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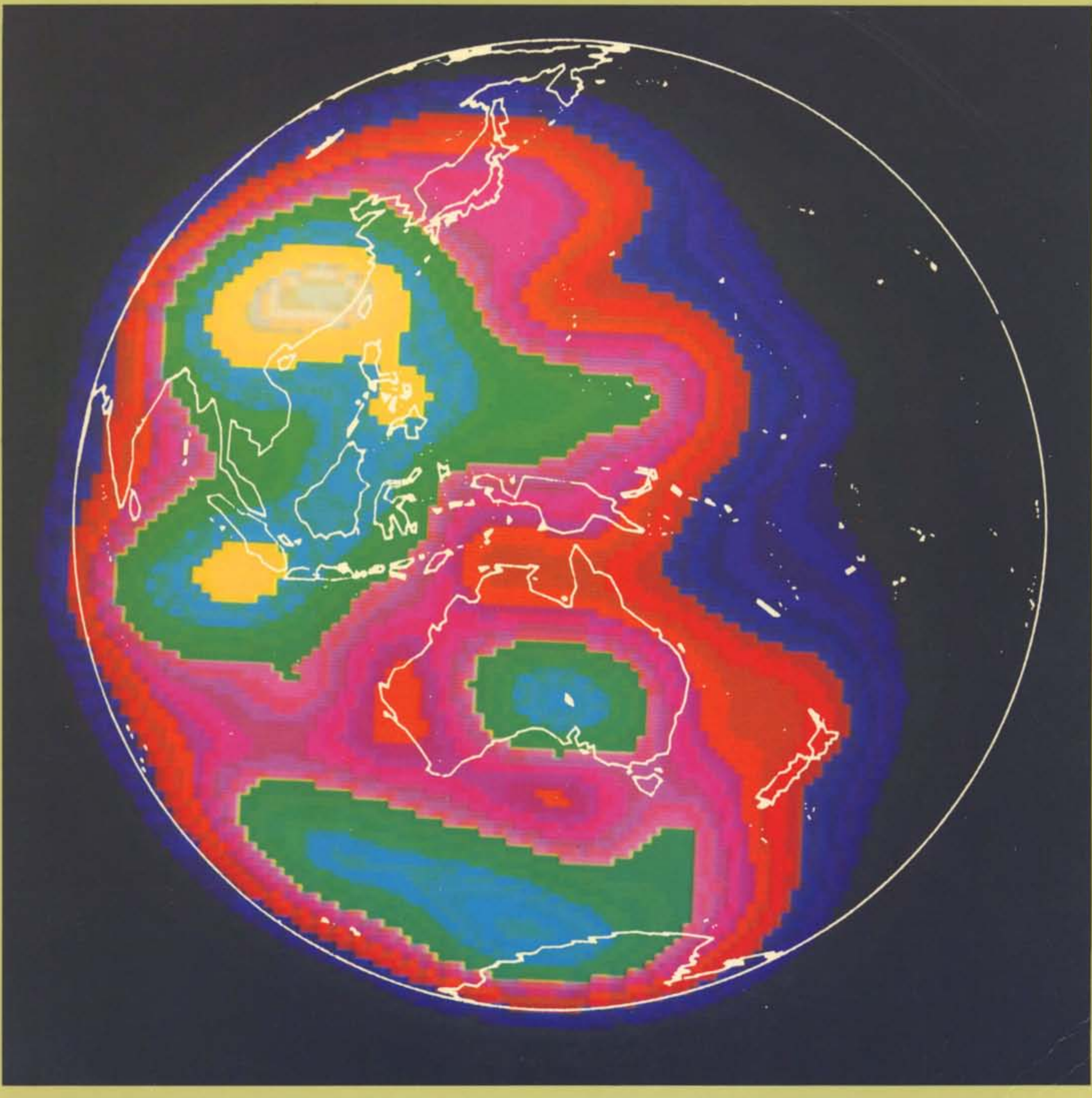

european space agency

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

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 Inspector General; the Director of Scientific Programmes; the Director of the Earth Observation and Microgravity Programme; the Director of the Telecommunications Programme; the Director of Space Transportation Systems; the Director of the Columbus Programme; the Director of Operations; and the Director of Administration.

The ESA HEADQUARTERS are in Paris.

The major establishments of ESA are:

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

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

ESRIN, Frascati, Italy.

Chairman of the Council: Dr. H.H. Atkinson.

Director General: Prof. R. Lüst.

agence spatiale européenne

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

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

(a) en élaborant et en mettant en oeuvre une politique spatiale européenne à long terme, en recommandant aux Etats membres des objectifs en matière spatiale et en concertant les politiques des Etats membres à l'égard d'autres organisations et institutions nationales et internationales;

(b) en élaborant et en mettant en oeuvre des activités et des programmes dans le domaine spatial;

(c) en coordonnant le programme spatial européen et les programmes nationaux, et en intégrant ces derniers progressivement et aussi complètement que possible dans le programme spatial européen, notamment en ce qui concerne le développement de satellites d'applications;

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

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

Le Directoire de l'Agence est composé du Directeur général; de l'Inspecteur général; du Directeur des Programmes scientifiques; du Directeur des Programmes d'Observation de la Terre et de Microgravité; du Directeur du Programme de Télécommunications; du Directeur des Systèmes de Transport spatial; du Directeur du Programme Columbus; du Directeur des Opérations et du Directeur de l'Administration.

Le SIEGE de l'ESA est à Paris.

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

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ESRIN, Frascati, Italie.

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Directeur général: Prof. R. Lüst.

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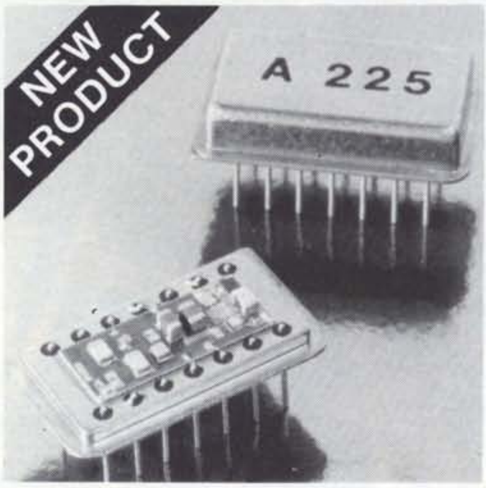

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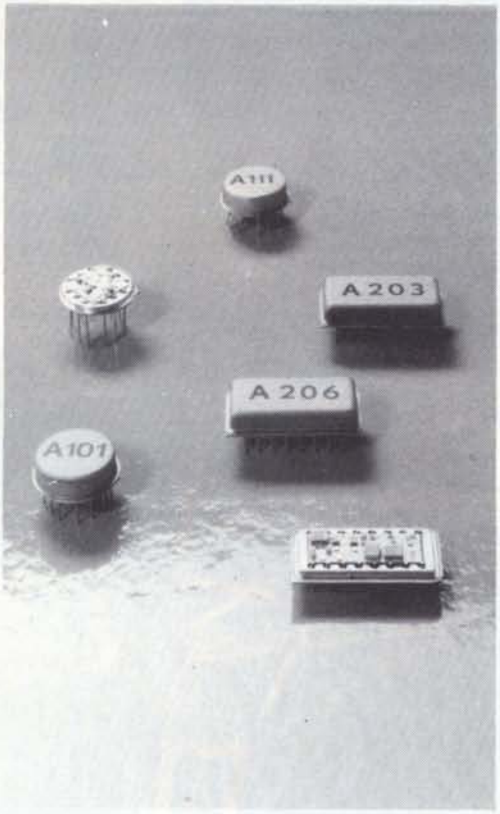

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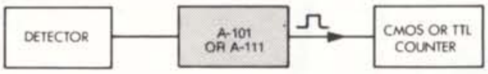

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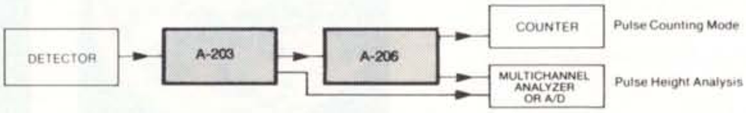

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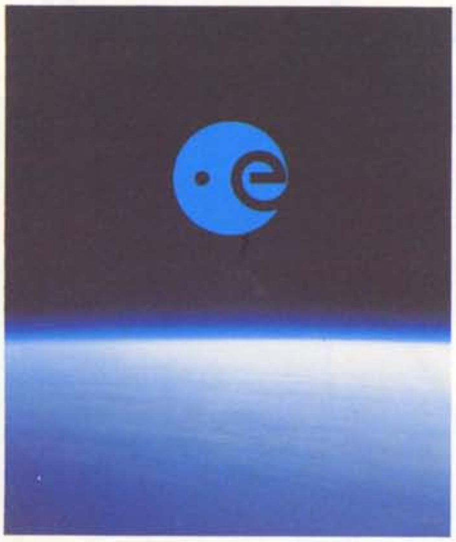


Europe's Future in Space*

Prof. R. Lüst, Director General, ESA, Paris

Introduction

Space is open and space has no known boundaries. It is therefore one of the most ideal domains in which to cooperate across national borders, especially across national borders in Europe. But this is not the only reason why European nations should collaborate in space. Access to space is neither simple nor cheap; it requires concentrated technical effort, and this is also true of every undertaking in space itself. But space holds promise and challenges beyond the scope of any single European nation.

When the ESA Council met at ministerial level in Rome in January this year, it was more than just another in the series of hesistant steps forward that had characterised the first two decades of European space development. In the beginning there had been doubts that the enthusiasm of the scientists could be turned into political reality, but the successes of the ESRO scientific satellites dispelled those misgivings to the extent that the next rather tentative step was the decision to add applications satellites to the programme.

Governments were increasingly interested in the wide social and economic benefits which it was felt would accrue from the development of applications satellites, and at the same time one saw the first real stirring of industrial interest. The Governments were not wrong, and the reception by the user communities of the meteorological satellites (Meteosat), the communications test satellite (OTS), and its maritime and communications satellite successors (Marecs and ECS) was clear evidence that we were in a growing and commercially interesting market.

Two events guided Europe's next step: the acceptance by the USA that Europe had emerged as a space power, leading to an offer to participate in the post-Apollo programme and, following the demise of the European Launcher Development Organisation (ELDO), the demand from some Member States that Europe should still seek autonomy in the launcher market.

So it was that the European Space Agency was formally born, and the story of Spacelab and Ariane is there for all to see.

With their immediate aims accomplished, the Member States now had to decide, at the highest political level, not so much on another step forward, but on the more fundamental issues of cooperation in space. The Governments of some countries faced pressure from lobbies which favoured the more lucrative elements in space industry being creamed off at a national or bi-national level: others wanted a much smaller, less technical role for ESA. Slowly, from the months of patient negotiation and discussion, a consensus was possible, stemming, I like to believe, from the knowledge that in ESA the Member States have a forum to which they can bring their aspirations and hammer out a policy in which regard for the wider interests of Europe plays a considerable part: in consequence, they had a much better appreciation of what Europe could accomplish as a whole.

* An Invited Address given on 19 September 1985 in Munich at the Western European Union's 'Colloquium on the Space Challenge for Europe'

Figure 1 – ESA Council Meeting at Ministerial Level in session in Rome on 30 and 31 January 1985

As a result, the Ministers have given us not just a decade of work, but a firm foundation upon which we can build so much, well into the twenty-first century. And when I say 'we', I am talking of Governments, intergovernmental agencies, institutions and universities, industrial companies, and commercial enterprises, as well as the ESA executive.

It was to my mind the strength of the political will in Rome that affected the environment so positively and made such a potentially dynamic situation possible. Instead of a compromise 'patchwork', the Ministers voted for a balanced programme, intended, in the words of their resolution, to:

> 'expand Europe's autonomous capability and Europe's competitiveness in all sectors of space activity.'

This is a clear indication that cooperation has reached a considerable level of maturity, where Member States can talk confidently of autonomy in space research and technology. This should not be interpreted as an aggressive or isolationist policy. Europe is not attempting to conquer all aspects of space alone. The initial step, as I see it, is to ensure that, when cooperating with other major space powers, we have the sureness to seek equitable partnerships.

Coming now to the decisions taken in Rome, and what they mean in terms of programme elements, I will start with the mandatory science programme.

The future programmes

Science

Science has suffered for more than a decade from having a 'frozen' budget. Some countries had not, in the last decade, subscribed to the need for an innovative and vigorous, coordinated science programme. However, the spirit of the early ESRO pioneers was still very much alive, and the science community had put together an imaginative but feasible and viable programme.

Much heart searching was called for on the part of several Delegations, and some Member States were pressed uncomfortably close to the limits of their financial mandates. However agreement was possible, and so the mandatory science budget will be increased by yearly increments of 5% until it reaches 162 million accounting units (US$ 132 million at 1984 economic conditions).

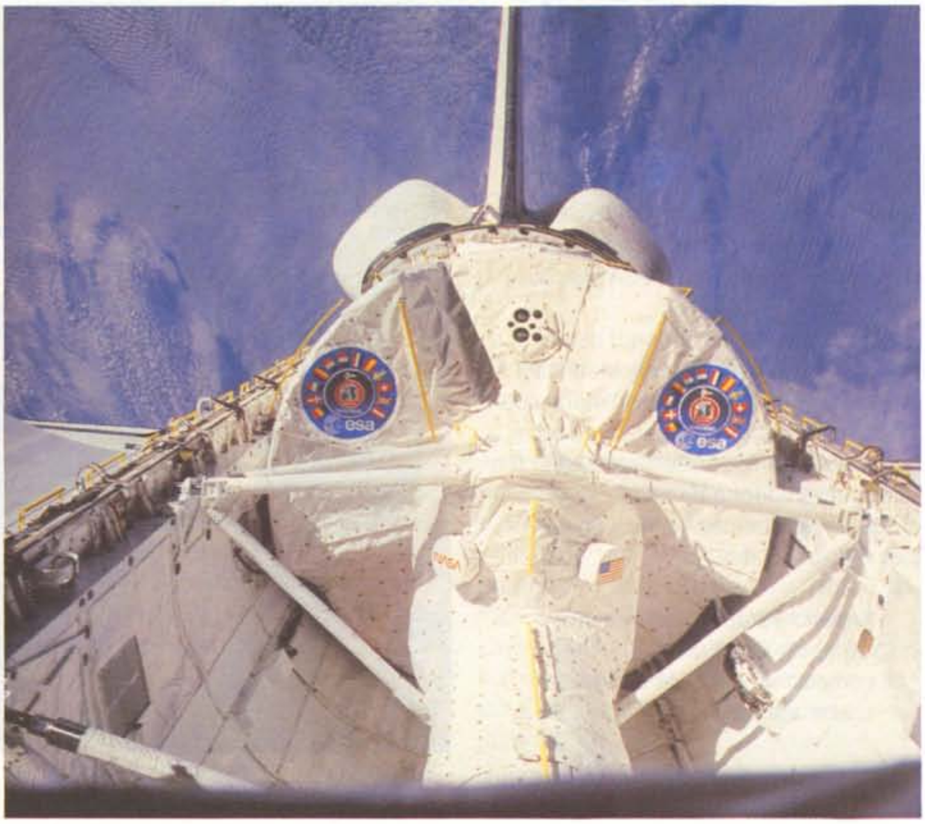
Of particular significance to the scientific community was a departure from the previous ad hoc method of selecting scientific missions. By building on four major mission concepts – the four 'cornerstones' of the science programme – and allowing a flexible approach for the medium and smaller projects, the scientists have devised an approach which should have a 'ripple effect' of some importance.

Universities and institutes will be able to attract graduates who see an exciting and well-defined future. Industry will be able to prepare itself for new R&D ventures in all aspects of instrument and spacecraft design. The world of computers must assess new demands for data handling and the operational control of spacecraft and experiments.

The science programme's central role in the Agency has been accepted, and work is already in progress to turn the plans into reality. Here is another accrued benefit of a settled programme. Those scientists and technologists concerned with the four cornerstone elements can now spend more time defining precise parameters for the missions, so that more detailed work is possible in the very early stages, thus saving time, money, and frustration later.

That the scientific programme will be increased is not only of importance for science in Europe itself, but also for the entire space programme, since this mandatory programme is the basis for future technical development in the satellite field – especially for applications

Figure 2 – Spacelab-1 in Earth orbit in the Space Shuttle's cargo bay in December 1983



satellites where one does not want to take any technical risk. Furthermore, the scientific programme is mandatory for all Member States and therefore it provides the cement for the Agency's entire programme and the organisation itself.

The Ministers recognised the key role of scientific research by requesting the Agency to study possible ways to extend the scope of the mandatory scientific activities to other scientific disciplines. This I have welcomed and, without prejudice to the traditional space sciences, we will find ways of accommodating the new sciences, building on the experience of our past endeavours.

Research and development in the microgravity environment

The life and materials scientists are still feeling their way in terms of both the potential of the microgravity environment and the development of facilities in which to carry out their experiments. Spacelab-1 gave life scientists an insight into the effects of microgravity on human physiology and the importance of gravity in cell growth, development and organisation. Bacteria and other small organisms were carried on board and examined after flight to assess the hazards of prolonged exposure to ultraviolet and cosmic radiation. Material scientists learned more about crystal growth, fluid physics and metallurgy, as a result of experiments carried mainly in the material-sciences double rack.

The pattern for the future is set, with much of the effort in Phase-1 assigned to the development and exploitation of multi-user facilities. Following the Spacelab D1 mission this October – on which Biorack, designed for experiments in cell and developmental biology, botany, and radio-biology, the Improved Fluid-Physics Module, and Space Sled, which will determine human response mechanisms to controlled linear accelerations in weightlessness, will be flown – new multi-user facilities will be developed.

This is a new field, and a considerable amount of basic research has yet to be done. Here we have disciplines that, while of a research nature, could have direct impact on the commercial world. Improved understanding derived from microgravity research is expected to influence and significantly improve a number of ground-based manufacturing processes. There is the prospect of new high-value products becoming available to the pharmaceutical and semiconductor manufacturers.

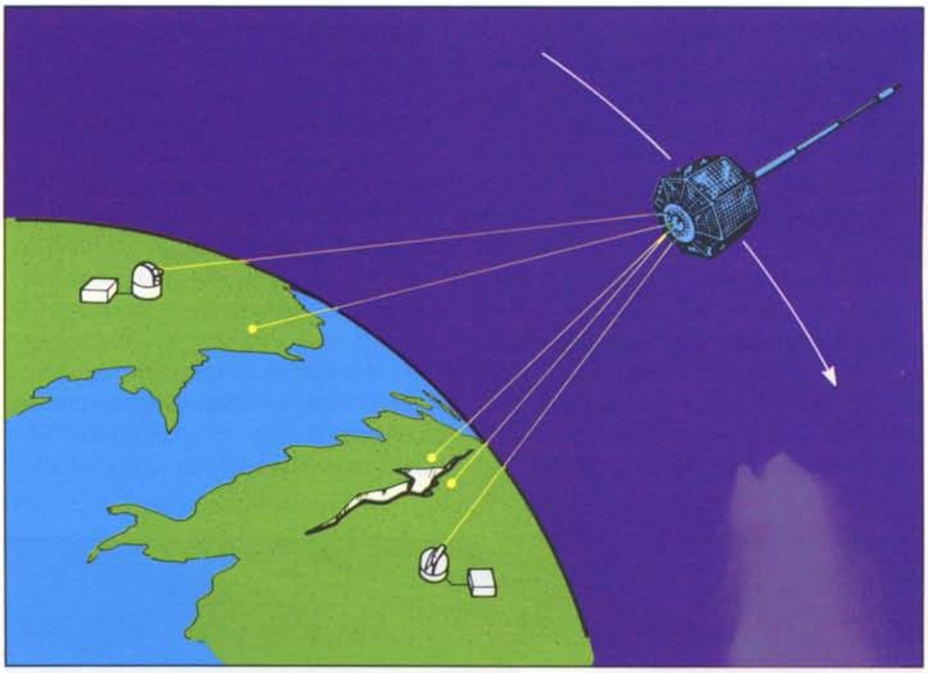
Earth observation

One element of the overall ESA programme that could have strong social and economic repercussions is that of earth observation. We have some experience from US remote-sensing satellites, and the Metric Camera on the Spacelab-1 mission, and, of course, the images from our own Meteosat are seen daily on TV screens in many European households. The first European remote-sensing satellite, ERS-1, due for launch in mid-1989, will provide an experimental, pre-operational system for the remote-sensing user community.

It is intended to define, develop and exploit the coastal, ocean, and ice applications of remote sensing data, and to increase the scientific understanding of coastal zones and global ocean processes. Apart from the data of scientific interest which will be generated, potential commercial users of ERS-1 data include those responsible for offshore oil activities, marine navigation, fisheries, and the monitoring of oil pollution. In this way, Europe should complete its preparations for an operational system for ocean, ice, coastal-zone and meteorological applications in the mid-1990s. Land applications have not been forgotten; an experimental, pre-operational satellite for land applications is a further stage in the programme. Here ESA will be seeking to exploit land applications of advanced all-weather remote-sensing data acquired from microwave instrumentation, and to

Figure 3 — False-colour enhanced Meteosat image of the globe

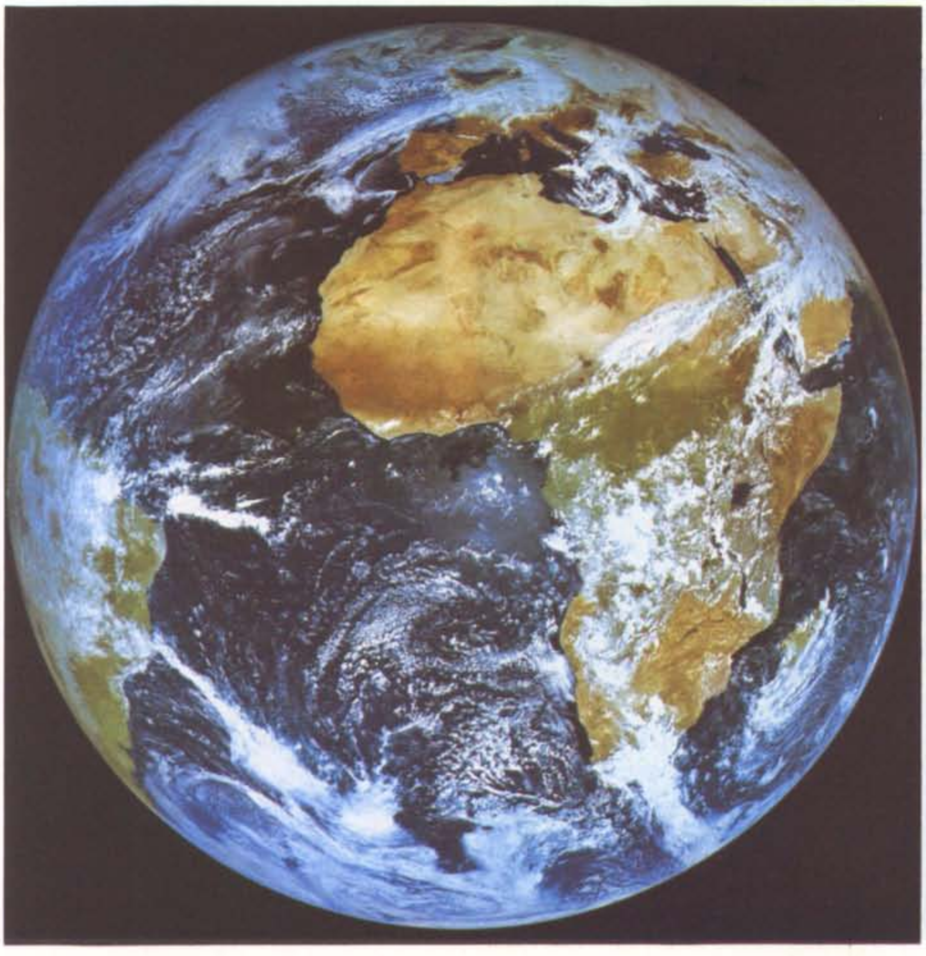
Figure 4 — Popsat: a candidate European satellite system for solid-earth sciences and applications



provide ways for Europe to improve its management of land-based activities and resources.

Although the Meteosat system is operational, there is no standing still with the techniques and instruments available, and the Agency looks forward to developing a second-generation meteorological satellite.

Scientists studying the physical forces and processes that are active in the interior of the Earth and are also responsible for catastrophic events on the surface, are excited by the potential that satellites hold for them. A precise orbit-positioning satellite (Popsat) could monitor the kinematics of the Earth's rotation, crustal distortion in earthquake areas and tectonic plate motions, and make precise determinations of points on the Earth's surface to an accuracy of a few centimetres. Further into the future, we can conceive of missions that will improve the understanding of the fine structure of the Earth's gravity field, allow crustal features to be inferred, and allow us, by means of a two-colour laser system, to monitor deformations in seismic areas.



Before continuing with the ESA programme, I would like to draw attention to one aspect of remote sensing, outside the direct control of the satellite builders and operators, which gives me some cause for concern. Satellites can draw attention to impending problems, and can often give a clearer picture of the scope of a catastrophy than can be gained from the ground. It is, however, up to Governments to devise and maintain the infrastructure and logistical support needed to make use of the information gleaned from the satellites. This is particularly true in the developing world. I am thinking of the desertification and crop-failure warnings which satellites can give. The means of turning such information to practical use is an essential element that must not be forgotten.

Figure 5 — The large Olympus telecommunications satellite, to be launched in mid-1987

Telecommunications

ESA's telecommunications satellites have already proved their commercial interest and success. That, however, is not the end of the story.

ESA must play its role in ensuring that European industry can maintain and expand its position in the space communications market. Olympus, the next demonstration mission, is well underway, and a further major demonstration mission is foreseen for the mid-1990s. Obviously no firm definition of the system yet exists, but possibilities include a cluster of two satellites with microwave and optical inter-satellite links, with the capability of performing rendezvous manoeuvres and possible docking experiments, and a multi-frequency and multi-service payload including a high level of onboard processing and using large reconfigurable antennas and possibly frequency-sensitive subreflectors.

The initial studies of many new space systems show that data-relay services will be an essential part of future space exploitation. The telecommunications engineers are already thinking in terms of a Data Relay Satellite system for the mid-1990s which would employ two satellites.

Europe will also play its part in navigation by satellite. Much will depend in the final analysis on whether an international institutional framework can be set up, rather on the lines of INMARSAT. In the meantime discussions continue with the International Civil Aviation Organisation (ICAO) and other international bodies, and with national authorities in India and Japan and other countries which have expressed interest. If a worldwide preoperational system were to be set up, Europe would have an important role to play in the development and operation of both the satellites and the earth stations.

Space transportation

I come now to the two major elements in our future programme. It was in the areas of space transportation systems and in-orbit infrastructure that one could sense in Rome that the political will for autonomous European capabilities was at its strongest.

Ariane models 1, 2 and 3 can meet today's launch demands, and the manifest for future flights is most satisfactory, but a much more ambitious programme is necessary if Europe wants to remain competitive and meet the expected needs of European and other users.

Attention has been focused on Ariane-5, but we must not forget that we have nearly a decade to go before Ariane-5 is available. The first and indispensable part of the programme is to continue improvements to Ariane-3, which has already been flown successfully, and to ensure that Ariane-4 is available on time.

By the 1990s it seems likely that Ariane-4 will have keen competition from a new US expendable launcher and a Japanese launch vehicle. The Ariane-4 design does not offer much potential for improvement.

Figure 6 – Launch of the ECS-2 and Telecom-1 satellites by Ariane-3 on 4 August 1984

The need for a new launcher, Ariane-5, is therefore paramount. The Member States had recognised this, and discussions had centred on what type of launcher should be developed. Central to this discussion was the high-thrust propulsion system necessary for enhanced performance. It has been decided that a cryogenic engine (HM60) should be developed as a main element of the Ariane-5 vehicle. Much development work will take place to meet a scheduled ground-qualification completion date in 1993 and a first flight in 1994 or 1995.

The criteria against which Ariane-5 is being developed include the need to achieve a significant improvement in cost-effectiveness for geostationary and low Earth orbits, very high reliability, the ability to accommodate satellites requiring a shroud diameter of 4.50 m, and the capability subsequently to be 'man-rated'. This would imply that Ariane-5 should be able to put a spaceplane weighing approximately 15 t into low Earth orbit.

The French Government, having made its intentions to undertake the Hermes manned spaceplane programme known, was invited by the Ministers to keep the Agency informed of progress made, with a view to including the programme as soon as feasible in the optional programmes of the Agency. I expect to be placing before the Member States a proposal for the Europeanisation of the Hermes programme in the next few months. There has been close cooperation between the Agency and the French authorities since the Rome Conference on working out ways and means to achieve this, and particularly to establish a procedure which meets the wishes both of the Member States and those presently engaged on the programme.

One should also add that it was encouraging to see the way in which the Ministers took note of other studies, particularly the UK's HOTOL programme, and asked all Member States who have such studies in mind or underway to keep the Agency informed.

In-orbit infrastructure

Language can often disguise in prosaic terms the most exciting of ideas. The phrase 'in-orbit infrastructure' is in that category. The concept of a Space Station, and particularly a European contribution, did not meet with universal acclaim. However, the politicians, in endorsing the Columbus programme 'as a significant part of an international Space Station programme', to quote the Resolution, have been bold in their judgement.

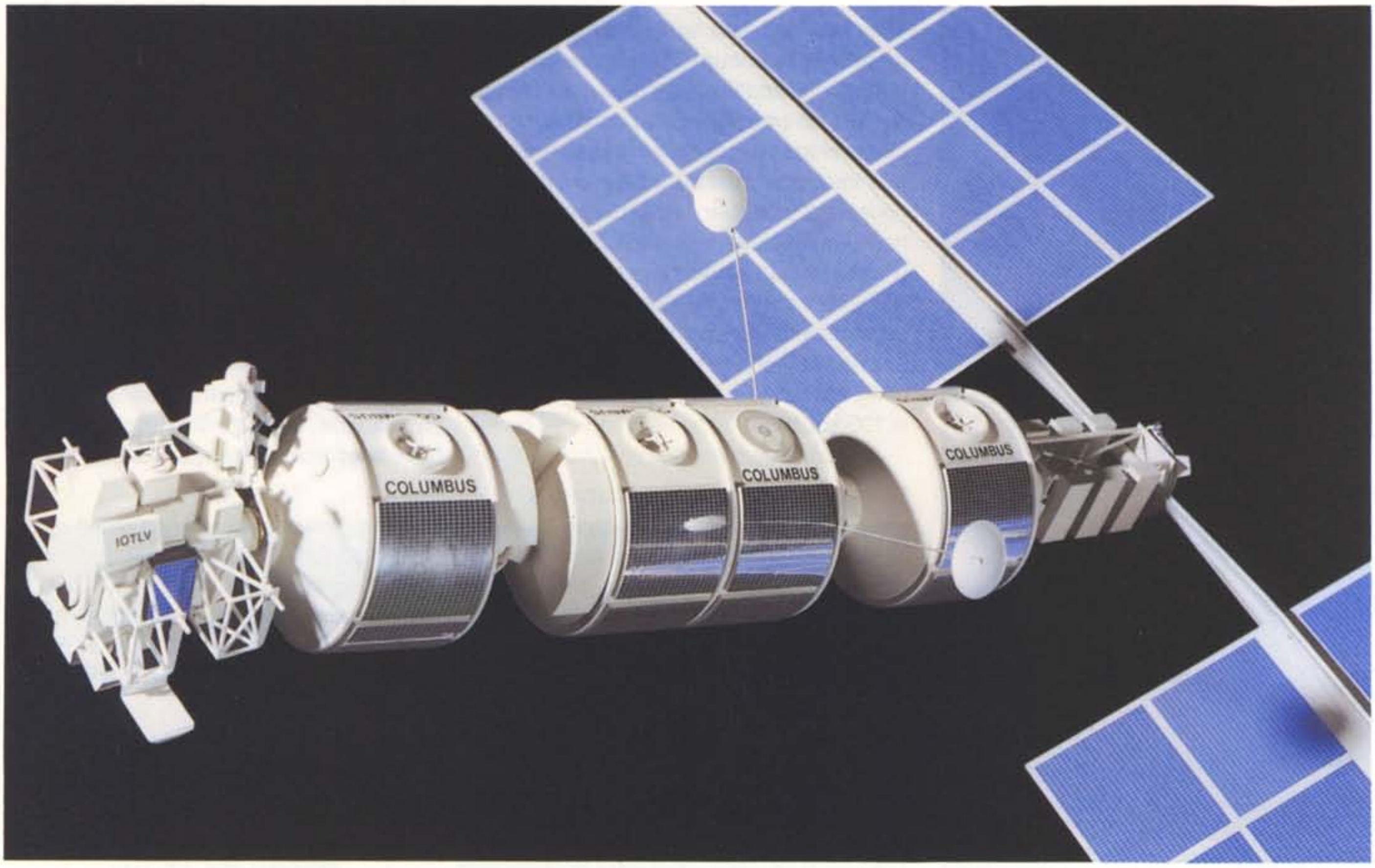
They did, however, lay down certain conditions for an equitable partnership, reinforcing this by calling on the Netherlands' Minister van Aardenne to put the European proposals to the US Government on behalf of the Member States.

Since then, I and my advisers have been in negotiation with the NASA Administrator and his team to determine a Memorandum of Understanding for a cooperative programme covering detailed definition and preliminary design studies to be carried out over a two-year period for a number of potential Space Station elements. Mr. James Beggs, the NASA Administrator, and I signed this MOU during the Le Bourget Airshow on 3 June 1985.

It will be some time before decisions are made on Europe's role in the Space Station, but the Member States lay emphasis on the need to go ahead with the pressurised module, which they see as essential in turning the political will for autonomy in space into reality.

While these studies are going ahead, we must not lose sight of the more immediate future. Spacelab, both the pressurised module which provides a 'shirt-sleeve' environment, and the unpressurised pallets, have already proved outstandingly successful. A number of researchers have found that the ability to

Figure 7 – Artist's impression of the pressurised-module concept for Space-Station/Columbus



have access to the crew and to direct operations on the experiments during flight adds a new dimension to their work and the results that they can achieve. The Instrument Pointing System has recently proved itself beyond expectations. More flights of all of these elements are planned, and much will be learned from their performance to aid the work on the Space Station.

At the same time, we look forward increasingly to the first flight of the European Retrievable Carrier (Eureca). Europe is providing the world with a 'first' in the shape of Eureca, because it seeks to combine the economic retrieval ability of the Shuttle with the demands of scientists for flights beyond the eight or so days that the Shuttle can give. Transported in the Shuttle Orbiter into low Earth orbit, the Eureca platform, with its cargo of experiments, will be launched and then boosted by its own built-in propulsion unit to an altitude of about 500 km. At the end of each mission (typically six months), it will descend, using its own propulsion system, to be recovered by the Shuttle and returned to Earth. Eureca will be available from 1988 onwards, and I believe that when its potential is fully realised it will afford scientists a unique vehicle combining the more desirable features of Shuttle and satellite flight.

Tasks and problems for the future
The scope of the programme that I have outlined in broad terms demands imagination, decisive management, and scientific skills if it is to achieve its objectives. ESA must play many parts. The Agency must foster the high technology R&D of the Member States in support of future space endeavours. This it does through its industrial policy and by acting as a 'clearing house' for ideas and bringing together the scientists, technologists, industrialists and Government representatives.

Turning to the industrial front, I acknowledge at once that it is an extremely difficult task not only to ensure that countries receive a fair industrial return for the funds they put into the Agency, but also to balance the expertise and specialisations that are arising from the relatively new space industry. In the early days, industry saw space work as an adjunct to its more established aeronautical and electronics activities. Now the acknowledgement by industry that space exploration and exploitation has reached a stage of maturity when it can be assessed as a profit centre, has far-reaching effects.

The evolution of industrial consortia that cross many national frontiers owes much to ESRO and ESA. The ability of industry to overcome the language, cultural, and

Figure 8 — The European Retrievable Carrier — 'Eureca'

especially the monetary and legal barriers, which bedevil attempts to set up truly European cooperative efforts, is most heartening.

The setting up of groups to take over responsibility from ESA when the 'production' stage is reached in a programme has given European industry a new dimension, epitomised by 'Arianespace'. Most significantly, many of the aerospace firms in the USA were quick to spot the growing 'knowhow' in the space divisions of European industry as a means of entry into specific markets.

All of this suggests a dynamic state in the industry, which is one of ESA's objectives, and the emergence of a sizeable commercial market beyond that of the traditional ESA and national space markets is gratifying. These changes have gone hand-in-hand with a growing political awareness of the potential spin-off from ESA programmes, not least in those countries that have not developed their industries as far as others. ESA has a special responsibility towards these smaller countries, without whom there could be no genuine unity in Europe.

For a consistent European space policy, we have to overcome and to solve problems that go much beyond the space sector. Let me mention just two of them:

1. We must give up the present national procurement policies in each European country, which are counterproductive, to establish stable industrial consortia or collaborations.
2. We must have a European currency.

But both steps would not only facilitate the work of ESA, but would of course have much wider implications. Nevertheless, why not start it in the space field?

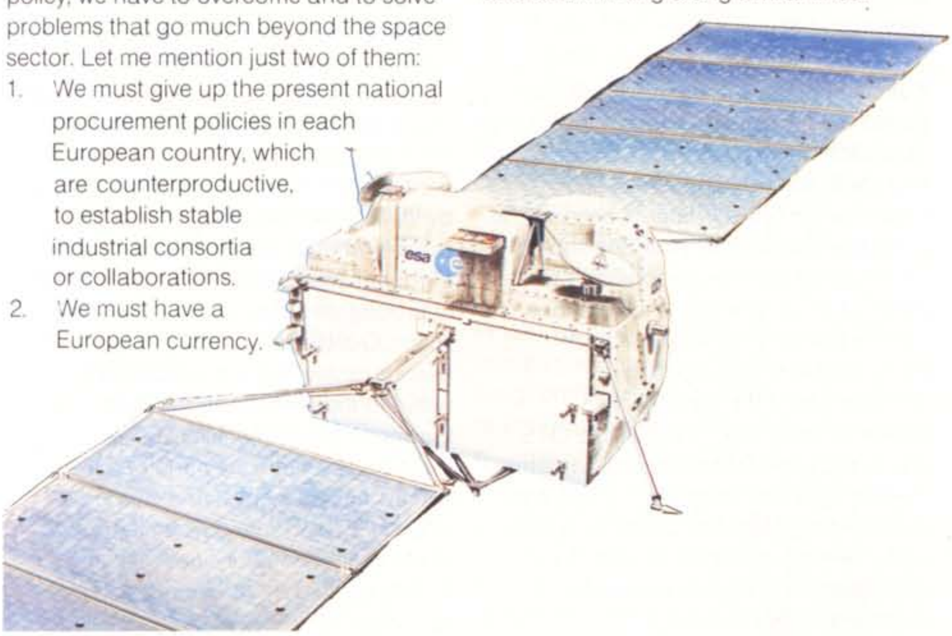
It is also important that ESA helps industry in its transition from the traditional disciplines inherited from the earlier days to the high-technology demands of the coming decades. Once again, a stable ESA programme will influence higher educational establishments to guide first-class graduates and technicians towards the appropriate industries and research.

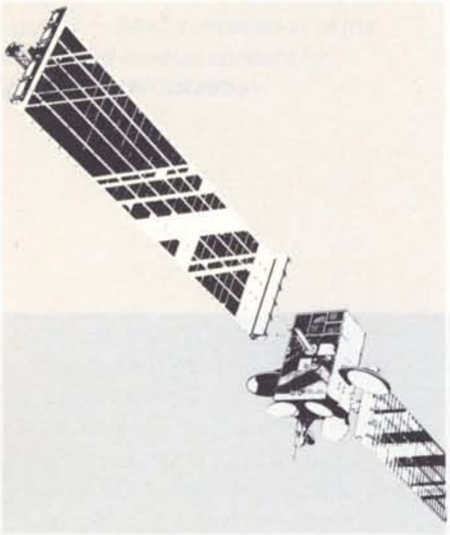
Another role ESA has played is in the establishment of sister international organisations. The national PTTs were unable to put across a cohesive request for the telecommunications satellites systems when each had a different point of view. Eutelsat brought them together and gave them a single voice, benefiting both ESA and the PTTs. The meteorologists are following suit and will join forces in EUMETSAT. Industry has its own Eurospace organisation to help it analyse market potential, and I can foresee the remote-sensing community and those interested in life and material sciences thinking along similar lines.

When the scientists in the early 60s had the courage and conviction to establish ESRO, it is doubtful whether they could have visualised the extent to which space cooperation in Europe would grow. We are now looking at a billion dollar industry which can have far-reaching effects on the development of Europe as a unit.

ESA holds a unique place among European intergovernmental organisations: it is not strongly civil-service oriented, as the EEC must be, and it has much more impact on political, social and industrial life than such scientific bodies as CERN. ESA is a catalyst not only for developing and introducing new space systems to serve Europe, but also for stimulating industry to develop, managerially as well as technically, to a level at which there will be a prominent European presence in the fast-developing space market.

We have the political will, the quality of scientists, technologists and managers, and the growing confidence and experience at all levels within Europe, to ensure that our achievements in space will be beneficial to our community far beyond our present expectations. ESA demonstrates that we can work together very successfully in Europe, and in this way ESA is contributing to the building of a united Europe.





Satellite Communications in Europe: The Earth-Segment Market

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European industry has so far been unable to supply more than a very modest number of Intelsat stations and Inmarsat ship terminals, and even the home market for large Eutelsat stations is being cornered by Japanese industry. Three reasons for this lack of success are: a lack of industrial policy at European level, excessive fragmentation of the market into small 'national' areas, and the inadequacy of high-technology development efforts. These issues are extremely important in economic terms for European industry, and some suggestions are made here as to how the situation can be improved.

Introduction

Satellites have now been used as relays for long-distance communications for more than twenty years. The first geostationary satellite, Syncom-2, became operational in 1964, and the Intelsat system started a year later with Early Bird, also called Intelsat-1. These early satellites were entirely products of the US aerospace industry, which has so far supplied 80% of the world's market for commercial telecommunications satellites.

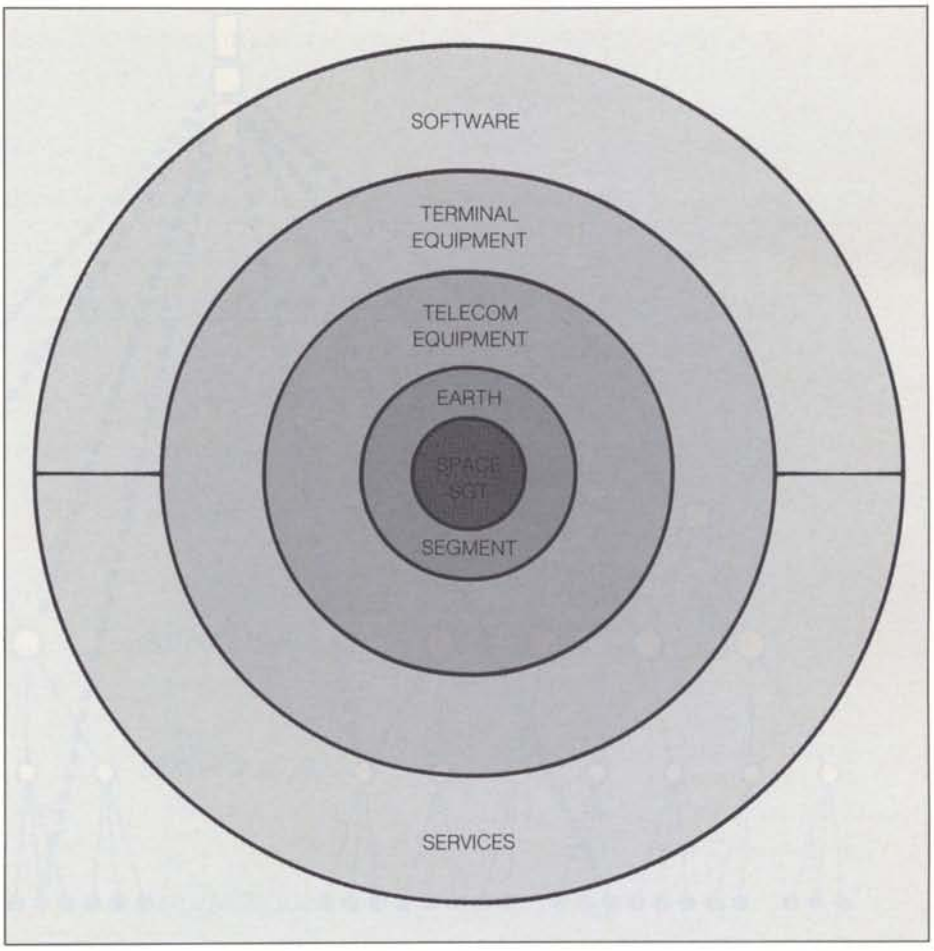
In the late 1960s, some European countries decided to set up their own national programmes in the hope that this would enable their industries to enter the competition or at least to take a useful share of the work of large international projects. The Sirio programme in Italy and the Franco-German Symphonie programme were thus initiated with this objective in mind.

It was not until 1970 that ten European governments decided to take a concerted approach to the problem and resolved that the European Space Research Organisation (ESRO), later to become the European Space Agency (ESA), should be entrusted with the responsibility to conduct a European communications satellite programme on behalf of its Member States. This led to the development of the European experimental Orbital Test Satellite, OTS, and to the series of operational satellites Marecs, ECS and Telecom-1. A new type of much larger satellite, Olympus, is now under development by ESA, with the prototype of this new series due to be launched in 1987.

The ESA telecommunications programmes have been reasonably successful to date, especially in conjunction with the development of the Ariane launcher, since Europe has achieved a quasi-complete independence in space telecommunications and has been able to provide itself with the operational Eutelsat and Telecom-1 networks. It has also provided and continues to provide a substantial contribution to the space segment of Inmarsat. Moreover, European industry is supplying important subsystems in the framework of large Intelsat contracts under the prime contractorship of US companies.

That US aerospace industry dominates the world markets practically unchallenged is a recognised and accepted fact. It is perhaps not so well known that a large part of the earth-segment market has already been captured by Japanese industry. There are also indications that European industry is not doing very well in conquering the earth-segment market created in Europe by the Eutelsat network and one may wonder whether the dominance of non-European manufacturers will be allowed to propagate further into the European scene. Questions are now being raised in various circles about the imbalance between the investments made by European governments in space technology on the one hand and the general lack of interest and support to industry by the same governments in all other fields of business activity created by communications satellites.

Figure 1 – Snowball effect of investments in space communications infrastructure



Investments made in a space infrastructure for telecommunications purposes trigger a snowball phenomenon, as illustrated in Figure 1. They necessitate corresponding investments in an earth-segment infrastructure, which then stimulate further investments in communications equipment, terminal equipment and software and generate a range of new activities in the services area.
This article attempts to assess the earth-segment market (the inner ring of Fig. 1) in Europe for the coming ten years (1985 – 1995), by reviewing the prospects in each of the three classical areas of communications services: fixed, broadcasting and mobile services.

The fixed-satellite service
The first commercial application of satellites made years ago under the auspices of Intelsat was the relaying of trunk telephone traffic and television programmes across the oceans. This fulfilled a real need because submarine cables had a very modest capacity and were totally inadequate for transmitting television signals. Performing a similar function across the European region was also the original mission of the Eutelsat network, although the advantages in this case were less obvious, since the continent was already well covered by an extensive terrestrial system. In the years that followed, many new types of uses were identified and some of them implemented.

In the European context, services already provided by satellite or in the course of implementation can be classified as follows:

a. international trunk telephony connections
b. international exchanges of television programmes (Eurovision)
c. national and multinational distribution of TV programmes to cable networks (CATV) and terrestrial broadcasting radio stations
d. national and multinational distribution of TV programmes to community networks (SMATV)
e. national and international multiservices
f. distribution of information to closed user groups
g. delivery of documents and other types of material containing large amounts of information such as earth-observation images and computer files.

Finally, as part one of the studies in the framework of its new long-term programme, ESA is investigating the use of satellites for yet another application:

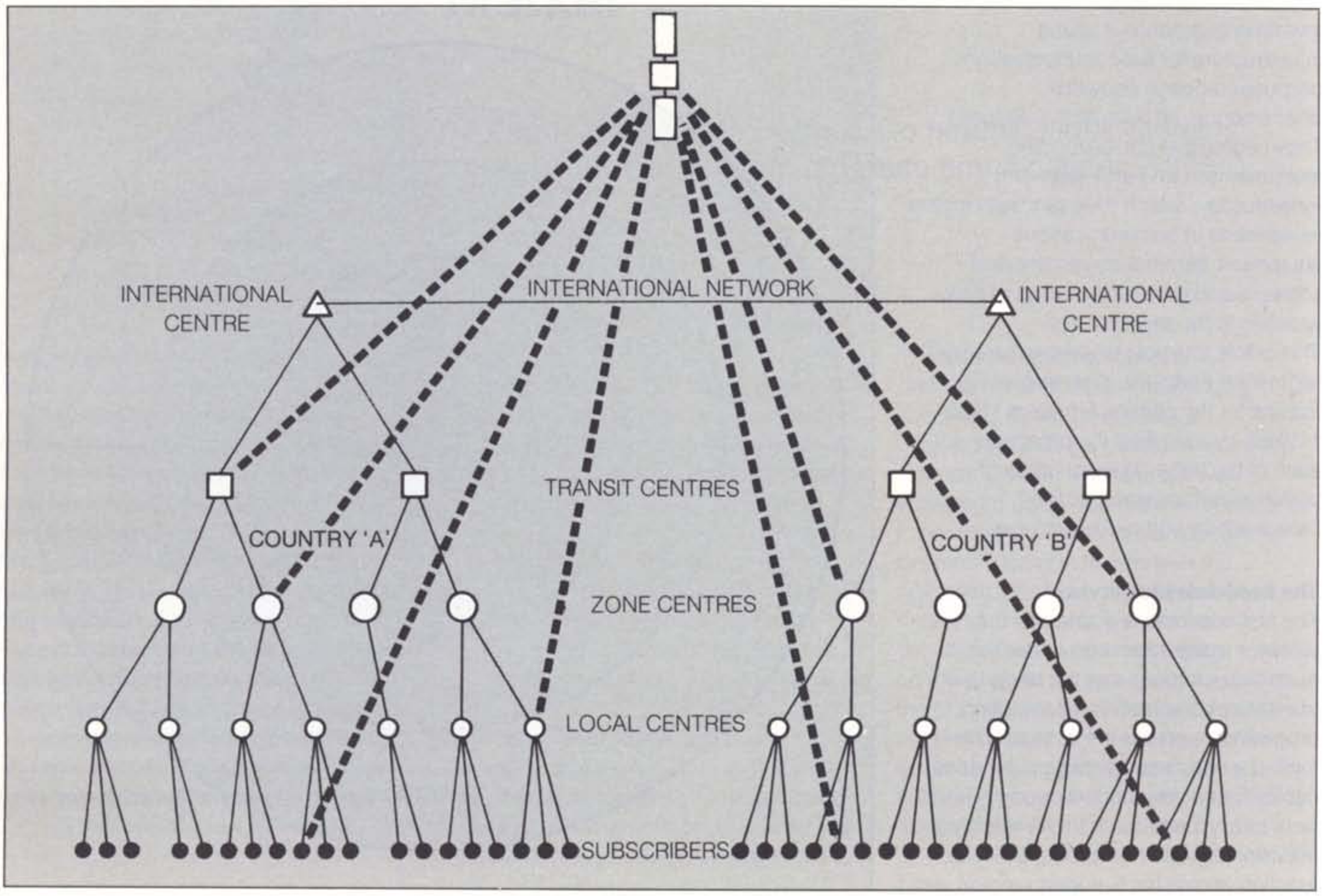
h. meshing of national and international connections between nodes at different levels in national PTT terrestrial networks (Fig. 2).

Before examining the potential market and requirements that may exist for each of these services and the associated earth segment, it is useful to characterise them in terms of the following features, which have an impact on the complexity and cost of the terminals:

i. the terminals need to transmit only, to receive only, and to transmit and receive simultaneously;
ii. the service is point-to-point, point-to-multipoint or both;
iii. the service is network-oriented or user-oriented.

While the first two features are self-explanatory, the last requires a word of clarification. As launcher and spacecraft technology progress, communications satellites tend to grow larger and become more powerful. In the early days, very large and costly installations were

Figure 2 – Concept of an integrated space/terrestrial network



necessary to interface with them and only telecommunications administrations and major operators could afford them. Nowadays it has become realistic to envisage direct access by the end user himself, using small and inexpensive terminal equipment. In conventional two-way telecommunications, however, it is a matter of system design which determines whether the satellite network is integrated with the terrestrial network or whether it can be operated independently of it. In the first case the satellite service is said to be 'network-oriented', in the second 'user-oriented'.

The main characteristics of the services mentioned above are summarised in Table 1.

International trunk connections

For services of types a and b, stations require large antennas (15 m to 30 m in diameter) and powerful amplifiers (± 1 kW). The market in Europe is very limited and offers few prospects. Eutelsat's plans do not forecast more than 20 stations by 1990, and most countries are already equipped with Intelsat stations.

For the coming ten years, the market may be estimated to be another 20 stations, which represent a total investment of the order of 100 MECU*. On the basis of

* MECU = Millions of European Accounting Units; 1 ECU = $0.8

Table 1 – Services already provided by satellite or in the course of implementation

Type of service	a	b	c	d	e option 1	e option 2	f	g	h
Transmit only			X	X			X	X	
Receive only			X	X			X	X	
Transmit/receive	X	X			X	X			X
Point-to-point	X				X	X		X	X
Point-to-multipoint		X	X	X	X	X	X	X	X
Network-oriented	X				X				X
User-oriented		X	X	X		X	X	X	

current trends, there is little doubt that most of this market will be reaped by Japanese industry. Indeed, as the largest market in Europe is still confined to individual countries and is in itself much too small to produce an adequate return on investment, none of the European station manufacturers has made the necessary investment. Even in the large countries, where contracts are preferentially awarded to local manufacturers, the latter are still heavily dependent on US and Japanese sources for critical high-technology components and subsystems.

Distribution of television programmes

For the distribution of TV programmes (c), stations need much smaller antennas. The transmit stations use antennas of 8 m maximum, while the receive antennas range from 3 to 6 m. The number of transmit stations should be directly related to the number of transponders in orbit available for this service. After the launch of the third ECS satellite, Eutelsat will have some 20 transponders allocated to TV distribution. Current forecasts are that, by 1990, the number of transponders available for this service aboard all satellites in orbit or under procurement will reach almost 100, as shown in Table 2. By 1995, it is likely to be between 100 and 200.

