphère dans des conditions de calme aussi bien que de perturbations. Les premiers résultats de ces études sont très prometteurs et l'on peut y trouver une justification supplémentaire de la décision d'exploiter Geos-2 en 1981.

Lors de sa réunion des 16 et 17 janvier 1981, le Comité du programme scientifique (SPC) a décidé que tant qu'il resterait des crédits les deux satellites Geos-2 et Cos-B devraient être exploités parallèlement en 1981.

OTS

OTS achève sa troisième année d'exploitation en orbite, tous les sous-systèmes continuant à fonctionner correctement. L'enseignement tiré de son exploitation à ce jour renforce les garanties de voir les satellites Marecs et ECS satisfaire leurs impératifs de performances lorsqu'ils seront lancés.

Un certain nombre d'expérimentateurs et utilisateurs actuels et potentiels se sont montrés extrêmement favorables à la poursuite de son exploitation au-delà des trois années financées initialement, période qui s'achève fin mai. Cette possibilité est actuellement à l'étude à l'Agence et chez Eutelsat intérimaire.

On commence à disposer d'un certain nombre de rapports émanant des différents groupes de travail Eutelsat qui

Cos-B

The gas filling of the Cos-B spark chamber was completely replenished for the last time in January, resulting in a dramatic restoration of performance, which had been below standard (though still generally adequate for useful gamma-ray astronomy) for some months. There still remains some gas in the tanks which can be used to effect an improvement in case of a future degradation. It is currently envisaged that Cos-B will continue to operate at least until October. If the experiment is still functioning nominally the spacecraft subsystems should be able to support operations for about six months beyond that date.

The main objectives of the 1981 programme lie in a more detailed investigation of various aspects of the results of earlier studies. It is intended that in future the pointing direction will be changed less frequently to ensure that the statistical significance of the measurements is adequate to enable a firm statement to be made on whether gamma-ray sources exhibit variability.

The first observation of the year was aimed at the source 2CG135+01, a candidate identification for which is the periodic radio source GTO236+610. This is being followed by a study of several sources in an intense region near the direction of the galactic centre. Later investigations will follow up new discoveries of enhanced gamma-ray emission at medium latitudes, which appears to be correlated with the distribution of gas in the local interstellar medium.

ISEE

This mission is now in its third year of overlapping operation of all three spacecraft. The health of the spacecraft subsystems is good except for the ISEE-1 battery subsystem which is no longer able to provide sufficient power when the spacecraft is in eclipse behind the Earth. There is still enough gas left on all three spacecraft for them to be operated for another 10 years at least. Tracking coverage is still very high, providing simultaneous data from all three spacecraft for more than 60% of the time. NASA has secured ISEE spacecraft tracking at least until October 1982, and probably through 1985, and ESA is at the moment planning operations beyond August 1981.

There has been no change in the status of the experiments since the last report in these pages.

IUE

IUE has continued to acquire UV spectra of stars, galaxies and other celestial objects. Interest among European astronomers remains high, with 165 proposals for satellite use received for the fourth year of operations starting April 1981. One hundred and fifteen of these have recently been accepted by the ESA IUE Observation Programme Selection Committee.

New image-processing software for low-dispersion spectra has been implemented at Vilspa and improvements to the data-reduction software developed at Vilspa will be implemented in the routine software (bright-spots flagging, microphonics flagging etc.).

Highlights of recent IUE results are:

(a) Discovery of dissociation bands of molecular C_2 in a degenerate white-dwarf star,

(b) The nova-like star T Tauri has been observed just after an unexpected dramatic drop in brightness. The spectrum is now similar to that of a dwarf nova,

(c) IUE again showed its capacity to react quickly to unexpected events by responding to the appearance of two supernovae: Wild in NGC 4946 and very recently Wischnjewsky-Naza in NGC 1316.

Geos

The Geos-2 spacecraft has been kept dormant during the period 1 August 1980 – 31 January 1981. When it was reactivated on 1 February no degradation was noted. Six of the seven experiments are still operational.

The data analysis has reached a stage where questions of large-scale phenomena and long-term variations in the magnetosphere can be addressed. Initial studies of this type dealt with the average distribution and short-term variation of plasma density and temperature at the geostationary orbit. Joint analyses of Geos-2 and ISEE data – in particular energetic-particle, electric-field and plasma-composition data – are now helping to establish a detailed large-scale picture of the magnetosphere both for quiet and disturbed conditions. The initial results of these studies are very promising and can be regarded as additional justification for operation of Geos-2 in 1981.

At its meeting on 16/17 January 1981, the Science Programme Committee (SPC) decided that both Geos-2 and Cos-B should be operated in parallel in 1981 until there are no more funds available.

OTS

OTS is now completing its third year of operation in orbit, with all subsystems continuing to perform well. The information learned from its operation to date provides added assurance that the Marecs and ECS satellites will perform as required when they are launched.

Enthusiastic interest has been expressed by a number of present and potential experimenters/users to continue the operation of OTS beyond its initially funded three years in orbit, which come to an end at the end of May. This possibility is now under active consideration both within ESA and by Interim Eutelsat.

A number of reports from the various Eutelsat working groups who have made communications tests in preparation for ECS are now becoming available. Early indications are that in nearly all areas very promising results have been obtained. Further TDMA tests are planned shortly by Eutelsat using the Bercenay (F), Fucino (I) and Goonhilly (UK) earth stations. The Goonhilly station has a newly completed 8 m diameter antenna which is used exclusively for OTS tests.

The experimental link between ESRIN Frascati (I) and the Royal Aircraft Establishment Farnborough (UK) is now operational as part of the SPINE network. The STELLA experiment between scientific establishments continues to operate successfully.

The satellite performance incentive-scheme tests carried out in November 1980 have now been analysed, together with various additional radio-frequency ont procédé à des essais de télécommunications préparant ECS. D'après les premières indications, des résultats très prometteurs ont été obtenus dans presque tous les domaines. Eutelsat prévoit de réaliser sous peu d'autres essais AMRT mettant en jeu les stations terriennes de Bercenay (F), Fucino (I) et Goonhilly (R-U). La station de Goonhilly, dotée d'une antenne de 8 m de diamètre, vient d'être terminée et est exclusivement destinée aux essais OTS.

La liaison expérimentale entre l'ESRIN à Frascati (I) et le Royal Aircraft Establishment (R-U) est maintenant opérationnelle dans le cadre du réseau SPINE. L'expérience STELLA entre établissements scientifiques poursuit son cours avec succès.

Les essais de performances du satellite liés au système d'intéressement qui ont été exécutés en novembre 1980 ont été analysés, en même temps que différentes mesures radioélectriques supplémentaires effectuées à la même époque. Les résultats obtenus en ce qui concerne la puissance de sortie de saturation correspondent tous aux prévisions. Les prochaines mesures seront faites en mai 1981.

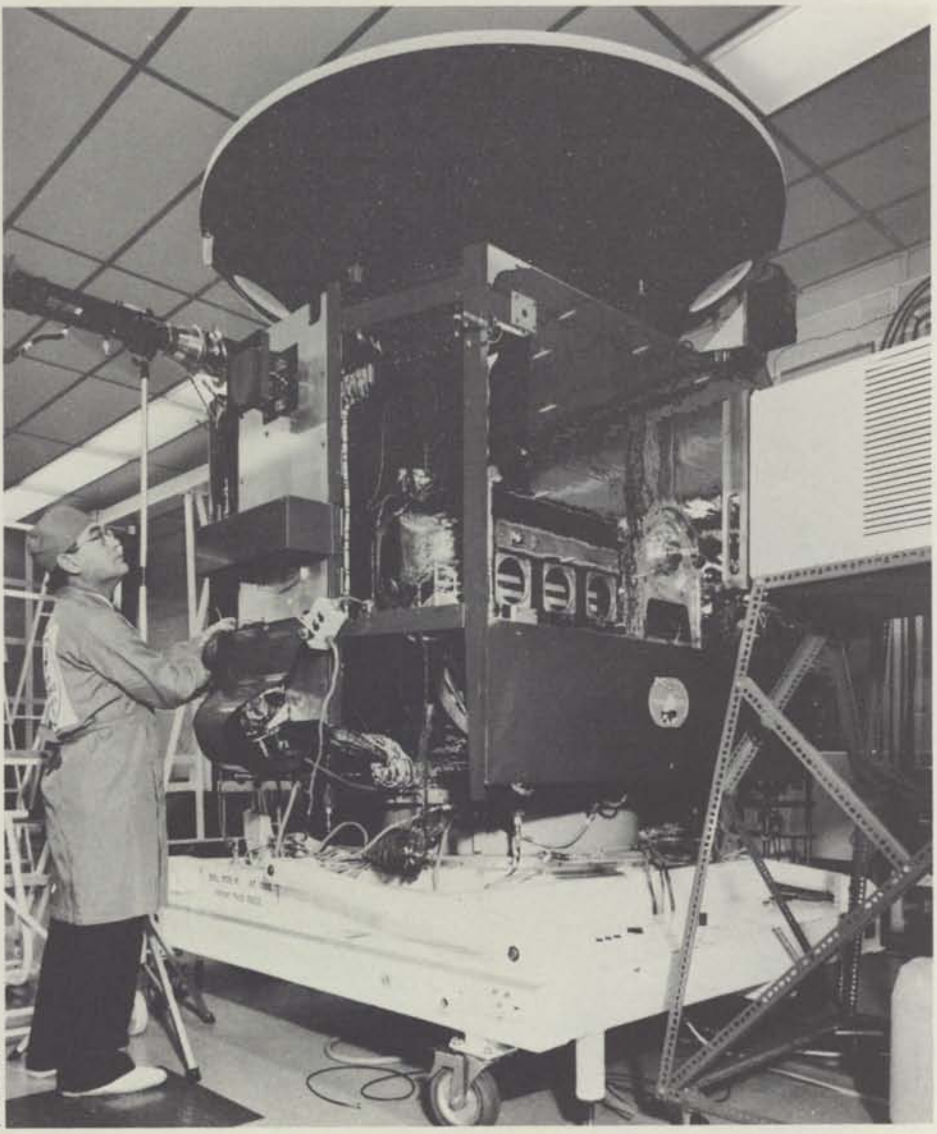


photo BAe

Vérification de l'alignement optique du détecteur terrestre infrarouge embarqué sur le premier modèle de vol de Marecs.

Technicians checking the optical alignment of the infrared earth sensor on the first flight model of the Marecs maritime communications satellite.

Exosat

Satellite

Le programme obligatoire d'essais de développement du modèle d'identification est terminé. A la suite d'essais de mise au point et de mise en service du logiciel, plusieurs unités ont été enlevées du satellite pour servir à des travaux préliminaires d'intégration et à des réparations sur le modèle de vol. Leur réintégration interviendra à temps pour les essais en ligne qui seront effectués plus tard dans l'année avec l'ESOC pour vérifier le logiciel opérationnel au sol.

Après l'intégration des circuits de propane et d'hydrazine chez MSDS, la structure du modèle de vol a été livrée à MBB, apparemment pour que l'intégration des équipements des sous-systèmes puisse commencer. Malheureusement, les seuls équipements de vol disponibles à ce moment-là étaient le câblage et le sous-système de puissance; ils ont maintenant été intégrés.

Les problèmes posés par d'autres matériels de vol – destinés notamment au sous-système de commande d'orientation et de correction d'orbite, au sous-système de traitement des données et aux expériences 'moyenne énergie' – ont encore retardé le programme d'assemblage, d'intégration et d'essais; le calendrier d'intégration est de ce fait beaucoup trop serré et donc trop risqué pour qu'un lancement soit possible pendant le créneau disponible à la fin de cette année (de novembre à janvier); il a donc fallu reporter le lancement au prochain créneau de la mi-1982 (de juin à août).

Les préparatifs de la partie B de l'examen des résultats du développement, qui doit se dérouler chez MBB en mars, sont bien avancés.

Charge utile

La réalisation des expériences 'faible énergie' de la charge utile progresse de façon satisfaisante: les essais du premier télescope imageur faible énergie (LEIT 1) sont en effet terminés et le montage du LEIT 2 chez Matra est en bonne voie. L'étalonnage des deux télescopes, utilisant l'installation de rayons X à long faisceau de Munich, doit en principe être terminé avant fin juin.

Les difficultés de fabrication qu'ont rencontrées les fournisseurs de feuilles minces de beryllium ont amené à prendre la décision d'utiliser un matériau plus épais (62 μm au lieu de 37 μm) pour les détecteurs 'moyenne énergie'. Le premier détecteur (il y en aura huit sur le véhicule spatial) a été doté de cette nouvelle feuille measurements made at that time. All saturated-output-power results have been as expected. The next measurements will be made in May 1981.

Exosat

Satellite

The engineering model (EM) has effectively completed its mandatory development test programme. Following software development and commissioning tests, several units have been removed from the satellite to assist preliminary integration work on the flight model (FM), repairs, etc. Re-integration will take place in time for on-line tests with ESOC to check ground-based operational software later in the year.

Following integration of the hydrazine and propane subsystems at MSDS, the flight-model structure was delivered to MBB, ostensibly for the start of subsystem equipment integration. Unfortunately, the only flight equipment available at this time are the harness and the power subsystems, both of which have now been integrated.

Problems encountered in other flight hardware, particularly with AOCS, data handling and the medium-energy experiments, have caused further delays in the assembly, integration and test (AIT) programme, leading to an impossibly tight and risky integration schedule to meet the launch window at the end of this year (November to January) and imposing a postponement of launch to the next window in mid-1982 (June to August).

Preparation of the Development Results Review (DRR Part B), due to be held in MBB in March, is well underway.

Payload

Payload work is progressing satisfactorily on the low-energy experiments, with LEIT 1 tests having been concluded and assembly of LEIT 2 at Matra well advanced. Calibration of both telescopes, using a long-beam X-ray facility in Munich, is scheduled to be completed before the end of June.

Manufacturing difficulties experienced by the suppliers of thin beryllium foil has led to a decision to use a thicker material (62 μm cf. 37 μm) for the medium-energy detectors. The first detector (eight on the spacecraft) has been fitted with this new foil using an improved bonding technique and is currently undergoing evaluation.

In the meantime, some 90 collimator elements have been delivered to Leicester University for X-ray measurements.

The flight-model gas-scintillation experiment has been delivered to ESA Space Science Department at ESTEC for calibration. Work on the spare flight model is proceeding satisfactorily.

Launcher

The Ariane vehicle injector problem is expected to be solved by the end of March allowing the launch sequence to be confirmed for the remaining promotional and the first operational flights.

ESOC activities

The first compatibility test between satellite and ground-station equipment is scheduled for June this year, assuming that the ranging equipment is delivered on time.

NASA support for tracking and back-up operations has been defined and cost estimates are expected shortly.

Preparation of operational software/documentation is proceeding on schedule.

Space Sled

The ESA Council decided at its December 1980 meeting to accept the German offer to fly the Sled on its Spacelab D-1 mission. The D-1 mission calls for delivery by ESA of the Sled facility, fully integrated with its experiments, as a payload element including the necessary standard Spacelab equipment rack(s). This payload-element integration task will be carried out by Spice after it has taken delivery of the Sled facility, the requisite funding for this task having been approved at an earlier Council meeting, in October 1980.

The Sled-facility development programme is proceeding on schedule. The training-model and flight-model electrical subsystems were delivered on time to ESTEC, in October 1980 and January 1981, respectively. Since these deliveries, both Sled models have been fully integrated and have successfully undergone electromagnetic-cleanliness, dynamic-performance and safety tests. The Sled has been successfully operated with the full European Experiment System through all worst-case modes, including safety tests with human subjects. Compatibility tests with the most critical US-developed experiment hardware are still to be completed.

The Sled system test phase is nearing completion and all test results will be presented for the Acceptance Review, which will take place at the end of March as scheduled. The Sled will then be delivered to Spice, where it will be stored until needed for the D-1 mission.

ECS

Interim Eutelsat, the organisation of European post office and telecommunications authorities, agreed at its December Council meeting to include European Specialised Services channels on the ECS satellites, starting with ECS-2 which is due for launch in April 1983. These channels will be used for business services such as facsimile, computer-data and video conferences. A rider to the ECS main development contract will be formalised after the ESA Council gives its approval to the modification in March 1981. Eutelsat also decided to hire capacity for business use on France's national communications satellite Telecom-I, which is the first non-Agency satellite to be built based upon the ECS design.

With regard to the ECS industrial development contract, the ECS-1 service-module structure built by Aeritalia (I) was despatched after installation of the reaction control subsystem from ERNO (D), to Matra, Toulouse (F) in February 1981. Assembly, integration and testing (AIT) of the satellite will commence in March, leading to a launch on Ariane-L7 in April 1982.

Marecs

The contract between ESA and Inmarsat has been signed and provides for two satellites to be supplied by ESA, so that an Inmarsat service can start between 1 January 1982 and 31 July 1982. One satellite is to be stationed over the Atlantic and one over the Pacific.

The Marecs 'A' satellite has been

au moyen d'une technique de collage améliorée; ce détecteur est en cours d'évaluation.

Entre-temps, près de 90 éléments du collimateur ont été livrés à l'Université de Leicester pour des mesures aux rayons X.

Le premier modèle de vol de l'expérience du compteur proportionnel à scintillateur gazeux a été livré au Département 'Science spatiale' de l'ESTEC pour étalonnage. Les travaux sur le deuxième modèle de vol (modèle de réserve) progressent normalement.

Lanceur
On espère régler le problème des injecteurs d'ici fin février, ce qui permettra de confirmer le calendrier des lancements pour les vols de qualification restant à effectuer et pour le premier vol opérationnel.

Activités ESOC
Le premier essai de compatibilité entre les équipements du satellite et ceux de la station sol est prévu pour juin prochain, à condition que les équipements de télémétrie soient livrés à temps.

L'assistance de la NASA pour les opérations de poursuite et de soutien a été définie, des estimations chiffrées seront établies prochainement.

La préparation du logiciel opérationnel et de la documentation se déroulent selon les plans.

Traîneau spatial

A sa session de décembre 1980 le Conseil de l'ASE a décidé d'accepter l'offre faite par l'Allemagne d'embarquer le Traîneau spatial sur sa mission D-1. Cette mission suppose la livraison par l'ASE – comme un élément de charge utile – du Traîneau complètement intégré avec ses expériences et le nombre nécessaire de châssis Spacelab normalisés. L'intégration de cet élément de charge utile sera effectuée par le Spice après livraison du Traîneau; le financement nécessaire pour l'ensemble de cette tâche a été approuvé à une session précédente du Conseil, en octobre 1980.

Le programme de réalisation du Traîneau spatial se déroule comme prévu. Les sous-systèmes électriques du modèle destiné à la formation de l'équipage et du modèle de vol ont été livrés à temps à l'ESTEC, c'est-à-dire en octobre 1980 et en janvier 1981 respectivement. Depuis, ces deux modèles ont été complètement intégrés et ont subi avec succès des essais de propreté électromagnétique, de comportement dynamique et de sécurité. Mis en service avec l'ensemble des expériences européennes le Traîneau spatial a correctement fonctionné dans les modes les plus pessimistes, y compris lors des essais de sécurité effectués avec des hommes comme sujets d'expérience. Il reste encore à effectuer des essais de compatibilité avec les matériels d'expérience les plus critiques réalisés aux Etats-Unis.

La phase d'essais au niveau système touche à son terme et tous les résultats en seront présentés à l'examen de recette qui aura lieu fin mars 1981 comme prévu. Le Traîneau spatial sera alors livré au Spice qui le stockera jusqu'à la mission D-1.

ECS

Eutelsat intérimaire, l'organisation qui regroupe les administrations européennes des postes et télécommunications, a décidé au cours de la réunion de décembre de son Conseil, l'adjonction sur les satellites ECS de canaux de services européens spécialisés, en commençant par le satellite ECS-2 qui doit être lancé en avril 1983. Ces canaux seront utilisés pour des services commerciaux tels que fac-simile, transmissions de données d'ordinateur et vidéo-conférences. Lorsque le Conseil de l'ASE l'aura approuvée en mars 1981 cette modification sera sanctionnée par un avenant en bonne et due forme au contrat principal de développement d'ECS. Eutelsat intérimaire a également décidé de louer une capacité de services commerciaux sur le satellite de communications français, Telecom-I, premier satellite non ASE dont la conception est basée sur celle d'ECS.

En ce qui concerne le contrat de réalisation industrielle d'ECS, la structure du module de service d'ECS-1 construite par Aeritalia (I) a été envoyée par ERNO (D) chez Matra à Toulouse (F), en février 1981, après installation du sous-système de pilotage par réaction. L'assemblage, l'intégration et les essais (AIT) du satellite commenceront en mars, pour aboutir à un lancement sur Ariane L7 en avril 1982.

Marecs

Le contrat prévoyant la fourniture par l'ASE de deux satellites a été signé entre l'Agence et Inmarsat, de sorte que les services d'Inmarsat pourront commencer entre le 1er janvier et le 31 juillet 1982. L'un des satellites sera mis à poste au-dessus de l'Atlantique et l'autre au-dessus du Pacifique.

Le satellite Marecs A a été intégré et subit actuellement des essais chez le contractant principal, les essais d'ambiance commenceront en avril.

Le module de communications du satellite Marecs B a été intégré et les essais doivent en principe commencer en mars, puis le satellite sera expédié chez le contractant principal en avril. Les modules de service et de communications seront alors intégrés pour que les essais d'ambiance de Marecs B puissent commencer en août/septembre 1981.

La station de télémesure, télécommande et poursuite (TTC) de Villafranca (Espagne) en est au stade final de réception. Un contrat a été passé avec KDD pour l'installation à Ibaraki (Japon) d'une station similaire destinée au contrôle du satellite qui sera mis à poste au-dessus de l'Océan Pacifique.

L-Sat

En novembre dernier les Etats membres participant au programme L-Sat ont approuvé le démarrage de la phase B2, sous réserve d'un ensemble de conditions au nombre desquelles figuraient la solution des arbitrages clés au niveau système et un accord définitif sur la désignation des contractants assumant la responsabilité des sous-systèmes dans un certain nombre de secteurs. Ces conditions ayant été remplies, les travaux ont démarré en décembre. La phase B2 couvre l'achèvement de la définition du satellite jusqu'au niveau des équipements, y compris la sélection, après mise en concurrence des fournisseurs d'équipements par les contractants responsables des sous-systèmes; cette phase doit se terminer par la proposition relative à la phase principale de réalisation (phase C/D), dont on prévoit la présentation par le contractant principal, British Aerospace, en mai 1981. Le planning industriel actuel est compatible avec le lancement de L-Sat 1 à la mi-1985.

integrated and is undergoing testing at the prime contractor before the start of environmental testing in April.

The communications module of the Marecs 'B' satellite has been integrated and testing is expected to start in March, before shipment to the prime contractor in April. The service and communications modules will then be integrated with the aim of starting Marecs-B environmental tests in August/September 1981.

The telemetry, telecommand and tracking (TTC) station in Villafranca (Spain) is in its final stage of acceptance. For control of the Pacific-Ocean satellite, a contract has been placed with KDD for the implementation of a similar station in Ibaraki (Japan).

L-Sat

Last November, the Member States participating in L-Sat approved the start of phase B2 subject to a set of conditions including resolution of key system trade-offs and final agreement on contractor nominations for subsystem responsibility in a number of areas. These conditions were subsequently satisfied and work started in December. Phase B2 covers the completion of the satellite definition, down to equipment level, including competitive selection of equipment suppliers by the subsystem contractors, ending with the proposal for the main development phase (phase C/D) which is scheduled to be submitted by the prime contractor, British Aerospace, in May 1981. Current industrial planning is compatible with the launch of L-Sat 1 by mid-1985. A holding phase is foreseen to maintain industrial continuity during the period June – September 1981 while Member States discuss and agree the legal framework for proceeding to phase C/D.

Meteosat

Space segment

Meteosat-1, launched in November 1977, continues to support the data-collection mission.

