european space agency

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number 66

may 1991

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 Austria, Belgium, Denmark, France, Germany, Ireland, Italy, Netherlands, Norway, Spain, Sweden, Switzerland and the United Kingdom. Finland is an Associate Member 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.

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The Directorate of the Agency consists of the Director General; the Inspector General; the Director of Scientific Programmes; the Director of Observation of the Earth and its Environment; the Director of the Telecommunications Programme; the Director of Space Transportation Systems; the Director of the Space Station and Microgravity Programme; the Director of ESTEC; the Director of Operations and the Director of Administration.

The ESA HEADQUARTERS are in Paris.

The major establishments of ESA are:

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

ESRIN, Frascati, Italy.

Chairman of the Council: Prof. F. Carassa

Director General: J.-M. Luton.

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, l'Autriche, la Belgique, le Danemark, l'Espagne, la France, l'Irlande, l'Italie, la Norvège, les Pays-Bas, le Royaume-Uni, la Suède et la Suisse. La Finlande est membre associé de l'Agence. Le Canada beneficie d'un statut d'Etat coopérant.

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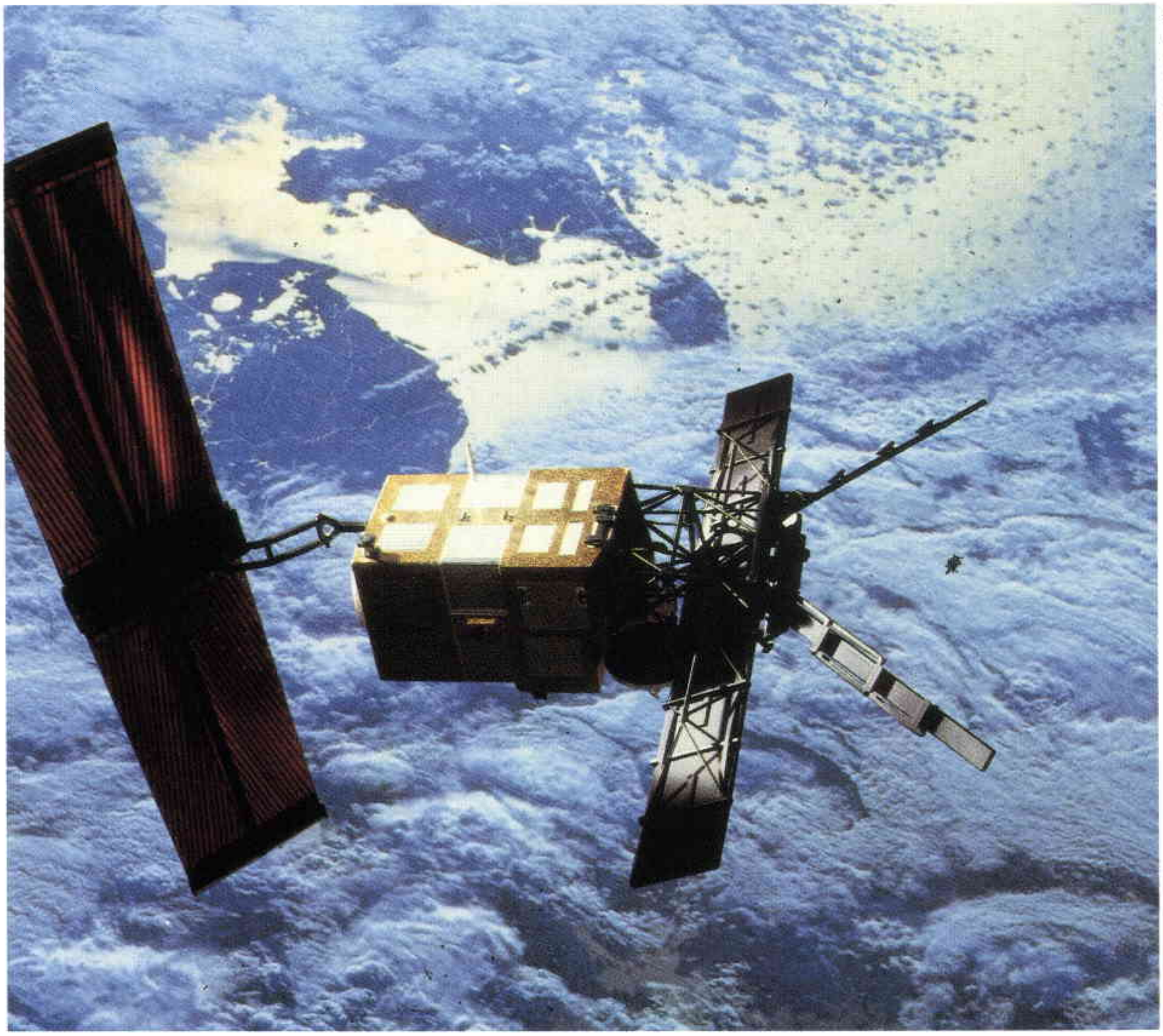
Milestones in Space.



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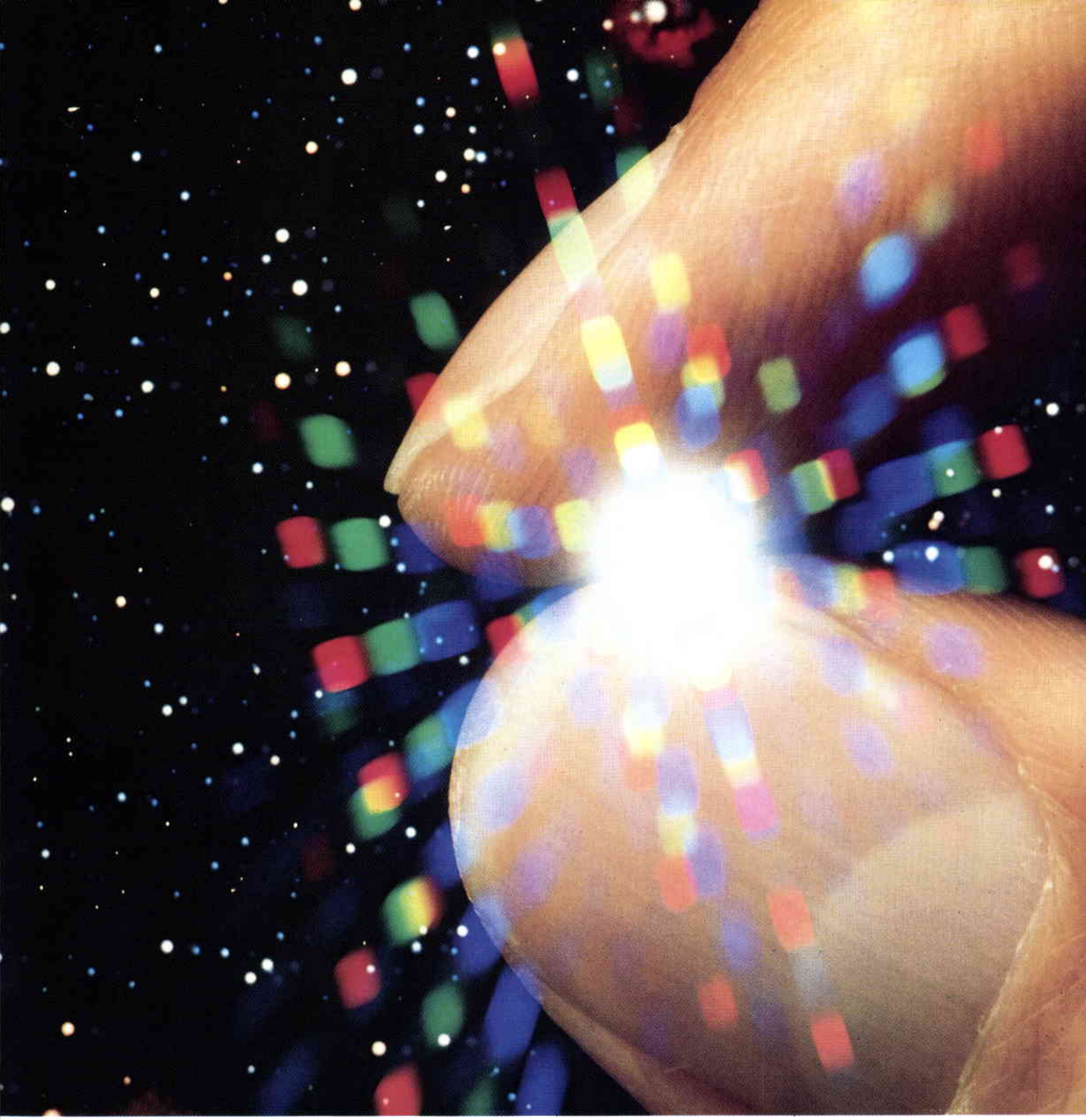

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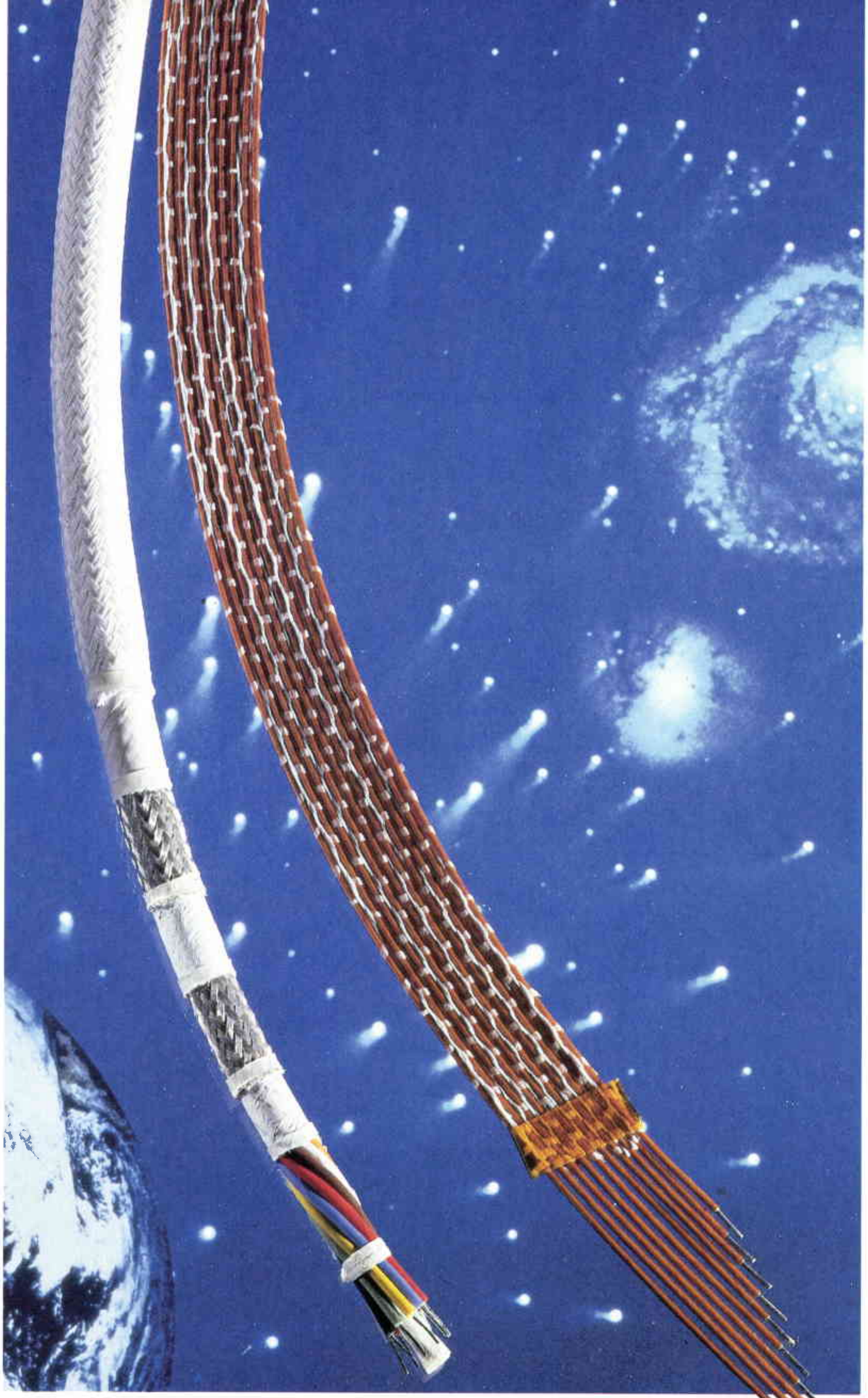

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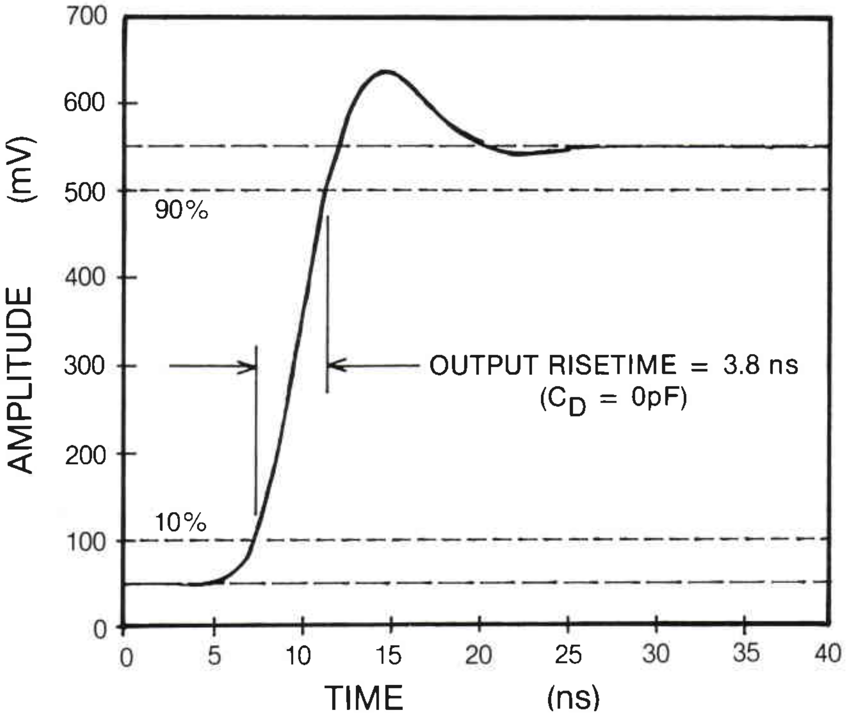

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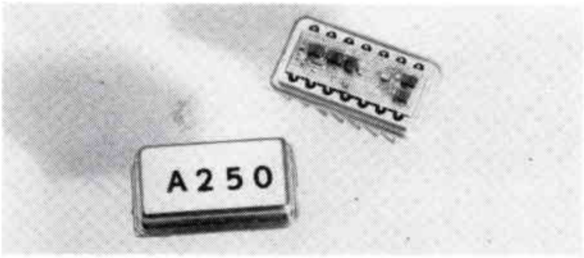

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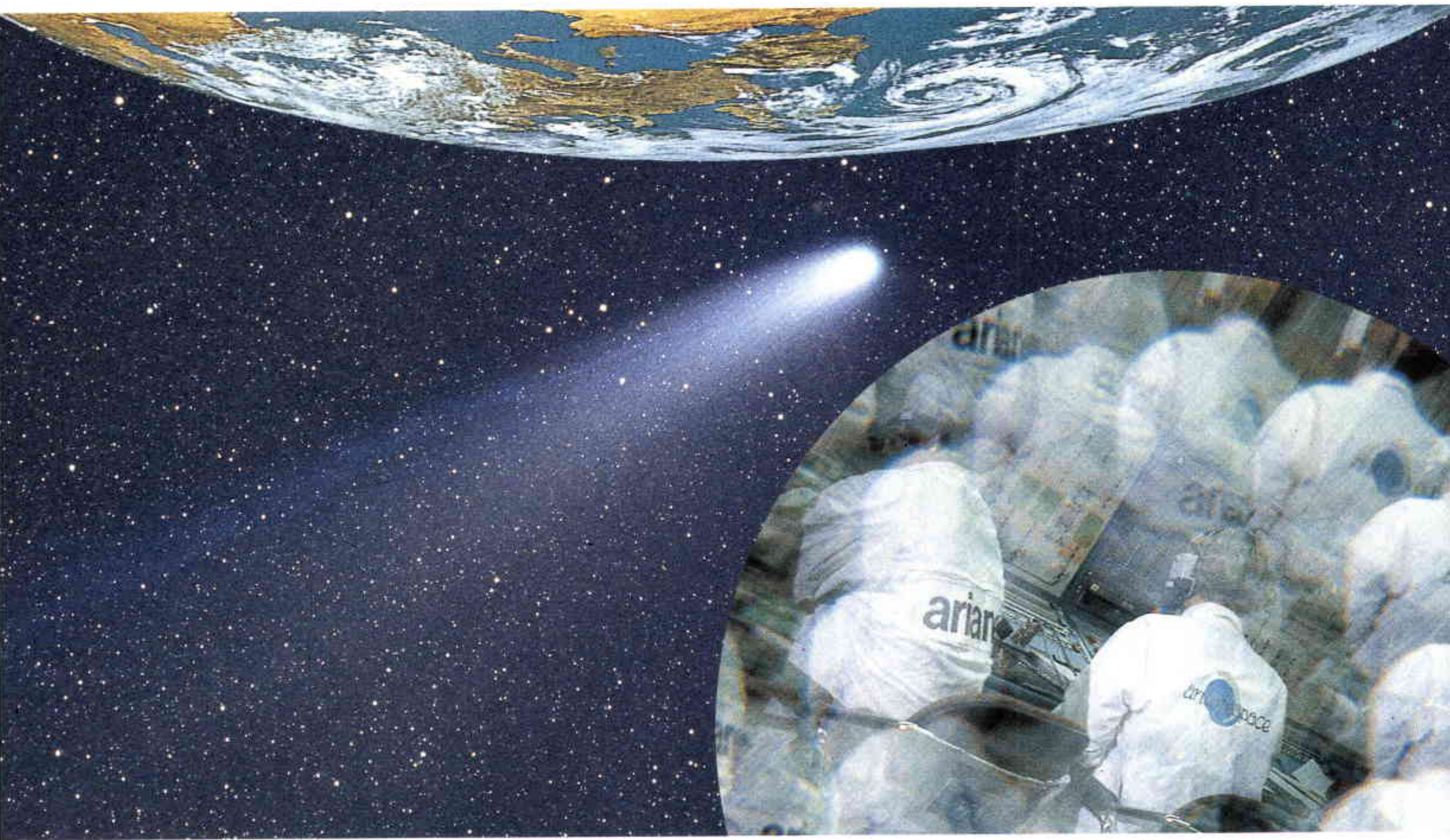
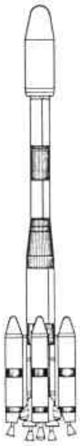
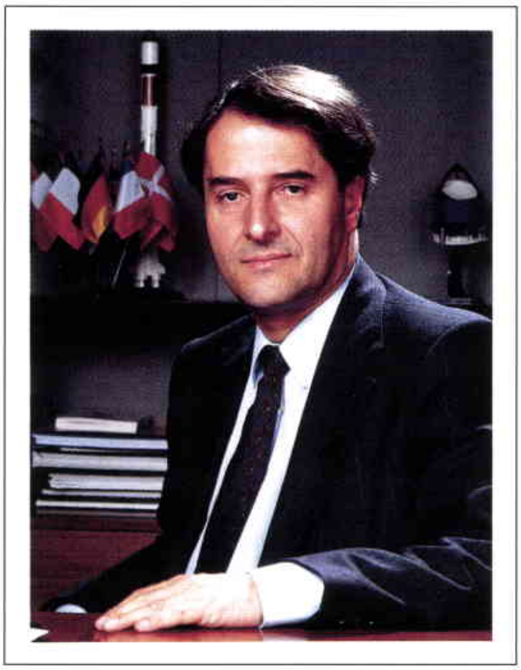






The Agency's Current and Future Policy

Jean-Marie Luton
Director General, ESA, Paris

My primary objective here is to present my overall assessment of the space situation in Europe, covering both the developments that have taken place since the ESA Council met at Ministerial Level in The Hague, in November 1987, and what the next months are likely to bring for European space in view of the decisions to be taken by the forthcoming Council at Ministerial Level.

Europe's long-term programme is ambitious. It is clear that we are going to spend a lot of money on the space programme in the years ahead and it seems only appropriate that we should now ask ourselves how best we can preserve the objectives set in The Hague, more than three years ago, with a programme adapted to the present political and economic circumstances.

Since The Hague Meeting, the background against which the European programme must be executed has changed significantly, not only in Europe itself but world-wide. These changes can be considered in two categories: space and non-space.

As far as space is concerned, all major participants have re-assessed their space programmes. If we look to the other side of the Atlantic, space policy in the United States has been the subject of a thorough review by the Augustine Committee, which has called for the setting of new priorities. Its report gives the highest importance to science, including Earth observation, and the project known as 'Mission to Planet Earth' focusing on environmental questions.

There are also signs of fundamental policy changes in the Soviet space programme. Past objectives of political prestige have been scaled back and have been complemented by a new range of goals aimed at developing commercial space efforts and at providing useful technologies to the domestic economy.

Meanwhile, the political landscape in Europe has also been changing. There are three particularly important factors here: the increased awareness that the environment needs to be protected; the long-term effects of the re-unification of Germany and the political and economic developments; and the shorter term effects of the recent evolution in the economy. These have put considerable strain on the financial resources of some Member States and have certainly also influenced public opinion on the priority to be given to space.

Finally, the Agency's role has changed and will continue to change. ESA is essentially an R & D organisation and there now exist a number of operational organisations such as Arianespace, Eutelsat and Eumetsat whose existence may be seen as the direct result of research and development spending by ESA. There is also a growing interest in space affairs on the part of the European Commission, and we are already looking at specific areas in which the ESA Programme is of relevance to the Commission's work.

The time has come to reflect on the Agency's role and to place it in a new perspective. In my view, ESA has been and should remain an effective instrument for innovation. Other entities will need to be created charged with operating the systems developed by the Agency. A case in point is telecommunications, which has reached a certain maturity and where ESA is striving to work with the users in the planning and financing of new services. This debate is only just beginning, but we have to give further thought to this issue in the longer term.

Following the re-appraisal of the Agency's targets and strategy, and taking into account the work and progress of the past three years, I will propose to Ministers a plan to maintain in essence the political commitments made in The Hague. This plan will be adapted to the new technical and political constraints. The proposal will also take into account the financial constraints of some Member States, and this will mean a more moderate increase in spending over the coming years than was foreseen in The Hague.

Science

Coming to specific programmes, I would like to turn first to the Science Programme. This is the only mandatory programme within the Agency, to which all Member States contribute according to their Gross National Product (GNP).

Today's 'Space Science: Horizon 2000' Programme was drawn up by the Agency in 1984, after a full consultation with the scientific community, in striving for a planned approach rather than the previous opportunistic system under which scientific missions were selected. A review of 'Horizon 2000' has recently been completed by an independent team chaired by Prof. K. Pinkau (Max-Planck Institute for Plasma Physics, Garching) and the Agency has already started to put the team's recommendations into effect. I will mention here just some of the items considered and the steps that have been taken, which I think will prove very beneficial for our Science Programme.

Last December, our Member States agreed to continue to increase the funding for the Science Programme by 5% per year until 1994. This decision is a real achievement and confirms that the Programme's concept and its content are indeed correct. In order to get the best value out of this increased financing, we are re-examining the Programme overheads and the incidental costs of managing industrial contracts.

In March, we organised a workshop with industry to identify possible changes in business practices that would lead to greater efficiency and reduced cost. We are now in the process of developing an even more vigorous Science Programme management philosophy which maximises the return for each accounting unit spent.

It is right that Member States should question from time to time whether their continuing investment in ESA is worthwhile. On the whole, the conclusion is that ESA provides good value for money.

Europe can point with justified satisfaction to the most imaginative science missions, such as Giotto and Hipparcos, and Ulysses, which will make the first-ever survey of the solar-polar regions. There can be no doubt that Europe knows how to do science, but we are perhaps not yet so good at selling it!

Earth observation

The Agency's Earth-Observation Programme is one that is not only very important scientifically, but will also have a lot of applications on a longer time scale.

The interest in environmental issues has emerged as a major new phenomenon to which we must respond. It should therefore come as no surprise that, as the Agency prepares proposals to be put to Ministers, Earth observation is one of the elements of Europe's space programme that will be given a high profile and will continue to gain in priority.

Currently ESA's only Earth-observing satellites are the Meteosat series, the first of which was launched in 1977. The system became operational in 1983 and was handed over for management to a new body, the European Meteorological Satellite Organisation (Eumetsat), to which ESA provides certain services under a contractual arrangement. The latest spacecraft in this series, namely Meteosat-5, was successfully launched on 3 March. A second-generation Meteosat system, with enhanced capabilities, is now being studied by Eumetsat in cooperation with the Agency.

We are all looking forward to the launch of ERS-1 on 3 May. The Along-Track Scanning Radiometer that forms one part of its payload will be the most accurate infrared radiometer ever to fly in space. By measuring the surface temperature of the world's oceans and providing data on cloud distribution, it is designed to make an important contribution to climate research.

Although ERS-1 represents a major step forward, its potential both for research and for applications can only be fully realised if the continuity of its important and unique data can be assured for the long term. Consequently, a follow-on satellite, ERS-2, has already been approved for launch in 1994.

In ESA's Long-Term Programme, the Polar Platform element of the Columbus Programme will be the workhorse for European Earth-observation activities for several decades to come, allowing a suite of comprehensive missions in polar orbit following ERS-1 and ERS-2.

It is presently planned to fly a first series of missions using the Platform focused on meteorology, ocean and climate, and a second series focused on surface characteristics and Earth resources.

Looking further ahead — i.e. ten to twenty years — it may well be that operational entities for Earth observation will need to be set up. These would then continue to fund the Earth-observation programme that we have started. I intend to give any such initiatives all the necessary support, but I believe that presently ESA is the most effective means of meeting the demand for better observational data from space relating to our global environment.

Another potential use of Earth-observation techniques is in the field of arms-control verification. The Convention of the Agency emphasises its remit which is for exclusively peaceful purposes, but I believe that the acquisition of the data required for verification could come under this heading. Certainly, the techniques we are developing for Earth observation could form the basis of a verification system.

The objectives of the Long-Term Programme

The objectives of ESA's future programme, which is already planned up to the year 2000, are:

- to strengthen Europe's international competitiveness in science and technology;
- to increase Europe's independence and autonomy wherever necessary; and
- to improve Europe's position in cooperative programmes, particularly those undertaken with the USA.

To achieve these objectives, we need, above all else, a comprehensive programme. Europe must exploit all the opportunities that space offers for scientific, Earth-observational, telecommunications, and microgravity research. A comprehensive programme needs balance. There must be a sensible equilibrium between the programmes, leading to manned operations — Columbus, Hermes, and enabling programmes such as Ariane-5 — and the programmes that make use of Europe's space capabilities, such as science, Earth observation, and telecommunications. Finally, the future programme must be coherent and the technical content, the schedule and the funding of its individual components must be carefully coordinated.