Table 2 – Numbers of satellite transponders available for TV distribution

		Available transponders			
		Minimum		Maximum	
Launch year	Satellite	Per satellite	Total	Per satellite	Total
1982	Intelsat-V F4	6	6	6	6
1983	ECS F1	10	16	10	16
1984	Telecom-1A	1	17	1	17
	Intelsat-V F10	6	23	6	23
	Eutelsat-1 F2	3	26	3	26
1985	Telecom-1B	6	32	6	32
1986	Eutelsat-1 F4	10	42	10	42
	Intelsat-VI F1	10	52	10	52
1987	Eutelsat-1 F5	10	62	10	62
	Intelsat-V1 F2	10	72	10	72
	GDL – SES F1*	16	88	16	88
1988	Copernicus F1	5	93	5	93
	ISI F1*	–	–	16	109
	Orion F1*	–	–	16	125
	EBS F1*	–	–	16	141
1989	Videosat F1*	–	–	12	153
	Eiresat F1*	–	–	16	169
	ISI F2*	–	–	16	185
	Copernicus F2	7	100	7	192
	Intelsat-VI F5	10	110	10	202

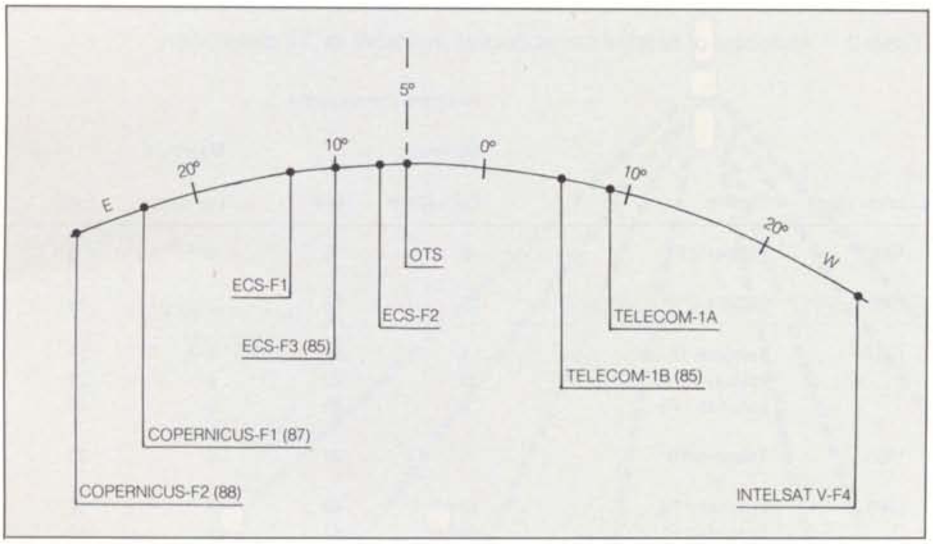
* In the planning stage

The question of whether demand will rise to match the availability of capacity remains open, but a reasonable market estimate would seem to be 50 transmit stations by 1995, or a total investment of the order of 50 MECU.

On the receive side, the number of stations is linked to the number of cable networks and broadcasting radio transmitters to be served, and also to the number of satellites used, since each of them necessitates a different station at each site. The number of European households receiving TV programmes through CATV is currently about 10 million; they are served by some 10 000 networks of different sizes. It is forecast that this service will expand by a factor of two in the next ten years, although the number of networks will not necessarily double. Considering that, by 1990, the number of satellites distributing TV programmes will include at least 3 Eutelsats, 2 Intelsats, 2 Telecom-1s and 2 Copernicus (Fig. 3), the market for receive-only stations can safely be estimated at 10 000 and 20 000 units, or 100 to 200 MECU.

In estimating the market for TV community receiving installations or SMATV (d), one should note that the development of this market depends very much on the relaxation of the regulatory climate in Europe. There has always been a very strict legal distinction made between the fixed-satellite service, which is concerned with communications between fixed stations, all of which are identified and licensed, and the broadcasting-satellite service, whereby signals are transmitted by identified stations for reception by the public at large. To be able to extend the present distribution service destined for CATV networks only to SMATV, i.e. to unidentified receivers, this legal distinction must be abolished. This has in fact happened in North America under the pressure of market forces, and is happening too in certain European countries such as Germany and the United Kingdom. If this trend spreads further into Europe, SMATV will develop into a huge market. As the number of SMATV installations is estimated to be well over half a million, the volume of sales within the next ten years would be of the order of 500 to 1000 MECU.

Figure 3 – Satellites available in geostationary orbit for television distribution



Business services
Table 1 shows two options for multiservices (e), namely the network-oriented version of which Telecom-1 is an example, and the user-oriented version such as the video/data service planned with Tele-X in Scandinavia. Stations for network-oriented systems need rather complex interfaces with the terrestrial network and this has a significant impact on their cost. The future of business services in Europe is still very uncertain at this stage as neither Eutelsat nor Telecom-1 have really had the time to prove themselves. A conservative estimate of the number of stations needed by 1995 is between 250 and 500 of the network-oriented type and 500 to 1000 of the user-oriented type. This should represent sales of 80 to 150 MECU for the first group and 50 to 100 MECU for the second.

Communications satellites are ideal carriers for distributing the same information to multiple destinations (f). This type of application is developing rapidly in the USA, as exemplified by the explosive expansion of the Equatorial Communications Company, a firm that deals with the distribution of specialised information to users equipped with very small receive-only stations, called micro earth stations. Some 20 000 of these terminals, each costing some $3000, are in service today. In Europe, no such development is yet taking place, and it is difficult to imagine how it could happen on anything but a very limited scale whilst the present regulatory environment persists. It is worth noting, however, that a very timid step in this direction is being taken for the benefit of the news agency Reuters, which will use Eutelsat to feed information from its London office to several of its branches in various European countries. Unless a radical relaxation of the regulatory constraints is brought about, one can only conclude that the market prospects in this area, which would otherwise be quite substantial, will remain negligible.

Receive-only stations for document delivery services (g), such as the joint ESA/European Community Apollo project, will need antenna dishes of 1.5 to 3 m diameter. If prices were in the range of 5 to 10 kECU, the market could be up to 10 000 units, or the equivalent of 50 to 100 MECU. Transmit stations would probably be included among the multiservice stations mentioned earlier, and are therefore not considered separately.

Integrated space/terrestrial network
The last type of application leading to the requirement for a specific earth segment is the satellite network, integrated with the terrestrial network (h). The feasibility and usefulness of such a network in a single country is being studied in Italy in the framework of the Italsat programme. There it is proposed that the satellite would interconnect more than 200 nodes of the terrestrial network. At the Europe-wide level, the feasibility of this concept remains to be demonstrated and it is currently the subject of studies at ESA. It is therefore premature to advance an estimate for the earth-station market, except to say that the number of units would run into thousands and the total investment into hundreds of millions of ECUs.

As already mentioned, Japanese industry is almost certain to capture most of the market for large stations in Europe, as local manufacturers have all but given up competing. They are, fortunately, more active when it comes to smaller stations. It would seem, however, that the danger in this area comes from the other extreme, with too many manufacturers trying to compete with each other and with foreign companies for a market that is still very modest and very fragmented by national barriers. Moreover, this market is not being allowed to grow due to regulatory constraints and the lack of a coherent and dynamic telecommunication's policy at the European level.

Direct broadcasting
Four Direct Broadcast Satellites (DBS) are currently under development in Europe: TV-Sat and TDF-1, the twin satellites being built jointly by Germany and France; Tele-X, which is a project led by Sweden, but of interest to all four Nordic Countries; and our own Agency's Olympus satellite. The latter will carry two high-power transmitters to be used primarily by Radiodiffuzione Italiana (RAI) for a pre-operational DBS service in Italy and by a few European Broadcasting Union (EBU) member organisations associated within the Europa TV Consortium. These are planning to broadcast programmes to wide European audiences. Several other European countries such as the United Kingdom, Ireland, Spain, Switzerland and

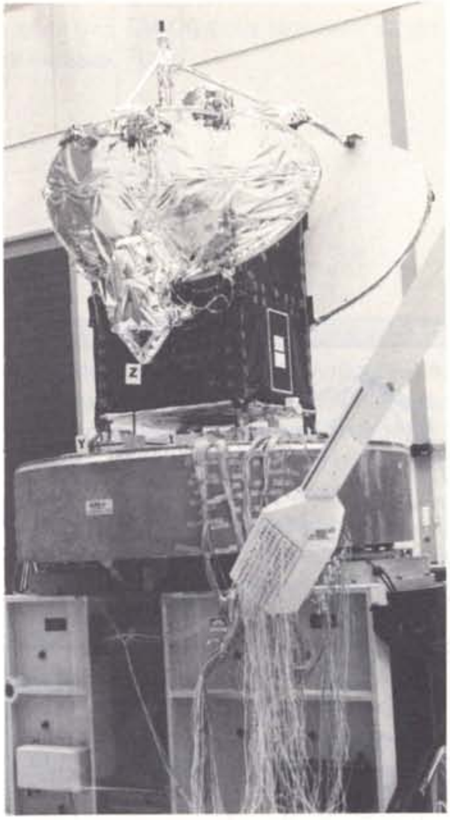


Figure 4 – The Nordic Tele-X satellite undergoing testing at ESTEC, Noordwijk

Figure 5 – DBS coverage concept for The Netherlands (individual receivers)

Luxembourg, are giving active consideration to various DBS schemes, but have not so far taken any decision. All four satellites under construction will operate at high power levels, very close to those specified by the World Administrative Radio Conference's WARC-77 plan.

Doubts are often expressed as to the future of high-power broadcasting by satellite, which at first sight can appear extravagant and expensive. One argument is based on the opinion that the development of cable networks will render broadcasting satellites useless. This opinion stems from the assumption that entire countries can be cabled in a few years at a lower cost than that of deploying a satellite system. That this is not the case is being demonstrated by various projects in Europe. The financial and logistical demands of cable laying are such that, even based on the most optimistic predictions, not more than 25 million homes, i.e. a fifth of the total population in Europe, will be cabled within ten years. Cables cannot therefore represent a realistic alternative to broadcasting satellites, nor have a detrimental effect on their future in the short and medium term.

Other objections suggest that satellite operating at lower power levels than those specified by WARC-77 would be less expensive to run, but still quite adequate considering that many households are connected to a cable network or could be connected to a community antenna, and that the progress made in the sensitivity of domestic receivers could allow a corresponding decrease in satellite transmitted power. However, this reasoning ignores several important aspects of the problem.

Firstly, the percentage of households connected to CATV or MATV is currently 26%, and it is not foreseen that this percentage will exceed 50% in ten years' time. This will therefore leave at least 60 million households with no choice other than individual reception. These households can only be served by direct broadcasting.

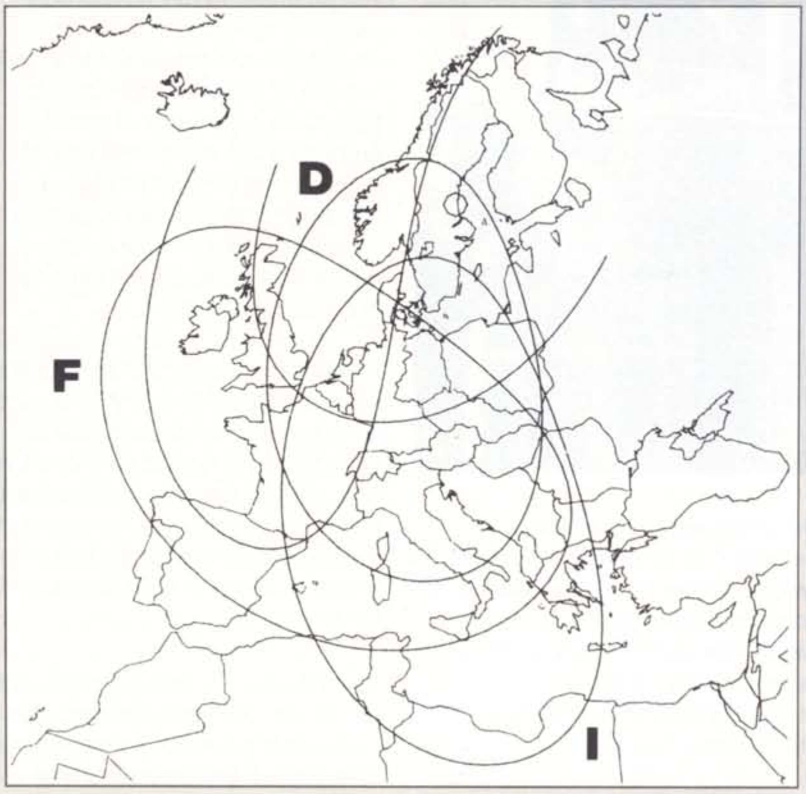
Secondly, broadcasting aims by definition at reaching the general public. This implies that the signal emitted by the satellite must be so powerful that reception is possible with the simplest and least costly equipment, suitable for mass production. The satellite power level specified in the WARC-77 plan was chosen to allow individual reception via 90 cm dishes. With today's receiver technology, the same signal quality could be obtained under the same conditions with dishes half this size. Doubtless, the lower cost of manufacturing, storing, shipping and installing a 45 cm dish would be much more attractive to the consumer. Reducing the satellite power would remove this benefit. Progress in receiver technology also makes it possible under good conditions to receive the signal further away from the beam centre, and thus increases the potential audience.

The significance of these developments, combined with the adoption of the new MAC transmission standard, is illustrated in Figure 5, which shows their effects in the case of a hypothetical DBS system for The Netherlands.

Figure 6 – Effective coverage areas for five DBS systems

Figure 7 – Pan-European coverage of ESA's Olympus satellite

The inner contour (A) represents the coverage area for individual reception with a 90 cm dish, as foreseen in the 1977 plan. The outer contour (D) shows the limit of the effective coverage obtainable with current technology and the MAC system. The intermediate contours (C&B) show the limits of the effective coverage if smaller (60 and 45 cm) dishes are used. The combined effect of an expansion of the coverage area and smaller antennas will undoubtedly be to increase considerably the potential trans-national audience of any national satellite. In Europe, the concept of high-power satellites radiating TV programmes to purely national audiences has in fact lost much of its appeal. The satellite is now seen as the ideal vehicle for trans-national or even pan-European broadcasting. If it is to accomplish this mission, it needs the high power.



When estimating the total size of the market for DBS receivers in Europe for the coming ten years, one has to distinguish between the mass-produced and compact equipment for individual reception and the more professional installations needed for feeding CATV and SMATV networks. For the former, the antenna sizes will range from 30 to 90 cm,, while for the latter they will extend typically to several metres at the edges of beams.

About 85 million households currently receive TV programmes directly over the air, of which 55 million are in the four largest countries, Germany, the United Kingdom, France and Italy, all of which are to be covered by the TV-Sat, TDF-1 and Olympus satellites (Figs. 6 and 7).

With the progress in cabling, the numbers are expected to decrease to 60 and 35 million, respectively. On this basis, it can be safely estimated that the potential market for individual receivers in Europe is well in excess of 10 million units, representing a sales revenue of the order of 10 000 MECU.

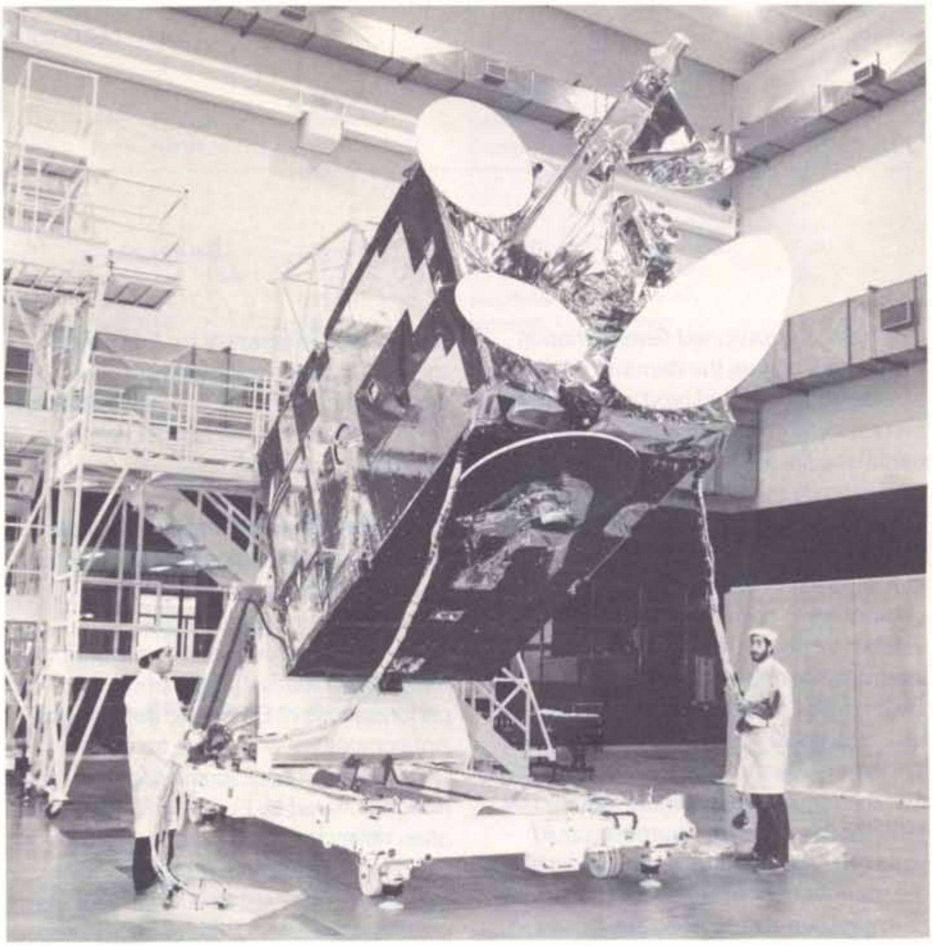


Figure 8 – The Olympus structural model at Aeritalia, Turin

The rest of the European population, connected to CATV or SMATV, represents 30 million households, and this number is expected to double in the next decade. They are at the moment served by 650 000 systems of greatly differing sizes. Remembering that DBS satellites will occupy other orbital positions and operate in a different frequency band from satellites used for distribution, one must assume little or no commonality between the stations of the two types. A market of 100 000 units can therefore be envisaged, which would represent an investment of 500 to 1000 MECU over a ten-year period.

So far most of the attention has been focused on receiving the programmes relayed by the national satellite in each country. As already mentioned, the interest among both established and prospective broadcasters is now shifting towards trans-national and even pan-European coverage. These new types of broadcast will not find the wide international audience they are aimed at unless two necessary conditions are fulfilled. Firstly, all transmissions must adopt the same format, and this should preferably conform to the C-MAC/Packet standard recommended by the EBU, or at least some compatible derivative such as D2-MAC which some European manufacturers prefer. The second condition is that industry must provide consumers with a 'European' type of receiver, i.e. one that can receive and process TV programmes emitted by different satellites.

As of 1988, TV-Sat, TDF-1 and Olympus will be broadcasting up to ten programmes from the same orbital position and it is imperative that they can all be received by one and the same receiver; the implications of this for receiver design are by no means trivial. Eventually, when satellites are broadcasting from different orbital positions, multibeam antennas may become necessary to satisfy the European viewer.

The mobile-satellite service

In the field of land-mobile communications, market prospects look extremely attractive. There is a great unsatisfied demand from travellers, in both business and private vehicles, who require continual access to the public telephone network, or simply wish to receive messages or paging calls. Such services are already available in a number of areas of Europe, but they have the disadvantage of severe geographical limitations and, in the case of radio-telephony, mediocre quality. The inadequacy of the frequency band available for these radio-telephony services limits their expansion. A recent development, however, known as cellular networking, allows multiple utilisation of the UHF channels and will provide considerable improvement in the quality of mobile communications and increased network capacity.

Two major problems remain: firstly, cellular networks will initially be installed in urban areas where the demand is greatest, leaving large areas of rural Europe without a service for many years. Secondly, the frequencies and techniques proposed for use in the cellular networks vary from one country to another, and there are already several different, incompatible standards. The traveller armed with a radio-telephone will therefore be unable to use it outside a predefined area, either because the adjacent area uses a different system, or because it is an inter-urban area with no system at all.

Satellites could be used to serve all of those areas of Europe not covered by terrestrial networks, and to reconcile the different national systems by acting as interfaces. They could also provide relays for overlay networks dedicated to entirely new services such as Europe-wide paging, message delivery and data transmission of various forms. Within the framework of its Prosat programme, ESA has embarked upon a demonstration campaign for pilot services involving the Marecs-A satellite and small terminals carried by vehicles of all types. One class of experiments will be concerned with services implying data transmission only, and will be available to very small terminals (G/T typically −24 dB/K). The other class will require heavier terminals (G/T −10 dB/K), suitable for installation on small boats or airliners, but will offer data as well as voice services, albeit with vocoder equipment.

ESA has commissioned several market studies to evaluate the demand for new services in the area of land mobile and aeronautical communications. Only partial results are available as yet, but they indicate that some very interesting prospects exist. In the road-transport sector, for instance, one study has identified a requirement from transport companies to communicate with their vehicles while on the move on international routes. There are currently seven million such vehicles in Europe, of which some 20% are constantly engaged in long-haul work. This study concludes that the number of terminals required by 1995 for this particular purpose could reach 100 000. Another study predicts that the number of people travelling in private cars between different regions of one country or between countries and interested in receiving messages or paging calls will reach 1.5 million by 1995. This could represent 1000 MECU of business.

In the maritime sector, the problem cannot be limited to the European region, although obviously many vessels never leave coastal waters. The worldwide shipping population is currently estimated at 100 000 commercial ships and 5 million private vessels. Many of these are potential users of satellite services such as simple message delivery, or telephony for those who can afford more than the simplest terminal. Here the market for small and medium-sized terminals is estimated to be well in excess of 1000 MECU over the next 10 years.

As far as the classical Inmarsat services are concerned, more than 3700 users are now equipped with Standard-A terminals of their equivalent. With the advent of the new Standard-B to be introduced in 1989, it is likely that this number will rise to 10 000 by 1995, generating sales of 50 to 100 MECU.

So far European industry's share of the ship-terminal market has been a modest 15%. If the situation is to be improved in the future, it is essential for European industry to prepare itself as soon as possible and to define a suitable strategy. The predicted volume of business is certainly worthwhile.

Competitiveness of European industry

Experience in the procurement of earth stations for the Agency's own requirements in supporting telecommunications satellite programmes has shown clearly that the prices and performances of European designs are not competitive with those from the United States or particularly Japan. The designs offered by European industry often reflect the limited requirements of a national rather than a European-wide market and they still tend to contain many key items bought in from outside Europe, such as transistors (FETs), oscillators, down-converters, up-converters, solid-state power amplifiers and tube power amplifiers. This makes for more expensive products and longer delivery times. The fact that European manufacturers are involved in relatively small production runs also serves to increase their handicap.

Moreover, the components available on the world market are not always the very latest, which tend to be used by their manufacturers to satisfy home demand in the first instance. The European integrator is therefore also at a disadvantage in terms of the overall performance that can be offered to customers.

Two remedies should be considered to improve the situation:
- broadening the size of the home market, thereby increasing volume and reducing costs;
- generating more high-technology 'building blocks' within Europe, thereby increasing the performance capability in relation to outside competition.

In the present situation, most procurements for telecommunications needs are undertaken by national administrations, each responsible for a small fraction of the total European market, each setting its own standards and regulations, and many having special relationships with national companies. This has resulted in a fragmentation into many small markets, all isolated from each other by artificial barriers. Removal of these barriers would clearly give an enormous boost to European industry, provided, of course, that widely disparate standards are not allowed to persist. A large home market and common specifications would help industry to gear itself to larger production runs and spread its design costs more effectively. This approach could be equally helpful as regards specialised earth-station requirements and the larger volume of domestic and semi-domestic equipment. Previous attempts to achieve such standards have involved international committees with national representatives. Progress in such committees is always slow and tends to generate disappointing results. A truly European authority with the power to set standards and, in some cases, to make European-wide procurements would be much more effective in generating a healthy home market.

The research and development activities in the telecommunications field are also fragmented among the European nations. Visits to the various national research laboratories have revealed relatively small sums being spent on duplicated R&D projects which have virtually no hope of forming the basis for future production needs on a European scale. An international telecommunications research and development organisation could command sufficient funds and expertise to make meaningful progress in telecommunications and earth-station technology. Such an organisation could also act as a channel for industrial support in the generation of production designs for high-technology building blocks. This would give industry some financial support in the development of new designs and also provide a much

Table 3 — Earth-station market forecast for Europe (1985–1995)

Application	Type of station	Frequency (GHz)	Size of antenna (m)	Potential market (units)	Market prices (kECU)	Market volume (MECU)
Fixed service						
1. International trunk telephony	Large gateway stations for Eutelsat and Intelsat	6/4, 14/11	15–30	Up to 20	3000–6000	100
2. International TV programme exchanges (Eurovision)	Large stations for Eutelsat	14/11	10–15	Negligible		
3. Distribution of TV programmes	Feeder stations	14	8	Up to 50	1000	50
	Receive-only stations for CATV networks and broadcast stations	11, 12	3–6	Up to 20 000	10	200
	Receive-only stations for SMATV installations	11, 12	3	Up to 200 000	5	1000
4. Multiservices	Transmit/receive stations for network oriented service	14/12	3–5	Up to 500	300–600	150
	Transmit/receive stations for user oriented service	14/12	1.5–3	Up to 1000	100	100
5. Distribution of information to closed user groups	Feeder station	14	1–3	Negligible		
	Receive-only stations	11, 12	0.2–2	Up to 100 000	3	300
6. Document delivery	Feeder stations	14	3–5	Negligible		
	Receive-only stations	12	1–3	Up to 10 000	5–10	100
Broadcasting service						
High-power direct broadcasting	Feeder stations	18	3–5	Up to 50	200–400	15
	Receive-only stations for CATV and SMATV	12	1.2–3	Up to 100 000	10	1000
	Individual receivers	12	0.3–0.9	Up to 10 million	0.5–2	10 000
Mobile service						
1. International telephony/telex (Inmarsat)	Coastal stations	6/4	10–15	Negligible		
	Standard-A/B ship stations	1.6/1.5	0.8–1.2	5000	20	100
2. Data and message transmission	Small terminals for all types of vehicles	1.6/1.5	0.3	Up to 1.5 million	1–2	2000
3. Data and voice transmission	Compact terminals for small vessels and aircraft	1.6/1.5	0.5–0.8	Up to 100 000	5–10	1000

better focus for development activities, avoiding the fragmented and duplicated national activities that are now prevalent.

The above concepts may seem rather radical in nature, but they appear to be the only way to improve the competitive position of European industry in the earth-station and related telecommunications market. One thing should be quite clear: continuation of the present situation will inevitably lead to further losses of business by European companies, not only in the global market but also, and more importantly, in the European home market, where indigenous products should have the advantage.

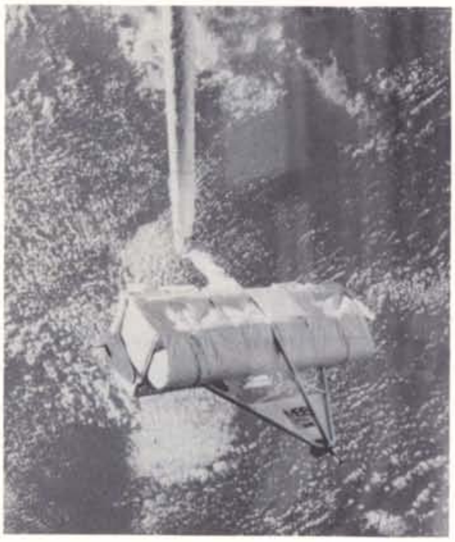
Conclusions

The share taken by European station manufacturers of the markets created by Intelsat and Inmarsat is disappointing, particularly in the latter system where they have supplied very few coastal stations and only 15% of the 3700 terminals currently in service. It now appears that the first market generated by Eutelsat, that of the large gateway stations for international telephone and television traffic, is falling largely into the hands of Japanese industry. Europe may have acquired its independence in the construction of communications satellites and their launching, but it has not acquired the independent means to use them.

Creating a space infrastructure for telecommunications systems in Europe is not an end in itself; it is only the beginning of a long economic chain reaction in which the cumulative and multiplicative effect is considerable. An attempt has been made here to quantify the size of the market contained in the first ring of Figure 1, namely the earth segment, for the various types of applications to which satellites are being or will be put. The results of this assessment are summarised in Table 3.

The last column of this table shows that the market volume could be very high in certain areas, particularly in television broadcasting and distribution, and in the mobile services. In all other areas, it is significant though not impressive. Except for TV broadcasting and distribution, where the probability of reaching these figures is high, the question of whether these markets will materialise or not is very dependent on the creation of a more favourable climate in terms of telecommunications policy and regulations at the European level.

Whether these new markets, once created, would be captured by European industry is yet another question. Unless drastic measures are taken to realise a genuine 'common market' in telecommunications and to achieve a real autonomy in the high-technology areas, there is little hope that the flood of foreign products will be stemmed. In any event, the issues at stake are sufficiently important to merit more attention from both European policy makers and industrialists.



The Need for In-Orbit Demonstration of Europe's Newest Space Technologies

H. Stoewer, Head of Systems Engineering Department, ESA Technical Directorate, ESTEC, Noordwijk, The Netherlands

The adoption of a more systematic approach to and a dedicated programme for flight verification of new European technologies is presently under discussion between the Agency and its Member States. A Request for Indications of Interest, which was issued to the space technology community in the Member States in August, has confirmed the strong interest of the technology developers in such a service. It is presently envisaged that experiments for the first flights could be selected in early 1986, following a formal Announcement of Opportunity for ESA and non-ESA-sponsored European experiments.

Background

Space technology has matured in the past decades to the point where operational space services catering for terrestrial everyday needs have become commonplace. There have been enormous advances in the technological state-of-the-art when one compares the first simple spacecraft of the 1960s with today's scientific and applications satellites or with the manned research facilities.

The technologies presently under development, from which the next generation of space vehicles will be built, are of a level of sophistication and complexity which represents another major step forward in terms of performance and operational flexibility.

As an example, the early telecommunications satellites 'transpond' at one fixed frequency and serve a user market that had been predicted many years before the satellites were launched and entered operational service. However, market requirements change and the spacecraft design may no longer be optimum. New technologies presently under development will allow the service to be re-configured in orbit by directing traffic to different locations and by offering a different mix of services, even after the satellite has been in operation for some time.

Another example is the area of thermal control. Early satellites were thermally balanced by careful selection of equipment locations, placing heater blankets at critical locations, and by covering large parts of their external surfaces with multiple layers of reflective insulation. Adjustment of the configuration of this multilayer insulation as a result of ground testing has generally sufficed to create an acceptable thermal environment. However, operational attitude adjustments, extra cool-down or warm-up phases, or temporary shut-downs of certain experiments have been needed to cope with anomalies and unexpected situations.

Future spacecraft will employ more and more active thermal control devices, such as heat pipes, louvres, pumped or capillary-driven fluid and 'two-phase' loops. These will allow easy adjustment to unforeseen heat loads, narrower temperature boundaries for critical electronic equipment, and the operational flexibility to modify the scientific experiment programme or the telecommunication-services mix even after the spacecraft has been put into orbit.

The drawback of these more refined and complex technologies is that some of them are less easily tested on the ground or that the design margins, which a prudent designer will build in for new technologies, sometimes lead to a heavier or an 'overpowered' satellite, thereby losing some of its competitive edge.

Many of these advanced technologies would benefit substantially from just short periods of exposure to the 'real' space environment, where the effects of gravity, radiation or thermal influences can be measured, and where performance and operational limits can be determined in the real working environment. As a result, the designer can then know what to design for, and project managers have a chance to acquire the confidence that the new technology will in fact perform satisfactorily in their (yet to be built) satellites.

Today's lower transportation costs for putting space technologies into orbit for short periods of orbital testing and verification, coupled with the possibility to retrieve and re-test, make more systematic early in-orbit testing economically practicable for many of the new space technologies.

During the past two years the Agency has evaluated developing technologies and transportation methods in this context, and has discussed its findings extensively with European industry. A proposal for a dedicated 'In-orbit Technology Demonstration Programme' (TDP) has been included in ESA's Long-Term Plan and in its proposals to the ESA Council Meeting at Ministerial Level in Rome earlier this year. That meeting welcomed and endorsed this initiative (Resolution, para II, 6).

Its objectives are to provide more regular in-orbit flight opportunities for European space technologies at component and equipment level, and hence to enhance achievement of the Agency's major technology goals, namely to ensure timely availability of technology for future programmes and to maintain a high level of competence in space technology in Europe.

Typical technologies needing early in-orbit testing

The Agency has screened almost 100 technological developments to assess the need, and justification, for in-orbit testing. It has selected 12 examples which are representative of the type and spectrum of components or equipment items that are candidates for early in-orbit flight, and which will be needed in the future for the projects that form part of ESA's Long-Term Plan:

1. Capacitive Accelerometer for Microgravity Measurements

This millimetre-sized device (Fig. 1) consists of a small mono-crystalline silicon plate with torsion bars which, when subjected to an electric field, provide a capacitance variation proportional to the forces acting upon the device. It is close to impossible to test the device on the ground as the bending of the torsion bars under the Earth's gravity causes calibration problems. This accelerometer would be combined for an orbital experiment with an off-the-shelf momentum wheel which would impart known microgravity vibrational forces to the device. Together with low-frequency forces arising from attitude control manoeuvres, this would allow calibration of the device to a high degree of accuracy, and also provide data on structural transmission of microgravity forces. The device would then be available as a 'standard' solid-state sensor to measure microgravity forces in the 10^{-7} to 10^{-3}g range for use with microgravity experimentation facilities in the biological or metallurgical sciences.

Figure 1 — The capacitive accelerometer for microgravity measurements

2. Space Rigidised Inflatable Antenna

This unique, European-developed large format antenna (Fig. 2) is representative of a new lightweight technology for space structures. It could be applied for large antennas such as the millimetre-wave reflectors for the scientific spacecraft, or the next generation of mobile telecommunications satellites, as well as for thermal shields or other bulky structures where a small transportation volume and a large deployed volume are beneficial. The technology relies on pre-shaped, pre-pregnated woven surfaces, which are folded to a very compact size for launch. Once in space, the antenna is inflated and rigidised to its final shape within a few hours by solar heating of the unique chemical pre-pregnated substance. A 3.5 m diameter model has been extensively ground-tested, but ultimate shape accuracy and behaviour during and following the orbital inflation process can only be properly verified by an appropriate in-orbit test.

photo contraves

Figure 2 — The space-rigidised inflatable antenna. Potential flight: As a Shuttle 'hitchhiker' or 'small payload' in early 1987

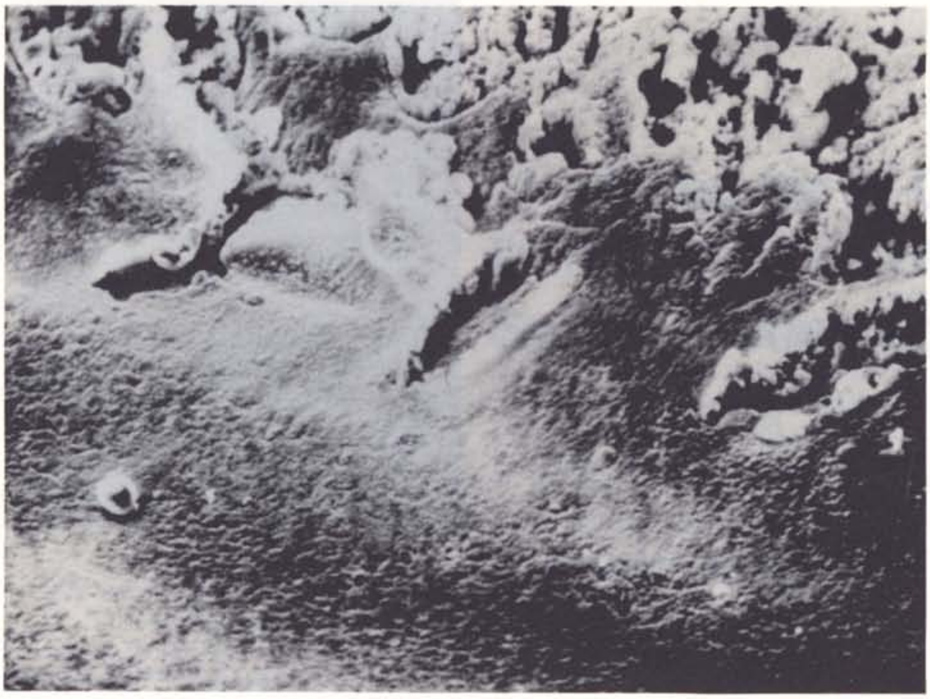


Figure 3 – Erosion effects of atomic oxygen on a sample of solar-array material. Potential flight: As an add-on experiment on any Shuttle flight, from mid-1986

Figure 4a,b – Yaw Earth sensor. Potential flight: As Shuttle Get-Away Special (GAS) cannister or 'hitchhiker' in mid-1987

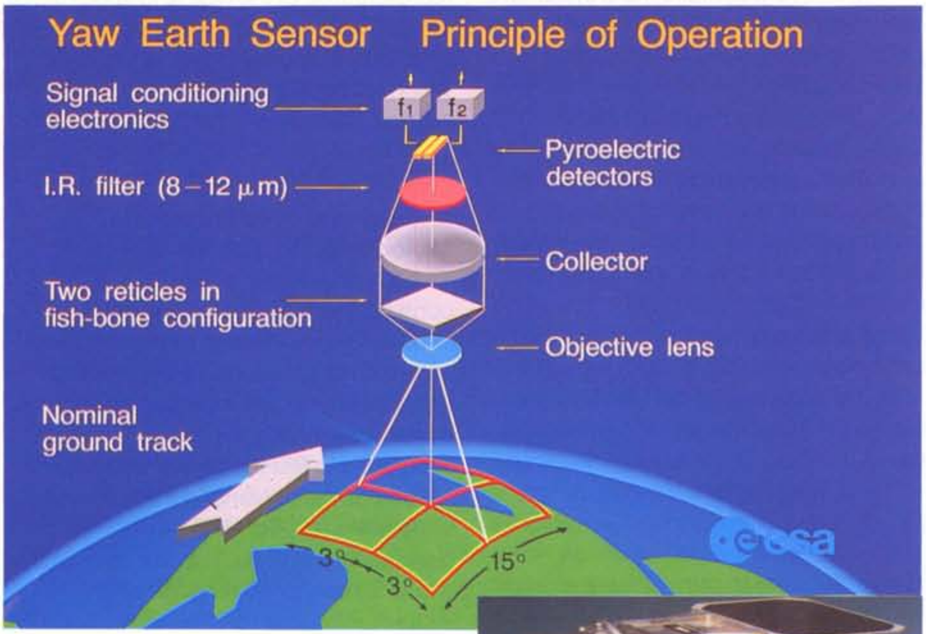
3. Atomic Oxygen Effects

During early Shuttle flights the degrading effects of bombardment by atomic oxygen in low Earth orbit have been observed on materials which were previously believed to be immune to the space environment. These effects are particularly critical for solar-array components such as substrates, interconnects or cells. Figure 3 shows an 'eroded' silver electrode solar-array sample.

In the meantime, questions have also been raised regarding other materials such as paints, epoxy materials and other commonly used synthetic materials. Extensive tests are already being conducted by the US authorities on materials manufactured in the USA. The purpose of this experiment is to enlarge the database and acquire such knowledge for all materials commonly used and particularly those manufactured in Europe for European spacecraft. The experiments would consist of attaching small off-the-shelf test samples of different types of materials to carriers such as Spacelab or Eureca, with a view to gaining sufficient understanding of the physical processes and material behaviours in orbit. Realistic ground testing is not possible because of the difficulties of producing beams of atomic oxygen and simulating the high impact velocities that occur in orbit.

4. Yaw Earth Sensor

Very accurate yaw measurements are essential ancillary data for certain types of



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low Earth-orbiting, Earth-observation instruments. The development of a new yaw earth-sensor concept is based on comparing the frequency content of signals received by two detectors, each observing ground features along the track of the Earth observation satellite through its own 'venetian blind' filter skewed to the track direction (Fig. 4a).

The sensor relies on actual Earth features as viewed from orbit for its functional verification and calibration for operational use. In this case, ground simulations would be considerably more expensive than in-orbit tests. A first partial prototype of the sensor (Fig. 4b) was therefore included in the initial Shuttle-SPAS flights

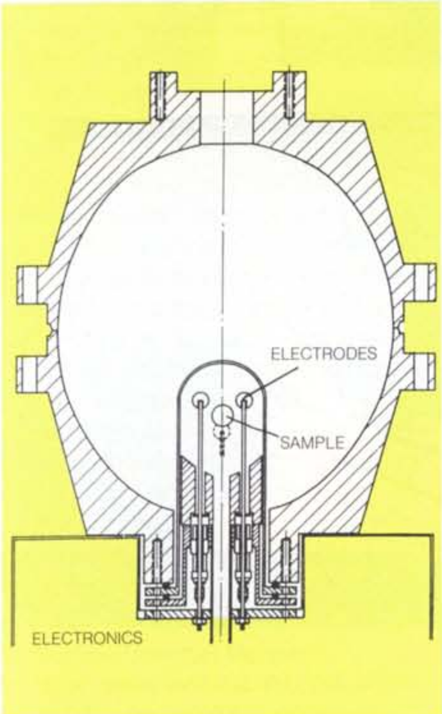
4b

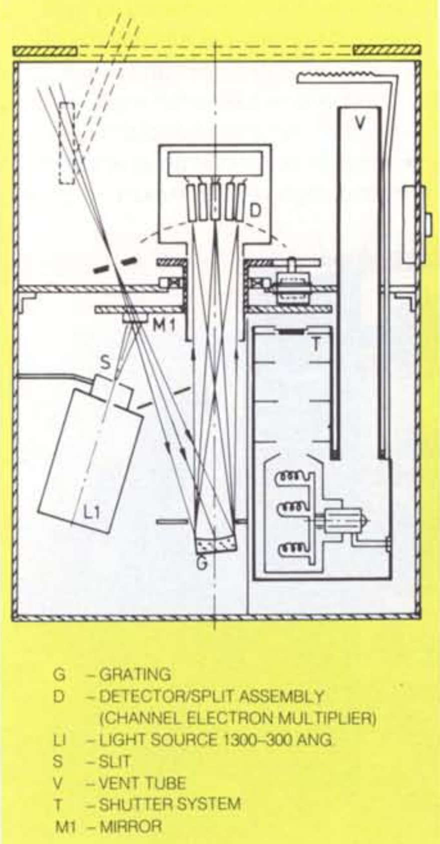
in 1983/84 to prove the principle of the device. Qualification for operational use will require at least one flight of a complete sensor and its associated signal-conditioning electronics.

Figure 5 — Electrostatic levitator for materials-sciences applications. Potential flight: As Shuttle double GAS cannister or 'hitchhiker' in mid-1987

Figure 6 — Aluminium coating experiment. Potential flight: As Shuttle double GAS cannister, in early 1988

Figure 7 — Helium cryostat. Potential flight: As Shuttle 'hitchhiker' or 'small payload' in mid-1988, or earlier





5. Electrostatic Levitator for Materials Sciences

This experiment is typical of advanced microgravity experimentation facilities, most of which need a true orbital microgravity environment for full functional and performance verification. This particular technological development (Fig. 5) consists of a mirror furnace with an electrostatic positioner, in which the molten sample is held in suspension by a tetrahedral electrostatic field, so that it does not come into contact with the container walls.

6. Aluminium Coating Experiment

Mirror coatings for scientific instruments are usually made by metallic vapour deposition, sometimes with a protective coating to prevent surface oxidation prior to launch. For high reflectivity at wavelengths below 1200 Å, coatings of pure, uncoated and as yet unoxidised aluminium would offer significant advantages. This experiment (Fig. 6) is designed to coat mirror sections in orbit and to measure their characteristics in a realistic space radiation environment. The technique will allow re-coating and the study of aluminium transport phenomena and reflectivity values and the effects of atomic oxygen erosion in low Earth orbit.

7. Helium Cryostat

European cryostat technology has been very well developed over recent years and has reached a point where further ground testing will not significantly advance predicted performance.

Whilst thermal-transfer computations should provide reasonable but conservative accuracies, the performances of complex components such as liquid/gas phase separators, cryogenic valves, etc. under orbital conditions are still critical factors in any such device. The technology (Fig. 7) is needed for future (infrared) observatories, notably ISO, and early testing of some of its critical components would be highly beneficial.

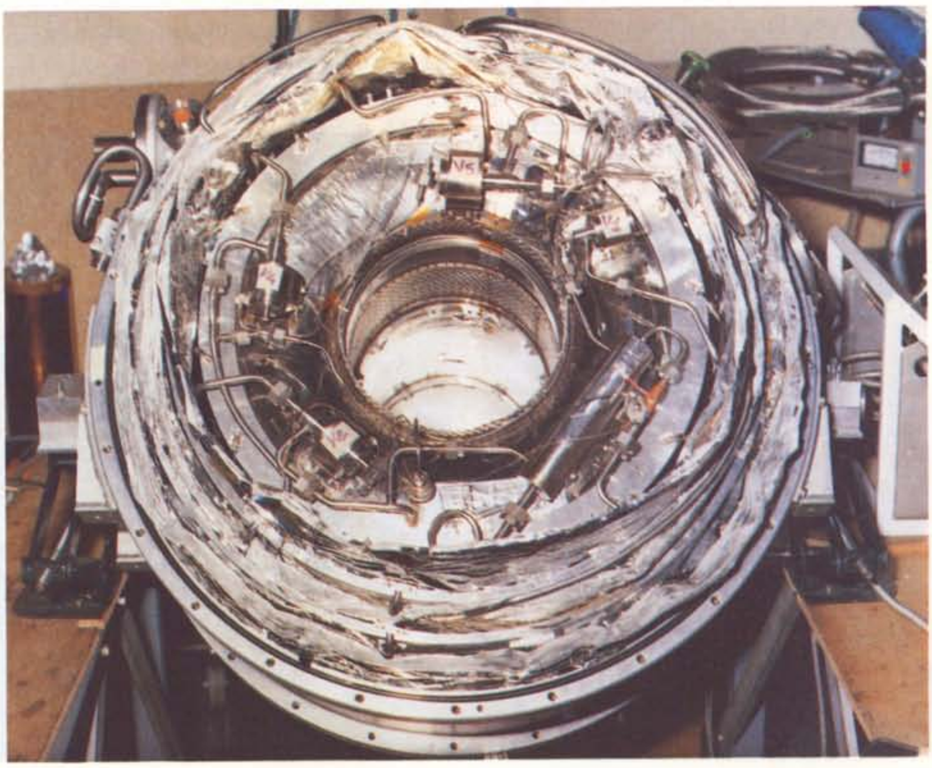


Figure 9 – Liquid slosh experiment flown on an earlier Shuttle mission. Potential flight: As single GAS cannister in 1989 or earlier

Figure 10 – Small section of an advanced bifacial solar array. Potential flight: As add-on experiment on Spacelab-D2 mission, in early 1989

8. Laser Diode Range Finder

Accurate measurements of distances and shapes in orbit is a requirement for many future space missions. While lasers can be tested quite accurately on the ground for functionality and general performance, their measurement accuracies – submillimetre accuracy for shape determinations, or centimetre accuracy for rendezvous and docking applications (Fig. 8) – are substantially impaired by atmospheric effects during ground testing. Fully representative measurements within a realistic space environment will contribute to bringing these technologies on-stream earlier and with greater confidence.

9. Liquid Slosh Experiment

The behaviour of liquids in zero-gravity can be modelled analytically to only a limited extent. These models are also very complex and require large amounts of computer time. The operational scenarios of the ESA Long Term Plan for the 1990s imply many missions involving the handling of large quantities of liquids, i.e. propellants or coolants, and their orbital transfer. To explore both the sloshing behaviour of fluids and their transfer from one vehicle to another, in compressed and noncompressed states, in-orbit tests are indispensable. Figure 9 shows an early, small experiment already flown on a previous Shuttle mission.

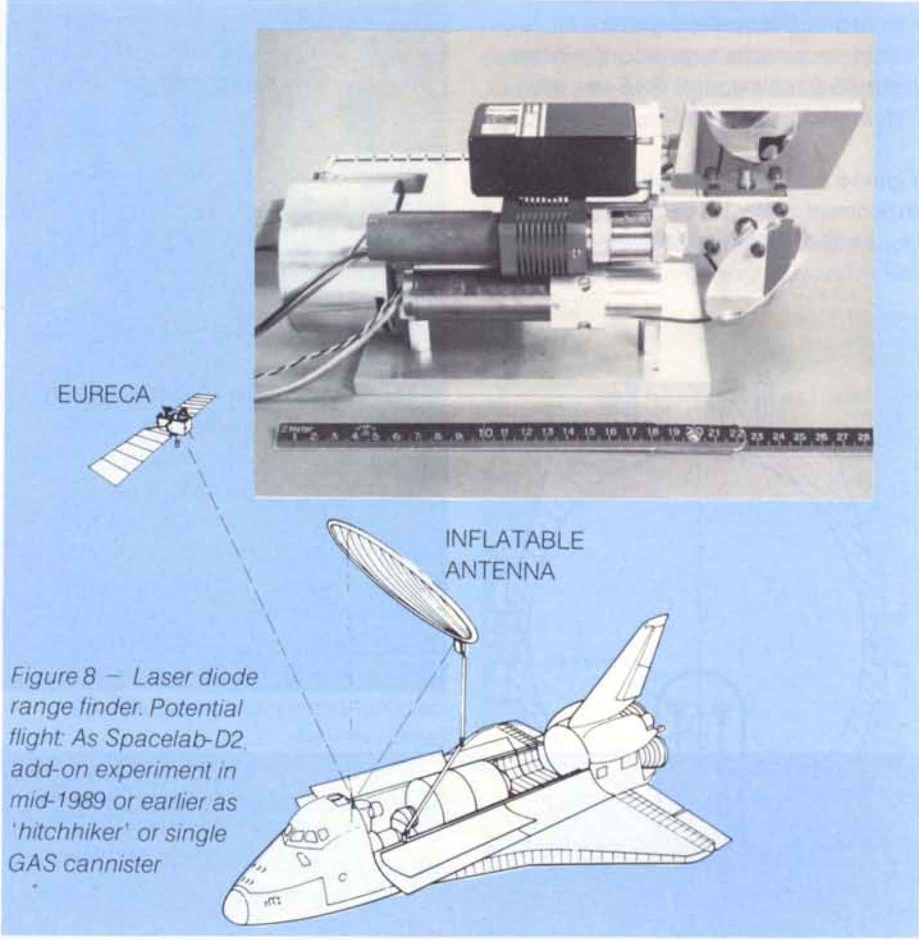
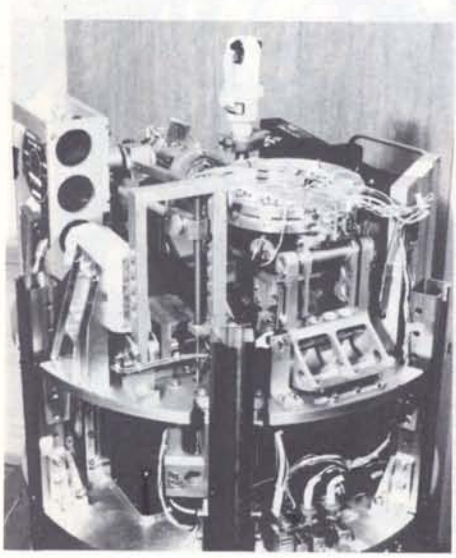


Figure 8 – Laser diode range finder. Potential flight: As Spacelab-D2 add-on experiment in mid-1989 or earlier as 'hitchhiker' or single GAS cannister

10. High-Voltage Solar Power Systems

The large amounts of electrical power needed by future orbital infrastructure systems such as Columbus (in the order of 15–30 kW or even 60 kW) necessitate that the electrical power be distributed at high voltages, i.e. in the order of 150 V, as the ohmic losses and mass implications of using today's low voltages over longer transmission distances are prohibitive.

However, high voltage levels carry with them the danger of interaction with the orbital plasma environment. Ground test methods are insufficient for determining proper thresholds and assessing the safety and operational implications of high-voltage solar arrays and power transport and distribution components. Figure 10 shows a small section of an advanced bifacial solar array which could operate at high voltage levels.



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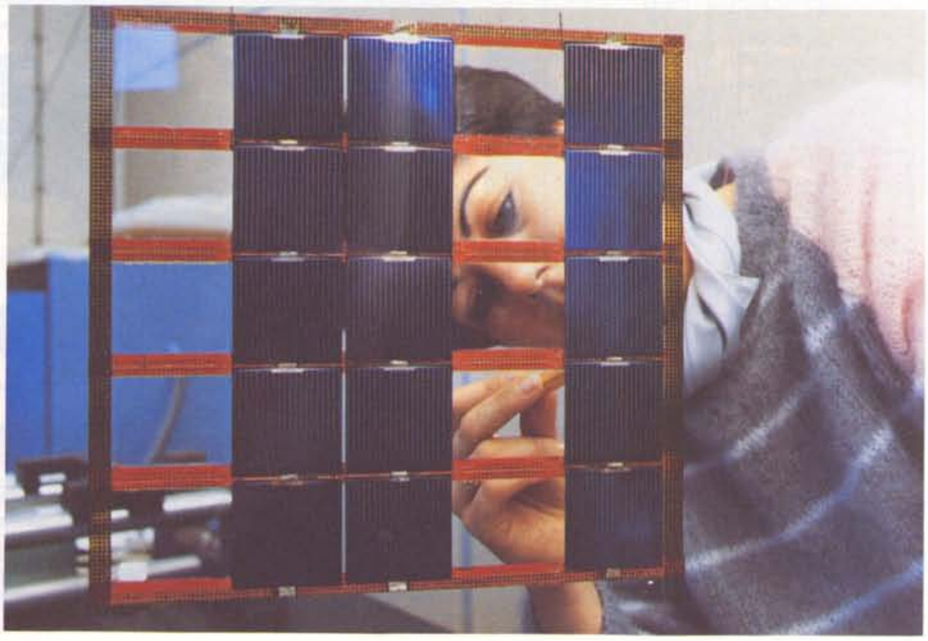

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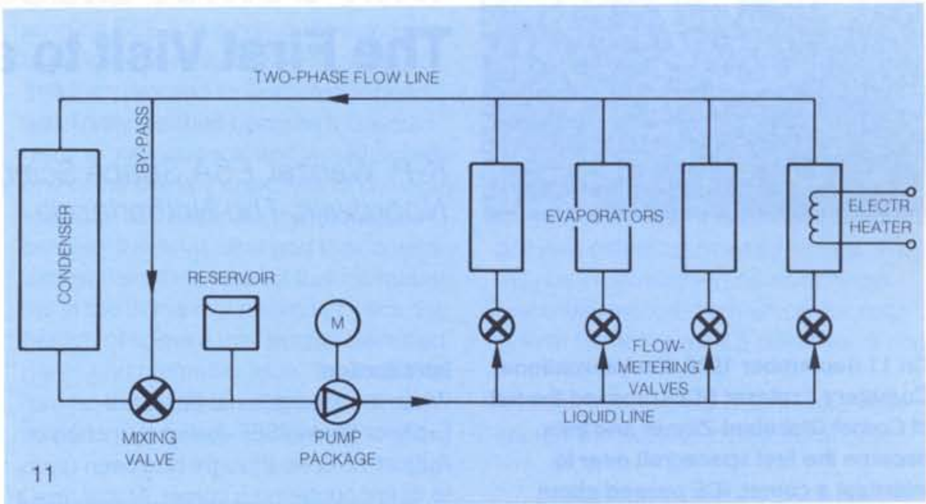

Figure 11 – Two-phase heat transport system. Potential flight: As Shuttle 'hitchhiker' or 'small payload' in mid-1989

11. Two-Phase Heat Transport System

One of the most promising techniques for the transport of high heat loads in orbital facilities such as Columbus is the two-phase heat transport technique. It utilises the heat absorption capacity of a liquid/gas phase change, which is about one order of magnitude higher than that of a purely liquid circulation loop. The behaviour of the gas/liquid mix and the performance of the components needed to transport and control the two-phase medium are gravity-dependent. This applies particularly to the evaporators, the accumulators, condensers, and possibly the pump package (Fig. 11). In-orbit tests are therefore important to understand and characterise this new technique accurately.