Meteosat-2 is ready for launch on Ariane-L03, now scheduled for June 1981. Tests at the solar facilities have indicated that the satellite thermal shield can adequately handle the predicted thermal impact from the Ariane second-stage retro-rockets.

STELLA data-transmission experiment antenna installed in Pisa (I) for tests via OTS.

Antenne STELLA installée à Pise (I) pour l'expérience de transmission de données via OTS.

Exploitation

The data-collection mission is now supporting 30 platforms. Taking advantage of the Meteosat-2 launch delay, the mainframes of the Meteosat ground computer system are being replaced with the aim of reducing exploitation cost and improving system availability.

Operational programme

The Intergovernmental Conference on an Operational Meteosat Programme held its first session on 28 and 29 January 1981 at ESA Headquarters in Paris. The Governments of 17 European countries were represented, expressing their interest in such an operational programme. As a result, a working group was set up to prepare system specifications and to recommend an institutional framework for the implementation of a Meteosat operational programme.

Sirio-2

Assembly, integration and test of the satellite electrical model have been successfully completed. The Final Design Review on 17–19 March 1981 will assess the results and recommend that go-ahead be given for the integration of the flight model. The contractual delivery date of the satellite to the Guyana Space Centre (CSG) is 24 August 1981. In view of the delay in the Ariane-L5 launch until February 1982, bridging activities will be negotiated with the prime contractor.

Preparations for the Sirio-2 exploitation phase are continuing according to schedule. Integration of the S-band station and associated data-processing facilities is about to begin.

The LASSO mission scenario has been defined with the help of representatives of the timing and geophysical user communities. The MDD experimental campaign is being organised with the support of the World Meteorological Organisation (WMO).

Remote Sensing

With the adherence of Norway, there are now 13 states participating in the Remote Sensing Preparatory Programme, which

Une phase d'attente est prévue au cours de la période juin-septembre 1981, de façon à préserver la continuité industrielle pendant que les Etats membres discuteront et approuveront le cadre juridique qui doit permettre de passer à la phase C/D.

Météosat

Secteur spatial

Météosat-1, lancé en novembre 1977, continue à assurer la mission de collecte des données.

Météosat-2 est prêt à être monté sur Ariane L03, dont le lancement est fixé maintenant à juin 1981. Les essais menés dans les simulateurs solaires ont montré que le bouclier thermique du satellite pouvait encaisser normalement le choc thermique des rétrofusées du deuxième étage d'Ariane.

Exploitation

La mission de collecte des données dessert actuellement 30 plates-formes. Tirant parti du retard du lancement de Météosat-2, on remplace actuellement les unités principales du système de calcul au sol de Météosat en vue de diminuer les coûts d'exploitation et d'améliorer la disponibilité du système.

Programme opérationnel

La Conférence intergouvernementale sur un programme Météosat opérationnel a tenu sa première session les 28 et 29 janvier 1981 au siège de l'ASE à Paris. Les représentants des gouvernements de 17 pays européens ont manifesté leur intérêt pour ce programme. Un groupe de travail a donc été créé en vue de préparer les spécifications du système et de recommander un cadre institutionnel pour la mise en oeuvre du programme Météosat opérationnel.

Sirio-2

L'assemblage, l'intégration et les essais du modèle électrique du satellite ont été menés à bonne fin. L'examen final de conception, qui aura lieu du 17 au 19 mars 1981, permettra d'en évaluer les résultats et de recommander que le feu vert soit donné à l'intégration du modèle de vol. La date contractuelle de livraison du satellite au CSG est fixée au 24 août 1981. Compte tenu du retard du lancement Ariane L5, reporté à février 1982, des activités intermédiaires seront négociées avec le contractant principal.

Les préparatifs de la phase d'exploitation de Sirio-2 se poursuivent conformément au calendrier. L'intégration de la station bande S et des installations associées de traitement de données va démarrer sous peu.

Le scénario de la mission LASSO a été défini avec l'aide de représentants des communautés d'utilisateurs (géophysique et chronométrie). La campagne expérimentale MDD est en cours d'organisation avec l'appui de l'Organisation météorologique mondiale (OMM).

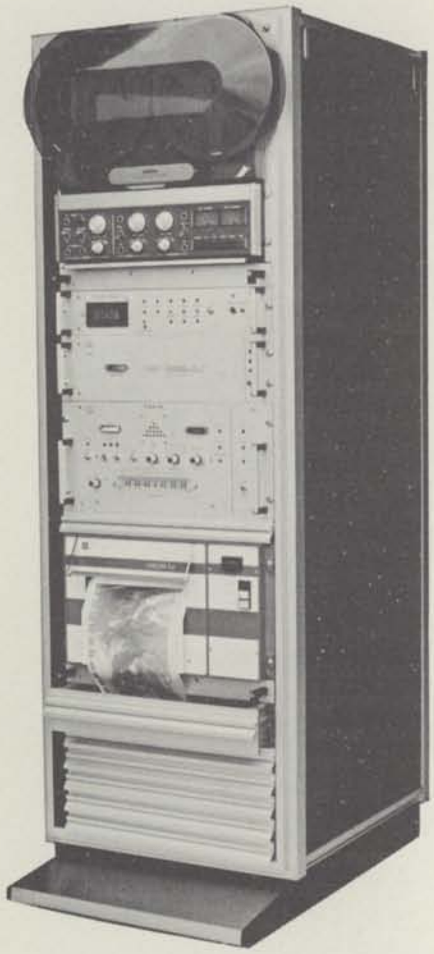


photo cit alcatel

Equipement fac-simile STR/2000 utilisé pour la réception des images WEFAX de Météosat.

STR/2000 facsimile equipment used for the reception of WEFAX pictures from Meteosat.

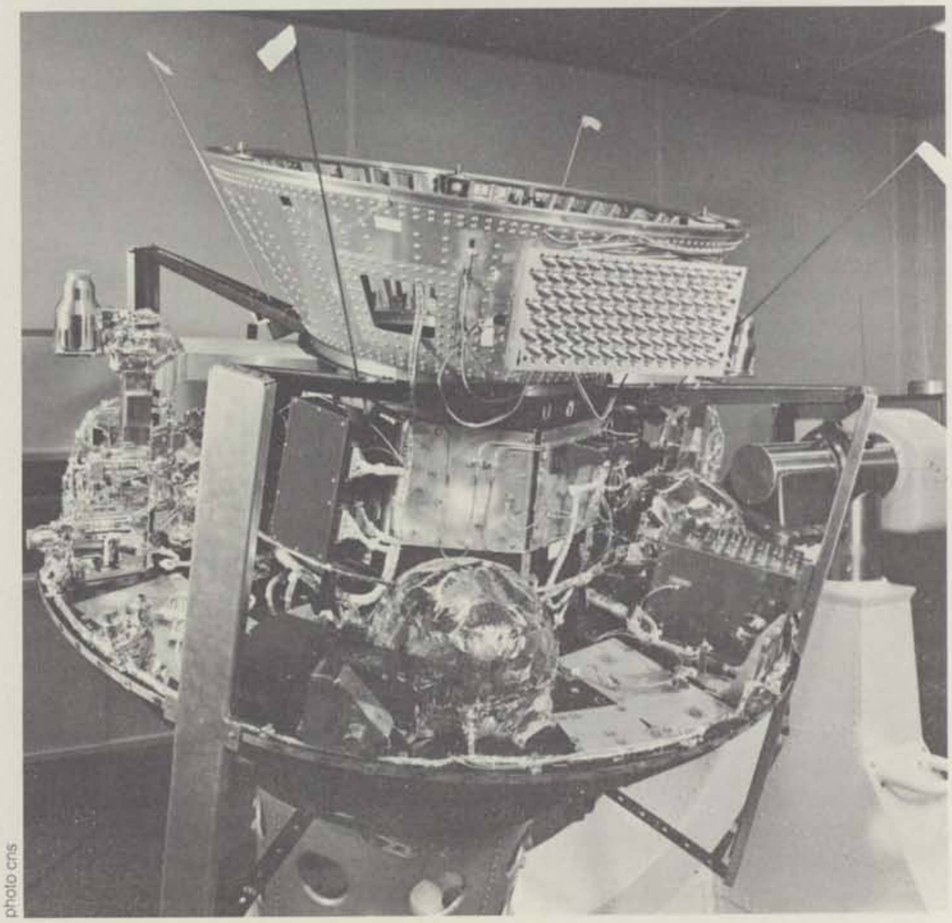


photo cns

Sirio-2 équipé de réflecteurs laser destinés à l'expérience LASSO.

Sirio-2, with its laser reflectors to be used for the LASSO experiment in position.

has been extended from March until December 1981.

The flight schedule for the SAR 580 campaign has now been finalised and the campaign will start on 22 May 1981.

The wind and wave scatterometer study has been completed and definition of the altimeter is progressing according to schedule. On 3 March 1981, the Remote Sensing Programme Board approved the proposed nominal payload for the first ESA Remote Sensing Satellite, ERS-1. This nominal payload is composed of:

- C-band active microwave instrumentation (AMI), combining the function of a synthetic aperture radar (SAR), a wave scatterometer and a wind scatterometer, primarily for wind-field and wave-spectrum determination and all-weather imaging,
- an ocean colour monitor (OCM), primarily for the measurement of sea-surface temperatures and determination of the ocean colour,
- a radar altimeter (RA) primarily for the measurement of significant wave heights.

The ERS-1 procurement proposal has been approved by the Industrial Policy Committee (IPC). It is planned to present the programme proposal for the overall ERS-1 system (including the ground segment) to the next Remote Sensing Programme Board (PB-RS) meeting in early June and the call for tender for the ERS-1 phase B is expected to be issued at the end of June.

Ariane

The injectors for the five engines of the Ariane launch vehicle for the L03 test flight have been successfully acceptance tested on the SEP test stands at Vernon, and are now being fitted.

These injectors have undergone the modifications adopted following the investigations and tests carried out in order to overcome the high-frequency phenomena that occurred during the L02 test flight.

Modified Ariane Viking-engine injector which underwent firing tests in January.

Cet injecteur modifié du moteur Viking d'Ariane a subi des essais de mise à feu en janvier.

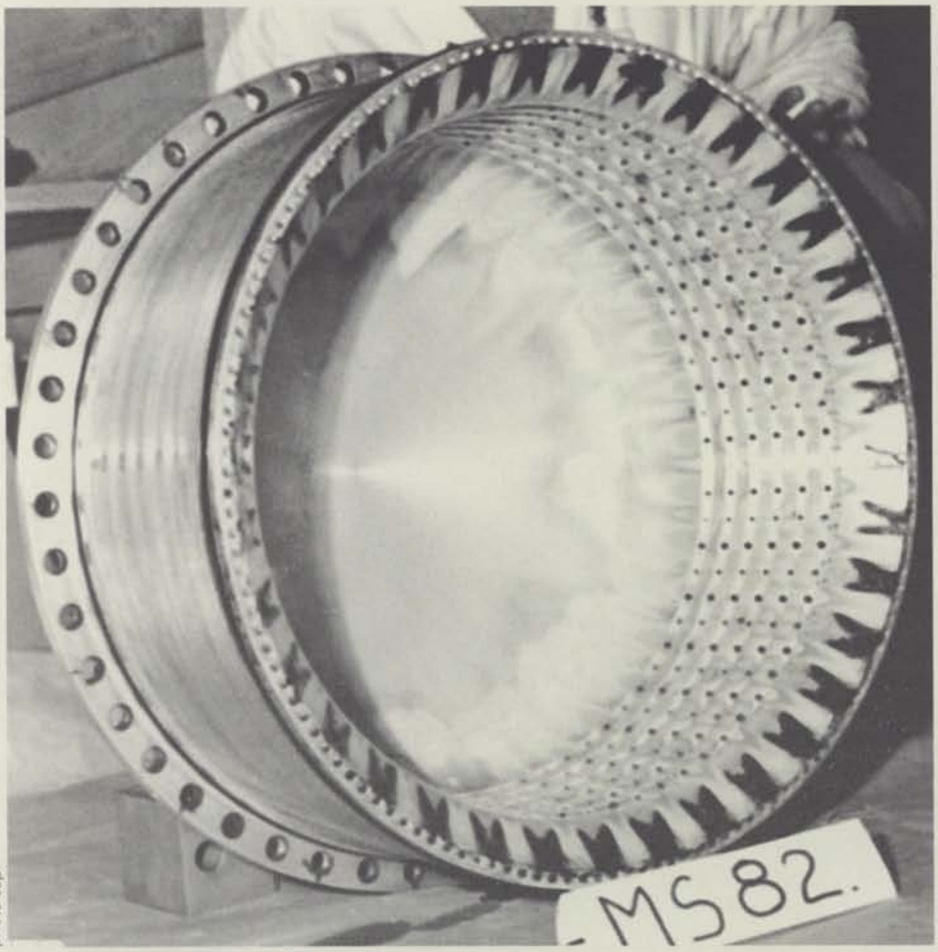


photo sep

Acceptance involves two 'hot' tests of each injector under conditions much more severe than those encountered in flight.

The results were very satisfactory and, as things now stand, the third Ariane test flight can be scheduled for the second half of June.

The Ariane L03 vehicle will fly:
- a technological capsule (CAT), scheduled for all the development flights, containing electronic equipment and environmental sensors
- the European meteorological satellite, Meteosat-2, to be shipped to Guyana in mid-April
- the Apple communications satellite, designed and constructed by the Indian Space Research Organisation (ISRO).

The satellite campaign will start in the second week of April and that of the launcher early in May. The launch slot will be fixed at that time.

Series production of the launcher has already started. To date, 13 firm orders for launches have been received, together with 12 options or reservations.

FSLP

Payload integration activities have continued at ERNO with the build-up of the bridge assembly which fits on the pallet. The transfer from NASA to SPICE of the staged Spacelab experiment racks will take place in late March. All mission-peculiar equipment needed to support the integration (such as harness, fixation elements) has been delivered. Thermal blankets will be cut and tailored during integration and finally fitted into position during US activities.

By the end of March, eight European experiments will have been delivered to ERNO for integration. Other experiments are presently undergoing acceptance testing at various facilities (mainly ESTEC and CNES), and deliveries will be made progressively until about July 1981.

Based on the launch date of late-1983, it is scheduled to complete European integration activities by early 1982.

Télédétection

A la suite de l'adhésion de la Norvège, 13 Etats participent désormais au Programme préparatoire de Télédétection qui durera jusqu'en décembre 81 au lieu de mars 81.

Le calendrier des vols de la campagne SAR 580 est définitivement arrêté; elle démarrera le 22 mai 1981.

L'étude des diffusiomètres 'vent' et 'vagues' est terminée et les travaux de définition de l'altimètre progressent conformément au calendrier. Le Conseil directeur du Programme de Télédétection a approuvé le 3 mars 1981 la charge utile nominale proposée pour le premier satellite de télédétection de l'ASE, ERS-1. Cette charge utile nominale se compose:

- d'un instrument actif à hyperfréquences (AMI) opérant en bande C et combinant les fonctions d'un radar à synthèse d'ouverture (SAR), d'un diffusiomètre 'vagues' et d'un diffusiomètre 'vent'; il a pour objet principal la mesure des champs de vent et du spectre des vagues ainsi que la prise d'images tous temps,
- d'un imageur 'couleur des océans' (OCM) ayant principalement pour objet la mesure de la température de surface et de la couleur des océans,
- d'un altimètre radar (RA) ayant principalement pour objet la mesure de la hauteur significative des vagues.

La proposition d'approvisionnement d'ERS-1 a été approuvée par l'IPC. La proposition de programme pour l'ensemble du système ERS-1 (secteur sol compris) doit être présentée à la prochaine réunion du PB-RS, début juin, et l'appel d'offres pour la phase B2 ERS-1 devrait être envoyé à la fin du même mois.

Ariane

Les injecteurs devant équiper les cinq moteurs de l'exemplaire d'essai L03 de la fusée Ariane ont été recettés avec succès aux bancs d'essais de la SEP à Vernon et sont maintenant en cours de montage.

Ces injecteurs ont subi les modifications retenues à la suite des recherches et essais entrepris pour pallier les phénomènes de hautes fréquences apparus lors de l'essai en vol L02.

photo sep

Le moteur Viking-V d'Ariane au cours des essais au banc PF2 à la SEP, Vernon, en janvier.

Ariane Viking-V engine being tested on stand PF2 at SEP, Vernon, in January.

La recette comprend deux essais de chaque injecteur 'à feu' dans des conditions très sévères par rapport à celles rencontrées en vol.

Les résultats obtenus ont été très satisfaisants et permettent d'indiquer, au stade actuel, que le 3ème essai en vol d'Ariane interviendra dans la deuxième quinzaine du mois de juin 1981.

Le lanceur Ariane L03 emportera:
- une capsule technologique (CAT) prévue sur tous les vols de développement et qui contient des équipements électroniques et des capteurs d'environnement,
- le satellite européen de météorologie Météosat-2, dont l'expédition en Guyane est prévue pour la mi-avril,
- le satellite de télécommunications Apple, conçu et réalisé par l'Organisation indienne de Recherches spatiales (ISRO).

La campagne satellites commencera la deuxième semaine d'avril et la campagne lanceur début mai. Le créneau de lancement sera précisé à ce moment là.

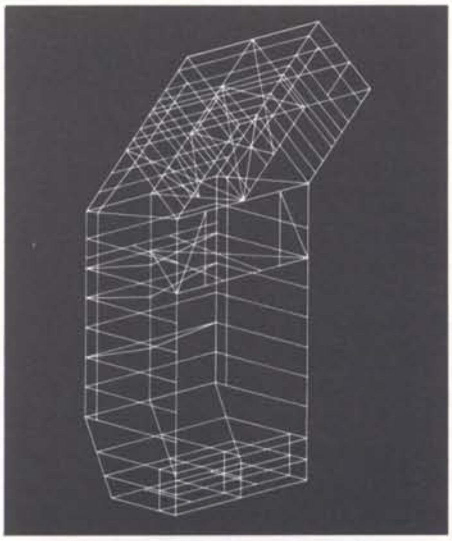
La production en série du lanceur est déjà engagée; à ce jour des commandes fermes ont été enregistrées pour 13 lancements auxquelles s'ajoutent 12 options et réservations.

FSLP

Les activités d'intégration de la charge utile ont été poursuivies chez ERNO avec le montage du pont destiné à prendre place sur le porte-instruments. Fin mars la NASA remettra au SPICE l'ensemble des baies d'expériences du Laboratoire spatial. Tous les équipements spécifiques nécessaires au soutien des activités d'intégration pour une mission donnée (tels que câblage et éléments de fixation) ont été livrés. Les couvertures de protection thermique seront taillées sur mesure au cours de l'intégration et mises en place aux Etats-Unis.

Outre huit expériences européennes, qui ont été livrées à ERNO fin mars pour intégration, d'autres expériences subissent actuellement les essais de recette dans divers établissements – principalement à l'ESTEC et au CNES – et leur livraison s'échelonnera jusque vers juillet 1981.

Dans l'hypothèse d'un lancement fin 1983, on prévoit de terminer les activités d'intégration en Europe au début de 1982.



Spacecraft Structural Analysis Activities at ESTEC

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The last two decades have seen a progression from small, rigid, spin-stabilised satellites towards large, flexible, sophisticated spacecraft with multi-axis stabilisation, and high pointing and alignment requirements. This evolution has necessitated the development of accurate and reliable structural design and evaluation techniques. Although a number of procedures are well established for evaluating spacecraft structural capabilities to withstand time-invariant loads, practical methods are still under development for determining the structural integrity of spacecraft subjected to time-dependent loadings such as lift-off transients. Spacecraft structural analysis relates essentially to the designing of structural hardware that deforms within acceptable limits when subjected to ground, launch, and in-orbit environmental conditions.

Historical background to structural analysis

The first quite general method of analysing statically indeterminate structures was evolved by Navier and expounded in his lecture at the Ecole Polytechnique in Paris in 1819. His technique was based on direct application of equilibrium and compatibility conditions. The evolution of the more modern methods can be traced back to the work of Maxwell in 1864 and Castigliano in 1878, who formulated energy principles and thereby laid the foundations for engineering mechanics. These early developments, summarised in Figure 1, provide the bases of structural analysis and design techniques to this day.

The application of early analysis methods to complex problems was limited by the availability and power of computational devices and the history of the finite-element method really only began at the time when digital electronic computers first became a reality (Fig. 2). The origins of modern finite-element practice are to be found in the needs of the aircraft industry, where the dual demands of minimum weight and maximum structural integrity have been the dominant factors of influence for improvement.

In the period up to 1955, both the 'force' and 'displacement' methods were postulated as completely general complementary techniques for structural analysis. Early papers by Falkenheiner, Langefors, Wehle, Lansing, Denke, Argyris and Kelsey support this view. Indeed classical papers by Argyris (originator of the finite-element method) appearing in Aircraft Engineering (1954–1955) strongly emphasise the duality of the variables within the two approaches and show that an identical series of matrix operations can be employed in proceeding from basic problem data to the total solution for both forces and displacements. It is generally acknowledged that the first complete formulation of the displacement approach was provided by Argyris and later independently by Turner et al. Some earlier work contributed to the fundamental theory of the discrete element analysis of complex structures with displacements as unknowns, but were incomplete with regard to the automation of the computational process. The period 1954 to 1965 was mainly devoted to establishing computer-based techniques and was dominated by proponents arguing the case of both force and displacement methods. Towards the end of this period the descriptive term 'matrix methods of analysis' gradually lost favour to the general title of 'finite-element methods'.

The finite-element method

The process of selecting only a certain number of discrete points in a body can be termed 'discretisation'. One of the ways of discretising a body or a structure is to divide it into an equivalent system of smaller bodies, or units. The assemblage of such units then represents the original body and, instead of solving the problem for the entire body in one operation, solutions can be formulated for each constituent unit and combined to obtain the solution for the original structure. The

Mathematical basis of the finite-element displacement method

For linear elastic problems, employing the principle of virtual work

$$\delta W_i = \delta W_e$$

an integral formulation of static compatibility is derived by equating the internal and external virtual work of the static field σ, p_v, and p_s with the virtual kinematic field $\delta\gamma$ and δu

$$\int_v \delta\gamma^t \sigma dV = \int_v \delta u^t p_v dV + \int_{S_\sigma} \delta u^t p_s dS$$

This equation is equivalent to the differential form of static equilibrium

$$D\sigma - p_v = 0$$

combined with the stress boundary condition on the surface S_σ

$$[Dn]\sigma = p_s$$

Implicitly it is permitted to employ only compatible virtual strain and displacement fields $\delta\gamma$ and δu

$$\gamma = D^t u \quad \text{and} \quad \delta\gamma = D^t \delta u$$

and the displacement boundary conditions on the surface must also be satisfied

$$u = u_s$$

In the previous equations D denotes a differential operator. The finite-element displacement method utilises the principle of virtual displacements to construct, via an approximate displacement field, a discrete set of equilibrium equations.

The procedure for the kinematic definition of a single finite element is as follows. The displacement field u is given by

$$u = \omega\rho$$

where the interpolation functions ω define the spatial variation of displacements u in terms of the nodal degrees of freedom ρ. The total strain field γ is given by

$$\gamma = D^t u = (D^t\omega)\rho = \alpha\rho$$

and is defined by linear contributions of the displacement gradient field as derived from the previous equation. For a linearly elastic material, the stress field σ is given by

$$\sigma = E\varepsilon = E(\gamma - \eta) = E\gamma + \tau$$

The concepts of initial strains and initial stresses are equivalent since

$$\tau = -E\eta$$

and they provide a mechanism to account for nonelastic deformations which may arise either from environmental conditions such as temperature, moisture, irradiation, or from mechanical conditions such as plasticity and creep.