Manned space activities

It is argued that the expensive feature of ESA's future programme is the drive to put man in space. Even those having a great deal of enthusiasm for space are asking if it really makes sense for Europe to put men in space if this cannot be directly linked to sound science? They worry, and I can understand them, that programmes like Hermes or Columbus will lead to disproportionate expenditures, overshadowing other aspects of our space programme.

The ESA Programme is designed to be a coherent whole. The manned element is very much smaller than the arguments about it might lead one to suppose. In fact, 60% of the total spending will be dedicated to unmanned space projects.

The basic policy underlying our Programme is as follows:

1. We must aim to exploit the complementary aspects of manned systems and unmanned systems.
2. Astronauts operating manned systems should be used only for essential tasks which cannot be performed without human intervention.
3. Everything else that needs to be done in space should be done by automatic means, including the launching of spacecraft.

The dangers inherent in using manned systems when they are not essential have been demonstrated by the recent unfortunate and costly experience of our American colleagues. The question is are there any tasks that cannot be performed without human intervention? To my mind, the answer is clear. Even on the ground, although we might like them to, robots cannot always replace humans. The same applies in space. The whole problem is whether the benefits of manned space flight will justify its cost, and whether this cost will have undesirable effects on the unmanned activities.

The ESA Member States gave all these arguments due consideration and decided in favour of manned European activities as long ago as 1973. In 1987, it was questioned whether Europe should have its own manned access to space. ESA had at this point to consider once again, in great detail, whether the earlier decision was still justified.

The presence of astronauts undoubtedly complicates matters from many points of view. Safety standards have to be stricter; there are problems with extra weight for life support; and there are higher costs.

After the 'Challenger' accident, there is renewed determination in the NASA programme to dispense with astronauts wherever possible. Likewise, for a long time to come, the majority of ESA missions will not require astronauts for their success.

Although robotic systems will increasingly replace humans, I do not think things will move so fast that we will be able to do without men in space altogether within the next twenty to thirty years, unless of course Europe deliberately choses not to take advantage of certain opportunities that space offers.

Astronauts are essential for the servicing of space laboratories, and their presence is also essential for certain categories of experiments. A space laboratory could function untended and unsupervised for periods in the order of six months, or even a year, but I do not think a laboratory installed in orbit can do without astronauts for years on end. The analogy would be a completely isolated and untended terrestrial laboratory designed to be used for a variety of experiments.

In considering the use of orbital laboratories one must not think only in terms of microgravity experiments. Such a laboratory could also carry Earth-observation and space-science instruments mounted externally and relying on the laboratory and its supporting astronaut team for essential supplies and services.

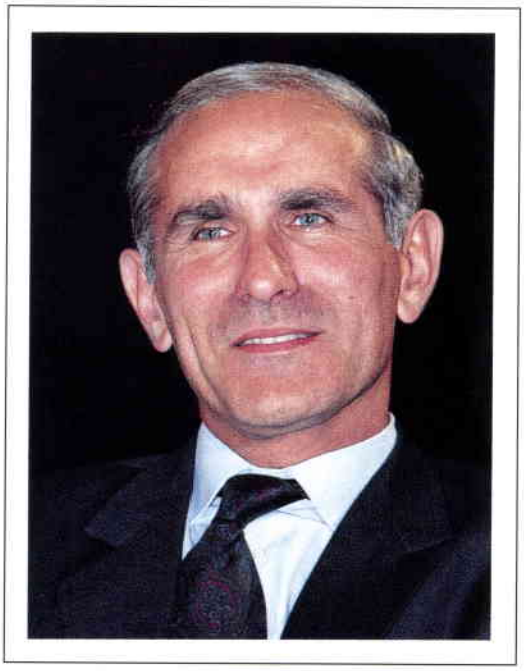
Astronauts will be needed to maintain and repair complicated instruments. This was the case with the Solar Max satellite as long ago as 1984. The Hubble Space Telescope presents a far greater challenge. I am not thinking here of the repair to the mirror, where an avoidable error occurred on the ground, so much as the fact that it was clear from the outset that this complex apparatus could not be operated for fifteen years without being serviced by astronauts.

The investment in terms of both financial and human resources required to develop and construct highly complex astronomical satellites will certainly increase in the future. Without the assistance of astronauts, such spacecraft will always have a relatively limited useful life in orbit. In some cases, it may be impossible to bring them into service at all without their help. Servicing in orbit will, if correctly conceived and applied, extend the useful working life of such instruments and not only increase the return on the original investment, but also open up the possibility for new applications to be developed as understanding of the data retrieved increases.

The purpose of these comments has been to point to the inherent logic of the European Long-Term Programme. The manned elements of the Programme were prompted by two events: first, the US President's invitation to the Europeans to participate in developing and building the International Space Station; and secondly the perception (not yet, I admit, unanimous) that Europe must have its own means to put man in orbit and develop a capability for manned operations.

The really important prospects for the future lie with the Columbus Programme's Free-Flying Laboratory and the Hermes space-plane. The free-flyer, which can be visited and tended by astronauts from time to time with the help of Hermes, sets the proper course for the future development of robotics. Hermes is a step towards the reusable manned transporter to orbit for the next century. With Hermes we will gain the necessary experience and master the aerodynamics, the new material technologies, and the organisation and operation of manned missions. This step is, in my view, essential. Without it, we would be faced with the prospect of designing an even more advanced vehicle without the benefit of the experience Hermes will bring us.

There are two key points concerning Europe's participation in the International Space Station. Firstly, this is a major joint American and European technology project and the foreign-policy dimension should not be underestimated. This was one of the reasons for accepting the American invitation. Secondly, Europe saw cooperation with the Americans as a door to gain early access to manned technologies. We need to consider how far this still holds good.



Europe's Future in Space – The Challenges Ahead*

Mr Paul Quilès
Minister for Posts, Telecommunications and Space, France

It is with great pleasure that I welcome you to our Space Ministry, which is so close to the European Space Agency. I am of course referring to the short distance separating this building and ESA's Headquarters, where your Council has been meeting. But I am thinking too of the importance that France attaches to the European space programme, a key element of its policy in this field.

In the twenty-five years and more of its existence, 'Space Europe' has established a reputation for achieving its goals. It has made a useful contribution to the advancement of knowledge with an ambitious scientific programme. Examples that come readily to mind are the results of the Cos-B astronomy mission, the Giotto mission and, at this very moment and despite the technical difficulties we have encountered, the information being collected by Hipparcos. The successful record of the Meteosat series of weather satellites is again being added to by the latest model placed in orbit by an Ariane launcher earlier this month.

'Space Europe' has also been active in exploiting the opportunities, particularly of an economic nature, offered by the demand for satellite launch services. In this connection the success of the Ariane launcher has exceeded all expectations. Where telecommunications satellites are concerned, Europe can also take pride in national satellites such as Telecom, DFS and Italsat, and European satellites such as ECS and Eutelsat II.

Mention should also be made of Earth-observation satellites such as Spot and ERS-1, which is soon to be launched. These satellites help us to gain a better understanding of our planet and hence enhance our ability to control our environment.

Heartened by these achievements, Europe has decided to move on to crewed flight, that is to developing the capability for sending Europeans into space using European resources by the end of the century.

Europeans in space

Human presence in space is regarded as of very great importance by the United States, the Soviet Union and also by Japan. Europe on the other hand is a relative newcomer to this field. This no doubt explains the lingering doubts on this subject, which stem from the fact that the policy adopted until 1984, with its emphasis on the cost-effective and the 'reasonable', proved such an undeniable success. But can Europe really confine itself to improving its launchers, developing a few new projects and keeping programmes ticking over, at a time when the major space powers are striking out in a new direction?

This question prompts another: Is it man's destiny to go into space? The answer to such a question cannot be purely of a scientific nature. History teaches that whenever access to a new physical environment becomes technically possible, man will occupy that environment, however hostile it may be. This is a powerful driving force. Human presence in space is tied in with what I would call our instinct as a species, the basic urge to acquire knowledge and survive. I am convinced that mankind will inevitably acquire the technical means to continue down this road.

So can the benefits that will flow from this great endeavour be left entirely to others? That would not perhaps be a bad thing in itself, since humanity as a whole has an interest in this activity. However, we must consider this reality: in the political and economic world now taking shape, the United States, the Soviet Union and Japan either already have this capability or will acquire it before too long. What Europe stands to lose by opting out must therefore be considered very carefully.

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* Address to ESA Council Delegates on 20 March 1991

A powerful force for technological development

The technologies connected with a human presence in space will in future years give those that possess them a very definite edge in the aerospace field. The acquisition by European industry, through Hermes, of the techniques of orbital flight and gliding atmospheric reentry is a stepping stone to the major hypersonic plane projects of the future.

There is another reason why this transitional stage is so necessary: only with a project such as Hermes can our industry be mobilised, the necessary skills forged, test methods and facilities developed, industrial teams built up, and our best specialists persuaded to stay in Europe. Work in these sectors will eventually feed into hypersonic aircraft construction, which is why the United States and Japan are investing not only financially, but also in terms of brainpower.

Furthermore, in a world of changing challenges in which the arms market can be expected to shrink, space technology can offer excellent opportunities and provide our firms with a large volume of activity in the high-technology sector. This is essential in preparing for the future.

Similarly, the ability to sustain human life in space being acquired through the Columbus Programme will pave the way for specific space activities. Assembly, construction and maintenance — essential tasks on which large space systems depend — very often require human intervention. Automation of these activities will be maximised, but it will never be possible to do without an on-board human presence.

A far-reaching political act

Programmes involving a human presence in space help crystallise a nation's aspirations, play a major role in establishing its image and place in the world, and in determining the way citizens view their country.

The ability to send people into space is the most effective peaceful expression of the technical and scientific power of a country or group of countries. The pursuit of space aims confers on countries or groups of countries that aspire to world status a significant external dimension.

The goal is not so much technical as political: to give Europe global standing and ambitions. In the new international context created by the arms-reduction agreements between the United States and the Soviet Union, and by the recent demonstration of the prime importance of space technology in determining the outcome of conflicts, or even in preventing them, the occupation of space will be of greater political importance than ever before.

The ability to achieve and sustain a human presence in space will make Europe a major player in worldwide cooperation on space-exploration projects made possible by the new relations being built between East and West, North and South.

Hermes and Columbus

Clearly, therefore, the debate surrounding the European presence in space does not come down to a question of scientific return or cost alone, although these are of course very important factors. In formulating policy in this area, account has to be taken of the technical and economic risks that would be incurred by Europe if it failed to pursue space aims with determination. More important still is the question of Europe's aspirations and of its status as a major technical and economic pole of attraction, alongside the United States and Japan.

A major effort is therefore required of Europe if it is to achieve its goals. But the skills acquired and exploited on the way will also be a reward in themselves. All this will depend on the creation of a space facility to which crews can travel in European spacecraft. This facility, itself a marvel of technology, will mobilise energies and help us learn what living and working in space is all about. Hermes and Columbus are the key to the achievement of these aims, and it is therefore essential that Europe continue to give these programmes its unwavering support.

That is precisely the support I will be giving these programmes when the Ministers of the ESA Member States meet in Germany a few months hence. With the United States reaffirming its supremacy and Japan going from strength to strength, Europe today has a unique opportunity to rise to the technological challenges of the twenty-first century.

Wherefore Manned Spaceflight?*

Prof. Dr. Walter Kröll
Chairman of the Board of DLR, Germany

What the wise men have to say

Exactly 500 years ago, at the behest of the Spanish king, a committee of experts met, the so-called 'Council of Wise Men of Salamanca'. Their brief was to evaluate an ambitious and highly controversial project proposed by Christopher Columbus. After three years of deliberations, the Council of Wise Men reported to their ruler: 'There can be no justification for your Majesty's support for a project based on extremely weak foundations and plainly, to anyone who knows anything about such things, impossible to achieve'. The subsequent carrying-out of the project was entirely due to a small number of influential people with faith in Columbus' idea. Today, another Columbus project is again the subject of public debate.

At issue this time, appropriately enough, is not a sea voyage but a major manned spaceflight project. If the Council of Wise Men were still in existence, would they advise similarly on this Columbus Programme as they did 500 years ago? And would their views be as misguided now as then? In the present debate, an increasing number of critical voices are being raised in scientific, economic, political and media circles. Comments are directed not only against the Columbus Programme, but against manned flight in general, a particularly high-profile but at the same time extremely costly form of spaceflight.

Unmanned space activities, for the purposes of extraterrestrial research, telecommunications, navigation and Earth observation, were themselves very much the target of criticism regarding the legitimacy of spaceflight, its cost and its usefulness until just a few decades ago; now such activities are above discussion. In the meantime, they have achieved convincing scientific and commercial successes, or are about to play an important part in tackling global environmental problems, of which the public has only recently become aware, such as the greenhouse effect, the ozone-layer depletion, and the destruction of the tropical rain forests.

Can manned spaceflight look forward to a similar improvement in its ratings? For the time being, on the contrary, it appears to many as an extravagant adventure, an embarrassment almost, while major problems remain to be solved on Earth, relating, for example, to food and energy supplies and the preservation of our environment. What, under these circumstances, is the point of putting humans into space? What can or ought they to be doing there, beyond succeeding in making the journey and, it is to be hoped, returning unharmed? 'The purpose of travel is not simply to arrive.' Goethe's observation on his Italian journey should apply equally to space travel.

From the beginnings of the relatively recent history of spaceflight, manned flight has always been the ultimate goal. Behind the very first experiments on the technical feasibility of spaceflight lay the objective of making manned flight possible. Manned spaceflight has, accordingly, been a significant component of the space programme in both the USSR and the United States.

In the meantime, a growing number of countries, including developing countries, have flown their own astronauts on United States or Soviet missions, or are actively preparing for such flights. Manned spaceflight is a reality. The question is, with us or without us?

Governments in Europe decided firmly in favour of manned spaceflight in 1985 in Rome, and again in 1987 in The Hague. The Columbus Programme is an expression of Europe's desire to be involved, with Japan and Canada, in the next major step in the development of manned spaceflight, the United States' Space Station Programme. Furthermore, with Hermes, Europe

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*Address to the Senate of the German Space Agency (DLR) at its Annual General Meeting, on 13 November 1990 is seeking to develop its own independent manned access to space. Have governments got it as right as 500 years ago? What were the factors influencing their decision? Our own wise men continue to debate these points vigorously.

The political dimension

There is no question that the decision to embark on manned space activities has been marked, to a greater or lesser degree, in all countries involved by considerations of national prestige. Thus, the East/West conflict, in particular, and competition between the different economico-political systems provided a considerable impetus for both the USSR and the United States to seek, through manned spaceflight, to demonstrate to each other and to the rest of the world their national strengths and technological capabilities. In addition, there was a military interest that has, in the meantime, substantially diminished on both sides. This is clear, for example, from the increasing withdrawal of the military from the United States' Space Shuttle Programme. It might seem logical in a world fortunately no longer dogged by the East/West conflict for the symbolic power of manned spaceflight to become less potent. But why should it not in fact be transformed from a symbol of confrontation into one of global cooperation?

I would like to return to this political side of things later on and to turn now to the research and development aspects. In this context, humans in space function as:

- scientific experimenters and experimental subjects in an in-space laboratory environment;
- technicians and engineers involved in the construction, operation, maintenance and repair of in-orbit infrastructures.

The astronaut as scientific experimenter

Europe's manned-spaceflight effort was dominated for a long time by scientific work by astronauts in in-space laboratories. Considerable importance was attached by Germany to research under microgravity conditions in the context of the Spacelab-D1 mission; the same applies for the Spacelab-D2 mission, scheduled for 1993. Germany takes a leading role internationally in this area. Could it be that we are heading in a completely wrong direction? Two main objections are raised on account of the high cost of microgravity research involving a human presence:

1. The scientific and/or commercial results of microgravity research achieved so far, or to be anticipated on the basis of existing physical phenomena, are not in proportion to the considerable expenditure involved. The yield, it would seem, is modest and set to remain so, meaning that the money would be much better invested in other areas of research.

2. All really useful microgravity research can, it is argued, be carried out just as well and at much lower cost in the absence of humans — the latter even having a disruptive effect on the microgravity environment — by using robot and tele-science technology.

This is correct, to the extent that practice has shown that valuable microgravity research can be undertaken without astronaut involvement, and that a good deal of this type of research activity can only be undertaken by automated machines, or is genuinely better and more cheaply carried out in that way. On the other hand, the same is true of an in-space laboratory as is generally acknowledged of a ground-based one, namely that the knowledge and creative capabilities of an on-the-spot scientist cannot be replaced by machines or robots. Humans are capable of greater flexibility in complex and unpredictable situations. Today's manned missions already include a high proportion of automated processes; the D1 mission proved the combination of astronaut activity and part-automated experiments to be a highly effective one.

The allocation of tasks between humans and machines is governed by the state of technological development and operational requirements. At the same time, everything that can be done by machines and robots should be handled that way. There is undoubtedly still considerable potential for increased use of machines and robot and tele-science technology. This potential needs to be fully exploited to reduce to a minimum the need for a human presence in space. However, to do away altogether with the possibility of a human presence in in-space laboratories in the context of manned spaceflight would, as in the earthbound laboratory, be to forgo many opportunities for successful experiments.

Even if the questions raised by microgravity research are of a less fundamental kind than those posed by extraterrestrial studies or elementary-particle physics, and although the effects of gravity can in many instances be discounted, there nevertheless remains a sizeable range of processes and procedures, in fluid-physics and crystallography, for example, and even more so in biology and physiology, where the effects of gravity have a noticeable influence. The only reliable way of determining whether or not such research yields scientifically or even commercially significant results is through such research itself.

Microgravity research, like any other research, offers no guarantees. As regards possible results, very different expectations are possible — sceptical or optimistic — although still at the level of pure speculation. The relatively small number of hours so far spent on experiments in manned space laboratories does not allow a reliable assessment, either positive or negative. In order to genuinely clarify the opportunities available, further systematic research is needed, including research in a manned-flight context.

As regards potential commercialisation, it seems to me that exaggerated expectations and promises have today been replaced by a more sceptical approach. However, even this question can in no way be regarded as settled: if the aim is to keep all major options open, opportunities for experimenters in in-space laboratories should not be excluded.

Humans as research subjects in space

Humans in space are not only biomedical researchers, but are themselves subjects of biomedical research. Investigation of the psychological, physiological, cardio-vascular and radio-biological effects on humans of periods spent in space is essential if there is to be manned spaceflight. In addition to this, such investigation also promises to provide important elements of information for basic research purposes, in view of the considerable impact of gravity on physiology, growth and evolution. It cannot thus simply be dismissed as a circular justification for manned spaceflight.

Astronauts as technologists and engineers

The same considerations as already mentioned in connection with scientific experimentation also apply more generally as regards the complex working processes in which humans in space can be involved as technologists and engineers. These include satellite recovery, the setting-up of space stations, and maintenance and repair of in-orbit systems. Some existing examples include the successful salvage of the Westar and Palapa communications satellites, the repair of Solar Max, the rescue of the LDEF platform, and the repair work recently carried out on MIR. Efforts are made to automate such tasks as far as possible, if only for reasons of safety. However, this in itself pre-supposes certain design and construction principles, and technologies (in robotics, for example), that first need to be developed and tested, in conjunction, inter alia, with a human presence in space.

The overall value of a system needs to be set alongside the greater risks involved in unmanned operations. The loss of an entire satellite or even of a large platform is a good deal more serious than the failure of a single experiment. The question of whether humans or machines can be more effective thus remains open. For the setting-up, maintenance and operation of major in-orbit systems, astronauts are essential, in the medium term at least, regardless of whether the end result is a manned or an unmanned system.

Developing space for mankind

Manned spaceflight has long-term objectives, extending way beyond the near-Earth-orbit activities so far described, and aimed at opening space up in the broadest possible sense for human benefit. President Bush expressed this view when he spoke on the occasion of the 20th anniversary of the first Apollo Moon landing:
'Back to the Moon. Back to the future. And this time back to stay. The Moon not as a destination but as a direction. And then, a journey into tomorrow, a journey to another planet, a manned mission to Mars'.

Behind these plans lies the more remote aim of exploring the opportunities for and limitations on human existence in space, seeking out resources there and, where they exist, making them available for mankind. It is only when set in such a context that manned spaceflight will take on a long-term dimension. Manned spaceflight serves to determine whether and to what extent the command to 'make the Earth your subject' can be extended to the whole Universe. Ultimately, it is a matter of examining under what circumstances and to what extent humans can live and work in space, of opening up new space applications and options, including the setting up of outposts in space for extraterrestrial research, in-space manufacturing and extraction of resources. There is not much more that can be said today regarding the potential for translating this vision into reality, except that it can only be envisaged on the broadest possible international basis. Cooperation in this area between East and West seemed altogether utopian until just a few years ago; today, in the case of Mars missions, for example, it is within reach.

None of the aforementioned human activities in space is in itself a sufficient reason for manned spaceflight. Nonetheless, each of them offers a potential that has hardly begun to be exploited, let alone exhausted, against the backdrop of previous manned and unmanned missions.
To explore and make the best possible use of

such potential seems to me to offer real and sufficient justification for an appropriate level of involvement in manned spaceflight.

The question of appropriateness

What is an appropriate level, given Europe's scientific, economic and political importance? Any question involving scale of commitment can be answered only in the wider context, since it is a matter of assessing the right proportions. The ESA Long-Term Plan, decided upon by European Governments, provides a good starting point. Current Federal Government planning provides for aapproximately DM 25 billion for the German spaceflight programme to the year 2000, including contributions to ESA and Eumetsat. Around one third of this amount can be reckoned to be for manned spaceflight. Is this too much?

International comparisons can give some guidance. In 1988, the Federal Republic spent 0.05% of its Gross National Product (GNP) on space. Civil space expenditure in the United States, expressed as a proportion of GNP, is approximately ten times higher and that in France approximately twice as high. The Federal Republic also falls some way behind Italy. Of the major industrialised nations, only the United Kingdom, at 0.03%, spends significantly less.

Similarly, when the proportion of national R & D development expenditure accounted for by civil space expenditure is looked at, Germany ranks distinctly modestly among the industrialised nations with 5.3%, compared with 13.1% for the United States, 9.4% for France and 10.4% for Italy.

Options and opportunities

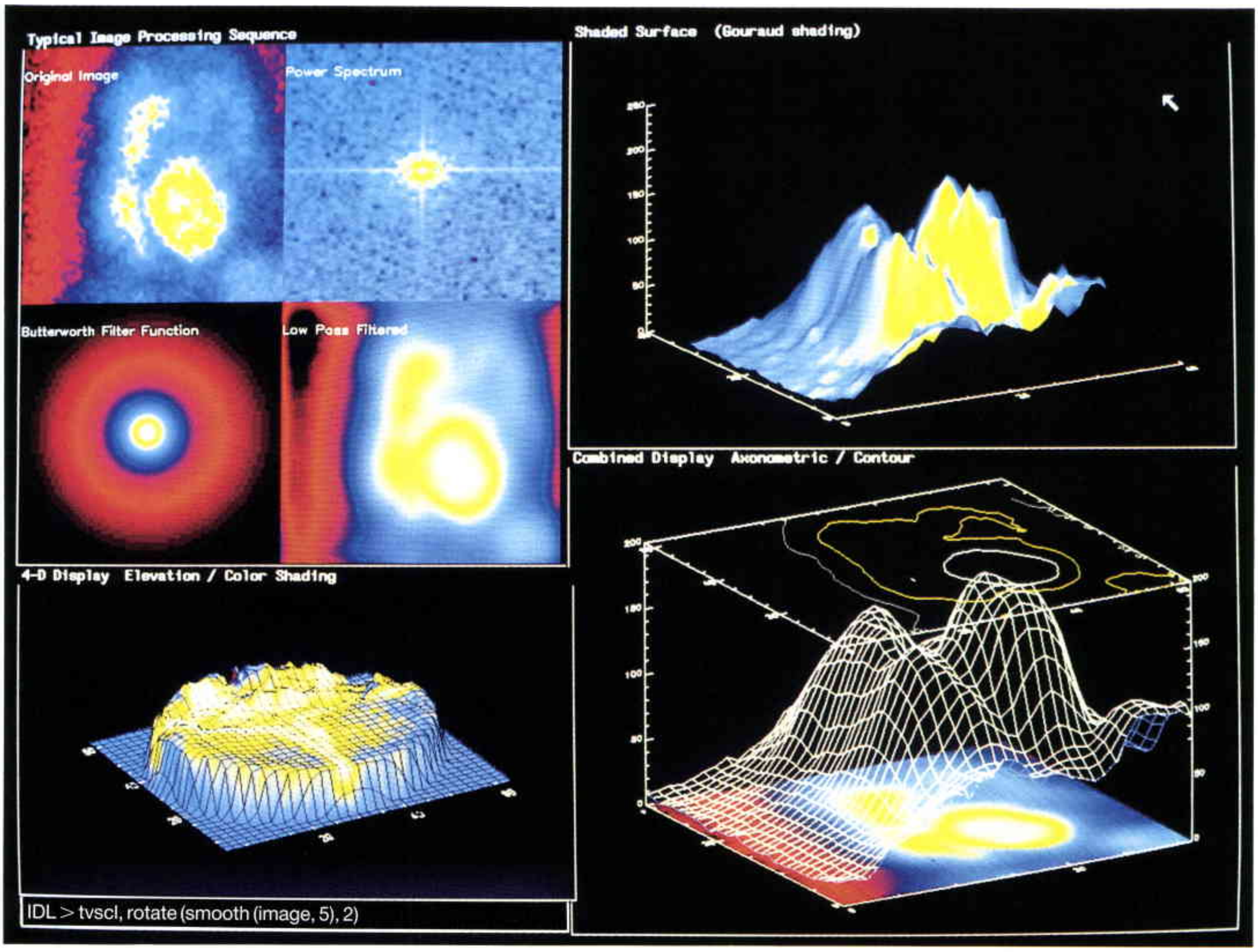
The total budget planned to the year 2000 will not suffice to satisfy the requirements of the ESA Long-Term Plan, including minimal utilisation requirements, nor those of a complementary national programme. If unacceptable erosion of the utilisation and national programmes is to be avoided given the existing budget, drastic changes are almost inevitable in the content and structure of the Columbus and Hermes Programmes.

DLR has been examining, from a scientific/technical point of view, possible options that would, at the same time as enabling the overall objectives of ESA's Long-Term Plan to be respected, be compatible with the existing budgetary framework and ensure a balance between utilisation and infrastructure development, as well as programmatic coherence between the individual elements. Possible solutions to emerge include a sizeable reduction in Columbus laboratory capacity, and postponing significantly the goal of European autonomy in manned spaceflight to some time beyond 2000. Such changes, acceptable from a scientific/technical standpoint, come up against major political problems that can only be resolved in agreement with our partners.

Is the autonomy sought in fact that urgent given today's much-changed global political situation? Direct commercial or operational applications of manned spaceflight are hardly to be expected in the short term. Besides, by its participation in the Space Station Programme, Europe is contractually committed over the long term (for some 30 years) to involvement in manned space activities. Also, the USSR's increasing openness also offers opportunities for European manned space projects. Everything points to the need for increased international cooperation on work and cost-sharing. For all the partners, this will mean mutual dependence and, in certain areas, giving up their autonomy.