12. Surface Potential Monitor

This experiment, which is a typical small add-on experiment for a geostationary satellite, serves to understand the behaviour of insulating surfaces in geomagnetic substorms. It should provide important data for the assessment of the electrostatic charging phenomena in geostationary orbit that have affected many of the satellites launched to date. The device (Fig. 12) measures the surface potential on the solar-panel surface and should allow correlation of geomagnetic substorms and the electrostatic behaviour of the satellite, with the objective of further improving measures to eliminate satellite service disruptions due to electrostatic discharges.

Conclusion

Flight verification of new European space technologies is not new. It has been done occasionally in the past on an ad-hoc basis, usually as add-on payloads on European spacecraft, or more recently on sounding rockets or Shuttle Get-Away Special flights. However, flight opportunities have usually become available only at very short notice, and the resources available to support such payloads were very limited. As a consequence, only a few experiments have been flown and the usefulness of the flight results has sometimes been limited because the scheduling of the flight demonstration and the subsequent application of the technology in a project were not compatible.

The adoption of a more systematic approach and a dedicated in-orbit verification programme would clearly be very beneficial for a great variety of the new European technologies, as the 12 examples discussed above have hopefully served to underline.

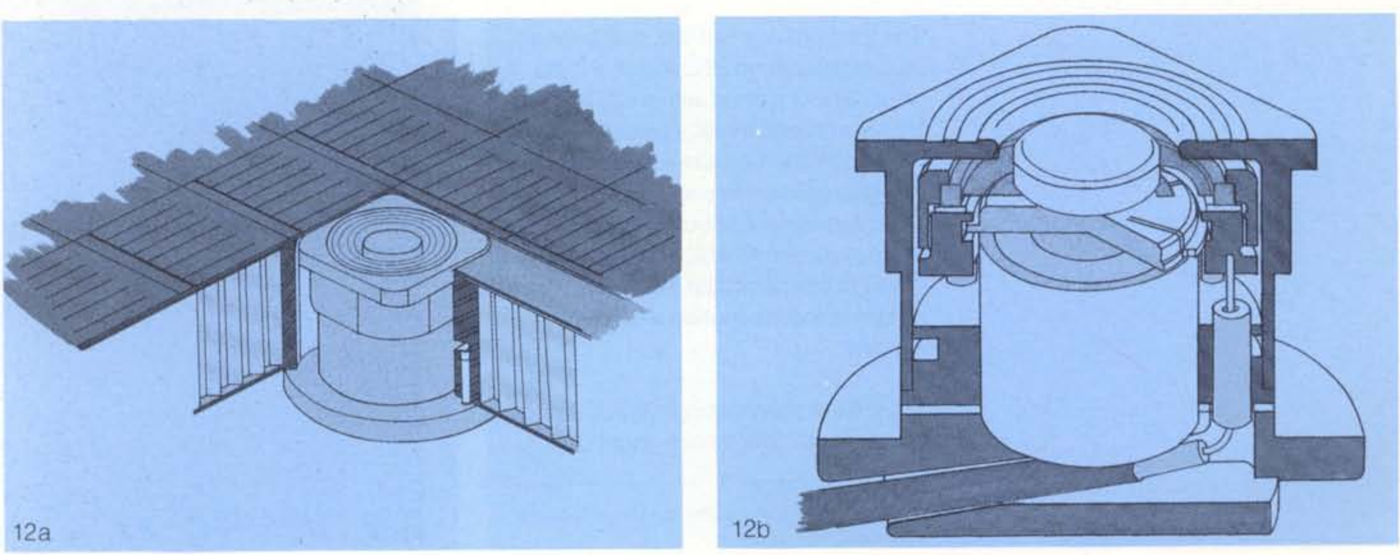

Figure 12 – Surface-potential monitor. Potential flight: As an add-on to an Ariane-launched spacecraft or as a dual experiment with an electric-propulsion experiment in low Earth orbit, at the end of 1986

The ICE Spacecraft's Encounter with Comet Giacobini Zinner: The First Visit to a Comet

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On 11 September 1985, the International Cometary Explorer (ICE) crossed the tail of Comet Giacobini-Zinner and thus became the first spacecraft ever to intercept a comet. ICE passed about 8000 km on the antisunward side of the comet's nucleus, and emerged undamaged and without any noticeable degradation from the cometary environment. The ICE encounter has produced a rich harvest of scientific information about the interaction between the comet's atmosphere and the solar wind. It has confirmed, by in-situ measurements, the basic picture of this plasma-physics interaction, which scientists could previously only model. ICE has also set the scene for the Comet Halley encounters next March.

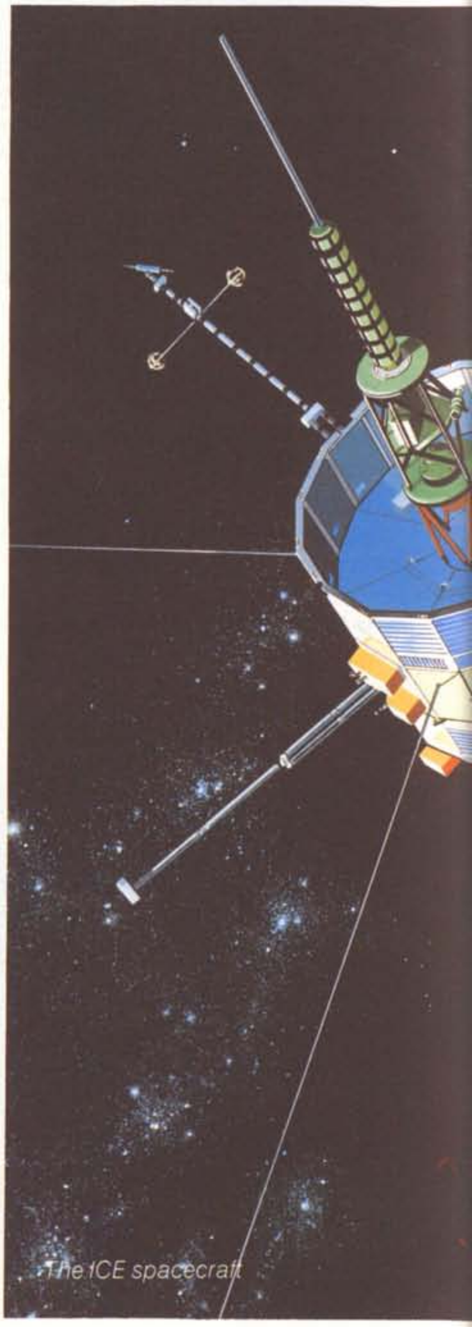
Introduction

When the International Sun-Earth Explorer Three (ISEE-3) was launched in August 1978, no thought had been given to its encountering a comet. At that time it was part of the joint NASA/ESA ISEE programme designed to study the Earth's magnetosphere. The role of ISEE-3, from its position 1.5 million kilometres sunward from the Earth, was to observe changes in the solar wind. ISEE-1 and ISEE-2 (the latter developed by ESA) simultaneously observed the response of the Earth's magnetosphere to those changes. ISEE-3's second phase began four years later, in 1982, when it was moved from its initial position in front of the Earth to one behind it, in order to study the unexplored distant region of the Earth's magnetotail far beyond the lunar orbit out to a distance of 1.4 million kilometres. Results from this geotail mission have been described, for example, in ESA Bulletin No. 37, February 1984 (pp. 46–50).

The third phase of ISEE-3, that of comet studies, began on 22 December 1983, when ISEE-3 passed within 120 km of the Moon, and was thereby propelled out of the Earth-Moon system to commence a two-year journey to encounter Comet Giacobini-Zinner about 70 million kilometres, or 0.47 AU*, from Earth (Fig. 1). It was at this point that the spacecraft was renamed the International Cometary Explorer.

Still, ISEE-3 was not originally designed for cometary studies, so one might question

* 1 AU is 1 Astronomical Unit, the mean distance from the Sun to the Earth

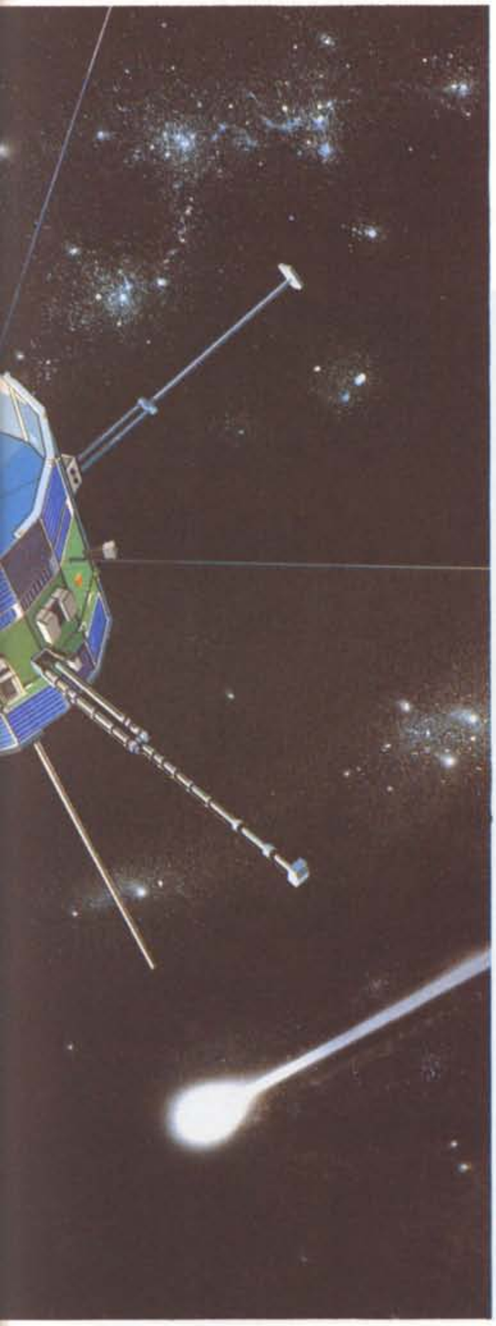

The ICE spacecraft

whether it made sense to have it try to study comets, particularly in view of the fleet of spacecraft now heading for Comet Halley. Wasn't it just a stunt to get to a comet first? To be first certainly played a role when, in 1982, soon after the collapse for financial reasons of its ambitious plans for a rendezvous mission to Comet Halley, NASA accepted the idea of sending ISEE-3 to a comet. The decision to explore the distant geomagnetic tail and then proceed to Giacobini-Zinner was finally reached because this would result in 'new science' and would achieve one of the primary objectives of cometary science – to investigate the interaction between the solar wind and the cometary atmosphere. One facet of this interaction lies in the domain of plasma physics, the branch of science that studies electrified gases and magnetic fields. Since ISEE-3 had no capability to image the comet nucleus, it was free – in contrast to the Halley missions – to pass through the tail of the comet, and it was this region that the spacecraft was best-instrumented to study.

The comet model

Comets are thought to be composed of a primitive collection of ices and dust. They may be invaluable remnants from the primordial mixture from which our solar system formed some 4.5 billion years ago.

The basic features of a comet are well-known: the nucleus, coma, hydrogen



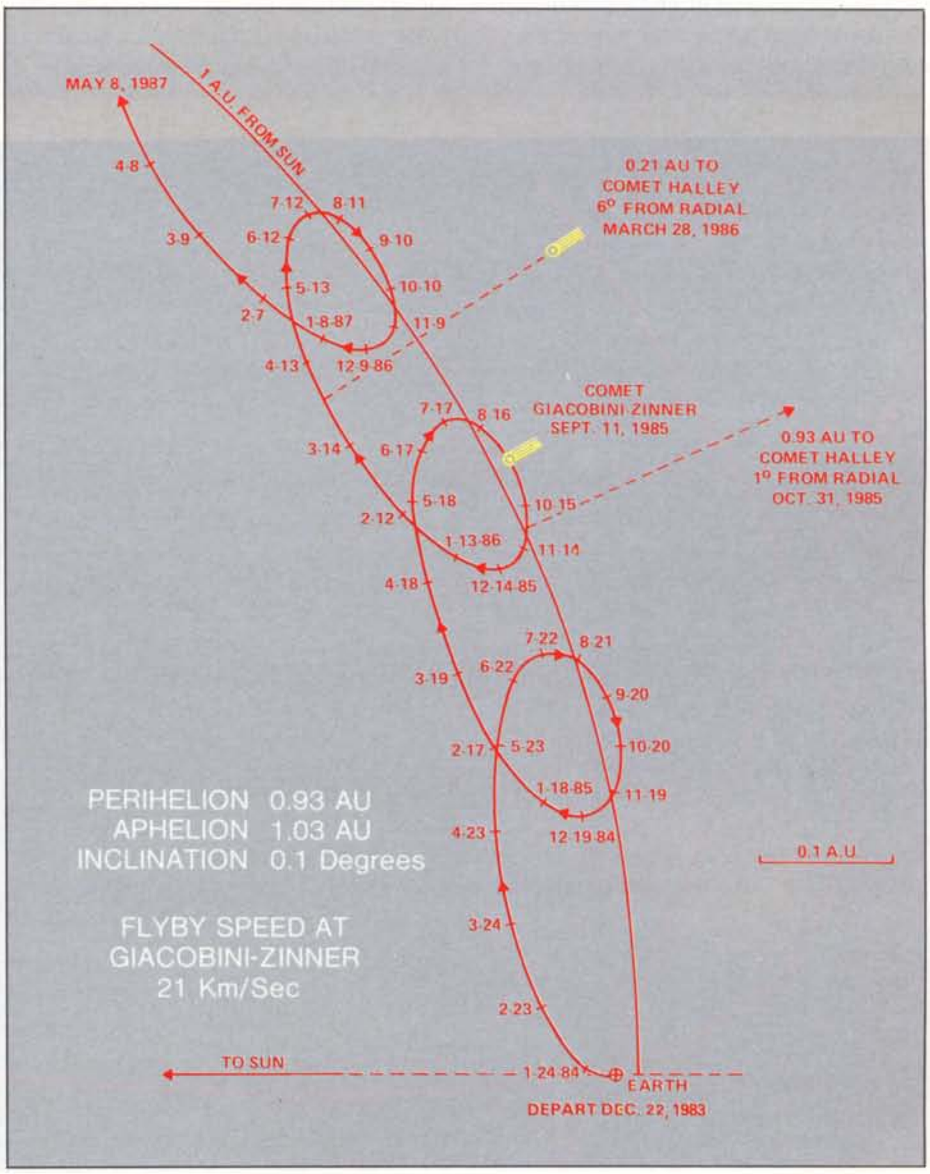


Figure 1 – The ICE orbit from the Earth to Comet Giacobini-Zinner, as viewed in a coordinate system with the Earth-Sun line fixed. The orbit lies close to the ecliptic plane. Upstream alignments with Comet Halley on 21 October 1985 and 28 March 1986 are also shown. The perihelion, aphelion, and inclination figures listed refer to the spacecraft's orbit (courtesy R. Farquhar)

Figure 2 — Comet Giacobini-Zinner photographed in 1959 by E. Roemer at the US Naval Observatory. Superimposed is a schematic of the ICE trajectory, spatial scale and approximate 'bow shock' location

cloud, and tails. Although the tails are the visually spectacular part of the comet, it is the comet's nucleus and its interaction with its environment that produces all of the cometary features.

The nucleus is a 'dirty snowball' composed mostly of water ice with some minor constituents and dust particles interspersed throughout. When the nucleus is far from the Sun, it is inactive and does not produce the other features. As the comet approaches the Sun and sunlight heats the surface, the temperature of the surface layers is increased to a value at which sublimation (the passage of matter directly from the solid to the gaseous state without going through the liquid state) occurs. As the comet continues its sunward motion, the sublimation process becomes more and more efficient, so that basically all of the energy in the sunlight falling on the comet's surface goes into the release of gases by sublimation. This process liberates other molecular constituents trapped in the ice and the embedded dust.

Due to the absence of gravity around the small nucleus, the released gases and dust can expand outward to form the approximately spherical volume that we see on photographs as the coma (Fig. 2). Water molecules (H_2O) are the primary released gas and they produce a large hydrogen cloud when dissociated into their constituents by sunlight. The hydrogen cloud surrounds the nucleus and is much larger than the coma.

Comet tails come in two distinct types and are formed by interactions with the Sun's light and particle emission. The radiation pressure of sunlight pushes the dust particles away from the Sun to form the smooth, curved dust tail. The structured, usually straight plasma tail is formed when molecules are ionised and then blown away in the antisolar direction by a complex interaction with the solar wind. Since ions cannot pass freely across magnetic field lines, the ionised cometary molecules capture a magnetic field from

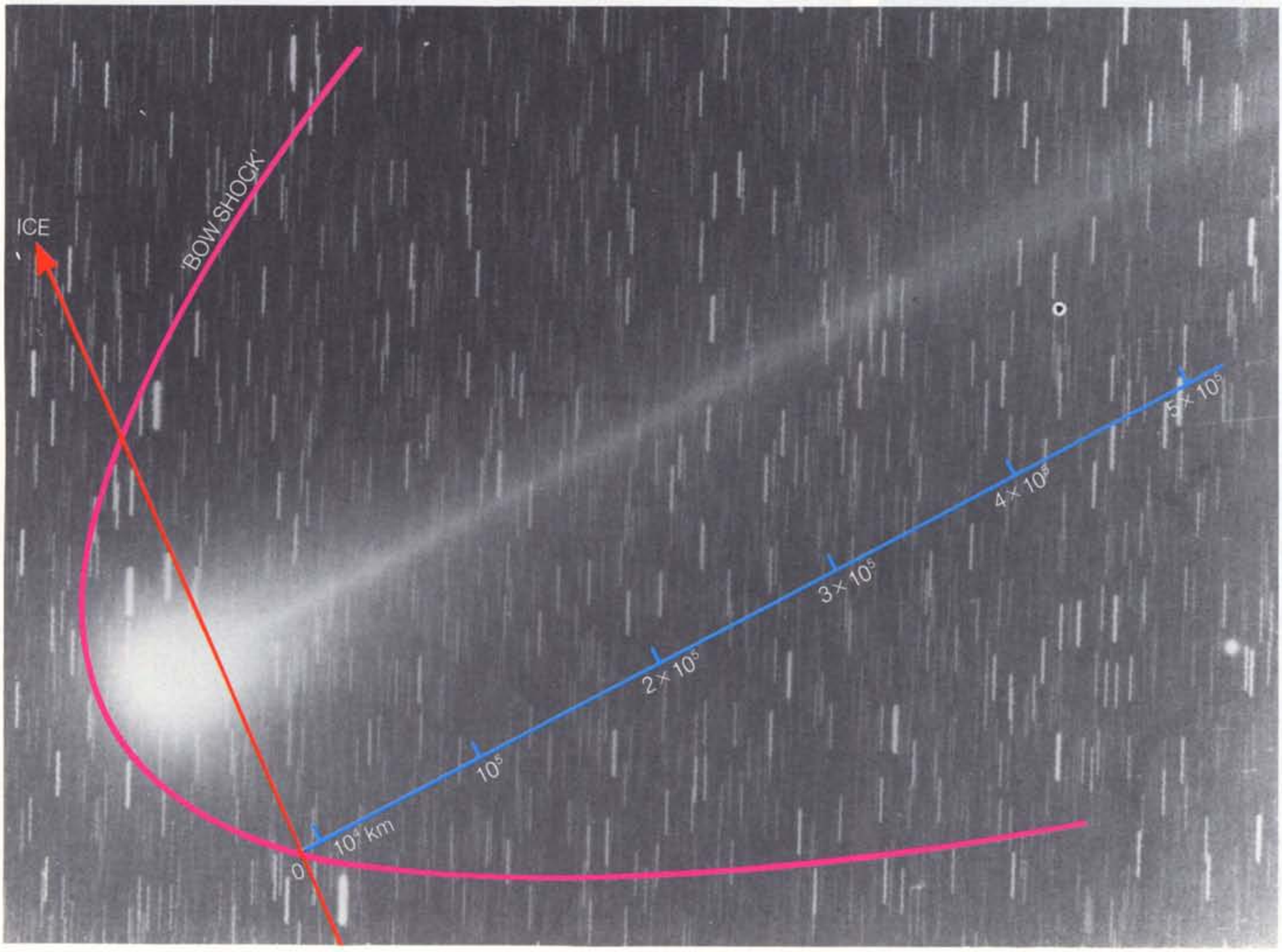
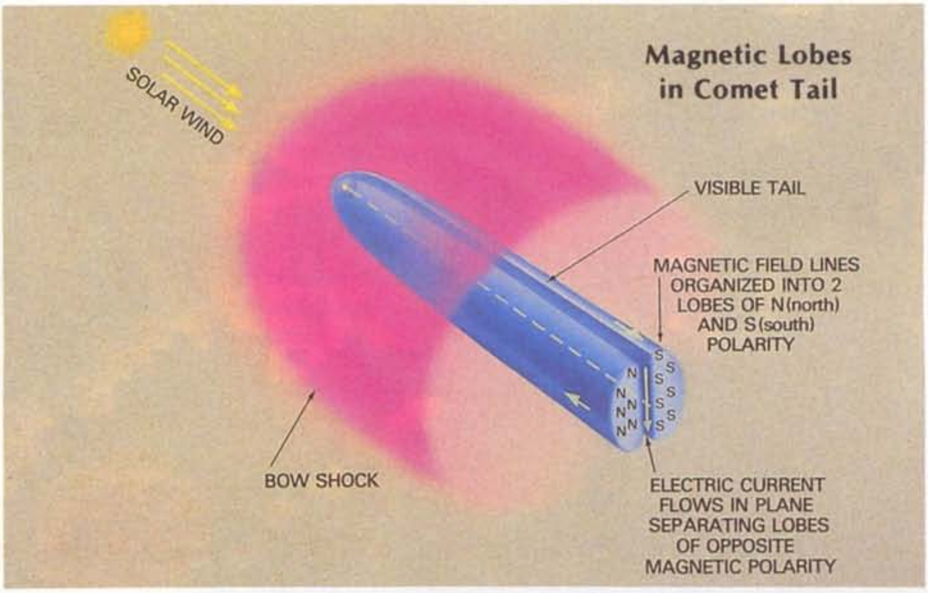


Figure 3 — Artist's impression of the interaction of a comet with the solar wind. As the solar wind flows outward, it drags magnetic field lines away from the Sun. To them, a comet's ionised coma and tail represent an obstacle that cannot be avoided. The field lines become draped over and behind the comet, forming polarised lobes that are separated by a neutral sheet through which an electric current flows. ICE's primary objectives were to penetrate both the comet's ion tail and, if it existed, the neutral sheet, and to search for the bow shock. ICE confirmed the basic features of this interaction (diagram courtesy of NASA; Sky and Telescope Sept. 85)



the solar wind. The dynamical situation causes the interplanetary field lines to wrap around the nucleus to form the plasma tail, a process that has been described as 'spaghetti draped over a fork'. This wrapping/draping process presses magnetic fields of opposite polarity together, a situation that requires (for stability) the flow of an electric current in the plane separating the two lobes of opposite magnetic polarity. A thin neutral sheet between the lobes arises (Fig. 3). The comet is also an obstacle in the supersonic flow of the solar wind, forming a 'bow shock' around the comet. Prior to the ICE mission, the current sheet and the bow shock had not been directly observed.

Comet Giacobini-Zinner

This short-period comet (6.5 years) of the Jupiter family, was discovered by M. Giacobini at Nice, France, in 1900, and was rediscovered in 1913 by E. Zinner at Bamberg, Germany. Generally, every other apparition leads to good viewing of the comet from the Earth. In 1985, on its 11th observed apparition, it was at its brightest at eighth magnitude, accessible to small telescopes but not visible to the naked eye (a star of magnitude 6 is just visible to the naked eye, and a star of magnitude 7 is 2.5 times fainter) (Fig. 4).

Typically, the plasma tail is observed to begin to develop at a heliocentric distance of about 1.7 AU and, at its fullest extent, has been observed to reach a length of at least 500 000 km. The perihelion distance of 1.03 AU occurs near the ecliptic plane, making Giacobini-Zinner well suited to spacecraft encounter during its interval of maximum nuclear activity.

Giacobini-Zinner has a fairly stable orbit, which is inclined to the ecliptic at an angle of about 30°. However, discontinuities in its orbital motion, caused probably by anisotropic outgassing ('jets'), qualify Giacobini-Zinner as an 'erratic' comet. A recent study based on detailed ground-based observations of the comet during its various apparitions between 1900 and 1972 concludes that Comet Giacobini-Zinner's nucleus is highly flattened, the equatorial diameter, estimated to be 2.5 km, being about eight times larger than the polar diameter. This flattened nucleus is spinning rapidly, making one complete rotation every 1.66 h. This period, if correct, may be close to the critical rate at which the oddly shaped iceball would literally fly into pieces. All fears that the nucleus might break apart prior to the encounter were fortunately unfounded.

Spacecraft payload

ISEE-3's payload had been designed to measure the solar wind, solar X-rays, energetic charged particles and the composition of galactic cosmic rays. Of the 13 instruments, seven were thought the most likely to return useful data during the cometary encounter (see Table 1).

Three instrument teams are headed by European Principal Investigators, including the team responsible for the Energetic Particle Anisotropy Spectrometer, jointly designed and built by the Solar and Heliospheric Science Division of ESA's Space Science Department, the Blackett Laboratory of Imperial College, London, and the Space Research Laboratory, Utrecht. Interplanetary observations with this instrument have been described, for example, in ESA Bulletin No. 27, August 1981 (pp. 4-12).

Spacecraft targeting

Prior to the encounter, major discussions took place on the question of where to target the trajectory through the comet's plasma tail. An aiming point far down the tail carried the increased risk of missing it altogether, because the movement of the 'wagging' tail in response to solar-wind velocity variations becomes more pronounced further from the nucleus. Aiming too close to the nucleus would have created a potentially serious dust hazard. It was also argued that directly in the wake of the nucleus conditions may be chaotic and that the tail may not be well organised. As a compromise between the respective disadvantages of a near-nucleus encounter and a pass far down the tail, the tail intercept was planned to be 10 000 km from the nucleus. A final orbital trim manoeuvre on 8 September, three days before the actual tail intercept, became necessary to account for the latest update in the comet's orbit. This slightly reduced the actual flyby distance, to about 8000 km.

Figure 4 – Image of Comet Giacobini-Zinner obtained by the International Ultraviolet Explorer (IUE) satellite on 30 August 1985. The arrow shows the direction from the comet toward the Sun; the comet's tail points in the opposite direction. The image was processed to provide a smoother depiction of the comet and to supply false colours that indicate relative brightness (red corresponds to the brightest light levels). Bracketed line alongside the comet indicates the scale of the comet image; the length of the line corresponds to 50 000 km at the position of the comet (photo courtesy of NASA)

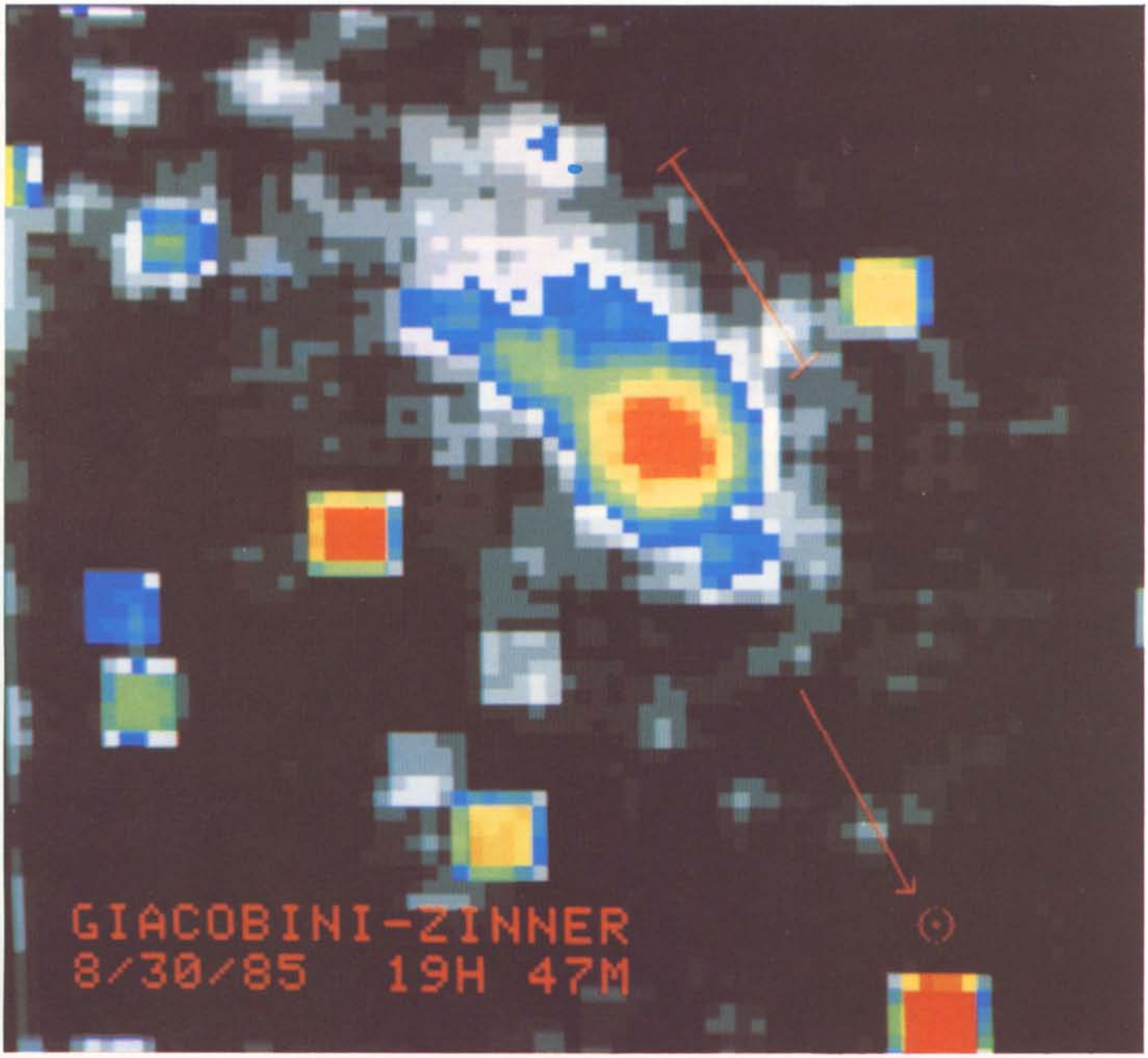


Table 1 – Scientific experiments on the ICE spacecraft which contributed to the in-situ cometary studies

Experiment	Principal Investigator	Affiliation	Collaborating European Institutes
Electron plasma	S. Bame	Los Alamos National Laboratory	
Magnetometer	E. Smith	Jet Propulsion Laboratory	
Plasma waves	F. Scarf	TRW Systems, Los Angeles	
Radio waves	J.-L. Steinberg	Paris Observatory, Meudon	
Plasma composition	K. Ogilvie	Goddard Space Flight Center	University of Bern
Low-energy cosmic rays	D. Hovestadt	Max-Planck-Institut für Extraterrestrische Physik, Garching	
Energetic particles	R. Hynds	Imperial College, London	SSD of ESA & SRL Utrecht

Getting the data back was, of course, just as important as getting to the comet. In fact, arranging for the reliable reception of the telemetered measurements is 'the unsung story' of the mission. The spacecraft telemetry system was designed to send back data from a distance of about 1.5 million kilometres, while at the time of comet encounter ICE was about 70 million kilometres from Earth. To counteract the loss of signal strength caused by this large increase in distance, the original data transmission bit rate was halved to 1024 bit/s, both transmitters onboard the spacecraft were used (originally intended to be redundant), and the 64 m dishes of the Deep Space Network were arrayed with 34 m dishes. In addition, the encounter was timed such that approximately 2 h of backup coverage was available from the very large radio-astronomy antenna at Arecibo in Puerto Rico.

Initial scientific results

The initial findings summarised here were reported by the Principal Investigators at a News Conference two days after the encounter. Data analysis is now in progress at the various institutes and first detailed results will be reported at a scientific meeting in December.

Figure 5 summarises schematically the main regions and phenomena originating from the hot energetic solar wind plasma colliding with the cometary atmosphere and observed during ICE's traversal through the comet's tail with a relative velocity of 21 km/s.

The first signs of the comet's presence were noticed in the energetic ion data about 1 day before the closest approach (see below). Around 0910 UT on 11 September some kind of a 'bow shock' was detected. Its characteristics were, however, quite different from the bow shock observed in front of planets like the Earth. No sudden change in the magnetic field was clearly detected, and no distinct time found where the plasma density rose to higher values inside than outside. The nature of this 'shock' is an open question. The high mass density of cometary heavy ions in the plasma (1 mass loading) may be a cause of this unexpected structure.

The spacecraft then traversed a region full of turbulence and structures ('interaction region') where the assimilation between cometary ions and solar-wind plasma takes place. Very

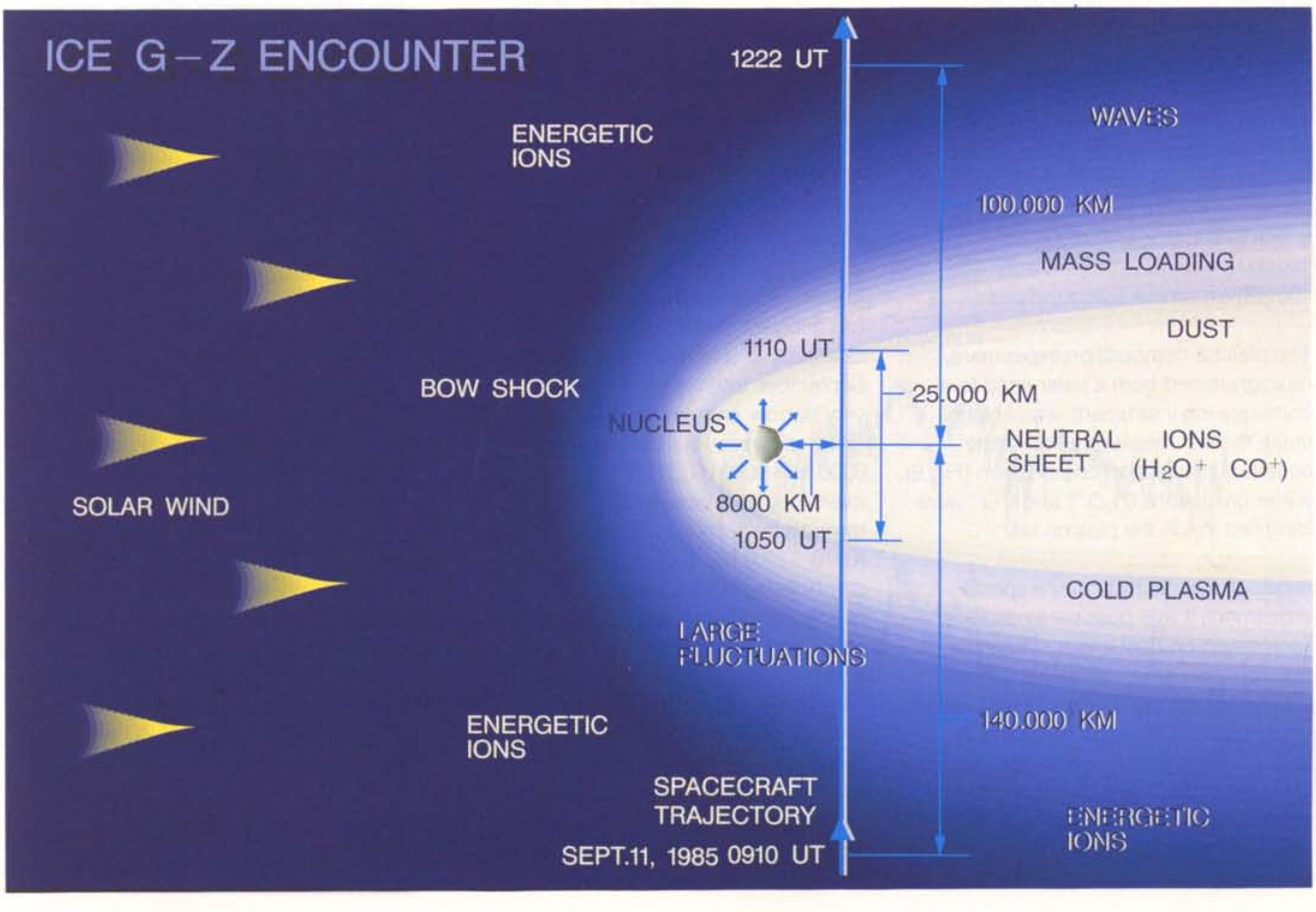


Figure 5 — Schematic of the cometary regions traversed by ICE. The spacecraft's trajectory and the main physical characteristics are shown. The approximate distances given are derived using the spacecraft-comet relative velocity of 21 km/s

strong signals in the plasma-wave data were detected. Further in the turbulence decreased. Around 1050 UT ICE entered the cold plasma tail. It saw this region for 20 min corresponding to a width of about 25 000 km. Here cometary plasma of very low energy (velocity) and high density dominated. The best values for the plasma parameters in this region were actually derived from the plasma noise detected by the radio wave experiment. A density of more than 600 electrons per cm^3 and a temperature of 20 000 K was found, which is a factor of 100 denser and a factor of 10 colder than the ambient solar wind. The magnetic field structure embedded inside this cold plasma tail was actually seen to be draped as predicted ('hairpin'-shaped), with two lobes of opposite polarity and – to the investigators' delight – the neutral sheet was crossed near the time of closest approach, which occurred at 1102 UT.

The outbound pass showed similar characteristics to the inbound one. Around 1220 UT, a similarly unusual 'bow-shock' structure to that found on the inbound leg was crossed. The total width of the cometary interaction region from shock to shock was 250 000 km, 140 000 km on the inbound and 100 000 km on the outbound pass.

The plasma-composition experiment, reprogrammed from a solar-wind to a cometary-ion instrument, was able to make the first measurements of the cometary plasma ion composition (Fig. 6). Water group ions (H_2O^+) and CO^+ were identified inside the plasma tail.

Although ICE did not carry a specific dust experiment, it was possible to deduce information on dust impacts from the plasma-wave data, rather like a similar experiment on the Voyager spacecraft when it passed through the plane of Saturn's rings. Micron-sized particles were detected during the crossing of the plasma tail, with a peak in the impact rate near the time of closest approach to the comet (Fig. 7). These very preliminary results of about 1 particle impact per sec over the cross-sectional area of the spacecraft are consistent with recent results of opacity measurements of Giacobini-Zinner's dust tail by ground-based telescopes. The dust impact rate was, however, much lower than had been feared prior to the encounter, based on a dust model that was originally developed for Comet Halley and scaled for Comet Giacobini-Zinner.

For many investigators some of the most surprising results of the encounter were the spatial extent and the intensities of the energetic cometary ions found by the Energetic Particle Instrument. The first signs of such ions were detected about 1 day, i.e. more than 1 million kilometres, prior to the closest approach, when highly collimated beams of heavy 'pick-up' ions were first observed. These pick-up ions originate from cometary neutral atoms and molecules which can escape freely into interplanetary space from the cometary environment at speeds of 1 km/s because of the comet's low gravitational forces. They become photo-ionised by solar radiation and are then accelerated by the solar wind to energies of several tens of kilo-electron volts.

Figure 8 shows the energetic ion intensity (on a logarithmic scale) in two energy channels as a function of time on 11 September. Intense bursts of ions, with very narrow angular distributions ('beams') were, for example, seen between 0300 and 0600 UT. The maximum intensities were observed during passage through the turbulent interaction region (0910–1220 UT). The dip in intensity coincided with the transit of the cold plasma tail. On the outbound pass the intensity dropped off much more slowly. The large-scale region of energetic cometary ions extended even further than on the inbound passes, with ions being seen for more than two days after the encounter. Based on the composition measurements in the tail, these energetic pick-up ions are probably water-dissociation products like OH^+ and O^+.

Conclusion

The ICE mission has demonstrated how ingenuity can overcome lack of funding and take advantage of an unexpected opportunity with hardware at hand. This 'new science' with an 'old spacecraft' would have been impossible without the ingenuity of the man who had conceived ISEE-3's first scientific hunting ground, the halo orbit around the sunward libration point. It was Dr. Robert Farquahr of NASA's Goddard Space Flight Center who proposed and then engineered the redeployment of ISEE-3 first as a geotail explorer and then as a cometary mission. Since the communications range needed for an encounter with Halley was too great for useful data to be acquired, his choice fell on Giacobini-Zinner.

The rich harvest of scientific results that will emanate from this first in-situ exploration of a cometary environment has exceeded all expectations. It has confirmed, in general terms, the picture of the interaction of the comet's atmosphere with the solar wind that had been developed from ground observations. There have, however, been surprises: the detailed structures in the plasma, magnetic fields and particle data, the high level of turbulence, the lack of a traditional bow shock, and the richness of the high-energy phenomena observed.

The ICE encounter with Comet Giacobini-Zinner was just the beginning of an exciting period of cometary physics. ESA's Giotto, the two Vega and the two Japanese missions are on their way to encounter Comet Halley next March. ICE, with its non-cometary payload, has set a high standard, and we are all eagerly looking forward to the wealth of data to be sent back by the spectacular Halley fleet, with their dedicated instruments and sophisticated imagery.

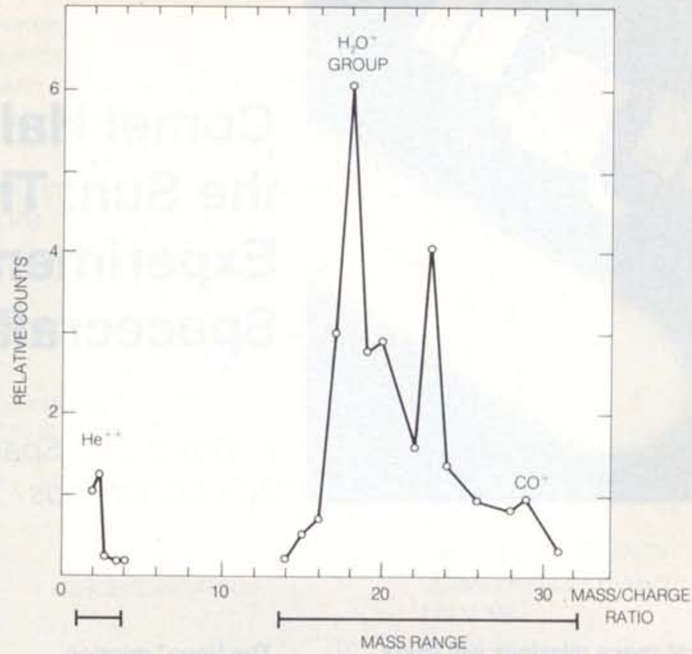


Figure 6 — Ion mass spectrum obtained by the Plasma Composition Experiment in the comet's tail region. The instrument covers two mass ranges depicted by the bars near the bottom. Singly charged water group ions are the most abundant species found in the cometary atmosphere, as expected from the sublimation of the 'dirty snowball'. The peak around mass 21 has not yet been identified (courtesy of K. Ogilvie)

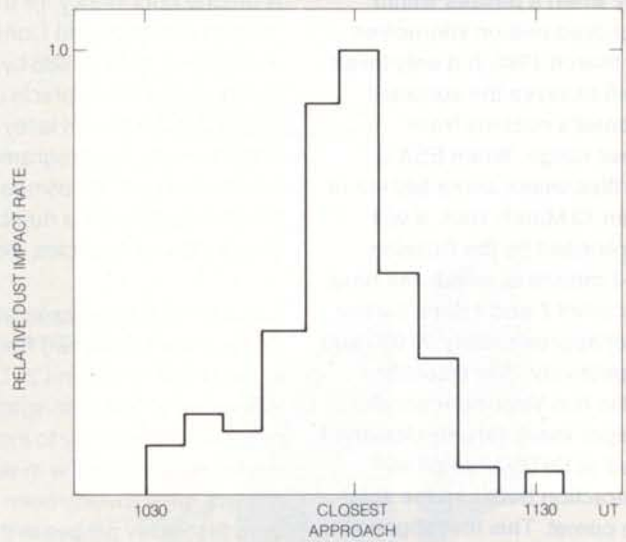


Figure 7 — Histogram of the micron-sized dust-particle impact rate as detected by the plasma wave data. The dust was concentrated around the time of closest approach to the nucleus (courtesy of F. Scarf)

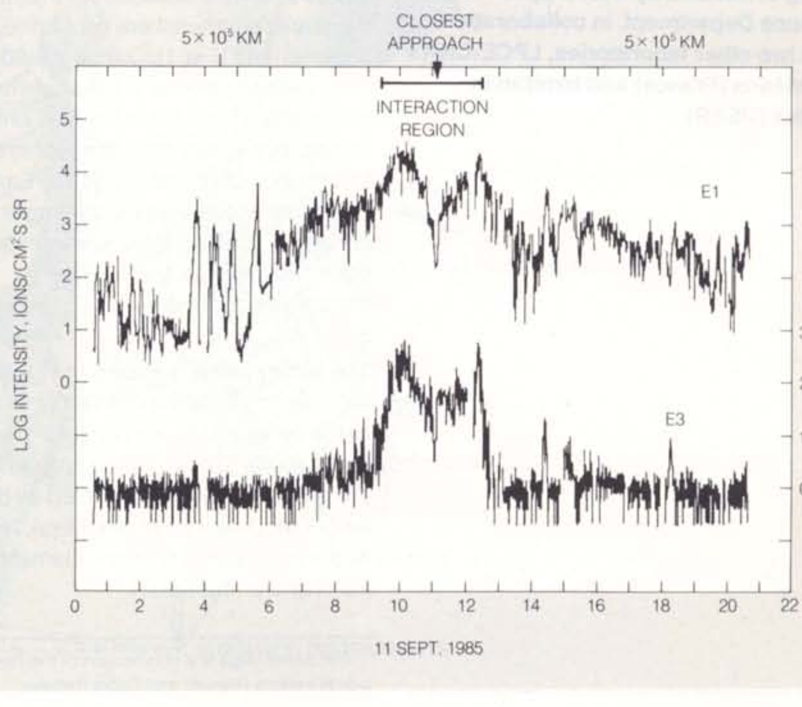
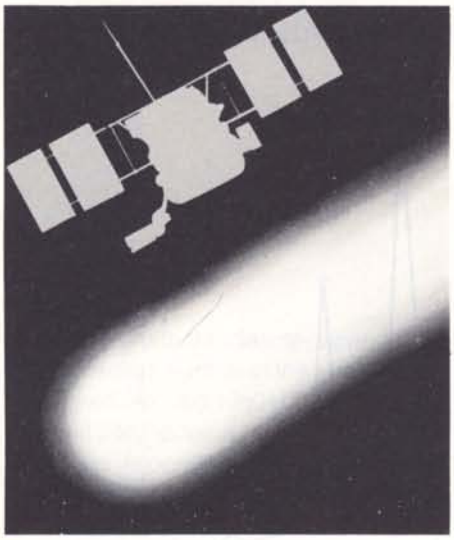


Figure 8 — Energetic cometary ions observed by the Energetic Particle Anisotropy Spectrometer on 11 September. Note the large spatial extent of the lower energy ions, which originate as neutrals from the comet and become ionised and accelerated in the solar wind. The crossing of the inner tail manifests itself as a pronounced dip in the ion intensity. The higher energy ions are mostly confined to the region inside the 'bow shock'. The energy ranges E1 and E3 correspond to oxygen ions of 63 – 93 keV and 138 – 205 keV, respectively



Comet Halley's Interaction with the Sun: The Plasma and Wave Experiment On-Board the Vega Spacecraft

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Several space missions will study Comet Halley when it passes within about one hundred million kilometres of the Sun in March 1986, but only three spacecraft will observe the sunward side of the comet's nucleus from relatively close range. When ESA's Giotto probe flies within some 500 km of the nucleus on 13 March 1986, it will have been preceded by the Russian Vega-1 and -2 missions, which will have flown by the comet 7 and 4 days earlier, at distances of approximately 10 000 and 3000 km, respectively. The scientific payloads of the two Vega spacecraft include an experiment, largely designed and fabricated at ESTEC, which will study the interaction between the solar wind and the comet. This investigation is being conducted by ESA's Space Science Department, in collaboration with two other laboratories, LPCE-CNRS in Orléans (France) and Izmiran in Troitsk (USSR).

The Vega* mission

A unique opportunity for a combined mission to Venus and Comet Halley is available in 1985–1986 by using a two-component space vehicle consisting of a Venus lander and a Halley flyby probe. This international programme is being conducted by Interkosmos (USSR) with the participation of a number of western countries and agencies, including ESA.

Two identical spacecraft, Vega-1 and Vega-2, were launched from Baykonour in the USSR on 15 and 21 December 1984, respectively. The dual-spacecraft redundancy is purely to increase the overall reliability of the mission. The landers have already been separated from the Halley probes in the vicinity of Venus and were successfully injected into the planet's atmosphere on 11 and 15 June 1985 (Fig. 1). During their descent, each lander released a balloon which was tracked from Earth for 48 h while drifting in the Venusian atmosphere. Data from the landers was relayed to Earth by the Halley probes, which are presently continuing their journey towards the comet, following a gravitational manoeuvre around Venus.

The Halley probe is shown in Figure 2 in its cometary flyby configuration. Its mass is of the order of 2.5 t and its solar panels span about 10 m. On its journey to Venus, the probe was still surmounted by the lander module (not shown here), which was a spherical unit with a diameter of 2.5 m and a mass of 2 t.

* The name Vega is a contraction of the Russian words Venera (Venus) and Gallei (Halley).

Each probe carries a scientific payload of 14 experiments, with a total mass of 127 kg and a power consumption of 178 W. It consists of electromagnetic field sensors, plasma, gas and dust detectors, and a pointing platform which carries three optical instruments, including two television cameras to observe the cometary nucleus.

The probes will be three-axis-stabilised during the cometary flybys, which will occur on 6 and 9 March 1986, at distances of the order of 10 000 and 3000 km from the comet's nucleus, with a relative velocity of 78 km/s.

The interaction between a comet and the Sun

The nucleus of a comet, assumed to be an icy 'snowball' with a radius of a few kilometres, heats up and partly sublimates when it approaches the Sun. One of the fundamental differences between this cometary gas environment and a normal planetary atmosphere is that the former is not bound to the nucleus because the gravitational attraction is too weak. The sublimated gas, which is mostly water vapour, can therefore escape with a velocity of a few 100 m/s, carrying away ice and dust particles and producing a visible coma, or 'head', which may achieve a radius of several hundreds of thousands of kilometres (Fig. 3a).