It is important to note that the virtual-work formulation does not depend on the stress/strain law since no assumption has to be made with regard to the existence of energy potential for deriving stresses. Employing the principle of virtual work, the following discrete form of element equilibrium is obtained

$$k\rho = Q + J$$

where the individual element quantities are defined as element stiffness k,

$$k = \int_v \alpha^t E \alpha dV$$

nodal loads Q kinematically equivalent to distributed body forces and surface tractions,

$$Q = \int_v \omega^t p_v dV + \int_{S_\sigma} \omega^t p_s dS$$

and nodal initial loads J kinematically equivalent to initial strains or stresses,

$$J = \int_v \alpha^t E\eta dV = -\int_v \alpha^t \tau dV$$

The individual element contributions can now be assembled using the Boolean connectivity matrix a_I which transforms element into structural degrees of freedom

$$\rho = a_I r$$

The overall structural stiffness

$$K = \sum_I a_I^t k_I a_I$$

and the structural loading

$$R = \sum_I a_I^t (Q_I + J_I) + R_G$$

The structural load vector R contains contributions from distributed body and surface tractions Q_I, from initial stresses or strains J_I, and from concentrated nodal forces R_G. Structural equilibrium is then described by

$$K r = R$$

This system of simultaneous equations can be solved for the nodal displacements r, which in turn define the state of deformation, strain, and stress within each element of the total structure.

basis of the finite-element method is, then, the representation of a structure by an assemblage of subdivisions called 'finite elements'.

The simplest mathematical definition for a finite element is perhaps that it represents a piecewise application of the Rayleigh/ Ritz procedure to discrete domains of the complete structure or continuum.

In fact, the assembly of these domains forms the so-called 'idealised representation of the physical system'.

The preceding paragraphs present only a very limited specification of the finite-element method, the general philosophy of which has a much broader framework. As a technique it is not restricted to structural or solid mechanics problems, but is also applicable to a wide range of physical phenomena described by a set of field equations, e.g. in hydrodynamics, thermodynamics, and structural dynamics as well as coupled problems such as 'pogo'.

Structural-analysis software

The structural work performed in ESA is conducted within the framework of:

- defining design specifications for spacecraft structural hardware
- defining test levels and procedures for spacecraft qualification
- monitoring in the design and development phase the capability of a design to withstand mission requirements
- acting as an interface between various European contractors and NASA, for the transfer of structural information and flight loads
- defining and monitoring research work in selected topics
- promoting the state of the art and assisting technology transfer in the structural field between ESA contractors.

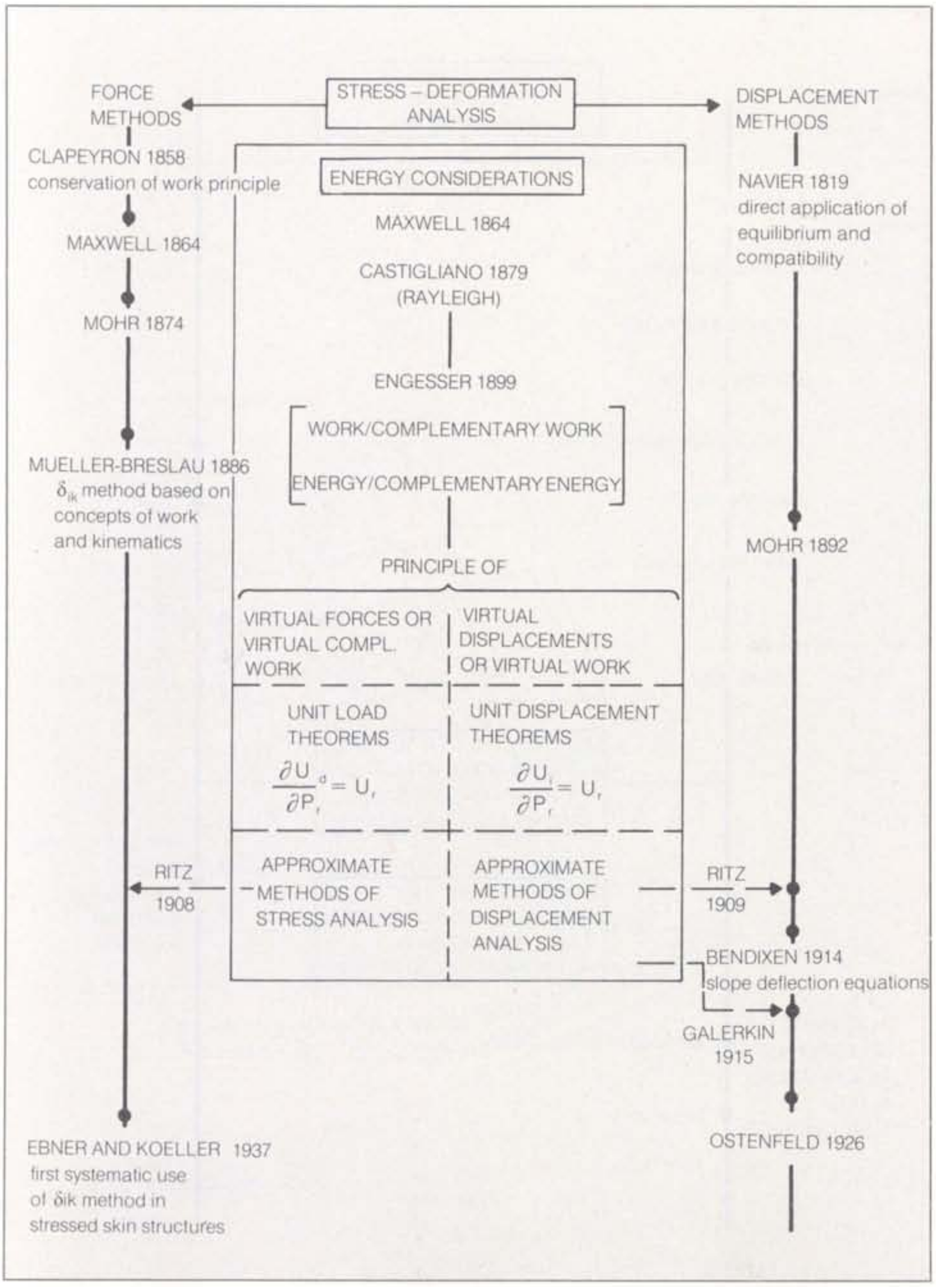
The efforts expended on structural-analysis software in the Agency are therefore directed towards grouping available capabilities and incorporating future acquisitions and improvements with a view to achieving maximum efficiency and flexibility in future investigations of the wide range of spacecraft-related structural problems.

(a) Library of structural-engineering computational procedures

This library contains procedures for evaluating spacecraft structural configurations and designs, for establishing static and dynamic test levels, and for deriving structural parameters for attitude-control evaluations. The following general procedures are available within the in-house software:

Static analysis
Load case combination
Tangent modulus

Figure 1 – Foundations of modern analysis methods



Eigenvalue, eigenvector extraction
Substructure technique
Frequency response
Transient response
Large displacement
Large strain
Buckling and post buckling
Heat conduction
Mode synthesis
Dynamic mass evaluation
Direct integration methods, Newmark Beta
Houbolt, central difference operator
Thermal stress
Fracture mechanics J-integral
Initial strain
Cyclic symmetry procedures
Random and acoustic vibrations

(b) Library of finite elements
The procedures mentioned above operate on structural data generated from the following element types:

Flange
Beam
Axisymmetric shell
Axisymmetric solid
Axisymmetric harmonic for shell and solid
Membrane 3-D
Curved shells
Pre-stressed membrane
Solid 3-D
Composite plate
Flat plate

Lower and higher interpolation functions are available for certain types of element. The order of the function employed in a problem depends on the accuracy desired and cost constraints.

(c) Library of material properties
The elements mentioned can accept material properties in the most general form encountered in spacecraft structural applications. Specifically, the following material properties can be introduced:

Elastic
Isotropic
Anisotropic
Nonlinear elastic
General material property definition
Fibre and matrix composite properties

(d) Library of load functions and test data
Flight-load and coupled response analyses performed for ESA spacecraft by the Thor-Delta, Ariane, and Space Shuttle launcher authorities, are gathered in a form that provides an overview when defining new spacecraft design and qualification levels. Moreover, such information can be applied to specific problems when assessing the integrity of a structure to withstand certain flight events.

Parallel work is performed with the information gathered to reduce the likelihood of overtesting, and to allow

Figure 2 — Significant contributors to the development of finite-element methods

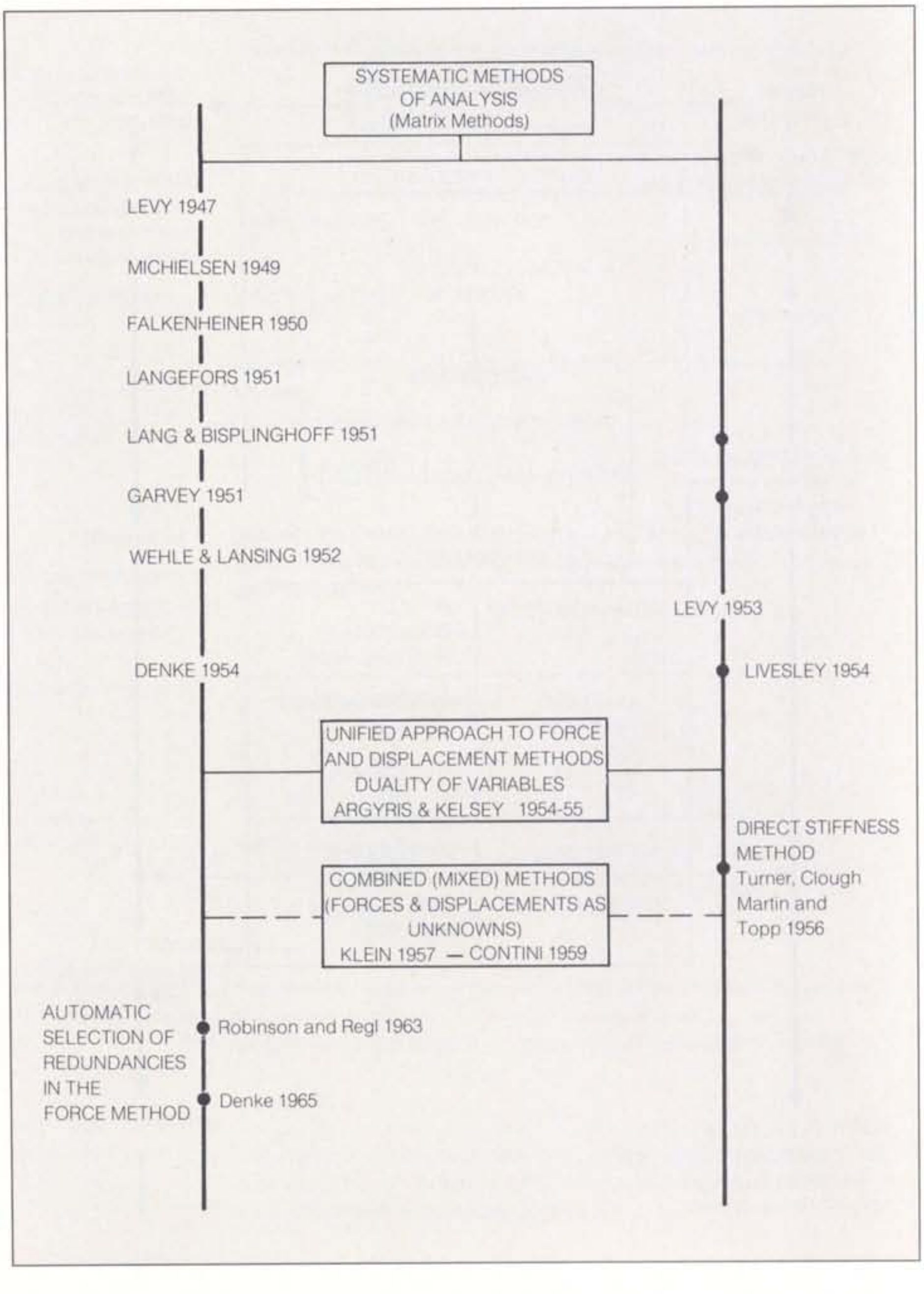
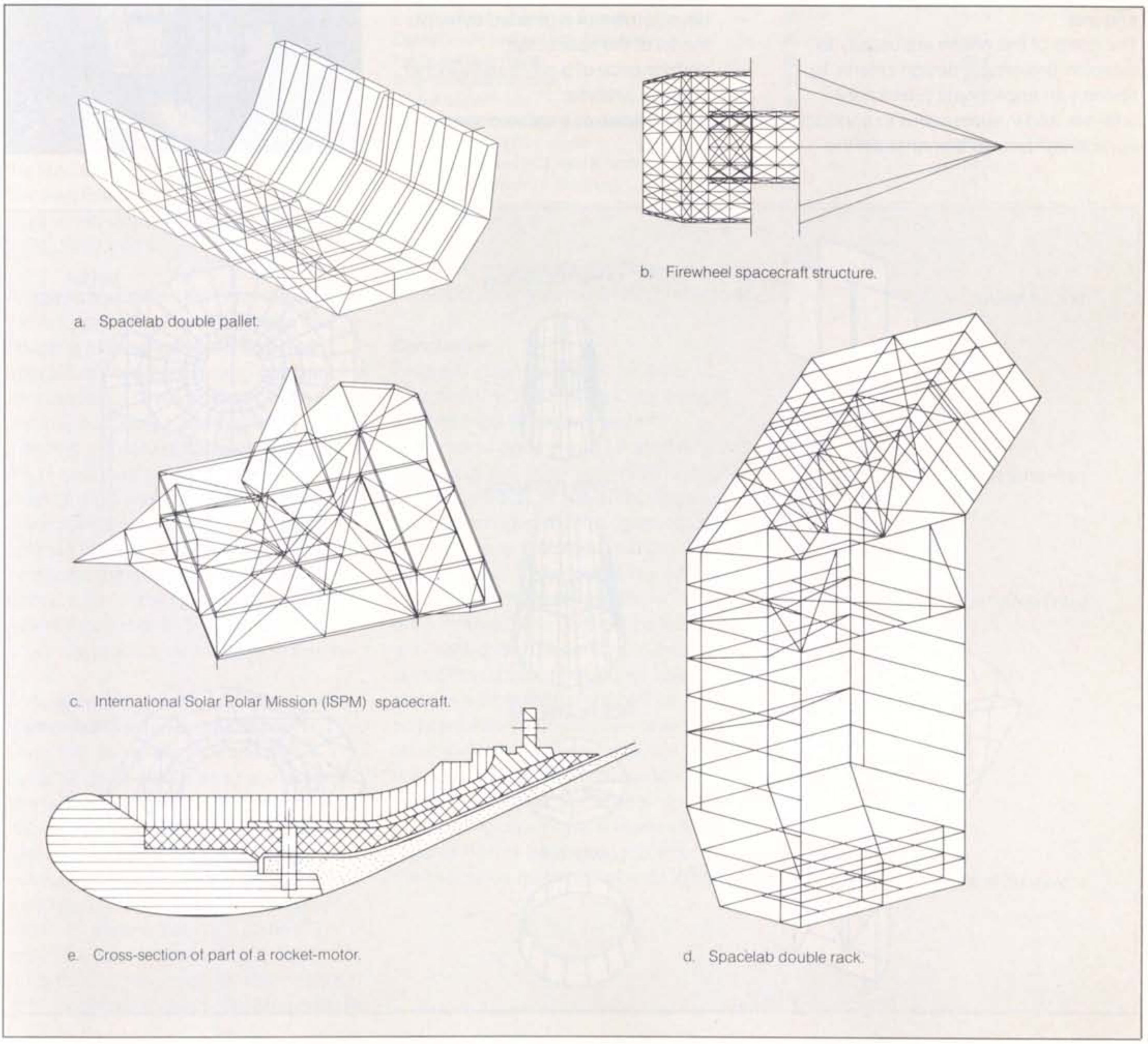


Figure 3 – Finite-element representations of ESA spacecraft

simple but accurate definition of dynamic design loads.

(e) Library of graphics packages
Data-generation, pre- and post-processors are employed to facilitate rapid and efficient handling of engineering problems. The related software includes mesh generators, selection of worst-loading cases, and display of undeformed and deformed structures.

The basis of all in-house software activities is the ASKA package. Its modular form, and the available flexibility in stirring and controlling job operations with simple commands has made this programme an invaluable tool in all structural-analysis work performed by ESA. In particular, the general concept of the database of the programme, with its general break and restart facilities, and the saving and recovery of data blocks, imposes virtually no limits on the size of problem that can be investigated. For large strains and deformations, the LARSTRAN programme is employed (both ASKA and LARSTRAN originate from the University of Stuttgart). For



a. Spacelab double pallet.

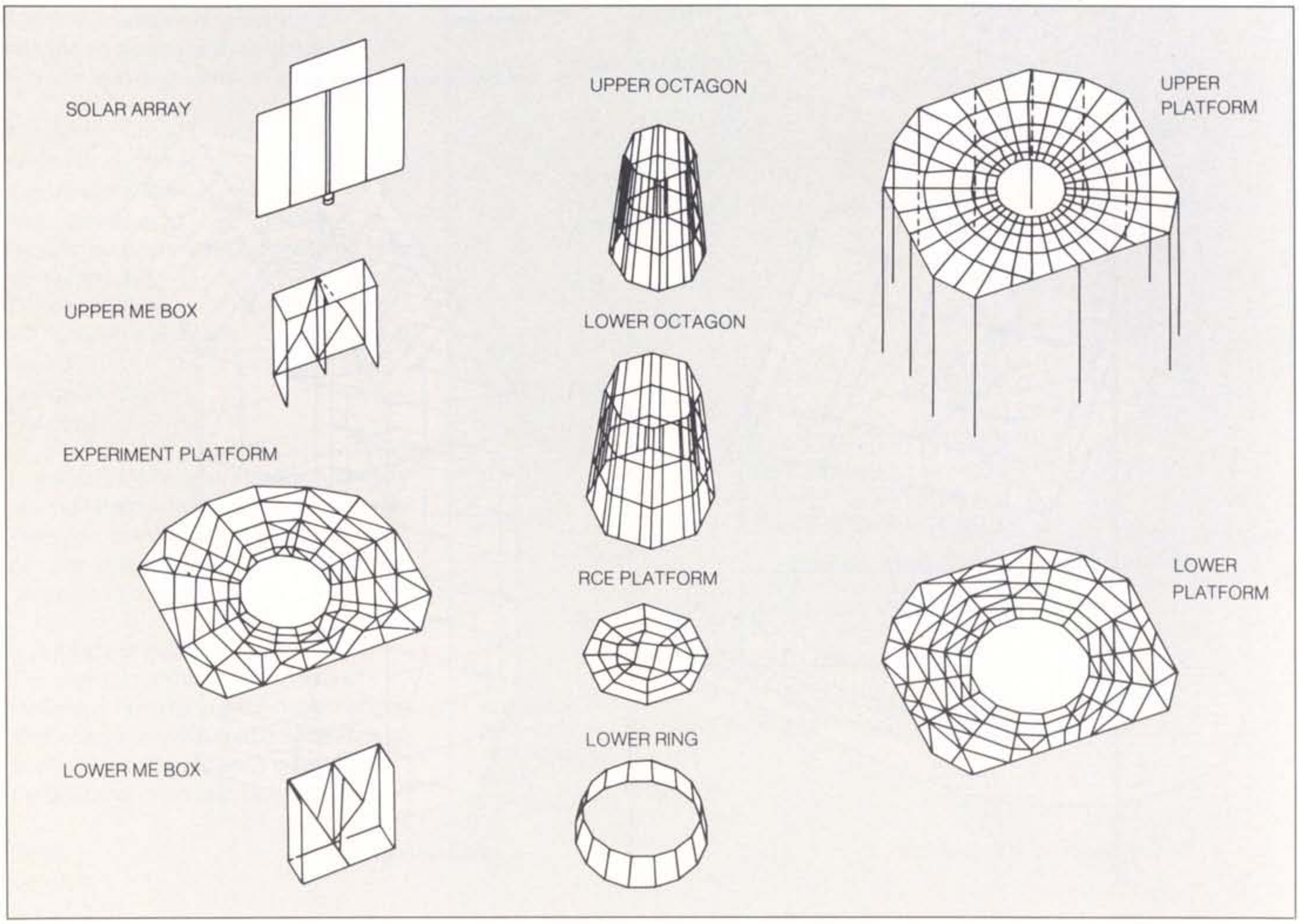
b. Firewheel spacecraft structure.

c. International Solar Polar Mission (ISPM) spacecraft.

d. Spacelab double rack.

e. Cross-section of part of a rocket-motor.

Figure 4 — The Exosat spacecraft structure



graphics applications, the FEMGEN and FEMVIEW packages are extensively employed.

Development and assessment of spacecraft structures

In developing and assessing spacecraft structures, a preliminary study is usually made before embarking on a detailed appraisal.

Preliminary structural design analysis and test

The goals of this phase are usually to establish preliminary design criteria, to perform an appropriate preliminary analysis, and in some cases to conduct appropriate tests to demonstrate the integrity of the primary structure. It is necessary to define lift-off static and dynamic loads, and to establish stiffness or strength criteria for secondary structures. The latter leads to a preliminary dynamic analysis.

Detailed structural design analysis and test

The objectives of the detailed analyses and tests that follow the preliminary development include:
- development of a detailed dynamic model of the spacecraft
- performance of a payload/launcher coupled analysis
- performance of a detailed stress analysis

- prediction of spacecraft-component responses due to the vibration test environment
- establishment of appropriate notching procedures
- performance of engineering-model tests
- execution of a detailed qualification test plan.

Structural analyses, involving definition of contractual specifications, monitoring of development phases and in some cases execution of certain work packages in ESTEC, have been performed for Spacelab and its instrument pointing system (IPS), for the Exosat and ISPM satellites, and for the Space Telescope, the MAGE booster motor, and for the German Firewheel experiment. A number of idealised structural models are shown in Figures 3 and 4.

A structural-analysis study for the Exosat project indicated at an early stage that coupling of experiment platform and optical benches, both having resonant frequencies at 70 Hz, would not occur and that the frequency matching was not inducing a severe load case. This allowed the project to proceed without redesigning the benches. The analytical predictions were confirmed at a much later stage with test data. Table 1 compares the analytical modes and frequencies for the Exosat mechanical model with test data. The validity of the analytical predictions is readily apparent.

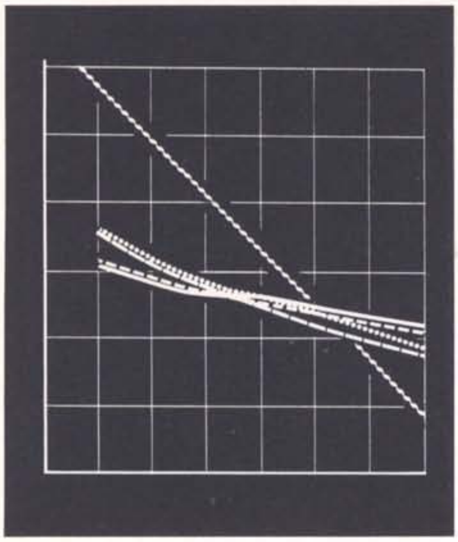
A study currently being performed for the Spacelab IPS involves the definition of structural design loads due to the dynamic lift-off and landing environments of the Space Shuttle. This work involves the introduction of dynamic transients derived by Rockwell for the Shuttle/pallet interfaces to obtain responses and forces for a representative pallet/IPS coupled model for various positions of the IPS within the Shuttle cargo bay. A single analysis loop here involves more than a million numerical values. Organisationally, it involves data interfacing between numerous European and US contractors.