Each individual partner does need to make significant efforts to ensure that their proven and recognised expertise plays its part in the international division of work in this area. Is it not fitting, in view of our economic and technological capacities and our intellectual claims, for us to take a clear lead in the global integration of manned spaceflight? The altered world political scene offers a chance, which the cost alone of the major objectives of manned spaceflight should encourage us to make the most of.

Spaceflight can be seen as a forerunner of Western European integration and as a possible example for global cooperation. A united Germany should use its many and diverse contacts and wide-ranging experience of cooperation, gained in distinct areas and with different partners, as the basis for a bridge between East and West. The same challenges and prospects apply to manned spaceflight.



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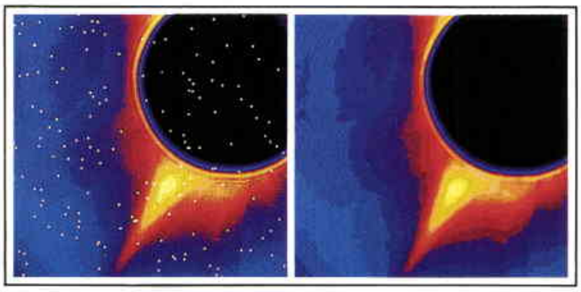


Left Image: solar transients with addition of random noise spikes. Right Image: with application of a 7x7 median filter to the original image.

Wings for European Spaceflight – The Future of Space Transportation

J. Feustel-Büechl, D. Isakeit & H. Pfeffer
Directorate for Space Transportation Systems, ESA, Paris

Over the last three years, the main effort in the space-transportation field has been concentrated on getting work on the Ariane-5 and Hermes Programmes firmly underway. Now that they are on the right path and a favourable decision can be expected on the second phase of the Columbus and Hermes Development Programmes, the time has come to give firmer shape to thoughts on space transportation in the more distant future. The preliminary studies on which work has started in various places need to be directed at a common goal, and hitherto separate efforts drawn together.

The road to Europe's present space-transportation systems

Unlike the United States and the Soviet Union – the two space superpowers – Europe could not draw on existing military rocket programmes in building up its civil space-transportation programme, nor could it exploit political competition between opposing systems as a driving force and financial lever. The European Ariane space-transportation system owes its success to the existence of a real demand for launch services and has, moreover, constantly had to look for pragmatic solutions, in view of the limited financial resources available to it.

This starting position was initially regarded as a handicap, but in retrospect it was if anything a positive factor, as it has given rise to an economically self-supporting space-transportation system that is independent of the changing political agenda. Whereas, with some European aircraft-building programmes, European taxpayers have to subsidise each plane that comes out of the factory, even after development has been completed and the production phase has begun, the construction of Ariane launchers is funded from the sale of launch services to satellite operators. Substantial funds are also recovered by the countries participating in the Ariane Programme in the form of tax receipts, and Ariane construction and operational activity provides challenging forward-looking jobs for some 16 000 people throughout Europe.

Of far greater importance, however, than these aspects of a direct financial nature is the fact that, without an autonomous launch capability, Europe would not have been able to build up its own satellite industry, nor make independent provision for Earth-observation, broadcasting and telecommunications services.

Europe's first steps in space were taken in the sixties with activity in the research field. Research satellites were built independently or in cooperation with the USA and, as pure research is to the general good and the direct financial benefits that derive from it are not immediately apparent, there were no problems as regards the launching of these satellites by the Americans. This situation began to change however when, with the advent of telecommunications satellites, the original pure research aims increasingly gave way to more commercial aspects, inevitably bringing substantial financial interests into play.

The turning point for Europe came with the problems associated with the launch of Symphonie, the telecommunications satellite developed jointly by France and Germany. The original intention had been for this satellite to serve commercial applications, including worldwide transmission of TV reports on the 1972 Munich Olympics. However, owing to the restrictive conditions placed on its launch on an American Delta rocket, it could in the end only be used for non-commercial purposes. Europe responded to this situation by deciding to pursue the Ariane Programme, the result of a French initiative, for the development of its own launcher system, designed specifically to place satellites into geostationary orbit.

The decision to focus efforts on the geostationary orbit was innovative at that time and of far-reaching importance. At a time when the potential of satellites in geostationary orbit was not yet fully proven, it took a great deal of courage and considerable powers of persuasion to talk convincingly of a likely market for such an application.

In view of the limited financial resources available, Ariane had necessarily to be a sensible combination of proven technology, namely liquid propulsion using so-called 'storable propellants', and advanced technologies, the prime example being the vehicle's cryogenic upper stage. Use of advanced technologies was not, however, an end in itself, but always a means to an end.

The Ariane Programme, initially based on a single product, evolved in the course of time into a complete product range (Fig. 1). The original Ariane, later known as Ariane-1, formed the basis for the higher-performance Ariane-2, 3 and 4 versions. The first use of solid-fuel propulsion technology in the European space-transportation programme came with the third Ariane version. Ariane-4, available to customers in six different configurations, today forms the backbone of Europe's space-transportation capability, and is able to launch all current types of commercial satellites. A further innovation, which has played a decisive role in helping Ariane to achieve its current market position, was the development of payload-accommodation structures allowing the simultaneous launching of more than one satellite.

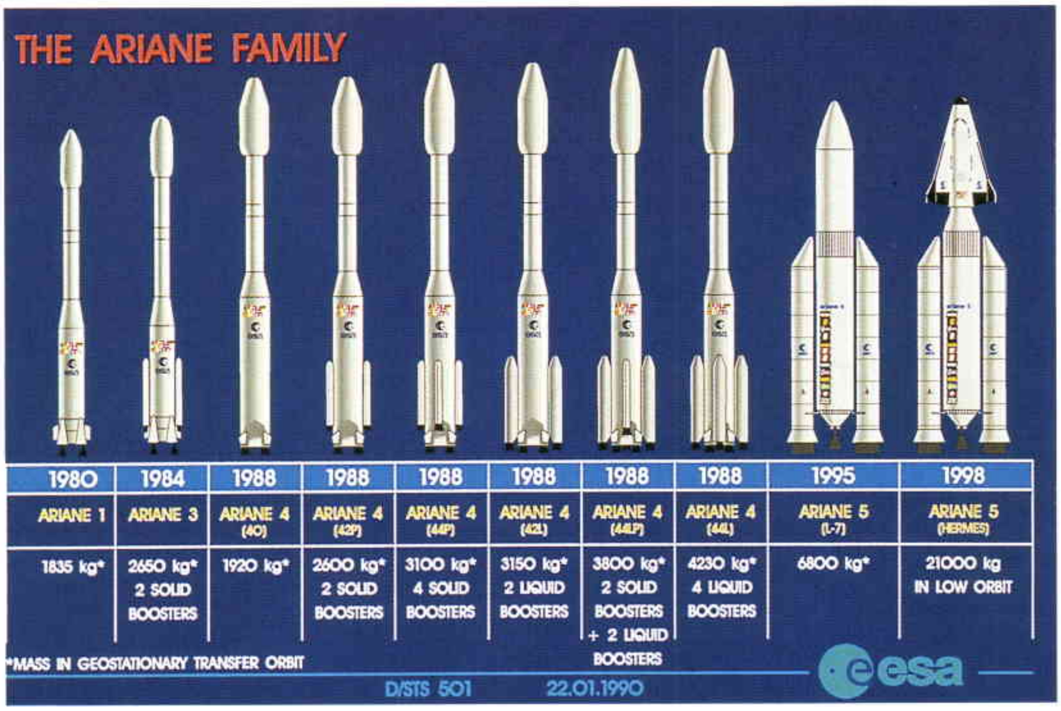
Europe's space-transportation system in the years ahead

Although the Ariane-4 launcher is today fully booked for years to come, Europe cannot allow itself to rest on its laurels, at the risk of endangering its autonomy in space transportation and of losing its place in the worldwide competition. There are four basic reasons why it is essential to adapt to changing conditions:

- the trend towards even larger satellites continues unabated
- in addition to the geostationary orbit, low Earth orbits will be of increasing importance in the future, with the need for a powerful launcher to transport Hermes- and Columbus-related elements to their respective orbits
- the emergence of new capabilities in the field of space transportation means there has to be a significant reduction in satellite launch costs, and
- due to the high cost of large applications satellites and their competition with other services, high launcher reliability has come to be regarded by satellite operators as one of the key criteria when choosing a launcher system.

To meet these various conditions, Europe decided in 1987 to develop the Ariane-5 launcher.

In order, in spite of the changing environment, to preserve the autonomy of and improve the position achieved by Europe, it is important to get the Ariane-5 product into operation as quickly as possible. The aim therefore is for the maiden flight to take place in 1995, with commercial flights beginning a year later.



1980	1984	1988	1988	1988	1988	1988	1988	1995	1998
ARIANE 1	ARIANE 3	ARIANE 4 (40)	ARIANE 4 (42P)	ARIANE 4 (44P)	ARIANE 4 (42L)	ARIANE 4 (44LP)	ARIANE 4 (44L)	ARIANE 5 (L-7)	ARIANE 5 (HERMES)
1835 kg*	2650 kg* 2 SOLID BOOSTERS	1920 kg*	2600 kg* 2 SOLID BOOSTERS	3100 kg* 4 SOLID BOOSTERS	3150 kg* 2 LIQUID BOOSTERS	3800 kg* 2 SOLID BOOSTERS + 2 LIQUID BOOSTERS	4230 kg* 4 LIQUID BOOSTERS	6800 kg*	21000 kg IN LOW ORBIT

*MASS IN GEOSTATIONARY TRANSFER ORBIT

Figure 1. The Ariane product range

For this reason, Ariane-5 is based on technologies that can, without major risk and within that time frame, be developed in Europe through to operational status. Ariane-5 nevertheless represents a considerable advance on the previous Ariane versions (Fig. 1). Work is centering on the development of a high-thrust cryogenic engine and large multi-segment solid-propellant boosters, and also on the construction of a new ground infrastructure at Kourou, in French Guiana, to support launcher- and payload-preparation activities.

As with the earlier versions, it is intended that Ariane-5 should pay its own way, as from the end of the development programme, which is jointly funded by the participating ESA Member States. This is why the design-to-cost principle will be applied consistently to all aspects of the Ariane-5 Programme, the first time this has been done in a major European space project.

In cooperation with the USA and USSR, Western Europe has already acquired some preliminary experience in crewed spaceflight. This experience has prompted ESA to work, in the long term, towards an independent European crewed space-station programme. Initial thought is already being given to the basic concepts involved, under the 'European Manned Space Infrastructure (EMSI)' theme. The necessary stepping-stone to achieving that aim is the Columbus Programme, being carried out within the framework of the International Space-Station proposed by the United States.

Europe has already learned, in the context of its earlier satellite programmes, that it is not enough just to develop and build satellites – it must also have the ability to place them into the appropriate orbits. Such a capability becomes all the more important as the main emphasis moves away from pure research activities and towards applications missions that ultimately have a commercial value. It is certainly not unreasonable to expect that much the same will apply where space exploitation involving human presence is concerned.

In order to preserve its autonomy also as regards man's presence in space, Europe must acquire an independent capacity to transport people and payloads into space and back. The European spaceplane Hermes (Fig. 2) is currently being developed for this purpose.

In pursuing this concept, Europe has been guided by a number of considerations:

1. Demand

It is not possible at the present time to produce comprehensive and reliable estimates of future demand for crewed transportation services. It is more likely that the stimulus will come from the supply side, with the availability of a crewed system determining the emergence of a demand and the creation of a market. The existence of a transportation system will not only be the key to the emergence of demand, but will also have a standardising effect on the technical and operational environment.

Figure 2. The European spaceplane Hermes and its resource module

This is why it is important for Europe to be able, as soon as possible, to influence the course of events in a constructive way with its own crewed transportation system. This argues in favour of short development times, and hence extensive reliance on proven technologies. Given the impossibility of predicting the operational context for possible future demand, the operational scenario for a crewed space-transportation system has to be flexible. A programme geared to a specific operational scenario is therefore not advisable, particularly when seeking to work together on space projects with other countries over whose space programmes one usually has little influence.

2. Autonomy

The Ariane Programme has clearly shown how important it is for we Europeans to have independent access to space. It is essential that the current programmes in the transportation sector – Ariane-5 and Hermes – carry this independent access into the crewed-spaceflight and recoverable-payload sectors and, in conjunction with elements of the Columbus Programme and perhaps further programme extensions, provide the conditions for the autonomous operation of independent European Space Stations. This is neither misplaced pride nor a refusal to cooperate with other space nations, but rather the desire to achieve a political and technological target appropriate to Europe and its capabilities.

3. Coherence

The function of Hermes is not just to meet an indeterminate, probable future demand for transportation services but also, in a more immediate way, to provide essential support for operation of the space-station elements that make up the European Columbus Programme. It must therefore be able to meet the Programme's needs in terms of transportation and other services. Account must also be taken of the fact that Hermes and Ariane-5 form a self-contained transportation system with a series of complex interfaces. Bearing in mind too the close technical links between Hermes and the Free-Flying Laboratory of the Columbus Programme, this means that in addition to the need for technical coherence there is also an extensive requirement for close coordination of the timetables for the two development programmes.

4. Technology

In addition to the practical task of transporting three astronauts and three tons of payload at regular servicing intervals to the free-flying element of the Columbus Programme, one of the main aims of the Hermes Programme is to develop the technology for crewed hypersonic spaceflight. Well over half a billion ESA accounting units of development-programme funds are being spent on acquiring applications-oriented knowledge in many fields of great importance for the future, including aerodynamics, high-temperature materials, power-supply systems, avionics, etc. This makes Hermes the biggest space-technology programme ever undertaken in Europe.

The technologies used for Hermes are a necessary prerequisite for all further work on hypersonic transportation systems, whether for space or aeronautical purposes. In addition to performing the specific tasks that constitute its mission, Hermes is thus also essential to the achievement of more distant goals.

5. Resources available for development programmes

Spaceflight is one of the many aspects of the drive to secure Europe's future and has therefore to share the available financial resources with many other areas of activity. Moreover, Europe's total developmental capacity is by no means unlimited. This makes it necessary to concentrate on specific key areas and to draw on the development potential existing in related space programmes.

It has therefore been decided to focus attention initially on the return phase, the essential last link in the whole chain of operations. The ascent stage will rely on the rocket technology to be used for Ariane-5, which is conventional in nature and will thus already be available at the time in question.

This will be made easier by the fact that, from the mid-nineties onwards, the demands placed by the market on uncrewed space transportation will, in a number of important ways, have come into line with the criteria for crewed spaceflight. This applies not only to the trend towards larger payloads and lower orbits, but above all to the higher levels of reliability that will be demanded in the future of uncrewed space-transportation systems.

It was in the light of these various considerations that the programme for the European spaceplane Hermes, as currently defined, was drawn up.

Further development of future space-transportation systems

In specific practical applications fields where a certain amount of experience has already been acquired, where demand is quantifiable and some growth can be expected, it makes sense to further develop and expand existing capabilities in a carefully targetted fashion.

In the aircraft industry, the traditional approach is to gradually develop existing systems. This approach has also found its way into the Ariane Programme, as can be seen from versions 2, 3 and 4 of the launcher. Ariane-5, in contrast, represents something of a quantum leap in relation to the preceding version, and for this reason could justifiably have been given a different name, had it not been for the wish to build on the reputation established by the Ariane-1 to 4 series, for commercial, political and psychological reasons.

This does not, however, change the fact that, just as with the series that began with the first Ariane launcher, Ariane-5 will also be the first in an evolutionary series. Such further development is warranted by the need to make the basic version of the Ariane-5 launcher more flexible, to give it access to a wider range of applications, to increase its payload capacity, and to reduce costs wherever possible. A few specific examples of what is meant here are given below (Fig. 3).

Various ways can be imagined of increasing payload capacity. The quickest and most cost-effective means of doing this is to enhance the performance of the liquid-oxygen turbopump of the engine that powers the cryogenic first stage. This would enable the mixture ratio and the combustion-chamber pressure to be increased. This line of approach is currently being considered under the study heading 'Vulcain Mark-2'. Further options include introducing a second cryogenic engine in the main stage and using modified or additional boosters.

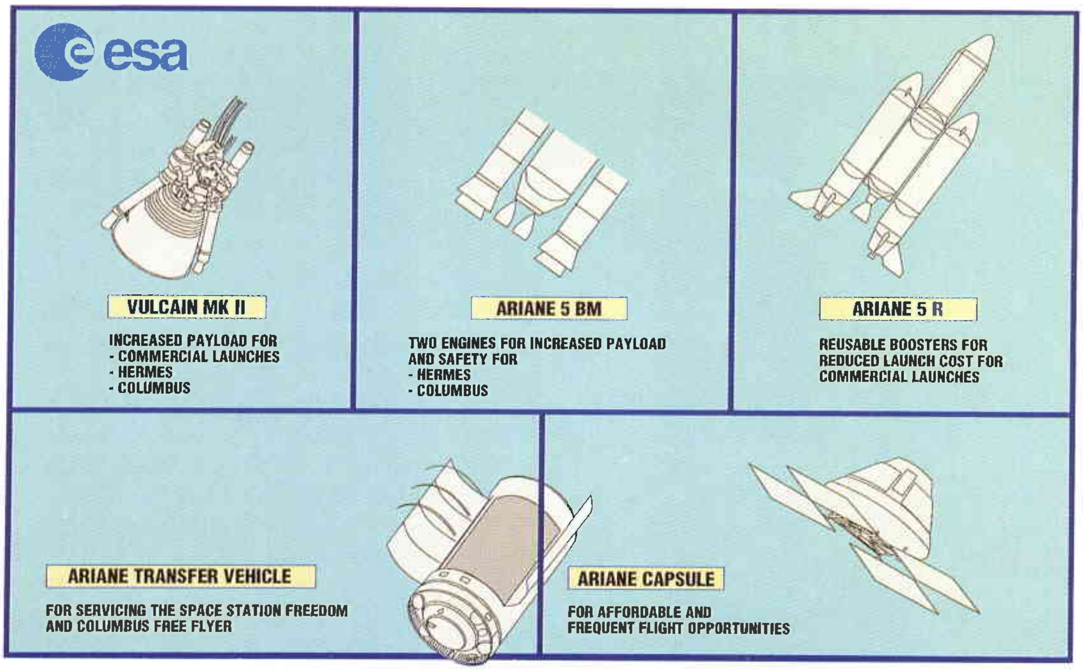


Figure 3. Possible evolutionary development of the basic version of Ariane-5

As far as can be judged today, there is little scope for achieving a significant reduction in the cost of Ariane-5, as the whole design is already specifically directed at keeping manufacturing and operating costs as low as possible. One possibility, the repercussions of which cannot at present be fully assessed, would be to develop Ariane-5 into a partially reusable launcher. This would involve replacing the present solid-propellant boosters with boosters using liquid propellant, which could then be given a winged design for flight back to Earth. Work on this concept is currently underway in the form of system studies.

With a view to opening up other possible applications, the concept of an uncrewed recoverable capsule is currently being studied. Such a capsule (being called the 'Ariane Recoverable Orbital Carrier', or AROC) would be launched by Ariane-5 and would enable automatic experiments to be performed in space and then brought back to Earth.

In the context of the construction and operation of crewed space stations and the associated transportation requirements, there is a clear need for an uncrewed transfer craft. Such a craft would in effect be an extension atop the Ariane upper stage and would allow automatic docking at a space station to take place. This concept is being investigated under the study heading of 'Ariane Transfer Vehicle', or ATV.

Many of these concepts, whose future usefulness can already be predicted, are in principle ready for a decision. Rather than Europe yielding at this stage to the temptation of completely novel projects, it would make more sense to take the next logical step, getting to grips with the obvious tasks first. This means increasing the power and extending the capabilities of systems that will be available in the near future.

New long-term space-transportation programmes

It is difficult enough to design a new product for an existing market, but infinitely more difficult to design a new product for a new market or even for an as yet unforeseeable market. To develop a space-transportation concept for an era some way into the future, it is necessary to begin by making assumptions about how demand is likely to evolve, the various possible options, and the basic approach that should be adopted.

As a starting point for the discussion, a number of hypotheses are offered below concerning the conditions that are likely to apply:

1. There is no prospect of an explosion in the demand for space-transportation services in the foreseeable future, and a cautious approach is therefore of the essence. This will mean carefully observing how demand develops and being ready to react with appropriate products to any clear new trends that might emerge.

2. There can be no doubt that space activity will for many years to come continue to centre on the Earth.

3. Differentiating between crewed and uncrewed transportation has hitherto proved its value and will probably continue to do so for the foreseeable future.

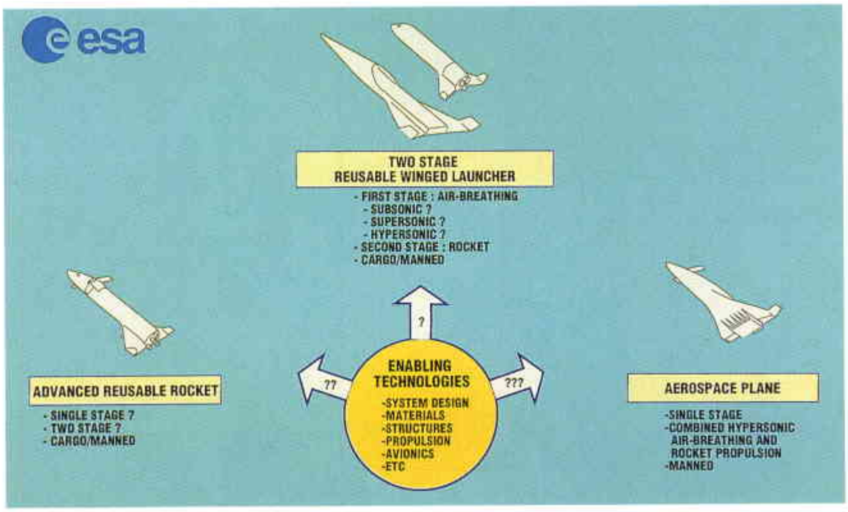


Figure 4. Possible long-term development trends in space transportation

4. The aeronautics and space sectors will become more closely intertwined in the future, at least as far as technology is concerned.

5. In view of the long development lead-times associated with high-technology programmes, it is essential – despite uncertainties on the demand side – that fundamental studies begin now in those key areas where it can be assumed that the work done will have general validity regardless of the concept eventually chosen.

6. Where over-ambitious goals are set, there is a risk of those goals not being reached at all for want of energy and staying power. Where the goals are too modest, it may well be that action in pursuit of them will never get underway due to lack of interest and motivation.

It is still too early to predict with any certainty what will come after Ariane-5 and Hermes. Certain trends can, however, already be made out (Fig. 4).

Where launcher systems for uncrewed missions are concerned, the downward trend in transportation costs can certainly be expected to continue. The non-reusable launchers currently under development (such as Ariane-5) are, however, already designed for optimum cost-effectiveness in construction and operation. Similarly, modern rocket propulsion technologies have already been taken almost as far as they will go. For these launchers there therefore seems to be relatively little technological scope, as matters stand at present, for further cost savings. For this to change there would have to be significant advances in rocket propulsion and structures. It is therefore probable that re-utilisation offers the only long-term opportunity for further significant reductions in transportation costs.

In this connection, it is interesting to consider a particular aspect that has little to do with technical and economic considerations and everything to do with the acceptance of space activity by the public at large. Public opinion is to some extent critical of today's 'throw-away' launcher systems, even though these represent the most cost-effective solution, and pressure from this direction can be expected to reinforce the trend towards reusable systems.

Crewed vehicles (or vehicle elements) must necessarily be capable of returning to Earth in view of the requirement to bring crews home. Reusability can thus be regarded as a natural design criterion. Here the likely trend will be towards fully reusable, self-propelled systems. Progress towards full reusability will, however, quickly be blocked by the inherent limitations of existing rocket propulsion technology, and there can therefore be no doubt that advanced, air-breathing propulsion concepts will be central to work on crewed vehicles.

Even if the criteria that apply to crewed and uncrewed space-transportation vehicles, particularly in interrelated areas such as reliability and economic viability, should lead to differing concepts – and this is something that from today's perspective cannot yet be predicted with absolute certainty – there is no doubt that advances in the critical technologies (especially propulsion and materials) will benefit both types of transportation.

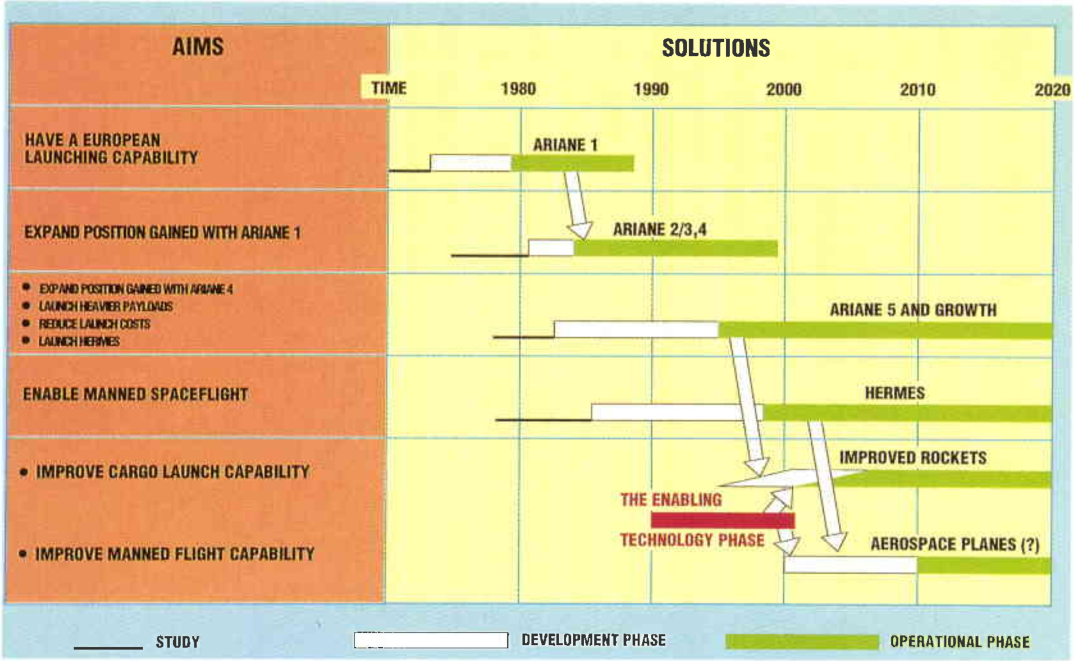


Figure 5. Development logic of European space-transportation systems

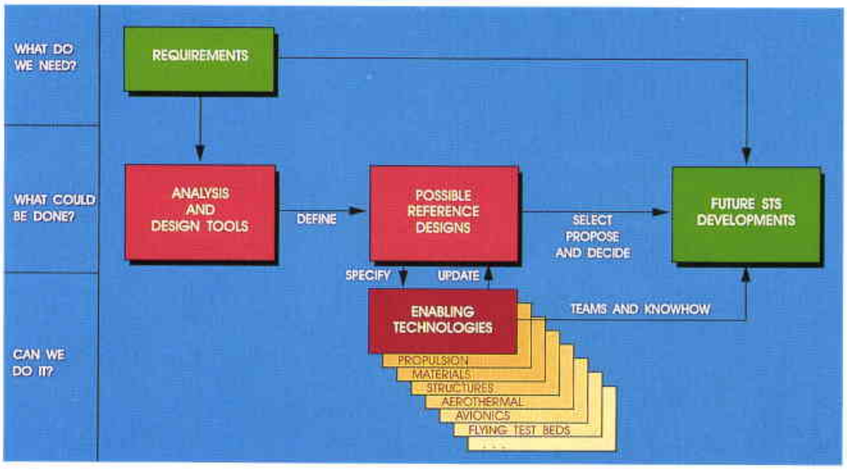


Figure 6. The preparation logic for future space-transportation systems

Research work on the key basic technologies that will be needed for future space-transportation systems, and development of those technologies, will not only cost money, but will above all take time. This is due in part to the technical and scientific complexity of the subject itself, but equally to the shortage of suitably trained specialists in the areas concerned. The earliest possible start must therefore be made on training up young people in this field. This is not unduly expensive, but is a long process.