The expanding gas is ionised by the ultraviolet solar radiation and by other processes which are not yet fully understood. The resulting plasma forms the cometary ionosphere. Its interaction with the solar wind, a mixture of electrons

Figure 1 – The paths of the Vega probes (a) from Earth to Venus, and (b) from Venus to Halley. The projection of the inner portion of the trajectory of Halley on the plane of the ecliptic is also shown. The Comet and the Earth are orbiting in planes that intersect at an angle of 18°. The nodes are the points where Halley's orbit intersects the ecliptic

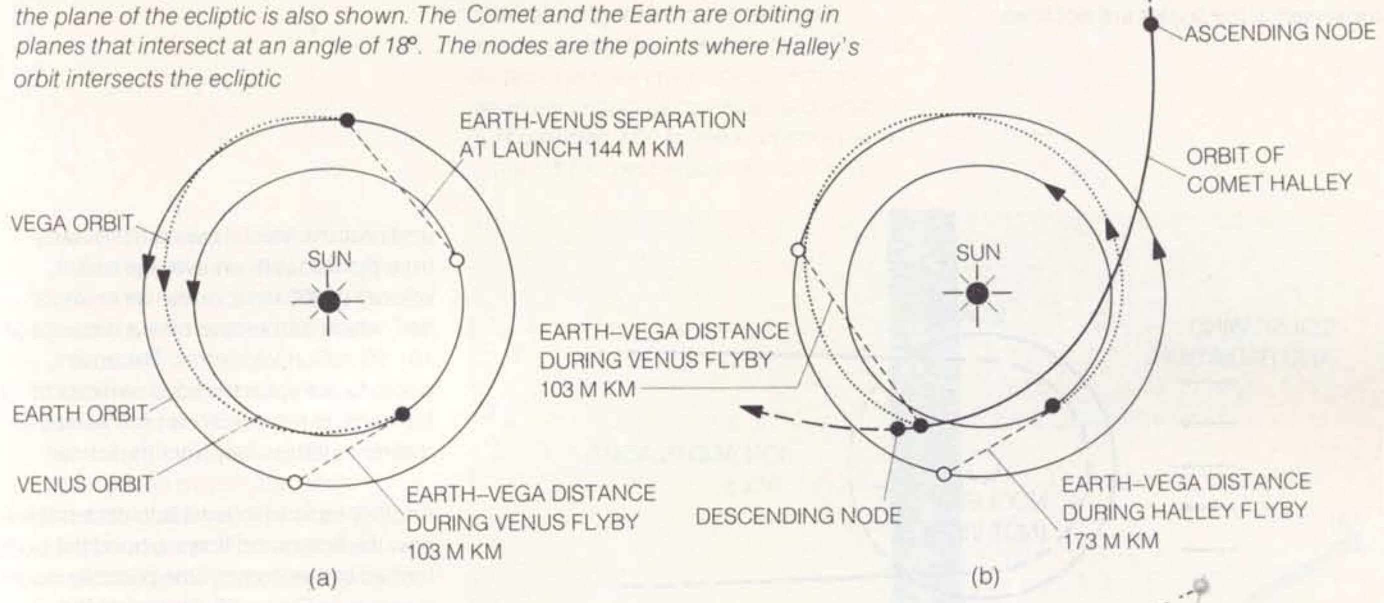


Figure 2 – The Vega spacecraft in cometary flyby configuration, after release of the Venus lander. The plasma and wave sensors are carried by the booms mounted on the outer solar panels. The two spheres which form the electrical antenna are 11 m apart

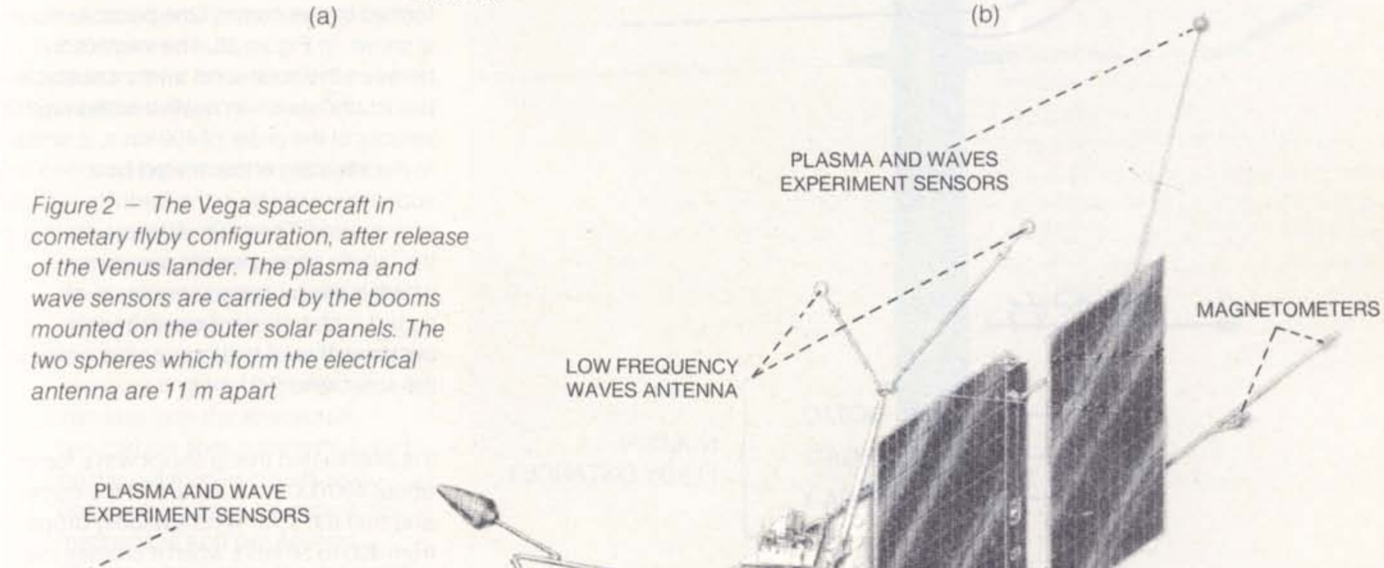
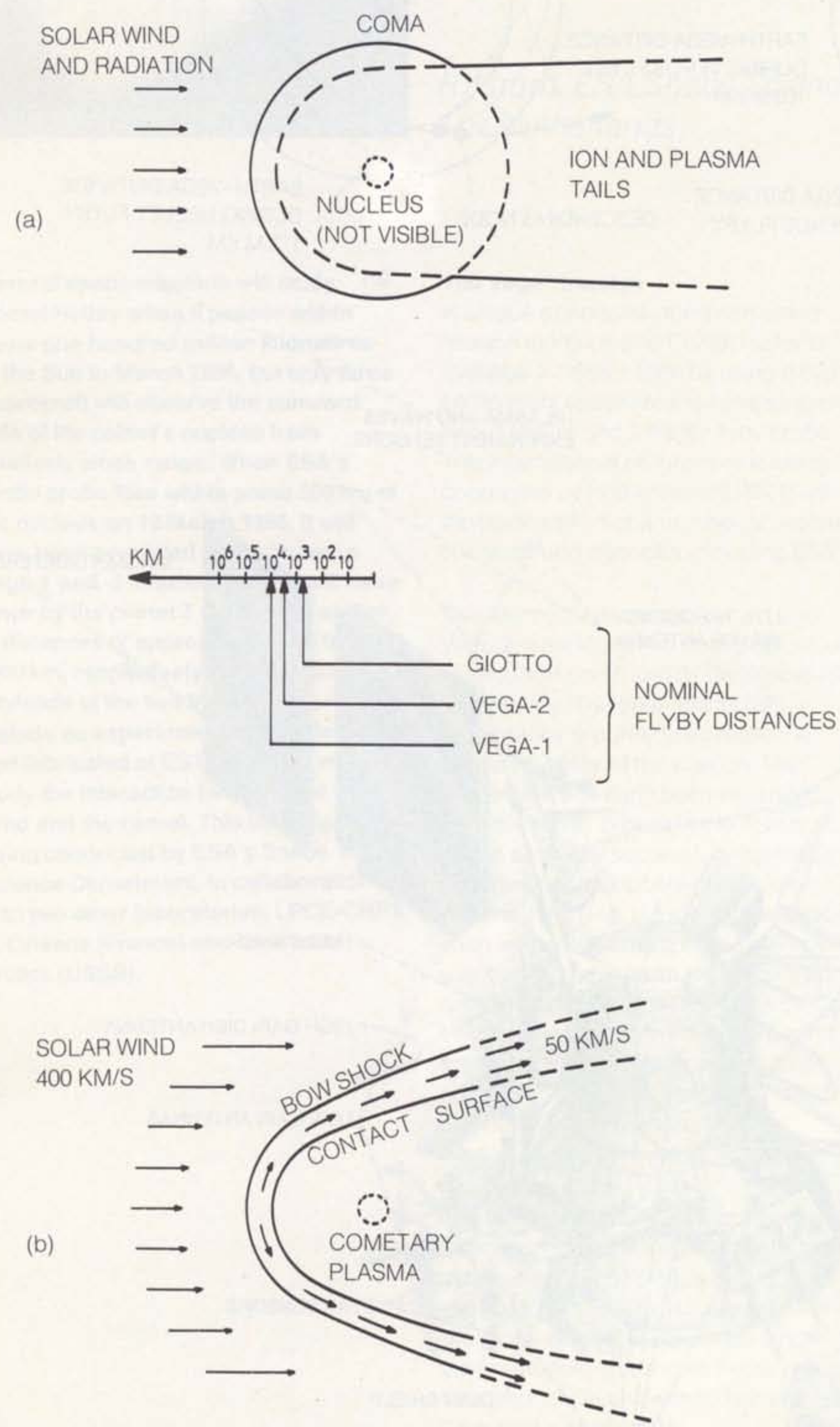


Figure 3 – The visible comet (a) and the flow pattern of the solar wind around the cometary obstacle (b). For clarity and convenience the scales are not linear



and protons which flows radially away from the Sun with an average bulk velocity of 400 km/s, gives rise to an ion 'tail', which can extend over a distance of 10 – 20 million kilometres. The solar photons act upon the solid particles to form a dust tail, which can sometimes be differentiated visually from the ion tail.

Another topic of interest is to understand how the solar wind flows around the body formed by the comet. One possible model is shown in Figure 3b. The interaction between the solar wind and an obstacle – planet or comet – in relative motion with a velocity of the order of 400 km/s, is similar to the situation encountered by a supersonic vehicle in the Earth's atmosphere. The main difference is that the latter's characteristic parameter, which is the propagation velocity of sound in our atmosphere (0.3 km/s), becomes that of hydromagnetic waves in the solar wind (50 km/s).

It is anticipated that a shock wave forms about 400 000 km sunward of the comet and that the solar wind's velocity drops from 400 to 50 km/s when it crosses this bow shock. The interface between the solar wind and the cometary environment is called the 'contact surface' or 'tangential discontinuity'. It forms the actual envelope of the obstacle and the solar-wind and cometary plasma pressures balance each other on each side of this discontinuity.

It must be emphasised that the validity of this idealised picture, which is rather well verified for planets, is as yet quite hypothetical as far as comets are concerned. More information should soon be available, however, following the successful flyby of Comet Giacobini-Zinner by the ICE spacecraft on 11 September (see page 32 of this Bulletin).

The Plasma and Wave Experiment
The scientific objectives of the Plasma and Wave Experiments on Vega-1 and Vega-2 are:

(i) to measure the density of the solar

wind just before it is influenced by the comet, thereby establishing a reference for understanding the subsequent solar-wind/comet interaction

(ii) to observe the deceleration of the solar wind in the vicinity of the comet, either directly or through the associated wave instabilities

(iii) to obtain plasma density and temperature profiles, as well as wave frequency spectra, during the cometary transit

(iv) to search for and identify the shock wave and the contact surface.

The onboard experiment equipment consists of:

(i) one electronics box, which commands the sequence of measurement cycles, controls the signal processing and data formatting, and provides the power, telemetry and telecommand interface with the spacecraft

(ii) two carbon-fibre booms mounted on the outer solar panels and deployed in space by means of mechanical and pyrotechnic devices, which carry the wave and plasma sensors.

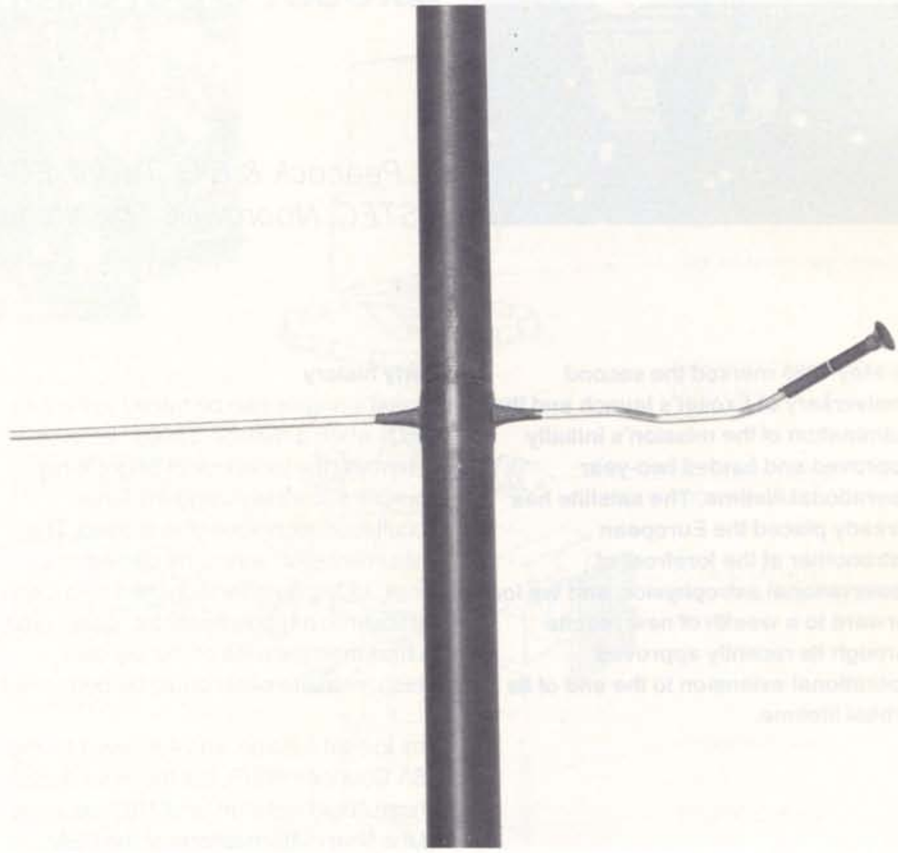
Two 10 cm-diameter spheres are mounted at the tips of the booms. They are separated by a distance of 11 m after boom deployment, to form an antenna for measuring electric fields. Langmuir probes are fixed at the mid points of the booms (Fig. 4).

The signals detected by the electric dipole are fed into a wave analyser. The potential of each sensor with respect to the spacecraft structure is continuously monitored, in order to determine the electrical potential of the vehicle with respect to its environment. The currents measured by the Langmuir probes are processed by two electrometers.

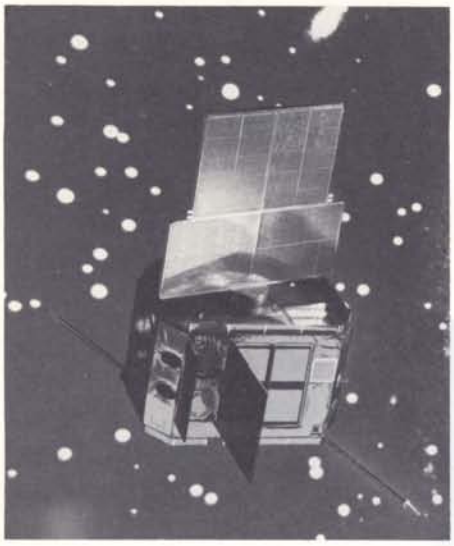
Once in the vicinity of Comet Halley, the experiments will be switched on two days before the encounter. The direct high-speed telemetry will be transmitted for 2 h starting 48 h before encounter and again 24 h before encounter, and for 2 h before and 1 h after the actual flyby. Complementary data will be stored by the onboard tape recorders to cover the two 22 h gaps whilst the high-speed telemetry is switched off.

The experiments are currently performing well and are being tested at regular intervals during the interplanetary transfer phase.

Figure 4 – The Langmuir probes are fixed at the centre points of the booms, and oriented such that their axis of symmetry is parallel to the gas flow velocity during the cometary flyby. Conical elements at their tips protect them from the direct impact of cometary gas and dust particles. The probe support extends to the left for mechanical reasons only



Acknowledgements
It is a pleasure to acknowledge the participation of the eleven ESA colleagues who have contributed to the design and fabrication of the Plasma and Wave Experiment: H. Arends, J. Bouman, A. Butler, J. Heida, K. Hjortnaes, D. Klinge, K. Knott, A. Pedersen, J. Postema, R. Scheper and A. Smit.



Reflections on Two Years of Exosat Operations

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

26 May 1985 marked the second anniversary of Exosat's launch and the culmination of the mission's initially approved and funded two-year operational lifetime. The satellite has already placed the European astronomer at the forefront of observational astrophysics, and we look forward to a wealth of new results through its recently approved operational extension to the end of its orbital lifetime.

Early history

Exosat's origins can be traced to the late 1960s when a mission, called Helos, to determine the locations of bright X-ray sources accurately using the lunar occultation technique was studied. The instrumentation was to be carried in a small, 150 kg satellite launched by a Delta vehicle into a highly eccentric 'polar' orbit, to maximise the area of the sky over which measurements could be performed.

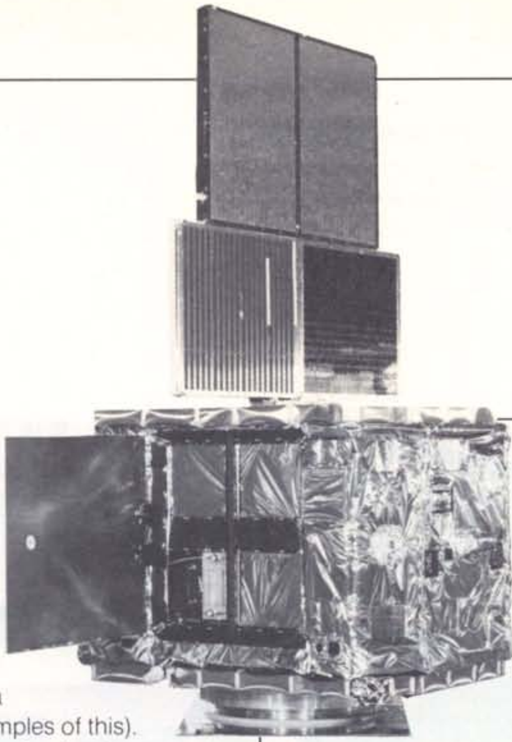
The Exosat mission was approved by the ESA Council in 1973, but the main design phase could not start until 1977 because of the financial limitations of the ESA Scientific Programme budget. Also in 1977 it was decided that Exosat should be launched on the Ariane vehicle. In the intervening eight years since the Helos study, the Uhuru and Ariel-5 satellites (to name but two) had been launched to give the first exciting views of the X-ray sky, and NASA's HEAO programme had been restructured to contain a powerful, few-arc-second resolution imaging telescope on the second satellite in that series, renamed Einstein after launch.

The Announcement of Opportunity (AO) to propose instruments for Exosat was issued by the Agency in 1973, with a model payload defined to include large-area proportional counters and crude non-imaging flux collectors for the lower energies. Instrument groups, known as hardware groups in Exosat parlance, were selected in 1974 and, following a so-called 'scientific model phase', the instrument complement was significantly upgraded. At the start of the main design and development phase of the mission (1977) it comprised (Fig. 1) the large-area proportional counter array (the medium-energy experiment), two imaging telescopes each with transmission gratings, position-sensitive proportional counters (PSDs) with good energy resolution as colour cameras, channel multiplier arrays (CMAs) as high-resolution black-and-white cameras, and a newly developed and unique instrument, a single gas scintillation proportional counter (GSPC).

One overall requirement maintained throughout the programme was compatibility with the Delta vehicle, which constrained both mass and dimensions. These constraints, together with programme cost limits, led to extremely innovative and state-of-the art designs in the areas of the medium-energy detectors' bodies (all beryllium) and collimators (microchannel plate technology), and the ultra-lightweight, imaging telescope optics (gold reflecting layers replicated within beryllium carriers). Eventually, 120 kg of a total satellite mass of 500 kg could be allocated to the instruments, but only 1 m-focal-length telescopes could be accommodated (compared with Einstein's 3.4 m).

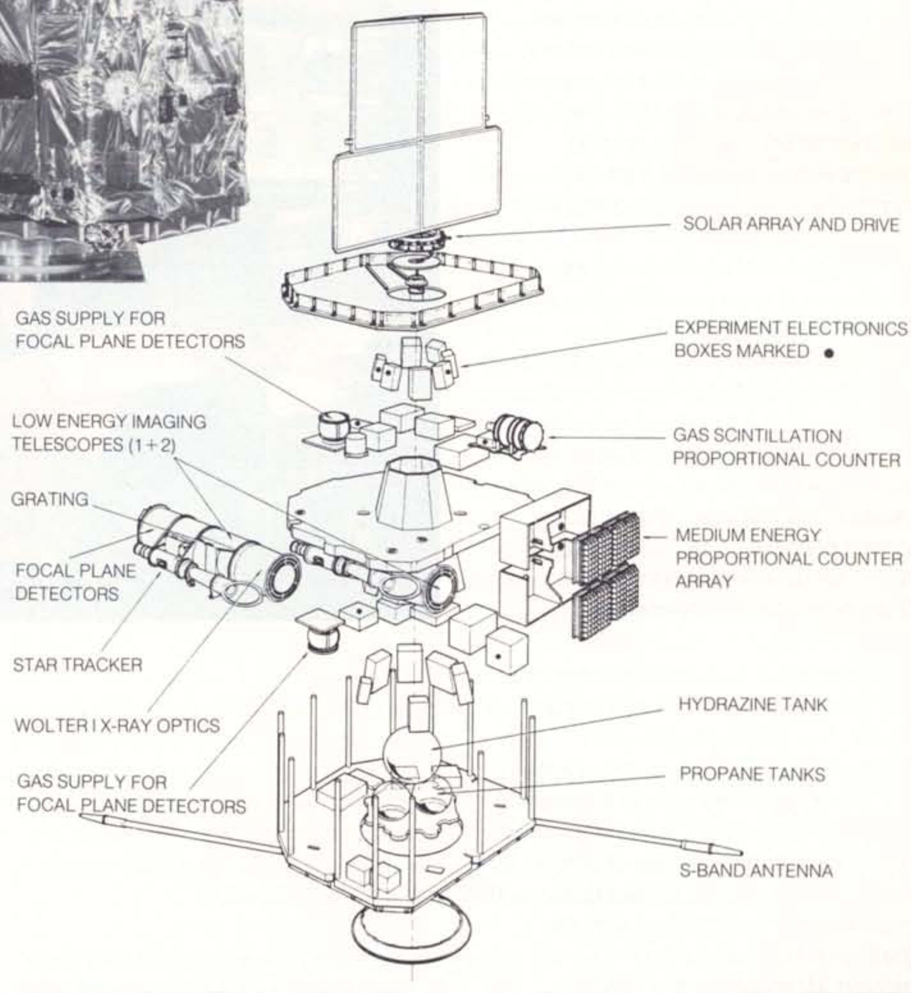
Payload/observing philosophy

It was decided at the start of the programme, in 1973, that Exosat should be a facility to be used by an 'observing community' on a European-wide basis and its use should not be restricted to the few responsible for the hardware. This decision had two important ramifications. For the first time in the ESA (ESRO) Scientific Programme it was decided that



the instrument procurement would be funded and managed by the Agency rather than nationally (Hipparcos and Space Telescope's Faint Object Camera are more recent examples of this). However, as noted earlier, hardware groups and instruments were selected through the AO process and responsibility for the instruments shared between the groups and the Agency.

Figure 1 — Exploded view of the Exosat spacecraft and its payload



It was further decided at that time that all observing time would be open to competition through the peer review process, with no time reserved for or guaranteed to the hardware groups. This approach was modified in 1979 by a decision of ESA's Scientific Programme Committee, which granted 'data rights' to the hardware groups for the calibration and performance-verification phases, with a guarantee of a percentage of observing time in the routine operational phase. Nonetheless, hardware-group observing proposals for this guaranteed time were still subject to the peer review process.

Four Announcements of Opportunity (AO) to participate in Exosat's observational programme have been issued. The first in 1981, circulated only in ESA Member States, solicited responses from which the observing programme for the first year was selected. Three further AOs have been issued on a worldwide basis in September 1983, August 1984 and August 1985. The responses to each of the first three were overwhelming, with the available observing time some five times oversubscribed. To assist in the selection of the observing programme proposals, a peer review team of leading European astronomers was established. The makeup of this team was reviewed at the time of each AO.

While Exosat was always expected to be a facility for use by the astronomical community, the mission plans approved in 1973 did not specify how this was to be achieved. In fairness, however, the final scope of Exosat, as flown, was radically different from the mission originally foreseen. Preliminary plans for the ground segment of the Exosat observatory were laid in 1978, though within very tight financial limitations, as this was seen as a new requirement, even though by this time the International Ultraviolet Explorer (IUE) was already operational. These limitations had an impact on the manpower levels and facilities that could be made available. By the time of launch, an observatory team and system (Fig. 2) had been established at ESOC, in Darmstadt, geared to carry out the scientific operation, to provide 'quick-look' data for observers, an observation data tape with instrument calibration files to a defined, standard format and a basic automatic scientific analysis (going far beyond 'quick-look'). The basics of an interactive analysis system were also established.

The observatory product, originally foreseen in 1973 was little more than a telemetry tape, but the 'miracle' was achieved by upgrading and extending equipment originally purchased to support the instrument ground test and calibration programme, at marginal extra cost.

In-orbit performance

Activation of the instruments began some 10 days after launch and initial results showed that all had survived the rigours of that event and were operating as expected. However within the first few months both PSDs of the two imaging telescopes failed, the CMA of telescope-2 stopped working and the grating mechanism of telescope-1 partially jammed and was left in the out position.

The provision of two independent telescopes to maximise throughput was intended to permit flexibility in observations (e.g. a PSD in one telescope together with CMA/grating in the other) and to provide a degree of reliability through redundancy or duplication. This concept was undone by the systematic failure of the PSDs and the random, indeed perverse, failure combination which left us with a working grating and CMA, but in different telescopes!

Figure 2 – The Exosat observatory facility at ESOC, in Darmstadt

With these malfunctions two important facets of the mission were denied us: broadband and high-resolution spectroscopy in the low-energy domain. The results obtained early in the mission did show, tantalisingly, what might have been. Nevertheless, greater observing time was achieved with the Exosat gratings in these first few months than with the grating on Einstein during the whole mission. Moreover, further grating observations towards the end of the mission are not precluded if the grating can be dragged back in. Thankfully, for the rest of Exosat's operational lifetime, to the time of writing, the instruments have operated fully satisfactorily and according to expectation.

On the spacecraft side the major concern has centred on the attitude-control system. In the first months of operations, various anomalies occurred, with the spacecraft switching from star pointing mode to slowly-rotating, Sun 'safety mode'. Eventually a working combination of on-board black-box functions was found, but not before a considerable mass of propane attitude-control gas had been lost. As the mission has progressed, the observing programme timeline has been constructed with increasing emphasis placed on the conservation of this resource – no easy task given the high percentage of observations conducted simultaneously with ground-based observatories and satellites like IUE, IRAS and TEMNA.

On 1 January this year, the X-axis gyro malfunctioned and in the following weeks numerous anomalies involving the triggering of safety modes occurred, with the resultant loss of a large amount of control gas. Spurious triggering of safety mode has been prevented meanwhile by disabling the hard-wired autonomous safety function and giving over this task to the on-board computer.

The on-board computer has proved invaluable for the mission, not only in this unforeseen application, but in its flexibility and application to the various instrument/telemetry operational modes, the vast majority of which have been modified or newly implemented since launch. Again it may be interesting to recall that there was considerable opposition 10 years ago to having such a facility on Exosat! Flexibility should not be confused with complexity and the built-in ability to cope with the unexpected or ill-defined is essential in any mission.

One other anomaly of the spacecraft which has affected mission performance concerned the large flap, used as a sunshade for the telescopes' apertures, which, by over-deploying by some few degrees into their fields of view, reduced the telescopes' effective area by about 30%.

Exosat's orbit, chosen primarily for the occultation role, is highly eccentric, with a 190 000 km apogee at high northern latitudes. This orbit has allowed uninterrupted observations for 72 h per orbit. Earth obscuration of the celestial sphere is essentially zero and the detectors do not have to cope with high backgrounds associated with the South Atlantic Anomaly. On the other hand, the particle background in the high orbit is a factor of only 2 or 3 higher than the low orbit, though solar-flare activity can disrupt operations for several hours. The orbit also allows continuous coverage from a single ground station and permits very efficient operation and control.

Figure 3 — Plots of X-ray intensity as a function of time for the source Algol for the medium-energy and low-energy bands (data taken 18/19 August 1983)

The satellite design and the orbit together have proved ideal for coordinated measurements and have allowed very quick responses to observation alerts. Many of the most exciting results from Exosat so far have stemmed from the long, uninterrupted look capability.

Support to the user community

As the mission progressed and observational data were disseminated, requests for help with analysis began to come in from the user community, especially from those with no previous experience in X-ray astronomy, some of whom lacked institutional computer and software support. Requests ranged from proposals to change data-tape formats (not done), to distribute auto-analysis software (done on a case-by-case basis) to distribute interactive analysis software (not done), and to provide an interactive analysis capability for external users within the observatory at ESOC (done).

The observatory system as a whole has had to be implemented within the existing resources of a very low budget and shows what can be done by a keen young team. With the hardware development costs of satellites as high as they are, with the flying of ever more complex instrumentation, and the ensuing nuances in analysis, it is a continuing problem deciding just where to draw the line on the services that ESA provides to a user community, to ensure the best possible return on the original investment.

Support is now given to process requests for archival research on those observations conducted a year or more ago, with operations of course having priority. However, this does open up a new window on Exosat, and, if IUE archival retrieval and research is any guide, a most important one.

Scientific results to date

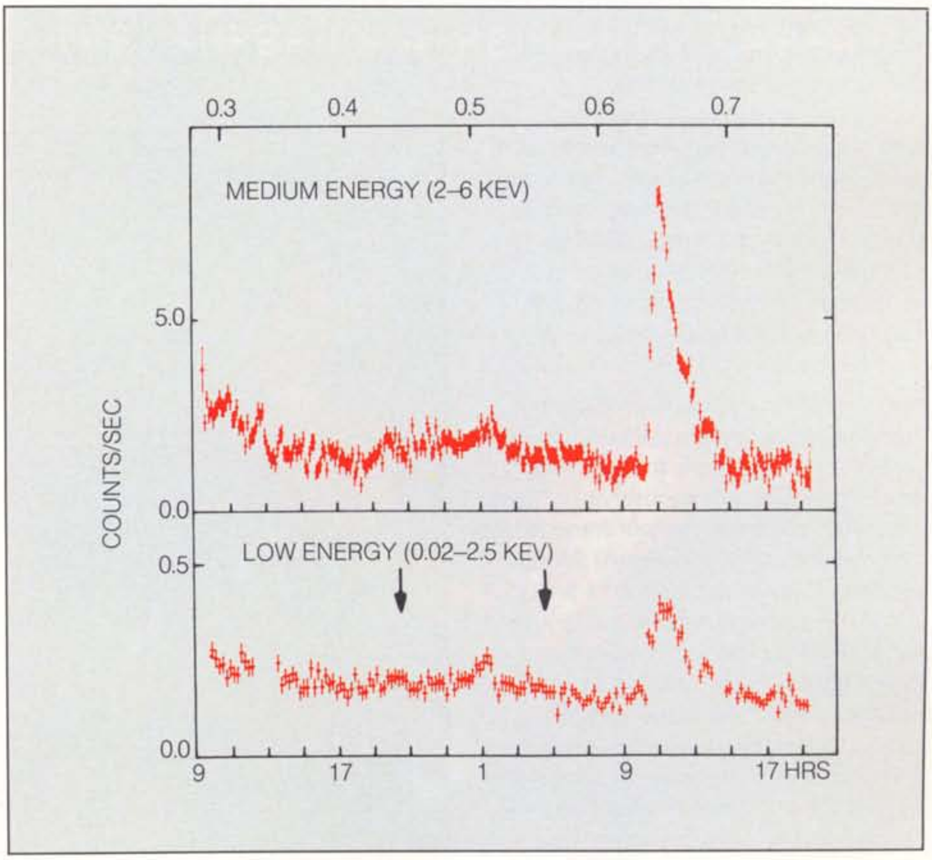
In about two years of operations, the observatory has performed over 1800 observations, which have attempted to solve a wide range of astrophysical problems. The principle scientific results have involved the study of the following classes of objects:

- Normal stars broadly similar to our own Sun.
- Cataclysmic variables – binary star systems containing a small compact star known as a white dwarf.
- Compact objects such as neutron stars or black holes in a binary system.
- Supernova remnants – the remains of stars which exploded hundreds to thousands of years ago.
- Active galactic nuclei – the central core of powerful X-ray galaxies.

Normal stars

Just as our own Sun produces X-ray emission, many other different types of normal stars emit X-rays. The Exosat observatory has performed a systematic survey of the X-ray emission from most types of main-sequence stars. The study of such emission allows us to establish the effects of magnetic activity and rotation on the structures of a wide range of stellar atmospheres involving both a chromosphere and corona.

An example of the type of physics that can be gleaned from such stars is the Exosat 35 h continuous observation of Algol. The X-ray emission is considered to originate in a corona associated with the K star in this binary system. Exosat observed the source during an eclipse by the companion star, so as to measure the structure of this corona. The size of the corona was found to be equal or larger than the size of the K star, with a temperature of 30 million degrees. A lower temperature component of 6 million degrees was also discovered and is probably associated with coronal loops with typical dimensions of ~30% of the K star's radius. An X-ray flare was observed (Fig. 3) lasting for 8 h. This flare arose in



one of the coronal loops where the plasma temperature rose to over 60 million degrees. Thus we see X-ray diagnostic studies which used to be performed only on the nearest star, our Sun, now performed on stars over 10 million times further away.

Cataclysmic variables (CV)

Cataclysmic variables are binary systems which contain a white dwarf star accreting matter from a late-type companion star. These objects as a class exhibit a variety of temporal phenomena including coherent and quasi-coherent pulsations, orbital variations, short-term irregular brightenings (outbursts), long-term variations and nova explosions. The X-ray properties of these stars are determined by the strength of the white dwarf's magnetic field compared to the rate of mass-accretion from the companion star. The study of CV systems at X-ray wavelengths can therefore provide valuable information on the dynamics of the system, the interaction of the white dwarf with its companion, and the physical properties associated with the compact white-dwarf star.

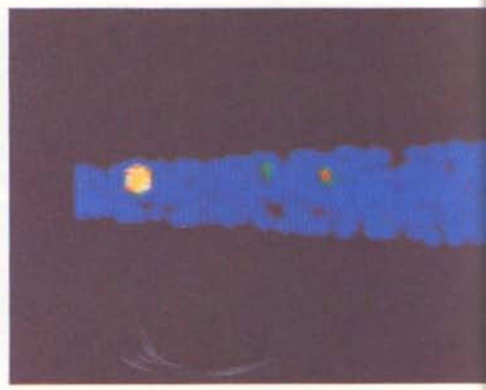
One of the earliest and most spectacular demonstrations of the abilities of Exosat came from the observation of one of these systems – the ex-nova GK Per. This white-dwarf star system has in recent years been undergoing dwarf-nova-like outbursts in the optical every year.

Another optical outburst was detected from the star during the performance-verification phase of the mission. The inherent flexibility of the observatory made it possible to observe the star immediately. This resulted in the discovery of strong coherent X-ray pulsations with a period of 351 s. This simple observation established the accreting star in this nova system to be a magnetic white dwarf. In a single observation we have measured the rotation period and magnetic field of the white dwarf and attempted to understand the physics of the mass transfer from the companion star onto the white dwarf.

Compact objects in binary systems

These binary systems contain a compact object such as a neutron star or black hole, which literally sucks material from a companion star. The infall of this material in the massive gravitational well of the compact star heats the plasma to X-ray emitting temperatures (10 million to 100 million degrees). The Exosat Observatory has observed many such systems and major results have to date come from these observations. The study of such systems provides information on the physics operating in systems where matter has been compressed to unbelievably high densities. The Exosat observations have determined orbital periods, neutron-star rotation rates, and the characteristics of X-ray bursts resulting from thermonuclear explosions on the surface of such neutron stars. The Exosat observatory, with its continuous-look capability for up to 72 h is ideally suited to discover these systems.

Another group of sources which have long been suspected to be neutron stars in binary systems have been examined by



Exosat. These are the galactic bulge sources which have no known orbital or rotation periods and have for many years been shrouded in mystery. The Exosat observatory has produced a major step forward in the understanding of the nature of such sources by discovering the phenomenon of Quasi-Periodic Oscillations (QPO) in these star systems. Figure 4 shows the power spectrum of one such system GX 5-1. More sources are now expected to exhibit this QPO phenomenon with periods in the millisecond range. The frequency of the oscillations, which is different from star to

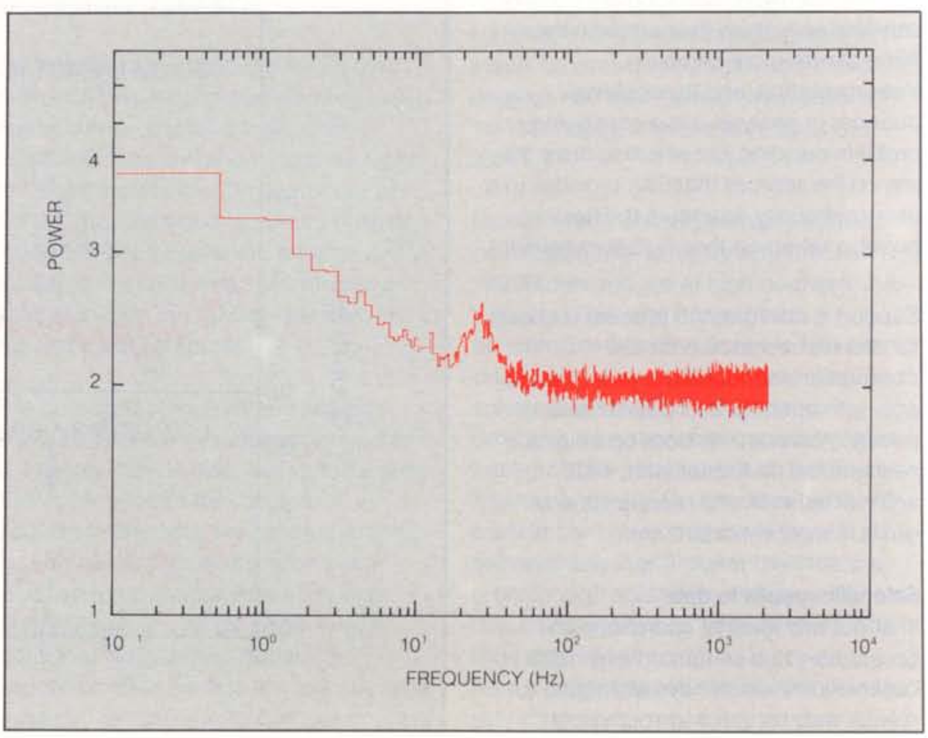
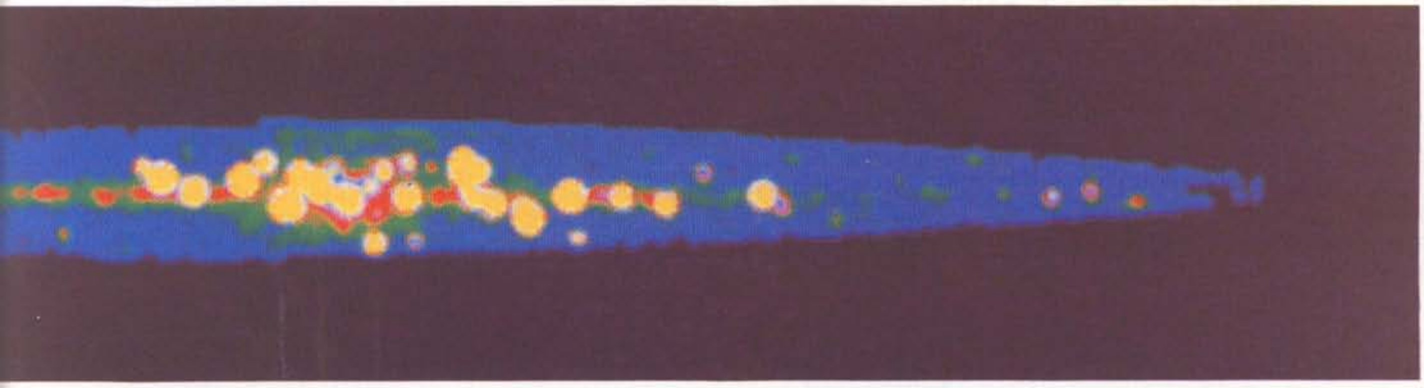


Figure 4 — Power spectrum of the source GX5-1 (data taken 18 September 1984)

Figure 5 – Scan of the galactic plane conducted with Exosat's medium-energy experiment. The brightest sources are colour coded yellow. The diffuse region (green) is clearly observed (photo courtesy of M. Turner, Leicester University)

Figure 6 – Exosat low-energy telescope (CMA) image of Cas-A. The supernova remnant is of the order of 12 light years across



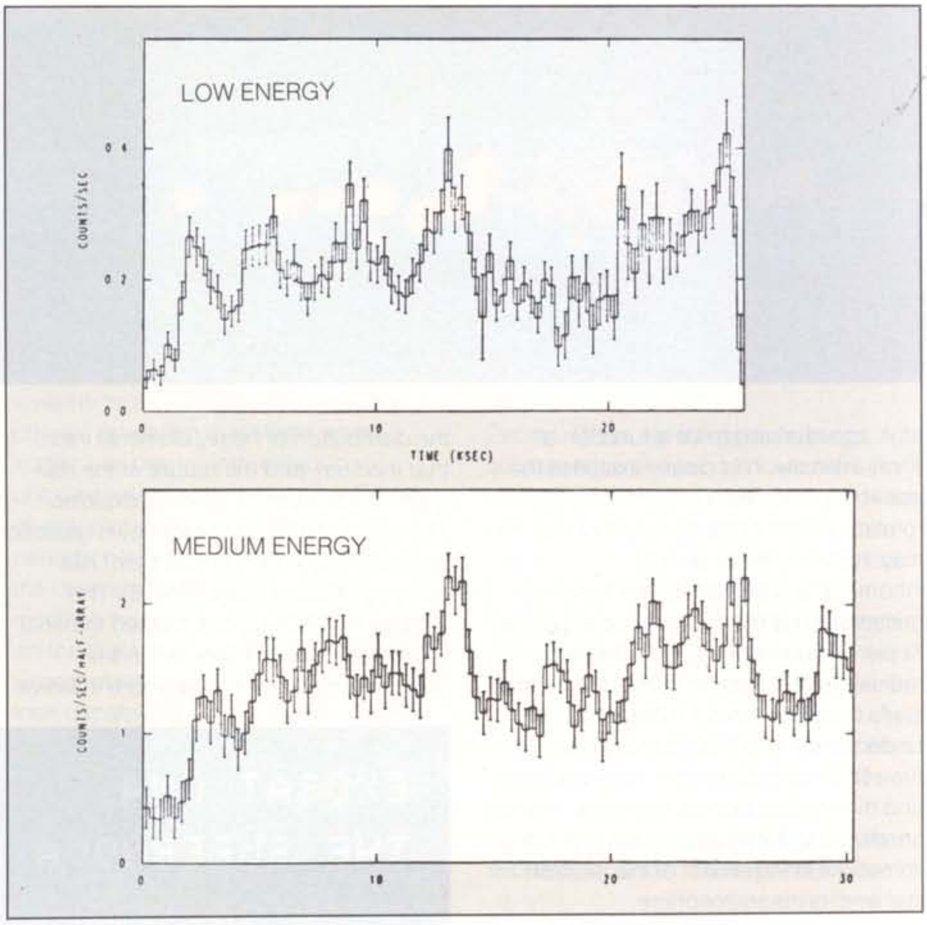
star, appears also to be a function of X-ray intensity. This clearly excludes the possibility that they represent a simple rotation period of the compact object. We may, however, be observing inhomogeneously distributed 'blobs' of matter orbiting the compact object at the Kepler frequency and at a preferred radius, which could be that of the neutron star's magnetosphere. A detailed understanding of this phenomenon will have to await both further observational and model data but it is now clear that we are studying the physics operating in the immediate environment of the neutron star and its magnetosphere.

Neutron-star-powered systems are among the brightest and most numerous X-ray sources in our galaxy. In the first year of its mission, Exosat performed a unique scan of the galaxy, allowing the medium-energy experiment to locate many of these hitherto unknown systems. Figure 5 shows the image reconstruction of this scan along the galactic plane. In addition to the observation of new sources, a diffuse ridge of emission was also discovered, possibly related to hot diffuse material lying between the stars.

Supernova remnants

A number of supernova remnants have been observed by the observatory, with a view to understanding their morphology and spectrum. X-ray observations of the remnants of these exploded stars are important in our study of the physical characteristics of the interstellar medium, the distribution of heavy elements into that medium, and the nature of the star which underwent the original explosion. The study of the youngest known galactic remnant Cas-A ($\sim$300 years old) has been particularly fruitful (Fig. 6). The X-rays come from shock-heated material (40 million degrees) expelled in the original explosion of a star more massive than our own Sun. From a detailed analysis of the spectrum coupled to the morphology, we can determine the physical conditions present in the ejecta, the surrounding interstellar material, and the type of progenitor star. In the case of Cas-A, the ejecta is moving into a dense inhomogeneous interstellar medium.

Figure 7 – Exosat medium- and low-energy light curves for the galaxy NGC 4051, showing the presence of quasi-periodic variability with a 4000 s cycle



Active galactic nuclei

The generally accepted model for these sources is one in which the primary power source is conversion of gravitational potential energy into luminous energy by accretion of cool material onto a central massive black hole. An accretion rate of three times the mass of the Sun onto a black hole 100–1000 million times more massive than our Sun is sufficient to produce the energy output. Very hot plasma is thus in orbit around a massive black hole. The X-ray data relates to the hottest emission regions very close to the black hole and by studying the variability in the X-ray flux on the shortest time scales, we can obtain an estimate of the mass of the black hole. This type of study has been a principal aim of the Exosat observatory over the last two years. One of the most important observations made by Exosat so far is the detection of repeated variability on a time scale of 4000 seconds in the nucleus of a galaxy called NGC 4051 (Fig. 7). This variability is probably related to hot material orbiting the black hole in an accretion disc. If further observations reveal any periodicity we will have, by simple Keplerian mechanics, a direct measurement of the black hole's mass. For the case of NGC 4051, if the 4000 s variation is periodic, the mass of the black hole is ~ one million times the mass of the Sun.

Conclusion

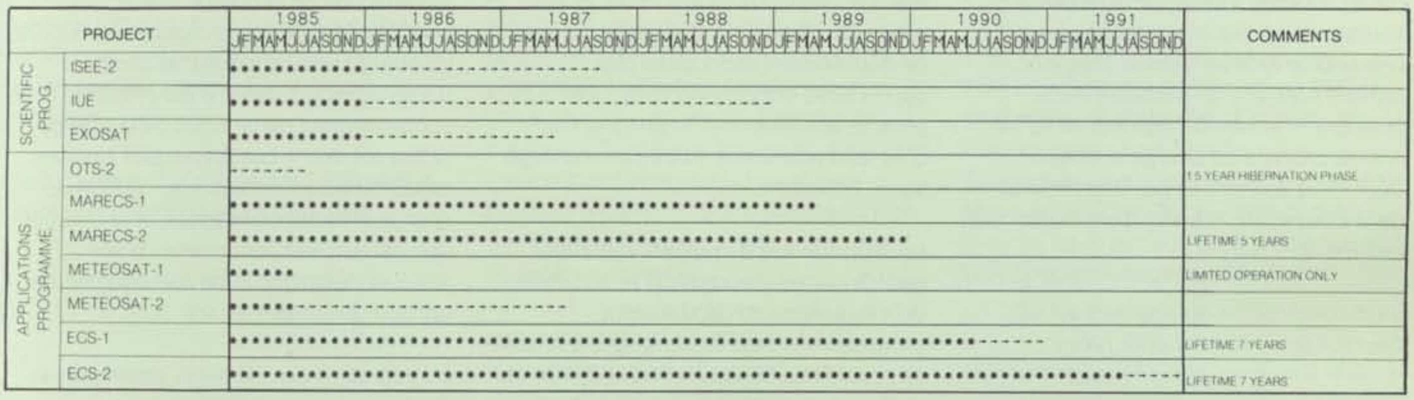
When Exosat was launched in 1983, the development cost of the spacecraft in industry was some 73 MAU (1 AU = ± 1 US$), while that of the scientific instruments was about 13 MAU. The total programme expenditure to launch in 1983, including internal costs, satellite testing, launch vehicle procurement, preparations for orbital operations, overheads, etc. came to about 155 MAU. Amortised over a two-year orbital lifetime, this represented an investment of approximately 2.5 AU per orbital second. The current yearly cost of Exosat is about 5 MAU for 24 hour per day, 7 days-a-week operations covering observations, data production, analysis and science.

It would appear that Exosat's scientific return as a function of these investments is well-recognised by ESA's advisory bodies, the Astrophysics Working Group, the Space Science Advisory Committee and indeed the community as a whole, who in the shape of the delegate body, the Scientific Programme Committee, agreed, at their meeting of 27/28 June 1985, that Exosat be operated through 1986, to the end of its useful lifetime, which will come about when the satellite's orbit decays or its propane supply runs out.

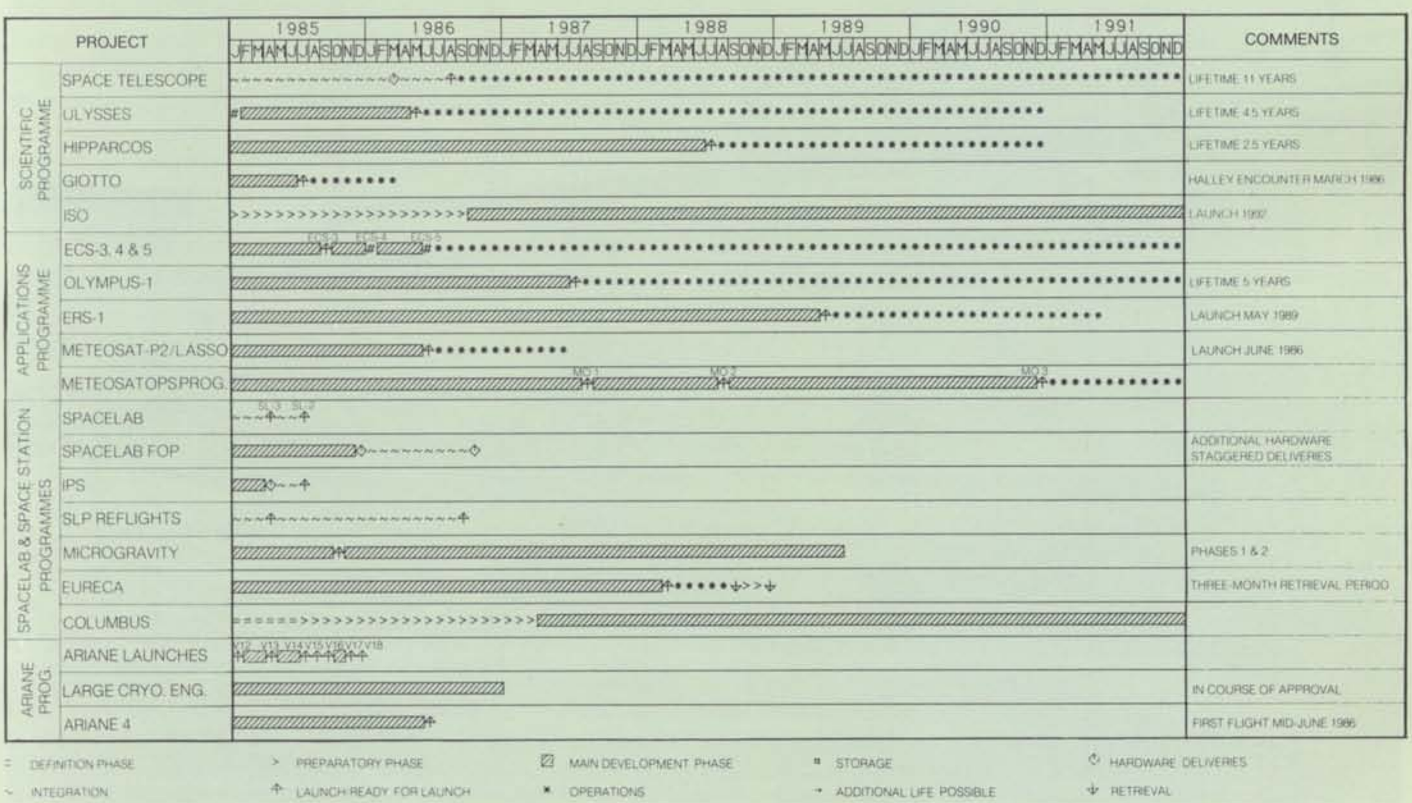
Having thus embarked on its final phase of operations, Exosat can certainly look forward to a wealth of new results, if the findings of the first two years are any guide.

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

In Orbit / En orbite



Under Development / En cours de réalisation



Météosat

Secteur sol

Les chiffres de performances concernant les trois missions fondamentales (prise d'images, collecte de données et diffusion de données) ont dépassé la limite spécifiée de 95% au cours du dernier trimestre.

On recherche actuellement si des vecteurs de mouvement des nuages pourraient être dérivés et être soumis à un contrôle de qualité quatre fois par 24 heures, au lieu de deux fois par jour comme c'est le cas actuellement.

Le 'bouche-trou' prévu pour la mission de la plate-forme de collecte de données (DCP), Goes-4, fourni par la NOAA, a souffert de graves interférences dues à une source externe dans la position orbitale prévue. Il va peut-être falloir positionner le satellite au-delà de 42°W afin de prendre en charge la mission DCP. Cela se traduira par une diminution de la couverture actuelle dans la direction de l'Est.

La modernisation du segment sol se poursuit selon le calendrier prévu.

Space Telescope solar array wing undergoing final deployment testing at BAe (UK)

L'aile du générateur solaire du Télescope spatial lors des derniers essais de déploiement chez BAe

Télescope spatial

Activités de la NASA

Ayant été incapable de rattraper le temps perdu au cours des premières phases de l'intégration du Télescope spatial, la NASA a dû redéfinir le calendrier. La date de lancement prévue a par conséquent été retardée de deux mois pour être maintenant fixée au 8 août 1986. Les activités récentes ont porté sur la livraison et le contrôle de l'adaptation du premier des trois détecteurs de guidage fin.

Générateur solaire

Des accords ont été conclus avec la NASA pour l'envoi dans l'espace de couvertures de panneaux solaires munies de cellules à haut rendement. La première aile a eu ses couvertures fixées, et les essais de déploiement primaire du bras et de déploiement secondaire des couvertures ont été effectués. Cette aile entame actuellement un programme d'essai d'ambiance avant son montage sur le Télescope.

La seconde aile a souffert de certains retards car les dispositifs d'actionnement du mécanisme de déploiement secondaire ont dû être changés à la suite de problèmes de synchronisation. Ce qui reporte à mars 1986 la livraison de la seconde aile.

Caméra à objets faibles (FOC)

La première phase des essais de performances électriques de la FOC dans le Télescope a été achevée avec succès. La FOC a ensuite été retirée pour réfection de la structure du plan focal. L'instrument a depuis été réintégré et est en train de subir la seconde phase d'essais électriques.

Hipparcos

L'intégration du modèle optique-structurel-thermique (OSTM) de la charge utile est maintenant achevée et le programme d'essais optiques et mécaniques de la charge utile a commencé. Une étude modale de l'OSTM de charge utile monté sur la structure d'interface du satellite a été effectuée et le comportement dynamique de la charge utile a été défini. Les préparatifs pour les essais de vide thermique de l'OSTM de charge utile ont commencé, et la charge utile est actuellement munie de son matériel thermique et de son équipement optique de soutien au sol.