Table 1 — Comparison of analytical modes and frequencies with test data for the Exosat mechanical model

Analytical and test mode shapes	Mechanical model test frequencies, Hz	Mechanical model analytical frequencies, Hz
First solar-array torsion	16	15.5
First bending (Y-direction)	23	24.6
First bending (X-direction)	24	27.4
Local longitudinal mode combined with solar-array lateral	35	32.7
Longitudinal lower platform mode	40	38.5
First fundamental longitudinal mode combined with solar-array lateral	42	41.9
Lateral mode coupled with solar array	46	45.7
Hydrazine tank mode	48	48.4
Solar-array lateral mode	50	49.8
Global lateral mode	55	55
Upper platform and lower platform mode	61	59.8
Experiments and RCE mode	65	64.8
Propane tank and RCE lateral mode	80	83.6
Global lateral mode (Y-direction)	85	83.7

Conclusion

Progress in the refinement of load definition and confidence in lightweight designs must keep pace with the demands of current and future spacecraft and space-structure requirements. Highly sophisticated payloads, stretching the limits of their own technologies, call for the assurance that performance demonstrated in the laboratory will not be destroyed by adverse launch environments. This confidence has to be achieved under the constraint that the supporting structure must not absorb the mass available for the spacecraft payload. Recent developments in computer technology have at last brought the capacity and speed demanded by structural analysts. Software is also now progressing rapidly, particularly as regards the pre- and post-processing of the enormous quantities of data involved.



Partners in Risk – Cost Incentives in Development Contracts

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Research and development programmes are bound to overrun their originally foreseen costs by large, and frequently disastrous, amounts: this is a commonplace view, treated by most laymen and professionals as a received truth, and the record of previous programmes does show that major increases over the planned – or at least the announced and approved – costs, are the norm. The reasons are many and much disputed and it is not the purpose of this article to discuss them. It is the intention, rather, to describe a contractual procedure used by the European Space Agency as one of the means of limiting and controlling such overruns within the context of its own research and development programmes, carried out on its behalf and under its supervision by aerospace industry working under contract.

The fundamental procurement policy of the Agency is laid down in its Contract Regulations [ESA/C(79)89], which came into force in January 1980, but which reflect largely the practice of the Agency (and its forerunner ESRO) since the inception of a cooperative European space programme. Article 4(4) reads:

'... Contracts shall wherever possible be placed at fixed prices provided they are substantiated, by competition or otherwise, as being fair and reasonable. If a fixed price cannot be agreed prior to signature, the contract may be placed at a ceiling price to be converted into a fixed price as early as possible during the course of the contract. If a ceiling price cannot be agreed, the contract may be placed on a cost-reimbursement basis. Incentives designed to achieve maximum economy and efficiency shall be included in contracts, where appropriate, particularly where they are to be placed on a cost-reimbursement basis...'

Whether any specific research and development programme, and in particular a satellite development contract, can realistically be placed at an overall fixed price is a difficult but fundamental decision, which determines to a large extent the way the programme will be conducted.

The basic, and generally accepted principle is that, where the costs of a programme can genuinely be estimated and agreed at or near the outset of a contract with a degree of accuracy that can be expressed in a mutually acceptable financial coverage of risk (say at most 10–15%), then a fixed price or ceiling price to be converted to fixed price is appropriate. Typical elements to be considered in determining the degree of certainty in the costing are:

- the degree of definition of requirements and solutions at the time the contract is placed
- the likelihood of the requirements fluctuating during the course of the contract
- the complexity, certainty and controllability of external interfaces, whether they be with a launcher, a payload or a cooperative partner in the framework of a more extensive programme
- the extent to which there has been competition between possible contractors
- the degree to which new, and possibly untried, technology is to be employed
- the experience of the contractor in similar programmes.

In addition to these evidently interrelated factors, the type of management approach that the customer wishes to use must be considered. A fixed price leads to relatively simple management, in which intervention by the customer in the contractor's efforts is more or less restricted. A cost-reimbursement contract allows a greater degree of visibility to and direction by the customer at the cost of significantly increased management effort. It cannot be excluded that in specific cases, and for good, if exceptional, reasons, a contract that by the above criteria would normally be placed at cost reimbursement, is placed

Figure 1 — Cost-sharing formulae

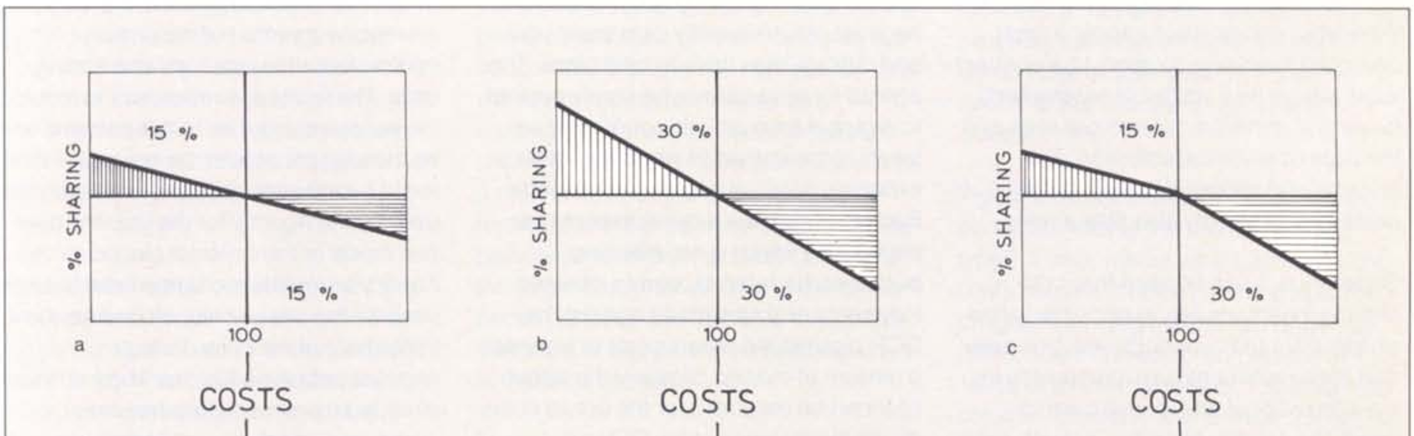
at fixed price. The consequences, perhaps acceptable in the specific case, are that the contract price will contain a large risk factor, and the possibility that the contractor might make either a large profit or a large loss.

The general practice of the Agency has been that scientific satellites, where the usually unique payload is developed separately and the striving towards perfection cannot be excluded, have been the subject of cost-reimbursement contracts, while applications programmes with a high degree of commonality, where the ultimate commercial viability is vital, and repeat or follow-on programmes, have been placed at fixed price.

It is thus in the nature of a cost-reimbursement contract that the uncertainty as to the cost at completion is large. It would nonetheless be imprudent and negligent procurement to leave the matter there, and merely note the costs as they accumulate. A sense of cost consciousness must be instilled and maintained both in the customer and the contractor, and no temptation must be placed in the way of the contractor to proceed in a way that is commercially or technologically advantageous to him, but of no real benefit to the customer's specified requirements. The Agency has, therefore, like other procurement agencies, developed 'incentives designed to achieve maximum economy and efficiency' in the form of cost-sharing agreements.

The basic principles of such a cost-sharing scheme are as follows. The parties agree, on the basis of the estimated cost presented in the contractor's offer, a target cost for the programme. This target cost should be a realistic and genuine estimate taking into account all the facts and elements known at the time. It should not be inflated to take account of all potential risks and uncertainties, nor is it sensible to negotiate an artificially low figure that lacks credibility. While the target cost constitutes the basis for calculating fixed fees, it does not contain them. At the end of the contract, the actual costs that have been incurred are compared with the target cost. If the incurred costs are less than the target cost, the 'savings' are apportioned between the customer and the contractor according to an agreed ratio. If the incurred costs are higher than the target, the contractor will not receive profits on those costs that are above the target, and will furthermore only be reimbursed a proportion of them, and thus himself contribute to the overall programme cost.

Various formulations of such schemes are shown in Figure 1, in which the target cost is in each case represented by 100. Figure 1a illustrates a simple scheme, with a sharing ratio of both cost underruns and overruns of 15/85%; i.e. the contractor



would receive 15% of the amount by which the target is underspent, as a bonus, but would only receive 85% of costs above the target. Figure 1b shows a sharing ratio of 30/70%, while Figure 1c illustrates a case where the ratio is different below and above the target.

It is sometimes considered appropriate in view of the technical uncertainties that the contractor should not begin to contribute directly the moment that the target is exceeded, and a neutral zone is introduced. If the incurred costs extend beyond the target into this zone (which typically may be 5%, or at the outside 10%, of the target) the contractor is paid his full costs, but without profit. His contribution only comes into play when the incurred costs exceed the target plus neutral zone. Figures 1d and 1e show possible configurations with neutral zones. Figure 1f shows how far, in principle, one could go by varying the sharing slope to a maximum. Such an extreme configuration might well provide the best possible incentive, but would be somewhat impractical to apply. Which particular formula is to apply to a contract must always be a matter of assessment, bearing in mind the commercial risks and the state of technical definition. The analysis and negotiation skills of the parties will obviously also play a role.

Stated thus, it can be seen that cost-sharing incentives are, in principle, rather simple. It should be recognised, however, that their implementation, particularly in the international environment within which the Agency operates, is much more complex. Some of the difficulties are described below.

Target cost

This may be expressed either as the total estimated costs of the programme, or of the cost-reimbursement part only (usually the prime-contractor activities) excluding any fixed-price subcontracts. Either approach is feasible and can be justified according to the situation. The target cost is fixed at the time of contract agreement and can only be modified due to changes to the scope of work which are the customer's responsibility (class-A changes in the Agency's terminology), and in which he has to pay the full costs.

Comparison of target and incurred costs

The target cost will have been expressed at the price level that forms the original pricing basis of the contract. The incurred costs will have been incurred at various times subsequent thereto. To compare the two, they must be brought to the same level. Either the target cost must be escalated up to the final level, in which case all intermediate incurred costs must also be escalated, or the actual costs must be de-escalated to the baseline pricing level. This is done by means of a formula based on national indices, which is a standard tool for fixed prices subject to price revision. It is not, however, always evident from the complex factors that go into agreeing a formula for a fixed price, that precisely the same formula should apply to a target cost, even for the same company over the same period, and negotiations, frequently long drawn out and difficult, may have to take place. The agreed formula cannot be simply applied to a global amount – account must be taken of the spread of time over which expenses occur or payments are made. Each contract has a development cost plan (DCP) which is, for planning purposes, updated at regular intervals. Payments might be made against the DCP, against the actual costs or against a mixture of the two. Similarly the target cost can be escalated, or the actual costs de-escalated, against the DCP or according to reality. A case can be made out for either approach, but a clear and unambiguous agreement has to be reached at the outset.

It is also evident that the final comparison can never be exact, but contains a certain arbitrariness based on the assumptions made and procedures utilised. To render the matter even more complex, class-A changes and the neutral zone are subject to the same adjustments, though in some cases the neutral zone has been expressed to be nonescalatable.

Exchange rates

A comparison between target and incurred costs must be made in a single real or artificial currency. A typical satellite contract, with a multitude of subcontracts, consists, however, of a mixture of national currencies. Even if the target cost covers only the classic prime contractor tasks, there are cases where these are distributed over two companies in different countries, both of whom participate in the cost-sharing. Furthermore, the prime contractor will have to pay sums of money during the course of the contract to subcontractors, which sums are allowable costs under the cost-reimbursement price without constituting class-A changes. Such sums, in a number of currencies, have to be taken into account in the final comparison.

At the time of placing the contract the target cost will be expressed in a single currency, either that of the prime contractor or the Agency's accounting units. The exchange rates used to reduce the various currencies to this baseline will be those applicable to the contract. These might be the annual fixed exchange rates used by the Agency for the year the offer was made or the contract placed, or the Agency's monthly exchange rates actually used for the offer, which will be retained if traceability of the price during negotiations demands this. There is, thus, already an element of arbitrariness introduced into the target at the outset.

The final costs can also be reduced to the common currency by the same exchange rates, or both final costs and target can be recalculated using some agreed exchange rates applicable at the end of the contract. The latter has, perhaps, the merit of slightly greater relationship to economic reality, but the first method, which is usual, does enable both parties to see clearly the development of costs measured against the target during the course of the contract, which is necessary if the incentive is to be effective. Neither approach can fully eradicate the possibility that revaluations of currency distort the picture to some extent to the detriment of one or other of the parties.

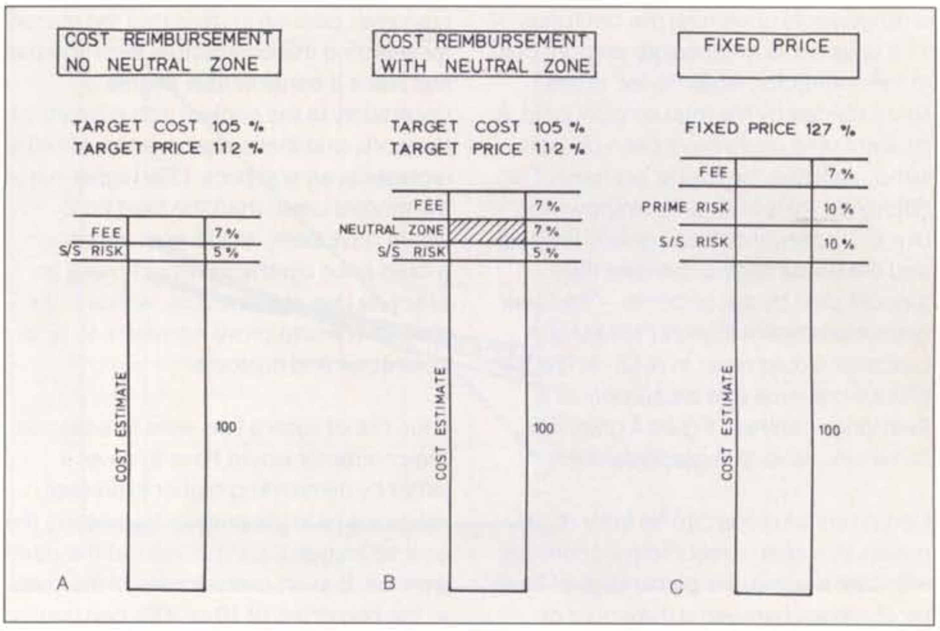
Technical performance

While keeping the end cost as low as possible is attractive, this should not lead to a technical performance below that required and specified. The balance between economy and technical excellence is a delicate one that varies from programme to programme, but a cost-sharing incentive without some balancing factor might tempt a contractor to take excessive technical risk in order to achieve a positive cost bonus. For this reason it is usual, in the end calculation of incentives, to combine the cost and technical incentive, 'technical' in this case including delivery on time. Thus a cost bonus due to the contractor will be multiplied by the factor expressing his technical performance under the performance incentive scheme of the contract. Likewise, his contribution in the case of an overrun will be divided by the performance factor. In the latter case a limiting factor is sometimes introduced on the overall potential penalty effect.

The unknowns and uncertainties of any development programme are such that the outcome of a cost incentive cannot really be foreseen, and even after the programme has ended it cannot be stated with confidence what the result would have been under a different contractual framework. Nevertheless, it is possible to create models based on reasonable assumptions which give enough of a picture to allow the negotiating parties to take sensible decisions.

Figure 2 gives a simplified cost and price structure for three different types of contract. In all cases it is assumed that the subsystems are at fixed price. The first

Figure 2 — Model contract (cost estimate = 100)



column shows a cost-reimbursement contract with cost sharing, but without a neutral zone. The basic estimate is expressed as 100 million accounting units (MAU), to which is added 5% to cover the prime contractor's risks in managing his subcontractors, and 7% nominal fee. The risk factor may be expressed as a contingency fund. The second column shows a somewhat riskier contract, where a neutral zone of 7% of the cost-reimbursement area is included. It should be noted that in both of these contracts the target cost (105 MAU) and the target price (112 MAU) are identical, though the likelihood of higher end costs is expected in the second case.

The third column shows a fixed-price contract, based on the same cost estimate of 100 MAU, but with a total risk factor of 20% to cover unforeseen events in both the subcontractor and the prime contractor tasks. It is of importance to note when making comparisons of the effectiveness of types of price and comparing end costs, that both of the cost-reimbursement contracts would be expressed and recognised as having a target price of 112, while the fixed price would be stated as 127 MAU.

It must be emphasised that the figures for risk factors and profits used in the models are not calculated in strict accordance with the ESA General Terms and Conditions, but are for the sake of simplicity taken as an approximate percentage of total cost. They do, nevertheless, represent typical and realistic totals.

Figure 3 demonstrates the commercial consequences of the use of the three types of price model, as a function of the costs actually incurred at the end of the programme, ranging from an underrun (80% total incurred) to an overrun of 140% of a nominal total of 100 MAU (first column). Blocks A and B show the effects for a cost-reimbursement contract with no neutral zone (A) and with a 7% neutral zone (B). In both cases the calculation has been made for both a 15% cost sharing and a 30% cost sharing, with equal slopes on either side of the target. The columns headed 'total paid by the Agency' give the total paid including both cost and fee. The equivalent for a contract without cost sharing will always be the total cost incurred plus either 7 MAU fixed fee or between 7 and 12 MAU depending on the contractual

Figure 3 – Cost and fee in the case of a cost underrun and overrun for three types of price model

arrangements governing the risk fund. 'Fee received' is an absolute amount paid to the contractor, while '% fee' is this figure divided by the total amount paid. A different ratio could have been chosen without altering the overall scenario. The equivalent for a fixed price is shown in block C, as regards the absolute fee paid and the percentage of fee over the amount paid by the customer – the latter of course remains static at 127 MAU. A customer would never in reality know the precise outcome and profitability of a fixed-price contract. Figure 4 gives the same calculations in graphical form.

Certain conclusions can be fairly readily drawn. In a cost-reimbursement contract with cost sharing, the percentage of final profit ranges between a maximum of approximately double nominal fee for a significant cost underrun, to a slight absolute loss for an overrun of 140%. This bandwidth appears reasonable and acceptable to both contractor and customer, bearing in mind that the reason for selecting this contractual form is in the first place a considerable degree of uncertainty in the content and difficulty of the work, and that a cost overrun of 140% represents an end price 13% higher (for the models used) than the fixed price would have been. At this level of overrun, a fixed-price contractor would make an absolute loss of some 10%, which in the long term would prove nonviable to both contractor and customer.

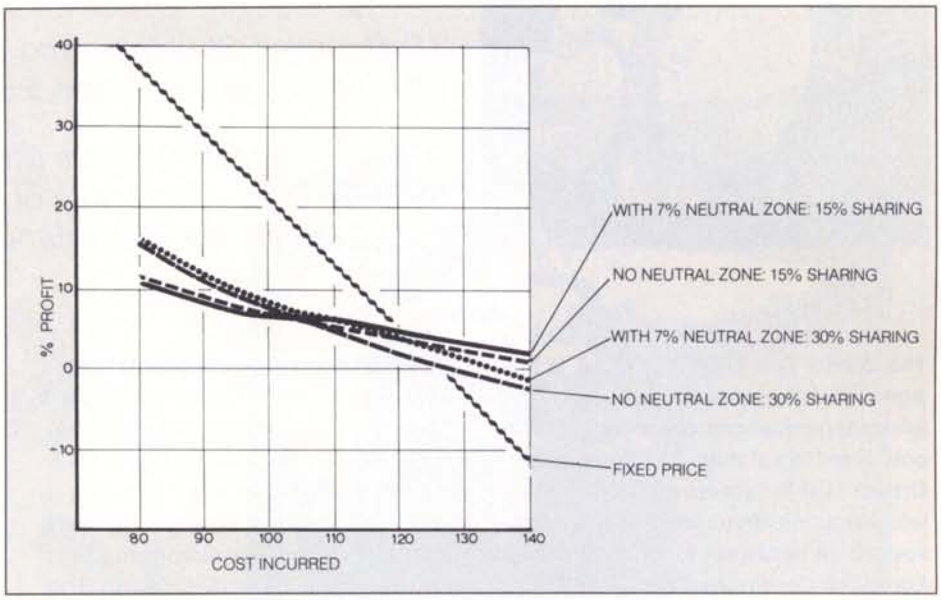
If the risk of such a loss were foreseeable, the contractor would have to cover it either by demanding higher expressed risk margins in the price or by inflating the cost estimates. It can be seen, at the other extreme, that an overestimate of the costs at the beginning of 10 or 20% can readily lead to profit margins of some 37 to 47%, which is unacceptable at least to a customer disbursing public funds. Where a fixed price is well estimated, and the potential risks do not occur, a profit of 21% can be earned, and if all the foreseen and costed risks do eventuate but are not exceeded, the profit is 5.5%. This corresponds approximately to a cost-reimbursement situation where the final incurred costs are between 100 and 110 MAU, where the customer pays between 108 and 117 MAU, as opposed to 127.

Conclusions

It is not proposed to examine the results of, or draw direct conclusions from, particular contracts that have been entered into by the Agency. The multiplicity of factors that play a role in the final outcome, technical and commercial, of a project are so complex that any such conclusions would be at best simplistic, if not misleading. It may nevertheless be of interest to note that the earlier contracts with cost sharing placed by the Agency tended to end with a final cost somewhere within the neutral zone, while more recent examples of such contracts, some of which have not yet been finalised, show a

	A: COST REIMBURSEMENT WITH COST SHARING (15 % - 30 %). NO NEUTRAL ZONE						B: COST REIMBURSEMENT WITH COST SHARING (15 % - 30 %) WITH NEUTRAL ZONE OF 7 % OF COST ESTIM.						C: FIXED PRICE	
ACTUAL COST	TOTAL PAID BY AGENCY		FEE RECEIVED (MAU)		% FEE = FEE / TOTAL PAID		TOTAL PAID BY AGENCY		FEE RECEIVED (MAU)		% FEE = FEE / TOTAL PAID		FEE (MAU)	%
	15 %	30 %	15 %	30 %	15 %	30 %	15 %	30 %	15 %	30 %	15 %	30 %		
80	90.75	94.5	10.75	14.5	11.8	15.3	90.75	94.5	10.75	14.5	11.8	15.3	47	37
90	99.25	101.5	9.25	11.5	9.3	11.3	99.25	101.5	9.25	11.5	9.3	11.3	37	29
100	107.75	108.5	7.75	8.5	7.2	7.8	107.75	108.5	7.75	8.5	7.2	7.8	27	21
110	116.25	115.5	6.25	5.5	5.4	4.8	117	117	7	7	6.4	6.4	17	13
120	124.75	122.5	4.75	2.25	3.8	1.8	125.8	124.6	5.8	4.6	4.6	3.7	7	5.5
130	133.25	129.5	3.25	- 0.5	2.4	- 0.4	134.3	131.6	4.3	1.6	3.2	1.2	- 3	- 2.3
140	141.75	136.5	1.75	- 3.5	1.2	- 2.6	142.8	138.6	2.8	- 1.4	1.9	- 1	-13	-10

Figure 4 – Graphical representation of the commercial consequences of the three price models of Figure 3



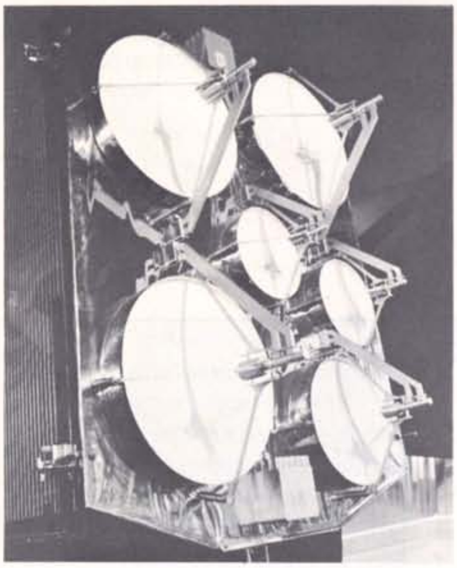
cost overrun, with the cost-sharing consequences. There is, at the same time, some evidence, which cannot be accurately substantiated, that in recent years some fixed-price contractors for scientific satellite projects are making losses to a degree not expected in the past.

Nor is it suggested that the selection of the type of price, and the way that this is applied, constitute a miraculous cure that solves all problems. They are but one element in a gamut that includes realistic requirements from the end user, whether this be the scientific community or customers for commercial applications, proper feasibility and preliminary definition with good estimates, sensible funding appropriations, a correct balance in the programme phasing between detailed definition and development, and competent management and engineering both by the procuring agency and the contractor. Nonetheless, the correct choice, negotiation and application of price type, like other aspects of contractual management, do contribute to the success of a programme.