In view of these long development times (Fig. 5), it would be ill-advised to settle as of now on one particular system. To do so would be to lose the freedom to exploit technological advances that can be expected and to deal flexibly with further developments on both the demand and supply sides. This does not, however, preclude working with certain guiding concepts as a framework for development effort – rather than going ahead without any idea of how the various key technologies could fit into a possible overall concept. However, the emphasis must be on the word *could*, and it must be made clear to all concerned that this does not mean the same thing as *necessarily must*.

A number of such concepts have been formulated over the last few years in Europe, the main examples being the Sänger concept in Germany, Hotol in the United Kingdom, and Star-H in France. It would be unreasonable at this stage to regard these guiding concepts as definitive design proposals for a later complete system. Each of them represents one of many possible combinations of the various basic technologies – no more, but equally no less.

The problem is that these basic concepts have, in the meantime, as a result of the interest that they have evoked in the public and the media, taken on a life of their own. The impression has to some extent been created that the German concept is in conflict with the British one, and the French concept in conflict with both of the others.

The time has come to get back to the common underlying content of these concepts, namely an effort to research and development of the necessary enabling fundamental technologies (Fig. 6), and to draw together under a common European umbrella the various divergent and hitherto competing projects. The work carried out to date as separate national projects should now be Europeanised under a single ESA Programme.

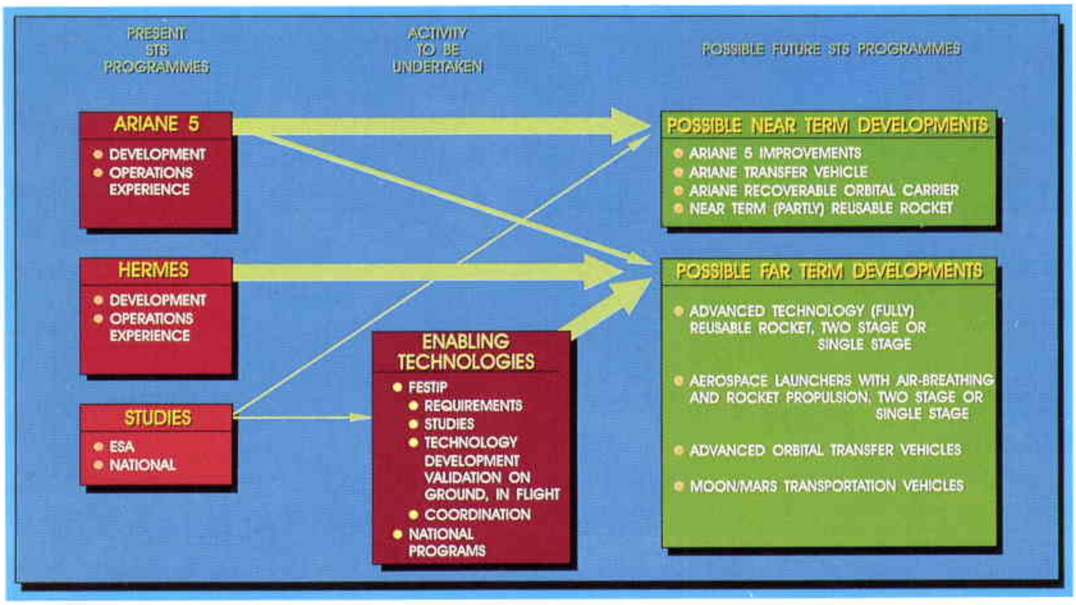


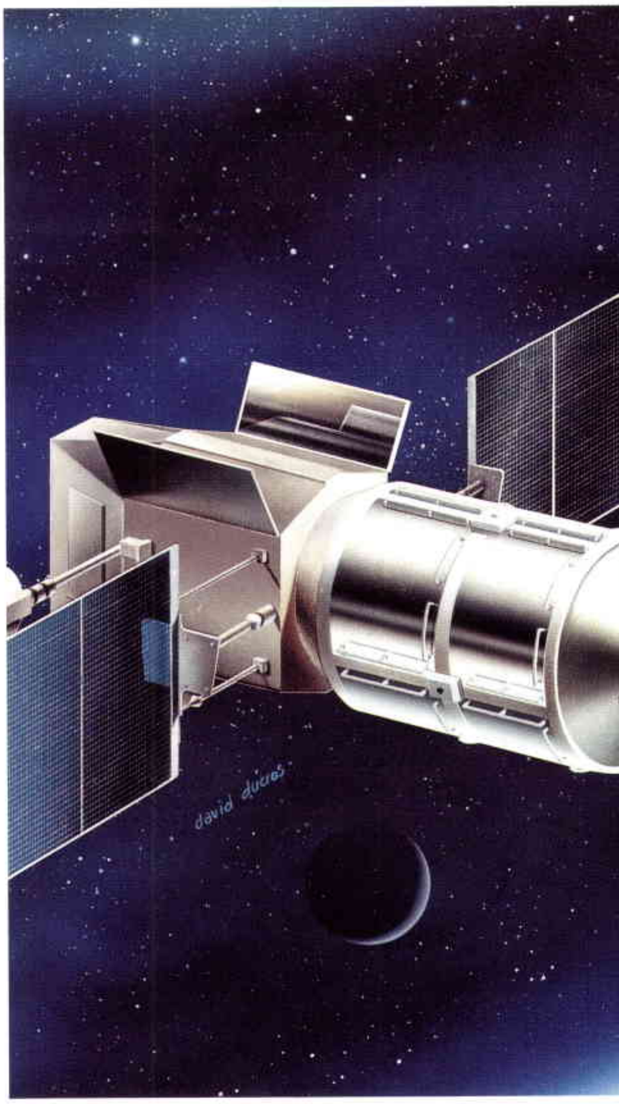
Figure 7. Crucial technologies as the key to future space-transportation systems

We at ESA have very definite ideas about how such a Programme should be structured and what the order of things should be:

It should begin with a study phase in which all possible future transportation concepts would be defined and compared. The results would then be used to identify the common, or even specific, enabling (i.e. key) technologies. The first study contracts for such work have already been placed by ESA with a number of European institutes and firms.

The second stage would then be for these key technologies to be thoroughly investigated under a major European technology programme and for pre-development work to be done on the most promising technical options. One question that needs to be addressed is whether it makes sense to build a special ascent demonstrator to support the development of a propulsion concept for the ascent stage.

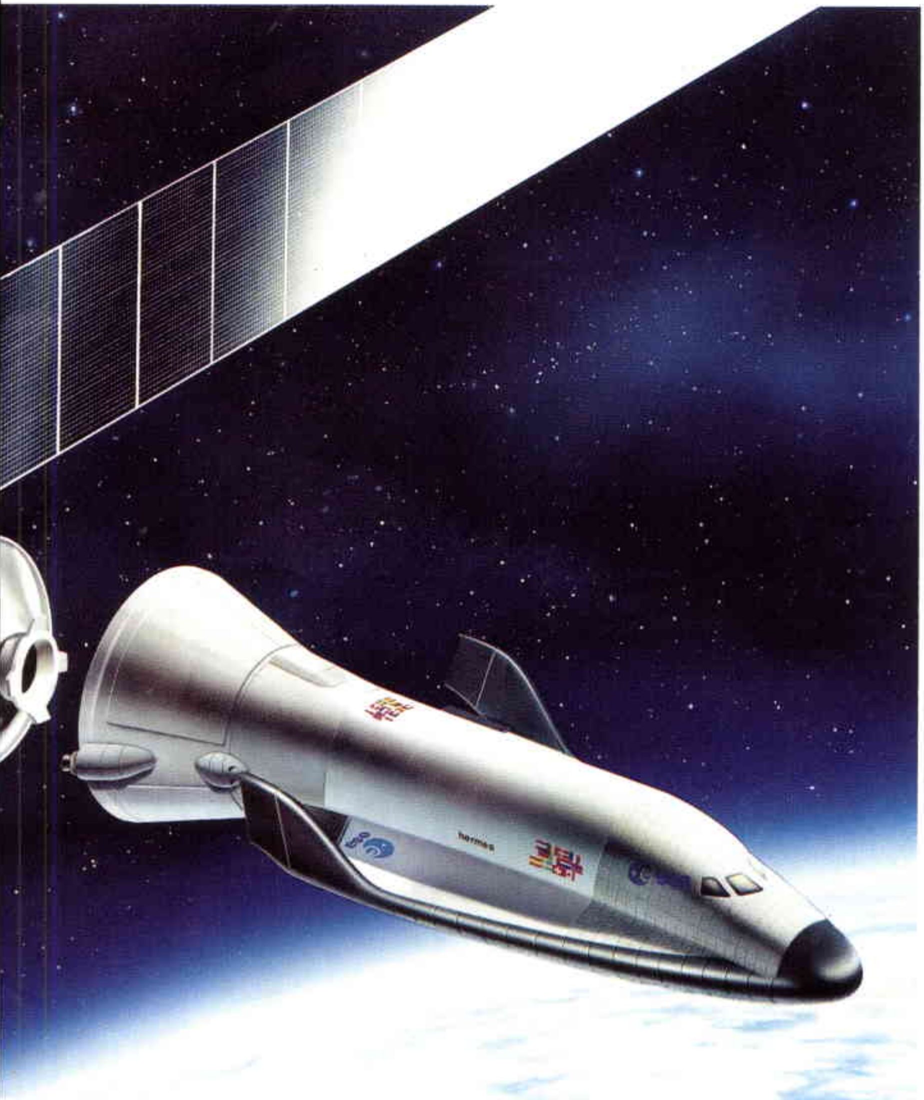
Having made progress in this way at the technology level (Fig. 7), Europe will then be in a position to decide on the direction it wishes to take in space transportation, particularly as the demand for crewed and uncrewed space-transportation services should have become clearer by that time. It will then be possible around the year 2000 to take a final decision on which particular space-transportation system should be built, and this with reasonable confidence as to the likely duration and cost of the development effort.



The Hermes Missions – An Overview

G. Valentiny & P. Brudieu
Directorate for Space Transportation Systems, ESA, Paris

Hermes, the European retrievable manned spaceplane to be launched on repeated missions by Ariane-5 vehicles, is one of the major elements of the European autonomous space infrastructure being developed during this decade. Its main mission is to rendezvous, dock with and service Europe's Columbus Free-Flying Laboratory. The built-in flexibility of the Hermes design will also enable missions to be undertaken to the International Space Station 'Freedom' and to other space stations such as the Soviet 'Mir'. It will also be possible to perform specific experiments onboard the spaceplane itself.



Introduction

The current ESA Programme covers the development and initial operation of the In-Orbit Infrastructure (IOI) elements required to support projects in the fields of science, applications and technology. Among the needs of such projects is the mastering of manned operations in orbit. As a first step towards meeting this objective, the ESA Programme includes the launch and the in-orbit maintenance of an automated Free-Flying Laboratory to be exploited and maintained through regular visits by Europe's Hermes manned spaceplane.

The Columbus Free-Flying Laboratory

The Columbus Free-Flying Laboratory, also to be launched using Ariane-5, is a serviceable facility designed specifically for automated in-orbit operation and utilisation. It is to be regularly serviced by Hermes (up to twice per year) and will communicate with the ground via the European Data-Relay Satellite (DRS) system. The current design for the Laboratory provides a volume equivalent to two Spacelab segments, offering accommodation for the equivalent of 40 single racks (22 for subsystems and general storage, and 18 for scientific payloads).

Hermes

Hermes is a manned, reusable, winged space vehicle, to be launched by Ariane-5, which will dock with the Columbus Free-Flying Laboratory (Fig. 1), support the operations to be carried out there and elsewhere by the crew, and return, once its mission has been completed, to make an aircraft-type landing at a pre-selected site.

Figure 1. Hermes mission to the Columbus Free-Flying Laboratory

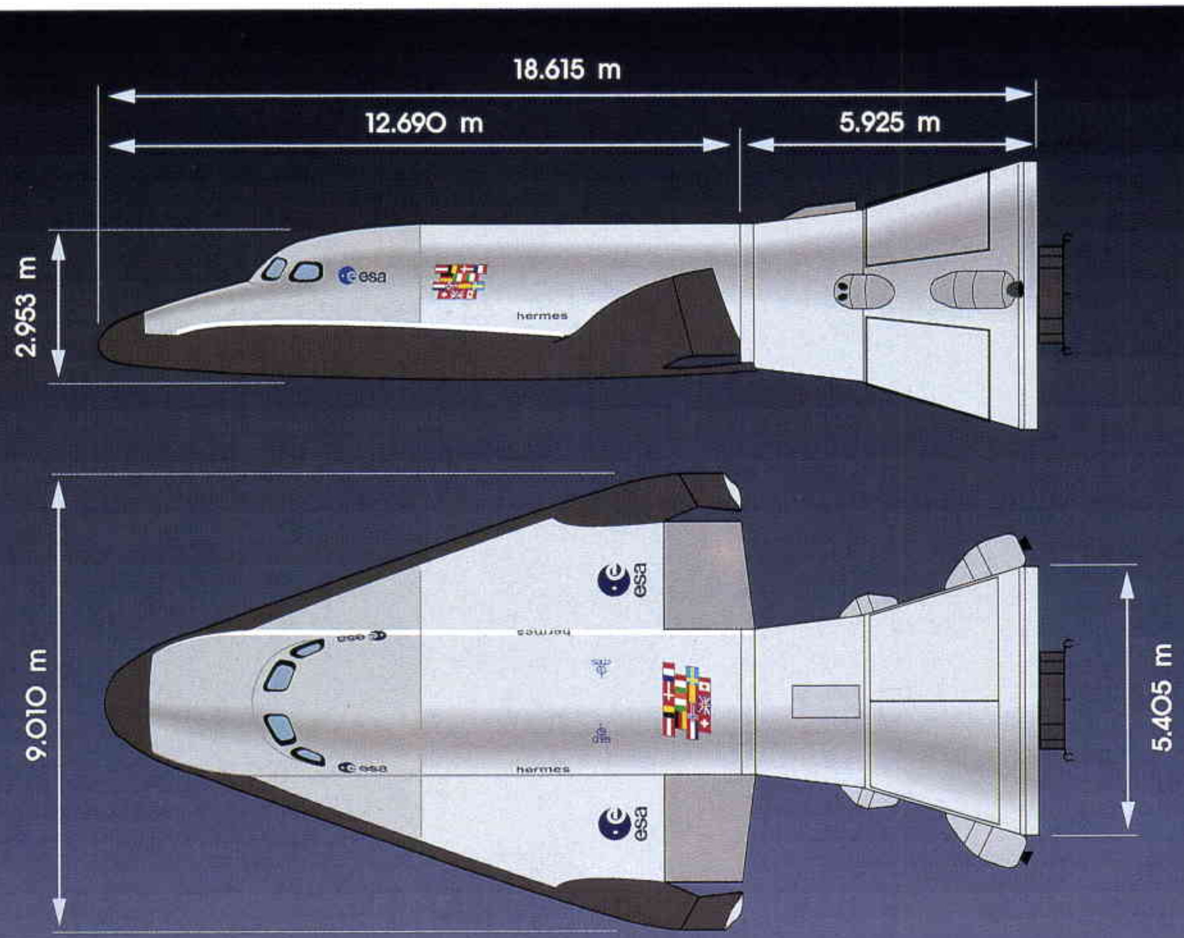


Figure 2a. The Hermes spaceplane and resource module

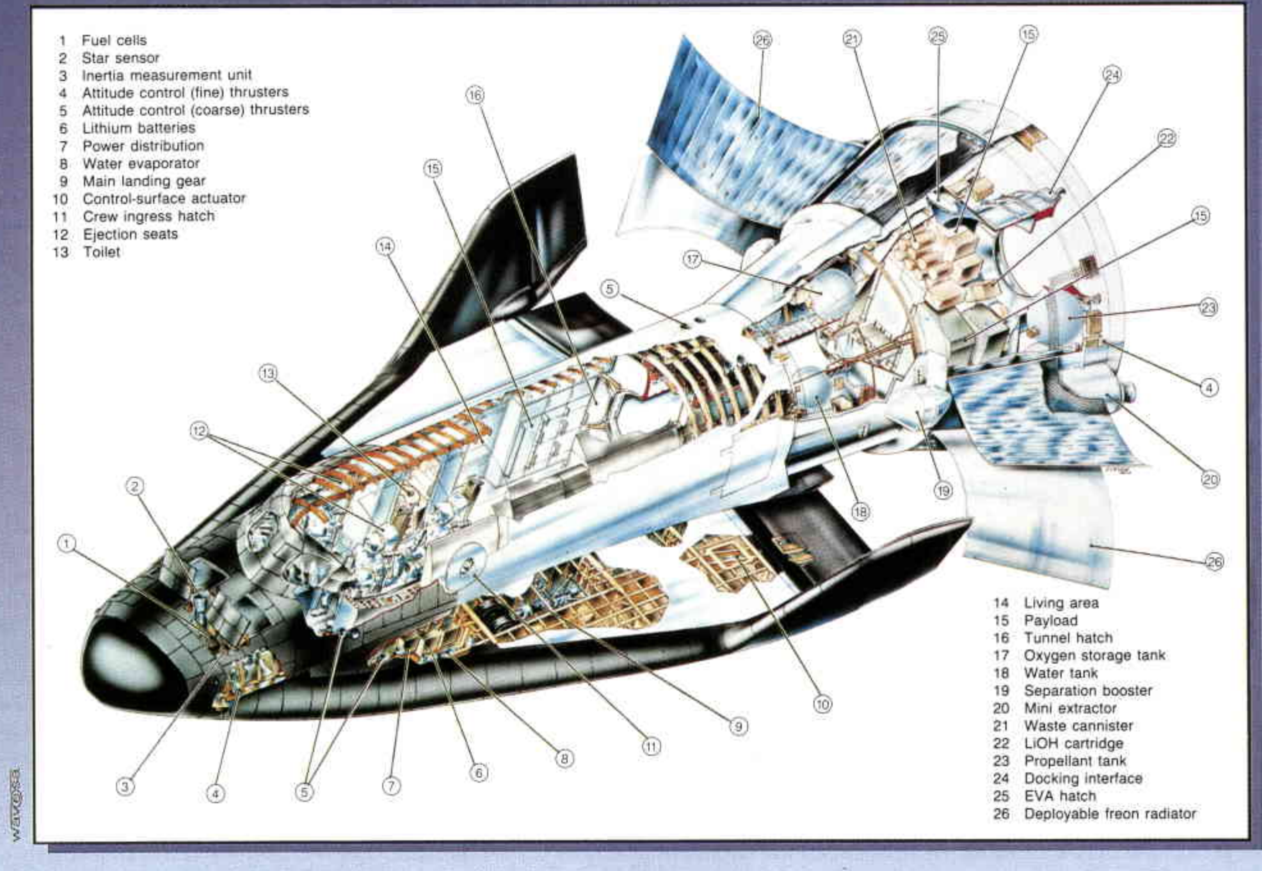


Figure 2b. The Hermes stage-1 space vehicle

LAUNCH	**HERMES—ARIANE-5 COMPOSITE** NO PROPULSION BY HERMES
INJECTION	**SEPARATION OF HERMES SPACE VEHICLE AFTER 600 SECONDS** HERMES MASS: 24 400 KG AT 100 KM, VELOCITY 8 KM/SEC
CIRCULARISATION	**HERMES REACHES TARGET WITHIN 48 HOURS** PROPELLANT CONSUMPTION APPROX. 1400 KG
SERVICING	**7 DAYS DOCKED TO TARGET** TRANSFER OF PAYLOAD AND CONSUMABLES. EXTERNAL, INTERNAL SERVICING OF MTFF
DEORBITING	**DE-ORBIT BURN, SEPARATION OF MRH** PROPELLANT CONSUMPTION ABOUT 1100 KG, RE-ENTRY AT ALTITUDE OF 120 KM, 1.4 DEG TRAJECTORY ANGLE
RE-ENTRY/LANDING	**UNPOWERED ATMOSPHERIC FLIGHT, HYPERSONIC TO SUBSONIC** MACH 25 TO FINAL APPROACH LANDING SPEED 215 KNOTS, RUNWAY LENGTH 3 KM, HERMES MASS: 15 000 KG

Figure 3a. Typical Hermes mission profile for the 'Reference Design Mission'

Orbit	Circular, 330–483 km altitude, 28.5° inclin.
Crew	3
Cargo	Upload 3000 kg to 463 km altitude Retrieved load 1500 kg
External Servicing	Using EVA suits and the Hermes Robotic Arm (Hera)
Mission Duration	12 days max.
Mission Frequency	2 per year

Figure 3b. Key features of the 'Reference Design Mission'

The Hermes space vehicle consists of (Fig. 2a,b):
- the *spaceplane* (retrieved), carrying the crew and part of the cargo
- the *resource module*, providing additional pressurised volumes, carrying the remainder of the cargo, and equipped with the airlock and docking facility.

The built-in flexibility of Hermes (e.g. carrying of kits, modularity in the design of the resource module enabling, in particular, the installation of mission-specific docking interfaces) allows for other missions to be considered, including docking to Space Station 'Freedom' or the USSR's 'Mir' Station, a long duration mission with the Columbus Free-Flying Laboratory, and even on-board experiments (i.e. autonomous Hermes missions).

Hermes missions to the Columbus Free-Flying Laboratory

The missions to the Columbus Laboratory represent the principal objective of the Hermes spaceplane. The current Hermes design is based on the so-called 'Reference Design Mission to the Free-Flying Laboratory', which has been used in defining both functional and operational requirements and performance objectives. Provision for additional flexibility has also been included to allow for the expected future evolution in the Laboratory's requirements.

Hermes performance and resources

The typical mission profile and the key features of the 'Reference Design Mission' are summarised in Figures 3a and b.

The 'upload cargo' is composed of: scientific payload (equivalent to nine single racks; so-called '9 SRE'), free-flyer preventive- and corrective-maintenance items (1 SRE), Hermes payload support, and any mission-dependent equipment required (e.g. EVA suits and tools, robotic arm).

The 'retrieved load' consists of: scientific payload (4 SRE), and Hermes payload-support and mission-dependent equipment.

The 12 day mission duration includes:
- 2 days for the phasing and rendezvous docking
- 1 day for the activation/de-activation of the composite interfaces
- 6 days for the free-flyer servicing
- 1 day for the return trip
- 2 days of margin.

The crew of three is made up of two Spaceplane Specialists (Commander and Pilot) and one Laboratory Specialist (Mission Engineer). At least two astronauts will be fully occupied by the Free-Flying Laboratory's servicing operations. Assuming a 10 hour working day, the minimum 'useful' working time

Figure 4. Hermes and payload processing facilities

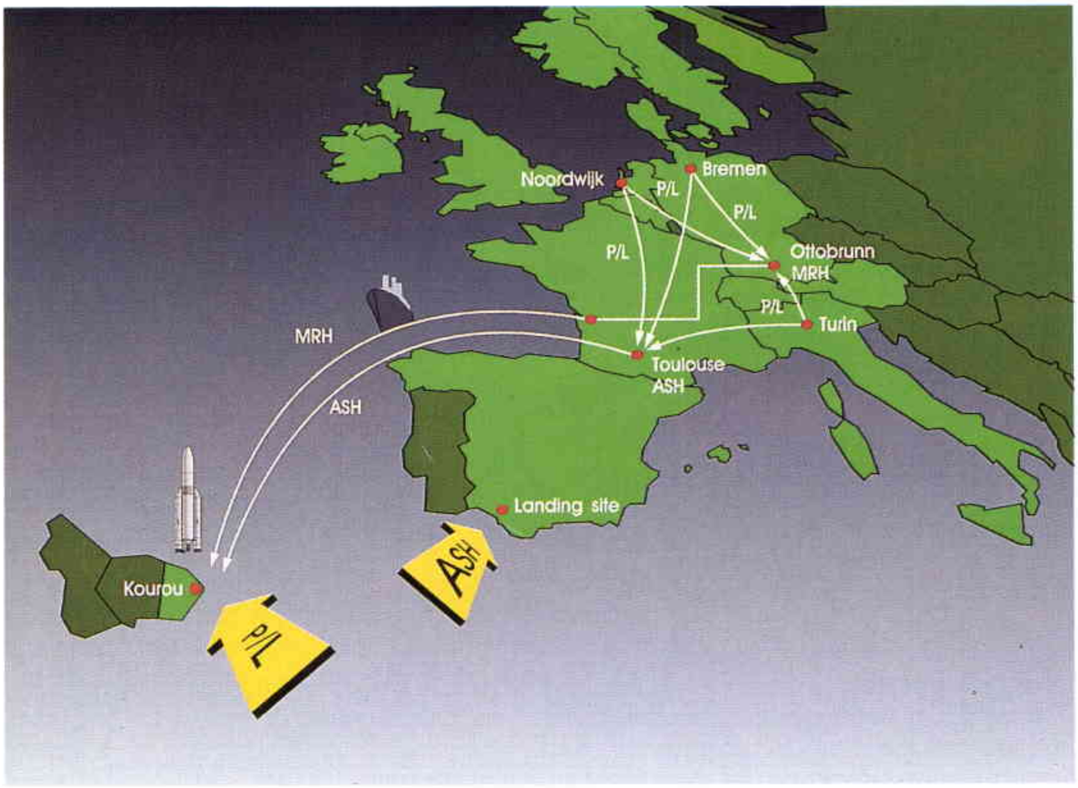
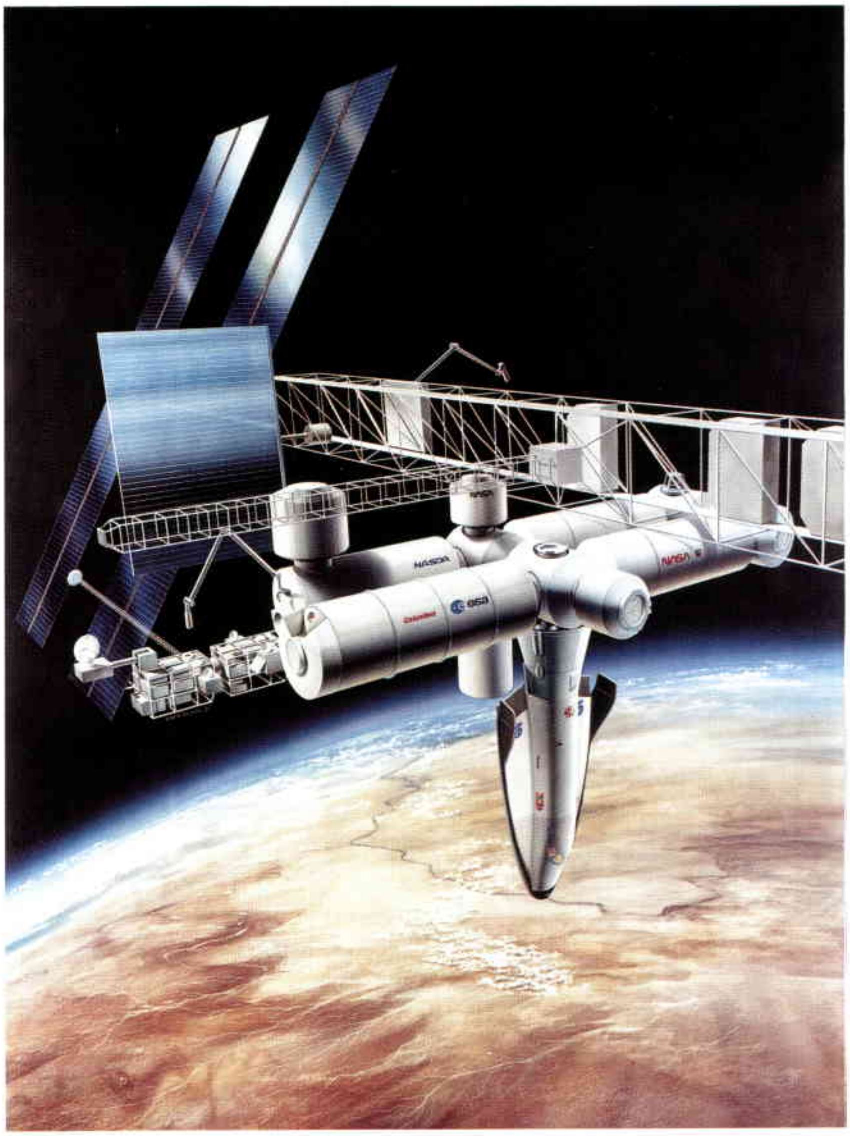


Figure 5. Hermes mission to Space Station 'Freedom'



corresponds to 120 manhours per mission (including the time required for extravehicular and robotic-arm operations). In addition, limited power and thermal-control resources are provided to the cargo.