L'intégration des éléments électriques et électroniques a commencé pour le modèle d'identification de la charge utile.

Meteosat

Ground segment
The performance figures for the three basic missions (imagery, data collection and dissemination) have been above the specified limit of 95% over the last quarter.

It is presently being investigated whether cloud-motion vectors could be derived and quality-controlled four times per 24 h, rather than twice per day as presently operated.

The planned 'gap-filler' for the data-collection platform (DCP) mission, Goes-4, supplied by NOAA, has suffered severe interference from an external source in the planned orbital position. The satellite may therefore have to be located beyond 42°W in order to take over the DCP mission. This will result in a reduction in the present coverage in the easterly direction.

Refurbishment of the ground segment is continuing according to schedule.

Space Telescope

NASA activities
NASA has been unable to make good the time lost during the early phases of Space Telescope integration and has therefore redefined the schedule. The scheduled launch date has consequently been delayed two months and is now 8 August 1986. Recent achievements have been the delivery and fit check of the first of the three fine-guidance sensors.

Solar array
Agreements have been reached with NASA on flying the solar blankets fitted with high-efficiency cells (HECs). The first wing has had its blankets attached and primary arm-deployment and secondary blanket-deployment tests have been performed. This wing is now undergoing an environmental test programme prior to delivery to the Space Telescope.

The second wing has suffered some delays as the secondary deployment mechanism actuators had to be exchanged due to synchronisation problems. This has delayed the second wing's delivery until March 1986.

Faint Object Camera
The first phase of the electrical performance testing of the FOC in the Space Telescope has been completed successfully. The FOC was subsequently removed for reworking of the focal plane structure. The instrument has since been re-integrated and is proceeding through the second phase of electrical testing.

Hipparcos

Integration of the payload Optical/Structural/Thermal Model (OSTM) has now been completed and the payload optical/mechanical testing programme has begun. A modal survey of the OSTM payload mounted on the spacecraft interface structure has been performed and the payload's dynamic behaviour characterised. Preparations for payload OSTM thermal vacuum testing have subsequently begun and the payload is currently being equipped with thermal hardware and optical ground-support equipment.

Integration of electrical/electronic elements has been initiated for the engineering model payload.

Progress continues on all payload optical aspects, with regular deliveries of optical hardware being achieved. A particularly pleasing event was the delivery of the engineering-model spherical mirror, with its surface accuracy of better than $\lambda/90$, unprecedented in Europe.

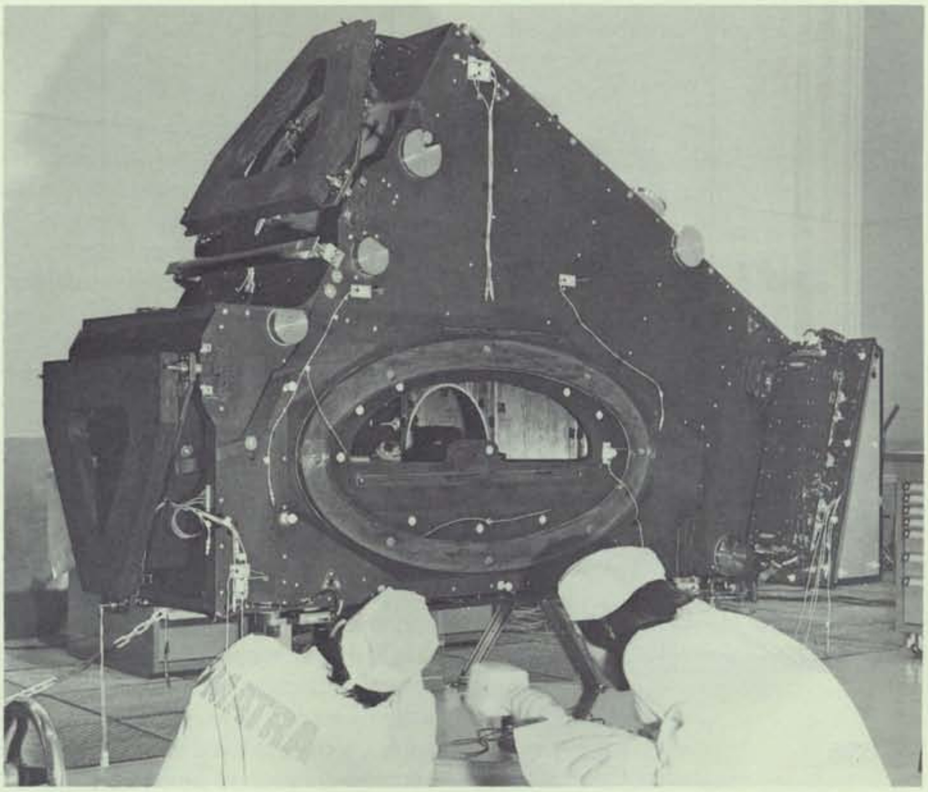
The payload vacuum-test facility, the FOCAL facility of the Institut d'Astrophysique de Liège, is nearing completion, with acceptance testing planned for the end of September 1985.

Two spacecraft-module events are worthy of note: decoder/transponder compatibility testing has been successfully performed, and the spacecraft structural/thermal model (STM) is being integrated. The next event for the STM is the modal survey test, which is planned for September 1985.

In June a Colloquium organised by the Input Catalogue Consortium (INCA) took place, dealing with all aspects of input-catalogue preparation. The Colloquium was attended by approx. 100 participants. The Proceedings of the meeting have already been published as ESA Special Publication SP-234.

Le modèle optique-structurel-thermique de la charge utile d'Hipparcos au cours des préparatifs pour les essais modaux chez Matra à Toulouse

Hipparcos payload OSTM being prepared for modal-survey testing, at Matra, Toulouse

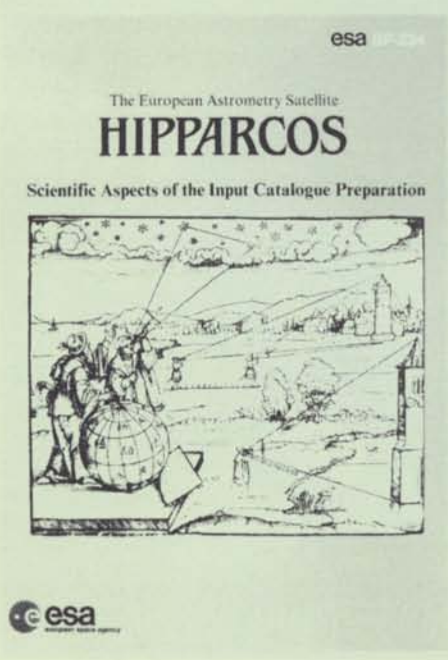


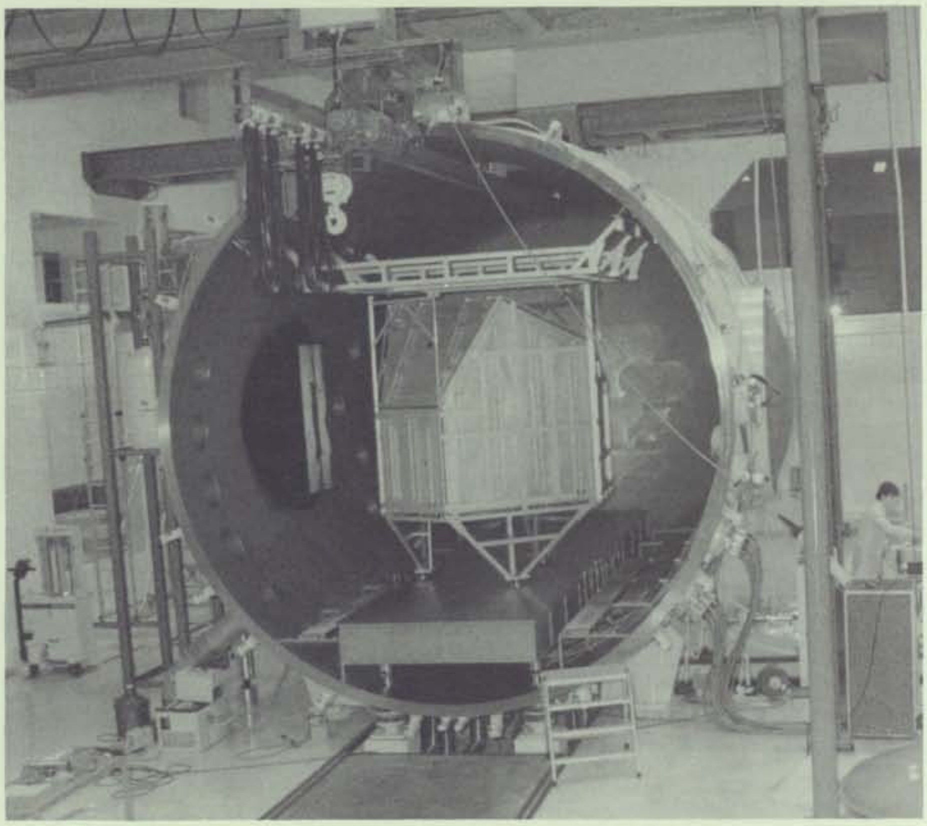
Le travail continue d'avancer sur tous les aspects optiques de la charge utile, des livraisons régulières du matériel optique étant réalisées. Un événement particulièrement heureux a été la livraison du modèle d'identification du miroir sphérique, dont la précision de surface est meilleure que λ/90, ce qui est sans précédent en Europe.

L'installation d'essai sous vide de la charge utile, l'installation FOCAL de l'Institut d'Astrophysique de Liège, est presque terminée, les essais de recette étant prévus pour la fin du mois de septembre.

Il faut mentionner deux événements concernant le module de satellite: les essais de compatibilité des décodeurs et des répéteurs ont été effectués avec succès, et le modèle thermique et structurel du satellite (STM) est en cours d'intégration. Le prochain événement concernant le STM est l'essai d'étude modale qui est prévu pour le mois de septembre.

Pendant le mois de juin, un colloque organisé par le Consortium du Catalogue d'Entrée (INCA), concernant tous les aspects de la préparation du catalogue d'entrée, a eu lieu. Environ 100 participants ont assisté à ce colloque. Les comptes rendus de la réunion ont été publiés dans la série 'publications spéciales' de l'ESA (SP-234).





Installation of thermal shrouds to simulate the Hipparcos spacecraft's 'shade structure', at the new FOCAL facility of Institut d'Astrophysique de Liège

Installation des coiffes de protection thermique pour simuler la 'structure d'ombre' du satellite Hipparcos au 'FOCAL' de Liège

Giotto

Giotto continue à se comporter de manière excellente, et le 1er septembre il se trouvait à environ 15 millions de kilomètres de la Terre. Tous les sous-systèmes fonctionnent de manière nominale, et diverses manoeuvres ont été exécutées avec succès, avec sous-utilisation importante du carburant hydrazine embarqué.

Trois expériences ont été déclenchées pendant le mois d'août. Il s'agissait de la caméra multicouleur de Halley, de l'analyseur de particules énergétiques et du magnétomètre. Toutes ont fonctionné avec succès et aucune n'a présenté d'anomalies. Le déclenchement du reste de la charge utile commencera le 6 septembre, dans le cadre du programme Giotto de soutien de la rencontre de la sonde ICE de la NASA avec la comète de Giacobini-Zinner le 11 septembre.

La première répétition de la rencontre avec la comète de Halley, qui suivra le plan de rencontre de Giotto et utilisera l'ensemble du système au sol principal et de secours avec l'interface scientifique, reste programmée pour la période du 9 au 17 octobre. Il s'agit de la prochaine étape prévue après le déclenchement du mois de septembre. Deux ou trois autres répétitions suivront en janvier et février 1986, la rencontre elle-même ayant lieu dans la nuit du 13 au 14 mars 1986.

Olympus

Certaines des Revues Critiques de la Conception (CDR) au niveau des sous-systèmes ont déjà eu lieu, et celles qui restent sont programmées pour les trois prochains mois.

Une revue satisfaisante des préparatifs d'essai en vue des essais dynamiques du modèle structurel de satellite a eu lieu au début du mois d'août, après achèvement des activités finales d'intégration, d'instrumentation, d'étalonnage et d'alignement. Les essais ont commencé le 17 août avec la première série d'essais de vibrations sinusoïdales et aléatoires pour le niveau de remplissage minimal de propergols fictifs. Il est prévu que le

Giotto

Giotto continues to perform excellently and on 1 September was approximately 15 million kilometers from Earth. All subsystems are performing nominally and various manoeuvres have been successfully executed, with significant under-utilisation of the onboard hydrazine fuel.

Three experiments were switched on during August. They were the Halley Multicolour Camera, the Energetic Particle Analyser and the Magnetometer. All were successfully operated and show no anomalies. Switch-on of the remainder of the payload will commence on 6 September, as part of the Giotto programme to support the NASA International Cometary Explorer (ICE) encounter with Comet Giacobini-Zinner on 11 September 1985.

The first Halley Encounter Rehearsal, which will follow the Giotto Encounter Plan and utilise the whole prime and backup ground system with the science interface, remains scheduled for 9–17 October 1985. This is the next scheduled milestone after the September turn on. Two or three further rehearsals will follow in January and February 1986, with the encounter itself taking place on the night of 13/14 March 1986.

Olympus

Some of the Critical Design Reviews (CDRs) at subsystem level have already been held, and the remainder are planned during the next three months.

A satisfactory test-readiness review for the dynamic testing of the structural-model spacecraft was held at the beginning of August, after completion of the final integration, instrumentation, calibration and alignment activities. Testing started on 17 August with the first series of sine and random-vibration tests for the minimum fill level of simulated propellants. The full dynamic test programme is scheduled to be completed by the end of the year.

Preparations are being made for the next tests on the thermal-model spacecraft early in 1986.

The power subsystem has been installed on the electrical integration model spacecraft and performance testing completed for both the power and telemetry and telecommand subsystems. Two of the EIM payloads have been delivered to the main payload contractor, while testing of the other two payloads has continued.

The flight-model spacecraft communications-module panels are being manufactured, and thermal equipping of the structural module prior to its delivery to the prime contractor has continued.

The final configuration review for the operational control station was held successfully in June.

Procurement activities for the test and demonstration ground stations has continued and some contracts have already been placed.

ERS-1

Detailed design of the ERS-1 satellite and its elements has continued during the past few months and is to culminate in the Development Baseline Review in October 1985. Reconfiguration of the payload equipment module has led to a delay in the start of the structural model and engineering model programmes, but it appears that the scheduled launch date can be maintained.

Work on the ground segment has also started and the Development Baseline Review for this part of the programme is scheduled for March 1986.

Preparations have started for a C-band wind scatterometer campaign over the Mediterranean in early 1986 and a campaign in late 1986 over the Brazilian rain forests to acquire essential data for the calibration approach to be followed for ERS-1.

Spacelab

Two attempts were made to launch Spacelab-2 (SL-2) aboard the Space Shuttle 'Challenger' into its 200 nautical mile circular orbit. The first attempt, on 12 July 1985, was scrubbed 3 s before lift-off when all three main engines, which had already been ignited, were shut down automatically by the Shuttle's onboard computers. This engine shut-down was caused by thermal sensors indicating a problem in one of the main engines.

The launch was rescheduled for 29 July 1985. This second attempt resulted in a circular orbit approximately 20% below the planned altitude of 200 nautical miles, due to a premature shut-down of one of the Shuttle's three main engines. This lower orbit did not affect the Spacelab/IPS verification programme, but was a disadvantage for the scientific investigations. This setback was somewhat compensated for when NASA later decided to extend the planned 7-day mission by one day.

The primary objective for SL-2 was defined as the verification of the flight-worthiness of the European-built Igloo + 3 Pallets configuration and the Instrument Pointing System (IPS). It also had very significant scientific objectives, carrying a total of 13 investigations in 7 scientific disciplines: solar physics, atmospheric physics, plasma physics, high-energy astrophysics, infrared astronomy, technology research, and life sciences. Several major new scientific instruments were introduced, while four others were making their second flights aboard the Shuttle. Several of the instruments were involved in joint investigations, observing the same phenomena with different measuring techniques.

IPS

This was also the maiden flight for the Spacelab Instrument Pointing System (IPS). After some initial operational difficulties in achieving fine pointing, which were overcome by programmable adjustments through commands sent from the ground half way through the mission, the IPS worked well within its pointing accuracy specification, using the Sun as the target. One anomaly as yet unexplained related to one of the three star trackers fitted to the Optical Sensor Package (OSP) of the IPS. This problem is being further investigated by system-level testing at KSC after unloading Spacelab-2 from the Orbiter. The cause of the anomaly may be located in the OSP or in other interfacing IPS hardware.

All other Spacelab systems performed according to specification throughout the *programme complet d'essais dynamiques sera terminé d'ici à la fin de l'année.*

Des préparatifs sont en cours pour les prochains essais sur le modèle thermique du satellite au début de 1986.

Le sous-système d'alimentation électrique a été installé sur le modèle d'intégration électrique (EIM), et des essais de performances ont été achevés pour les sous-systèmes d'alimentation électrique et de télémesure et télécommande. Deux des charges utiles de l'EIM ont été livrées au maître d'oeuvre de la charge utile, tandis que les essais des deux autres charges utiles se sont poursuivis.

Les panneaux du module de communications du modèle de vol du satellite sont en cours de fabrication, et l'équipement thermique du module structurel avant sa livraison au maître d'oeuvre s'est poursuivi.

La revue de configuration finale pour la station de commande opérationnelle a eu lieu avec succès au mois de juin.

Les activités d'approvisionnement pour les stations sol d'essai et de démonstration se sont poursuivies, et quelques contrats ont déjà été adjugés.

ERS-1

La conception détaillée du satellite ERS-1 et de ses éléments s'est poursuivie pendant ces derniers mois et doit culminer avec la revue de référence du développement prévue en octobre. Une reconfiguration du module de matériel de charge utile a entraîné un retard dans le début des programmes de modèle structurel et de modèle d'identification, mais il apparaît que la date de lancement prévue pourra être respectée.

Le travail sur le secteur terrien a également commencé, et la revue de référence concernant cette partie du programme est prévue pour le mois de mars 1986.

Les préparatifs ont commencé pour une campagne 'diffusiomètre vents' en bande C au-dessus de la Méditerranée au début de 1986, et une autre campagne à la fin de 1986 au-dessus des forêts tropicales du Brésil, en vue d'acquérir des données essentielles pour la campagne d'étalonnage prévue pour ERS-1.

Spacelab

Deux tentatives ont été faites pour lancer Spacelab-2 (SL-2) à bord de la Navette spatiale 'Challenger' sur son orbite circulaire de 200 milles nautiques. La première tentative, prévue le 12 juillet a été annulée trois secondes avant le décollage lorsque les trois moteurs principaux, qui avaient déjà été allumés, ont tous les trois été arrêtés automatiquement par les ordinateurs de bord. Cet arrêt des moteurs a été provoqué par des détecteurs thermiques signalant l'existence d'un problème dans l'un des moteurs principaux.

Le lancement a été reprogrammé pour le 29 juillet. Cette seconde tentative a permis d'atteindre une orbite circulaire située environ 20% au-dessous de l'altitude prévue de 200 milles nautiques, du fait d'un arrêt prématuré de l'un des trois moteurs principaux. Cette orbite plus basse n'a pas eu de conséquence pour le programme de vérification de Spacelab et d'IPS, mais a représenté un inconvénient pour les études scientifiques. Cet inconvénient a été quelque peu compensé ultérieurement lorsque la NASA a décidé de prolonger d'un jour la mission qui était normalement de 7 jours.

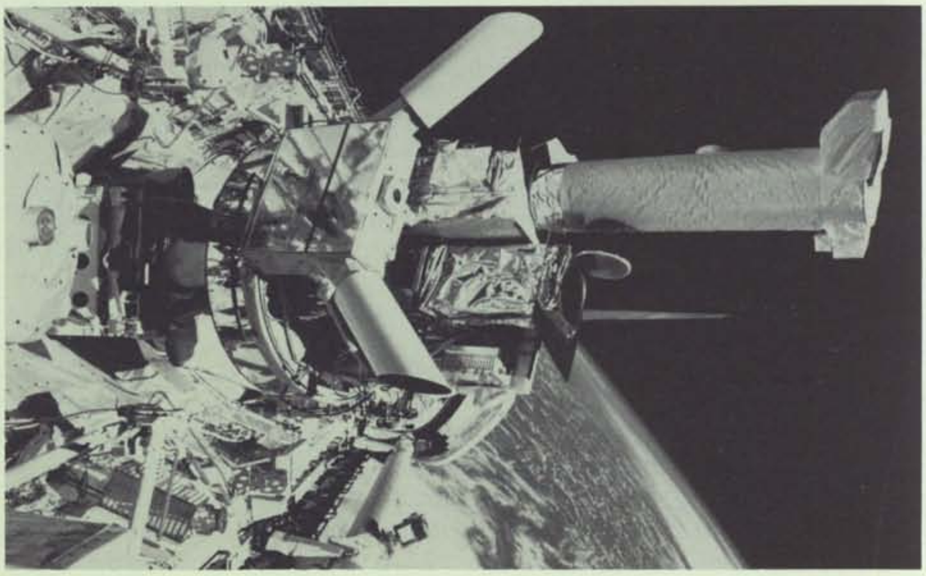
L'objectif premier de SL-2 a été défini comme la vérification de l'aptitude de vol de la configuration Igloo plus 3 palettes de construction européenne, et du système de pointage des instruments (IPS). Il avait également des objectifs scientifiques très importants, emportant un total de 13 moyens d'investigation dans 7 disciplines scientifiques: physique solaire, physique atmosphérique, physique des plasmas, astrophysique à haute énergie, astronomie infrarouge, recherche technologique, et sciences de la vie. Plusieurs nouveaux instruments scientifiques majeurs étaient introduits, tandis que quatre autres effectuaient leur second vol à bord de la Navette. Plusieurs des instruments étaient mis en jeu dans des investigations conjointes, observant les mêmes phénomènes avec des techniques de mesure différentes.

IPS

C'était le premier vol du système de pointage des instruments (IPS) du Spacelab. Après quelques difficultés initiales dans la réalisation du pointage fin, qui ont été surmontées par des réglages programmables par l'intermédiaire d'instructions envoyées à partir du sol vers le milieu de la mission, l'IPS a fonctionné avec une précision de pointage largement égale à celle prévue par les spécifications, en utilisant le Soleil comme cible. Une anomalie encore inexpliquée concernait l'un des trois suiveurs stellaires montés sur l'ensemble détecteur optique (OSP) de l'IPS. Ce problème fait actuellement l'objet de nouvelles investigations par des essais au niveau du système au Centre spatial Kennedy après déchargement du Spacelab-2 de l'Orbiteur. La cause de cette anomalie pourrait se trouver dans l'OSP ou dans un autre matériel d'interface de l'IPS.

IPS in orbit on board Spacelab-2

L'IPS monté sur Spacelab-2 en orbite



mission. The Spacelab-2 flight, in combination with the results of the Spacelab-1 mission in 1983, completes the Spacelab flight-verification programme.

Further details of the SL-2 mission, which ended on 6 August 1985 with the safe landing of the Orbiter at Edwards Air Force Base in California, can be found on pages 75 – 79 of this issue.

Follow-on-Production
Delivery of Spacelab spares under contract to NASA continues. The FOP IPS was delivered to NASA on 8 July 1985 and arrived safely at KSC on 10 July 1985. A first set of IPS spares was also accepted.

Microgravity

Biorack
A number of minor modifications to Biorack hardware have been implemented.

The D1 Spacelab Mission Sequence Test was conducted at Kennedy Space Center (KSC) during the second half of July, and Biorack operated satisfactorily. The Biorack Acceptance and Safety Compliance close-out reviews have been completed. All open work, except for the handover of the late stowage and late-access stowage, has been closed-out.

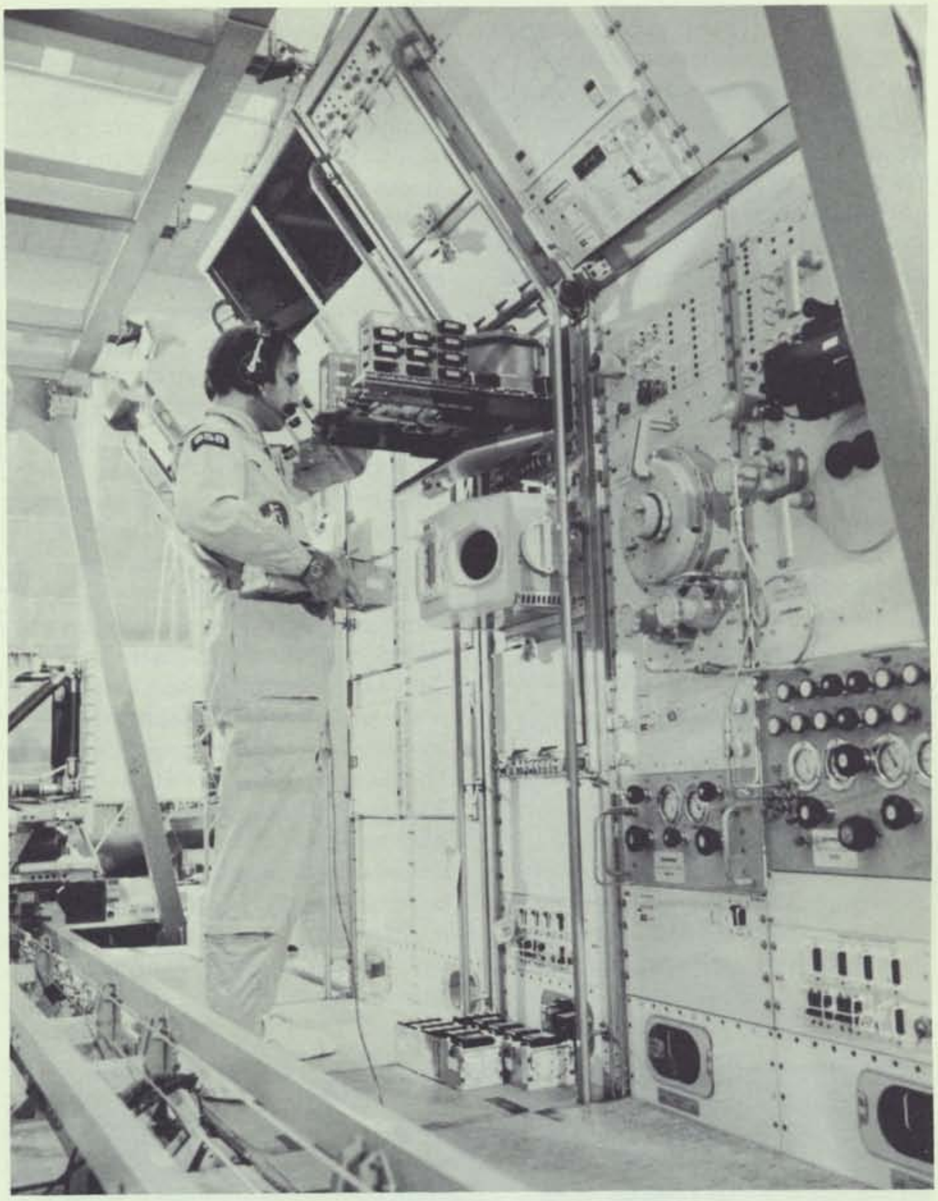
The training model, to be used for the ground-control experiments, and the pump station for the Passive Thermal Control Units (PTCUs), have been installed at the Life Science Support Facility (LSSF) at Kennedy Space Center. Two mission simulations were supported by Biorack Teams at the German Space Operations Center (GSOC) and at KSC on 8/9 August and 20/21 August. Some principal investigators participated in the second simulation. Communications, data distribution, nominal and malfunction procedures were successfully rehearsed.

The D1 Spacelab integration activities at the O&C Building have been completed and activities are progressing according to schedule for a launch on 30 October 1985 (for latest information see page 00). The landing at Dryden is now confirmed and the required measures, to guarantee that the flight experiments are returned to the experimenters within the prescribed times, have been defined.

A preliminary assessment of the accommodation of Biorack experiments for the reflight of Biorack on the IML-1 mission has been completed and distributed to the Science Peer Group members. The final selection of the experiment complement will be made at a meeting on 12 – 13 September 1985.

Progress meetings were held on 5/6 and 29 August concerning the interface with the mission integration authority (NASA Marshall Space Center).

The Investigators Working Group also met at KSC on 28/29 August.



Entraînement de W. Ockels – astronaute de l'ESA – sur le Biorack embarqué en octobre sur la mission Spacelab D1

ESA astronaut W. Ockels training with the 'Biorack' flown in October on the Spacelab D1 mission

Fluid Physics Module (FPM)
The FPM is being readied for launch on the Spacelab D1 mission. It has been successfully integrated with Spacelab and checked out. The experiment hardware has been tested and is being installed in Spacelab. Crew training has continued to enhance their proficiency in operating the FPM.

Vestibular Sled
Like the FPM, the Sled is being prepared for flight on the Spacelab D1 mission. To test experiments, critical measurements have been performed onboard an aircraft (KC135) flying parabolic trajectories to provide weightlessness for periods of about 20 s per trajectory flown.

Tous les autres systèmes du Spacelab se sont comportés conformément aux prévisions tout au long de la mission. Le vol Spacelab-2, en combinaison avec les résultats de la mission Spacelab-1 en 1983, complète le programme de vérification de vol du Spacelab.

On lira aux pages 00-00 d'autres détails de la mission SL-2, qui s'est terminée le 6 août avec l'arrivée à bon port de l'Orbiteur à la base de l'Armée de l'Air d'Edwards en Californie.

Production ultérieure

Les pièces de rechange du Spacelab sous contrat avec la NASA continuent à être livrées. L'IPS du programme de production ultérieure a été livré à la NASA le 8 juillet et est bien arrivé au Centre spatial Kennedy le 10 juillet. Un premier jeu de pièces de rechange de l'IPS a également été accepté.

Microgravité

Biorack

Un certain nombre de modifications mineures ont été apportées au matériel de Biorack.

L'essai de séquence de la mission Spacelab D1 a été mené au Centre Spatial Kennedy (KSC) pendant la seconde moitié du mois de juillet, et Biorack a fonctionné de manière satisfaisante. Les revues de clôture de recette et de conformité de sécurité de Biorack ont été achevées. Tout le travail en suspens a été parachevé, à l'exception des équipements à brève durée de vie et des expériences biologiques qui ne seront intégrés au Biorack qu'au dernier moment avant le lancement.

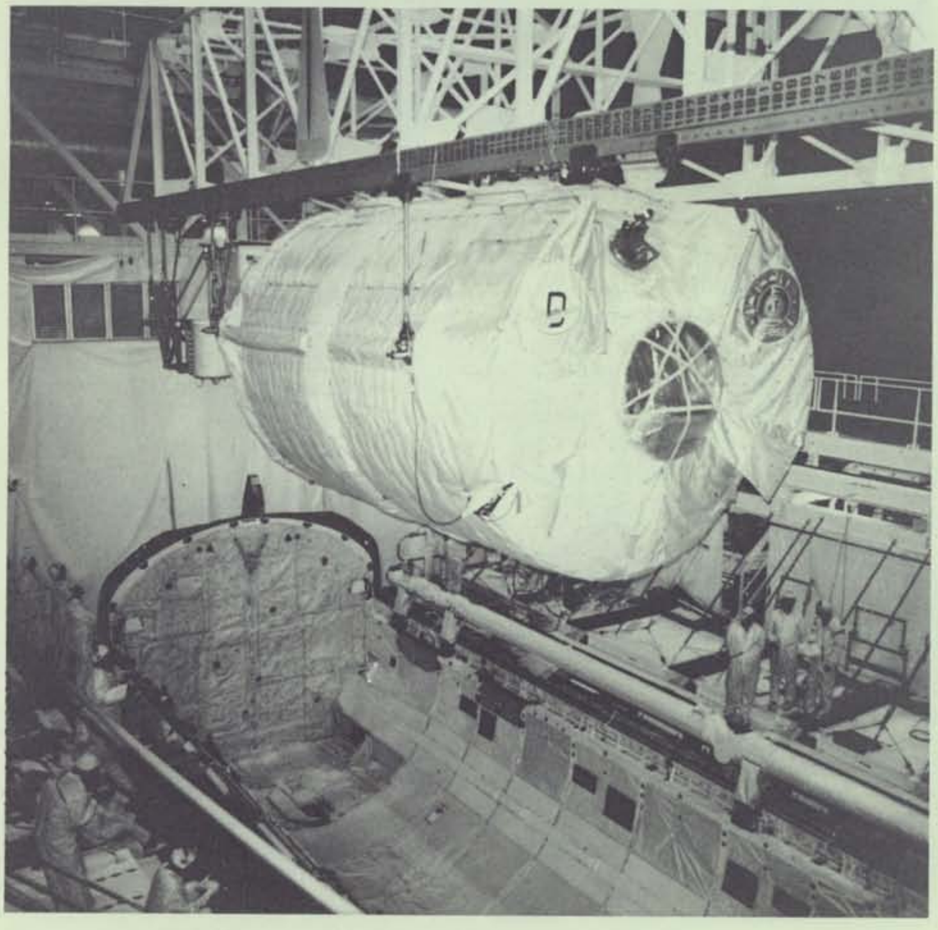
Le modèle d'entraînement, devant être utilisé pour les expériences de commande à partir du sol, et la station de pompe pour les unités thermiques passives (PTCU), ont été installés dans l'installation de soutien des sciences de la vie (LSSF) au Centre Spatial Kennedy. Deux simulations de mission ont été prises en charge par les équipes Biorack au Centre Allemand d'Opérations Spatiales (GSOC) et au KSC les 8-9 et 20-21 août. Quelques chercheurs principaux ont participé à la seconde simulation. Les procédures de communication, de distribution de données, de fonctionnement nominal et de fonctionnement défectueux ont été répétées avec succès.

Les activités d'intégration de Spacelab D1 dans le bâtiment 'Opérations & Contrôles' ont été achevées, et les travaux progressent selon le calendrier en vue d'un lancement le 30 octobre (voir page 75). L'atterrissage à Dryden est maintenant confirmé, et les mesures requises pour garantir que les expériences de vol seront rendues aux expérimentateurs dans les délais prévus ont été définies.

Une évaluation préliminaire du logement des expériences en vue d'un nouveau vol de Biorack sur la mission IML-1 (Laboratoire international de microgravité) a été achevée et distribuée aux membres du Groupe des pairs scientifiques. La sélection finale du complément d'expérience sera faite lors d'une réunion les 12 et 13 septembre.

Des réunions d'avancement se sont tenues les 5, 6 et 29 août concernant la liaison avec le Centre Spatial Marshall de la NASA, responsable de l'intégration de la mission.

Le groupe de travail des chercheurs s'est également réuni au KSC les 28 et 29 août.



Integration of Spacelab D1 and Space Shuttle 'Columbia', at Kennedy Space Center, in preparation for their October flight

Intégration de Spacelab D1 à la Navette Columbia au Centre spatial Kennedy

Entraînement des astronautes R. Furrer et W. Ockels sur le traîneau de simulation des fonctions vestibulaires en vue de la mission D1

Astronauts R. Furrer and W. Ockels training with the Vestibular Sled in preparation for the Spacelab D1 mission

A Call for Experiments for the reflight of Sled on the D2 mission has been released. At the same time, technical investigations are underway to examine potential improvements to Sled for this reflight.

Anthrorack

The Phase-B study of Anthrorack, a Spacelab double rack for the investigation of the crew's physiological behaviour under weightlessness, has been started. This facility will be developed under the leadership of Kayser-Threde (Phase-B) in Germany and Aerospatiale (Phase-C/D) in France. The Call for Experiments has resulted in a large number of experiment proposals.

Fluid Physics Double Rack (FPDR)

The FPDR will be flown as a Spacelab payload in the pressurised Module. Definition of the various elements of the FPDR – Autonomous Fluid Physics Module, Critical Point Facility, Bubble Drop and Particle Unit – has been initiated. It is intended to release the Request for Experiment Proposals before the end of the year.

Eureca

On 13 June 1985, the Phase-C/D contract for Eureca, including all of the contract appendices, was signed by ESA and MBB/ERNO in Bremen.

The Contractor Preliminary Design Reviews (CPDRs) were held for all subsystems except the thermal control subsystem, which is due in September 1985. In spite of a very tight schedule, the design baseline for Eureca has essentially been established.

The Software Architectural Design Review (SADR) was successfully held in July 1985. With the contractor reviews completed, industry is currently preparing for the Eureca Design Review (EDR), covering the entire Eureca carrier system, later this year.

An Integrated Interface Review for the payloads, with all 15 instrument developers present, was held in Bremen in June 1985. This led to agreements being established for the majority of the instruments. All Instrument Interface Agreements (IIAs) are to be finalised in the next three months.

The first Instrument Safety Review, conducted with NASA at Kennedy and Johnson Space Centers in July 1985, has been successfully completed, with no major items left unresolved.

Discussions with the user community have continued in the fields of solar physics, astrophysics, microgravity, earth resources, and technology, with a view to defining subsequent Eureca missions. Possibilities for joint ESA/NASA missions are also under investigation.

Space Station/Columbus

Five industrial contracts are underway for the major work packages of the Columbus Phase-B1 study. They are with MBB/ERNO (System Architecture), Aeritalia (Pressurised Module), British Aerospace (Platforms), Aerospatiale (Service Vehicle) and Dornier System (Resource Module). The first part of the study, culminating in the first Study Review (SR1), produced a draft system-requirements document, a reference

Maquette du module pressurisé de Columbus à Aeritalia

Mock-up of the Columbus Pressurised Module, at Aeritalia

Module de physique des fluides (FPM)
Le FPM subit actuellement des préparatifs de lancement sur la mission Spacelab D1. Il a été intégré avec succès au Spacelab et vérifié. Le matériel d'expérience a été essayé et est actuellement installé dans Spacelab. L'entraînement de l'équipage s'est poursuivi afin d'augmenter sa capacité à faire fonctionner le FPM.

Sled vestibulaire
Comme le FPM, le Sled subit des préparatifs de vol sur la mission Spacelab D1. Pour essayer les expériences, des mesures critiques ont été effectuées à bord d'un avion (KC135) suivant des trajectoires de vol paraboliques pour fournir des conditions d'apesanteur pendant des durées de 20 secondes environ par trajectoire de vol.

Un Appel aux expériences en vue d'un nouveau vol du Sled sur la mission Spacelab D2 a été lancé. En même temps, des études techniques sont en cours pour examiner les améliorations qu'il serait possible d'apporter au Sled pour ce vol.

Anthrorack
L'étude de la phase B d'Anthrorack, double baie du Spacelab permettant l'étude du comportement physiologique de l'équipage dans des conditions d'apesanteur, a démarré. Cette installation sera mise au point sous la conduite de Kayser-Threde (phase B) en Allemagne et de l'Aérospatiale (phase C/D) en France. Cet appel aux expériences a suscité un grand nombre de propositions d'expériences.

Double baie de physique des fluids (FPDR)
La FPDR sera envoyée dans l'espace en tant que charge utile du Spacelab dans le module sous pression. La définition des divers éléments du module autonome de physique des fluides, de l'installation à point critique, de l'unité 'bulles, gouttes et particules' de la FPDR, a commencé. Il est prévu de lancer l'appel aux propositions d'expériences avant la fin de cette année.

Eureca

Le 13 juin, le contrat concernant les phases C et D d'Eureca, y compris l'ensemble des annexes, a été signé par l'ESA et par MBB/ERNO à Brême.

Les revues de conception préliminaire des contractants (CPDR) ont eu lieu pour tous les sous-systèmes à l'exception du sous-système de régulation thermique, laquelle doit avoir lieu en septembre. En dépit d'un calendrier très serré, la base de conception d'Eureca a pour l'essentiel été établie.

La revue de conception architecturale du logiciel (SADR) a eu lieu avec succès en juillet. Les revues de contractants terminées, l'industrie se prépare actuellement à la revue de conception d'Eureca (EDR), couvrant l'ensemble du système porteur Eureca, qui doit avoir lieu plus tard cette année.

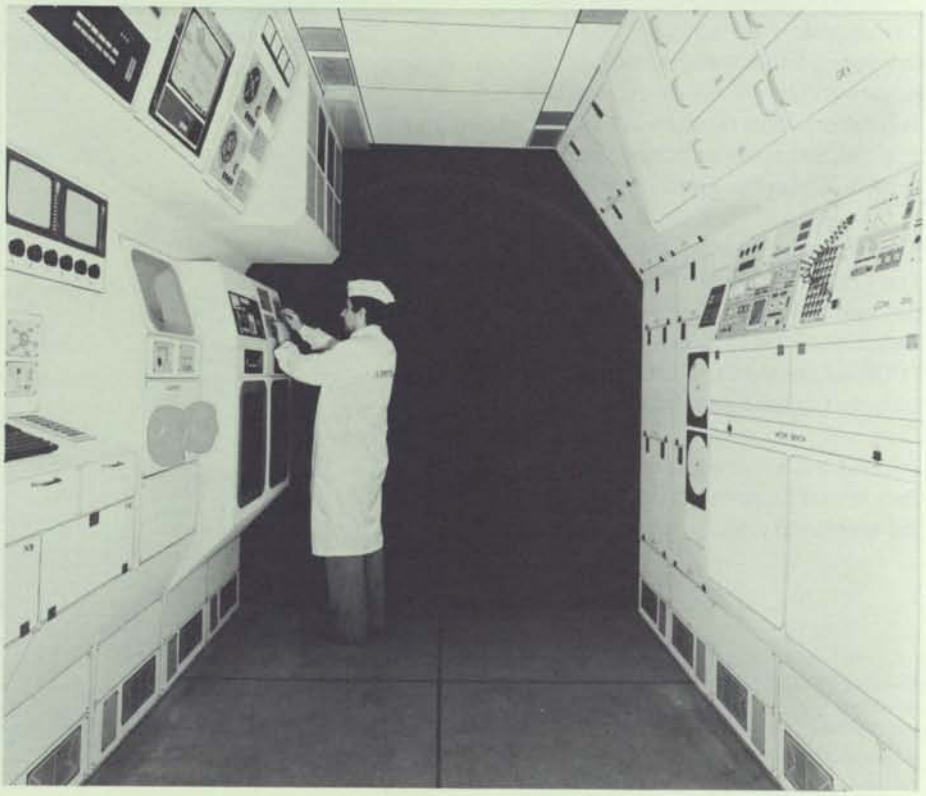
Une revue d'interface intégrée pour les charge utiles, à laquelle assistaient tous les responsables de la mise au point des 15 instruments, a eu lieu à Brême en juin. Cela a conduit à l'établissement d'accords pour la majorité des instruments. Tous les accords d'interface avec les instruments (IIA) doivent être définitivement établis dans les trois prochains mois.

La première revue de sécurité des instruments, menée avec la NASA aux centres spatiaux Kennedy et Johnson, a été achevée avec succès, aucun des problèmes majeurs ne restant sans solution.

Des discussions avec la communauté des utilisateurs se sont poursuivies dans les domaines de la physique solaire, de l'astrophysique, de la microgravité, des ressources terrestres, et de la technologie, en vue de définir des missions ultérieures d'Eureca. Des possibilités de missions conjointes ESA-NASA sont également en cours d'étude.

Station spatiale/ Columbus

Cinq contrats industriels sont en cours pour les lots de travaux majeurs de l'étude de la phase B1 de Columbus. Ils concernent MBB/ERNO (architecture du système), Aeritalia (module sous pression), British Aerospace (plates-formes), Aérospatiale (véhicule d'intervention), et Dornier System (module de ressources). La première partie de l'étude, culminant avec la première Revue d'Etude (SR1), a permis d'établir un projet



Interior of the mock-up of the Columbus Pressurised Module

Intérieur de la maquette du module pressurisé de Columbus

Les sites de lancement ELA-1 (à droite) et ELA-2 de l'ESA à Kourou. Le lanceur sur le pas de tir d'ELA-1 est un véhicule Ariane-3

The Agency's ELA-1 (right) and ELA-2 launch bases in Kourou, French Guiana. The launcher on the pad at ELA-1 is an Ariane-3 vehicle

configuration, operational scenario documents and a cost report format document. Work is now underway towards the Mid-Term Review, to be held at the end of September 1985, which will concentrate on the establishment of the Reference Configuration Document and several specific technical topics in support of meetings with NASA in October.

Switzerland, Austria and Norway have proposed participation in the Columbus Preparatory Programme, with 2%, 1% and 0.5%, respectively. The Austrian participation has already been approved by the existing Member State participants; that for Switzerland and Norway is expected soon.

Ariane

ELA-2

The acceptance procedure for the second Ariane launch site (ELA-2) started on 1 August. Once the Test Review Board had completed the task of evaluating the acceptance results for the various systems of the new launch complex, the Agency formally accepted ELA-2 for Ariane-2 and -3 launchers. The validation tests for Ariane-4 launchers are expected to be completed early next year.

This new launch site will provide Europe with a more modern and more efficient launch capability, able to handle Ariane-2, -3 and -4 launchers. The ELA-2 concept will permit two launches per month, with a limit of 10 launches per year, while simultaneously reducing the running costs.

The new complex, close to the ELA-1 launch site, consists of two separate areas, the launcher preparation area and the launch area, 1 km apart and connected by a runway. This configuration allows two launch campaigns to be conducted in parallel, while giving greater flexibility of utilisation. A launcher can be assembled in the preparation area while the previous one, transported to the launch area on a mobile table, is undergoing the final pre-launch verification.

Begun in 1981 by the Agency, ELA-2 has been completed over four years in three main phases:

- Detailed study: mid 81 – mid 82
- Construction in Guyana: mid 82 – mid 84
- Completion and validation: mid 84 – mid 85

The Agency has now handed over ELA-2 to Arianespace for commercial exploitation.

Future Ariane launches will normally use the ELA-2 launch complex, with ELA-1 being maintained as a back-up.

de document concernant les exigences du système, un document de configuration de référence, un document de scénario opérationnel et un document de format de compte rendu de coût. Le travail est maintenant en cours vers la revue de mi-durée du contrat, qui doit se tenir à la fin de septembre, et qui se concentrera sur l'établissement du document de configuration de référence et sur plusieurs sujets techniques spécifiques à l'appui de réunions qui doivent avoir lieu avec la NASA en octobre.

La Suisse, l'Autriche et la Norvège ont proposé de participer financièrement au programme préparatoire de Columbus, pour 2%, 1% et 0,5% respectivement. La participation de l'Autriche a déjà été approuvée par les actuels Etats membres participants; celle de la Suisse et de la Norvège est prévue pour bientôt.

Ariane

ELA-2

L'Agence a procédé le 1er août à la réception du deuxième Ensemble de Lancement Ariane (ELA-2) à Kourou. C'est à l'issue des travaux de la Commission de Revue des Essais, qui avait pour mission d'évaluer les résultats des acceptations des différents systèmes du nouveau complexe de lancement, que l'Agence a conclu à la réception d'ELA-2 pour les lancements Ariane-2 et -3; les essais de validation pour les lancements Ariane-4 devant s'achever début 1986.

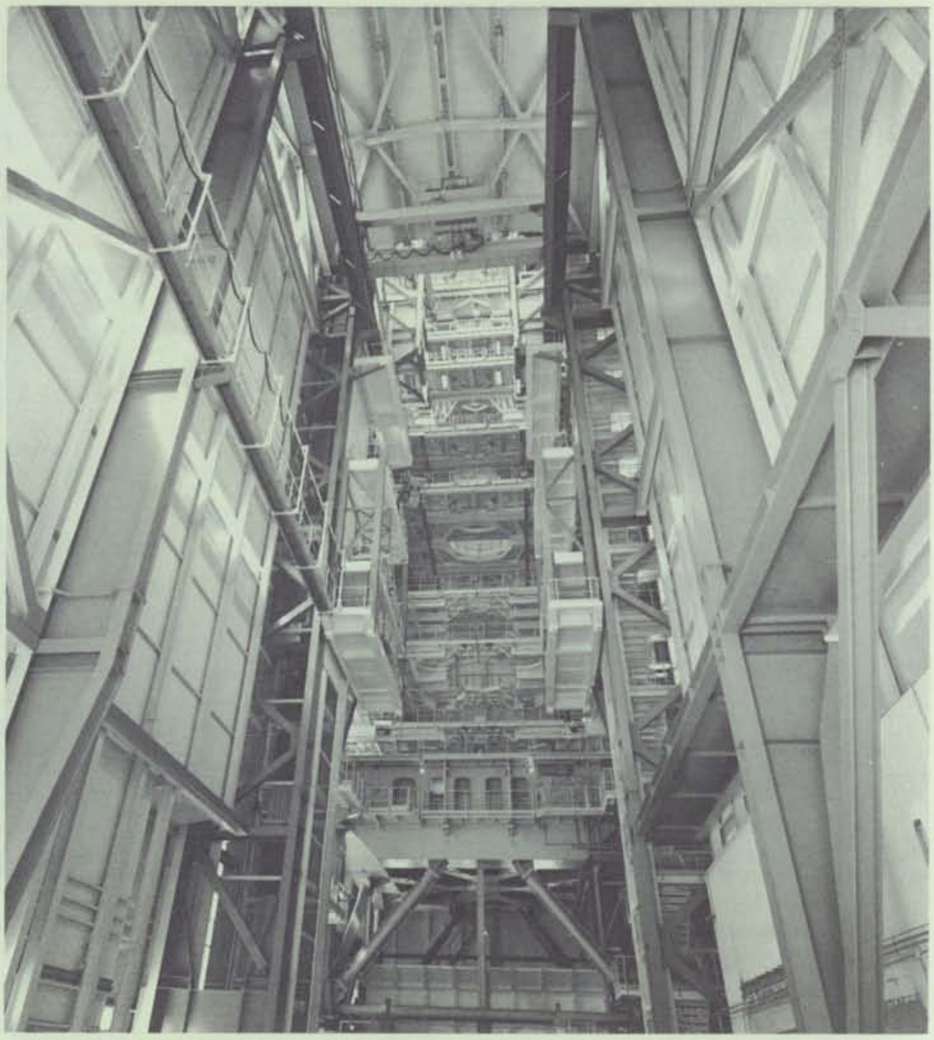
Ce nouvel ensemble de lancement dotera l'Europe de moyens plus modernes et plus performants, capables d'assurer le lancement des versions Ariane-2, 3 et 4. La conception d'ELA-2 permettra d'effectuer deux lancements à un mois d'intervalle dans la limite de 10 lancements par an et de réduire les coûts d'exploitation.

Le nouveau complexe de lancement ELA-2 réalisé à proximité de l'actuel Ensemble de Lancement Ariane (ELA-1), est constitué essentiellement de deux zones distinctes: la Zone de Préparation des Lanceurs et la Zone de Lancement, géographiquement éloignées l'une de l'autre d'un kilomètre et reliées par un chemin de roulement. Cette configuration permet de conduire deux campagnes de lancement en parallèle et de bénéficier d'une grande souplesse d'utilisation des moyens de lancement puisqu'un lanceur peut être assemblé en Zone de Préparation alors que le lanceur précédent, amené sur table mobile en Zone de Lancement, y subit les derniers contrôles avant le lancement.

Commencé en 1981 par l'Agence Spatiale Européenne, ELA-2 a été réalisé en quatre ans avec échelonnement des principales phases des travaux:
- *études détaillées: de mi-81 à mi-82*
- *réalisations en Guyane: de mi-82 à mi-84*
- *finitions et validations: de mi-84 à mi-85.*

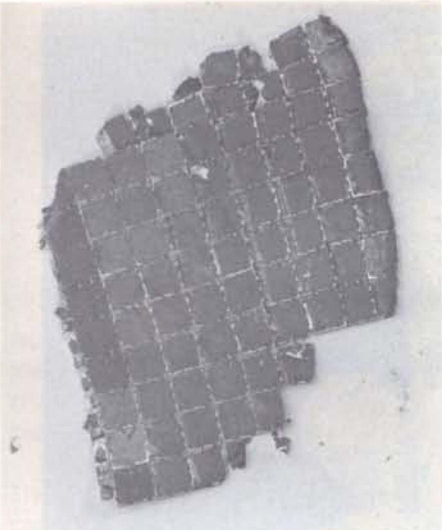
L'Agence Spatiale Européenne a mis ELA-2 à la disposition de la société Arianespace en vue de son exploitation opérationnelle.

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



Interior of the new ELA-2 launcher assembly hall in Kourou, French Guiana

Intérieur du nouveau hall d'assemblage des lanceurs d'ELA-2



Space Debris – A Hazard for the Space Station?

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Since the launch of the first artificial satellite in October 1957, man has made virtually uncontrolled use of outer space. An ever-increasing number of satellites of all kinds have been launched each year and, at the same time, numerous additional objects have been put into orbit. There are now a large number of man-made objects orbiting in near-Earth space and it becomes legitimate to ask how safe is manned spaceflight? In particular, what is the potential risk to large structures like the Space Station, which will remain in orbit for extended periods?

Only a few years have passed since it was first recognised that the safety question could become a major issue in the not too distant future. In an important paper published in 1978, the authors D.J. Kessler and B.G. Cour-Palais from NASA/Johnson Space Center analysed in detail existing and future hazards facing man-made objects in near-Earth space. The problem has since been fully recognised, and bodies like the International Astronautical Federation (IAF) and the Committee for Space Research (COSPAR) are now allocating special sessions to this subject at their meetings. NASA is also devoting an increasing amount of effort to this problem.

Effects of air drag

In most cases a launch puts not only the satellite into orbit, but also a considerable number of additional objects, such as the spent rocket casing, parts of the separation device, protective covers, etc. Although the higher atmosphere (exosphere) is extremely tenuous, at altitudes between 200 km and 500 km it is still dense enough to produce a measurable degree of air drag. This drag contracts the orbit so that, depending on the object's initial height and area-to-mass ratio, it decays after weeks, months or even years. The object eventually re-enters, usually burning up in the dense atmosphere. For higher orbits, say between 800 km and 1100 km, which are of interest for navigational satellites, for example, the air density is still measurable, but the drag now becomes so weak that the satellite's lifetime can be measured in hundreds or even thousands of years.

In the lower part of near-Earth space in particular, air drag has an efficient 'cleaning' effect, eventually removing all orbiting objects. Without this cleaning effect, it is almost certain that space would no longer be usable for manned flights. It is important to note that air drag is the *only natural mechanism* that leads to the decay of a near-Earth orbit.

Catalogued population

More than 3000 payloads have been put into orbit since 1957 and an additional 12 000 objects have also been introduced. More than 60% of the orbits have already decayed. This shows that space-population record-keeping is an important, but also an expensive task, which is currently entrusted to NORAD, the North American Aerospace Defense Command. The task is made more difficult by the fact that most of the objects are inactive and do not cooperate in their detection! Their observation therefore requires an active technique, such as radar. To track the population continuously, a large and powerful radar system is needed, together with large high-speed computers for identification and cataloguing.