Cost-reimbursement type prices do appear appropriate in certain circumstances as described above, and have certain advantages, in particular visibility and flexibility of management. The inclusion of cost-sharing schemes in such contracts does keep the programme costs within limits which both parties can regard as reasonable. This effect starts at the proposal and negotiation stage, where an analysis of the risks, an analysis that is less important under pure cost-reimbursement, has to be made seriously by both parties. Such analysis, properly done, highlights future difficulties that will have to be faced and solved, and initiates a degree of cost consciousness. Experience shows that contractors do, in fact, take negotiations of cost-sharing formulae extremely seriously, recognising that any agreement will be an active influence throughout the programme. Senior management, and in particular finance departments, involve themselves in these discussions, and tend to monitor the costs of a contract measured against the formula more frequently than for pure cost-reimbursement contracts and, it is submitted, more constructively than for fixed-price contracts. This monitoring and intervention by management augments the cost consciousness of the project team. Efficiency brings its own rewards, and the effect is also likely to benefit the engineering.

Another advantage of such formulae is in the control of changes to the work to be performed. Under fixed-price contracts where the customer has no visibility of cost developments during the course of the programme, there is a regrettable tendency for the negotiation of changes and their contractual consequences to become a dominant and even, in extreme cases, bitter dispute, with the contractor trying to maximise his profit, or stave off a significant loss. Programmes can be harmed at critical times, such as the period of assembly, integration and test, where the engineering requires flexibility and speedy response, but where the contractual situation tempts the working engineer to react to the needs in the manner of a contracts negotiator. The tendency in pure cost-reimbursement contracts is the reverse – a risk that changes are carried out without proper recorded agreement on the consequences until such time that the accumulation may have virtually changed the shape and overall cost of the programme in an uncontrolled way. Cost-sharing contracts steer a not unhappy line between the two. A competent project manager cannot allow changes to be tacitly introduced without proper and timely agreement. This could prove too expensive in the end. The financial consequences of the change negotiations are, however, for each party at the most 15% or 30% of the actual costs involved, and this is not usually enough to jeopardise the smooth progress of the work.

It is, finally, an elusive mixture of firm professional control combined with a spirit of cooperation and joint venture that best ensures the successful completion of a research and development programme, and cost-sharing formulae are one of the means for instilling and encouraging such an attitude.



The Orbital Test Satellite OTS-2 – Two Years of Orbital Thermal-Control Experience

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The Orbital Test Satellite, OTS-2, is the Agency's first experimental telecommunications spacecraft in orbit, conceived to validate, in a three-year Orbital Test Programme (OTP), the telecommunications technologies and spacecraft hardware to be used in the European Communications Satellite (ECS) programme. Most of the tests performed to date within the OTP have consequently been dedicated to the telecommunications payload, but tests were also planned at regular intervals to evaluate the performance of other subsystems. In particular, the thermal-control subsystem's performance has been observed in a unique series of tests, the conditions, results and interpretation of which are recounted here.

Thermal-control concept for OTS-2

Having in mind the future development of ECS and other space-communication systems, the three-axis-stabilised OTS spacecraft was conceived as a 'bus' (Fig. 1) to house all service subsystems and carry a communications module dedicated to a particular mission. The spacecraft was built for ESA by the European MESH industrial consortium, the thermal-control subsystem being one of the responsibilities of ERNO Raumfahrttechnik GmbH, one of the consortium partners.

The basic thermal-control concept, which was required by ESA to be passive, is summarised in Figure 2. Two platforms supported by a central tube carry the electronic components. The north/south faces are used as the primary means of radiating dissipated power to space. Dedicated radiators are provided for the travelling wave tubes (TWTs) to make efficient use of their elevated operating temperature and to reduce their influence on the spacecraft. Two extra TWTs are carried for redundancy on the central TWT radiator of each north and south panel, but only one on each radiator is energised at any time. The shunt electronics also has its own radiator because of its highly concentrated and widely varying power dissipation. All radiator surfaces are covered with rigid quartz optical solar reflectors (OSRs) to limit solar input. The east/west faces are insulated with multilayer insulation. On the Earth-viewing face, the set of white-painted antennas is mounted onto a rigid antenna platform with low-conductance brackets, to limit the influence of the antennas' large temperature excursions on the spacecraft itself. The two infrared sensors are also mounted on low-conductance brackets. On the panel facing away from the Earth, the launcher adapter, the apogee boost motor (ABM), the VHF antennas, and 12 hydrazine thrusters break the continuity of the insulating blanket.

To prevent freezing of the hydrazine in the tanks, in the lines, or in the flow-control valves, a set of heater circuits are activated by ground command. To limit the number of switches required, the various heaters have been sized individually and grouped into eight circuits. Five circuits are implemented on valves, tanks and lines for seasonal operation and one of them also activates the heater of one battery 'half'. The other battery 'half' has a separate heater, to limit the temperature difference between the two halves (OTS has what is considered electrically to be one battery, but which, for mass-distribution reasons, is located as two separate units on opposite sides of the spacecraft). Two heater circuits are reserved for boost heating of the hydrazine components prior to the solar-eclipse periods, which have to be survived without heating.

Tests performed

During the course of the OTS development programme, thermal tests were performed to simulate space temperatures and solar irradiation under extreme equinox and solstice conditions using selected, fixed solar-input angles (steady-state tests). Their purpose was to verify that spacecraft performance was

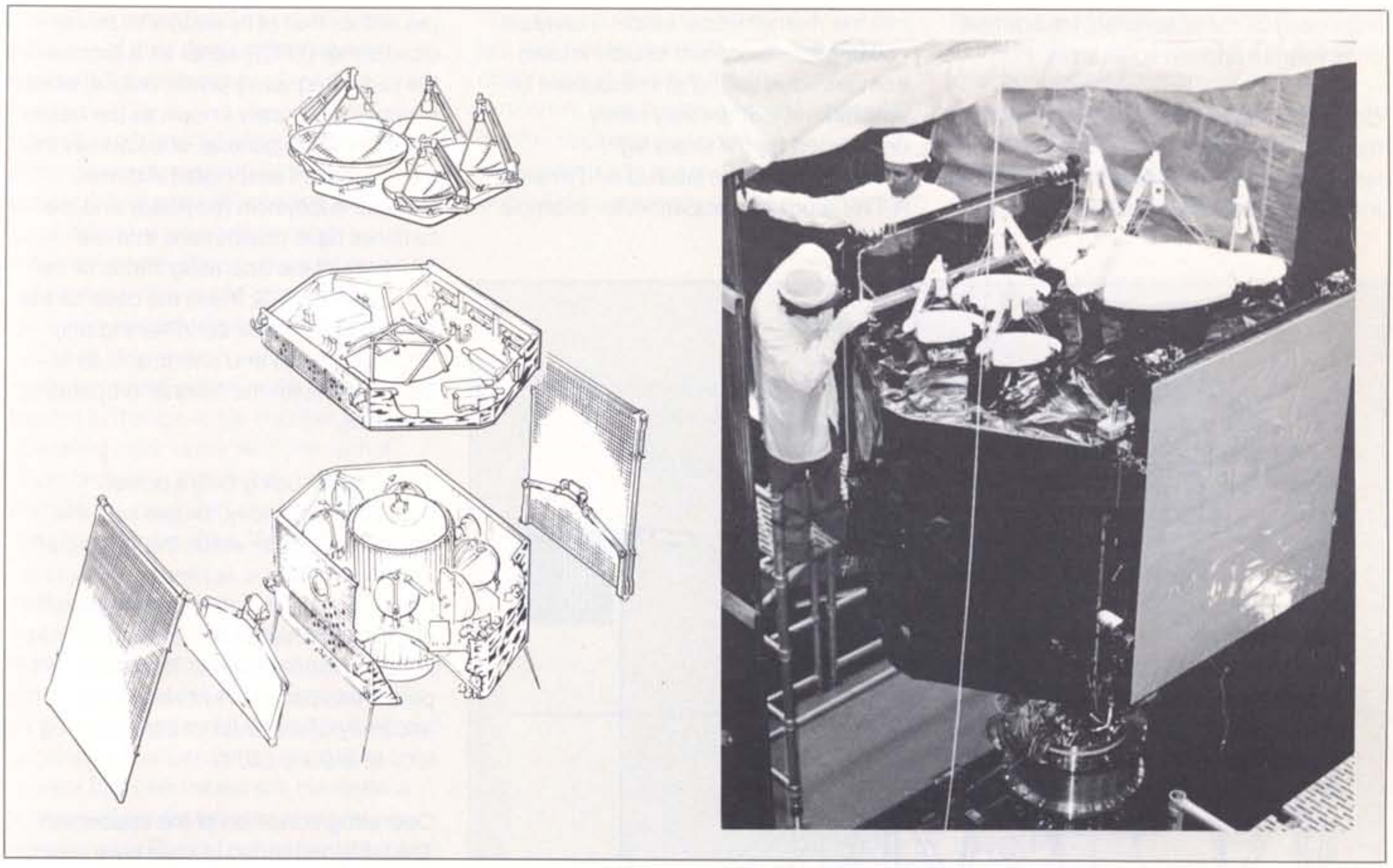


Figure 1 – The OTS-2 spacecraft

within acceptable limits in a simulated space environment. Another objective was to verify that the mathematical model used for the extreme hot and cold design cases could reasonably predict test results, thus giving confidence in orbital predictions.

OTS being a test satellite, it had been decided early in the programme to include the thermal subsystem in the planned in-orbit performance testing. The objectives of such an endeavour were to be somewhat different from those of the ground testing and can be summarised as follows:

- to assess the adequacy of the thermal-control subsystem in providing the proper environment for the various items of spacecraft equipment
- to compare flight temperatures with analytical predictions for the same electrical configuration, and to ascertain the degree of accuracy of such orbital predictions
- to provide the possibility of assessing the thermal distortion in a large antenna dish
- to detect and quantify any degradation in thermal coatings due to the space environment.

Since its launch into geostationary orbit at 10°E in May 1978, dedicated thermal tests have been performed on OTS at each equinox and solstice and at other ad hoc periods, these tests lasting approximately two days on each occasion.

Available data

To achieve the objectives noted above, OTS-2 was instrumented with 152 thermistors, thermocouples and platinum-resistance sensors to provide good spacecraft temperature mapping. The total number of sensors was constrained by telemetry-channel availability. The sensor apportionment is summarised in Table 1 for the different subsystems, including 36 sensors internal to equipment and required by the manufacturers. Of the 152 sensors, 60 are mounted on components outside the

Table 1 – Sensor distribution

Subsystem	Sensors
Reaction control	38
Power	13
ABM	2
Attitude and orbit control	14
Telemetry and telecommand	9
Antenna	24
Repeater	40
Structure	12
Total	152

main body of the spacecraft, for example on antennas and the solar array.

One of the major problems confronting the thermal analyst when making temperature predictions is the accuracy of the power dissipations to be introduced into the mathematical model. Individual power dissipations are usually known from previous testing at component or system level, but are very rarely determined for the exact flight configuration to be studied and analysed. A TWT's power dissipation, for example, [as well as that of its electronic power conditioner (EPC)] varies as a function of the radio-frequency power output, which is not as accurately known as the heater dissipations. In general, one can say that the equipment associated with the repeater subsystem (payload) and the batteries have dissipations that are functions of the operating status of the payload. For OTS, this is the case for the TWTs, EPCs, power conditioning unit (PCU), batteries and shunt, and, to a lesser extent, for the filters and operating networks.

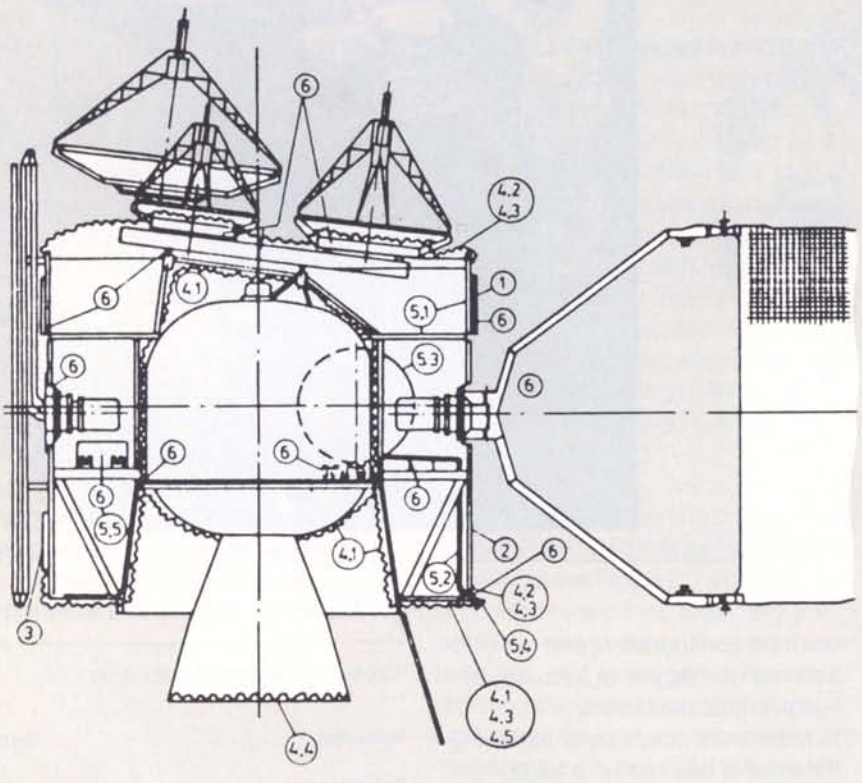


Figure 2 – The thermal-control concept for OTS-2

1. TWT radiators
   - Profiled honeycomb sandwich
2. Control radiators
   - SSMs
   - Foil for trimming
3. Shunt radiator
   Conductively decoupled from structure
4. Multilayer insulation

4.1 Kapton concept (high temperature)
4.2 Mylar concept
4.3 VHF shield
4.4 Blow-off insulation for ABM nozzle

5. Heaters

5.1 Payload simulation
5.2 Hydrazine line heaters
5.3 Tank heaters
5.4 Hydrazine valve heaters
5.5 Battery heaters

6. Low-conductance flanges and brackets
   - Antenna dishes
   - Radiators
   - Bearing and Power-Transfer Assembly (BAPTA)
   - Batteries
   - Tanks
   - Lines
   - FCVs
   - ABM
   - Antenna platform

It is possible, using OTS's power-subsystem telemetry, to calculate the power dissipation within the spacecraft. This information is applied to correct the dissipation used in the mathematical model and which is not identical to that known to occur in orbit. The total in-orbit power dissipation is known with an accuracy of the order of 8 to 10 W in a total of around 500 W.

Operating condition of the spacecraft

The tests performed to date have always been very well defined beforehand in order to model the dissipation of individual equipment items accurately. In particular, as thermal orbital tests call for constant and well-known power-dissipation conditions, repeater activity is kept to a minimum and as few channels as possible are operated. This reduces the uncertainty as to the TWT and EPC power dissipations, the remaining TWTAs being substituted with heaters of well-known power dissipation.

Nevertheless, due to operational constraints, the aim of having identical operating conditions for all comparable in-orbit tests has not been fully realised. Heater switching occurs at certain periods of the year and in particular in eclipse seasons, when boost heaters are used before entry into eclipse. Any heater switching activity or other change in the power distribution has an immediate influence on the shunt power dissipation. The latter and its variations are well

Figure 3 – Histograms of the deviations between predicted temperatures and those measured on 25/26 May 1978 with OTS-2 in geostationary orbit in normal operational mode

monitored throughout in-orbit testing because of their direct influence on spacecraft temperature.

A small variation in a heater dissipation or in the power dissipation within the spacecraft (a small RF change for instance) may have only a minor influence on the shunt's dissipation if it is operating in the middle of its range. Near the upper or lower limits of the shunt's capability, however, a variation of a few watts in internal power consumption may require a change in the number of operating solar-array sections, with a displacement in the shunt's operating point to the other end of its range (a variation of more than 100 W).

Test evaluation

To the fundamental question about the thermal subsystem's performance – namely whether the subsystem supports all planned spacecraft operations without generating malfunctions – a positive answer has been obtained. However, a spacecraft equipped with as many sensors as OTS, and subjected to such a comprehensive series of tests, has also provided answers to much more detailed questions.

As the performance of a thermal-control subsystem cannot be fully verified on the ground, the first point of interest to the thermal designers is verification that the temperatures of the electronic and other components do indeed stay within the tolerances computed, using worst-case assumptions for the spacecraft's full mission lifetime. The next important question is the precision of the thermal mathematical model, formulated analytically and improved by ground testing, for a given operational spacecraft configuration.

In view of the bright future for space communications in general, the most important thermal-control questions concern the long-term stability in the geostationary-orbit environment of the thermal technologies employed. It is known from ground tests performed during the last two decades and also from in-orbit observations, that the thermo-optical properties of materials degrade under the electromagnetic and particle environments in space. The extent of this degradation depends on the material, the technology of application, the cleanliness of the surface, and disturbances from the spacecraft itself (contamination either directly or by reflection at appendages). It is further suspected that differential electrostatic charging and the subsequent arc discharges that may

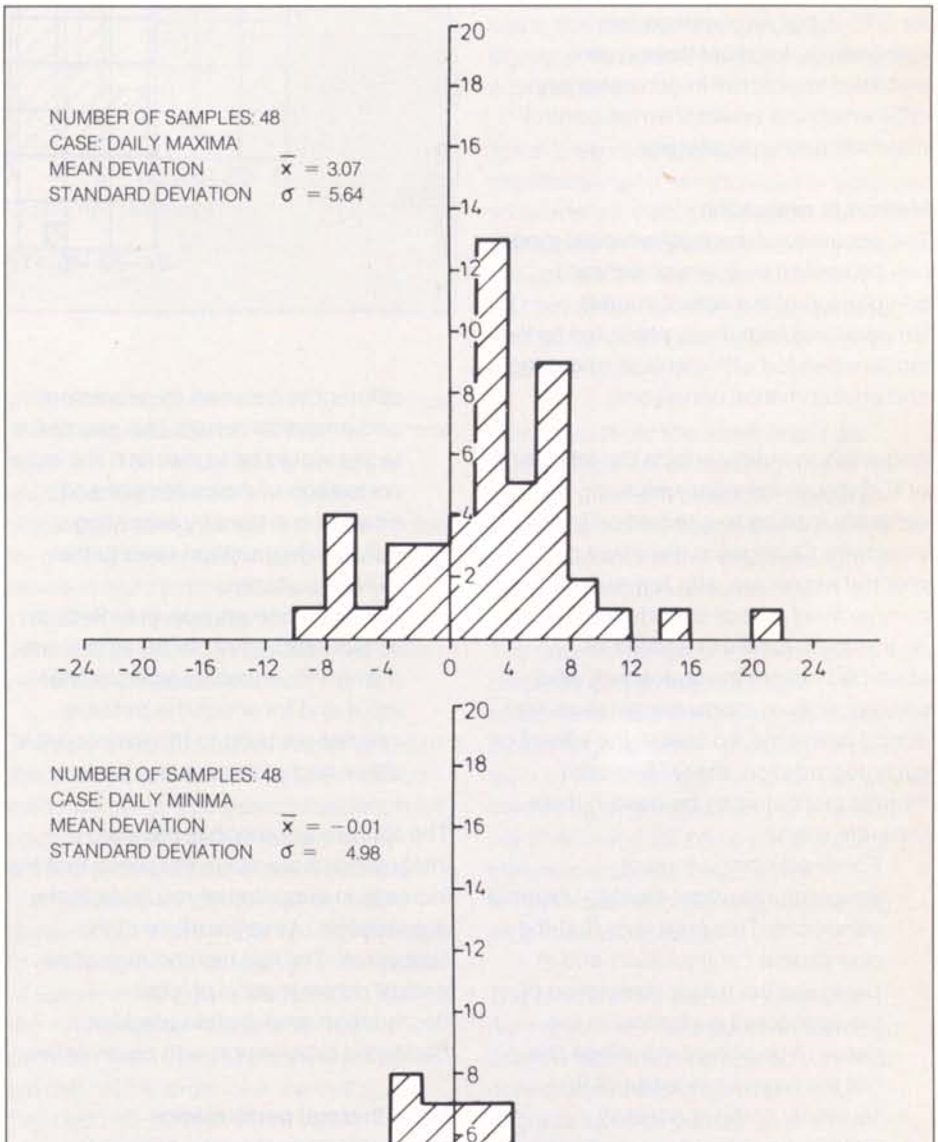
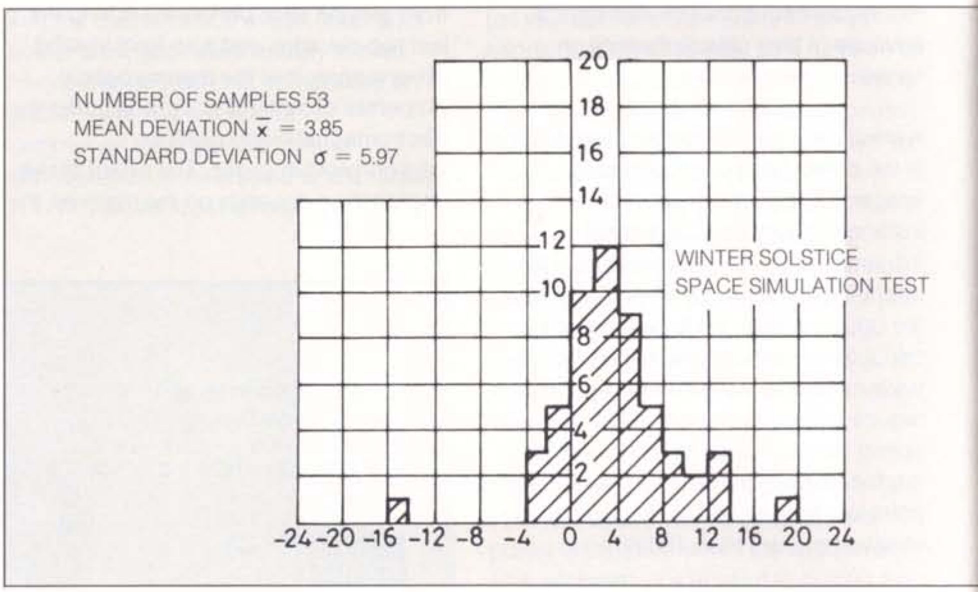


Figure 4 – Histograms of deviations between predicted temperatures and those measured during spacecraft acceptance testing



occur on spacecraft surfaces in geostationary orbits can damage thermal-control elements like the multilayer insulation and optical solar reflectors.

The data available from the thermal tests performed in orbit provide some answers to these questions that are valid not only for OTS-2, but also, with certain reservations, for other three-axes-stabilised spacecraft in geostationary orbit which use similar thermal-control materials and technologies.

Method of evaluation

The accuracy of the mathematical model can be verified by a straightforward comparison of the actual in-orbit temperatures with those predicted by the model when fed with identical operating and environmental conditions.

Degradation mainly affects the reflectivity of surfaces in the solar spectrum, generally leading to a reduction in that reflectivity. Changes in the infrared spectral region are, with few exceptions, of comparatively minor importance. Thus degradation results in additional absorbed heat in the spacecraft, and consequently in a slow temperature rise during its lifetime. To assess the effects of such degradation, the OTS in-orbit thermal test data can be used in three separate ways:

- For direct comparison of temperatures under identical external conditions. This presumes that the operational configuration and in particular the power dissipation of the spacecraft is identical in the cases to be compared. When this is not the case, knowledge of the sensitivity of the spacecraft temperatures to power variations is a prerequisite for this approach.
- For duplication of the orbital measurements with a mathematical model that takes into account the actual operational configuration of each test, and indicates the effect of degradation by increasing differences between measurement and analytical results. (An alternative to this would be to maintain the initial correlation of measurement and analysis constant by allocating suitable degradation rates to the various surfaces.)
- For direct comparison of individual sensor readings from areas that are mainly influenced by external heat input and for which the possible internal coupling to the spacecraft is either negligible or quantifiable.