Constraints on Hermes resource utilisation

The current concept for Hermes ground processing is shown in Figure 4.

It calls for the delivery of cargo items:
- 3 months before launch for non-standard or non-urgent items (consumables, preventive maintenance, reconfiguration, etc.)
- 6 weeks before launch for standardised, urgent items (corrective maintenance, samples)
- from 48 hours to a few hours before launch for fragile items to be placed in a special temperature-control device.

Payload recovery will take place shortly after landing for survival-sensitive and urgent items, and a few days after landing for the remaining payloads.

Hermes missions to Space Station 'Freedom'

Another objective of the Hermes Programme is to permit missions to the Space Station (Fig.5).

These missions are foreseen in the Memorandum of Understanding between ESA and NASA and work is already in progress, jointly with Columbus and US representatives, on the consolidation of such missions. Among the possible missions being examined are:

- a visit to Space Station 'Freedom' for the in-orbit validation of rendezvous/docking and Hermes/Space-Station composite performances and operations
- provision of additional transportation resources or operational flexibility to the European users of the Columbus Attached Laboratory
- a Shuttle-backup mission to the Space Station, involving mission replanning for and the reconfiguring of a ground-based Hermes vehicle. The time required to achieve Hermes readiness for such a mission is between one and three months following the decision, depending in particular on when in the Hermes ground-processing cycle (Fig. 6) the request is received. Hermes could transport spares and consumables to safeguard minimum Station operation, or be used to retrieve safely a crew of up to eight Space Station 'Freedom' astronauts (depending on the capability of NASA's Assured Crew Return Vehicle, currently under study).

The curves in Figure 6 give the probabilities of having one of the two Hermes vehicles prepared at short notice. The three modes are:

- nominal: current working hours, i.e. one shift, working 5 to 6 days per week
- mode 1: two shifts in Europe, one shift in French Guiana (Kourou), working 7 days per week
- mode 2: same as mode 1, but working three shifts in Europe.

It can be seen, for example, that there is a 90% chance of getting one Hermes vehicle ready for a rescue mission to 'Freedom' within 60 days after a request with mode 2. The corresponding Hermes mission profile and performances are close to those for a nominal mission to the Columbus Free-Flying Laboratory, except for: the proximity operations (approach to manned the Space Station, possibly berthing using the Station's manipulator arm rather than direct docking); provision of Space-Station/Hermes composite interfaces; and training of the Hermes crew in Space Station features.

Hermes mission to 'Mir'

Candidate mission objectives are being evaluated in the framework of the ESA/USSR Agreement on cooperation in space activities. Examples of such missions are:

- a visit to the 'Mir' Station for in-orbit validation of compatibility (similar to the Hermes mission to Space Station 'Freedom')
- a rescue mission
- support to the exploitation of a European experiment package on board 'Mir'.

The Hermes performances and resources needed for a mission to 'Mir' are expected to be close to those for its primary mission, except in those areas specifically related to:

- the target orbit, 'Mir' being in a circular 450 km-high, 64°-inclination orbit
- the up/down cargo masses (expected to be 1000 kg and 1500 kg, respectively).

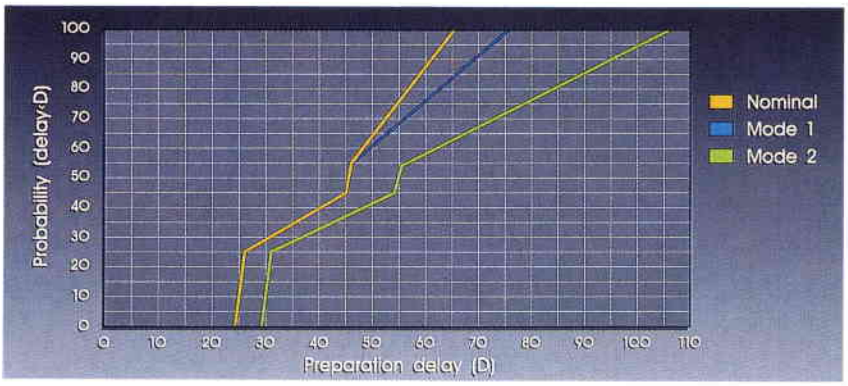


Figure 6. Hermes availability for a Space-Shuttle-backup mission to Space Station 'Freedom'

Other missions

In addition to providing the necessary shuttle service between stations in space and the ground, the Hermes spaceplane could carry onboard experiments, subject to the necessary resources (e.g. power, thermal control, and data processing) being available in kit form.

Any spare Hermes resources in terms of, for example, payload mass and volume, crew time, power during a servicing mission, etc., could be exploited by the European user community via Hermes get-away standard containers or kits, whenever they are compatible with the specific characteristics of the available resources.

Operational aspects

The Hermes system is designed for a total lifetime of 15 years, with a total of up to 30 missions for each of the two spaceplanes.

For each mission, such activities as:

- flight operations control and monitoring
- spaceplane maintenance and reconfiguration
- cargo definition, preparation and integration
- crew training

will have to be carried out to meet the nominal schedule of two visits per year to the Columbus Free-Flying Laboratory.

More specifically, we have:

- the *Flight Operations Activities* covering: operations planning, mission analysis, astronaut training, preparation of control centres, training of ground personnel, testing and simulations, spaceplane and resource-module in-orbit monitoring and control, in-orbit servicing, two-way communications, interfacing with control and engineering support centres, ground support to the crew, management of spaceplane/resource-module resources, and post-flight assessment of mission performances.

- the *Processing Activities* including: Spaceplane processing
  - at element level (spaceplane maintenance, resource-module production and acceptance), and
  - at integrated system level,
    (i) in Europe (spaceplane/resource-module integration and checkout, preparation for transport)
    (ii) at the launch site (spaceplane/resource-module integration, Hermes/Ariane-5 mating, crew support, roll-out and final countdown), and
    (iii) at the landing sites (preparation of sites, post-landing processing of spaceplane, and support to the crew).

  Cargo processing:
  - from delivery by the customer up to final checkout before take-off: integration in Europe and/or at the launch site with the spaceplane and resource module, transportations and verifications, late access;
  - from landing up to delivery back to the customer: retrieval at the landing site or in Europe, transportation, de-integration and inspection.

- The *Logistics Activities*, including the procurement of spares and consumables, the transportation and ground-handling capabilities and the maintenance and operation of the ground facilities.

Figure 7 summarises the relationships between the major blocks of activities prior to launch.

The planning activities covering the above operations will be secured through a three-level mechanism common to both the Hermes and Columbus Programmes. The strategic level will analyse the mission requirements for a five-year period with a view to issuing a consolidated 'Operations and Utilisation Plan', which will provide a 'first cut' of the resources required to support the selected missions. The next step in the planning process will be to issue the 'Tactical Operations Plan' (TOP), which will provide key planning data on detailed system operations and user requirements for all missions selected in a two-year manifest.

The TOP will then form the basis for the preparation of all mission-specific documentation, including the plans and procedures supporting execution of the operations.

The *Crew Training Activities*, distributed over three main phases:

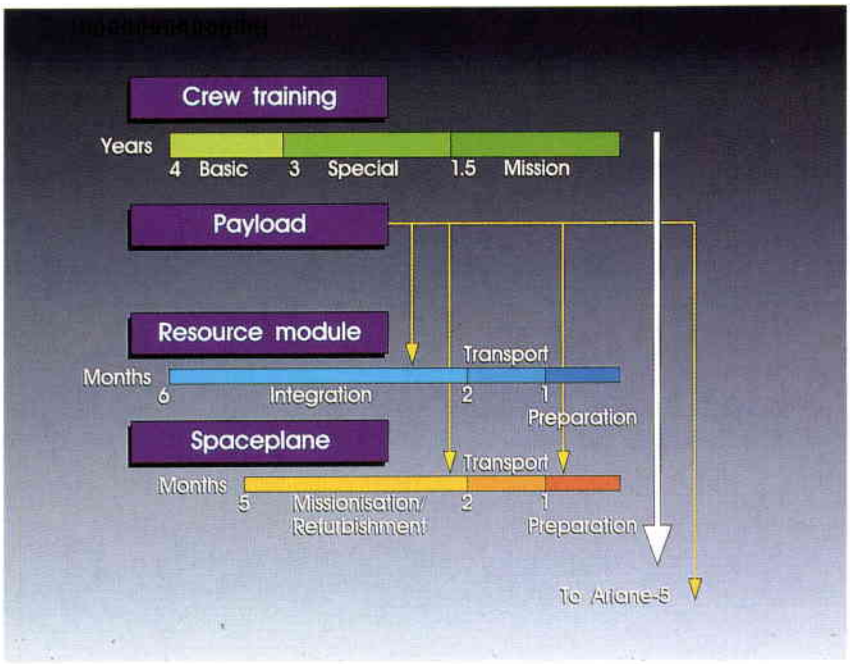
- one year of basic training for familiarisation, and acquisition of basic knowledge and skills;
- eighteen months of specialised training on space-element systems and subsystems (including their associated ground segment), piloting, EVA, and RVD;
- eighteen months of mission training for both the assigned crew and a backup crew for a specific mission.

Overview of the ground system

The ground system required to support the preparation and execution of the Hermes missions is being defined along the following lines:

- A Central Mission Control Centre will perform operations requiring central authority, such as mission planning,

Figure 7. Hermes mission preparation



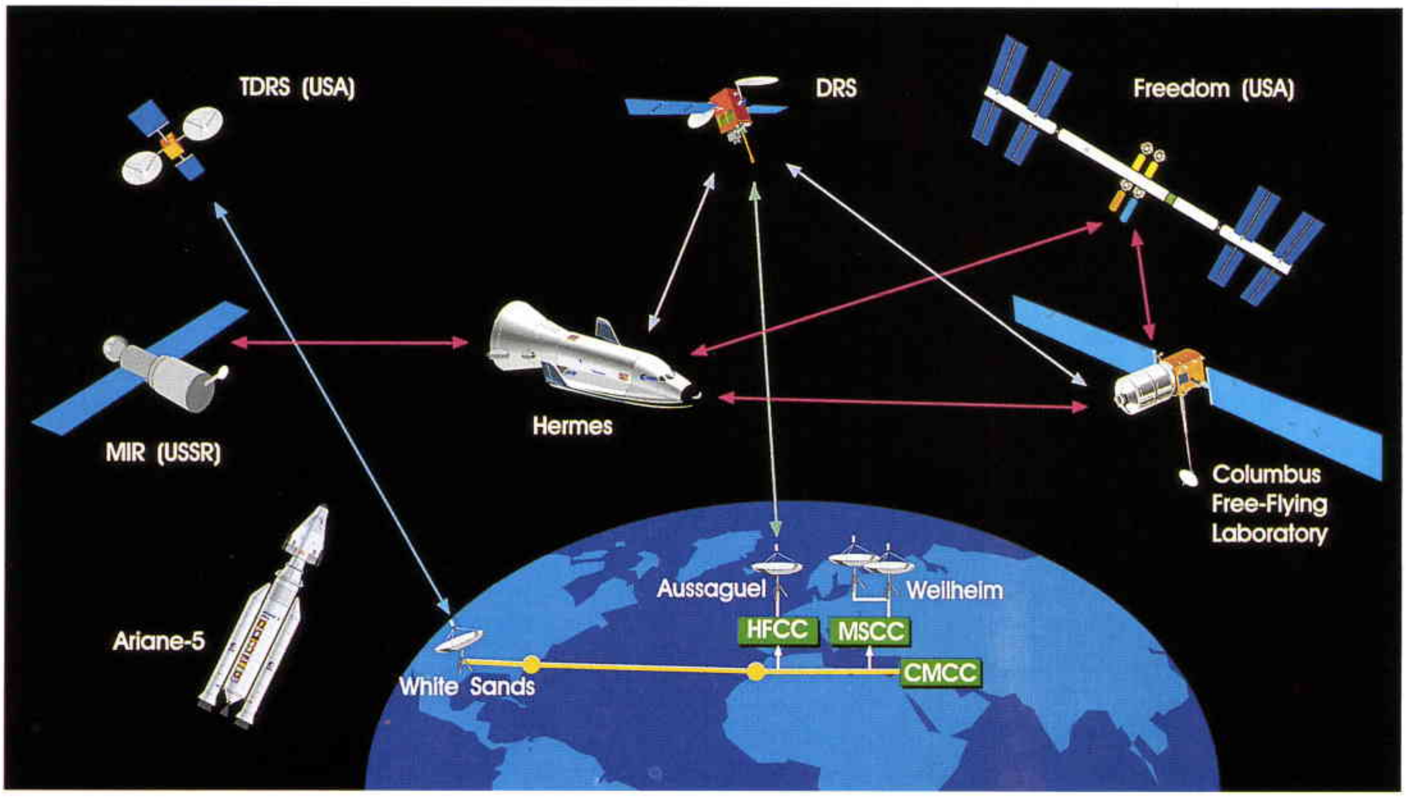


Figure 8. Main operational interfaces for Hermes missions

mission preparation, mission direction, management of communication resources, and central navigation support.

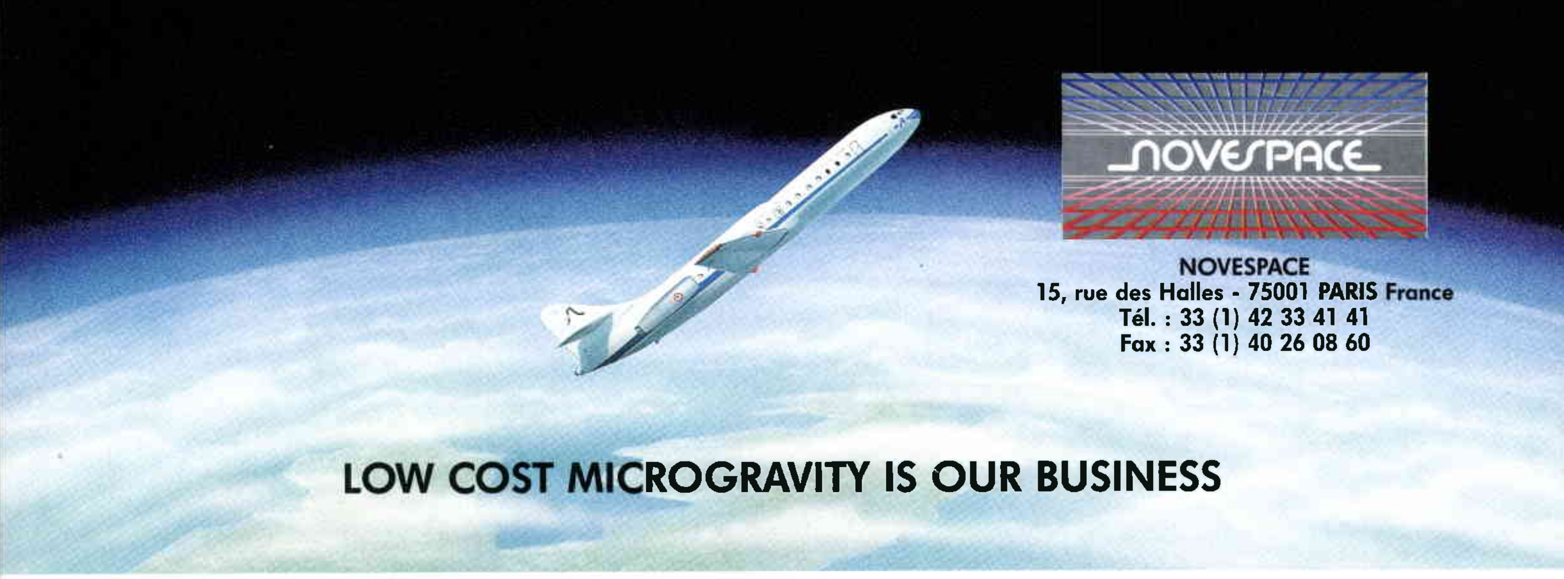
- Control of the Hermes flight operations will be carried out by the Hermes Flight Control Centre, in cooperation with the Manned Space Laboratories Flight Control Centre responsible for control of the Free-Flying Laboratory, particularly for the latter's servicing operations. The main flight operations interfaces are summarised in Figure 8.
- The ground processing for the spaceplane will take place at the Hermes integration buildings, either in Europe or in Kourou, depending on the mission preparation phase.
- The ground processing for the cargo will be carried out: at the Engineering Support Centre for in-orbit servicing, as far as cargo definition and overall preparation planning are concerned; at the Free-Flying Laboratory Centre for cargo acceptance testing; at the resource-module manufacturer for integration of the module cargo; and at the spaceplane integration sites.
- The final integration and verification of the Hermes space vehicle (spaceplane + resource module + cargo) will be performed at the Hermes integration building in Kourou.
- The Hermes/Ariane-5 integration will be executed at the assembly building in Kourou.
- The spaceplane will be able to land at various sites; the current baseline is for two primary landing sites (Almeria in Spain, and Rochambeau in French Guiana) and five backups (three for emergency landing from orbit and two for launch abort).
- Astronaut training for Hermes missions will be conducted using various facilities, ranging from classroom and computer-aided instruction to such specialised training tools as the Hermes Flight Simulator, Hermes Trainer Aircraft, Hermes Subsystem Simulator (including robotics), Neutral Buoyancy Facility, Man-Rated Vacuum Chamber, EVA Suit Simulator, and several mock-ups.

In addition, access to the Columbus Free-Flying Laboratory, Space Station 'Freedom' and Mir training facilities will be necessary to ensure that the Hermes crew is familiarised adequately with the station to be visited.

Conclusion

The mission objectives and operational scenarios summarised above serve to illustrate the technical complexity and the challenging character of the tasks faced by Europe in acquiring experience in manned missions through its development of the Hermes spaceplane. Additional work on the concepts outlined is currently being carried out with a view to further consolidating all mission-related aspects.


PARABOLIC FLIGHT
SOUNDING ROCKET
RECOVERABLE CAPSULE
ORBITAL FACILITY


LOW COST MICROGRAVITY IS OUR BUSINESS

Towards the Selection of ESA's Next Medium-Size Scientific Project (M2)

R.M. Bonnet
Director of Scientific Programmes, ESA, Paris

On 15 June 1989, the Directorate of Scientific Programmes issued a 'Call for Mission Proposals' for the Next Medium-Size Project (M2) to the wide scientific community. In response to this Call, twenty-two proposals were received, of which six were selected by the Agency's Space Science Advisory Committee (SSAC) for study at assessment level. This study phase was completed with presentations of the projects to the scientific community on 9 and 10 April 1991. Following these presentations, the SSAC further narrowed down the number of candidate missions, selecting four projects for study at Phase-A level. This more detailed study phase will be completed by early 1993, at which time the final selection of a single new project will be made by the Agency's Science Programme Committee (SPC).

The 'Horizon 2000' Long-Term Plan

The selection of the Agency's Next Medium-Size Project is part of the Long-Term Plan 'Space Science: Horizon 2000' (described in detail in ESA Special Publication SP-1070). This Plan was established in 1984 with wide involvement of the scientific community and was adopted by the Agency in 1987. Its realisation was made possible by the commitment of ESA's Member States to provide a 5% annual increase in funding for the Scientific Programme over about a decade.

'Horizon 2000' consists of a well-balanced mixture of four large, four medium-size, and possibly also a number of small projects, covering all major fields of space science. A further element of this Long-Term Plan consists of technology studies for missions 'beyond Horizon 2000'.

The centrepiece of this programme is a set of four so-called 'Cornerstones', which are major missions (each costing of the order of 400 MAU*, at 1984 economic conditions) with scientific aims that were determined at the programme's outset, covering the interests of the wide community of space researchers in Europe:

— In the Solar-System Exploration discipline:
  - the Solar-Terrestrial Science Programme (STSP), comprised of a solar-physics (Soho) and a magnetospheric-physics mission (Cluster) to be launched in 1995

  and further into the future
  - the Rosetta mission, involving a landing on a comet nucleus and return of a sample of cometary material to laboratories on Earth for detailed analysis.

— In the Astronomy/Astrophysics discipline:
  - the high-throughput X-ray spectroscopy mission XMM, a facility-class X-ray astrophysics observatory with an anticipated lifetime of more than ten years, to be launched in 1998,

  and further into the future
  - the Far-Infrared Space Telescope (FIRST), a spectroscopy mission in the largely unexplored 200 μm–1 mm region of the electromagnetic spectrum.

In contrast to the Cornerstones, for which the general scientific aims were defined at the outset of Horizon 2000, the medium-size and small missions are selected competitively one by one. A medium-size mission is defined as one costing of the order of 200 MAU (1984 economic conditions), while a small project would cost significantly less than 200 MAU.

The first medium-size mission (M1) is Huygens, a probe to be launched in 1995 together with NASA's Cassini spacecraft. Cassini will carry the Huygens probe to the vicinity of Saturn's moon Titan, where it will be released for a descent through Titan's atmosphere and a landing on its surface.

At present, candidate missions for the second medium-size mission (M2) are being studied. Of the twenty-two missions proposed in 1989 in response to ESA's Call for Mission Proposals (twelve in Astronomy/Astrophysics,

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* Million Accounting Units;
1 AU = ±1.2 US $

five in Solar-System Exploration, and five in Fundamental Physics), six were selected by the SSAC for a study at assessment level. These are:

- In Astronomy/Astrophysics:
  - INTEGRAL, an International Gamma-Ray Astrophysical Laboratory
  - IVS, an International VLBI* Satellite
  - PRISMA, a satellite for Probing Rotation and Interior of Stars: Microvariability and Activity

- In Solar-System Exploration:
  - MARSNET, a network of three semi-hard landers on Mars
  - OPT, an Orbiting Planetary Telescope

- In Fundamental Physics:
  - STEP, a Satellite Test of the Equivalence Principle.

With the exception of PRISMA, all missions would exceed significantly the financial threshold set for medium-size missions if carried out by ESA alone, and they are therefore being studied in the context of collaboration with other space agencies.

The six missions are described in more detail in the following pages.

Concepts for small projects were solicited by the Science Directorate on 18 June 1990 with a 'Call for Ideas'. ESA is currently evaluating the 52 proposals (11 Astronomy, 12 Space Plasma, 12 Planetary, 7 Solar Physics, 7 Earth Science, and 3 in other disciplines) received in response to this Call, with a view to determining whether or not small missions should be incorporated into the Long-Term Plan.

For the more distant future, 'beyond Horizon 2000', ESA is carrying out technological studies for:
- a solar probe, 'Vulcan', that would approach the Sun to within four solar radii
- elements of a mission to Mars, in particular a network of hard and semi-hard landers, a rover, and a Mars orbiter
- astronomical imaging through two-dimensional interferometry from space
- opportunities that might be offered by a lunar base for science 'from the Moon' and science 'of the Moon'.

Selection procedure for medium-size missions

The selection is made in three steps:

(i) selecting from the missions proposed by the scientific community, *up to six* missions for a study at assessment level
(ii) selecting from the missions under study at assessment level, *up to four* missions for a study at Phase-A level
(iii) selecting from the missions under study at Phase-A level, *one* mission to be carried out.

The selections (i) and (ii) are made by the Space Science Advisory Committee (SSAC) based, for astronomy/astrophysics missions, on a recommendation by the Astronomy Working Group (AWG), and for solar-system exploration missions on a recommendation by the Solar System Working Group (SSWG). In the case of the selection for M2, there were also proposals in the discipline of fundamental physics, and here selection (i) by the SSAC was based on a recommendation by an ad-hoc Working Group on Fundamental Physics, and selection (ii) by the SSAC was based on the advice of a Science Advocate. The final selection (iii) is made by the Science Programme Committee (SPC) based upon the recommendations of the SSAC.

The number of candidate missions is reduced from one selection to the next and the remaining missions are studied in increasingly greater depth. The objective of the two study phases is to define the mission science objectives, the scientific model payload, the spacecraft, launch, operations and, where applicable, the sharing of tasks between collaborating space agencies, to a level where a schedule and cost-to-completion can be estimated with increasingly higher confidence.

At assessment level, a study typically lasts six months, followed by a consolidation phase of three months. At Phase-A level, a study typically lasts twelve months, followed again by a consolidation phase of three months. The consolidation phase is needed for cost and technical reviews, identifying cost drivers, potential descoping of missions, and for fine-tuning of international collaborative scenarios.

All technical work at assessment level is carried out in-house; at Phase-A level, non-competitive technical studies are done by industry under ESA contract. During both study phases, ESA is advised on scientific matters by a Study Team composed of external scientists, selected by ESA based on their competence in the particular discipline of the mission under study.