There are also passive tracking methods that can be used, but only under favourable conditions. Optical tracking, for example, is feasible whilst the ground station is in darkness and the satellite is still sunlit, but such conditions exist only at dusk and at dawn.

NASA regularly publishes a 'Satellite Situation Report', based on data provided by NORAD. It is the only catalogue listing

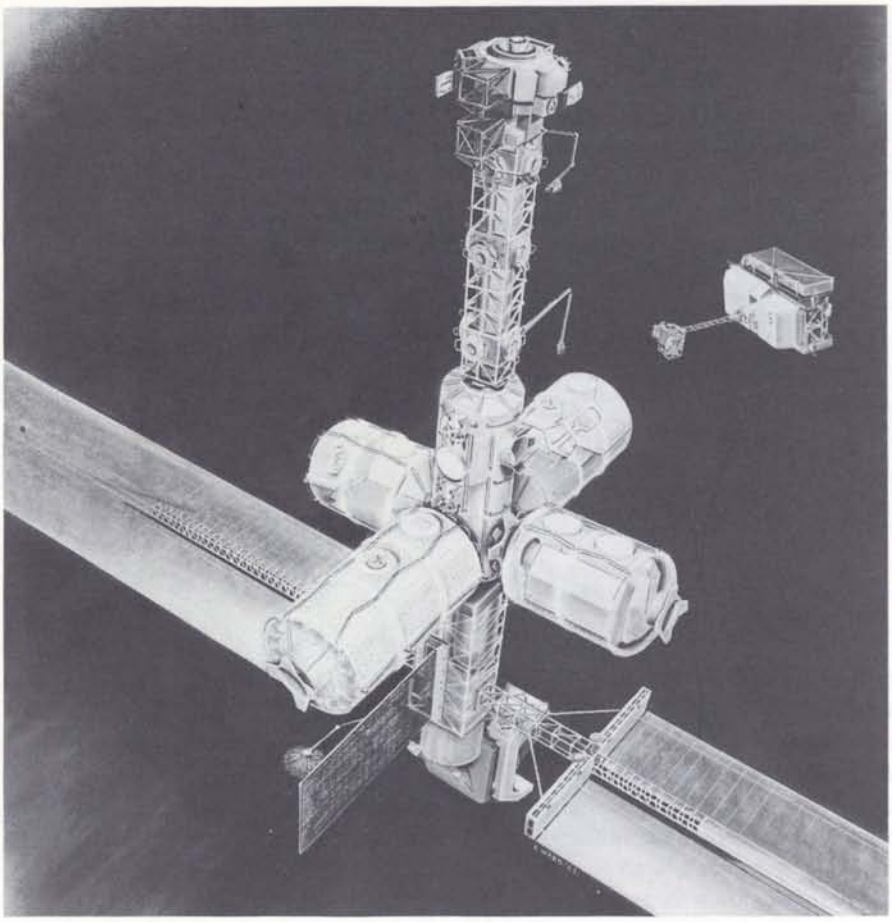


Figure 1 – The Space Station

most of the observable space objects. The December 1984 issue shows that at the end of that year 5408 objects were in orbit, whereas 10 078 objects were reported 'decayed'. The types of objects still in orbit can be classified approximately as follows:

Operational payloads	5%
Nonoperational payloads	20%
Mission-related objects	25%
Satellite breakups	50%

The first surprise here is that only 5% of all orbiting objects are active satellites, and that the great majority are 'dead' items. The second is that half of the objects have been created by satellite breakups! More than eighty such breakups have been recorded, each creating some tens to several hundreds of smaller pieces. Accidental breakups are mostly propulsion-related. A number of Delta second stages have exploded, for example, some of them months or years after injection. These explosions can be avoided by venting the residual fuel. Deliberate destruction has been observed with Russian reconnaissance satellites which have encountered recovery or other problems, a recent case being Cosmos 1654, which blew up on 21 June. In some cases, the cause of a breakup is unclear, and the question of whether it was due to a catastrophic collision arises.

Uncatalogued objects
The NASA catalogue is reasonably complete for objects larger than about 10 cm, since smaller objects, which are of only secondary interest to NORAD, cannot be tracked with most existing radars. Special studies have shown that there is indeed a considerable amount of debris smaller than 10 cm.

It has to be concluded therefore that there is a significant uncatalogued population of debris. The size of this population is unknown and only 'reasonable' guesses are possible. The number of objects between 1 cm and 4 cm in size may be 3 to 10 times the known population. This is a very unsatisfactory state of affairs, because an object 4 cm in diameter could have a mass of 100 g. In view of the high relative velocities involved, which are of the order of 10 km/s, the impact of such a small object on a satellite or abandoned rocket stage may be catastrophic, creating a large number of secondary objects, and thereby having far-reaching repercussions.

How can the situation be improved? There is already a new generation of optical sensors for ground stations which are able to detect objects as small as 1 cm across. NORAD is therefore constantly refining its observation system, but with the primary objective of tracking objects more than 6000 km from Earth. One alternative is observation from space, where active methods based on radar or lidar can be used. In both cases, objects between 1 cm and 10 cm across can be detected, but the mass and power requirements are relatively high. A simpler and more efficient method would be passive optical tracking. There are so far no known plans for the implementation of such sensors, but they could form an additional payload on a satellite designed primarily for some other near-Earth mission.

Growth of the population
The Satellite Situation Reports show that the number of observable objects is steadily increasing. During the last ten years the number of recorded objects has grown by more than 2200, the annual growth rate being in excess of 200 objects/year. The primary source of new objects is new launches, which for several years now have been almost constant at 120 to 130 launches per annum. About two per week of these are of Russian origin. Bearing in mind that several associated objects go into orbit with each spacecraft launch, the result is many hundreds of new objects each year. Hence, despite the natural decay of 400 to 500 objects each year, there is currently an annual net increase in the population.

With the increasing amount of debris, including the presently unobservable smaller objects, another source will begin to play a role, namely fragmentation of existing orbiting objects by collision. The debris spectra of such hypervelocity impacts are not precisely known, but the number of objects will certainly be increased considerably.

Such collisions could lead to a self-regeneration of the debris population, representing a great hazard for future manned spaceflight. Certain regions of near-Earth space could eventually become unusable.

The evolution of the debris population can, of course, be modelled on a computer. Several such models have already been developed using 'realistic' assumptions. However, there is the problem of deciding what is 'realistic', until the following fundamental questions can be satisfactorily answered:

- What is the evolution of the population of unobservable objects?
- How many items and what size of debris is created by satellite breakups?
- How much and what size of debris is created by hypervelocity collisions?

What we can do already is to compare the influences of various optimistic or pessimistic assumptions, in order to set limits on the possible evolution in population, estimate the risks, and gauge the efficiency of proposed countermeasures. However, what we urgently need are ground-based and space-based systems and appropriate studies to gather the requisite facts and data.

Reducing the hazard

There is already a small but finite collision probability for large structures (100 m), even taking into account only the tracked population of orbiting objects. It seems, therefore, to be time to think about appropriate measures to avoid aggravating the situation. Considering the main sources of debris, it is already possible to identify certain measures that will have a beneficial effect by slowing down or even halting the growth in the debris population. Some of these are even relatively easy to implement via spacecraft design changes or by improving operational procedures:

- minimising the number of objects at separation
- de-orbiting large satellites at the end of their useful lifetimes so that they re-enter
- depleting the residual fuel of the launcher's final stages to prevent subsequent explosions
- conducting satellite-destruction tests at low altitudes, so that the debris decays rapidly.

Some of these measures are now being applied; for example, the Soviet Salyut stations that are no longer used are commanded to re-enter, and the second stages of the American Delta launch vehicles are vented.

Conclusion

The question of what hazard space debris represents for a larger Space Station cannot yet be answered satisfactorily. It is only known that such a hazard exists and that it is increasing. Too many effects are not sufficiently understood and much more effort is required. Ground-based or in-orbit observations with advanced sensors, which have still to be developed, are called for. At the same time, an effort to model the evolution of the debris population is necessary, in order to study the influence of various parameters and to assess the efficiency of proposed countermeasures. One thing is certain: it is of the utmost importance to reduce the growth of the debris population, and some of the simpler countermeasures could and should be implemented immediately.

IN MEMORIAM

Ernst A. Roth 1921–1985

The sad news of the passing away of our friend and colleague Ernst A. Roth came on 4 October.

Dr. Roth was a mathematics graduate of the Swiss Federal Institute of Technology in Zürich, where he also obtained his PhD. He joined ESRO/ESA in January 1966, and shortly afterwards was appointed Head of the Section of Theoretical Research. In 1971, he was made Head of the Spacecraft Trajectory Division and had been Head of the Mission Analysis Office since January 1981.

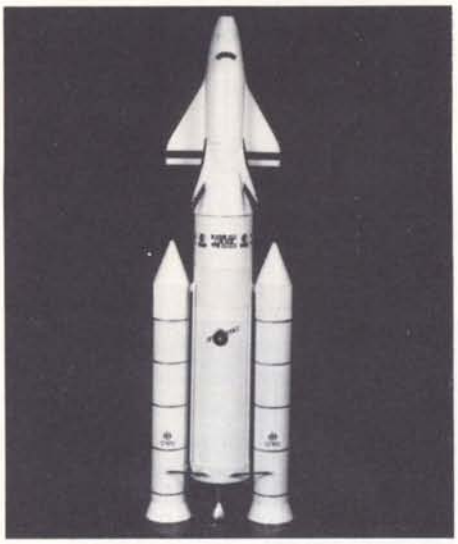
In all these functions, Dr. Roth made major contributions to the successes of the Agency. In particular, as an enthusiastic supporter and advocate of space activities, he played an important role in the concept and design phases of many ESRO/ESA missions. His practical attitude, combined with a solid theoretical foundation, led to international recognition, his advice frequently being sought on many of the more difficult aspects of space dynamics. Numerous publications and contributions to international meetings give evidence of his extensive work in celestial mechanics.

He was regularly invited to participate in the Oberwolfach Conference on Celestial Mechanics and was Chairman of one of the astrodynamics sessions at the annual congress of the International Astronautical Federation.

More recently, he had become very interested in the problems of satellite collision, space debris and crowding of the geostationary orbit. In September 1985, he organised a Workshop at ESOC on Re-entry of Space Debris, which his illness sadly precluded him from attending.

He helped many young people entering the space field, and post-graduates often found inspiration as Visiting Scientists within his group. He also lectured regularly on spaceflight dynamics at Darmstadt's Technische Hochschule.

Ernst Roth will be remembered by his friends and colleagues as a man of great experience who contributed much to space dynamics, and who was always willing to help others with his much-valued expertise.



Développement du grand moteur cryotechnique HM60 (Vulcain)

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L'évolution des besoins en systèmes spatiaux tant géostationnaires que sur orbites basses et la nécessité de réduire les coûts de lancement ont conduit à définir le futur lanceur Ariane-5 qui permettra à l'Europe de confirmer sa capacité et sa compétitivité de lancement à partir de 1995.

Introduction

Les différentes configurations et performances du lanceur Ariane-5 dans le concept retenu (Ariane-5P) sont présentées par la Figure 1. Toutes les versions du lanceur ont une partie commune comprenant l'étage central cryotechnique H120 (120 t d'hydrogène et d'oxygène liquides) et deux propulseurs à ergol solide P170 (170 t d'ergol chacun). Les versions du lanceur se différencient ensuite par l'adjonction d'un étage supérieur soit à moyenne énergie du type L4 (4 t d'ergols stockables) soit à haute énergie du type H10 (10 t d'hydrogène et d'oxygène liquides).

Au cours des études de lanceurs futurs, toutes basées sur l'utilisation d'ergols cryotechniques, et ayant finalement conduit au choix de la configuration d'Ariane-5, la nécessité est apparue de développer un moteur cryotechnique de forte puissance du type HM60 (60 t de poussée). Les études préliminaires de conception d'un tel moteur ont alors été engagées dès 1980 sur les plans nationaux en France (SEP), en Allemagne fédérale (MBB-ERNO) et en Suède (Volvo) en vue de préparer le dossier de développement au plan européen.

Les études de définition du lanceur ont ensuite conduit à établir les principales spécifications de dimensionnement de la version du moteur HM60, également appelé 'Vulcain', devant équiper l'étage central H120. Ces études ont également montré que parmi les éléments du lanceur, ce grand moteur cryotechnique HM60 (Vulcain) exige le plus long délai de développement ainsi que la construction de nouveaux moyens d'essais.

Afin de pouvoir tenir l'objectif de qualification au sol du moteur en fin 93/début 94, le programme européen de développement a alors débuté dès la fin de 1984 au titre d'un 'programme préparatoire' et par anticipation au développement du lanceur Ariane-5 proprement dit.

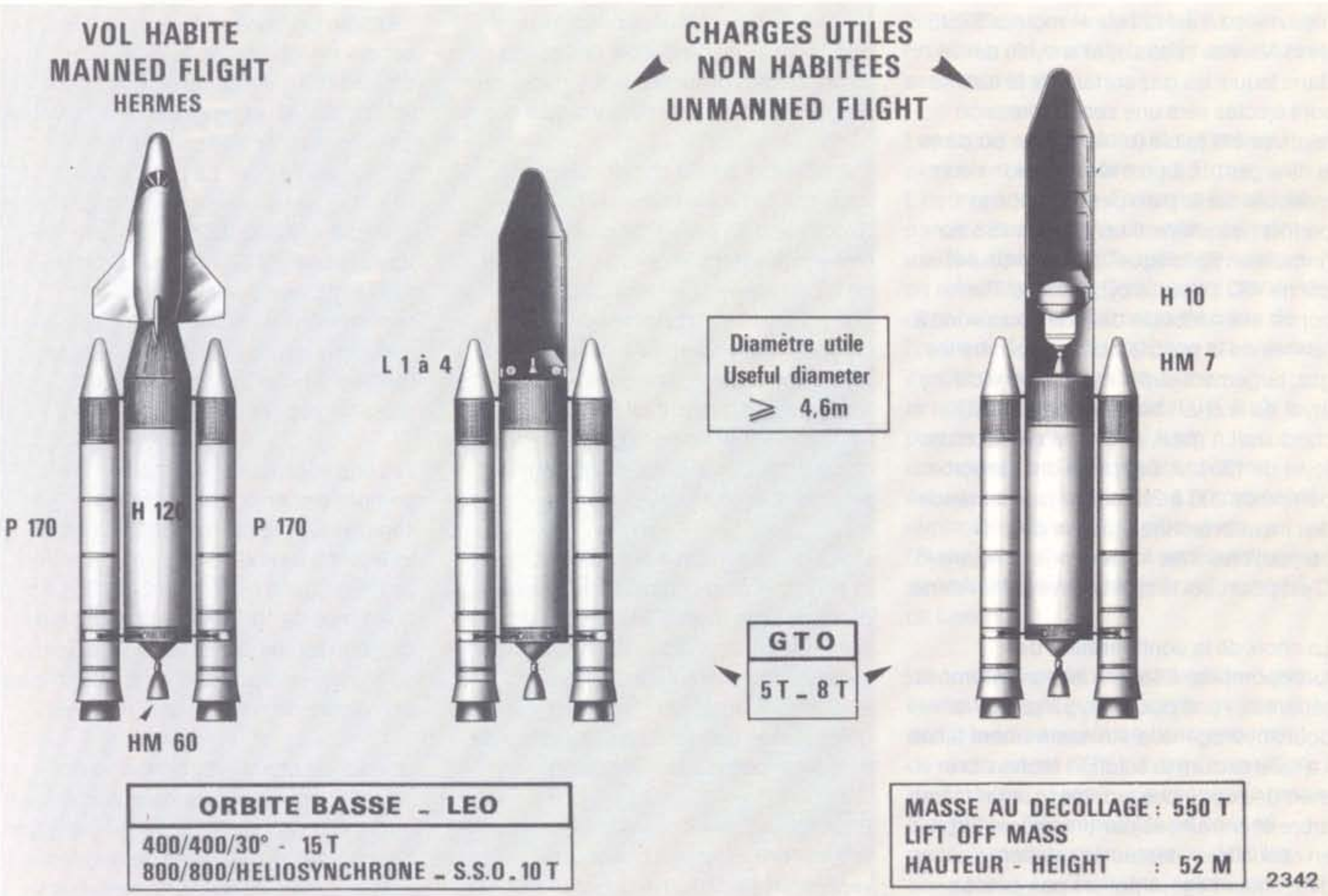
L'Agence spatiale européenne assure la direction d'ensemble du programme et délègue au Centre national d'Etudes spatiales (CNES) la direction technique et la gestion financière.

Le présent article expose les principaux éléments concernant:
- la genèse du programme
- les grandes options techniques retenues pour le moteur
- la description et les performances de la configuration retenue
- les caractéristiques techniques et les performances des nouveaux moyens d'essais
- le plan de développement du programme
- l'organisation industrielle correspondante.

Genèse du moteur HM60 (Vulcain)

La famille Ariane a été conçue selon une stratégie générale consistant à permettre des gains de performance (masse et volume des charges utiles) en introduisant des modifications successives à un modèle de base (Ariane-1). Cette approche a conduit à la famille des lanceurs Ariane-1 à 4. La version Ariane-5 a évolué avec le temps, s'écartant de cette

Figure 1 – Configurations et performances d'Ariane-5



philosophie avec l'évolution des besoins des charges utiles et compte tenu d'analyses de coût de plus en plus précises. Les études initiales, commencées en 1978, visaient un lanceur dérivé du lanceur Ariane-4 en remplaçant le deuxième étage à propergols stockables par un étage cryotechnique et en ajoutant un 5ème moteur au premier étage. La poussée du nouveau deuxième étage devait être de 50 à 80 t dans le vide.

En 1983, la performance demandée avait augmenté à 4,5 t en orbite de satellite géostationnaire (GEO) et à 15 t en orbite terrestre basse (LEO). Parmi les trois concepts étudiés à savoir A5-R (dérivé d'Ariane-4), A5-C (tout cryotechnique) et A5-P, le choix s'est porté à la mi-84 sur cette dernière configuration, ceci sur la base d'analyses comparatives en matière de performance, de fiabilité, d'aléas techniques et calendaires, ainsi que de coûts de développement et de fabrication.

Dans ce concept la poussée du moteur cryotechnique est de 100 t dans le vide. La désignation de 'HM60' longtemps utilisée auparavant (moteur commun à toutes les configurations Ariane-5 étudiées) a toutefois été conservée pour des raisons de commodité.

Les grandes options technologiques retenues pour le moteur

La définition du moteur a exigé des choix importants fondés sur des analyses de système.

Le premier choix a été celui de la **pression de chambre.** Elle doit être aussi haute que possible de manière à limiter la masse et les dimensions de la chambre. Une pression haute nécessite toutefois des pressions de sortie de pompe élevées, ce qui conduit à des pompes complexes (pompes à plusieurs étages, problèmes de joints et de comportement dynamique) et à des problèmes de transfert de chaleur (refroidissement de chambre). Après des études d'optimisation une pression de chambre relativement modérée a été choisie (100 bar), ce qui était compatible avec une conception de pompe hydrogène à deux étages et de pompe oxygène mono-étage. Cette pression est également voisine de l'optimum de fonctionnement du cycle dérivé dont il est question ci-après.

En parallèle a été effectué un second choix relatif au **cycle du moteur.** Deux cycles étaient en compétition: le cycle à combustion étagée, dans lequel les gaz entraînant les turbines sont ensuite injectés dans la chambre de combustion (comme cela est fait sur le moteur SSME de la Navette spatiale) et le cycle dérivé dans lequel les gaz sortant de la turbine sont éjectés vers une zone à pression relativement faible (à l'ambiante ou dans le divergent). La première solution est la meilleure sur le plan performance et permet typiquement un gain de 15 s sur l'impulsion spécifique* soit environ 445 s contre 430 s pour le cycle dérivé. Par contre elle nécessite de fortes pressions à l'entrée de la préchambre qui génère les gaz, largement supérieures à celle du foyer de la chambre principale. Ceci conduirait à avoir, pour une pression de foyer de 100 bar, des pressions de sortie pompe de 200 à 250 bar ce qui demande des travaux technologiques peu compatibles avec le calendrier d'Ariane-5. C'est pourquoi le cycle dérivé a été retenu.

Le choix de la **configuration des turbopompes,** à savoir des turbopompes séparées, l'une pour l'oxygène, l'autre pour l'hydrogène, a été relativement facile. Il a fallu exclure la solution monoarbre avec deux pompes montées sur un même arbre et entraînées par une même turbine en raison des vitesses de rotation différentes exigées par les pompes. La solution à deux pompes liées par un engrenage (comme sur le HM7) a été exclue du fait de la forte puissance que cet engrenage aurait à transmettre. La solution à deux turbopompes séparées a donc été adoptée.

Il a également été retenu **d'alimenter les deux turbines** à partir d'un générateur unique pour des raisons de masse, de coût et de fiabilité. Il a fallu de plus définir si les turbines devaient être alimentées en parallèle ou en série. Bien que le montage en série présente un petit avantage en performances, il nécessite des travaux de mise au point supplémentaire puisque sur le moteur les turbopompes ne fonctionnent pas indépendamment et qu'il faudrait en particulier des essais de turbopompes groupées pour mettre au point la séquence de démarrage.

Par ailleurs il a fallu décider si les gaz issus des turbines devaient être éjectés directement à l'ambiante ou s'ils devaient être injectés dans le divergent du moteur de façon à éviter des recirculations de gaz au voisinage du moteur et à contribuer à la fourniture de la poussée. L'injection dans le divergent a été abandonnée lorsqu'il fut établi que l'accroissement de complexité n'était pas compensée par le gain, trop faible, en sécurité et en performances.

Un choix important a été aussi de munir la chambre de **dispositifs atténuateurs d'oscillations** dues à des instabilités de combustion, ceci dès la conception du moteur. Un programme de travail approfondi, aussi bien théorique qu'expérimental, doit alors permettre de minimiser ces risques d'instabilité.

Enfin, les optimisations au niveau système lanceur ont conduit à choisir une impulsion spécifique du moteur de 430 s (conditions de vide) et un rapport de mélange de 5,1 (rapport des débits massiques oxygène sur hydrogène).

Sur un plan général il est important de noter que ces choix et ceux qui résulteront de la conception détaillée du moteur sont guidés par les lignes directrices suivantes:

- Coût de production minimum
- Fiabilité et aptitude à la maintenance et à la mise en oeuvre
- Coûts et délais de mise au point minimaux (méthodes de l'analyse de la valeur et de la conception à coûts objectifs)
- Performances au delà du nominal exigé.

Description du moteur et performances

Le moteur (Fig. 2) a une hauteur d'environ 2,9 m et son diamètre dans le plan de sortie de la tuyère est d'environ 1,8 m. Sa poussée spécifiée dans les conditions vide est de 1025 kN (soit environ 100 t). Alimenté en hydrogène liquide à 21 kN et en oxygène à 91 K sous une pression de 3 bar, il consomme 241,6 kg/s d'ergols. La pression dans la chambre de combustion est de 100 bar et la température de 3500 K. La durée de fonctionnement en vol est environ 500 s mais le moteur devra avoir une endurance d'au moins 600 s. La masse maximale spécifiée est de 1100 kg. Le schéma fonctionnel du moteur est présenté par la Figure 3.

Les ergols alimentant le moteur sont pompés par deux **turbopompes séparées.** La turbopompe hydrogène tournant à 34 850 t/mn élève la pression de l'hydrogène à 159 bar et fournit une puissance de 10,7 MW. La turbopompe oxygène fournit une pression d'oxygène de 130 bar une puissance de 2,8 MW pour une vitesse de rotation de 13 070 t/mn.

Le rotor de chaque turbopompe est monté sur des paliers à billes refroidis par l'ergol circulant dans la pompe. Les joints d'étanchéité dynamiques de ces rotors sont du type à bague flottante ou labyrinthes. Une attention particulière est portée aux études d'équilibrage dynamique des rotors et du comportement lors des transitoires de démarrage.

Les turbopompes sont entraînées par des turbines alimentées par un **générateur de gaz** qui fournit 8 kg/s de gaz sous une pression de 80 bar et une température de 900 K, lui-même alimenté à partir d'ergols prélevés en sortie de pompes. Ce générateur est une véritable chambre de combustion: son débit (8 kg/s) est du même ordre de grandeur que le débit de la chambre principale du moteur HM7 du 3ème étage des Ariane-1 à 4.

Son corps, non refroidi, est réalisé en Inconel et son injecteur fait l'objet de travaux en tout point similaires à ceux de l'injecteur de chambre principale, aussi bien en ce qui concerne le rendement de

* L'impulsion spécifique est l'indice de mérite de la performance du propergol et de l'efficacité de son utilisation: c'est le nombre de kilos de poussée que l'on obtient pour chaque kg/s de débit le propergol éjecté.

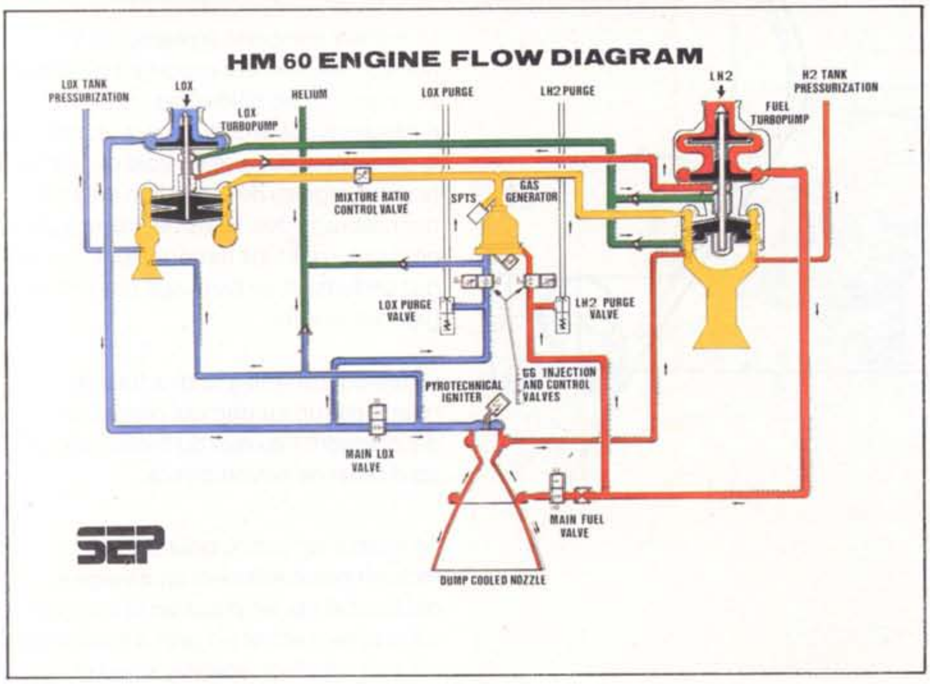


Figure 2 – Le moteur HM60

Figure 3 – Schéma fonctionnel du moteur

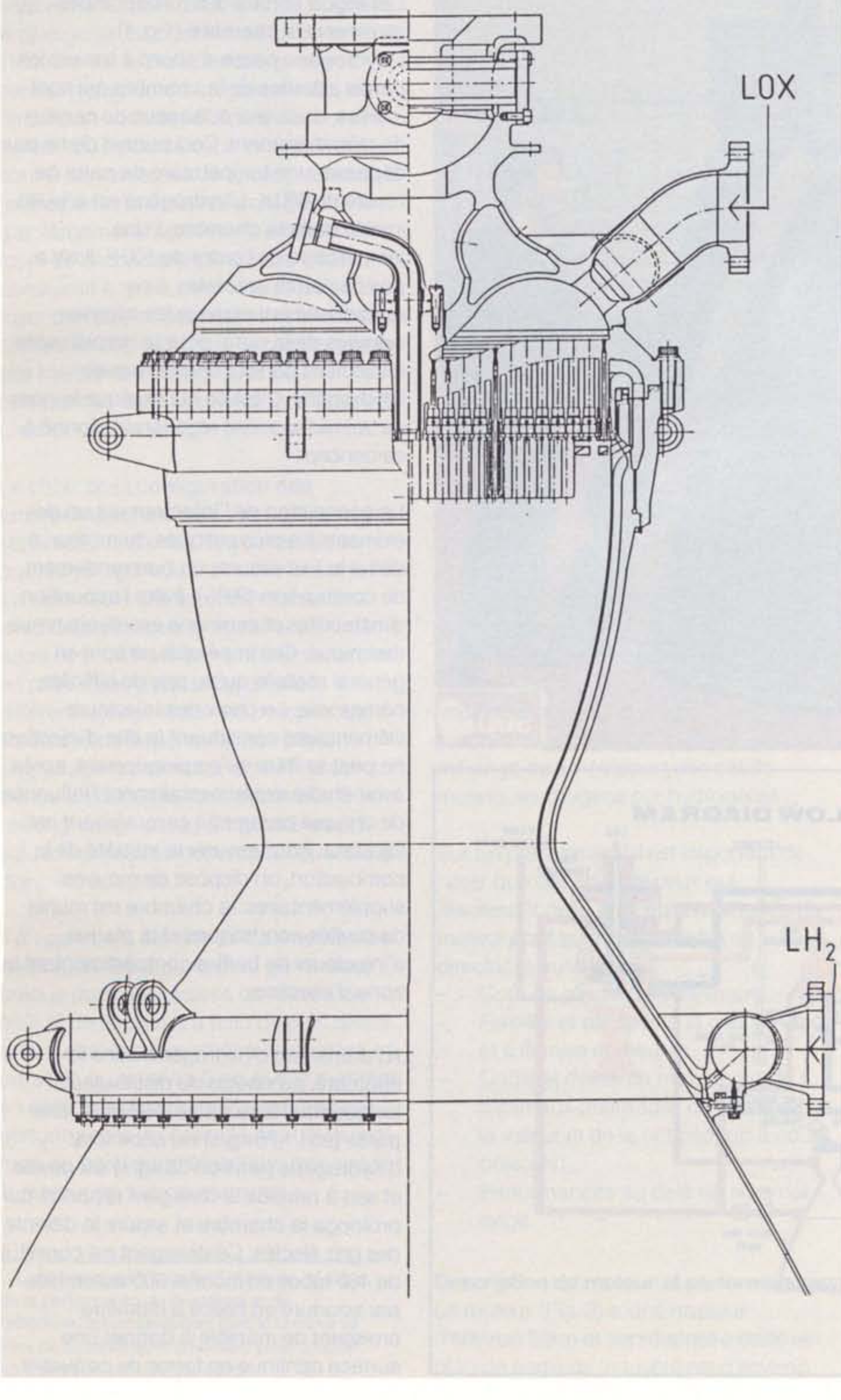
combustion que la stabilité. En particulier l'injecteur est muni de cavités acoustiques amortissantes.

Les ergols sortant des turbopompes alimentent la **chambre** (Fig. 4). L'hydrogène passe d'abord à travers les parois externes de la chambre qui sont munies, dans leur épaisseur, de canaux de refroidissement. Ceci permet de ne pas dépasser une température de paroi de l'ordre de 600 K. L'hydrogène est ensuite injecté dans la chambre à une température de l'ordre de 100 K. Il n'y a pas de pertes associées à ce refroidissement puisque les calories extraites de la paroi pour la refroidir sont réinjectées dans la chambre avec l'hydrogène. C'est ce qui explique le nom de 'refroidissement régénératif' donné à ce concept.

La conception de **l'injecteur** est un des éléments les plus critiques du moteur. Il doit à la fois assurer un bon rendement de combustion (99%), éviter l'apparition d'instabilités et avoir une excellente tenue thermique. Ces impératifs ne sont en général réalisés qu'au prix de difficiles compromis. Le choix des injecteurs élémentaires constituant la tête d'injection ne peut se faire qu'empiriquement, après avoir étudié expérimentalement l'influence de chaque paramètre caractérisant cet injecteur. Pour assurer la stabilité de la combustion, on dispose de moyens supplémentaires: la chambre est munie de cavités acoustiques et la plaque d'injecteurs de baffles compartimentant la zone d'injection.

A l'admission d'hydrogène dans la chambre, au niveau du distributeur torique situé à sa partie inférieure, une partie (soit 1,75 kg/s) du débit total d'hydrogène (environ 35 kg/s) est déviée et sert à refroidir le divergent rapporté qui prolonge la chambre et assure la détente des gaz éjectés. Ce divergent est constitué de 460 tubes en Inconel 600 assemblés par soudure en hélice à diamètre croissant de manière à donner une surface continue en forme de coquetier.

Figure 4 – Vue schématique de la chambre de combustion



L'hydrogène de refroidissement traverse ces tubes et est rejeté vers l'ambiante dans la section de sortie du divergent en contribuant à fournir de la poussée. La perte de ce fluide explique la désignation de 'dump-cooling' donnée à ce mode de refroidissement. Ce divergent permet d'assurer aux gaz un rapport de détente de 330.

Le moteur est équipé de deux types de **systèmes pyrotechniques:**
- les allumeurs destinés à la mise à feu du générateur de gaz et de la chambre principale. Leur conception est dérivée de celle utilisée sur la chambre HM7. Leur rôle est d'envoyer un jet de gaz chauds par la partie centrale des injecteurs à des instants précis de la séquence de démarrage du moteur;
- le démarreur qui est un générateur de gaz à poudre 'froide' (de l'ordre de 1200°C) destiné à lancer les turbopompes au démarrage jusqu'à une vitesse de l'ordre du tiers ou de la moitié des vitesses nominales de rotation. L'allumage du générateur fournit ensuite les gaz qui font accélérer les turbopompes jusqu'aux vitesses nominales.

Le moteur comporte également un nombre relativement important de **vannes** pour assurer les différentes fonctions d'injections des ergols dans la chambre et le générateur de mise en froid des lignes (vannes ergols), de régulation de débit par calibrage des débits de gaz chaud du générateur vers les turbopompes (vannes gaz chauds) et de balayage des circuits (vannes hélium).

Le moteur est relié à la structure de l'étage par un cardan qui permet un débattement maximal du moteur de ±6° sous l'effet de servomoteurs.

Le moteur est conçu pour pouvoir recevoir éventuellement un divergent déployable qui ferait passer la longueur à 4,5 m et permettrait un gain d'environ 20 s sur son impulsion spécifique en vol.

Caractéristiques techniques et performances des moyens d'essais
L'architecture du moteur à 'flux dérivé' offre l'avantage de pouvoir essayer séparément les sous-systèmes importants du moteur. Toutefois les niveaux de débit, pression et poussée excédant largement les capacités des bancs actuellement disponibles en Europe, de nouveaux moyens d'essais doivent être créés.

Les moyens d'essais principaux concernent les bancs turbopompes, chambre et moteur; on peut aussi mentionner le banc-générateur de gaz. Les essais de l'étage complet en configuration de vol sont directement prévus sur la table de lancement ELA-3 en Guyane.

Un nombre important d'autres bancs d'essais (bancs technologiques) sont nécessaires pour la caractérisation des composants et des équipements du moteur.

Moyens d'essais principaux
Le banc d'essais turbopompes
Le banc d'essais turbopompes appelé PF52 sera construit sur le site de la SEP à Vernon (Fig. 5) afin de permettre la réalisation des essais de mise au point, de caractérisation et de qualification des turbopompes oxygène et hydrogène liquides en position de lancement (position 'verticale'). Les turbopompes pourront être alimentées soit indépendamment à partir d'une source d'hydrogène gazeux à haute pression ou d'un générateur de gaz alimenté par des réservoirs d'hydrogène et d'oxygène liquides à haute pression, soit couplées avec le générateur de gaz à partir des ergols prélevés en sortie des pompes.

En sortie des turbopompes, l'oxygène liquide sera récupéré dans un réservoir tandis que l'hydrogène sera brûlé à l'état gazeux.

La durée d'un essai sera d'environ 100 s suivant la configuration d'essai, les essais de longue durée étant reportés au niveau moteur.

Le banc d'essais Chambre
Le banc d'essais chambre appelé P3.2 sera construit sur le site du DFVLR à Hardthausen (RFA) afin de permettre les essais de caractérisation et de qualification de la chambre de combustion du moteur en position horizontale (Fig. 6).

Les essais seront normalement effectués à pression atmosphérique correspondant aux conditions d'allumage du moteur au sol. Toutefois les mesures sont prises au niveau de la conception du banc pour pouvoir implanter un dispositif de simulation d'altitude permettant les essais de versions de moteur soit allumé au sol avec divergent déployable, soit allumé dans le vide avec divergent à grand rapport de section.

La durée des essais sera de 15 à 25 s selon le point de fonctionnement, les essais de longue durée étant reportés, comme pour les essais turbopompes, au niveau moteur.

Les bancs d'essais Moteur
Compte tenu du nombre important d'essais de moteurs qui doivent être réalisés pendant la phase de développement (environ 80 essais par an) et pour des raisons de sécurité, la

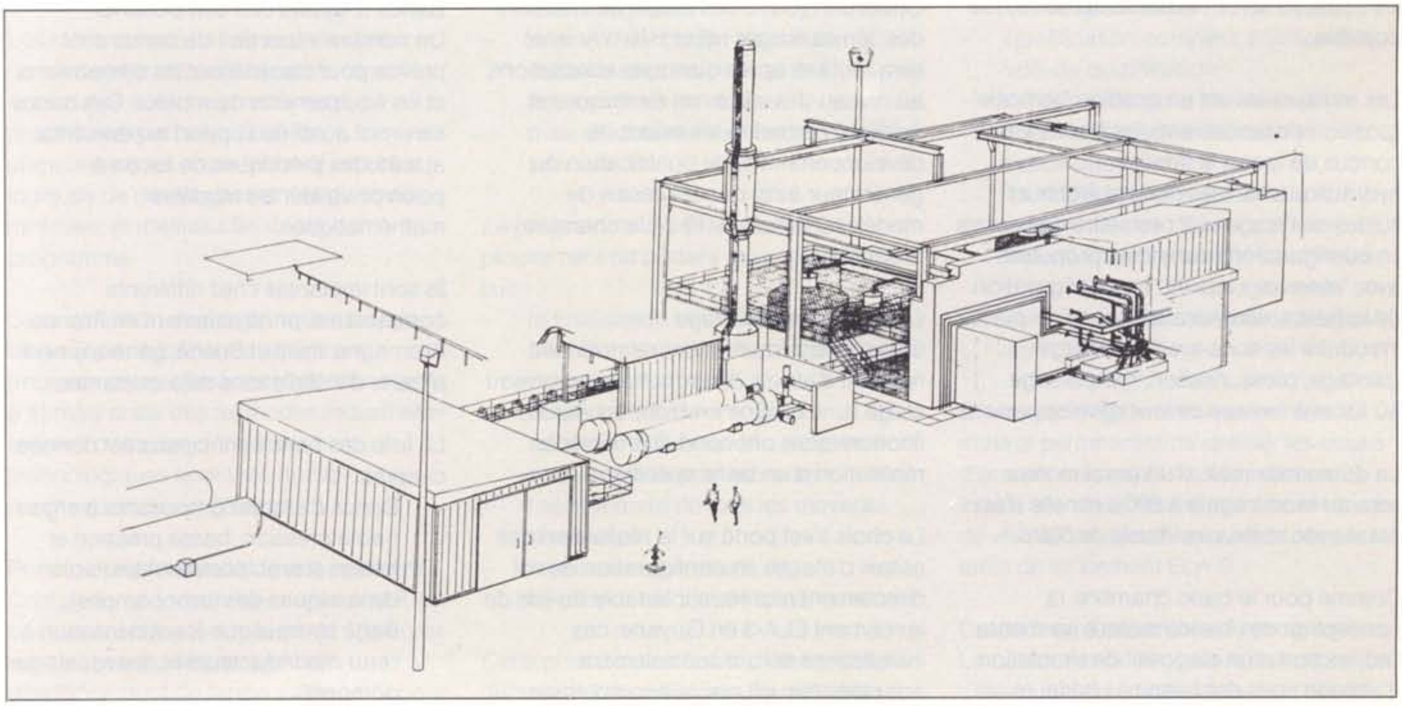
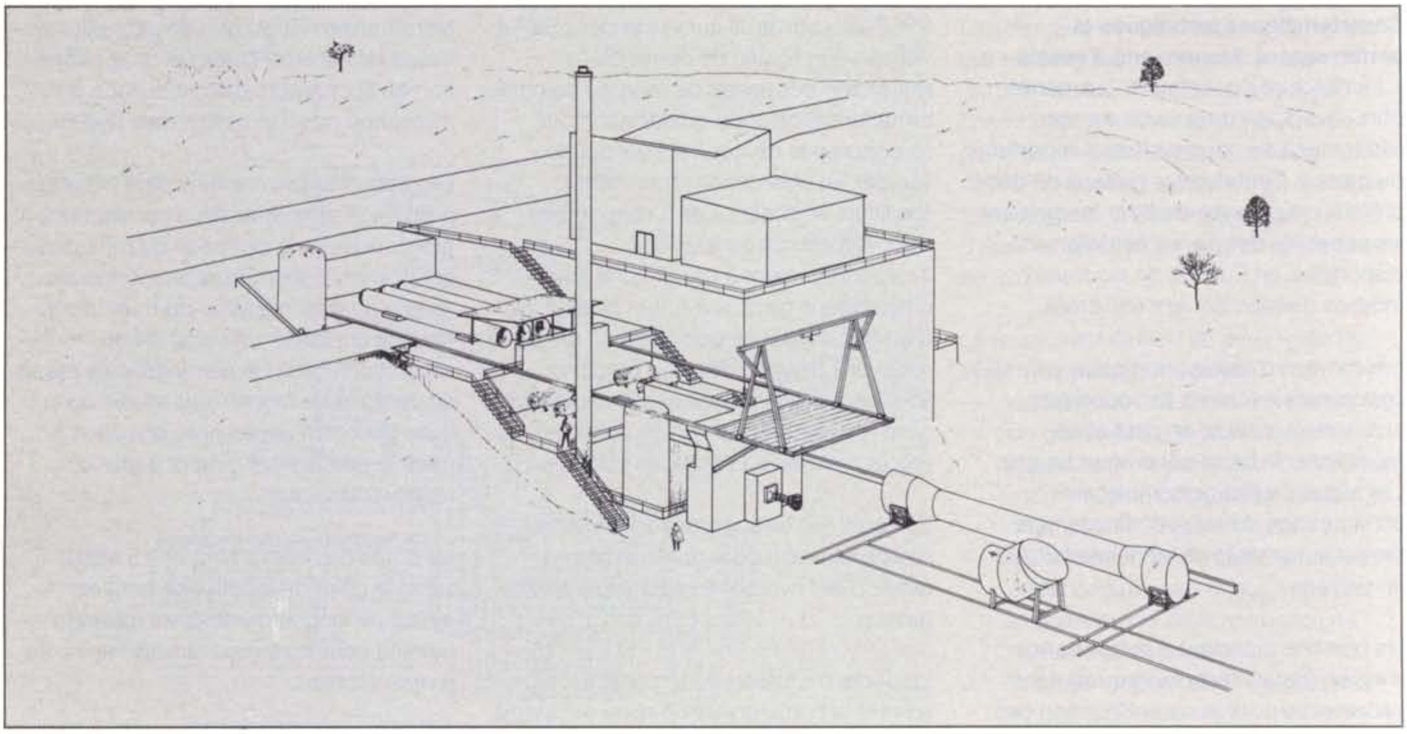


Figure 5 – Le banc d'essais Turbopompes (PF52 - SEP)

Figure 6 — Le banc d'essais Chambre (P3.2 - DFVLR)



réalisation de deux bancs a été jugée indispensable.

Ces bancs seront implantés, l'un (PF50) sur le site SEP à Vernon, l'autre (P5) sur le site DFVLR à Hardthausen. Afin de limiter les coûts, ils seront aussi semblables que possible.

Les moteurs seront en position 'verticale' (position de lancement), les bancs étant conçus de façon à simuler hydrauliquement les circuits ergols et fluides de l'étage et à permettre des essais en configuration ensembles propulsifs avec 'réservoirs lourds'. La configuration de la baie arrière sera telle que l'on puisse introduire les·sous-systèmes étage (pilotage, pressurisation, remplissage...) au fur et à mesure de leur développement.

La durée maximale d'un essai moteur sera au moins égale à 600 s et celle d'un essai avec réservoirs lourds de 500 s.

Comme pour le banc chambre, la conception des bancs moteur permettra l'adjonction d'un dispositif de simulation d'altitude pour des besoins ultérieurs éventuels (utilisation d'un divergent déployable ou allumage dans le vide).

Banc d'essais générateur de gaz
Le banc chambre existant dans l'établissement de MBB/ERNO à Ottobrunn (banc des essais de chambre des 3èmes étages H8 et H10 d'Ariane) sera réutilisé après quelques adaptations au niveau des systèmes électriques et fluides. Il permettra les essais de développement et de qualification du générateur ainsi que les essais de modèles à échelle 1/10 de la chambre propulsive.

Le banc d'essais Etage
Compte tenu du nombre relativement restreint d'essais de propulsion au niveau étage (une dizaine environ), les études économiques ont conduit à rejeter la réalisation d'un banc spécifique.

Le choix s'est porté sur la réalisation des essais d'étages en configuration de vol directement montés sur la table du site de lancement ELA-3 en Guyane; ces installations seront spécialement adaptées (structures, support d'étage, protections thermiques et acoustiques...) pour permettre la réalisation de ces tirs 'captifs' de durée correspondant à la pleine capacité des réservoirs soit 500 s environ.

Bancs d'essais des composants
Un nombre important de bancs sont prévus pour caractériser les composants et les équipements du moteur. Ces bancs serviront aussi de support expérimental aux études théoriques de façon à pourvoir valider les modèles mathématiques.

Ils sont implantés chez différents contractants, principalement en France, Allemagne, Italie et Suède, généralement à partir d'installations déjà existantes.

La liste des bancs principaux est donnée ci-après:
- Bancs d'essais composants à ergols haute pression, basse pression et hélium (caractérisation des joints dynamiques des turbopompes).
- Banc hydraulique (caractérisation à l'eau des inducteurs et des rouets des pompes).

- Banc pompes, à l'air (caractérisation à l'air des pompes complètes).
- Banc de caractérisation dynamique des rotors.
- Bancs de centrifugation des turbines et des rouets de pompes (caractérisation de la tenue mécanique).
- Banc de tenue mécanique des inducteurs de la pompe oxygène (caractérisation des efforts de flexion sur les aubages en prenant en compte les phénomènes de cavitation).
- Banc de caractérisation des turbines à air chaud (utilisés pour les recettes des turbines afin d'éviter les essais complexes et onéreux avec générateur de gaz).
- Bancs équipements pour les essais de développement et de recette des divers équipements du moteur (vannes, clapets, détendeurs . . .).

Plan de développement du programme
L'objectif calendaire du programme est d'aboutir à la préqualification au sol du moteur en fin 93/début 94 pour permettre le premier vol d'essai sur Ariane-5 au deuxième trimestre 1994.

Les méthodes de l'analyse de la valeur et de conception à coûts objectifs seront appliquées à tous les matériels et procédures, ceci afin d'orienter efficacement les choix techniques et les logiques de développement et donc de minimiser et maîtriser les coûts du programme.

Cette définition de programme s'inspire bien sûr de l'expérience antérieure (moteurs cryotechniques HM7 d'Ariane-1 à 4) mais aussi des méthodes industrielles utilisées dans des domaines technologiques similaires (turbo-machines, moteurs d'avion . . .).

Principales phases de développement
Compte tenu du calendrier ainsi établi, les travaux ont débuté dès la fin de 1984 (par anticipation au démarrage du développement du lanceur Ariane-5) pour être menés selon les deux phases principales consécutives suivantes:
- le 'programme préparatoire' allant jusqu'en décembre 86 avec une extension prévue jusqu'en mars 87 dans le cadre du programme préparatoire Ariane-5 dont l'approbation est en cours et qui incorporera alors les travaux relatifs au moteur;
- la 'phase de développement' proprement dit allant jusqu'à la qualification du moteur en vol autorisant sa mise en service opérationnelle (1995).

Il faut noter que le programme préparatoire du moteur HM60 a pris le relais des études de conception préliminaires effectuées dès 1978 sur les plans nationaux en France par la SEP (moteur), en Allemagne par MBB-ERNO (chambre) et en Suède par Volvo (turbines et divergent).

Le programme préparatoire porte sur les éléments essentiels suivants:
- définition détaillée du moteur et de ses sous-ensembles;
- réalisation du programme technologique;
- mise en fabrication des sous-ensembles principaux et des équipements du moteur;
- mise en chantier des bancs d'essais principaux.

Le programme de développement proprement dit portera essentiellement sur:
- la finalisation des dossiers de définition et de fabrication du moteur complet;
- la fabrication des modèles nécessaires aux niveau équipements, sous-ensembles et moteurs;
- l'achèvement de tous les moyens d'essais;
- l'exécution des essais de développement et de qualification.

Cette phase est en cours d'élaboration dans ses grandes lignes. Sa définition détaillée progressera sur la base des résultats du 'programme préparatoire'.

Logique des essais
La logique des essais a été partiellement abordée dans les paragraphes précédents. Les essais débuteront au niveau du 'programme technologique' qui sera suivi par les essais successifs aux niveaux équipements, sous-systèmes et moteurs complets.

Du fait de la limitation de capacité des bancs sous-systèmes (turbopompes-chambre), les essais d'endurance de ces derniers, à durée nominale ou supérieure, sont reportés au niveau moteur.

Outre les essais d'endurance dans les conditions nominales et hors nominales, les essais au niveau moteur permettront en particulier la mise au point des séquences de démarrage et d'arrêt ainsi que la vérification des performances dans le domaine de fonctionnement.

La qualification au niveau moteur sera faite selon les trois étapes suivantes:
- essais de préqualification au sol autorisant la revue d'aptitude au 1er vol de qualification du lanceur;
- qualification complète à l'issue des vols de qualification;
- qualification pour les vols habités avec les systèmes de sécurité spécifiques. Cette phase n'est toutefois pas incluse dans le programme de développement actuellement défini; elle sera traitée dans le cadre d'un programme complémentaire ultérieur, spécifique au vol habité.

On rappelle également que les bancs moteur permettront de réaliser les essais d'ensembles propulsifs avec réservoirs lourds alors que les essais avec réservoirs de vol seront directement effectués sur la table de lancement ELA-3.

Calendrier d'ensemble du programme
Le calendrier du programme complet s'étend sur une durée d'environ 10 ans.

Figure 7 – Participation industrielle au Moteur

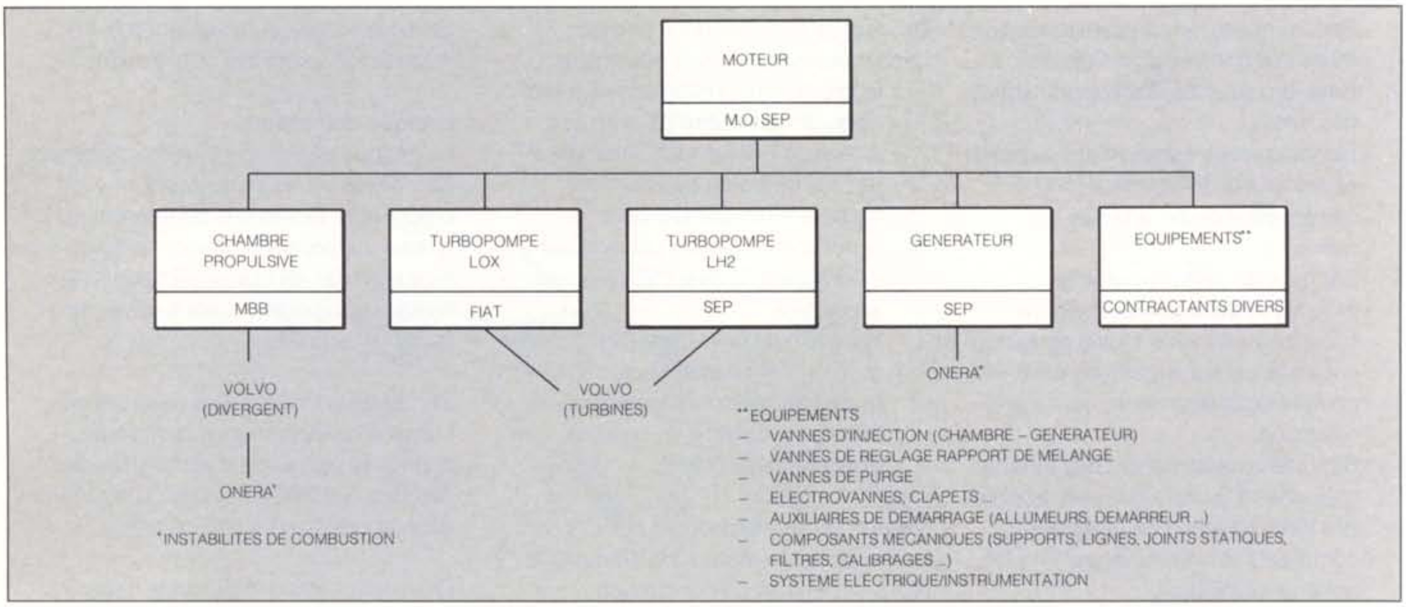
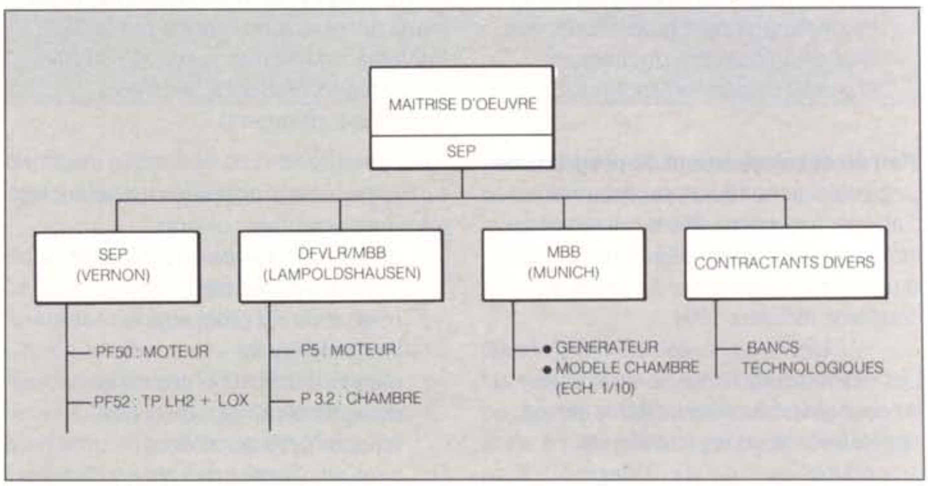


Figure 8 – Participation industrielle aux Moyens d'essais



Cette durée est surtout conditionnée par le délai de construction des nouvelles installations d'essais.