The first two approaches have an integrating character in the sense that the increase in temperature results from the degradation of every surface of the spacecraft. The last method may allow precise determination of local degradation, and is often used for dedicated experiments with calorimeters.

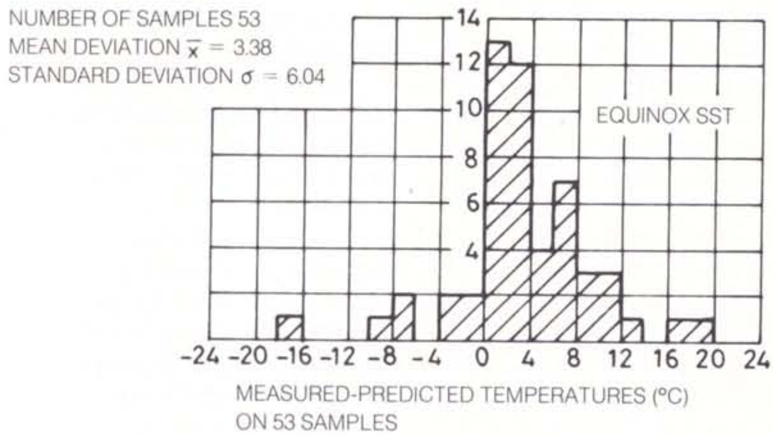
Initial thermal performance

The mathematical model needed to establish and verify the thermal design for OTS was used to predict both steady-state thermal conditions during acceptance testing, and the transient temperature response to the daily cycle of the spacecraft relative to the Sun and to variations in power dissipation. Reports have already been published* on the quality of these models and therefore only a brief résumé will be included here.

The first in-orbit thermal interpretation was conducted on 25/26 May 1978, after the spacecraft had reached its final geostationary position and was in normal operational mode. Histograms of the deviations between individual-sensor-measured and predicted temperatures were generated (Fig. 3) and these show that the mean diurnal temperature was approximately 1.5°C above predictions, with a standard deviation of the order of 5°C. The mean variation in diurnal temperature was approximately 3°C larger than predicted. When these results are compared with the acceptance-test results shown in Figure 4, the initial in-orbit thermal performance is shown to be in line with what could be expected for this spacecraft.

This initial performance test confirmed the mean and standard deviations observed with OTS-2 during acceptance tests,

* Paper by J.P. Bouchez, D.H. Howle & D. Stümpel and paper by D. Stümpel in ESA SP-139, November 1978



which are similar to the deviations observed with various other spacecraft and were considered satisfactory. The larger diurnal variation was unexpected, and some of it was traced back to an underestimated solar input into the spacecraft adapter and the cavity of the ABM. This area of the spacecraft had never been exposed to simulated solar radiation during ground tests because the adapter was used to mount the spacecraft onto the test facility. Corrections in the solar input and the ABM region improved the mathematical model in that:

- the average diurnal mean temperature difference between the orbital results and predictions was reduced from 1.5 to 0.8°C
- the deviation of the average diurnal variation was improved from 3 to 2°C
- the standard deviation was also improved by approximately 0.5°C.

Thermal degradation of the spacecraft

By performing a thermal analysis for the exact operational conditions of an in-orbit test, one can define a characteristic difference between the test values and the beginning-of-life (BOL) analysis results. Interpretation of this difference as a function of time in orbit can lead to the determination of the temperature increase due to degradation of the thermal-control materials. The results of the computer-aided comparison are interpreted statistically, using histograms constructed by plotting the temperature difference between flight temperatures and predicted temperatures for the 48 sensors selected (as shown in Fig. 3 for the initial performance assessment).

The operating conditions implemented in the analysis are determined from orbital measurements. The power dissipation for each equipment item is known from ground testing and is entered into the mathematical model. As mentioned earlier, a correction must be incorporated to account for the difference in the value of total internal power dissipation used in the mathematical model and that deduced from the telemetry data. This is typically of the order of a few watts, and has been 10–12 W in some cases.

The histograms are a good tool for obtaining the variation in the mean temperature of the chosen sample as a function of time spent in orbit. At solstice, the temperature maxima and minima are used. At equinox, the temperature maxima occurring during the Sun-illuminated portion of the orbit are used, as well as the specific times of beginning and end of eclipse.

The mean deviation between test and analysis is displayed against time-in-orbit in Figure 5. This figure shows the mean temperature increase experienced by the spacecraft over the last two and a half years, the rates of change being significantly different between solstice and equinox tests.

If one presumes that degradation manifests itself in an increase in absorbed solar energy, then the surfaces that participate in degradation during equinox periods are the multilayer insulation, the painted antennas, the spacecraft adapter and some small Earth and Sun-sensor apertures.

During solstices the same areas are illuminated plus, depending on the season, the north or south radiators, which are mostly covered with optical solar reflectors with a small amount of multilayer-insulation trimming.

The equinox temperature increase, presently of the order of 2°C, is reasonable, and can be largely explained by the degradation in the outer kapton layer of the multilayer insulation as well as the strong degradation in the antenna paint. Allowing for some other surface effects mentioned, the equinox temperature history is what one would expect for this mission.

The temperature increase observed during solstices is larger than expected, and the difference compared with that during equinoxes is caused by the degradation that occurs on the additionally illuminated surfaces. This analysis is supported by two facts that can be derived from Figure 5: at the beginning of the mission, the deviation between test data and analysis is quite similar for the first solstice and equinox and increases steadily at subsequent solstices; also, the daily variation

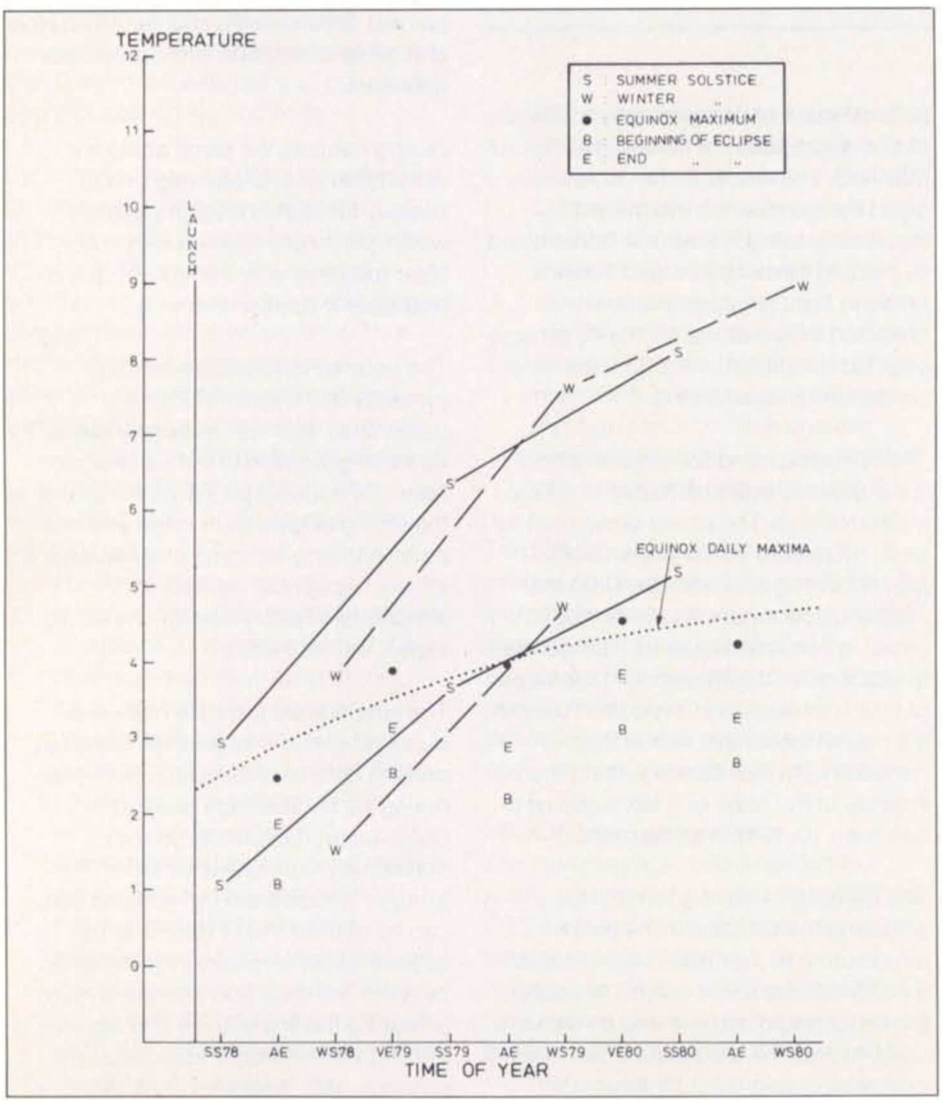
Figure 5 – Mean deviation between test and analysis temperature increases as a function of time in orbit

increases more at solstice than at equinox. The increase in temperature during the first two years (summer-solstice cases) can be interpreted, through the results of a sensitivity analysis that has been made, as a possible increase in absorptance.

A recent study placed with the OTS thermal contractor had the purpose of assessing the thermal orbital data in a different way, by comparing directly the different tests and by assessing individually the sensors located on the north and south-facing control radiators. It is interesting to note that the results of an individual assessment using the radiator sensors leads to good agreement with the earlier results. Direct comparison between tests allows the degradation effect to be defined in °C, and this is also in agreement with previous results.

It has to be borne in mind that the ground tests to study thermal-surface degradation were performed in a clean facility free of any contamination source, and that the UV and particle environment was simulated to allow accelerated testing. The exact causes of the optical-solar-reflector degradation are not known, but they could be a combination of:

- pure degradation of the OSRs. The real space environment could generate higher degradation than ground tests
- contamination of the OSRs with subsequent degradation of the deposit. This contamination could stem from spacecraft-materials outgassing
- contamination stemming from expendables, i.e. firing of the ABM and/or attitude-control thrusters
- damage caused by electrostatic discharges. In ground testing, destruction of both the quartz surface and the silver layer of mirrors has been produced under electron charging and arc discharge.



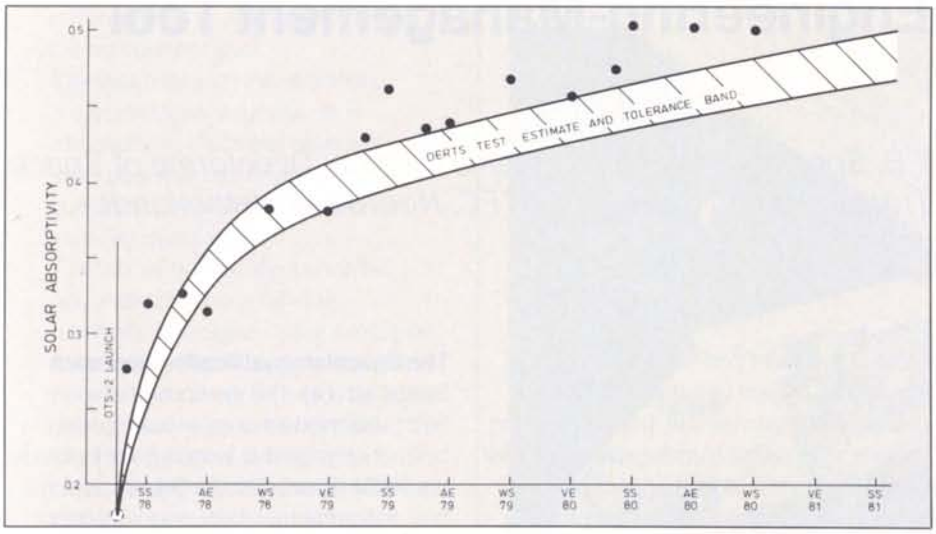
Arguments can be presented for and against the above hypotheses, but a definitive conclusion is not possible. Contamination by expendables is, however, assumed to be the cause of degradation on many US spacecraft, both geostationary and low-Earth-orbiting.

Thermal degradation of antenna white paint

As mentioned elsewhere, the OTS antenna dishes are coated with a matt-finish white paint of relatively low initial solar absorptivity, although like all white paints it degrades significantly with time in the space environment. The Spotbeam antenna dish was instrumented with a total of 14 temperature sensors (3 platinum-resistance type and 11 thermistors), mostly under the front skin of the dish but with a few at the rear skin, to allow the investigation of thermal deformation effects.

As the temperature gradients front to rear were observed to be of the order of only 2 to 6°C when the dish was at its maximum temperature of around 60°C, it was decided to use all 14 sensor outputs, plus a few simplifying assumptions, to attempt to estimate the solar absorptivity of the front paint surface at different times in the spacecraft's history. On each occasion,

Figure 6 – Predicted and measured solar-absorptivity values for the matt-finish white paint on the OTS-2 antenna dishes



the appropriate solar intensity and angle of the solar vector to the antenna platform were obtained and the maximum incident solar flux density could then be calculated for each sensor.

A maximum possible value of solar absorptivity was next calculated for each sensor, at that selected date, by assuming that an emissivity of 0.9 existed on the front face, and that no absorbed heat travelled through the dish from front to back (a small quantity does, but it is very small) or laterally (more true still). Typically, the 14 values so obtained showed a fairly large percentage spread, even after normalisation for position on the dish; much of this spread is due to the fact that these initial calculations took no account of view factor (either averaged or individual) of each sensor area element to the feed, the trusses, or the rest of the dish. However, as the various values changed their relative magnitude positions at different times of the year – again showing the varying effects of individual view factors – it was decided to use the arithmetic mean of the 14 as a gross estimate of dish solar absorptivity.

A sensitivity study was carried out to assess view-factor effects, and it was concluded that all gross solar-absorptivity values should be reduced by about 10%.

However, only the gross values are used in Figure 6 and these are calculated from soon after the launch of OTS-2 up to the recent 1980 winter solstice. On the same graph is the nominal beginning-of-life absorptivity for the matt-finish white paint (0.18), and a predicted band of absorptivity values as a function of in-orbit time prepared from ground tests (irradiation with ultraviolet light, electrons and protons, to simulate the space environment) carried out for ESA at DERTS in Toulouse.

It can be seen that while the first two values after launch are significantly greater than expected, subsequent values are generally only a little above the prediction band, with some in or below it; remembering that all gross values as plotted should be reduced by about 10%, the fit of orbital data and pre-flight estimates is seen to be good. White paint is notoriously susceptible to contamination and dirt in its original low-absorptivity state, and a degree of contamination may well have occurred before the first orbital results could be obtained, since telemetry from the sensors on the antenna dish could be obtained only after ABM firing and solar-array deployment. This could explain the otherwise anomalous result for the immediate post-launch period.

Conclusion

Based on the information collected in 12 OTS thermal-performance tests, the following conclusions could be drawn.

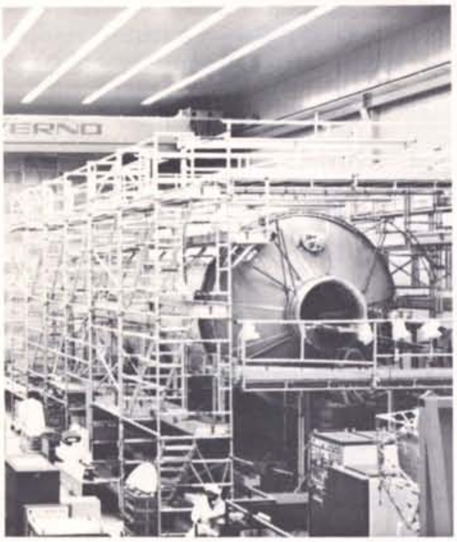
The initial performance of the OTS-2 thermal subsystem was as close to predictions as could be expected with a passive thermal subsystem on a three-axis-stabilised, geosynchronous-orbit spacecraft.

Like many other geosynchronous spacecraft, OTS underwent a rapid temperature rise in the early part of its orbital life. The temperature increase over the first two years has in fact been larger than expected, but it is now showing a definite tendency to level off, at a similar magnitude to those reported by other sources. The exact reason for the degradation is not yet known, but it is likely to be the result of contamination generated at the beginning of, or during the mission.

The equinox data show a small increase in temperature over the two-year period in orbit, the curve exhibiting a strong tendency to flatten off. This behaviour was expected, and is related to degradation of the coatings on the surfaces rotating with respect to the Sun vector.

The increase in temperature experienced during the spacecraft's first two years in orbit is expected to continue at the solstices, but with a decreasing slope.

It is now proposed to continue the very successful OTS operations beyond the originally funded period of three years in orbit. This would, incidentally, give more insight into, and information on, longer term degradation effects on the surface materials and technology employed. OTS has already shown and will hopefully go on proving, that European technology is more than ready to support the future telecommunications programme.



The Spacelab System Verification Programme – A Powerful Engineering-Management Tool

F.B. Sperling, Spacelab Systems Division, Directorate of Space Transportation Systems, ESTEC, Noordwijk, Netherlands

Flight qualification of the Spacelab design has posed unique problems. Classical methods, such as prototype environmental qualification or large-aircraft practices, are prohibited by Spacelab's size and plurality of flight configurations. Environmental and functional tests at various assembly levels must be combined by and with analytical assessments and extrapolations in order to develop, incrementally, a total qualification picture. The Spacelab System Verification Programme was set up to effect and control this process.

Most of the effort connected with a spacecraft project usually goes not into design and manufacture, but into making as sure as possible that the spacecraft will survive its launch and, if applicable, its landing, and that it will function properly for the intended lifetime in the environment it encounters.

A fundamental task in this effort is to demonstrate that the spacecraft design commands the necessary capabilities and invulnerability, a process commonly referred to as 'qualification'. Starting at the component level, qualification has, for many years and countless spacecraft, culminated in an 'all up' full-size prototype test series under conditions simulating the launch and operational environments with an escalation factor of 50%, the classical qualification margin.

While this approach seems natural and reasonable, it is not without flaws; some environments, like mechanical vibrations, are very difficult to simulate realistically and attempts in that direction have often resulted in severe overtesting; other environments, most prominently the absence of gravity, cannot be simulated at all. The main disadvantage of qualifying in this manner, however, is the cost involved in building and maintaining the necessary test facilities, particularly as spacecraft become larger.

For a while, thermo-vacuum chambers, shaker tables and other test equipment grew along with the spacecraft, but eventually this became economically unfeasible.

The Spacelab qualification approach
Spacelab (Fig. 1) is comprised of a habitable module and an open pallet, both of changeable length. It will fly inside the NASA Space Shuttle Orbiter payload bay, fully attached throughout the flight; opening of the payload bay doors will expose Spacelab, enabling it to perform its task by operating on-board payload equipment. Like the Orbiter, Spacelab can be re-used many times.

With module dimensions of 7 m (length) by 4 m (diameter) and a mass of more than 6 t, Spacelab definitely belongs to the class of spacecraft for which full-size prototype environmental qualification was not a realistic option.

While not the first in this class, Spacelab is the first spacecraft offering a considerable variety of distinctly different flight configurations; hence, qualification programmes developed for other large spacecraft such as Skylab, or qualification procedures of the sort in use for large aircraft, could not be directly applied to Spacelab.

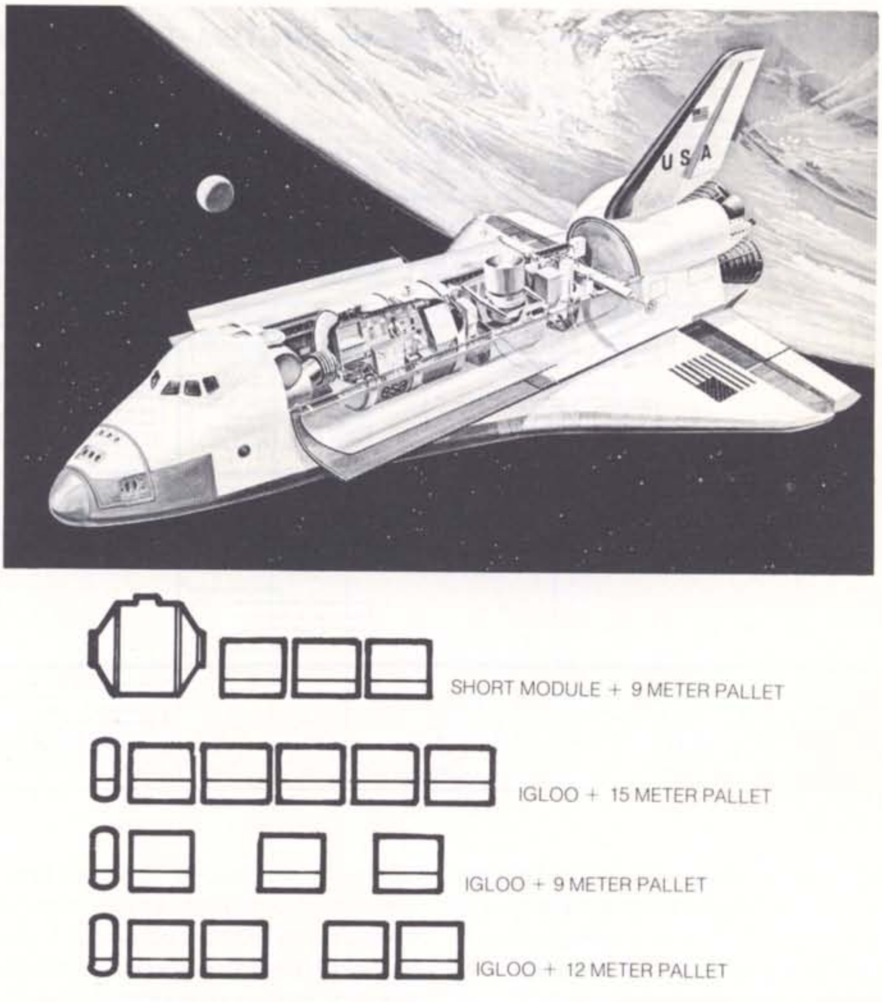
Consequently, Spacelab developed its own qualification approach, establishing the following principles:

1. Load-carrying and pressure integrity of the primary structure (i.e. the module shell and the basic pallet element) shall be ascertained by tests on representative, full-size structural test models.
2. Environmental qualification for atmospheric, temperature, and induced acoustic and mechanical

environments shall be performed at the component level.

3. Compatibility with the radiation, meteoroid, geomagnetic, and atmospheric electricity environments shall be shown by analytical means, supported by selected component tests, as necessary.
4. Functional qualification shall be accomplished on a full-size, functionally representative prototype for as many flight configurations as necessary to cover all potential flight configurations by extrapolation.
5. Mechanical and thermal system compatibility with the Orbiter interface and the operational environment shall be established by structural and thermal systems analyses. These analyses must be supported by physical test models, e.g. the structural analyses must be confirmed by physical determinations of natural vibrational behaviour (modal surveys).
6. Electromagnetic compatibility (EMC) of the system shall be established by tests on a functionally representative prototype.
7. Life expectancy of structural items shall be established by fatigue and crack-propagation analyses, supported by component tests.
8. Life-expectancy requirements of other than structural items shall be complied with by lifetime analyses, identification of life-limited items, and according spare provisioning.
9. Items identical to those of other programmes, primarily the Orbiter, may be qualified 'by similarity', provided that an analysis shows Spacelab's operational constraints and environmental conditions to be not more severe than those in the other applications.

Figure 1 — Spacelab in the Shuttle Orbiter's cargo bay and various Spacelab flight configurations



The verification programme

Though the above list of principles appears to be exhaustive and clear, it soon proved to be not at all sufficient for establishing a comprehensive qualification programme for, in a complex system, things have a tendency to resist being put into separate, clearly labelled drawers.