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* VLBI = Very-Long-Baseline Interferometry

Through the strong involvement of the scientific community at all study phases, and in all steps off the selection process, and by coupling the competence of external scientists with in-house scientific and technical expertise, it is possible to select ultimately the single best mission from the large number proposed at the outset.

INTEGRAL

The INTEGRAL (INTErnational Gamma-Ray Astrophysics Laboratory) mission is dedicated to the fine spectroscopy and imaging of celestial gamma-ray sources in the energy range 15 keV to 10 MeV. The instruments on INTEGRAL will achieve a gamma-ray line sensitivity of 3×10^{-6} ph.cm^{-2} s^{-1}, a continuum sensitivity of 3×10^{-8} ph.cm^{-2} s^{-1} keV^{-1} at 1 MeV ($\approx$10 mCrab at 1 MeV), and imaging with an angular resolution of better than 20 arcmin. This represents an order-of-magnitude improvement over the Gamma-Ray Observatory (GRO) in line sensitivity, energy resolution and angular resolution.

Comparison with SIGMA also shows a major advance: the continuum sensitivity improvement is considerably more than one order of magnitude between 100 keV and 1 MeV, while the narrow-line sensitivity is increased by nearly two orders of magnitude.

INTEGRAL consists of two main instruments: a germanium spectrometer and a caesium-iodide coded-aperture mask imager. These instruments are supplemented by two monitors: an X-ray monitor and an optical transient camera.

Scientific overview

In the 15 keV–10 MeV region, line-forming processes such as nuclear excitation, radioactivity, and positron annihilation become important. Unique astrophysical information is contained in the spectral shift, line width, and line profiles. Detailed studies of these processes require the resolving power ($E/\delta E$=500) of a germanium spectrometer such as that employed on INTEGRAL. Lower resolution spectrometers

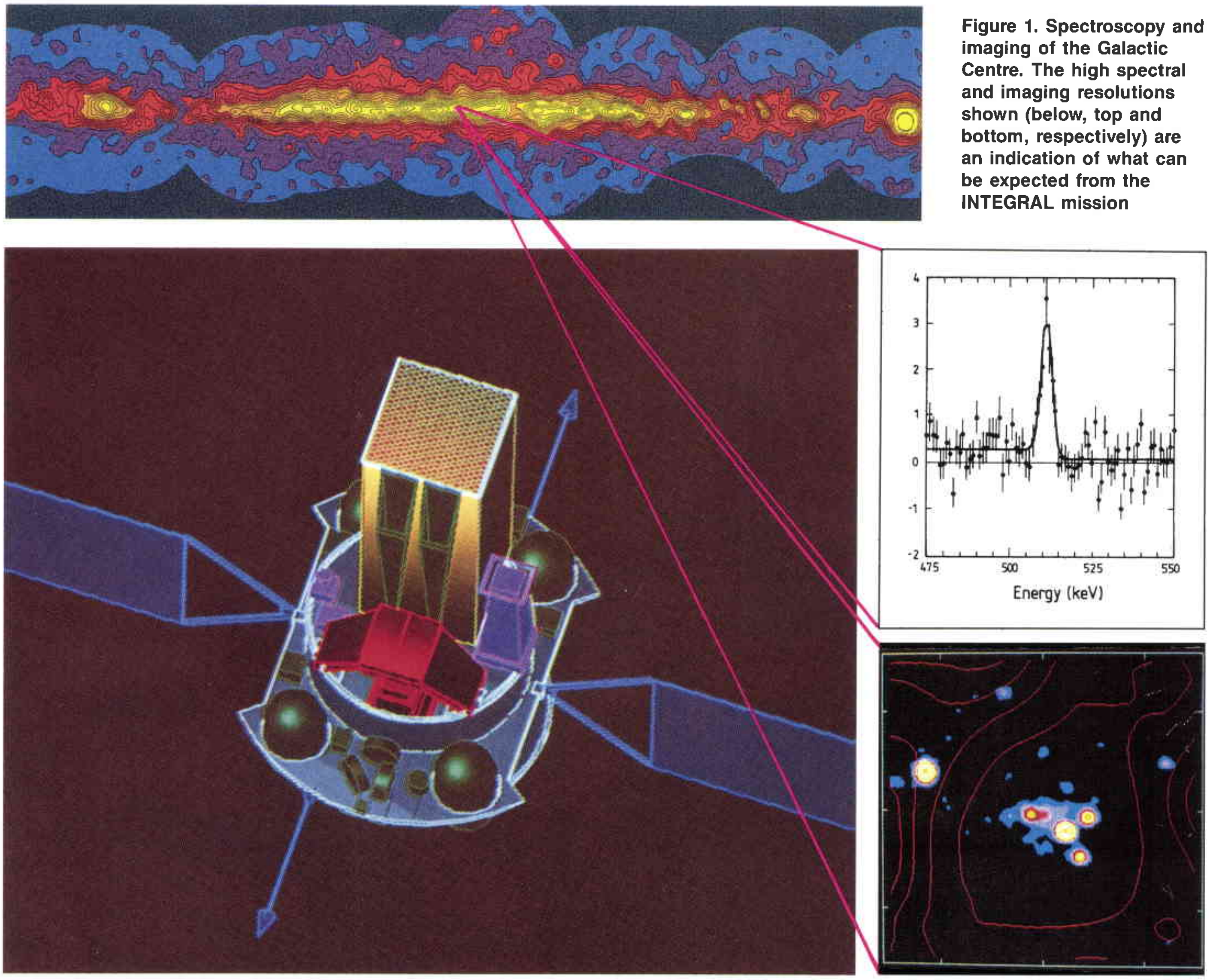

Figure 1. Spectroscopy and imaging of the Galactic Centre. The high spectral and imaging resolutions shown (below, top and bottom, respectively) are an indication of what can be expected from the INTEGRAL mission

(e.g. SIGMA, OSSE, COMPTEL) will not have sufficient resolution to study the parameters of these lines. The last high-resolution space instrument, flown on HEAO-3 in 1979/80, was 100 times less sensitive than INTEGRAL. Solid observational and theoretical grounds already exist for predicting detectable emission from various celestial objects (e.g. Galactic Centre, compact galactic objects, supernovae).

The gamma-ray emission from the Galactic Plane will be mapped on a wide range of angular scales from arcminutes to degrees, in both discrete nucleo-synthesis lines, such as ^{26}Al and the positron annihilation line, as well as the wideband continuum. At the same time, source positioning at the arc-minute level within a wide field of view, of both continuum and discrete line emissions, is required.

The study of active galaxies in both fine and broadband spectroscopy will yield unprecedented knowledge of the particle interactions that take place in the region where the central engine's energy meets the galaxy's matter. Because of the greatly improved sensitivity of INTEGRAL, sub-degree resolution imaging is absolutely necessary to avoid source confusion from the large population of AGN and to associate gamma-ray sources unambiguously with their optical, infrared and radio counterparts.

Key mission features

- INTEGRAL is the first high-resolution spectral imager in the 15 keV–10 MeV region
- High-resolution spectroscopy (2 keV at 1 MeV)
- Fine imaging with <20′ FWHM angular resolution and <1′ source positioning within 50 sq. deg field of view
- Line sensitivity: 3×10^{-6} ph.cm^{-2} s^{-1}, and continuum sensitivity of 3×10^{-8} ph.cm^{-2} s^{-1} keV^{-1} (at 1 MeV, 3σ, 10^6 s)
- Three-axis-stabilised spacecraft, pointing accuracy: 15′ (absolute), 1′ (relative), 40 kbit/s science data rate
- Two mission scenarios (HEO, LEO) with equitable division of responsibilities between ESA and NASA:
  (i) Highly Elliptical Orbit (HEO):
  Titan-III class launcher; XMM bus; orbit 24 h, 28° inclination, 4000 km perigee; mission control: ESA

  (ii) Low Earth Orbit (LEO):
  Ariane launcher; EES bus; orbit: 90 min, 0° inclination, 550 km altitude; mission control: NASA

During the mission lifetime, a significant number of transient events are expected to occur. Some of these will be gamma-ray bursts within the field of view, whilst supernovae events out to and including the Virgo cluster will also be studied by periodic re-orientation of the telescope.

System aspects

HEO (Highly Eccentric Orbit)
This concept employs the XMM Common Bus in combination with a Titan-III or equivalent launcher. The orbital parameters chosen are a 24 h period, a 28° inclination and a high perigee (>4000 km), in order to provide long (>15 h) uninterrupted observation periods at nearly constant background and away from trapped radiation. ESA would be responsible for the bus and mission control, with one European ground station baselined. A second station could be provided by NASA.

LEO (Low Earth Orbit)
This option employs the NASA Expendable Explorer Spacecraft (EES) or equivalent bus, and an Ariane-4 to launch the payload into a near-equatorial orbit which provides a low background environment, essentially free from passages through the South-Atlantic Anomaly. A dedicated control-moment gyro arrangement will be employed to maximise the observing efficiency to typically 75%. Mission control will be the responsibility of NASA via TDRSS. An ESA ground station could be used.

Both options are capable of meeting the full scientific requirements.

Management

The mission scenarios have been devised for an equitable division of responsibilities between ESA and NASA, and within the overall individual M2 and Explorer constraints.

A Guest Observer Programme will be established. For maximisation of scientific return, the concept of dual data centres — one in Europe and one in the US — is envisaged. Such centres will be managed by the scientific collaboration and serve the entire guest-observer community.

Key staff

S. Volonte, Chairman, ESA HQ
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IVS

The International VLBI Satellite (IVS) will be a radio telescope in space. Its main goal will be to provide a space-based Very-Long-Baseline Interferometry (VLBI) element, acting as an extension to one of the modern generation of ground-based VLBI arrays with which it will observe in concert. It will be similar in sensitivity to, and cover most of the frequencies of, an element in such ground-based arrays.

The primary reason for placing a VLBI element in space is to achieve baselines larger than the size of the Earth. High-sensitivity, high-quality images of radio sources at wavelengths spanning the radio band from centimetres to millimetres with the greatly increased angular resolution made possible by IVS will open up exciting new opportunities for VLBI observations. The scientific objectives span a wide range of topics including the physics of masers and stars, galactic and extragalactic distance determinations, and the physics of normal and Active Galactic Nuclei (AGNs), including such phenomena associated with AGNs as jets and superluminal motion. In addition, direct distance determinations out to the distance of the Virgo galaxy cluster will be performed.

Key staff

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Key mission features

The International VLBI Satellite (IVS) will be a three-axis-stabilised spacecraft consisting of a service module (derived from the Standard Space Platform) and a propulsion module provided by the USSR Academy of Sciences, and a payload module provided by ESA.

IVS will:

- Image a wide range of compact radio sources, both in total intensity and polarisation, with resolution as fine as 10 microarcsec, and provide simple structural information on the 1 microarcsec scale.
- Have a 20 m primary-reflector diameter and a maximum bandwidth of 256 MHz for continuum VLBI observations.
- Have state-of-the-art dual-polarisation radio receivers for 4.5–8.5, 15–23, 42–63, 86–120, and if feasible 218–222 GHz.
- Together with a 70 m ground telescope, readily detect a 4 mJy radio source in a 5 min integration, and a 0.4 mJy source with phase referencing in a 12 h integration time, in the lowest frequency band.
- Have onboard VLBI signal-conditioning electronics, spectrometer, and CMBR total power receiver.
- Have absolute, relative, and reconstituted pointing errors of no more than 10, 5, and 5 arcsec, respectively; and allow offset pointing up to ±0.5°.
- Have three operational orbits, with perigees of 6000 km, inclinations of 63.4°, and apogees of 20 000, 40 000 and 150 000 km, respectively.
- Have launch masses of 7500, 4747 and 15 000 kg (including 11 500 kg of propellant) for the service, payload, and propulsion modules, respectively; giving a total launch mass of 27 247 kg.
- Be launched by the Soviet Energia vehicle.

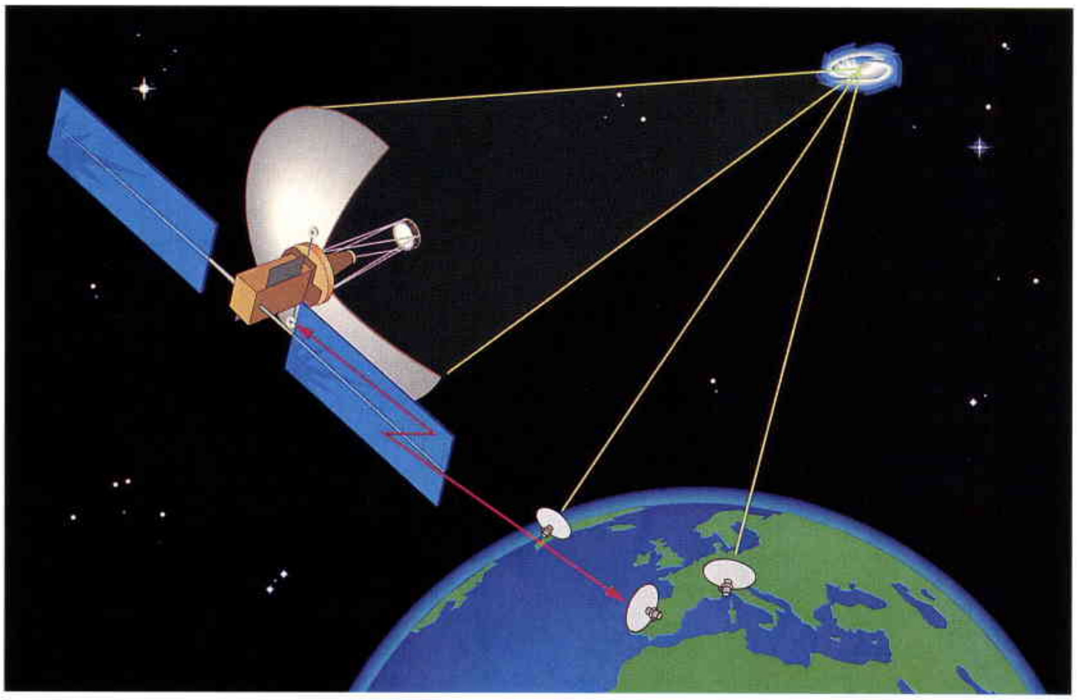

Figure 2. IVS observing as part of a VLBI array. Each ground-based telescope in the array has its own independent frequency standard and VLBI data tape-recorder, whereas for IVS these are located at the tracking station. After the observation, the tapes are sent to a central data-processing facility for correlation

IVS will also have a useful autonomous capability. Taking advantage of the absence of an atmosphere above the telescope, it will operate as a stand-alone radio telescope, enabling it to explore new frontiers in spectral-line and cosmic microwave background radiation (CMBR) research. The molecular oxygen lines in the 56–63 GHz range cannot be observed from the ground because of atmospheric blockage. Data on the gas-phase oxygen are absolutely necessary to understand the chemical and dynamical evolution of interstellar molecular clouds into star-formation regions. Ground-based CMBR observations are limited in sensitivity primarily by atmospheric fluctuations, which do not affect IVS, which is very well suited for making two-dimensional maps of the CMBR towards galaxy clusters. Together with X-ray data, such maps can be used to infer distances on cosmological scales.

The main element of the IVS payload module is a 20 m-class Cassegrain reflector capable of operating with high efficiency at 60 GHz. The science payload is a space-qualified version of the standard ground-based radio-telescope instrumentation, and includes actively cooled HEMT radio-astronomy receivers and the necessary electronics for carrying out the VLBI, spectroscopy and CMBR observations.

The choice of an optimum orbit is difficult for a space VLBI mission, as it is always a trade-off between imaging capability and maximum resolution. In order to benefit from the best of both worlds, IVS will be provided with the ability to change orbit in the course of the mission.

In its VLBI mode, IVS must be in real-time two-way contact with a telemetry station, which supplies the stable reference signal required and receives the VLBI data. After reception on the ground, the data will be recorded on magnetic tape in digital form, and transported to the central processing facility. IVS will be operated in observatory mode with data correlation and ground-based observing being carried out for the astronomer in absentia. In its autonomous mode, data will be stored onboard and relayed to the ground once or twice per day.

IVS will be a collaborative mission with ESA and the USSR Academy of Sciences as major partners, with DSN and potentially other additional participation.

PRISMA

The PRISMA (Probing Rotation and Interior of Stars: Microvariability and Activity) mission addresses one of the most elementary questions in astronomy, namely: What are stars? For the first time, the combination of asteroseismology and stellar activity monitoring will be able to answer this question.

In the case of the Sun, the application of seismology and simultaneous multi-wavelength observations led to significant discrepancies between solar models and measurements. This stimulated an on-going theoretical effort to refine the ideas of basic stellar physics. The point has now been reached where observations of other stars will allow significant improvements to the models and help to clear up points that are still controversial. The effort in the solar work will also allow a better understanding of the stellar data, as it is not possible to directly observe stellar discs.

The primary scientific objectives of PRISMA are to study:

- the internal structure and dynamics of stars by measuring the characteristic frequencies, amplitudes and lifetimes of radial and low-degree non-radial oscillation modes, and
- the internal magnetic dynamos, the photosphere and the outer atmosphere of stars by measuring the temporal variations of the ultraviolet and X-ray fluxes together with the previous measurements.

PRISMA exploits three of the fundamental advantages of space observations: their temporal stability, the possibility to perform observations with only few interruptions, and the unhampered access to ultraviolet and X-ray spectral ranges. Stability is a prerequisite as the photometric amplitude of solar-type oscillations is a few parts per million. Long uninterrupted observations provide the temporal resolution needed to separate modes with periods ranging from a few minutes to a few days and to determine frequency splits. Phenomena due to magnetic activity tracing the internal magnetic dynamo will be observed simultaneously for a large number of stars by observing their ultraviolet and X-ray fluxes.

As no presently available satellite, or any under consideration, fulfils all the scientific objectives, a model payload consisting of four instruments is proposed:

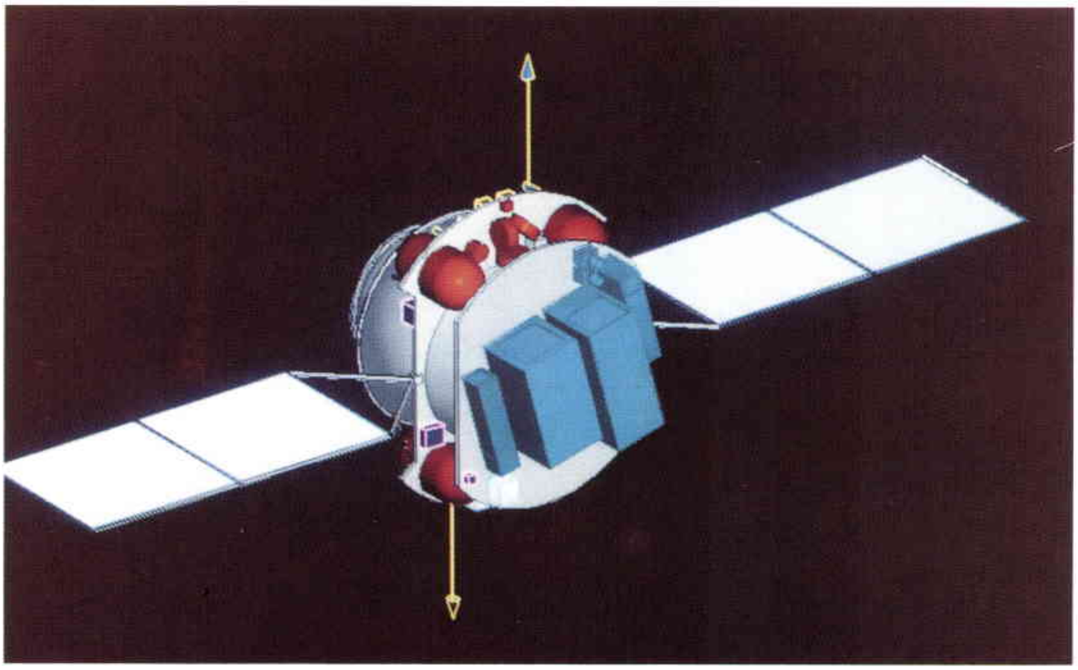

Figure 3. The PRISMA spacecraft

- A Large Photometer (LP), with an aperture equivalent to 40 cm diameter, with a 1.5°×1.5° field of view. The LP uses a three-mirror, off-axis design to reduce the effects of stray light. It collects simultaneously the broadband visible flux of stars brighter than magnitude 8 to detect micromagnitude flux variations.
- A Small Photometer (SP), with an aperture equivalent to 15 cm diameter, with a 3°×3° field of view. It has the same purpose and design as the LP, except that micromagnitude flux variations will be detected on stars brighter than magnitude 6. An internal mirror allows a wide selection of fields offset from the line of sight of the other instruments.
- An Ultra-Violet Spectrometer (UVS), optically aligned with the Large Photometer, with a 40×30 cm aperture and covering the 120–280 nm wavelength range that includes chromospheric and transition region lines. A high-resolution, cross-dispersed echelle system allows observation of one star at a time in a 1.5°×1.5° field of view (resolution 0.01–0.02 nm).

Key staff

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Key mission features

Observables	Range	Accuracy	Scientific keywords
Photometry			
Frequencies	0.02 mHz – 0.1 Hz	0.1 μHz	Stellar structure, g-modes, He content, neutrino physics
Amplitudes	$10^{-6} - 10^{-1}$	$10^{-7} - 10^{-5}$	Excitation, stellar spots and plages, non-linear pulsators (?), convection
Line widths	1 – 10 μHz	0.05 μHz	Excitation, convection, surface structure
Frequency separations	>0.3 μHz	0.1 μHz	Basic stellar parameters, stellar structure, rotation, magnetic fields
Spectroscopy			
UV flux	$10^{-13} - 10^{-17}$ Wm^{-2}	5%	3D pictures
UV lines profiles	120 – 285 nm	0.02 nm (resolution)	Doppler imaging
17 nm X-ray flux	$10^{-14} - 10^{-17}$ Wm^{-2}	20%	Corona, flares

- A normal-incidence eXtreme Ultra-Violet Telescope (XUVT), imaging the same 1.5°×1.5° field as the Large Photometer. A multilayer off-axis mirror selects a 3 nm bandwidth, centred at 17 nm, including the Fe VIII-XI lines sensitive to coronal temperatures.

The photometers have passively cooled detector arrays, allowing more than one star to be observed at the same time, while the spectrometers use microchannel plate detectors. All the instruments except the XUVT use active mirrors to stabilise the stellar images against spacecraft motion.

The preliminary PRISMA catalogue gives priority to solar-type stars, binaries with known masses, late-type giants and subgiants, open clusters (containing solar-like or early-type stars), δ Scuti, and rapidly oscillating Ap stars. Even coverage of the Hertzsprung-Russel diagram has been maintained as far as possible. The observing strategy imposed by the scientific requirements is defined as follows:

- The Large Photometer and the Small Photometer will observe separate fields continuously for at least one month.
- The Ultra-Violet Spectrometer will observe successively the stars in a field identical to that of the Large Photometer. Characteristics of the individual stars determine the observing sequence.
- The eXtreme Ultra-Violet Telescope will observe the same field as the Large Photometer, also continuously for at least one month.

The spacecraft assumed for PRISMA is the XMM bus defined by an internal ESA study performed in 1989. PRISMA can be launched as a lower Ariane-4 passenger (dual launch) into a 24 h period orbit with a perigee altitude of 3070 km, an apogee of 68 500 km, and an inclination of 7°. This orbit both provides good sky coverage and permits the scientific objectives to be achieved.

Payload instruments will be provided by Principal Investigators (PIs) with national funding. During the development phase of the payload, a scientific team wll coordinate the establishment of the target catalogue. After some months of operation, a 'Call for Guest Investigators' will be issued. The data gathered will be available to the scientific community after one year.

MARSNET

A fundamental goal of astronomical research in the 21st Century will be to determine whether the Earth is unique in the Milky Way. Related to this is the problem of the origin of life and its cosmic abundance. One way to approach these outstanding questions is to search for planets orbiting neighbouring stars, making use of increasingly sophisticated observational equipment. Another way to infer the uniqueness of our planet is to compare the Earth with other terrestrial bodies in the Solar System. Mars, the most Earth-like planet, will play a prominent role in such endeavours.

An essential question in the comparison of the Earth and Mars is to establish whether biological activity has ever been present on the Martian surface. Regardless of the outcome of the search for past or present biochemical reactions on Mars, the result will strongly influence our understanding of the Earth as a planet. The investigation of gas and dust clouds surrounding certain newly born stars represents the realm where astronomy and planetary science meet. The scientific exploration of Mars will then give us new insights into the physical and chemical processes that took place in the primordial solar nebula, since the chemical composition of a planet depends on its location in the nebula during condensation. In addition, the study of Mars will deepen our understanding of the evolution of planets.

Spacecraft exploration of Mars started in the 1960s. The first global orbital survey was conducted by Mariner-9, but the most significant mission to date was Viking, withits two orbiters and two landers. Following in their footsteps, the next phase would be to establish a network of small stations on Mars. The basis for the network is to land a number of seismological and meteorological stations on the Martian surface, to infer the internal structure of the planet, and the atmospheric circulation and weather patterns. These long-term investigations would require an operational lifetime of at least one Martian year (687 d). Other important scientific goals would be the chemical and mineralogical analysis of Martian surface rocks and soils, as well as other physical properties of the surface materials. The surface stations would also conduct exobiological investigations to determine the present conditions on the planet that would allow biochemical activity to take place.

The MARSNET mission consists of a network of three semi-hard landers to be placed on the surface of Mars, about 3500 km apart, thereby defining a global seismological network. Each semi-hard lander would be carried on-board its own aeroshell and deployed at 15 km altitude for landing at about 25 m/s. The small stations would be targetted for impact and landing at scientifically interesting sites in the Tharsis region of Mars, which is the most likely area to still show tectonic activity that would allow the seismometers to determine the internal structure of the planet.

In addition to studying the internal structure and activity of Mars, the other main scientific objectives would focus on science from the surface, and in particular the mineral and chemical composition of rocks and soils, the magnetic properties of minerals, and surface meteorology at sites at various latitudes and altitudes. Also, atmospheric pressure and temperature profiles would be obtained during entry and descent, and surface and descent imagery would allow interpretation of the geological setting of each landing site. The instruments onboard the small stations would also allow the surface and subsurface properties of Mars' upper layers to be identified, as well as the amount of solar-ultraviolet radiation reaching the Martian surface, to infer the present exobiological conditions on the planet. The MARSNET mission would therefore help to provide a global perspective of Mars.

NASA is also actively studying a network mission to Mars called MESUR (Mars Environmental SURvey). An existing understanding of future cooperation between the two agencies could develop into a joint ESA/NASA global Mars Network mission, in which ESA could provide three surface stations (MARSNET), and NASA a number of additional ones (MESUR), therefore complementing each other.