Les principales étapes-clés du programme sont les suivantes:

- disponibilité de la technologie des éléments critiques: 1987
- recette banc turbopompes: mi-87
- recette banc chambre: fin 87
- recette bancs moteurs: 1er semestre 89
- revue critique de définition du moteur: mi-91
- préqualification au sol: fin 93/début 94
- premier vol d'essai sur Ariane-5: fin 94
- qualification finale et mise en disponibilité opérationnelle: courant 95.

Organisation industrielle

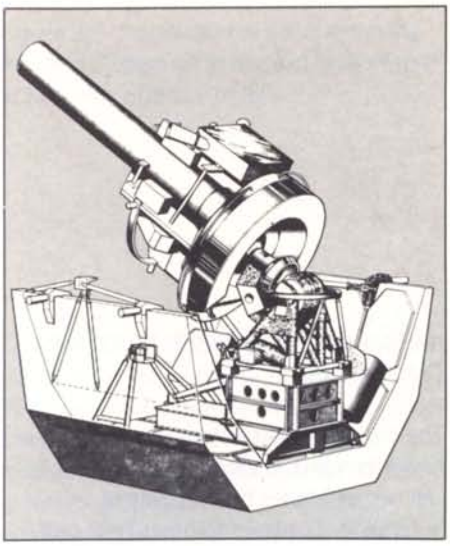
La Société Européenne de Propulsion (SEP-France) assure la maîtrise d'oeuvre industrielle de l'ensemble du programme. Les travaux sont répartis dans les firmes européennes au prorata des contributions financières des Etats participants.

Outre la SEP, les principaux contractants sont MBB/ERNO et DFVLR (Allemagne), FIAT Aviazione (Italie) et Volvo (Suède). Leurs participation aux travaux relatifs au moteur et aux bancs d'essais sont indiquées par les Figures 7 et 8. Il est à noter que l'ONERA (France) apporte sa contribution au programme pour les travaux relatifs aux instabilités de combustion dans la chambre propulsive et le générateur de gaz.

Conclusion

Le programme HM60 est un programme ambitieux mais jugé tout à fait réalisable pour l'Europe dans les délais impartis. Du point de vue technologique il s'appuie au maximum sur l'acquis de développement des moteurs HM7 d'Ariane-1 à 4. La conception et la réalisation du grand moteur cryotechnique HM60, quinze fois plus puissant que le HM7, représentent un progrès technologique important pour l'industrie européenne et nécessiteront des efforts importants pour respecter les objectifs de performances, de fiabilité, de coûts et de délais.

Les illustrations de cet article ont été aimablement communiquées par le CNES, la SEP, MBB/ERNO et Aérospatiale



The Spacelab Instrument Pointing System (IPS) and Its First Flight

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With the dramatic launch of Space Shuttle 'Challenger' on 29 July, which carried the second Spacelab for the final in-orbit verification flight, the ESA Spacelab Programme has come to a successful conclusion after 12 years of intensive international collaboration. The main Spacelab component on this pallet-only mission was the unique Instrument Pointing System (IPS), developed for ESA by Dornier System as part of the overall Spacelab system. Undisturbed by crew motion and Shuttle thruster firings, the IPS succeeded in pointing its 1.3 t solar-physics payload towards the Sun with a pointing error of less than 1 arcsec.

In 1973 the ESA Member States participating in the Spacelab Programme decided to develop and build a space laboratory consisting of a Module providing a shirt-sleeve working environment, and open Pallets for exposing experiments directly to space. In addition, certain subsystems were identified that were essential in the sense that one could not fly Spacelab without them. These included subsystems for power supply, environmental control and life support, and command and data management. After the intergovernmental agreement – the 'Memorandum of Understanding' – for the development of Spacelab had been established, ESA and NASA worked out the highest-priority programme requirements and established that 'the experiment/payload accommodations may include one or more stabilised platforms'.

Unlike the Spacelab Module and Pallets, the dimensions, masses, power-consumptions and heat-rejection needs of which were largely defined by the mother vehicle, the Shuttle Orbiter, nothing was defined for the stabilised platform other than the general nature of its payload, namely an experiment to be pointed, possibly a telescope. The astronomers, used thus far to thinking only in satellite-compatible-payload terms, did not have ready plans for payloads in the 1000 kg class, or even heavier, adapted for the Shuttle era.

During 1974 and 1975, therefore, ESA and NASA engineers reasoned that a three-axis-controlled platform was to be preferred to a two-axis one, and that technology was advanced enough to try to achieve 1 arcsec rather than 1 arcmin pointing, since the Shuttle Orbiter could already provide 6 arcmin pointing.

In order to arrive at a versatile system, stellar as well as Sun- and Earth-pointing modes were established as requirements.

The IPS concept

The only large pointing system that had flown previously was the Apollo Telescope Mount (ATM) which had formed part of the Skylab mission. It had performed very well, pointing a dedicated 2000 kg cluster of experiments towards the Sun, with a two-axis control and roll-axis positioning system approaching the 1 arcsec pointing regime. The overall pointing range was limited to ±2°, forcing the complete vehicle to face the Sun.

Like an Earth-bound telescope, the ATM's centre of mass coincided accurately with the intersection point of all three control axes. For a facility-type pointing mount to be easily adaptable for different payloads, which was a requirement for the IPS, this feature of having to fit the experiment cluster into an inner girth-ring and align its centre of mass was not acceptable. A novel solution was therefore proposed for IPS making use of a so-called 'inside-out gimbal' configuration, which sits like a universal joint between the perturbed Shuttle – rocked by crew movements and by the small thruster firings for attitude-control purposes – and the inertially stabilised payload. With this scheme, the payload can be any size, constrained only by the Orbiter's payload-bay dimensions and weight considerations. The overall

Figure 1 – An early (1974) concept for the Spacelab Instrument Pointing System (IPS)

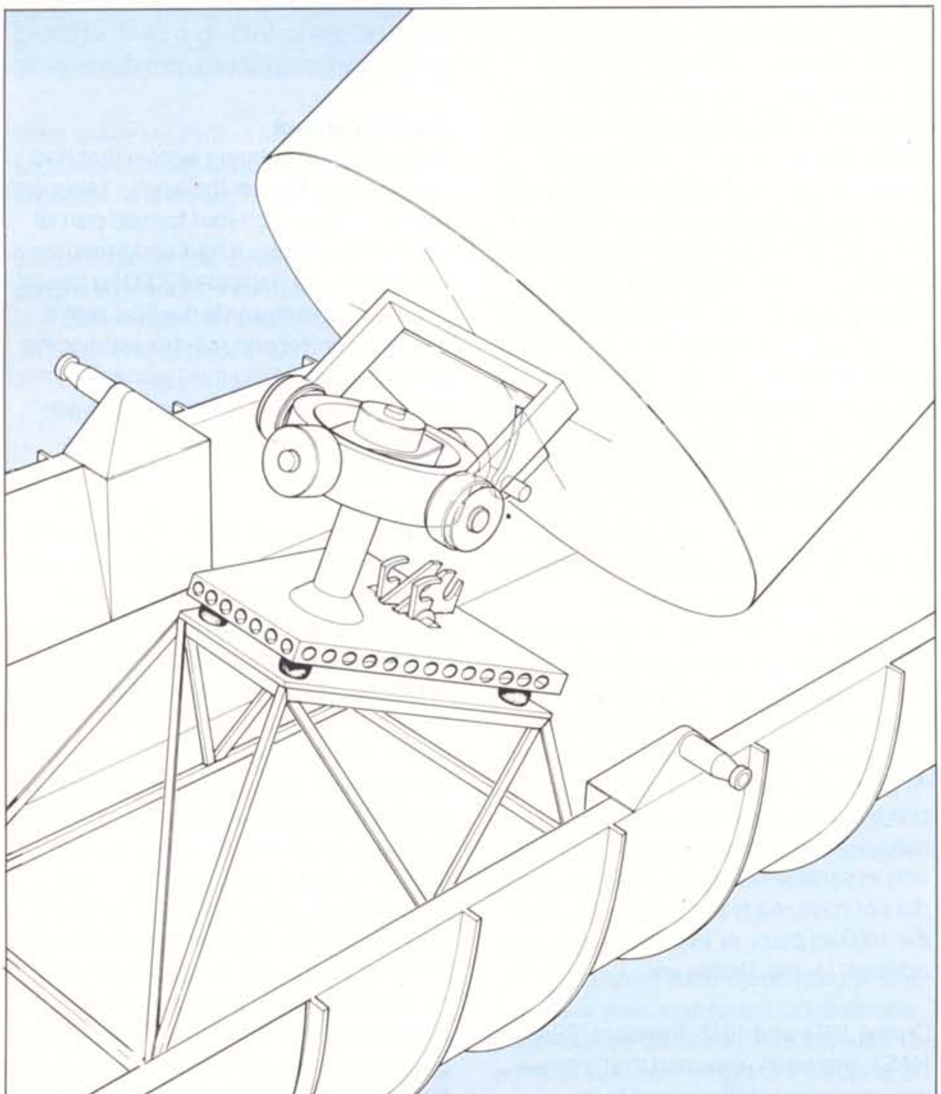
pointing range can, moreover, be close to hemispherical.

This arrangement is complemented by a payload/gimbal separation device, which leaves the payload and the gimbal system unconnected during ascent and descent, the payload then being supported by a dedicated clamping system. Once in orbit, the separation device pulls the payload towards the gimbal system and combines the two rigidly for pointing operations.

The advantage of this arrangement is that the gimbal system's design could be optimised for its main objective, namely accurate pointing from orbit, rather than having also to be able to support a huge payload mass throughout the launch phase.

Design and manufacture

Novel ideas are often hard to sell, but the advantages of the 'inside-out-concept' over the conventional girth-ring mounting in terms of cost, mass and, most of all, payload accommodation, were obvious. ESA therefore let an industrial contract in 1976 with the aim of flying its novel pointing system on the second Spacelab mission, then scheduled to take place in October 1980.



The design period was particularly rich in new findings and ideas, and we can cite just two examples here by way of illustration. Control engineers hate ball bearings because of their nonlinear behaviour. Tiny bearings were therefore chosen for IPS to minimise friction, but their similarly small load-carrying capability turned out to be a problem. Appropriate tests showed, however, that there is no friction or stiction for small movements ($\pm 3/4°$) around the rest position and the bearings need not therefore be modelled in the computer pointing-performance simulation, given that the Orbiter's motion is typically only $\pm 0.1°$.

The other idea was to sense the Orbiter's acceleration, generated by crew movement, for example, with a three-axis accelerometer package, calculate its disturbing effect on the payload, and command the gimbal axes torquers to counteract the disturbance at the same moment that it manifests itself at the payload. This gives what the control engineer calls 'feed-forward control', and this is the first time that it has been employed on an in-orbit pointing system.

IPS is controlled exclusively by software under the crew's command, except for emergency functions. Pre-programmed commands from a pre-selected display, which reflects the instantaneous operational situation, are executed by keying their command number into a typewriter-type keyboard. This sounds simple enough, but it has taken years of coordinated effort to build what is in practice the most complex European control system so far for space application. Every major control step, such as activation, Sun acquisition, fine pointing, etc. calls for a new memory configuration and software has to be loaded from mass-memory into the Spacelab subsystem computer to support that particular operational step.

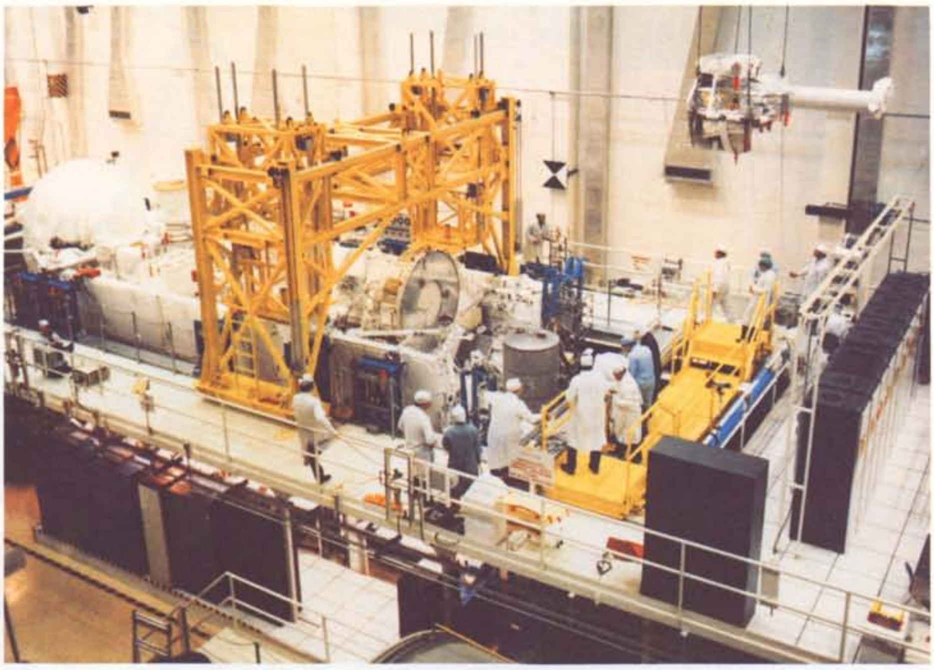


Figure 2 – Installation of the Instrument Pointing System (IPS) aboard Spacelab-2 at Kennedy Space Center

The complexity of the IPS software system results from the multitude of operational modes and requirements which have to be covered with the limited computer resources available in orbit. The process of target acquisition and precision pointing at the targets is based on a set of pre-programmed target data, such as the positions and visual magnitudes of stellar objects. The latter can be either the scientific targets or merely guide and reference points for the IPS control loop. Once the IPS operator has selected and loaded the scientific 'objectives', the acquisition and pointing operation is completely automatic. Three computers communicate and task-share in synchronous mode during IPS acquisition and pointing operations, in order to execute astronomical and control-loop computations, and to maintain a safe overall Orbiter/payload configuration.

In 1980 it became apparent that the Shuttle-Orbiter-induced loads during lift-off, particularly during the first 6 s of flight were higher than expected. This forced ESA to rethink some of the major structural parts of the IPS. This need for a major redesign at a time when the first flight model IPS was already in final system testing was exploited by ESA to convert all experience gained thus far into a completely updated set of detailed customer requirements.

Flight objectives

The prime mission objective on the Spacelab-2 flight was to flight-qualify the IPS and exercise all its intended functions as completely as possible. In the expectation that the IPS would indeed perform nominally, a payload package for scientific experimentation was also carried.

This payload was solar-physics-oriented, calling for the IPS to be exercised only in its solar pointing mode on this flight. It consisted of a Solar Magnetic and Velocity Field Measurement System (SOUP), a Coronal Helium Abundance Spacelab Experiment (CHASE), a Solar Ultraviolet Resolution Telescope and Spectrograph (HRTS), and a Solar Ultraviolet Spectral Irradiance Monitor (SUSIM), all of which were non-ESA experiments (total mass 1.3 t).

To evaluate the IPS's performance in orbit, deployment, Sun-pointing, manual pointing control, scanning and parking ('gimbal hold') were to be performed. Of the contingency functions, only stowage was to be exercised. The payload release and jettisioning functions, intended only for those emergencies in which proper stowage of the IPS and its payload for a safe return to Earth cannot be achieved, could not be checked.

Flight experiences

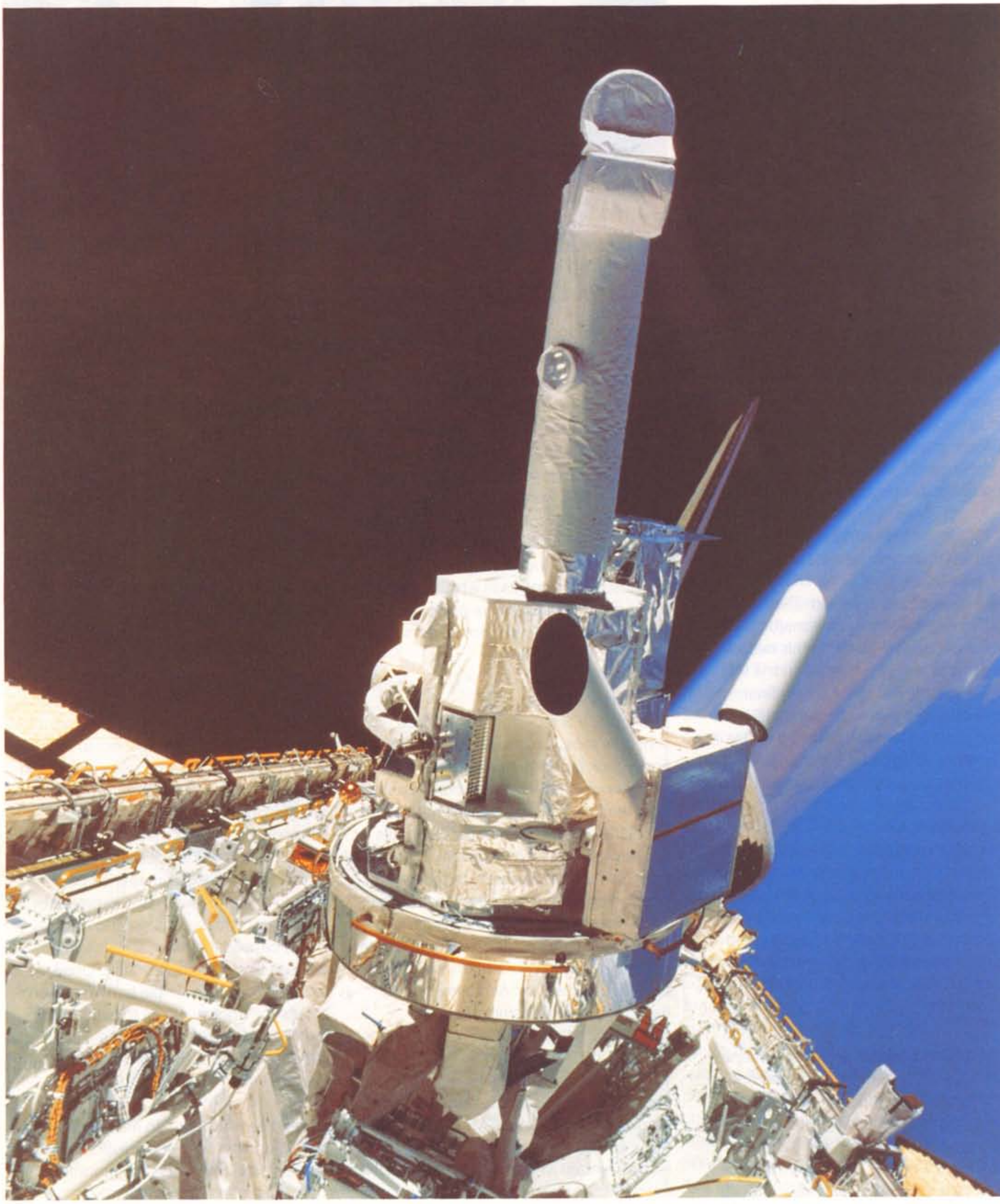
Due to the IPS redesign and Orbiter schedule slips, the maiden flight of the IPS finally took place in July/August 1985. The slightly lower than nominal orbit resulting from the Shuttle engine problems did not affect the IPS's performance. During its first deployment a small deviation from the nominal smooth trajectory to the upright position was observed. The reason was soon detected however: the elements of the Orbiter state vector containing Orbiter attitude and rate information, which are used to calculate the deployment trajectory, were transmitted out of sequence by the Orbiter.

The second anomaly detected was more serious in that Sun acquisition was irregular. The European Mission Support team, a mix of contractor and ESA staff, recommended to NASA to slow down the internal scanning speed of the Sun tracker and to correct the tracker's count rate for a somewhat lower sunlight level than anticipated. Both problems had already been expected before the flight, and these suggested corrections were totally successful. The result was perfect solar acquisition, leading over into solar fine pointing of better than specified accuracy, with a quiescent stability error of better than 1 arcsec. IPS performance was then very satisfactory, but for the fact that the solar-acquisition process, once commanded to start, was sometimes taking as long as 10 min to occur, for reasons unknown.

It was some days before the software designers were able to isolate the reason: next to its Sun tracker, the IPS has two star trackers for roll-axis control, mounted at an angle of 45° with respect to the Sun sensor. Due to this large skew angle and the comparatively low Earth orbit of the Shuttle, one star tracker was being blinded by the Earth's albedo radiation for a large range of the roll angles required by the scientific experiments on this particular flight. This was interpreted by the control software as an anomaly, which caused the solar acquisition process to stop unnecessarily. Once recognised, it was simple to avoid these critical roll angles, or just to wait until the Earth disappeared from the field of view of the offending star tracker before manoeuvring.

It would be erroneous to assume that the period leading up to the solution of this problem was lost to the IPS-mounted experiments. In fact, in the early

Figure 3 – The IPS in orbit



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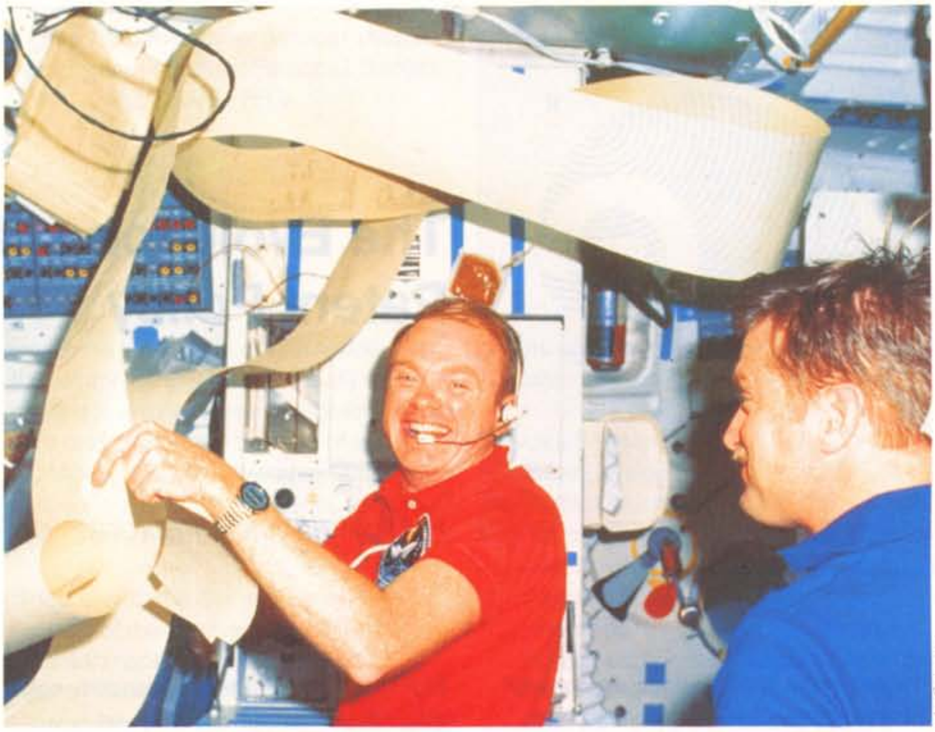

Figure 4 – Spacelab/Shuttle astronauts acquiring data from the IPS

photo nasa

requirements definition, a design requirement that the IPS be able to accept signals from the experiments themselves to replace its own sensor signals had been introduced. Since there were two Sun sensors elsewhere in the Spacelab-2 payload, they were used very successfully for the early part of the mission whenever fine pointing was required, until the IPS's anomalous behaviour was resolved.

For the remainder of the mission, the IPS worked flawlessly in every respect.

Project management aspects

The IPS project-management task was unique in several respects, both for the ESA team and for the Dornier System GmbH-led industrial consortium. The 'first' IPS had evolved almost to completion, with a flight model having been completely assembled, when it was realised in a specifically contracted verification study that the flight model would not support the increased low-frequency dynamic launch loads predicted by NASA for the Space Shuttle. It was an extreme challenge for the ESA/Industry team to determine whether it was feasible to conduct a fundamental redesign and redevelopment effort with the extremely limited funds and time remaining, given the politically determined fixed-price contract constraints and the very limited manpower resources.

It was boldly decided in 1981 that it was possible to slowly phase out the first IPS with the execution of system qualification testing for experience and database gathering for the redesign, and to design, build and qualify a second IPS to a new set of requirements which had meanwhile been generated by the ESA team, and to complete all of this by the end of 1983. The funding constraints and structural problems in the industrial setup required a painful streamlining of the industrial consortium and imposed a heavy burden of industrial risk on the IPS Prime Contractor. There was also a continuously mounting pressure from the US users for modifications and extensions to the originally agreed IPS baseline, resulting in approximately thirty significant modifications to customer requirements.

These changes and the inevitable difficulties in the design and qualification of the multitude of heavy mechanisms of the IPS, all of which had to be qualification tested for the space environment, caused a delay in completion from 1983 to 1984. However, when the new IPS was delivered to NASA and quickly mated into the Spacelab/Payload configuration, there were almost no interface problems. This was all the more remarkable because the IPS had 'seen' very little Spacelab/Orbiter hardware and software, because it was out of phase programmatically with Spacelab, which had long been delivered to NASA. It demonstrated that the rigorous interface control document process maintained by ESA's IPS team had been successful.

Conclusion

It is by no means a trivial task to design a controller for a large pointing system like the IPS, with 'flexible' structures inherent in the gimbal system itself, the payload, the Spacelab pallet, and the Orbiter.

The IPS control system is highly nonlinear, the system parameters varying with the look angle, and several feedback and feed-forward branches with multiple high-order filters being necessary.

All IPS structural elements withstood the launch and orbital loads, all temperatures stayed well inside the predicted flight values, all mechanisms worked smoothly and all electronics and sensors (optical sensors, accelerometers, gyroscopes) worked perfectly, except for an intermittent link problem between one computer and one star tracker which is believed to be a simple problem of marginal link timing, which can be easily corrected.

The flexibility of the system allowed full system performance to be achieved merely by adjusting software parameters, and the mission objectives of flight qualification and verification were fully achieved. In spite of the schedule delays in building IPS and the various technical difficulties, all of which were finally overcome, its first flight was a total success.

The second IPS unit, purchased by NASA under the Follow-on-Production programme, is presently being integrated into the Astro-1 mission for the observation of Halley's Comet, ready for a launch in March 1986. Three more missions are already foreseen for the IPS by NASA for Science and Application Payloads: Astro-2, Astro-3, and Sunlab-1 (reflight of the Spacelab-2 IPS payload). There are also three more potential IPS missions for which Shuttle flights are as yet unassigned: the Solar Optical Telescope (SOT), the Shuttle Infrared Telescope Facility (SIRTF), and Starlab.

The Evolution of the Agency's Patent Policy

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Traditionally, the 'intellectual property' of an organisation embraces patents, trademarks and franchising, copyrights, including rights of privacy and publicity, industrial designs, technology transfer and unfair competition, including trade secrets and unauthorised disclosures. This article focusses on one particular aspect of intellectual property as it affects the Agency's day-to-day working, namely patent policy and practice.

ESA's policy on intellectual property rights may be seen a 'licence policy', as opposed to a 'title policy', in that the inventor retains title to the patents for his inventions, which allows him to exploit them commercially; the 'Government' retains only a royalty-fee licence. One of the main reasons behind adoption of this policy is that vesting title in the 'Government' would limit commercial exploitation of the patented inventions. In the case of 'title policy', the 'Government' itself takes title to all patents for inventions made under its contracts.

ESA's current policy and practice in the field of intellectual property rights has its origins in the regulations of the former European Space Research Organisation (ESRO), and those of the former European Organisation for the Development and Construction of Space Vehicle Launchers (ELDO).

The purpose of ESRO, as laid down in Article II of the Convention for the establishment of a European Space Research Organisation, which entered into force on 20 March 1964, was 'to provide for, and to promote, collaboration among European States in space research and technology'. Bearing in mind that at that time research unquestionably meant scientific research, it was normal and logical that information and data generated by or through ESRO should be made available to the general public without limitation. No special provisions on intellectual property rights existed at that time, and if inventions were made in the course of work paid for by the Organisation, these belonged to the contractor, without any restriction being imposed.

In 1967 a first step was made towards limiting the availability of the scientific and technical results of ESRO's activities. The ESRO Council decided that it would be proper, as a standard practice, for the ownership of intellectual property rights to remain with the contractor, and for the rights acquired under the contract to be limited to ensuring that technical results generated in the performance of the contract should be available for use, free of charge, by the Organisation and its Member States, solely within the field of space research and space technology, and with the right to grant sublicences only in this field. A Member State would have the right to grant sublicences only to individuals, companies and organisations under the jurisdiction of, and resident in, the territory of that Member State. At the same time, new general conditions for ESRO contracts were approved in which the right to grant sublicences was extended to some degree.

In 1971 a royalty clause was introduced into ESRO's general conditions for contracts. This clause was a direct result of the change in the scope of activities of the Organisation, which occurred in 1970–1971 and which led to the inclusion of the promotion of space applications in ESRO's mandate. It was felt that since this new orientation increased the probability of ESRO's R&D being used for industrial applications, a special provision should be introduced into the contract conditions to enable the Organisation to recoup its R&D investments in cases where a contractor benefited directly from contracts paid for by the Organisation.

The (main) purpose of ELDO, as laid down in Article 2.1 of the 'Convention for the Establishment of a European Organisation for the Development and Construction of Space Vehicle Launchers', was the development and construction of space vehicle launchers and their equipment suitable for *practical* applications and for supply to users. Article 8 of the ELDO Convention, which concerns access to information and data, was written in a more exhaustive manner than the equivalent article of the ESRO Convention, for two reasons. Firstly, the information and data related directly to *practical* applications, rather than purely scientific research, and secondly, since launchers can be used for nonpeaceful applications, extra protection of information and data might be required. Under Article 8, inventions covered by patents or other forms of legal protection could be used without payment not only by the Organisation itself, but also by all Member States for any purposes of their own and, for purposes within the field of space technology, also by individuals, companies and organisations resident in the territory of the Member State. For purposes outside the field of space technology, individuals, companies and organisations did not have a priori authority to make use of inventions without payment. Moreover, the information and inventions could be used only within, and could not be transferred outside, the territory of a Member State.

Under this protocol, any individual, company or organisation under the jurisdiction of and resident in the territory of a Member State had the right to use inventions for purposes outside the field of space technology on commercially reasonable, nondiscriminatory terms. The conditions applicable to ELDO contracts were modified in accordance with this protocol, and in the application of these conditions the Organisation and individuals, companies or organisations under the jurisdiction of and resident in the territory of any Member State were entitled to a royalty-free licence for their own purposes within the field of space technology. Also, the Member States were entitled to a royalty-free licence for any purposes of their own.

Since, during the discussions on the drafting of the 'Convention for the Establishment of a European Space Agency', it was the intention of the participants that this Agency should take over all the rights and obligations of both ESRO and ELDO, preference was given to introducing into the Convention only a general statement on intellectual property rights and postponing the drawing-up of detailed rules.

Articles III 3, 4 and 5 of the ESA Convention, signed on 30 May 1975, read:

'3. When placing contracts or entering into agreements, the Agency shall, with regard to the resulting inventions and technical data, secure such rights as may be appropriate for the protection of its interests, those of the Member States participating in the relevant programme, and those of persons and bodies under their jurisdiction. These rights shall include in particular the rights of access, of disclosure and of use. Such

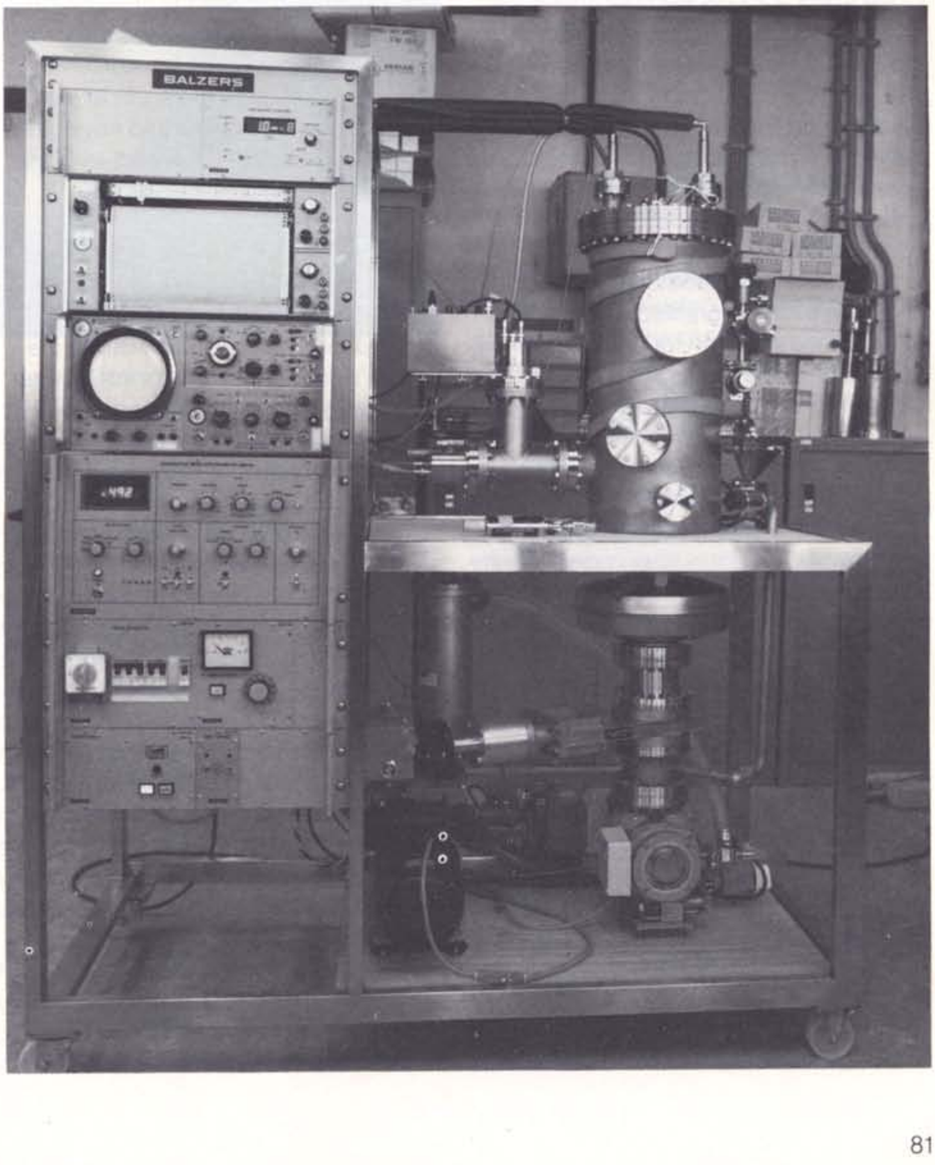


Figure 1 – Multi-tracer gas leak detector for spacecraft testing (Patent: G. Sänger & A.K. Franz, ESA/ESTEC)

inventions and technical data shall be communicated to the participating States.

4. Those inventions and technical data that are the property of the Agency shall be disclosed to the Member States and may be used for their own purposes by these Member States and by persons and bodies under their jurisdiction, free of charge.

5. The detailed rules for the application of the foregoing provisions shall be adopted by the Council, by a two-thirds majority of all Member States.'

In order not to compromise the interests of the Agency and its Member States, the conditions applicable to ESA Contracts were made more specific from the outset.

According to these contract conditions, the rights on inventions made in the course of or resulting from work undertaken for the purpose of the contract remain with the contractor, subject to an irrevocable, nonexclusive, royalty-free licence granted to the Agency to exploit the invention for purposes within the field of space research and space technology and the right to grant sublicences for these purposes to anybody and in any country. In addition, the contractor must notify the Agency of each filing of a patent application.

This 'provisional policy' was neither a 'licence policy' nor a 'title policy', since, as explained above, under a licence policy the contractor is given title to the rights in the invention, with a royalty-free licence retained *solely* by the Agency and its Member States for their own purposes (thus, the contractor is not obligated to grant a royalty-free licence to anyone else). Under a 'title policy', the Agency would take title to the patents, with the possibility for individuals and companies to make use of the invention through licencing.

In 1977, an internal study of the number of patent applications notified to ESRO, ELDO or the Agency during the period 1967–1977 revealed that only 21 patent applications had been notified (24% French original patent applications, 72% German original patent applications). During the same period, in the field of attitude control alone, 54 patent applications were filed in France, the national breakdown being:

France	20
Germany	10
United Kingdom	2
United States	16
Japan	4

If we take into account that during those years (1967–1977) a large part of all research and development in Europe in the field of attitude control was done for ESRO, ELDO and ESA, it is astonishing that only 4% of all patent applications filed in France in this field and having their origin in Europe were notified to the Agency.

It was evident therefore that industry was reluctant to notify patent applications to the Agency. Discussions with industry revealed that this was mainly due to the Agency's policy in the field of intellectual property rights, and this was confirmed in a study of the role of the Agency in technical innovation and the transfer of technology. In order to overcome this problem, in 1977 the ESA Council approved guidelines for the implementation of Article III of the ESA Convention, which stipulate that:

- 'A contractor who is proprietor of inventions and technical data, whether or not protected by patent or other similar form of protection arising from his contract work, shall be bound to grant a nonexclusive and irrevocable licence free of charge to ESA and its Member States who may, for their own requirements in the field of space research and technology, use them, or grant sublicences for use by persons and bodies under their jurisdiction.
- When the owner or holder of the inventions or technical data arising from his contract work, whether protected by a patent or not, wishes to exploit such inventions and technical data outside the Member States, he shall inform ESA accordingly and the Agency shall be entitled to claim fair and reasonable royalties ...'

These guidelines were implemented in the new contract conditions put into practice in 1982.

This new policy is, then, a new step towards a total licence policy. Indeed, title to the rights in the invention remains with the contractor, with a royalty-free licence retained solely by the Agency and the participating States for their *own* purposes in the field of *space research and technology*. However, the Agency may, in three distinct cases, take title to a patent for an invention made during the execution of the contract:

- If the contractor does not wish to patent the invention, he is obligated to inform the Agency immediately and transfer his rights free of charge.
- If the contractor intends to abandon the patent, the Agency is entitled to maintain it for its own benefit.
- The Agency has the right to patent the invention in any foreign country in which the contractor does not elect to secure a patent.

In respect of any patent secured by the Agency under these terms, the contractor is entitled to receive, free of charge, an irrevocable nonexclusive licence, without the right to grant any sublicences in addition to such licences as he may already have granted.

The only difference between this policy and a 100% licence policy lies in the fact that, should the contractor assign or grant a licence under a patent for an invention resulting from work undertaken for the purposes of the contract, the contractor will have to pay royalties to the Agency (this obligation ceases ten years

Figure 2 — Sleeping bag/restraint system for astronauts (Patent applicants: H. Stoewer & W. Ockels, ESA/ESTEC)

after the date of final acceptance of the work performed under the contract). This royalty obligation may sometimes be waived and is anyhow not applicable whenever these licences are required for purposes in the field of space research and technology, and their space applications in the States participating in and contributing to the programme under which the invention has been made. Furthermore, the total amount of royalties paid may not exceed the total of the research and development costs paid for by the Agency under the contract.

Background patents
A contractor may hold patents for inventions not made during the performance of the contract, but which have been or will be used for the execution of the contract.

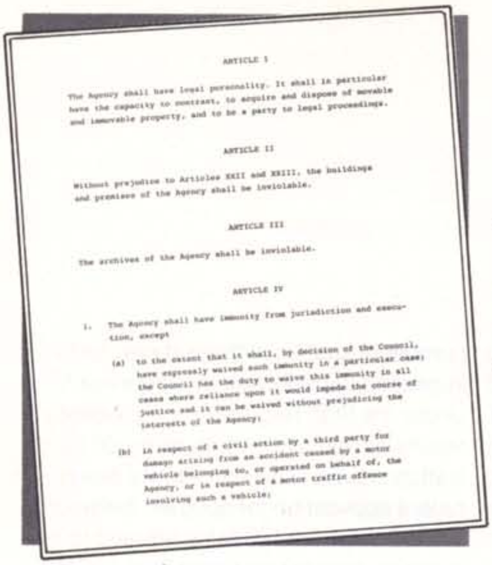
Except for reproduction purposes, the Agency does not include any contract provision whereby the contractor is obligated to license his background patents to others. Before exercising the reproduction right through a third party, the Agency undertakes to inform the contractor and, provided that he is able and willing to undertake the work at a fair and reasonable price, to commission the work with him, subject to the Agency's usual industrial-policy requirements. If the reproduction right is exercised by a third party, the contractor will be indemnified for the use of his background patents and data.

Patents for in-house inventions
Up to now, we have been considering only inventions made outside ESA, but inventions are also made in-house. The number of such inventions has in fact increased considerably in recent years. Under the Staff Regulations, the Agency retains all rights in inventions made by its staff members, but if the Agency files a patent application for such an invention, a basic award of 100 AU is granted to the inventor. An additional award of 500 AU is granted to the inventor if corresponding patent applications are filed in at least one other country. Finally, a second additional award may be paid to the inventor, even after his departure from the Agency, if an examination five years after the filing of the first patent application reveals that the exploitation of his invention has been successful.

For these Agency-owned inventions, the Member States are entitled to a nonexclusive, royalty-free and irrevocable licence for their *own* requirements in the field of *space research and technology*.

Further development of ESA's policy
Further development of policy matters in an intergovernmental organisation like ESA depends strongly on the way in which policy is developing in its Member States. Since in the case of patent law the situation is still different in each of them, it is inevitable that ESA's policy will change only very slowly.

International cooperation in patent law might improve this. Although an important effort is being made in this field, however, we are far from a unified patent law, as illustrated by the fact that none of the four new international agreements in the world patent field has been signed by all ESA Member States.


ARTICLE I

The Agency shall have legal personality. It shall in particular have the capacity to contract, to acquire and dispose of movable and immovable property, and to be a party to legal proceedings.

ARTICLE II

Without prejudice to Articles XXII and XXIII, the buildings and premises of the Agency shall be inviolable.

ARTICLE III

The archives of the Agency shall be inviolable.

ARTICLE IV

1. The Agency shall have immunity from jurisdiction and execution, except

(a) to the extent that it shall, by decision of the Council, have expressly waived such immunity in a particular case; the Council has the duty to waive this immunity in all cases where reliance upon it would impede the course of justice and it can be waived without prejudicing the interests of the Agency;

(b) in respect of a civil action by a third party for damage arising from an accident caused by a motor vehicle belonging to, or operated on behalf of, the Agency, or in respect of a motor traffic offence involving such a vehicle;

The Privileges and Immunities of International Organisations and Their Staff

W.M. Thiebaut, Legal Affairs Department, ESA, Paris

The Convention for the Establishment of a European Space Agency, which was signed on 30 May 1975 and entered into force on 30 October 1980, contains in its Annex I the Privileges and Immunities of the Agency and its personnel. These provisions are similar in many respects to those contained in the constitutions of other International Organisations. They are the result of the clarification of the scope and content of international privileges and immunities made necessary by the intense development of International Organisations. Indeed, the latter have a rather short history and, although some forms of International Organisation can be traced back to the nineteenth century, the first International Organisation in the strict sense was created in 1919 with the Covenant of the League of Nations. The real growth in the creation of International Organisations occurred after 1945 and with it the need to define in greater detail the privileges and immunities that they and their personnel should be granted.

In the early fifties the attitude of Governments towards International Organisations was very liberal and often resulted in very favourable privileges and immunities for the Organisations themselves and their staff. However, the extraordinary growth of International Organisations, and the growing trend to reduce the granting of privileges, have led Governments in later years to restrict those privileges and immunities. In fact, this tendency has become very clear since 1960 and was apparent in the reduced privileges and immunities granted to ESRO and ELDO. Nowadays, new International Organisations are faced with even stronger opposition to the granting of privileges and immunities, although Governments are also conscious of the fact that certain basic privileges and immunities are necessary for the proper functioning of these Organisations*.

The basic privileges and immunities are founded on the general acceptance of certain principles that are now regarded as the foundations of international privileges and immunities. Those principles are laid down in three basic propositions:

1. International Organisations should be protected against control or interference by any State in the performance of the functions for the effective discharge of which they are responsible.
2. No Member State of an International Organisation should derive any national financial advantage by levying fiscal charges on the funds contributed in common by the Member States.
3. The International Organisation should, as a collectivity of Member States, be accorded the facilities for the conduct of its official business customarily extended to each other by its individual Member States.

These general considerations are reflected in the terms of various general Conventions and Agreements concerning privileges and immunities, and in a number of Headquarters and Host Agreements**. Indeed, General Conventions, Agreements and Protocols are often complemented by Headquarters and Host Agreements between International Organisations and States on whose territory they have established their Headquarters or other offices. These Headquarters and Host Agreements play a role in the policy of individual States concerning International Organisations. If a State wishes to attract International Organisations onto its territory, it can, in addition to the privileges and immunities

* See the Legislation Texts and Treaty Provision concerning the Legal Status, Privileges and Immunities of International Organisations, United Nations, 1959.

** Agreements concluded with the Netherlands, Germany and Italy for ESTEC, ESOC and ESRIN contain specific provisions complementing the Protocol on Privileges and Immunities of ESRO. In France, no Headquarters Agreement has been concluded as such. Correspondence with the Ministry of Foreign Affairs has defined detailed provisions applicable to ESRO staff living in France. A similar arrangement exists with the Spanish Government for the personnel working at Villafranca, near Madrid.

contained in the general Convention or Protocol, propose favourable conditions for this Establishment and for its staff.

The rationale of privileges and immunities for International Organisations is different from those for Diplomatic Missions, as will be outlined below.

Diplomatic privileges and immunities and those of staff of International Organisations

The staff of International Organisations, with a few exceptions which will be dealt with later, do not enjoy diplomatic status. The functional needs of International Organisations are, of course, not identical to the needs of diplomatic missions. International Organisations are emanations of the will of a number of States to achieve together a common objective, whereas the diplomatic relations between States are based on the need for good relations between Sovereign States. The Member States of International Organisations may well decide to relinquish part of their sovereignty to the Organisation, whereas this will not be the case in diplomatic relations.

The three major differences between diplomatic and international immunities are the following:

1. Diplomatic staff of a mission are nationals of the sending State. Sometimes, the sending State may appoint diplomatic staff from among the nationals of the receiving State, but then only with the express consent of that State.
   This express consent of a State does not exist within International Organisations. However, as mentioned in Article XXIV of Annex I to the ESA Convention, no Member State shall be obliged to accord certain privileges and immunities to its own nationals or persons who, at the moment of taking up their duties in that Member State, are permanent residents thereof.
2. The immunity of a diplomatic agent from the jurisdiction of the receiving State does not exempt him from the jurisdiction of the sending State.
   In the case of the privileges and immunities of International Organisations, there is no sending State and an equivalent for the jurisdiction of the sending State has to be found either in waiver of immunity or in some international disciplinary or judicial procedure.
3. The effective sanctions that secure respect for diplomatic immunity are the principle of reciprocity and the danger of retaliation by the aggrieved State. International Organisations enjoy no such similar protection.

In conclusion, it can be said that the privileges and immunities of International Organisations are formulated in the relevant texts of the International Conventions and are restricted to these texts, whereas the diplomatic immunities are based on customary law among States. This customary law is laid down in the Vienna Convention on Diplomatic Relations of 1961.

Privileges and immunities of staff of International Organisations

As noted above, the staff of International Organisations do not enjoy diplomatic status, with just a few exceptions. High-level civil servants enjoy diplomatic status; in the United Nations, for example, the Secretary General and the Assistant Secretaries General enjoy such status. In the European Space Agency, the only official to enjoy such status is the Director General. Article XV of Annex I of the ESA Convention states that the Agency's Director General, and, when the office is vacant, the person appointed to act in his place, shall enjoy the privileges and immunities to which diplomatic agents of comparable rank are entitled.

For the other staff of International Organisations, the privileges and immunities are those set out in the Convention or the Protocol supplemented by a Host Agreement or Headquarters Agreement.

As a corollary to the unimpeded functioning of the Organisation, the ESA Convention recalls the necessary independence of the staff in its Article XIV, 4 as follows:

'The responsibilities of the Director General and the staff in regard to the Agency shall be exclusively international in character. In the discharge of these duties they shall not seek or receive instructions from any Government or from any authority external to the Agency. Each Member State shall respect the international character of the responsibilities of the Director General and the staff and shall not seek to influence them in the discharge of their duties.'

Annex I to the ESA Convention notes the following privileges and immunities for the staff and their families:

1. The staff members of the Agency shall have, even after they have left the service of the Agency, immunity from jurisdiction in respect of acts, including words written and spoken, done by them in the exercise of their functions: this immunity shall not apply, however, in the case of a motor traffic offence committed by a staff member of the Agency nor in the case of damage caused by a motor vehicle belonging to or driven by him.
2. They shall be exempt from all obligations in respect of military service.
3. They shall enjoy inviolability for all their official papers and documents.
4. They shall enjoy the same facilities as regards exemption from all measures restricting immigration and governing aliens' registration as are normally accorded to staff members of International Organisations and members of their families forming part of their households shall enjoy the same facilities.
   Consequently, a non-national does not fall under the rules applicable to foreigners. ESA staff do therefore not require work permits or a 'carte de

Figure 1 – Signature of the ESRO Protocol with The Netherlands, in 1967, by Prof. Pierre Auger (left), then ESRO's Director General, and Minister Joseph Luns (right), then Dutch Minister of Foreign Affairs

séjour'. A special identity card is issued for them by the appropriate authorities.

5. They shall enjoy the same privileges in respect of exchange regulations as are normally accorded to staff members of International Organisations. For this reason staff members of the Agency in Member States with exchange control, except nationals, have the right to a foreign account. This account, however, is restricted to receiving the salaries paid by the Agency or money transfers from other foreign accounts.
6. They shall, in time of international crisis, enjoy the same facilities as to repatriation as diplomatic agents, and this shall extend to their families.
7. They have the right to import duty-free their furniture and personnel effects at the time of first taking up their post in the Member State concerned, and the right on the termination of their functions in that Member State to export free of duty their furniture and personal effects, subject, in both cases, to the conditions considered necessary by the Member State on whose territory the right is exercised. Implementing measures are in each case defined by the Member State concerned.
8. They enjoy also exemption from national income tax on the salaries and emoluments paid by the Agency. However, the Member States shall retain the right to take these salaries and emoluments into account for the purpose of assessing the amount of taxation to be applied to income from other sources. This is called the progression proviso.
9. As the Agency has established its own social security scheme, the staff members are also exempt from all compulsory contributions to national social security bodies, subject to agreements concluded with the Member States.
   This exemption may lead to some conflicts with national social security systems, but should prevail if it is recognised that the Agency's social security scheme offers the same protection as the national compulsory scheme.

The above-mentioned privileges and immunities are not granted to ESA staff members for their personal advantage. They are provided solely to ensure, in all circumstances, the unimpeded functioning of the Agency and the complete independence of the persons to whom they are accorded. They are therefore limited to the official activities of staff members. In all their other relations with the Member State were they are established, staff members are subject to the laws of that country. In other words, their non-resident status is based only on their official activities and staff members should be considered residents in all other cases.

Privileges and immunities of ESA staff outside Member States

The International Organisations are emanations of Member States and their privileges and immunities do not have to be recognised by Non-Member States. In fact, recognition of privileges and immunities by other States will only result from the conclusion of Agreements between these States and the International Organisation, or from appropriate action by the Non-Member State. In the case of the Agency, the Association Agreements with Austria and Norway, as well as the Cooperation Agreement with Canada, contain provisions regarding the privileges and immunities of ESA staff.

ESA staff based in the United States enjoy the privileges and immunities contained in the United State's International Organisations Immunities Act, as the result of an Executive Order made by the President of the United States.

Conclusion

International Organisations have functional needs that require the granting of privileges and immunities to them and their staffs. The latter, however, usually have no diplomatic status and enjoy only those privileges and immunities that are expressly laid down in Conventions, Protocols and Headquarters or Host Agreements.

'ESANET', The Agency's General-Purpose Communications Network

K. Blank, ESA Computer Department,
Directorate of Operations, ESOC, Darmstadt, Germany

Since the Agency began to establish its own computer centres in 1966, data communication has developed into an important facet of the efficient use of that computing power. Today's computer centres could no longer run efficiently without the extensive use of modern communications networks such as ESANET, which has three primary objectives:

- **to provide wide-area communications services between ESA centres and external institutes;**
- **to provide local communications within each establishment;**
- **to provide a gateway function for various public and value-added networks.**

Background

The growing demand for integrated data-processing support dictated the need for some form of interconnection between ESRO's distributed data-processing facilities and the users of databases (originally the ESRO RECON system) as far back as the late 60's and early 70's. The rapid growth in the information processing field in the intervening 15 years has boosted not only the demand for interprocess communication, but also the interactive use of electronic data processing (EDP) facilities. This trend has been particularly dramatic in recent years in the area of office automation, which is no longer a classical application of EDP, but spans a much wider field.

The acronym for the Agency's current network, 'ESANET', was adopted some 10 years ago, when switching and routing functions were introduced for the first time. At that time, ESANET blossomed from a mere point-to-point static interconnection of systems to a full communications network, allowing the interconnection of internal services and access to ESA computer facilities via the public switched telephone network. ESANET now serves the Agency's general-purpose communications requirements (Fig. 1), as opposed to the more specific needs for the operational (real-time) support of spacecraft operations, which are serviced by a separate network. ESANET is not dedicated to specific projects, but supports all kinds of digital communications generated or being exploited by the Agency in its day-to-day work.

The network, managed by ESA's Directorate of Operations, falls under the responsibility of the ESA Computer Department. A small team of experts within this Department is responsible for the network's maintenance and updating (Fig. 2).