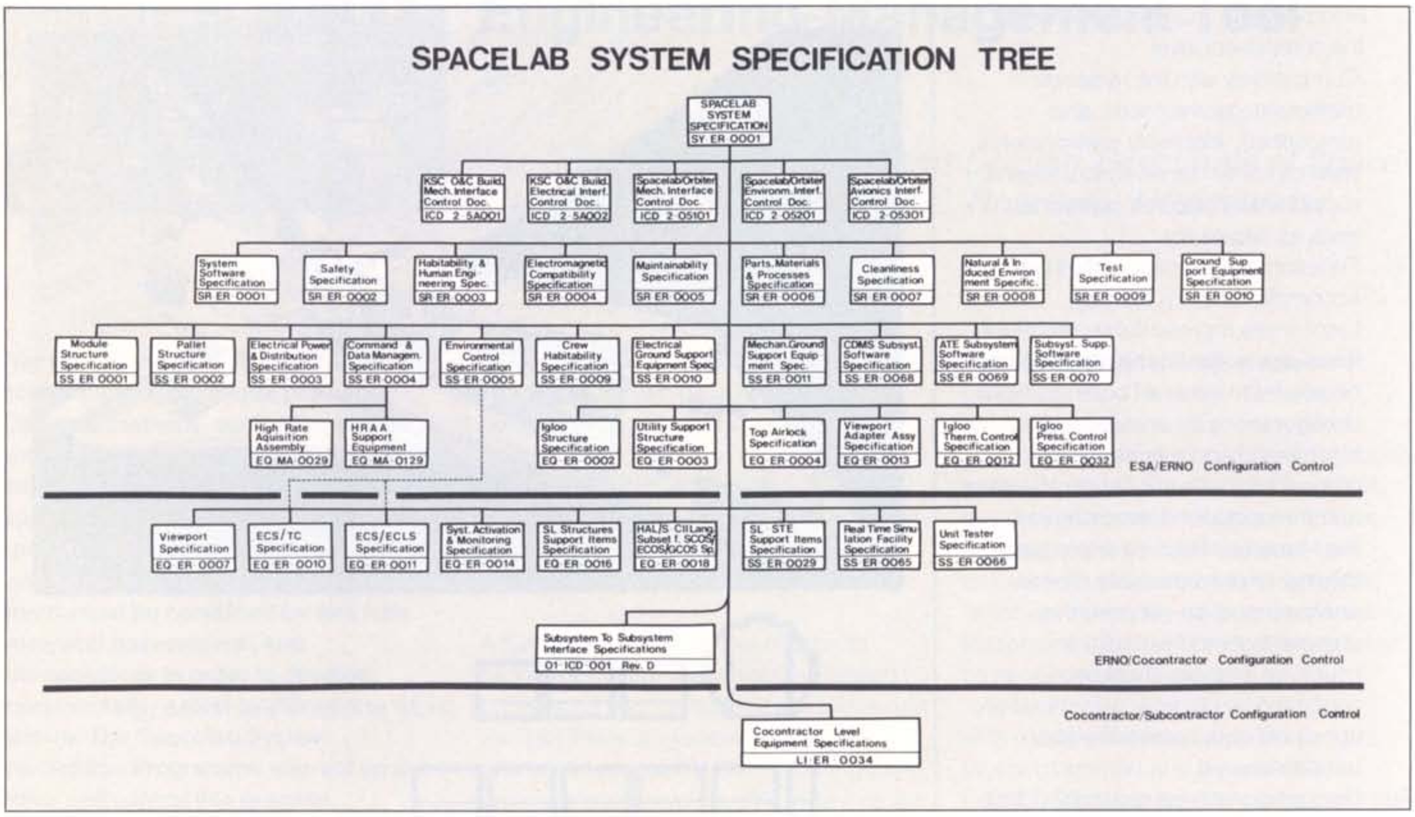
To avoid overlap and to assure completeness of qualification, it was necessary to determine the applicable qualification methods (test, analysis, similarity or other assessment, or any combination of these) and the qualification level (equipment, subsystem, and/or system) on a case by case basis, i.e. in a component by component versus requirement by requirement matrix. Once this existed, it seemed sensible to add some mechanism of control to ensure complete and satisfactory qualification.

The Spacelab System Verification Programme was set up to do both these tasks: constitute the Spacelab qualification programme, and monitor and control its completion.

The verification logic

The basic verification logic is extremely simple: it is based on the design and performance requirements, as stated in the specifications; to establish for each piece of equipment, subsystem, and system, the suitable method of qualification; to identify and/or prompt the necessary activities; to monitor these activities as to their capability of satisfying the underlying requirements; and eventually to report completion, based on

Figure 2 – Basic requirements of the system specification, expanded and supplemented into five interface, eight discipline, and 30 subsystem/major equipment specifications



approved documents such as test reports, analyses, similarity assessments, etc.

Practical implementation: first step – establishing Verification Control Documents

The set of specifications used for Spacelab is shown in Figure 2. The overall design and performance requirements of the System Specification are detailed in two directions: one according to disciplines or generic system constituents (third row, designated 'SR' and referred to as System Support Specifications) and one according to subsystems and major equipment items (all marked 'SS' and 'EQ'). In addition, due to the simultaneous maturing of the Spacelab and the Orbiter design definitions, a number of requirements do actually appear in the Orbiter and NASA facilities Interface Control Documents (marked 'ICDs').

To use these specifications directly, i.e. by simple reformatting to allow for the necessary annotations, as a basis for verification, turned out to be impractical for two reasons: first, the two-way expansion described above had resulted in a large number of double or even triple requirement redundancies; secondly, many statements in the specifications are general design guidelines, goals, definitions, optimisations, etc., and do not lend themselves to a clear yes/no compliance verification; they receive their proper assessment during project design reviews.

To remove the redundancies and to essentialise the requirements, with the exception of three specifications for diciplines that claimed to have compliance verification control of their own [safety, parts, materials and processes (PMP), cleanliness], all specifications in Figure 2 were transformed into Verification Control Sheets, the format of which is shown in Figure 3.

Briefly, column 3 contains first the specification requirement, either repeating the specification text, or – more often – in a condensed form; the paragraph number in column 2 and the specification identification in the page head identify the source. Column 1 shows the assigned verification identification number, and a classification letter. The Spacelab configuration(s) to which the requirement applies, affected equipment items, operational conditions, or other relevant information and/or constraints are also stated in column 3. Columns 4, 5 and 6 allow for identification of qualification method and level; columns 8 and 9 are to show documents attesting to preparation and completion of the addressed qualification activity.

Once all specifications and ICDs had been so transcribed (columns 1 through 3), they were assembled into 20 Verification Control Documents (VCDs), one addressing the system, 17 for the

Figure 3 – As the basic working tool of the verification programme, the Verification Control Sheet reflects the specification requirements (columns 2, 3), establishes the qualification approach (columns 4, 5, 6), and monitors and reports the necessary activities (columns 8, 9)

VFW-FOKKER ERNO Modular SPACELAB

SYSTEM VERIFICATION CONTROL SHEET

SPEC. TITLE: SPACELAB SYSTEM
SPEC.: NO.: SY–ER–0001 ISSUE: III CHANGE DATE: ____

DOC. NO.: LI-ER-0030
ISSUE: 3 DATE: DEC. 77
CHANGE: ____ DATE: ____
PAGE: 2-23

IDENT. NO.	SY/SR SPEC. PARAGRAPH	VERIFICATION REQUIREMENTS	VERIFICATION METHOD EQUIPMT. LEVEL	SUBSYST. LEVEL	SYSTEM LEVEL	TRACE NO.	VERIFICATION REF. DOC.	FINAL VERIFIC. DOCUMENT (E.G. TEST, ANALYSIS, INSP.) REPORT)	REMARKS
101077 B	3.4.3 Elec. Power/ Energy Alloc.	Verify max. continous power consumption on ECS/ECLS basic SL Equipment does not exceed: CONF | PARA/FUNCT. LM SM3P | 1507 Watt	(Test)	(Anal) (Test)	Anal		PL–ER–0058	RP–ER–0007	
10178 B		Verify max. continuous power consumption of ECS/TC basic SL Equipment does not exceed: CONF | PARA/FUNCT. LM | 120 Watt SM3P | 485 Watt 5P | 370 Watt 3P | 370 Watt	(Test)	(Anal) (Test)	Anal		PL–ER–0058	RP–ER–0007	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	

subsystems and major equipment items, and two for software. In this process, the discipline-oriented specifications and the ICDs were 'absorbed', i.e. distributed into the VCDs, as relevant. This required copying many parts of those specifications as often as they were applicable to the various subsystems and equipment items, seemingly increasing rather than diminishing the number of requirement duplications. But they have all been sorted now, and put together in one document per system/subsystem; hence removal of the obvious, often verbatim, requirement redundancies within each VCD is a simple task.

Next, all requirements were screened for their ability to be verified by at least one of the qualification methods described above. This exercise showed that there were numerous requirements that were not subject to formal qualification, such as physical accommodation of components, instrumentation layouts, accessibility requirements, interchangeability requirements, etc.; however, compliance of the design with these requirements should be checked, and it should be checked early in order to avoid, or at least minimise, mismatches and rework during integration. To cover this, a verification activity called 'Review of Design' (ROD) was instituted, to be based on functional layouts, manufacturing drawings, etc., and all affected items were marked accordingly in columns 4, 5 and 6.

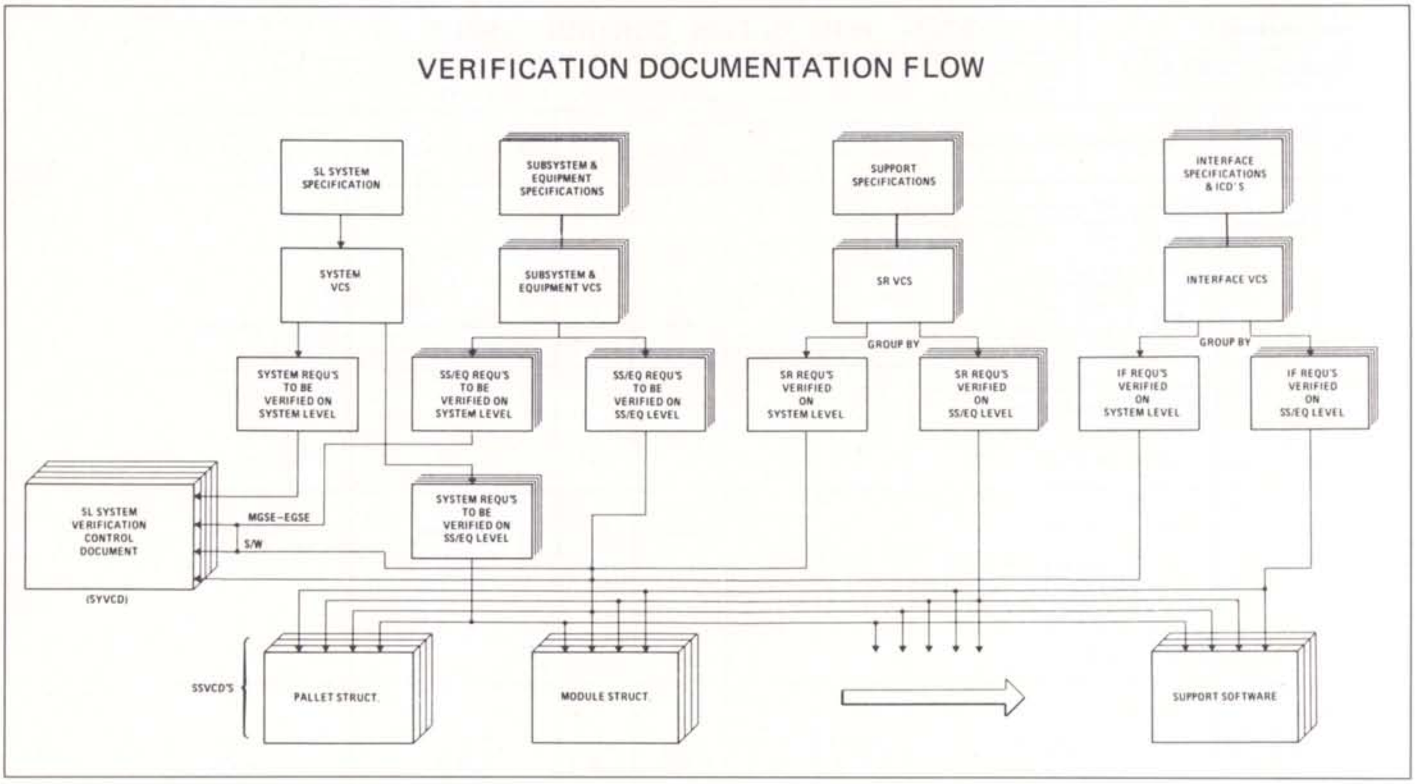
All requirements for which neither ROD nor any of the qualification methods applied, as well as all those covered by one of the three activities excluded from verification tracking (safety, PMP, and cleanliness), were marked 'NTBT' (not to be tracked) in the remarks column, together with a brief comment or explanation as to why tracking was considered not suitable or not necessary. These line items were not removed from the VCDs, so that the Verification Review Board, described in the next implementation step, could confirm or re-open them.

The complete requirements flow from the set of specifications into the set of Verification Control Documents, as described above, is shown graphically in Figure 4. This figure also shows the allocation of requirement into the VCD according to the level on which qualification takes place, as explained below.

Practical implementation: second step – engineering approval of Verification Control Documents and qualification activity planning

Step one was performed by verification engineers with the support of subsystem experts to ensure an 'intelligent' specification transcription. Nevertheless, a more formal assessment and approval of the VCDs was considered appropriate.

Figure 4 — Spacelab specifications (Fig. 2) were transcribed on Verification Control Sheets (Fig. 3) and, following the logic shown, re-assembled into a manageable set of hardware/software-related Verification Control Documents



The Verification Review Board (VRB) was set up for this purpose, as well as to oversee all other verification activities.

The VRB is chaired by the head of the Spacelab prime contractor's (ERNO, Bremen) Verification Section and co-chaired by his ESA counterpart. Its members, from both ERNO and ESA, are the responsible verification engineers, subsystem engineers from ERNO and from the co-contractor, system engineers, integration and test engineers, and other experts as required by the Board's business.

The VRB reviewed each draft VCD, checking it for completeness, proper ROD and NTBT entries, still existing requirement duplications, and correctness of requirements wording.

The primary task of the second step, however, was to complete the qualification method and level entries in columns 3, 4 and 5.

This process necessitated one more document reorganisation, because many requirements stated in the equipment or subsystem specifications could, by their nature, only be verified at system level; in other words, many components cannot be regarded as qualified before their performance is demonstrated on the engineering-model prototype or, perhaps, the flight unit. On the other hand, a number of requirements stated in the System Specification are, in fact, to be verified at a lower level, e.g. all environmental qualifications.

The intention of the verification programme, however, was to track primarily the final, i.e. highest-level, qualification and to do so in the VCD addressing that level. Hence, requirements had to be cross-transferred accordingly, resulting in subsystem sections in the system VCD, and system sections in all subsystem and equipment VCDs, in addition to the discipline-oriented and ICD sections already there (from the support specification and ICD splitting of step one, described above). In this transfer, the requirements kept their identification number (column 1, Fig. 3), to facilitate cross-checking. To avoid ambiguity, all qualification activities indicated but not tracked in the VCD at hand were put into parentheses (Fig. 3). This cross-transfer procedure is also illustrated graphically in Figure 4.

Since, in the Spacelab Programme, this iterative VRB activity took place at a time at which subsystem qualification had been largely planned and was already partly in progress, the task became more one of aligning existing qualification elements into the overall programme, and, in particular, of identifying and closing uncovered areas, rather than the less constrained planning activity it would have been if conducted earlier.

Agreement of the Verification Review Board with a VCD item, a column, or an entire page is signified by affixing a dated validation stamp next to the item, on the bottom line of the column, or in the lower right hand corner of the page.

Practical implementation: third step – verification control

After proper and complete listing of the requirements (step 1, columns 1, 2, 3), and after full designation of the Qualification Programme (step 2, columns 4, 5, 6), the tasks remaining for the third and final step are monitoring of all qualification activities and control mechanisms – or to exercise control in areas where no such mechanisms exist – and recording of the results in columns 7, 8, and 9 of the Verification Control Sheets (Fig. 3). Column 7 is provided for cross-referencing to other control or monitoring systems, such as the Spacelab system test requirements scheme; column 8 (Verification Reference Document) is to list documents that indicate the corresponding qualification activity to be in preparation, typically test procedures. Column 9 (Final Verification Document) is for all documents that show the activities addressing the requirement to have been completed. Eventually, all entries must be VRB-validated, indicating that the referenced test report, analysis, etc. is correct and sufficient. To make this determination, the VRB depends on either monitoring of the activities and dispositions of other control institutions, e.g. for component and subsystem tests the Test Control Group, or the Board conducts the necessary evaluation itself, engaging support of course from the subsystem or system engineers concerned, independently on both sides (the prime contractor and ESA). In the case that a requirement has been waived, in general or for specific components, the corresponding request for waiver or deviation is entered into the remarks column and validated upon approval of the Materials Review Board or other proper authority.

Upon validation of column 9, the verification process is completed; the Verification Control Document then constitutes proof and documentary reference for full qualification of the equipment, subsystem, or system addressed.

Auxiliary tools

Actually conducting the Spacelab verification programme required a number of supplementary tools and mechanisms for document change control, loop closure with the three exempted disciplines, systematic engineering change proposal, deviation, and waiver tracking, etc., which need not be further elaborated here. What should, perhaps, be discussed briefly is the requirement categorisation, which is more of a crutch than a tool, and was introduced about halfway through step 2 when the number of line items to be closed reached its peak and there appeared to be no way of ever completing the job in the time left in the then valid project schedule.

The obvious measure to take in a case like this is 'prioritisation' with the most important requirements, those that would, if not met, ruin the entire mission receiving the highest classification, and so on. In verification control, however, there exists a second parameter equally important for prioritisation, namely the 'self-verification' potential, i.e. the probability of discovering an unfulfilled requirement by means other than verification control.

Based on these two criteria, all requirements were subdivided into three groups (A, B, C) with only those put into the lowest group (C) that are either totally self-verifying (e.g. physical fit requirements, etc., which automatically come into the open during integration), or those that have a high probability of self-verification combined with minor technical importance. Nevertheless, about 50% of all requirements could be so classified; close-out of 'C' items was degraded to a nonessential 'as time permits' activity of verification. The classification letter was entered in column 1 for all line items to be tracked.

Contractual significance of Verification Control Documents

As part of the Spacelab design and development contract, ESA requests the contractor to produce Certificates of Qualification (COQs) for all major pieces of equipment, all subsystems, and the system as a whole. Proof of full qualification, by these COQs, is, in turn, an essential prerequisite for flight unit acceptance.

For the system, all subsystems, and the eight equipment items produced to ESA-controlled specifications (see Specification Tree, Fig. 2), a completed VCD is required as COQ backup. Hence, the Verification Control Documents constitute, by virtue of being a convenient tool for ascertaining completion of qualification, an essential link in demonstrating contract completion.

Interrelation with acceptance

A second relation between verification and acceptance developed from the fact that some of the Spacelab ground support equipment (GSE) is not required to be qualified in the classical sense. Only a performance check of each unit is requested prior to prime contractor acceptance. Since all GSE is included in the Verification Programme, these 'acceptance tests' had to be admitted as a substitute for qualification. For some other components, acceptance tests partly substitute for qualification; in fact for all those components for which no qualification models exist (primarily, again, GSE), the distinction between acceptance and qualification tests becomes more or less a matter of semantics.

In order not to lose any information here, it was decided to track all acceptance tests in the same manner as qualification activities, with close-out now required per serial item. As a side benefit, a compendium of all acceptance tests and their completion status is assembled. This, however, is not an essential part of verification, and the question of whether

Figure 5 – Sample page from a draft specification for Spacelab Follow-On Development. The format is that of a Verification Control Sheet (Fig. 3); completion of columns 4, 5, and 6 is considered an integral part of the specification-writing process

SPECIFICATION/VERIFICATION CONTROL DOCUMENT

SPEC. TITLE:
SPEC. No.: ISSUE: CHANGE DATE:

DOC. NO.
ISSUE: DATE:
CHANGE: DATE:
PAGE:

IDENT. NO.	SS/EQ SPEC PARAGRAPH	SPECIFICATION/VERIFICATION REQUIREMENTS	VERIFICATION METHOD EQUIPMT LEVEL	SUBSYST. LEVEL	SYSTEM LEVEL	VERIFICATION REF. DOC.	FINAL VERIFIC. DOCUMENT (E.G. TEST, ANALYSIS, INSP. REPORT)	REMARKS
	3.1.2.4.2	CDMS Interface The PIA shall interface to the RAU data bus via an Interconnecting Station Stub. The interface shall be identical to that in the RAU. It shall meet the signal characteristics, bus error rates and redundancy requirements of the present RAU. The active Bus Interface Unit will be selected by the BIU control line. For communications to the PIA individual address the bus protocol shall be identical to those for an RAU. For broadcast commands and data transfers to multiple PIA's, only the designated master will acknowledge successful receipt. Master designation shall be achieved by a simple command to that PIA's individual adress.						
	3.1.2.4.2.1	Additional BIU Requirements The BIU shall be initialized into its receive mode with all output error discretes reset under the following conditions : a) at power on b) when selected by switching of the BIU control line.						
	3.2	Characteristics						
	3.2.1	Performance						
	3.2.1.1	Life Requirements						
	3.2.1.1.1	Operating Life The PIA shall be designed to be operational for a least fifty (50) seven-day missions, with low-cost refurbishments and maintenance. The PIA design shall not preclude 30-day mission capabilites.						
	3.2.1.1.2	Useful Life The PIA shall have a useful life of ten (10) years.						

or not GSE should be included in a rigorous verification programme is debatable.

Project-mangement aspects of verification

Up to here, the Verification Programme has been presented as a rather complicated and tedious book-keeping system which, in fact, it is. But due to its systematic and all-encompassing nature, it offers a number of project-management capabilities of considerable potential for three principal project-management tasks: project planning, project monitoring, and project completion.

For Spacelab, not all of them – in particular the planning features – could be fully utilised because the verification system was not available at the beginning of the design and development phase. For Spacelab follow-on development, which is getting underway at this time, however, full advantage is being taken by combining the classical specification with the Verification Control Document from the start (Fig. 5).

Project-planning phase

The principal application for verification during the project set-up phase is – as already mentioned in the introduction – the idea of writing the specification, or at least that part of the specification stating the design and performance requirements from the very beginning in the form of a combined design and verification requirements document. The following advantages are apparent:

- Layout and formulation of the specification requirements benefit from the necessity to consider, at the time of writing, how and on which level compliance should be demonstrated. There is no room for vague and nonverifiable requirements, and a clear separation of individual requirements is necessitated. In short, more desciplined and concise specifications than at least some of the Spacelab ones result. In addition, one could adopt the VCD structure with discipline-oriented subsections, eliminating the need for separate support specifications.
- Once columns 4, 5, and 6 (Fig. 5) are completed – either by the customer or by the contractor during the preliminary design phase – not only the design requirements but also

those for testing and analytical work are established. This eliminates the need for separate test and analysis planning, and greatly facilitates manpower and cost estimates for both the contractor and the customer.

Project-monitoring phase

The visibility necessary for progress monitoring is provided by the verification documentation in two areas: column 8, Verification Reference Document, gives an indication as to what extent the activities required for qualification are in work (entry), and how much of such preparatory work has been completed (entry validated). This facilitates timely prompting of all necessary tasks.

Correspondingly, column 9, Final Verification Document, shows the completed qualification elements by entry of an analysis report, test report, etc. and – again by validation – all approved, i.e. in all respects completed, qualification activities. Periodically extracting the status statistically, which is easily done at any time, reveals the areas needing more attention, or perhaps a streamlining of their procedures, in order to maintain overall progress. An essential prerequisite for this to function is, however, a fairly high frequency of Verification Review Board sessions; in the Spacelab Programme, such sessions are convened approximately every two to four weeks for each VCD subject.

Project-completion phase

The function of verification in project completion, i.e. customer acceptance of the product, is – as already discussed – primarily that of providing evidence of satisfactory close-out of all qualification activities. If, as it is the case in the Spacelab project, all Verification Review Board dispositions are made in concert between the contractor and ESA, VCD completion is nothing more than the last increment in a long step by step procedure. No re-review of already validated line items is necessary.