The delivery of the three ESA Mars semi-hard landers could be performed by moderate- to high-performance expendable launch vehicles, such as Delta-II, Ariane-4, Ariane-5, Titan-II/Centaur and Proton. The higher performance vehicles would deliver more modules per single launch. In the MARSNET baseline scenario, a composite, consisting of a carrier spacecraft (Mariner Mark-2 class) and a number of entry modules could be launched towards Mars in appropriate reference launch windows (1998, 2001, and 2003) and subsequent launch opportunities. The carrier spacecraft would then deliver and target the modules for atmospheric entry.

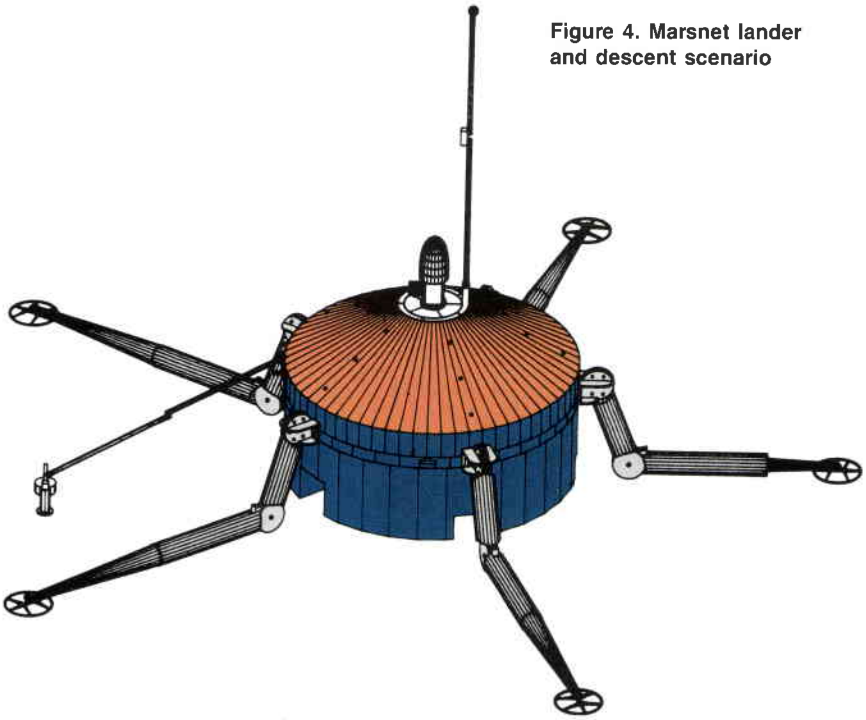
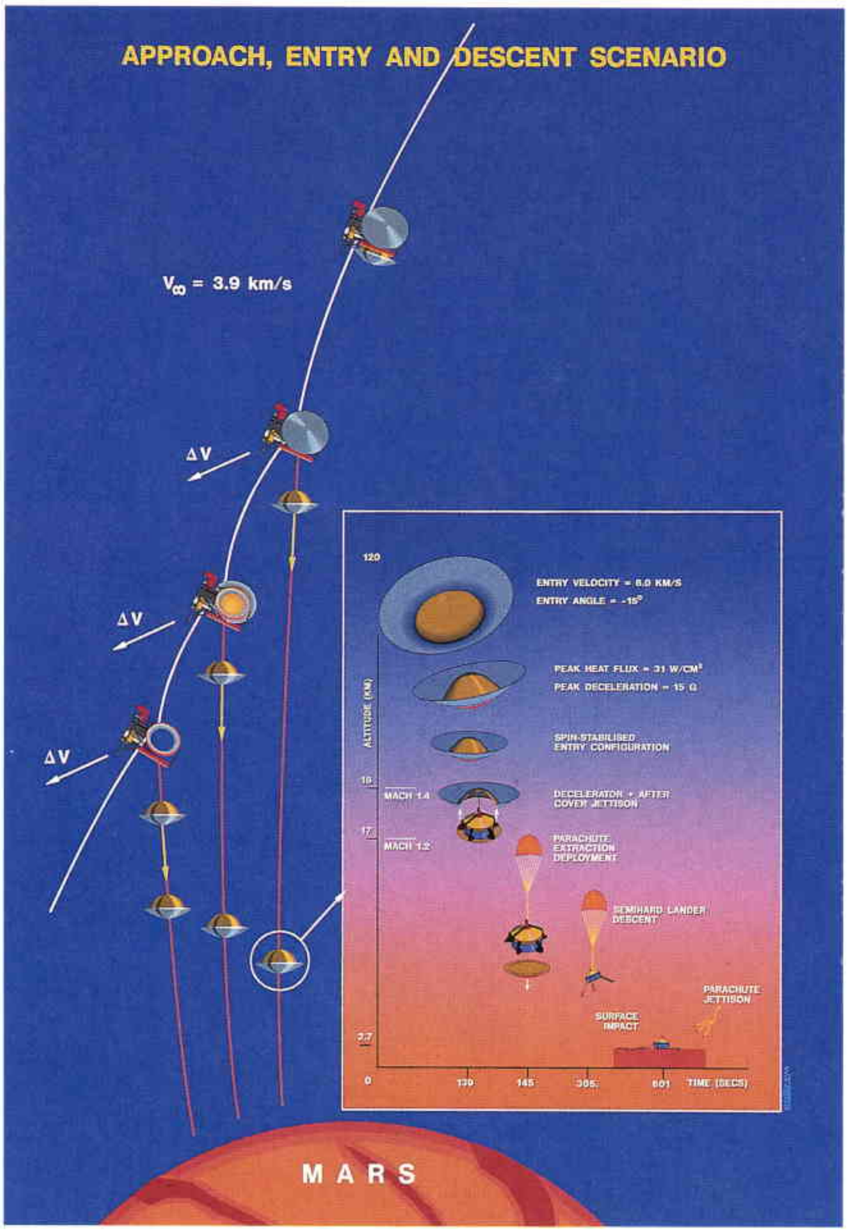


Figure 4. Marsnet lander and descent scenario



Key staff

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Key mission features

The Landers

Aeroshell diameter : 2 m
Lander diameter : 90 cm
Lander height : 90 cm
Lander mass : 84 kg
Payload mass : 8.7 kg
Power supply : Solar-cell array and battery

Model Payload for each Lander

Disciplines	Instruments
Geophysics of the interior	Seismometer Magnetometer
Geology	Television camera Descent imager
Geochemistry and mineralogy	α-backscatter/XRF-spectrometer Neutron detector γ-ray spectrometer
Magnetic properties of minerals	Coil experiment Resonance circuits
Meteorology	Meteorological package Atmospheric-structure instrument
Surface properties	Thermal-array probe Permittivity meter
Exobiology	Solar-UV dosimeter

OPT

The Orbiting Planetary Telescope (OPT) is a 1 m Ritchey-Chrétien reflector combining diffraction-limited imaging quality with panchromatic simultaneous medium/high-resolution spectroscopy, long integration times, and accurate on- and off-target tracking of fast-moving planetary objects.

The spectral range (110 nm – 20 μm) is covered by a complement of spectrometers and cameras that can be operated simultaneously. The capability of this telescope to investigate time-variable phenomena is unique. All objects, from Mercury and Apollo asteroids to distant stars and galaxies, are within its reach.

The OPT will make the impact on planetary science that the International Ultraviolet Explorer (IUE) has made in astronomy. Not only will it be a superb research instrument on its own right, but it will also support the Planetary Mission Programme by extending the discoveries of deep-space missions such as Galileo (to Jupiter), Mars Orbiter and Mars 94, Cassini/Huygens (to Saturn and Titan), CRAF and Rosetta (the cometary-rendezvous and sample-return missions).

OPT will stimulate comparative studies of solar and stellar planetary system formations and collaborative efforts by the solar-system and astronomy scientific communities. Near-real-time operation from home institutes of a state of the art complement of spectrometers and imaging cameras will stimulate interest

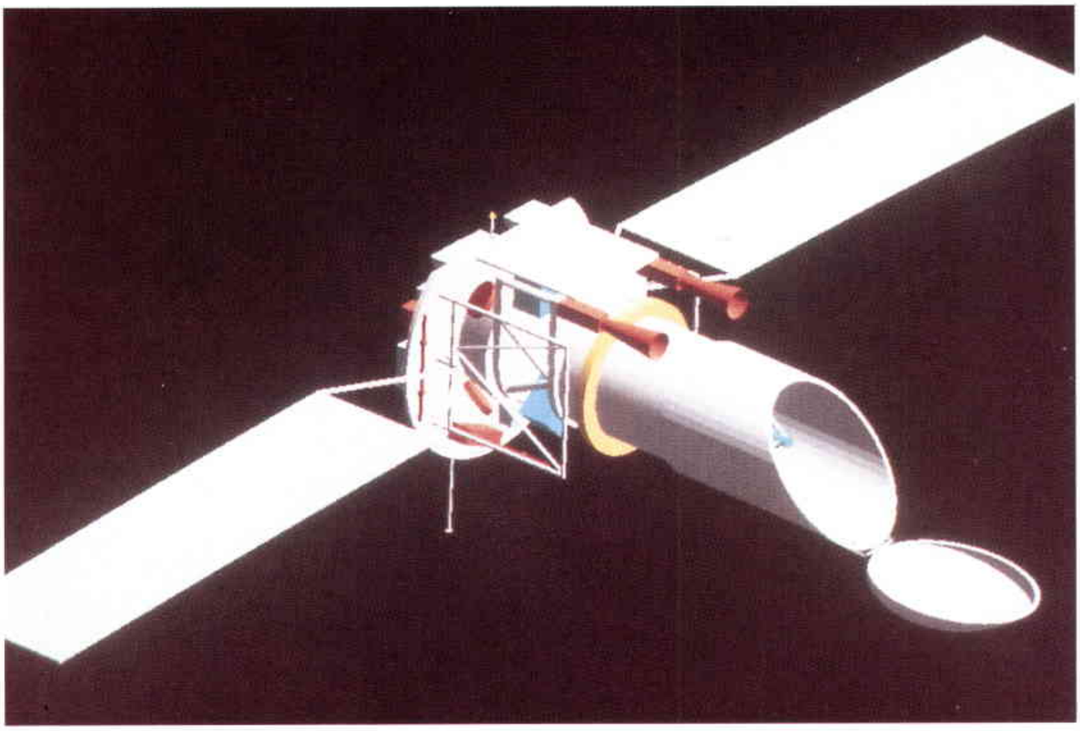


Figure 5. The Orbiting Planetary Telescope (OPT)

in planetary science. It will also inspire the academic education of large numbers of students and hence supplement the achievements of deep-space missions in a formidable way.

The proposed OPT mission is a joint ESA/DARA/NASA endeavour. ESA will coordinate the programme and provide the spacecraft, its attitude-control system, and final integration. DARA will provide the payload module (including telescope) and operations. NASA will provide the launch, the light distribution unit and integration of the spectroscopic package, and participate in the operations.

Scientific focus

Observations of time-variable solar-system phenomena:

- Planet–magnetosphere–satellite interactions, such as Io's plasma torus.
- Cometary jets of dust and parent molecules expanding away from the spinning nucleus (about 20 comets will be observable per year).
- Atmospheric circulation as exhibited by dust storms and polar-cap evolution on Mars, the rotation of the large spots in the atmospheres of Jupiter, Saturn and Neptune, and the varying atmospheric features of Venus and Pluto.
- Planetary oscillations providing data on the interior of the giant planets.
- Occultation of stars by planetary atmospheres and ring systems.

Observations of time-invariant solar-system phenomena:

- Geochemical provinces on planetary and satellite surfaces.
- Global characteristics of a multitude of primitive bodies, such as the albedo, size, and rotation of asteroids and cometary nuclei.
- Shapes and surface features of the largest asteroids.

Astronomical and astrophysical observations:

- Stellar and planetary formation.
- Galactic and extragalactic HII regions.
- Starburst galaxies, astrophysical jets and cataclysmic variables.
- Time-variable phenomena.

Key staff

M. Coradini, Chairman, ESA HQ
G. Scoon, Study Manager, ESA/ESTEC
R. Grard, Study Scientist, ESA/ESTEC

Key mission features

- Ritchey-Chrétien telescope with a primary-mirror diameter of 100 cm and a focal ratio of f/30.
- Field of view >10 arcmin.
- Diffraction-limited imaging at wavelengths >300 nm, angular resolution 0.07 arcsec.
- Pointing accuracy better than 0.05 arcsec over a 1 h integration time.
- Focal-plane instrumentation comprising three spectrometers (110 nm – 20 μm), an imaging photon-counting camera and a CCD camera (110 nm – 1 μm).
- Minimum solar elongation less than 25°.
- Highly eccentric orbit, ensuring about 70% of operation time above the radiation belts and minimum eclipse interference.
- Near-real-time, interactive operation.
- Expected lifetime in excess of 5 yr.

• Mission duration:	2 yr (consumables for 5 yr)
• Reference orbit:	1000 × 70 000 km, inclination 28.5°
• Scientific telemetry rate:	133 kbit/s
• Telemetry coverage:	60 – 96% with one European and one American 15-m station
• Total mass of payload module:	580 kg
• Target tracking accuracy:	0.4 arcsec over 12 min; 0.1 arcsec over 10 h.

STEP

STEP (Satellite Test of the Equivalence Principle) is a 'fundamental physics' mission, being studied as a cooperative venture with NASA, assuming a 50/50 sharing of mission elements. Its primary scientific objective is to measure any difference in the rate of fall of test masses in an Earth-orbiting satellite to one part in 10^{17} of the total gravitational acceleration.

STEP is the modern version of the experiment attributed to Galileo which involved dropping two weights from the Leaning Tower of Pisa. It compares the inertial to gravitational mass ratios of the test masses, any difference in the ratio appearing as a difference in the rate of fall. If this ratio is the same for all test masses, we can regard inertial and gravitational mass as being equivalent measures for the same thing. This 'Equivalence Principle' is fundamental to our understanding of gravity.

The 'weak' Equivalence Principle postulates that all test objects in an external gravitational field fall with the same acceleration, which is independent of their composition. Einstein generalised this to say that all of the non-gravitational laws of physics (i.e. the laws of special relativity) are the same in any local, freely-falling, non-rotating reference frame. He used this 'Einstein Equivalence Principle' as the basic postulate of general relativity. It follows that any violation of the uniqueness of free fall also violates the Einstein Equivalence Principle, and hence Einstein's Theory of General Relativity.

Newton, using pendulums, determined the Equivalence Principle to be correct to one part in 10^3. Using a torsion balance, Eötvös, in 1896, achieved a sensitivity of 5×10^{-8}. Since then others, using progressively more refined experiments, have achieved a sensitivity of about 10^{-11}. Thus, STEP should achieve a factor of 10^6 improvement over the best existing ground-based experiments.

To achieve this very high accuracy, the test masses would be placed in a near-circular orbit around the Earth at several hundred kilometres altitude. In this way the test masses never strike the ground, and any difference in the rate of fall can build up for a long time. The experiment is roughly equivalent to a free fall from a tower R_E/π km high, with the difference that the signal is periodic and the experiment can be repeated several thousand times. Displacement measurement sensitivities as small as 10^{-13} cm are provided by SQUID (Superconducting QUantum Interference Device) magnetometer circuits.

An essential function of the STEP satellite is to 'shield' the test masses from any environmental disturbance (mostly air drag). The test masses are completely surrounded by a shield, which follows the proof mass (one of the test masses) without touching it. It does this by measuring the position of the proof mass and compensating for any displacement by firing a combination of sixteen proportional thrusters.

Inside the shield, or experiment chamber, the major disturbances stem from gas pressure and temperature effects. To achieve the desired accuracy, the gas pressure inside and the temperature gradient across the experiment chamber have to be as small as possible. A vacuum of 10^{-13} torr and a temperature difference of 10^{-3} deg can be achieved by cooling to 2 K. Very low temperatures are also required to operate the

Key mission features

Spacecraft
- Three-axis stabilised
- Mass: 824 kg (at launch), of which 226 kg is payload
- Size: 1.36 × 1.36 × 2.63 m (octagonal)
- Drag-free to level of 7.10^{-12} g/$\sqrt{\text{Hz}}$
- Pointing control: 30 arcsec/$\sqrt{\text{Hz}}$
- Pointing measurement: 1 arcsec
- Power supply: four solar panels, each 2 m^2
- Data storage: solid-state memory, 14 Mbit capacity
- Data rates: downlink: 42.5 kbit/s
  uplink: 2 kbit/s

Launch
- Four-stage Taurus launch vehicle (commercially available)
- Annual launch window: 19 February – 16 April
- Launch site: Western Test Range, California, USA

Orbit (for launch on 21 March)
- Sun-synchronous (i = 97.84°)
- Perigee: 550 km; Apogee: 690 km
- Mean ascending node: 90°
- Period: 97.1 min.

Lifetime
- Six months

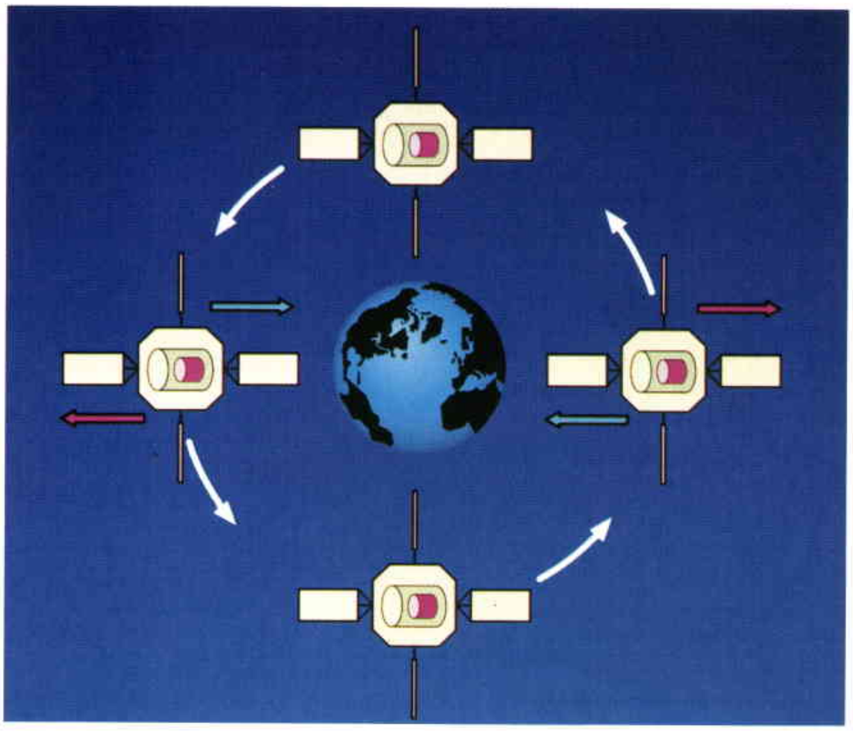
Key staff

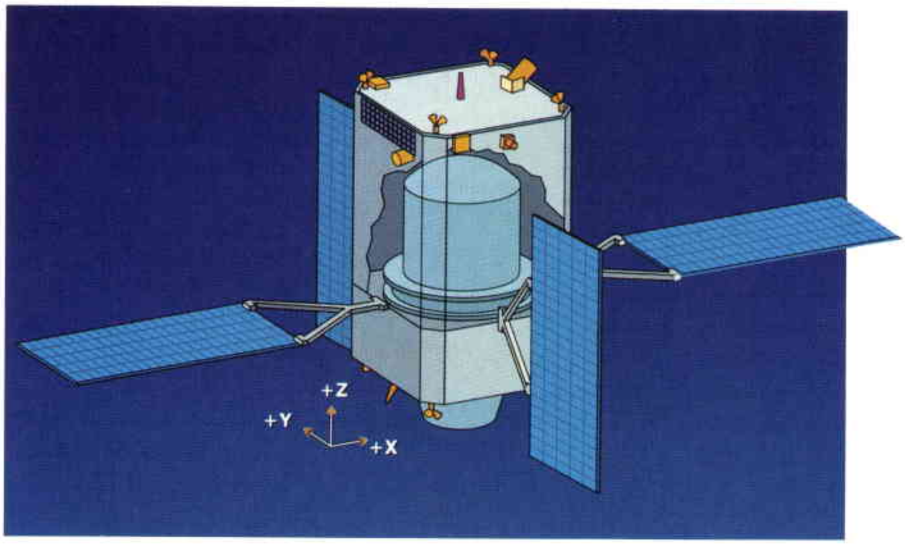
G. Cavallo, Chairman, ESA HQ
O. Pace, Study Manager, ESA/ESTEC
R. Reinhard, Study Scientist, ESA/ESTEC

SQUIDs, to reduce the thermal expansion of the apparatus, and to provide nearly perfect electromagnetic shielding using superconducting lead shields. The bulk of the spacecraft, therefore, is a dewar holding a supply of roughly 200 l of superfluid helium, which will last about six months. The boil-off from the dewar is used for the drag-free thrusters.

Inside the dewar is the STEP instrument itself, consisting of three accelerometers and six test masses made of five different materials. Superconducting magnetic bearings constrain the test masses to one-dimensional motion. Each accelerometer measures any differential acceleration of its two test masses. Whether the acceleration is due to a violation of the Equivalence Principle or to a disturbance (e.g. gravity gradient, helium slosh, temperature effects), can be tested by performing a series of well-defined attitude manoeuvres.

The STEP spacecraft provides an extraordinarily quiet 'laboratory', which gives the possibility of measuring the fundamental gravitational constant G very precisely. G is presently known only to about one part in 10^3, and therefore the masses of all celestial bodies are known only to that accuracy. If one mass in an outer accelerometer is intentionally displaced, the spacecraft compensates for the gravitational attraction between it and the other mass by self-accelerating (rotating). This rotation can be observed by the spacecraft's star trackers with arcsecond accuracy, corresponding to a one part in 10^5 accuracy in the measurement of G — i.e. a two-orders-of-magnitude improvement.





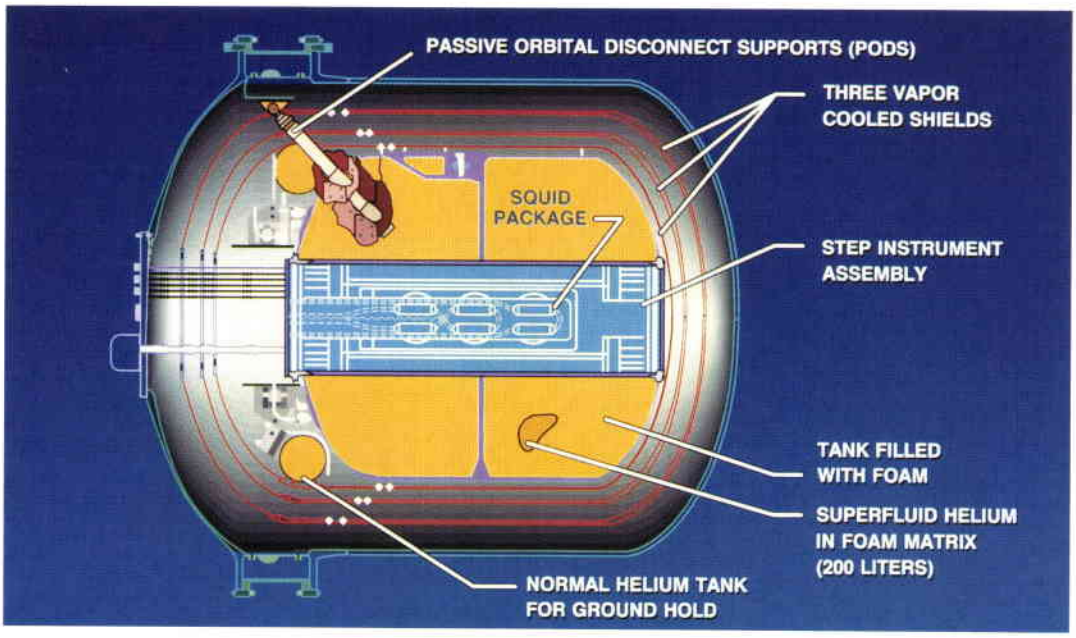


Figure 6. Three-axis-stabilised STEP spacecraft in low Earth orbit. A pair of test masses is indicated in the centre of the spacecraft. The centre and lower sketches are enlargements of the spacecraft and the dewar housing the STEP experiment

Tracking a drag-free satellite with high precision (of the order of a few cm) allows improvement of geopotential data, in particular of the lower harmonics. STEP offers a geodesy experiment of extraordinary interest because it combines relatively low altitude (550 km), drag-free and gradiometer measurements on a single satellite. The STEP spacecraft is tracked using the Global Positioning System (GPS) in differential mode and by laser ranging.

The thrust data from the drag-free controller for STEP will provide valuable information to the aeronomy community. The thrust that keeps the spacecraft in a purely gravitational orbit is proportional to the drag force, which in turn depends on the atmospheric density, temperature, motion, and composition. STEP will provide data with high time resolution which will be especially valuable for the verification and further improvement of thermospheric dynamic models.

As a fundamental-physics mission, STEP would be a 'first' for ESA. To test the Equivalence Principle is undoubtedly of fundamental scientific interest. The assessment study concluded that the STEP experiment is feasible and that the desired improvement of 10^6 over ground-based measurements is achievable.

In this joint ESA/NASA STEP mission, ESA would provide the STEP spacecraft and the European scientific community 50% of the instrument hardware, while NASA would provide the launcher, the operations and the other 50% of the instrument hardware.

Selection of Phase-A studies

The six missions described above were presented to the scientific community on 9 and 10 April 1991 in Paris. The Astronomy Working Group (AWG) and the Solar System Working Group (SSWG) met on the following day to discuss the missions and formulate their conclusions, which included ranking the missions within their purview. The AWG considered the INTEGRAL, IVS and PRISMA missions, the SSWG the MARSNET and OPT missions. As OPT would undoubtedly also be of interest to the astronomy community, this mission was also discussed during a joint AWG/SSWG session. STEP, being a fundamental-physics mission, did not belong to the purview of either the AWG or the SSWG and was therefore not included in the ranking made by the two working groups. The joint session, however, provided an opportunity for the working group members to discuss STEP and to ask questions for clarification.

The selection of the four Phase-A studies was made on 12 April by the Space Science Advisory Committee (SSAC), taking into account the recommendations by the two working groups and, in the case of STEP, the recommendations of a Science Advocate. The recommendations by the two working groups and the selection by the SSAC are given below.

Recommendations by the Astronomy Working Group

Following presentation of the assessment-study results for the six M2 candidate missions, the AWG, at its 73 rd Meeting held on 11 April 1991 at ESA Headquarters, discussed the three projects falling within its purview and came to the following conclusions:

INTEGRAL

This is an observatory facility devoted to the rapidly developing field of gamma-ray astrophysics (15 keV–10 MeV). The experiment combines two separate instruments: a high-angular-resolution imager (having moderate energy resolution), and a high-energy-resolution spectrometer. The proposed model payload is judged suitable for achieving the stated scientific objectives. It will guarantee an unambiguous identification of sources, except perhaps in very crowded fields, along with – for the first time – essential spectroscopic information on the nature of the emission mechanisms in this energy range. Particularly impressive is the ability to resolve emission-line profiles, with the physical and dynamical information this implies. The inclusion of an X-ray monitor provides spectral continuity with other existing and future missions.