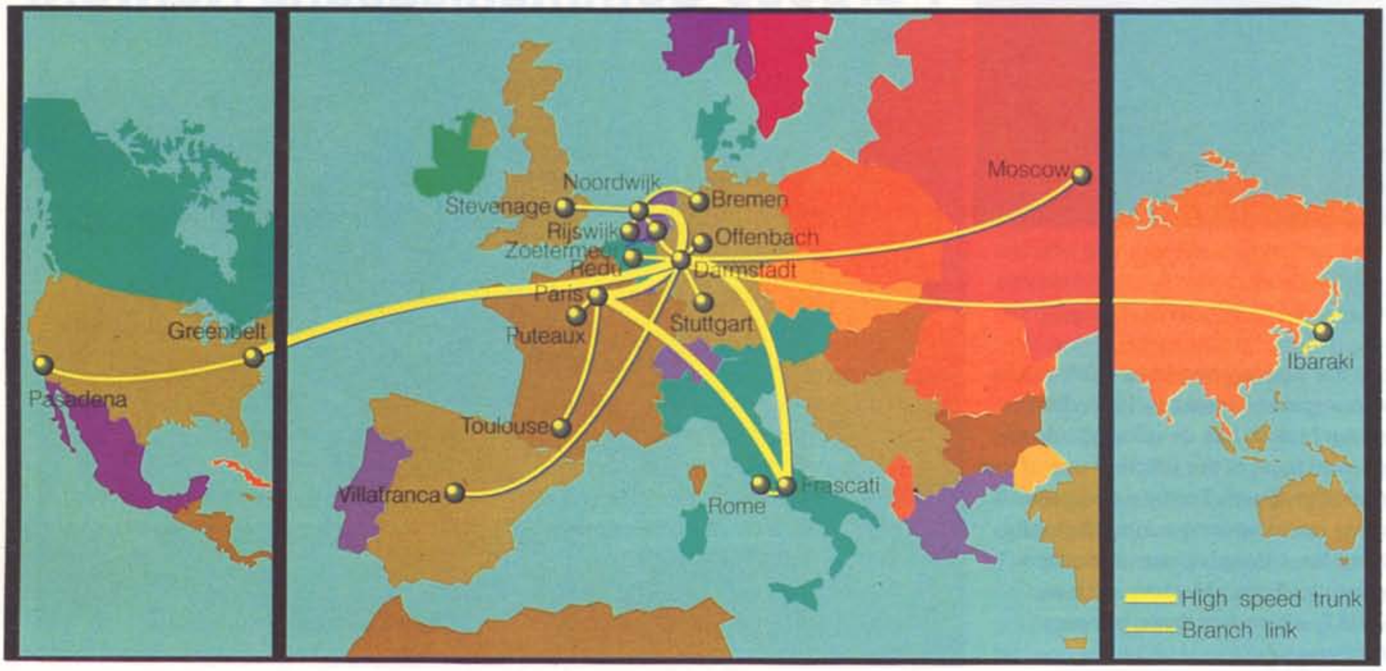
The technology of the network

ESANET has been designed so that it can grow without impairing the operation of currently connected systems or jeopardising the associated investments. The first component of ESANET, the Wide-Area Network (WAN), is currently formed by 4 kHz analogue circuits permanently leased from national PTT Administrations and the company International Record Carriers (IRC). State-of-the-art modems are used to derive maximum digital signalling capacity from these analogue circuits. Typically, data rates of 9.6 kbit/s are achieved as a minimum, whilst the trunk links between ESA Head Office, ESTEC, ESOC and ESRIN are already being operated at speeds of 14.4 and 16 kbit/s, respectively.

Recent developments lead one to believe that a further speed enhancement to 19.2 kbit/s might be feasible. Although modern technology has been improved considerably during the past ten years, with speeds increased by a factor of 7–8, the ultimate goal is to utilise digital links, as they become available on a European-wide basis, rather than the current analogue circuits. This would not only improve network capacity by a further factor of 4–5, to 64 kbit/s, but would reduce investment costs whilst improving overall network efficiency and reliability.

Figure 1 – Geographical overview of the current ESANET network

Figure 2 – The ESANET control console at ESOC, in Darmstadt



Currently, however, the European PTTs are not yet in a position to offer such services, at least at an international level. It is planned to make use of such 64 kbit/s links as main trunks between the Agency's various centres as soon as they become available.

For reliability, maintainability and compatibility reasons, ESANET has been developed entirely from standard equipment available off the shelf from the telecommunications industry. Special emphasis has been given to modularity in order to facilitate future adaptations as and when new techniques become available or user needs change.

The second component of ESANET is the Local-Area Network (LAN). This element, sometimes referred to as ESALAN, now forms the backbone of digital communications within the Agency. It is the link between the user device and the target facility, which can either be a local in-house service or a remote system elsewhere in the world accessible via a communications network of some kind. Unlike the WAN, ESALAN is already based on a 440 MHz wide broadband system, making use of a cable-TV-type

(CATV) system with a single 75 Ω coaxial cable and a 'branching-tree' topology. CATV technology is mature, stable and reliable, as evidenced by the millions of miles of existing installations throughout the world. It provides the large bandwidth needed to accommodate multiple data simultaneously, i.e. video and voice applications, and transmit them over large distances.

The concept selected for ESALAN will allow the Agency to handle several entirely independent data networks simultaneously on a local basis, as well as voice and video requirements for applications such as security surveillance, closed-circuit television, tele- or video-conferencing, educational programmes, general broadcasts, public addresses, public information systems, etc., on a single cable (Fig. 3).

The ESALAN system has been successfully implemented at ESOC and ESTEC since 1982, and is currently being extended to cover ESRIN, near Rome, and the Agency's Villafranca ground-station complex near Madrid.

Besides satisfying the technical needs, ESALAN will overcome some of the organisational and infrastructural problems that have occurred during recent years, because the user stations are no longer limited to a particular physical location. The user can unplug the network interface unit, carry it to a new location and reconnect it to the cable, thereby eliminating costly rewiring when departments or individuals relocate. It also makes the adding of new stations to the network a simple task (Fig. 4).

Moreover, as the ESALAN concept is based on broadband technology, it does not have an inherent manufacturer dependence, unlike most baseband LAN systems. This will allow any future broadband product to be used, provided it adheres to a frequency allocation plan. The medium can therefore be shared by a variety of different data networks which are not necessarily compatible with one another.

A Network Control Centre function available on ESALAN provides the following essential services:

- Name Server: Menu of services accessible to the user
- Access Control: Password-protected access to the network, including time/date stamping of access and recording of invalid attempts, password administration
- Network Management: A comprehensive tool for network administration and maintenance
- Statistics: Loading and error statistics.

External network interfaces

Two categories of networks are accessible via ESANET, namely Public Networks (PN) and Value-Added Networks (VAN) operated primarily by commercial network entities.

A functional overview of ESANET, showing the numerous types of networks currently directly or indirectly interconnected to it, is given in Figure 5.

The networks currently connected are:
- PSTNs (Public Switched Telephone Networks): Spain, Germany, France, The Netherlands, Italy
- PDNs (Public Data Networks):

– Datex-P Deutsche Bundespost Packet-Switched Network
– Datex-L Deutsche Bundespost Circuit Switched Network
– DN-1 Dutch PTT Packet-Switched Network

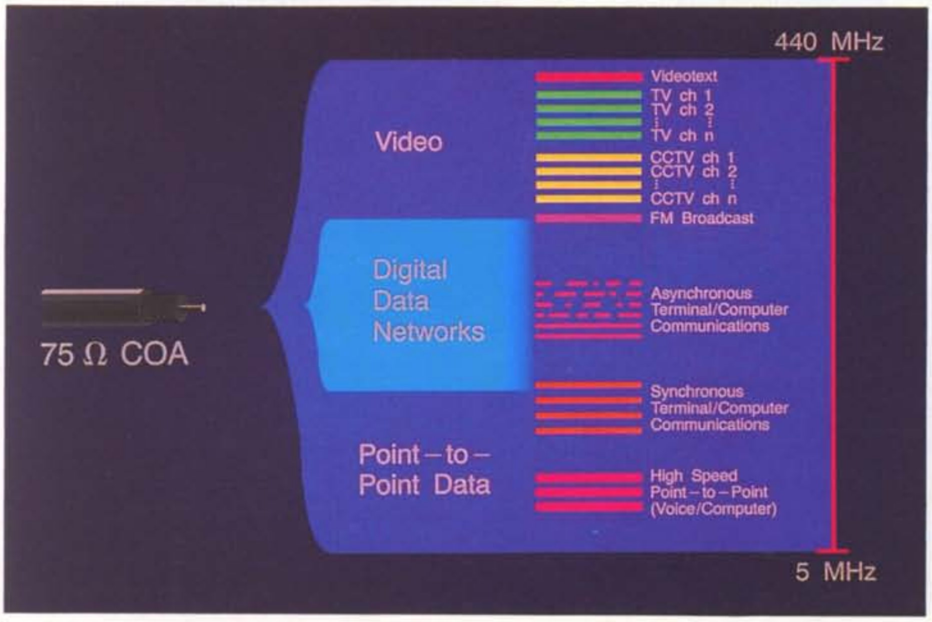


Figure 3 – Merging of several communications functions on a single ESALAN cable

Figure 4 – Typical ESA access station, consisting of facsimile transceiver, modem and multiplexer

- Telex Dutch PTT Public Telegraph Network
- Teletex Deutsche Bundespost Public Text Network
- TRANSPAC PTT France Packet-Switched Network
- VANs (Value-Added Networks):
  - TELENET GTE USA Network
  - TELEMAIL GTE USA Electronic Mail Service
  - TELEBOX Deutsche Bundespost Electronic Mail Service
  - EARN European Academic Research Network (IBM)
  - SPAN Space Physics Analysis Network

Terminals and protocols supported
ESANET supports a wide range of asynchronous (ASCII) terminals, with speeds ranging from 110 bit/s to 19 200 bit/s. In addition to host-computer access, direct terminal-to-terminal communication can be provided. The network also supports the de facto standards for synchronous remote-job entry terminals, such as the IBM 2780 and 3780.

Telecopiers adhering to the CCITT Group 3 recommendation are also supported by ESANET, provided they allow access to an internal modem via an RS232 or V24/28 interface. The individual speeds can range from as low as 1200 bit/s to as high as 19 200 bit/s. At present, only point-to-point connections are possible, but improvements to the telecopiers are currently being evaluated to allow network switching.

The above-mentioned protocol types are used to support four main application classes:

- EDP Support
  - interactive programme development and execution
  - file transfer
  - remote printing
  - remote job entry
  - interactive graphics
  - data entry

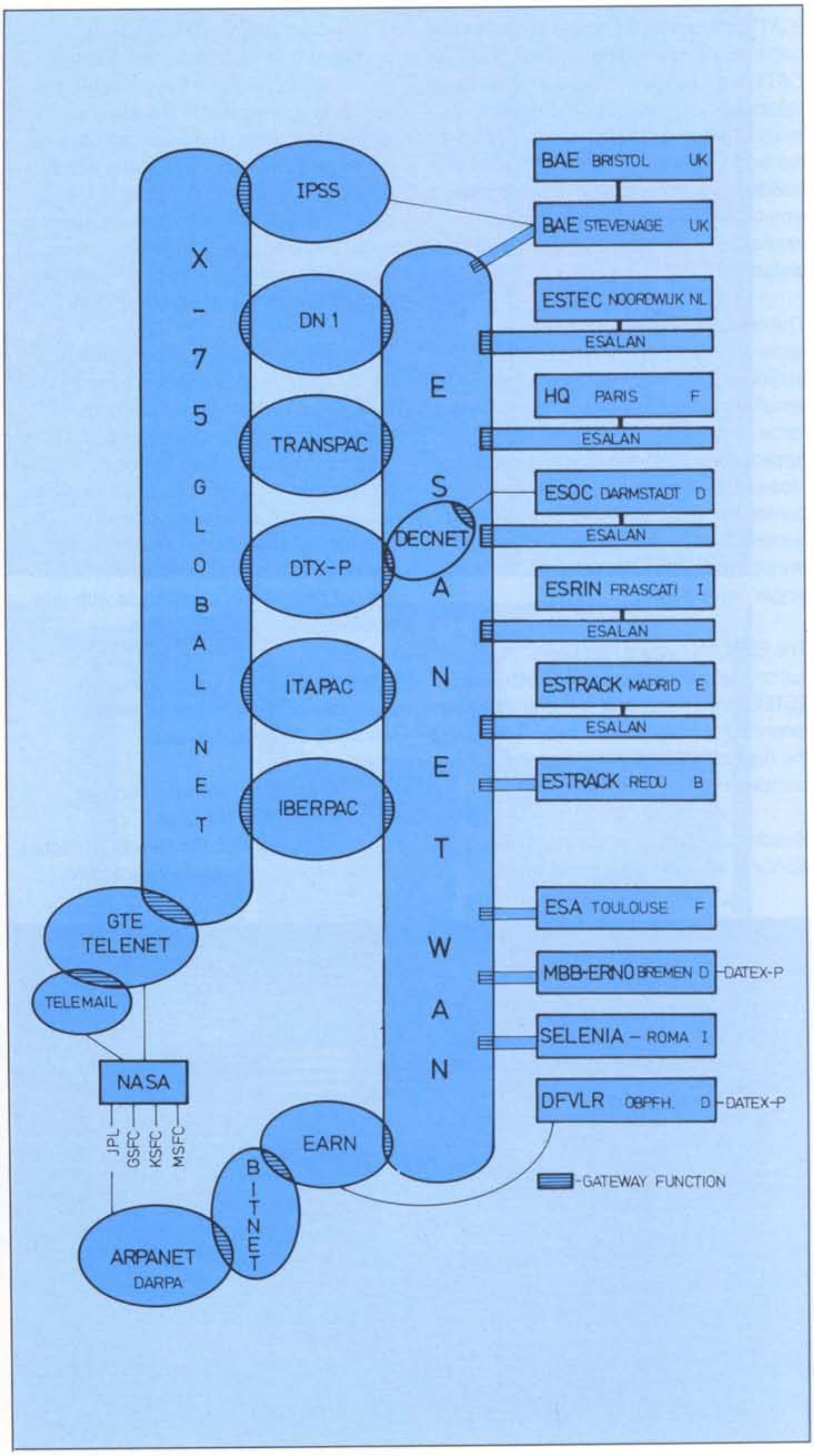
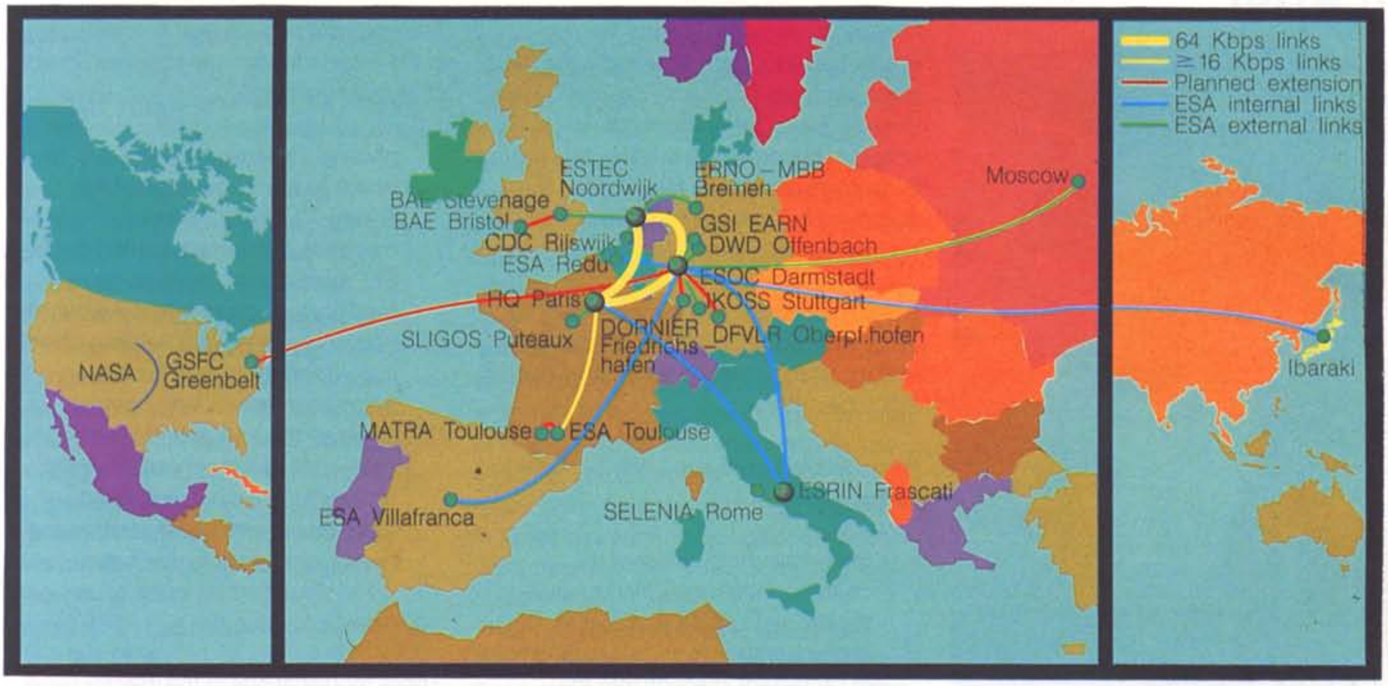


Figure 5 – Functional overview of ESANET, showing the various types of network currently connected (directly or indirectly)

Figure 6 – The current scope of ESANET's Wide-Area Network (WAN) and the extension foreseen in the next two years



- Office Automation
  - word processing
  - message service
    - electronic mail (TELEMAIL, DIALCOM, TELEBOX, PROFS)
    - Telex (Netherlands only)
  - document transmission
    - facsimile (telecopier)
    - TELETEX (Germany only)
    - communicating word processors
- Administrative/Management Services
  - financial management system
  - contract/purchase management system
  - personnel management system
  - library administration system
- Database Retrieval Systems
  - IRS-QUEST
  - IUE image database
  - star catalogues.

Future prospects

As the cost of individual work stations constantly decreases, it is expected that network-terminal proliferation will reach a saturation level closely approaching the current population of office telephone equipment within the Agency. Some 3000 units are therefore foreseen by the end of the decade, demanding both LAN and WAN communications support. Figure 6 shows the current WAN element of ESANET, together with an extension foreseen within the next two years.

In addition to the aforementioned quantitative considerations, further qualitative enhancements are major targets for the future. In particular, the following potential applications and services have been identified:

- CAD (Computer-Aided Design)
- Voice mail
- Voice communication
- Tele/video-conferencing
- Gateway functions to proprietory networks and network architectures (e.g. SNA)
- CEPT Viewdata
- Gateway functions via CCITT X-75
- Support of speed classes: 64 kbit/s – 2 Mbit/s
- Support of long-delay satellite links
- Support of CCITT X-400 message-handling protocols
- Improved accounting and network-control features.

The future functions of ESANET are planned to be directed even further towards a comprehensive general-purpose network, which should form the basis of the Agency's communications infrastructure. As such, it is intended to support both project-specific and general administrative/managerial communications requirements within the Agency, as well as communications with the delegate bodies, research institutes and aerospace industry directly involved in the conduct of the Agency's programmes.

In accordance with the published plans of the PTTs and IRC, the current division between data and voice networks will gradually disappear during the coming decade. This development will drastically change today's networks and transform them into a single Integrated Services Digital Network (ISDN). ESANET is geared towards ISDN and intends to make use of this new service as soon as possible. Investments are therefore being made with this goal in mind, in order to avoid any long-term commitment to an obsolete concept.

In Brief

Failure of the Ariane-3 V15 Launch

The Ariane-3 launcher for flight V15 lifted off from the ELA-1 launch site at Kourou on 12 September 1985 at 23:26:00 h UT, carrying a dual payload made up of the European ECS-3 and American Spacenet-F3 communications satellites.

After the launcher's first and second stages had functioned normally, the third stage separated correctly but then failed to ignite. Because of the resulting unavoidable deviation in trajectory, the third-stage composite had to be destroyed by telecommand from the Kourou Safety Officer.

A Board of Enquiry was immediately set up by Arianespace, and its conclusions and recommendations were submitted on 1 October 1985.

From detailed analyses it was possible to conclude that:

- the pyrotechnic igniter of the chamber had functioned properly;
- the failure to ignite was due to excessive deviations in the conditions of propellant injection into the chamber (mixture ratio and chamber pressure);
- the problem originated from a temporary but substantial leak via the hydrogen injection valve during second-stage flight. This had an effect equivalent to that of the nominal (subsequent) chamber pre-cooling phase. The superimposing of these two phases then led to overcooling of the chamber circuits (regeneration circuit and injectors), so that the injection conditions were outside the permissible limits.

The essential corrective action called for in the recommendations from the Board of Enquiry covers:

- revising the design of the valve, to return to a configuration of the Ariane-1/L7 type. Thermo-mechanical analyses carried out by SEP have shown that the main modification made from L8 onwards (incorporating a counterseal) could, in some circumstances, have an undesirable effect, with contact between the seal and the rotating valve seat no longer certain in the transient state of valve cooling;
- fuller qualification and acceptance-test programmes for the valves, set up to simulate their cycle of use with adequate margins.

These modifications in the injector valve manufacture and test programmes mean a delay in the launch schedule. The next flight, V16 (of Ariane-1 carrying SPOT and Viking), is now planned for mid-January 1986.

His Majesty King Carl XVI Gustav of Sweden (left) and General S.O. Hökborg, President of the Swedish Society of Aeronautics and Astronautics (centre), are welcomed at the ESA Stand by M.P. Hubrecht of ESA Public Relations

ESA at 36th IAF Congress in Stockholm

The 36th International Astronautical Federation (IAF) Congress was held in Stockholm, 7–13 October 1985. Many of the symposia covered topics related to ESA activities including space systems, Earth observation, space transportation systems, microgravity sciences and processes, life sciences and satellite communications, and a number of ESA staff presented papers.

Recent ESA achievements were on view at the Space Technology Exhibition held during the Congress. The ESA stand displayed full-scale models of two ESA scientific spacecraft, Exosat and Giotto. Other models included Meteosat, Marecs, Ariane-4 and Spacelab.

Spacelab D1 – Another Successful Mission for ESA's Spacelab

With the landing of the Space Shuttle Challenger at 17.44 UT on 6 November 1985, the German seven-day D1 mission, the fourth mission of the European Spacelab, was brought to a successful conclusion.

ESA, which was responsible for 38% of the payload in terms of critical resources – mass, energy and crew time – is particularly satisfied with the results of the mission. The Agency's participation consisted of the flight of three major payload facilities: the **Space Sled**, an ESA-developed facility for studies of the behaviour of the human body under microgravity conditions; the **Biorack**, a multipurpose facility for the biological investigation of the effects of microgravity and cosmic radiation on such life forms as tissues, cells, bacteria, insects and plants; and the **Fluid Physics Module** for the study of basic fluid phenomena in space. In addition, ESA's payload specialist, Wubbo Ockels, was a member of the flight crew.

All three ESA facilities performed perfectly, with no operational or technical failures, and the individual investigators were delighted with the results obtained from their experiments. Each new Spacelab mission on which experiments in the microgravity sciences are performed is providing new insight into this relatively new field and bringing us closer to the commercialisation of space.

ESA's Space Sled performed particularly well and about 20% more runs than scheduled were made. The first results confirm and indeed amplify to a great extent those obtained from the vestibular experiments carried out during the first Spacelab mission in 1983, when the Sled was not aboard. In particular, they have provided a great deal of information about the effects of microgravity on the human body, information that is of vital importance for the future, when man will be expected to live and work in space for extended periods.

Very interesting results have also been derived from the Biorack experiments, which show interalia that cell proliferation and differentiation are strongly affected by the space environment. Such information could be extremely important in furthering our knowledge of the body's immune responses.

The Fluid Physics Module, which has been improved upon since its first flight on Spacelab-1 in November/December 1983, worked perfectly during the D1 mission. The eight experiments planned were successfully carried out and the crew had sufficient time available to carry out several additional, unscheduled experiment runs in consultation with the Principal Investigators in the Payload Operations Centre in Oberpfaffenhofen. The FPM experiments are designed to investigate the static and dynamic behaviours of liquids and the solid/liquid interface under microgravity. The results of such investigations are providing the fundamental knowledge on which materials processing in space will build.

Wubbo Ockels entering the ESA sleep restraint system (currently under patent application), which provides an even distribution of pressure over the astronaut's body by means of inflatable tubes.

ESA's Director General Receives T. von Karman Award

Professor Reimar Lüst, ESA's Director General, has been elected 1985 recipient of the T. von Karman Award of the International Academy of Astronautics (IAA) for his sustained contribution to the advancement of space science and technology and the peaceful uses of outer space.

The T. von Karman Award, established by the IAA in honour of the 100th anniversary of the birth of Dr. von Karman (1881 – 1963), was presented to Professor Lüst by the IAA president Dr. George Mueller (left) on 10 October at the IAA luncheon during the 36th IAF Congress.

Ulysses Orbit Selected

The accompanying photograph shows the members of the Ulysses Science Working Team (SWT) who gathered at ESTEC on 30 and 31 May 1985. The SWT, composed of the scientific investigators from Europe and the US, has met regularly since the start of the joint ESA/NASA programme in 1978. At this last meeting in Europe prior to launch, final spacecraft test results and plans for orbital operations and data analysis were discussed.

Specifically, the SWT opted for a south-going mission, i.e. to have the spacecraft first go over the southern solar pole.

Ulysses (formerly known as the International Solar Polar Mission) is due for launch by the Shuttle and Centaur upper stage in May 1986. The Ulysses spacecraft underwent final system testing in ESTEC earlier this year and will be shipped to Eastern Test Range, Florida, in January for launch preparation.

Balloon Crew Communicates by Satellite

In early 1984, ESTEC was approached by a Dutch trans-Atlantic Balloon Expedition enquiring about the possibility of obtaining a satellite communication link. The Agency's PROSAT (an ESA mobile-satellite-communication programme) team, which had already performed several experimental communication campaigns on board small ships, trucks and aircraft, therefore became involved.

With the help of ESTEC's RF System Division's laboratories and the ESTEC Engineering Workshop, a light terminal with a small hand-held helical antenna was quickly designed and constructed to provide voice communication (see below).

In addition, at ESA's request, Inmarsat granted a dedicated communication channel via the Marecs-A satellite. The channel worked in a double-hop, through ESA's Villafranca (Spain) station, in order to link the balloon crew with their Flight Centre at Amsterdam airport, which was equipped with a small ship earth station.

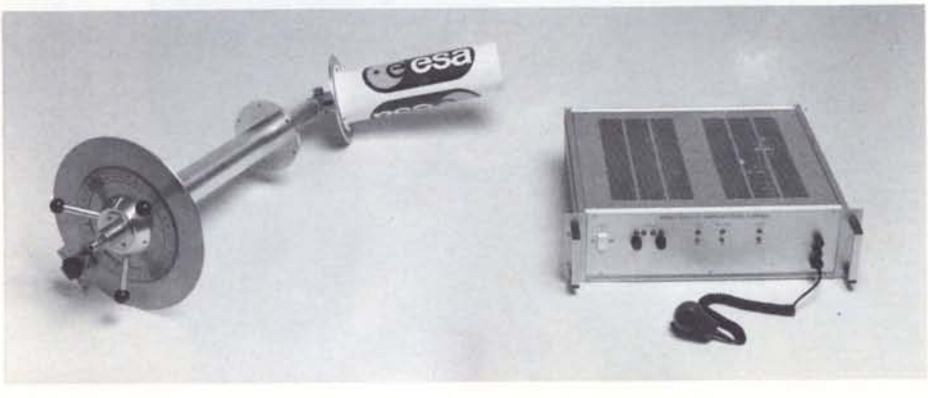
The aim of the expedition was to perform the first trans-Atlantic crossing between Canada and Holland on board a hot-air and helium balloon in less than three days. The crew – two men and one woman – were accommodated in a modified polyester lifeboat, replacing the traditional basket, for improved protection and greater safety.

After several false alerts, a suitable meteorological situation developed in late August and the balloon left New Foundland on 26 August. After a perfect 33 h flight during which the satellite link was used extensively for real-time transfer

of information, a valve malfunction forced the 'Flying Dutchman' to ditch in the sea in mid-Atlantic. Nevertheless, several flight records had already been established.

Via the satellite link, the crew were able to communicate the nature of the problem and their distress beacon was picked by a Pan Am flight. They were subsequently recovered in good health by a nearby tanker.

The team is determined to make another attempt next year, with of course satellite communication.



First Giotto Encounter Rehearsals a Success

On 14 and 16 October 1985, ESA's Space Operations Centre (ESOC) successfully simulated Giotto's encounter with Halley's Comet by testing the spacecraft's systems, the different scientific instruments and the associated ground systems in the first of a series of rehearsals which will take place up until the final 'dress rehearsal' a few days before encounter. The rehearsals showed that both the spacecraft and its payload were working satisfactorily and have helped both the experimenters and the engineers working on the project to gain a better insight into the type of situation that they may have to face on 13 March 1986.

Prior to this first formal rehearsal, all scientific instruments (see accompanying table) had been switched on and tested.

The two Plasma Analysers and the Ion Mass Spectrometer have already produced measurements of the solar wind and its composition, while the magnetometer has provided data on the interplanetary magnetic field. The on-board camera has already made important observations of the star Vega, the planet Jupiter and, on 18 and 23 October, of the Earth (see next page).

Giotto is now over 21 million kilometres from Earth on a trajectory which, if no further corrections were made, would take it to within 10 000 kilometres of the nucleus of Halley's Comet. Orbit corrections over the coming months will reduce this distance to the planned 500 kilometres from the nucleus. Weekly payload operations are planned until the end of this year, with somewhat more extensive payload operations from January 1986 onwards.

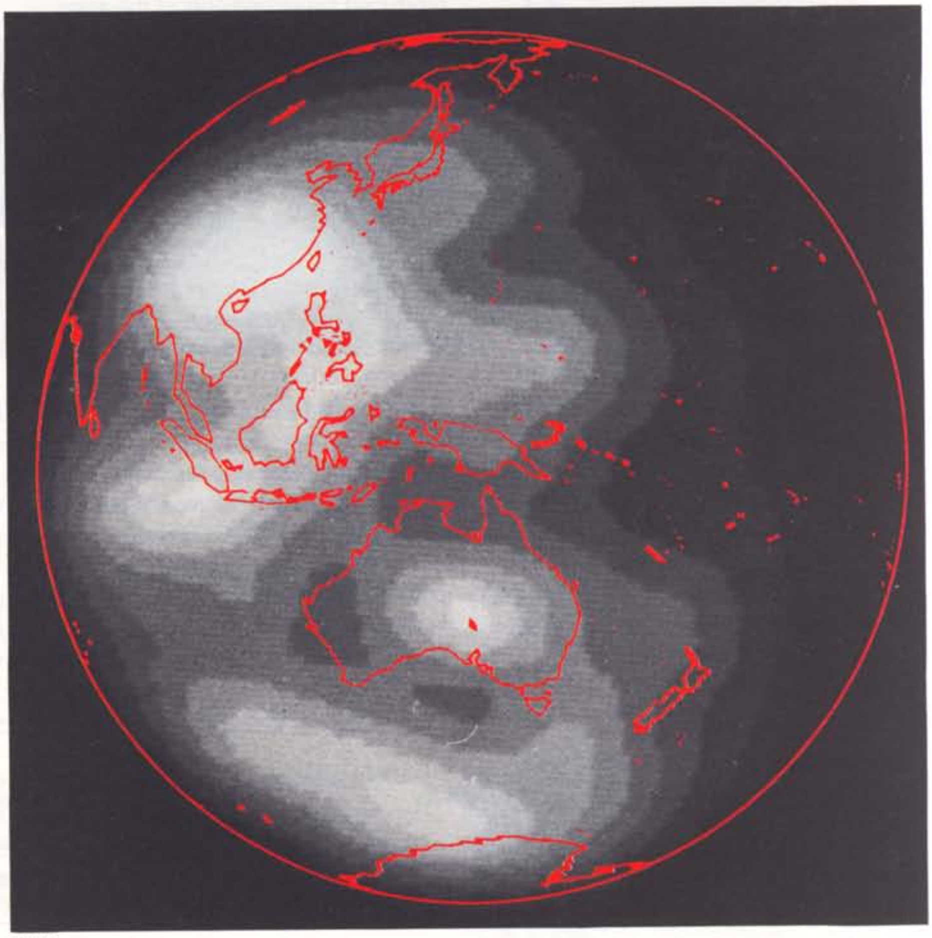
Giotto scientific payload

Experiment	Principal investigator	Institute	Measurement	First switched on
Camera (HMC)	Dr. H.U. Keller	Max-Planck-Institut für Aeronomie Lindau (D)	Colour imaging of cometary nucleus and inner coma	9 August
Neutral Mass Spectrometer (NMS)	Dr. D. Krankowsky	Max-Planck-Institut für Kernphysik Heidelberg (D)	Energy and mass of neutrals	12 September
Ion Mass Spectrometer (IMS)	Dr. H. Balsiger	University of Bern Bern (CH)	Energy and mass of ions	7 September
Dust Mass Spectrometer (PIA)	Dr. J. Kissel	Max-Planck-Institut für Kernphysik Heidelberg (D)	Mass and composition (1–110 amu) of individual dust particles	13 October
Dust Impact Detector System (DID)	Prof. J.A.M. McDonnell	University of Kent, Canterbury (UK)	Determination of the mass spectrum of dust particles from three different detectors	8 October
Plasma Analysers (JPA)	Dr. A. Johnstone	MSSL, University College London (UK)	Solar wind ions, cometary ions in the outer coma	8 September
Plasma Analysers (RPA)	Prof. H. Rème	Centre d'Etudes Spatiales des Rayonnements, Toulouse (F)	Solar wind electrons, cometary ions in the inner coma	8 September
Energetic Particles (EPA)	Dr. S. McKenna-Lawlor	St. Patrick's College, Maynooth (IRL)	3-D measurement of protons, electrons and alphas	22 August
Magnetometer (MAG)	Prof. F.M. Neubauer	Universität zu Köln, Köln (D)	Interplanetary and cometary magnetic field	22 August
Optical Probe Experiment (OPE)	Prof. A.C. Levasseur-Regourd	Service d'Aéronomie du CNRS, Verrières le Buisson (F)	Coma brightness in four continuous (dust) bands and at four discrete wavelengths (gaseous emissions of OH, CN, CO^+, C_2)	13 September
Radio Science (GRE)	Prof. P. Edenhofer	University of Bochum (D)	Cometary electron content. Cometary mass (coma dust and gas) fluence	No on-board hardware. First measurements early September

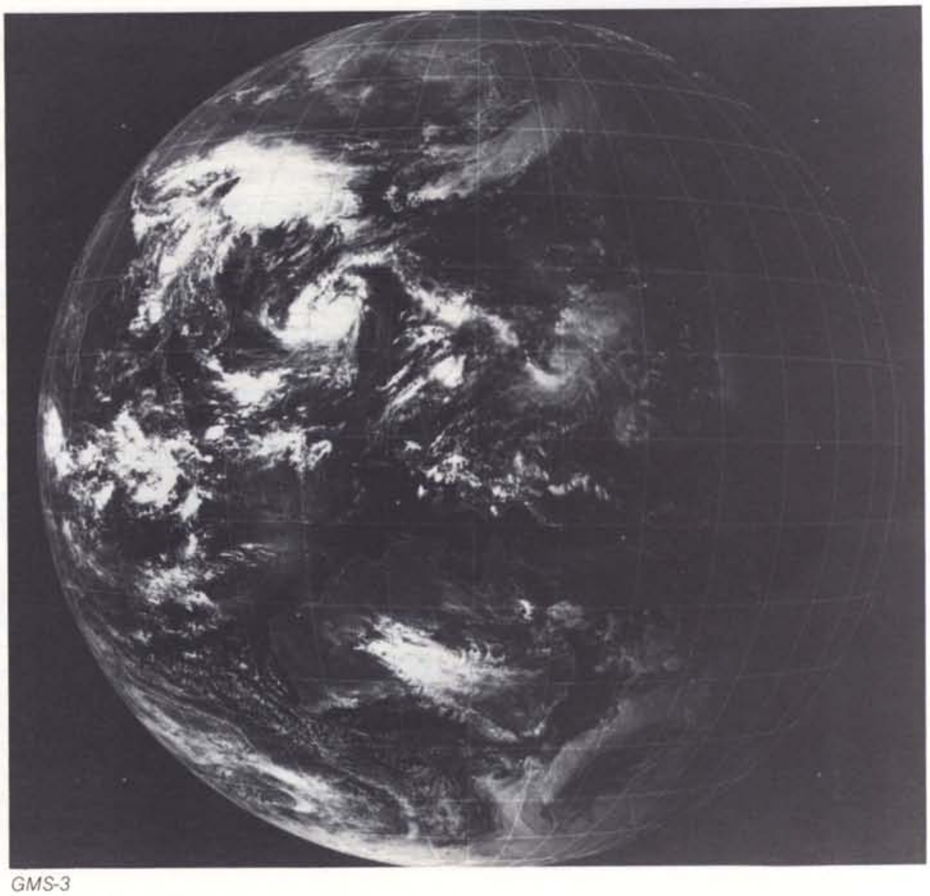
First Images from the Halley Multicolour Camera On-Board Giotto

The Halley Multicolour Camera (HMC) is part of the scientific payload of the Giotto spacecraft, which was launched on 2 July and is now on its way to encounter Comet Halley on 13 March 1986. The Camera is a high-resolution imaging system specially designed to operate from the rotating, spin-stabilised (15 rpm) space probe. It will function in a completely self-contained, automatic mode during the close, fast flyby of the cometary nucleus, and can search for, acquire and track the comet automatically.

The scientific objectives of the HMC are to detect the cometary nucleus and to investigate its size, shape and morphology as well as the interaction of gas and dust during the evaporation process by providing images in various filter bands. A telescope of 1 m focal length and 16 cm aperture focusses the light onto two CCD (Charge-Coupled Device) detectors, each having 2 × 292 × 390 picture elements, which operate in a line-scan mode. Four pictures in different colours can be taken at the same time. A filter wheel provides 11 different pass bands. The HMC's extremely complex operations are controlled by three microprocessors using about 50 kilobytes of onboard software. The spatial



HMC



GMS-3

Figures 1 and 2 — A comparison of images taken by the Halley Multicolour Camera (HMC) and the GMS-3 weather satellite, looking at the Earth from the same longitude (140°E). The HMC picture was taken at 5:18 UT, 42 min earlier than the satellite image, and from a southerly declination of −8°, rather than from the equator. The Sun – Earth – observing platform phase angle was thus 10° smaller for the HMC image and the Earth was therefore slightly 'fuller'. The Giotto spacecraft was 21 million kilometres from Earth, i.e. nearly 600 times further away than the weather satellite in geostationary orbit. The good correlation of the cloud formations is obvious. The black and white reproduction uses only 10 grey-scale levels. The same image is shown in false-colour representation on the front cover of this Bulletin (GMS-3 picture courtesy of Meteorological Satellite Centre, Tokyo)

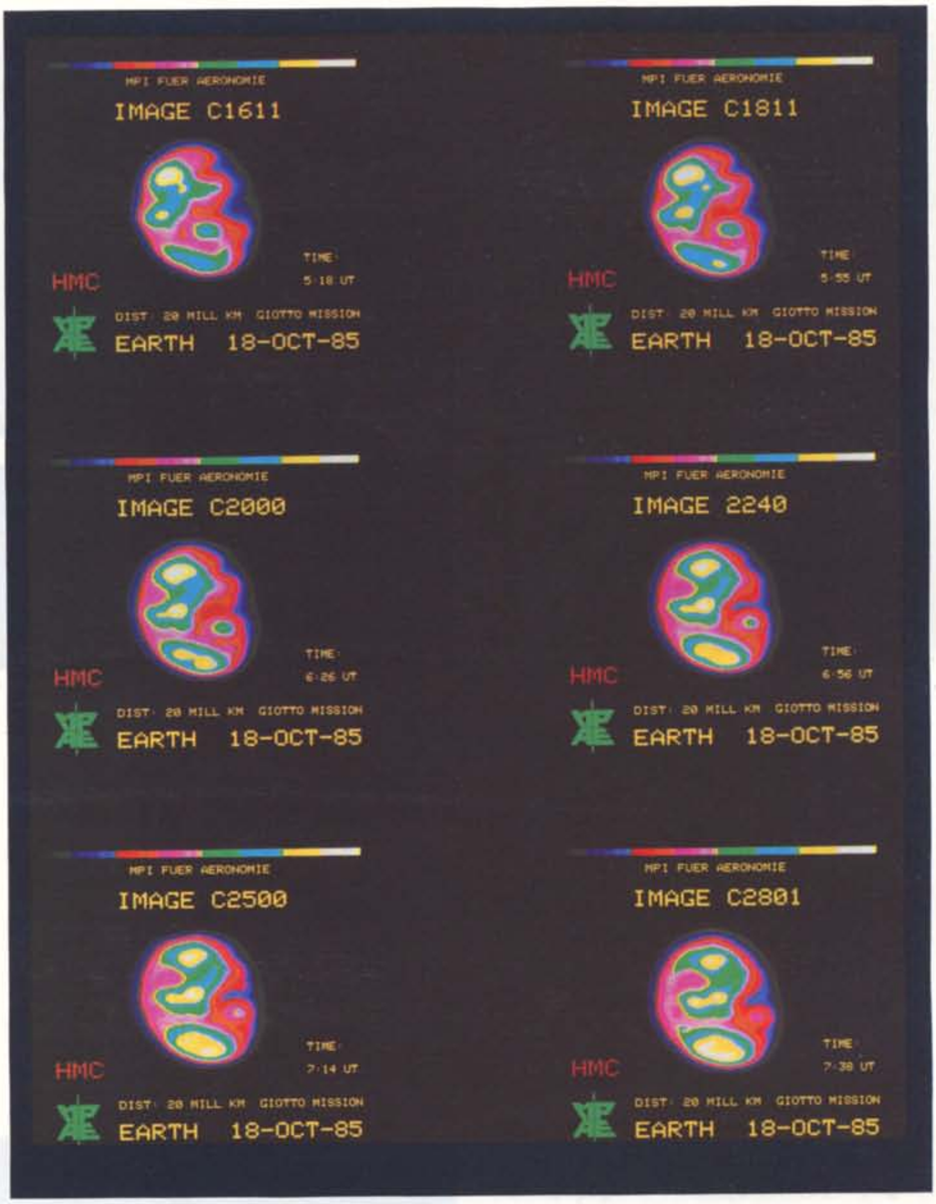


Figure 3 – Six images of the Earth taken between 5:18 UT and 7:38 UT on 18 October 1985. The Earth's rotation is clearly visible. The cloud patch above Australia disappears into the terminator. Note that the Earth's rotation axis is slightly tilted (north pole to the left). The images are presented in false colour and the intensity scale is the same for all images

resolution of the HMC corresponds to 22 m per picture element from a distance of 1000 km, and its exposure time varies from 14 to 1000 microseconds per line, depending on the offset angle from the spacecraft's spin axis. For comparison, the HMC would be able to take a portrait picture, with five millimetre resolution, of the pilot of a jet aircraft passing within 200 metres of the camera at the speed of sound, namely 1200 km/h.

After initial tests involving observation of the star Vega and planet Jupiter, the Camera was rotated by 135° to look back at the Earth on 18 and 23 October 1985. By then, Giotto was already 21 million kilometres, or 70 light seconds, from Earth, the apparent diameter of which corresponded to only 2 arcmin (1/15 of that of the lunar disc as seen from Earth), or 27 picture elements of the Camera's CCD detectors.

The Earth is an ideal test target for the HMC's observational modes and the 135° rotation corresponded to the 45° position from which the Camera will look at the cometary nucleus just before encounter. Four images are taken quasi-simultaneously in different colour bands (red, orange, blue and clear).

All of the images shown here were processed on ground-support equipment which is still in a preliminary form. The raw data were decompressed and the contrast was stretched, followed by slight smoothing. The overlay indicates the continents.

Acknowledgement
The development, manufacturing and testing of the Camera would not have been possible without the dedicated support of many individuals, organisations and institutes, too numerous for inclusion here. Their endeavours are gratefully acknowledged.

H.U. Keller, W.K.H. Schmidt & K. Wilhelm, MPAE

The Halley Multicolour Camera Team

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ESA Stand at 'Darmstadt Innovativ'

The Agency's Operations Centre (ESOC) has recently participated in 'Darmstadt Innovativ', an exhibition held to promote industry in the Darmstadt region and to present recent innovations in technical and scientific fields to the general public. The exhibition, which lasted from 26 September to 6 October, was visited by about 100 000 people.

On the ESA stand the Meteosat 'live weather map' and the planetarium, with its visual display on the Giotto mission, were particularly popular. Lectures on the Giotto mission and the Meteosat, Marecs, and ECS systems were also given by ESA staff members serving at ESOC.

Austria and Norway Full Member States

At its 71st meeting on 23 and 24 October 1985, the ESA Council unanimously approved the accession of Austria and Norway to full membership status, bringing the number of ESA Member States to 13.

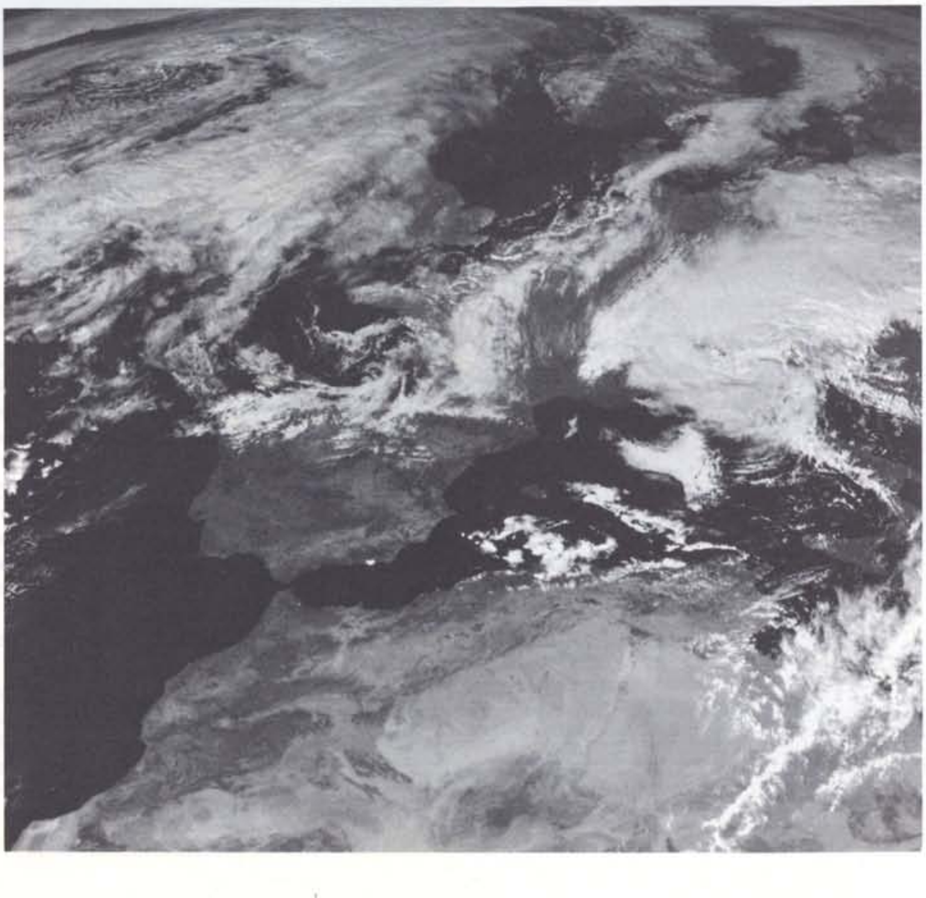
The Agreement between the Governments of the Republic of Austria and of the Kingdom of Norway and the Agency will now be put forward for governmental approval and parliamentary ratification in the two countries concerned with the aim of achieving formal full membership status on 1 January 1987.

Both Austria and Norway have been closely associated with many of the Agency's activities over the past twenty years including, in particular, the Spacelab, Marecs and ERS-1 programmes. They have been Associate Member States since 1 April and 1 November 1981, respectively.

Meteosat-F1 End-of-Lifetime

ESA's first pre-operational meteorological satellite, Meteosat-F1, has finally run out of hydrazine fuel and can no longer be maintained in position by the Agency's Space Operations Centre (ESOC). It has now drifted to the extent that it is no longer visible from the Michelstadt (D) ground station.

Launched on 23 November 1977 and originally designed for a three-year lifetime, Meteosat-F1 has successfully supported the data collection mission for the last eight years.



Publications

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

ESA Journal

The following papers have been published in ESA Journal Vol. 9, No. 3:

FEASIBILITY OF SATELLITE TRACKING WITH A DUAL-WAVELENGTH LASER RANGING SYSTEM
MASTROCINQUE G

COMPUTER SIMULATION OF QUANTISATION EFFECTS ON ERS-1 WAVE-MODE SPECTRA
PIKE T K & WOLFRAMM A P

A PRAGMATIC APPROACH TO COLOUR-TABLE HANDLING
KERR G W

ESA-SPONSORED DEVELOPMENTS IN THE FIELD OF DEPLOYABLE MASTS
AGUIRRE-MARTINEZ M A

LONG LIQUID BRIDGES ABOARD SOUNDING ROCKETS
MARTINEZ I & SANZ A

MICROWAVE HOLOGRAPHIC MEASUREMENT OF REFLECTOR SURFACE ACCURACY
ORTA R

A CHANNEL-SIMULATION FACILITY FOR MOBILE COMMUNICATIONS
HART N R

EPOXY JOINTS AND MATRICES FOR COMPOSITES THAT MUST ENDURE THERMAL CYCLING
DVORKO I M ET AL

AN EVALUATION OF THE TIME-DOMAIN COMMUNICATION SYSTEM SIMULATOR TOPSIM III
KRISTIANSEN E ET AL

THE GIOTTO SPACECRAFT'S PERFORMANCE DURING THE GEOSTATIONARY TRANSFER-ORBIT AND NEAR-EARTH MISSION PHASES
TRACY J L ET AL

Special Publications

ESA SP-209 // 210 PAGES
METRIC CAMERA WORKSHOP (APR 1985)
GUYENNE T D & HUNT J J (EDS)

ESA SP-229 // 400 PAGES
SEVENTH ESA SYMPOSIUM ON EUROPEAN ROCKET AND BALLOON PROGRAMMES AND RELATED RESEARCH, LOEN, NORWAY, 5-11 MAY 1985 (AUG 1985)
GUYENNE T D & HUNT J J (EDS)

ESA SP-234 // 274 PAGES
THE EUROPEAN ASTROMETRY SATELLITE HIPPARCOS – SCIENTIFIC ASPECTS OF THE INPUT CATALOGUE PREPARATION (AUG 1985)
GUYENNE T D & HUNT J J (EDS)

ESA SP-236 // 314 PAGES
RECENT RESULTS ON CATACLYSMIC VARIABLES – PROC ESA WORKSHOP HELD AT REMEIS OBSERVATORY, BAMBERG, GERMANY, 17-19 APRIL 1985 (JUNE 1985)
BURKE W R (ED)

ESA SP-244 // 191 PAGES
THE USE OF SATELLITE DATA IN CLIMATE MODELS (SEPT 1985)
HUNT J J (ED)

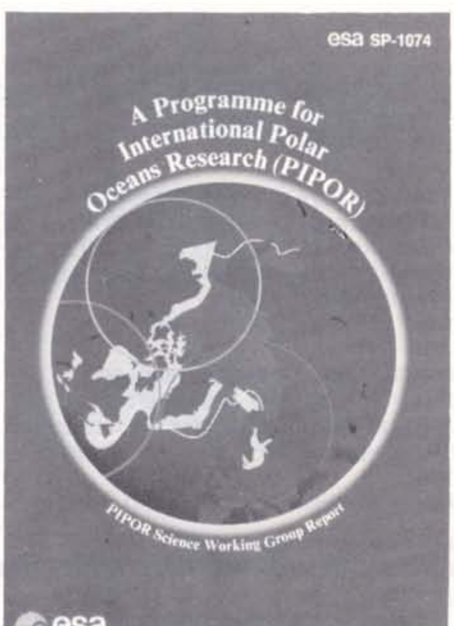
ESA SP-1074 // 42 PAGES
A PROGRAMME FOR INTERNATIONAL POLAR OCEANS RESEARCH (PIPOR) – PIPOR SCIENCE WORKING GROUP REPORT (SEPT 1985)
BATTRICK B & ROLFE E J (EDS)

Procedures, Standards & Specifications

ESA PSS-01-603 ISSUE 2 // 82 PAGES
ESA PREFERRED PARTS LIST (JUNE 1985)
PRODUCT ASSURANCE DIVISION, ESTEC

ESA PSS-01-708 ISSUE 1 // 80 PAGES
THE MANUAL SOLDERING OF HIGH-RELIABILITY ELECTRICAL CONNECTIONS (MAR 1985)
PRODUCT ASSURANCE DIVISION, ESTEC

ESA PSS-01-709 ISSUE 1 // 29 PAGES
MEASUREMENT OF THERMO-OPTICAL PROPERTIES OF THERMAL CONTROL MATERIALS (JULY 1985)
PRODUCT ASSURANCE DIVISION, ESTEC



ESA PSS-01-720 ISSUE 1 // 19 PAGES
DETERMINATION OF THE SUSCEPTIBILITY OF SILVER-PLATED COPPER WIRE/CABLE TO RED PLAGUE CORROSION (JUL 1985)
PRODUCT ASSURANCE DIVISION, ESTEC

Scientific & Technical Reports

ESA STR-214 // 114 PAGES
DETERMINATION OF SPECTRAL DISTRIBUTIONS AND INSTRUMENTAL MAGNITUDES OF PLANETS (MAR 1985)
HOVENIER J W, CORNET C & STAMMES P

ESA STR-215 // 36 PAGES
AN OUTLINE OF THE PRACTICAL USE OF LIE SERIES (APRIL 1985)
HA L C VAN DER

Contractor Reports

ESA CR(P)-1512 VOL 2 // 122 PAGES
ANALOGUE SAR SIGNAL PROCESSING – VOLUME 2: ARCHITECTURE AND TECHNOLOGY (MAR 1979)
FERRANTI, UK

ESA CR(P)-2034 // 87 PAGES
GUIDELINES ON BASIC ASPECTS OF JOINTING TECHNOLOGY FOR ADVANCED FIBRE REINFORCED PLASTICS USED IN SPACE STRUCTURES (SEP 1985)
FULMER RESEARCH LABORATORIES LTD, UK

ESA CR(P)-2059 // 310 PAGES
A HIGH-POWER, PULSED MICROWAVE TUBE FOR A SYNTHETIC APERTURE RADAR – ELECTRICAL MODEL: PHASE 2: MANUFACTURE AND TEST – FINAL REPORT (SEP 1984)
THORN EMI VARIAN, UK

ESA CR(P)-2061 // 123 PAGES
SURFACE POTENTIAL MONITOR – FINAL REPORT (DEC 1984)
SEP, FRANCE

ESA CR(P)-2062 // 407 PAGES
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