However, there may be reasons for wanting to conduct such re-reviews, at least for selected hardware items or activities. One reason, certainly applicable to Spacelab, may be that ESA, in turn, must convince its 'customer', NASA, of the integrity of the product; one way of doing this is by inviting NASA to re-review the qualification close-out, generally or selectively.

A second, more general reason for wanting to go back is that it may become necessary to re-examine the qualification history of a component that has failed, or shown unsatisfactory performance, in ground or flight operations. To make this possible, all documents called up in all VCDs must, of course, be kept available. For Spacelab, a special repository was set up by the contractor for storing and maintaining all VCD-referenced documents for as long as ESA may determine.

Conclusion

The Spacelab Verification Programme described above was developed during the design and development phase with the primary purpose of ascertaining completeness and satisfactory execution of flight hardware, software, and ground-support equipment qualification. The methods and documents used have been tempered by more than five years of working experience, a process still continuing. The system can be regarded as having proven its effectiveness, both as a working and as a management tool. The latter would be considerably enhanced if introduced at the start of a project. This applies, in particular, to the suggested restructuring of the specification documentation by combining design and verification requirements as discussed earlier and as shown in Figure 5.

The experience accumulated in converting a very simple logic into a working project tool, and some suggestions on how to expand its utility, have been presented here in the hope that future projects can use them to advantage.

Finally, special credit is extended to F. Enners of ERNO, Bremen, Germany and R. Klamt of McDonnell Douglas, Huntington Beach, California, USA, for their decisive roles in establishing the Spacelab Verification Programme and – most importantly – for making it work.

In brief

Association Agreement with Austria Enters into Force

On 16 January 1981 the Austrian authorities and the Agency carried out the exchange of notification of the fulfilment of the conditions required for the entry into force of the Agreement between the Republic of Austria and the Agency, signed on 17 October 1979. By virtue of its Article 13, this Agreement of Association therefore comes into force on 1 April 1981.

The accompanying illustration shows the handing over to Mr. E. Quistgaard, ESA's Director General, by Ambassador P. Jankowitsch, Austria's permanent representative to OECD in Paris, of the official letter confirming the entry into force of the Agreement of Association.

Operational Meteorological Satellite System Proposed for Europe

The first session of the Intergovernmental Conference on an Operational Meteosat System was held in Paris on 28 and 29 January 1981, at ESA Headquarters. It was chaired by Sir John Mason (UK).

The object of this session was to allow interested Governments to express their desire to establish an operational meteorological satellite system in Europe. Seventeen European Governments were represented at the Conference:

Austria
Belgium
Denmark
France
Germany
Greece
Ireland
Italy
Netherlands
Norway
Portugal
Spain
Sweden
Switzerland
Turkey
United Kingdom
Yugoslavia

All participants felt that ESA's Meteosat-1, launched in November 1977, had already successfully demonstrated the great value of an operational meteorological satellite system and therefore concluded that the establishment of such a system would

The Intergovernmental Conference on an Operational Meteosat System in session at ESA Headquarters provide substantial benefits to European and other countries and would constitute a valuable European contribution to the global observing system of the World Meteorological Organisation.

It was agreed that a working group should be set up to prepare the system requirements and outline specifications and to recommend an appropriate institutional framework for the implementation of a Meteosat operational programme.

The findings of this working group will be submitted to the next session of the Intergovernmental Conference which is expected to be held at plenipotentiary level in October this year.

Agreement between Norway and the European Space Agency

An Agreement was signed at ESA headquarters in Paris on 2 April 1981 by Mr Odd Gøthe, Deputy Secretary General of the Norwegian Ministry of Industry and by Mr Erik Quistgaard, ESA's Director General. Under the terms of this Agreement (subject to approval by the Norwegian Parliament), Norway will have Associate Member status with the Agency for a period of five years, during which time it may consider acceding to the Convention of 30 May 1975 and thus becoming a full Member.

As an Associate Member, Norway will be able to participate in the Earthnet programme and in the general studies concerning future projects, which are part of the Agency's basic activities. Norway may also take part in other mandatory, optional and operational activities conducted by the Agency.

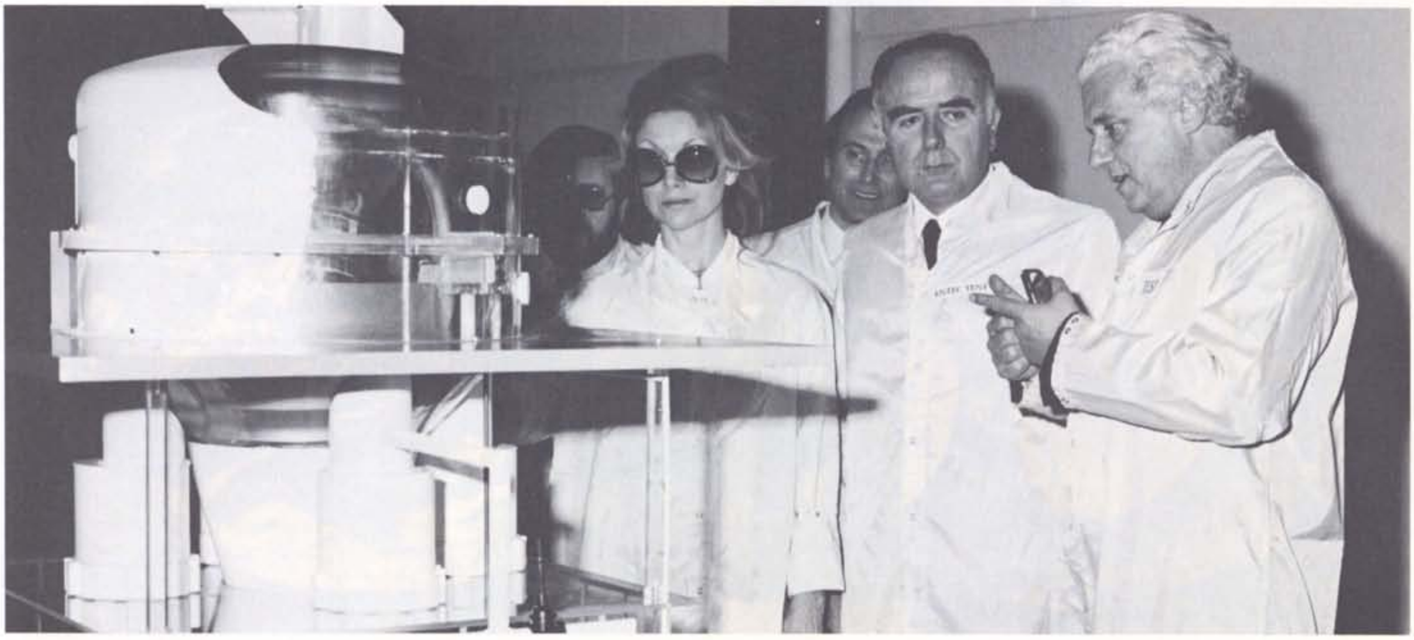
Norway already participates in the Marecs programme and in the preparatory European remote sensing satellite programme.

Italian Minister Visits ESTEC

On 5 March, the Italian Minister for Scientific Research, the Honourable Mr. Pierluigi Romita, visited ESA's Space Research and Technology Centre in Noordwijk. He was shown around the establishment by Professor Massimo Trella, the Agency's Technical Director.

The accompanying photographs show Mr. and Mrs. Romita in the course of their tour, during a visit to ESTEC's Test Floor.

From right to left: Prof. Massimo Trella and the Honourable Mr. and Mrs. Pierluigi Romita ▼



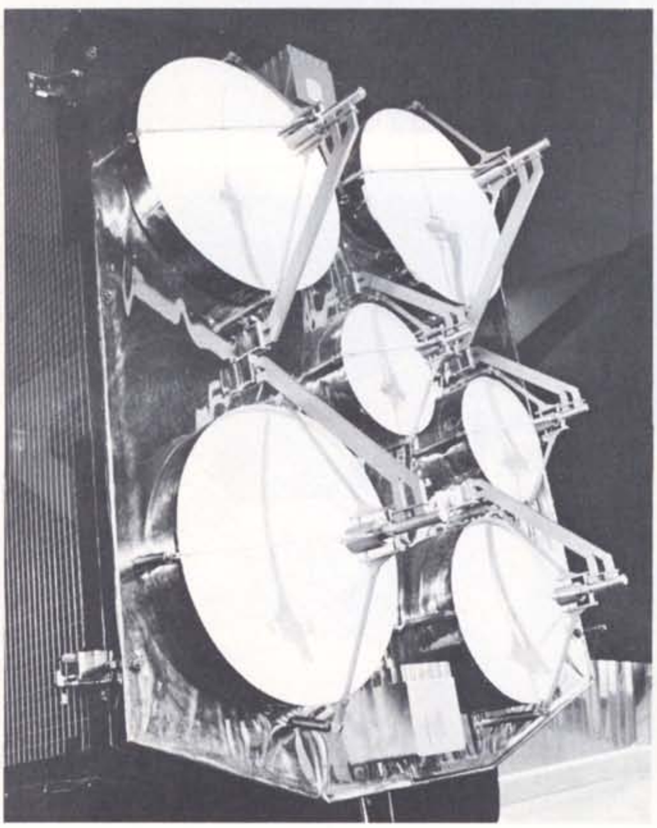
ESA's Participation in the 28th Rassegna Elettronica

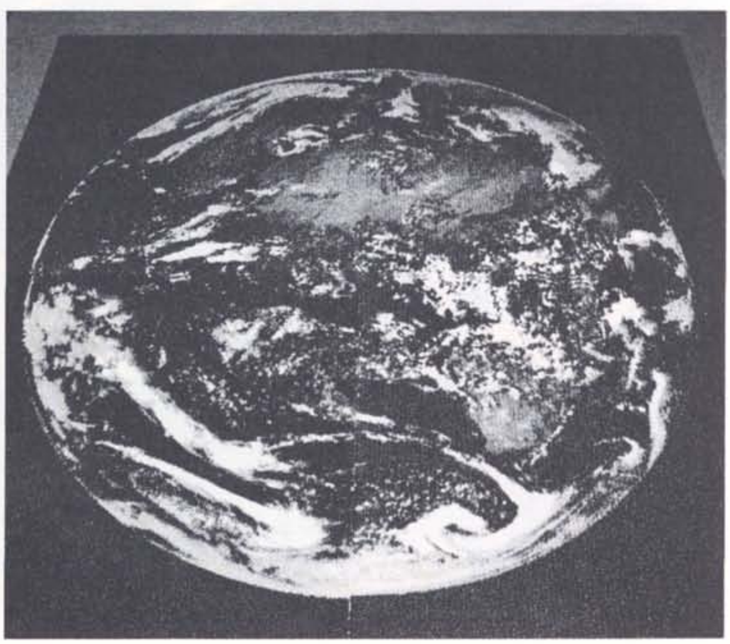
ESA's stand at the 28th Rassegna Internazionale Elettronica Nucleare ed Aerospaziale, at the Palazzo dei Congressi in Rome from 20 to 29 March, highlighted the Agency's current activities and underlined the importance of today's European space programmes.

Among the models exhibited were a 5 m high mock-up of Ariane, and models of the ECS communications satellite, of the meteorological satellites Meteosat and Sirio-2, of the Exosat scientific satellite, and of Spacelab in the Space Shuttle Orbiter.

These exhibits were supported by video and sound recordings and a photographic display. ESA's Information Retrieval Service, which provides on-line access to 18 million bibliographic references, was also demonstrated on the stand.

The two subjects chosen as the themes for the Convegno Internazionale Scientifico sullo Spazio held during the course of the Rassegna Elettronica, on 25 and 26 March, were Energy from Space – How to Make it Possible (including the use of solar-power satellites) and the scientific and technological experiments on the first Spacelab mission.





European Instrument Chosen for NASA's GRO Spacecraft

The scientific instruments that will be flown aboard the Gamma Ray Observatory, due to be launched in 1987 by the Space Shuttle, have recently been selected by NASA's Office of Space Science.

The instruments chosen are:

- a Transient-Event Monitor, to detect and localise gamma-ray bursts
- a High-Energy Gamma-Ray Telescope, featuring a spark chamber to measure the energy spectrum and arrival directions of the high energy (>30 MeV) gamma rays
- a Low-Energy Gamma-Ray Spectrometer, for the detection of low energy gamma rays
- an Imaging Compton Telescope, sensitive to medium energy gamma rays from 1 to 30 MeV to provide gamma-ray maps of the celestial sphere with good energy and spatial resolution.

The principal investigator for the last of these is Dr. V. Schoenfelder of the Max-Planck Institute in Munich, supported by his co-principal investigators:

Dr. B.G. Taylor of ESA's Space Science Department;
Dr. B.N. Swanenburg of the Cosmic Ray Working Group, Leiden;
Dr. J.A. Lockwood of the University of New Hampshire.

Prof. K. Pinkau of the Max-Planck Institute Garching is a co-principal investigator on the high-energy instrument.

For European scientists these instruments on-board the GRO will provide the next step in their study of gamma-ray sources and gamma-ray production processes following on the Agency's Cos-B satellite, which in August this year will complete six years of investigation of high-energy gamma-ray sources.

The Gamma Ray Observatory with a mass in excess of six tonnes will be placed into a 400 km high, 28.5° inclined, circular orbit by the Space Shuttle and is planned to operate for two years.

Ariane L03 Launch set for 19 June

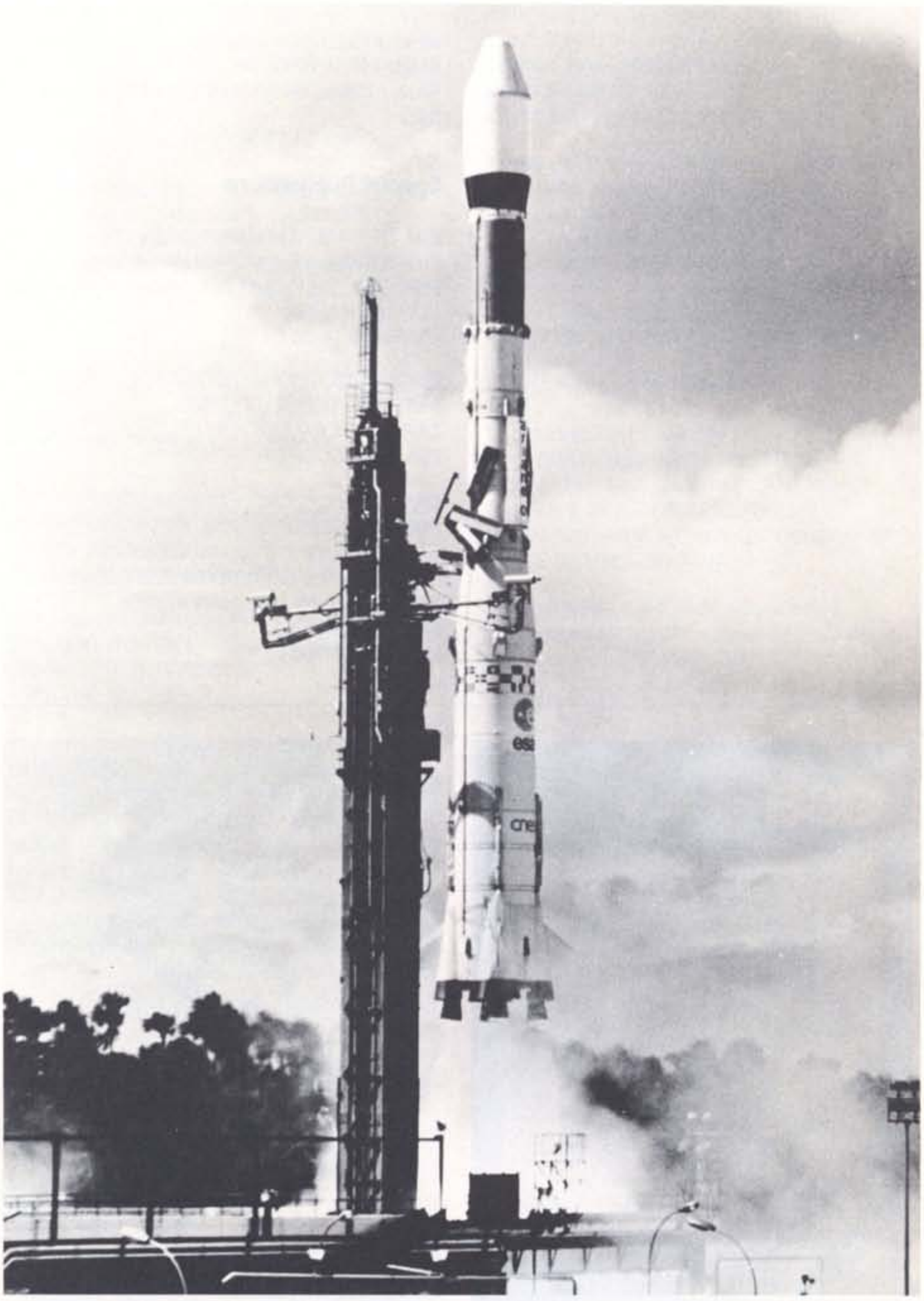
The injectors for the five engines of the Ariane launch vehicle for the L03 test flight have been successfully acceptance tested on the SEP test stands at Vernon, and are now being fitted.

These injectors have undergone modifications following the investigations and tests carried out to overcome the high-frequency phenomena that occurred during the L02 test flight.

The acceptance has involved two 'hot' tests of each injector under conditions much more severe than those encountered in flight. The results have been very satisfactory and the third Ariane test flight is expected to take place on 19 June 1981.

The Ariane L03 vehicle will fly:

- A technological capsule (CAT), carried on all four development flights, containing electronic monitoring equipment and environmental sensors.
- The second European meteorological satellite, Meteosat-2.
- The Apple communications satellite, designed and constructed by the Indian Space Research Organisation (ISRO).



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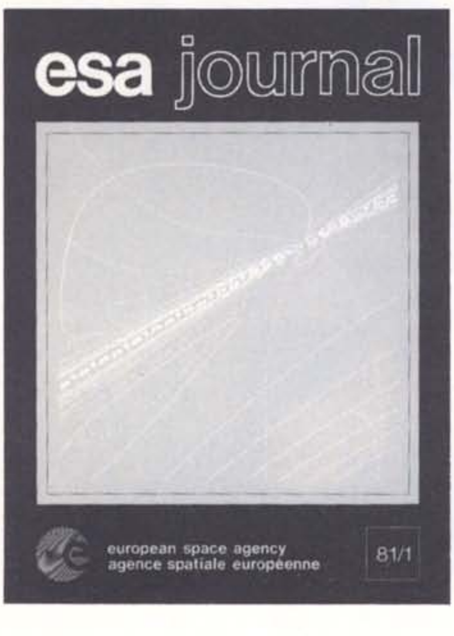

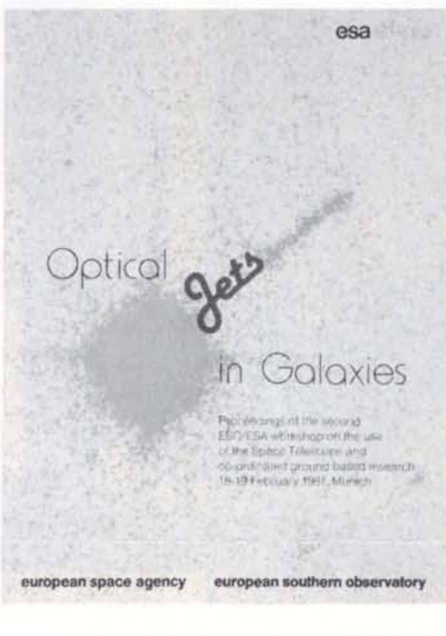

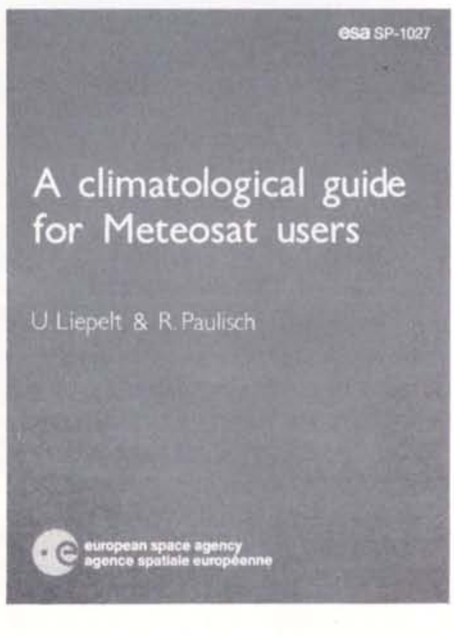

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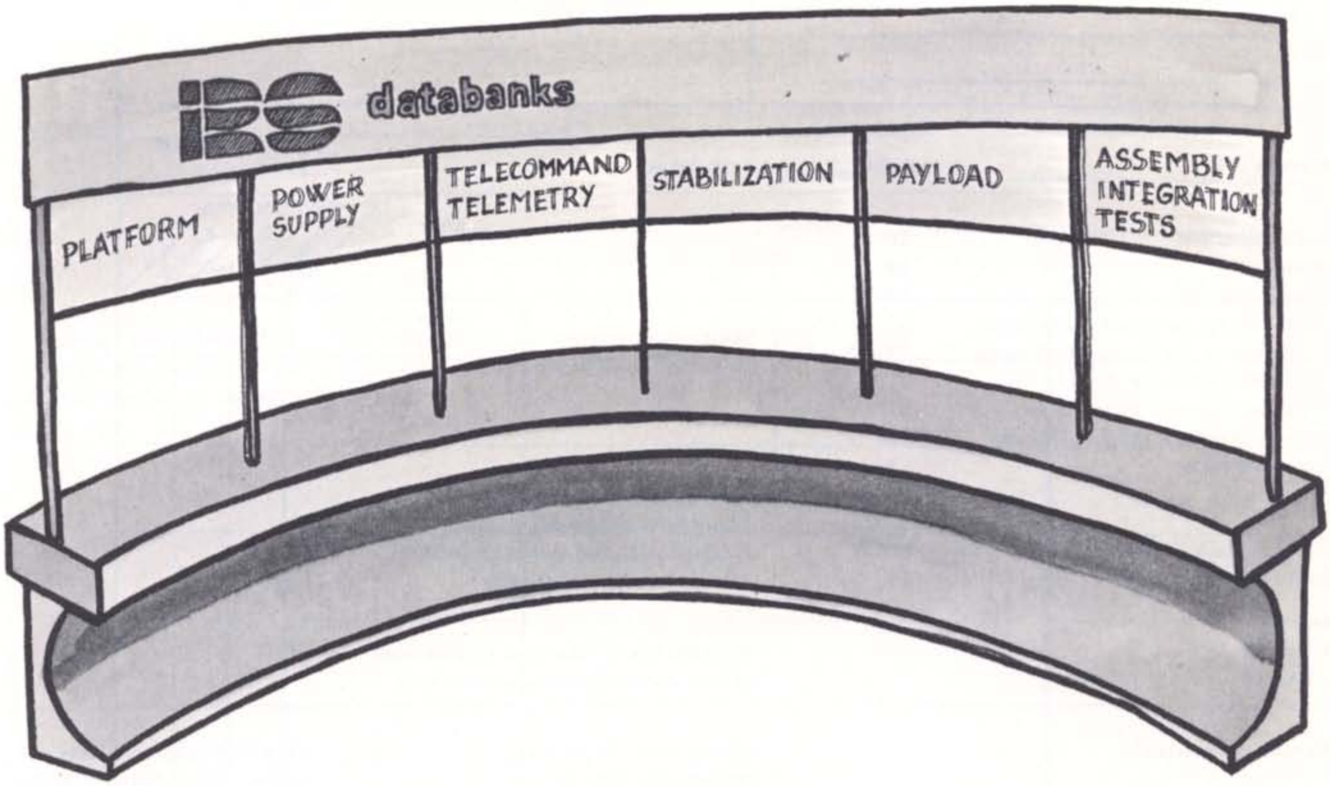

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