The combination of instruments is very well suited to building on the discoveries that have, and will be, made with instruments such as SIGMA and the recently launched GRO. INTEGRAL offers substantial improvements in sensitivity and resolving power over present instruments.

INTEGRAL is a mature instrument, based on well-tested technology, and the scientific objectives are built on a large body of theoretical work. It can address a great variety of astrophysical problems ranging from stars to quasars. It will also provide data of direct relevance to many problems of basic physics. During the course of the mission, a variety of important scientific objectives can be achieved and a large number of sources (about 1000) can be observed, most of them for the first time.

There is, therefore, no doubt that INTEGRAL will make a first-class observatory mission, very well suited to a quest-observer type of operation similar to Exosat or IUE, and serving a very large user community.

IVS
This mission promises major progress in several fields of astronomy. Space VLBI is the only technique available for obtaining spatially resolved information on the scale of micro-arcseconds. The proposed investigations, aimed at the cosmological distance scale, distribution of matter in the Universe, distortions and fluctuations of the cosmic microwave background, and very detailed studies of the nature and cosmic evolution of active nuclei and jets and star-forming regions, are the outstanding ones. The single-dish option opens up completely new possibilities related to star formation and cosmology.

Europe has pioneered and currently plays a leading role in VLBI, which will be enhanced by IVS. There is a very large European VLBI community and a strong commitment from the VLBI networks. With the addition of its single-dish capabilities, IVS will be able to serve a large community of guest observers and will benefit from the well-established data-reduction facilities of VLBI.

The technical feasibility of the payload complement is well demonstrated. An antenna with a diameter as large as 20 m is desirable for achieving many of the astronomical goals of IVS. However, the implications for the mission of the size and accuracy of the antenna should be carefully considered.

IVS is a natural and timely outgrowth of the ground-based VLBI network, as well as of the first dedicated space-borne VLBI missions now being prepared for launch (RADIOASTRON and VSOP).

PRISMA
This is a dedicated mission to explore stellar oscillations and surface-activity phenomena, an area of astrophysics that has so far barely been touched upon.

The project opens up new ways of addressing problems related to fine and important details of stellar structure.

The payload is designed on the basis of present-day technology and appears technically feasible. The scientific return is expected to be large and to stimulate theoretical and experimental work in the field.

An important feature of PRISMA is its truly European origin, with much of the expertise available in Europe.

Conclusions
In view of the scientific excellence of the above-mentioned missions, the AWG strongly recommends that all three be subjected to a Phase-A study, with the following order of priority:

1. INTEGRAL
2. IVS
3. PRISMA

In addition, the AWG wishes to stress the need and importance of clearly defining the structure, role and responsibilities of the Science Data Centres associated with these missions.

Recommendations by the Solar System Working Group

The Solar System Working Group, at its seventieth meeting held in Paris on 11 April 1991,

- — having thoroughly discussed and analysed the results of the MARSNET and OPT Assessment Studies
- — having ascertained the extremely high scientific quality and the very large involvement of the community addressed by the two studies
- — having considered the model payloads suitable to achieve the identified scientific objectives and as being technically feasible

strongly recommends that both MARSNET and OPT be considered for a Phase-A study.

In particular, the SSWG wishes to emphasise the outstanding science that MARSNET can provide in the study of the unknown interior of the planet, its atmospheric processes and its surface geochemistry. These studies would be carried out in the context of an international collaboration, to which MARSNET would strongly contribute.

Observations carried out by OPT can provide novel information on minor bodies, interplanetary matter, planetary oscillations and time-variable phenomena. Moreover, a wealth of astrophysical issues can be addressed successfully.

The SSWG, recognising the necessity to rank the two missions, considers that, if needed, a slight priority should be given to MARSNET, mainly on the basis of its timeliness due to the present international conjuncture.

Selection by the Space Science Advisory Committee

The SSAC, at its 59th meeting held in Paris on 12 April 1991, having heard the recommendations of the AWG and the SSWG and the report of Prof. Hans Balsiger, who had been appointed to advocate for the STEP proposal, unanimously recommends the following four missions for Phase-A studies (alphabetical order):

- INTEGRAL
- MARSNET
- PRISMA
- STEP.

The Phase-A studies will be carried out in 1992, aiming at a final selection in the 1993 time frame.

The considerations that led to the above selection are briefly summarised below for each mission (alphabetical order).

INTEGRAL

The SSAC ranked INTEGRAL highly. They felt that the spectroscopic capability in particular rendered INTEGRAL a major step forward compared with the current Granat and GRO missions.

IVS

The SSAC was impressed by the science proposed for IVS, but was of the opinion that moving to Phase-A was not appropriate at this time, in particular considering the as-yet unproven design of the large antenna.
Proof of the scientific impact of the space-based VLBI concept and technique would emerge from the VSOP and RADIOASTRON missions already under way. Results from these missions could substantially influence scientific and engineering priorities for any subsequent mission. Therefore the SSAC ranked IVS lower than PRISMA, reluctantly reversing the ordering recommended by the AWG. The SSAC stressed the importance of the Agency developing technical competence in the flight of large radio antennas in the long term.

MARSNET

The SSAC considered that MARSNET offered a potential major European contribution to the exploration of our neighbouring planet and to the development of our understanding of physical processes occurring there. The SSAC felt that a unique and substantive European role needed to be more clearly identified in any future collaborative mission, but was convinced of the existence of a European scientific base from which this could be drawn.

OPT

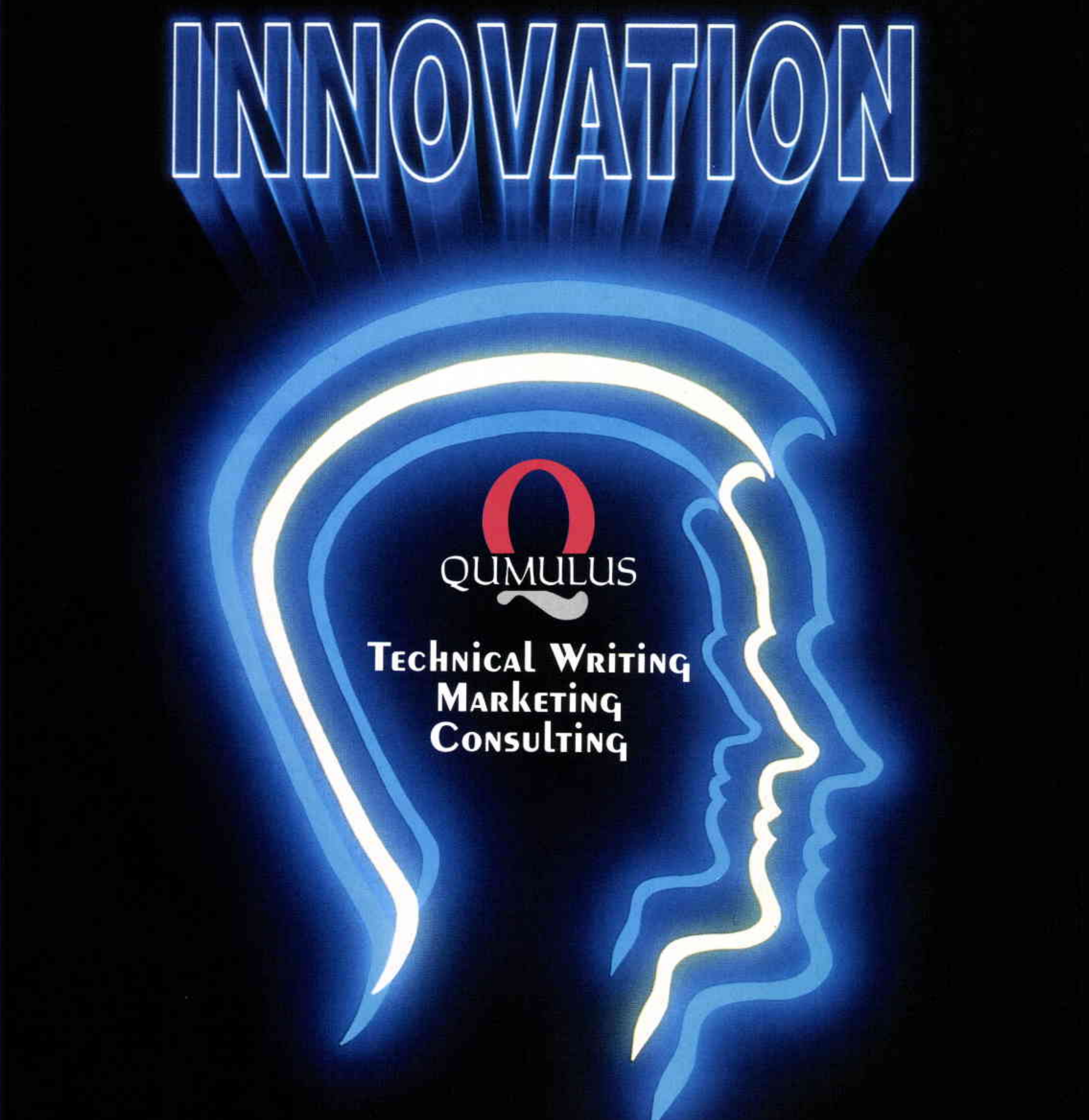
The SSAC did not rank the mission as highly as the other missions proposed, despite recognising its scientific usefulness for a broad range of solar-system research.
The telescope's special importance lies in its capability for panchromatic extended observation of solar-system objects. The SSAC did not feel that the use of the telescope for astrophysical purposes could have dramatically increased the impact of the mission.

PRISMA

The SSAC were impressed with the potential of the mission and the opportunity that it offered for Europe to make a unique advance in space stellar astronomy. The SSAC regretted that links to solar seismology had not been made as well as they might be, and recommended that advice be sought and expertise tapped from the large helio-seismology community. Furthermore, the specific advantages of doing the experiment in space need to be firmly established.

STEP

The SSAC were convinced of the importance of the prime scientific aim of the mission, the test of the equivalence principle, and the subsidiary aims in geodesy and the determination of the gravitational constant. The SSAC believed that European involvement could be developed further, but that the European scientific and engineering contribution was already an important component of the proposed mission.


INNOVATION
DOCUMENTATION

Some New European Developments in Chemical Propulsion

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ESTEC, Noordwijk, The Netherlands

ESA has been promoting new developments in chemical spacecraft propulsion for several years now. The last six years in particular have seen important developments such as 'dual-mode propulsion', with which bipropellant engines using hydrazine as a fuel in conjunction with catalytic thrusters become feasible, as well as improvements in the classical bipropellant engines. New liquid-, solid- and hybrid storable-propellant combinations have also been identified, which not only produce 'more environment friendly' combustion products, but also have markedly better performances than the classical storable propellants. Considerable, and in many cases novel, work has also been done on motor, igniter, and propellant gauging and storage technology which will improve the performances of the spacecraft of the future.

Introduction

Spacecraft propulsion encompasses all propulsion-related systems such as liquid or solid Apogee Boost Motors (ABMs), tanks, valves, filters, mono- and bi-propellant thrusters for attitude control and North-South Station-Keeping (NSSK). Most satellites nowadays employ such systems and as they constitute a major portion of the spacecraft's initial mass, mass reductions and/or performance improvements are highly desirable.

Reliability of the propulsion system is also extremely important because any malfunctioning could jeopardise spacecraft performance or operational life, or even the mission itself. Part of the reliability is directly related to a profound understanding of the processes involved: combustion, cooling, erosion, corrosion, precipitation of compounds solved in liquid propellants, and so on.

The availability of components and European autonomy is another aspect of interest to the Agency.

ESTEC is therefore involved in a number of activities, together with its industrial contractors in the Agency's Member States, aimed at stimulating European autonomy and raising the technology level in the propulsion field. This not only improves the European capability in propulsion, but also results in new components and systems being designed and manufactured in Europe for space propulsion.

Dual-mode propulsion

Until now, most liquid apogee-boost engines have used Mono-Methyl Hydrazine (MMH) and Mixed Oxides of Nitrogen (MON) as propellants, well-known examples being the MBB 400 N and the American Marquardt 100 lbf engines. The availability of a bipropellant apogee-boost engine leads to the use of bipropellant thrusters for Attitude and Orbit Control (AOC) (unified propulsion). Such bipropellant engines, whilst yielding good performance, require a propellant supply system for oxidiser and fuel. Each satellite needs a minimum of six such engines (two opposing directions on each orthogonal axis). For redundancy, every satellite carries two sets of AOC engines, bringing the minimum to 12. Moreover, the engines cannot always be optimally sited for many reasons, and so one often finds 16 or 18 small thrusters mounted on one satellite. This implies a large amount of propellant piping, valves and a complex regulating system, as every engine is connected to both fuel and oxidiser lines.

Because of some specific advantages, new hydrazine-based AOC propulsion systems are currently under development, the Power-Augmented Catalytic Thruster (PACT) and the Arcjet being of particular interest. These thrusters, which use hydrazine as a propellant, match or exceed a bipropellant thruster in performance. By using monopropellant hydrazine, and PACTS or Arcjets for orbit control, the feed system can be simplified and only one propellant is required. It then becomes necessary, however, to have an apogee boost motor that operates on hydrazine and MON.

Hydrazine/MON apogee boost engines in combination with hydrazine PACTS or Arcjets improve the overall performance of the propulsion system, while at the same time simplifying design and testing. To distinguish the Hydrazine/MON engine from its classical MMH/MON counterpart, it is also called a 'Dual-Mode Engine'.

The Leros I

Royal Ordnance in the UK, with a combination of private, national and ESA funding, has developed the first successful dual-mode engine, known as the Leros I (Fig. 1). Ironically, the first satellite to use dual-mode propulsion is not a European one, but the American GE-Astro Astra-1B, launched by Ariane V42.

The engine, which was flight-qualified last summer, is manufactured from Niobium, one of the refractory metals that has found wide application in rocket technology. To prevent rapid oxidation and corrosion, the Niobium is treated with a disillicide coating. The injector, which remains much cooler, is made of Titanium.

The Power-Augmented Catalytic Thruster

The PACT is a hydrazine monopropellant engine in which the hydrazine decomposition products are heated electrically to boost performance. The hydrazine from the tanks is decomposed by feeding it over a catalyst bed (Shell 405, CNESRO, KC 12GA, or a similar catalyst), a process accompanied by the release of a large amount of heat.

In the normal monopropellant thrusters presently being produced and marketed, the decomposition products are expanded in a nozzle to yield a specific impulse of 230 s. In the PACT, however, an approximately 30% performance improvement is obtained by leading the decomposition products through, or along, an electrical heater, which increases their temperature to about 2200 K. The Agency has already developed a 'breadboard' model of such a PACT in conjunction with MBB-ERNO in Bremen (Fig. 2). The electrical heater in this case is a spirally-wound hollow resistive coil made of Rhenium, through which the decomposition products flow, thereby raising their temperature to 2200 K.

In combination with a dual-mode apogee engine, the PACT leads to both a reduction in the dry mass of a satellite's propulsion system, and a simplification of the layout of propellant lines, filters, regulators, etc. onboard the satellite. This in turn reduces

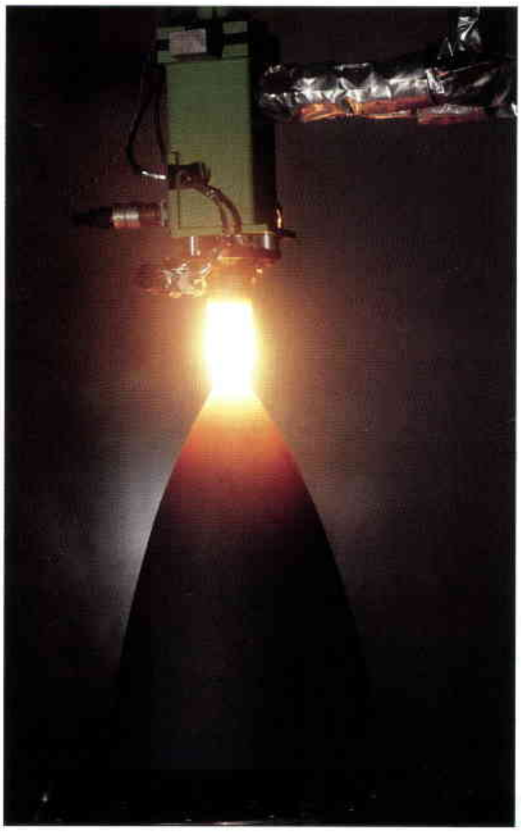
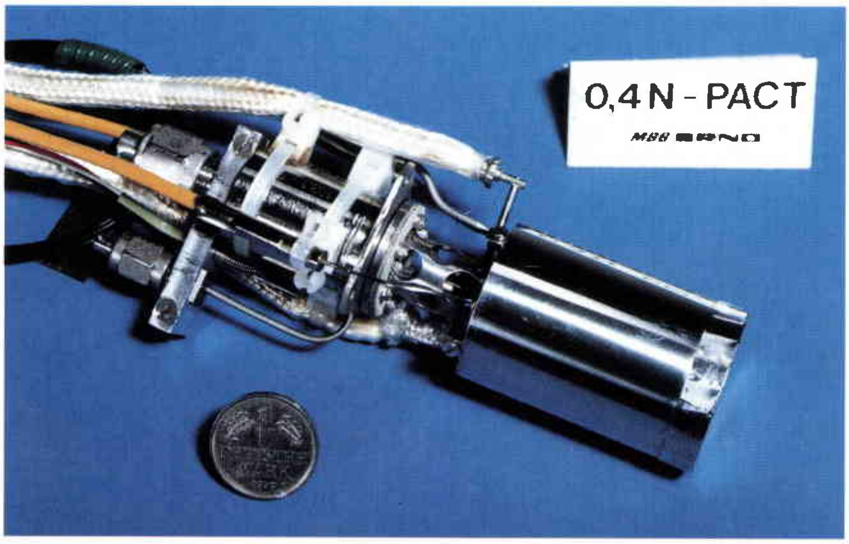


Figure 1. The Leros I engine undergoing vacuum testing

Characteristics of Leros I

Thrust	500 N ±25 N
Specific Impulse (I_{sp})	314 s or 3090 m/s
Mixture Ratio MON/Hydrazine	0.8
Expansion Ratio (A_e/A_t)	150
Inlet Pressure	1.65 MPa
Chamber Pressure	0.7 MPa
Injector	Unlike doublets + film cooling
Maximum Outside Temp.	1640 K
Dry Engine Mass	4.2 kg
Length (total)	666 mm
Diameter (max.)	288 mm

Figure 2a. The ERNO PACT engine (0.4 N)



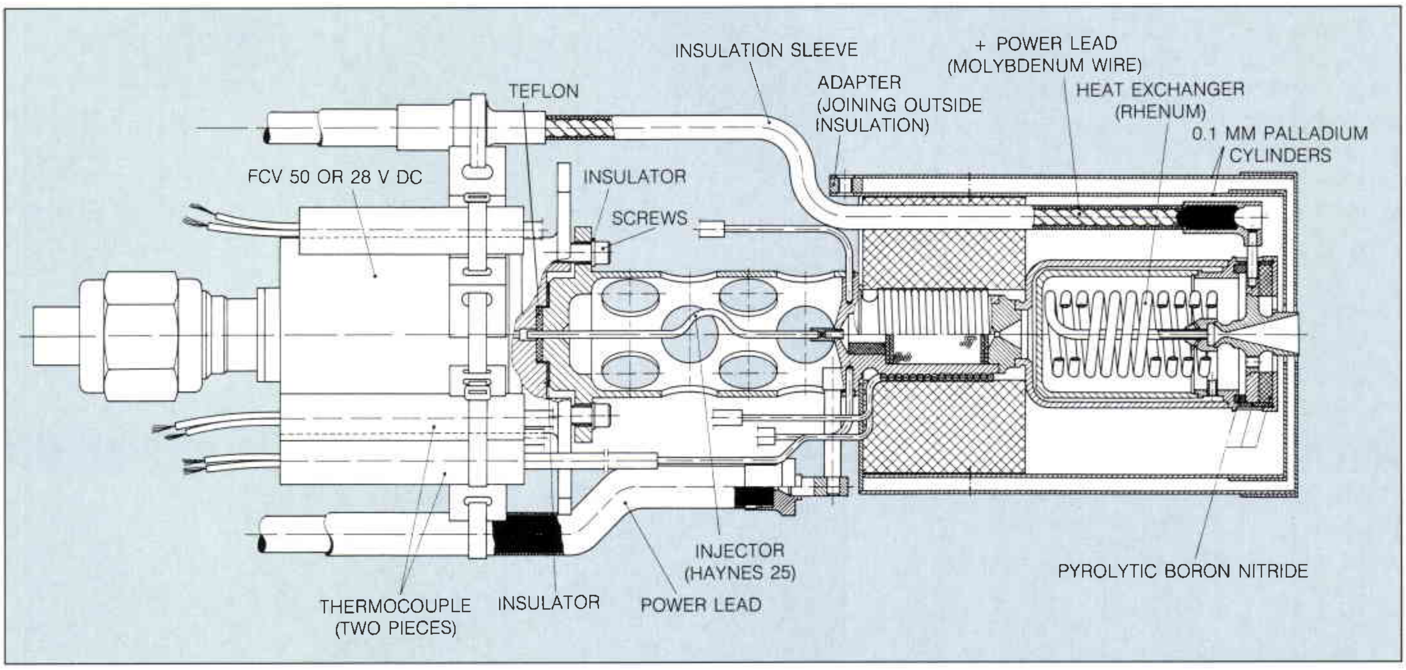


Figure 2b. Cross-section of the ERNO PACT engine

Characteristics of PACT

Performance (Steady State)

Inlet Pressure (MPa)	Thrust (N)	Specific Impulse (s)	or (m/s)
2.2	0.5	309	3030
1.6	0.35	306	3000
1.1	0.25	298	2925
0.55	0.15	286	2800

Electrical Power

Power	1100 W (2 heat exchangers)
Voltage	28 V (DC)
Current	30 A (2 heat exchangers)
Resistance	1 Ohm (2 heat exchangers in series)

Thruster Characteristics

Thruster Inlet Pressure	0.55 to 2.2 MPa
Chamber Pressure (at nozzle entrance)	0.35 to 1.3 MPa
Nozzle Expansion Ratio (A_e/A_t)	53
Dry Thruster Mass (excl. Power Control Unit)	0.300 kg
Mass Power Control Unit (for two thrusters)	4.90 kg
Total Thruster Length	165 mm (incl. valve)
Maximum Thruster Diameter	20 mm
Maximum Outside Thruster Diameter	40 mm

mass and cost, and simplifies the ground test procedures.

In conclusion, one can say that dual-mode propulsion can yield substantial benefits in mass, performance and simplicity for satellite propulsion systems. This is especially applicable for those missions that have large station-keeping and attitude-control requirements. A 1–2 kW hydrazine Arcjet, with its high specific impulse of more than 500 s, will increase the performance of satellite propulsion systems still further, but this development effort is not yet as far advanced in Europe as the PACT.

New bi-propellant engines

Despite the promise of dual-mode propulsion, classical bi-propellant engines will be needed for a number of years to come. Many future satellite systems are already in the conceptual design stage, and the choice between unified or dual-mode propulsion also depends on mission requirements. In addition, many satellites, for cost reasons, use existing satellite buses, where one cannot easily change from a classical bi-propellant to a dual-mode system. It is therefore likely that any switch to dual-mode propulsion will be made for a completely new generation of spacecraft, and hence that the classical MMH/NTO bi-propellant engines will be used for some time to come.

It would be useful to have an inventory of European apogee-boost engines available, but the only engine currently available in this class is the MBB 400 N (regeneratively MMH-cooled). The Agency is therefore presently involved in the development of two new apogee-boost engines: the Leros II from Royal Ordnance, and the 400 N Mark II from MBB.

The Leros II

Derived from the Leros I dual-mode engine, the Leros II uses the same technology in terms of titanium injector and Niobium thrust chamber and nozzle. The injector, however, has been modified to accommodate the different propellant (MMH) and mixture ratio (Table 1).

Table 1. Characteristics of Leros II

Thrust	500 N ±25 N
Specific Impulse (I_{sp})	310 s
Mixture Ratio MON/Hydrazine	1.65
Expansion Ratio (A_e/A_t)	150
Inlet Pressure	1.65 MPa
Chamber Pressure	0.7 MPa
Injector	Unlike doublets + film cooling
Maximum Outside Temperature	1640 K
Dry Engine Mass	4.2 kg
Length (Total)	666 mm
Diameter (Maximum)	288 mm

The Leros II is expected to be ready for qualification during 1991.

The MBB 400 N Mark II

The earlier version of this engine (Mark I) has already flown successfully on a number of European satellites: Symphonie, Amsat, Galileo, TV-Sat, TDF, Telex, DFS and Eutelsat-2. It is a stainless-steel design, which is regeneratively cooled to keep the wall temperatures within acceptable limits. As a higher combustion temperature immediately yields a better performance, this is of interest to the satellite user and also to the engine manufacturer. The American, and also Royal Ordnance approach has been to use a refractory metal in combination with a coating to achieve sufficient oxidation and corrosion resistance.

The MBB 400 N Mark II (Fig. 3), however, employs a different technique. As regenerative cooling is impractical at higher temperatures, MBB has opted to make the 'hot' parts of the new engine from a Platinum-Rhodium alloy, with which excellent results have already been obtained with two small 5 N and 10 N bi-propellant thrusters. This alloy has the additional advantage of being a catalyst for MMH decomposition, thereby reducing both combustion time and the amount of unburnt propellant .

The upper part of the new engine (injector and upper part of the chamber) will be made of stainless steel; the lower part, and that part of the nozzle exposed to the most severe heat loads from Platinum-Rhodium. The technology for joining the two materials is being developed at MBB and does not seem to pose too many difficulties.

The new MBB 400 N engine yields a significant improvement over the existing one due to the increased chamber pressure (from 0.7 to 1 MPa) and higher expansion ratio (from 150 to 220). It is expected to be ready for qualification in 1992 at the latest.

The Advanced Technology Engine

With the advent of Ariane-5, launch capacity will increase substantially and it will be possible to launch very large satellites, or

Figure 3. The MBB 400 N Mark-II engine on the test stand (development version)

Characteristics of MBB 400 N Mark II

Thrust	404 N
Specific Impulse (I_{sp})	316 s
Mixture Ratio (MON/MMH)	1.643
Expansion Ratio (A_e/A_t)	220
Inlet Pressure	1.4 MPa
Chamber Pressure	1 MPa
Injector	Swirl injector (double cone)
Dry Engine Mass (incl. valve)	3.35 kg
Length (total, with valve)	551 mm

even a stack of smaller satellites (18 000 kg into Low Earth Orbit, or LEO, and 6004 kg into a Geostationary Transfer Orbit, or GTO). If payloads are first placed in LEO, another engine will have to inject the satellite(s) into a geostationary orbit. This implies at least two engine burns: one to reach GTO, and a second at GTO apogee to circularise the orbit.

For Earth missions, significant velocity increments (delta-V's) have to be provided by the satellite propulsion system. For a GTO-to-GEO transfer, the engine has to provide a delta-V of 1502 m/s, while for a LEO-to-GEO transfer 3940 m/s is required. Interplanetary missions require an even larger delta-V.

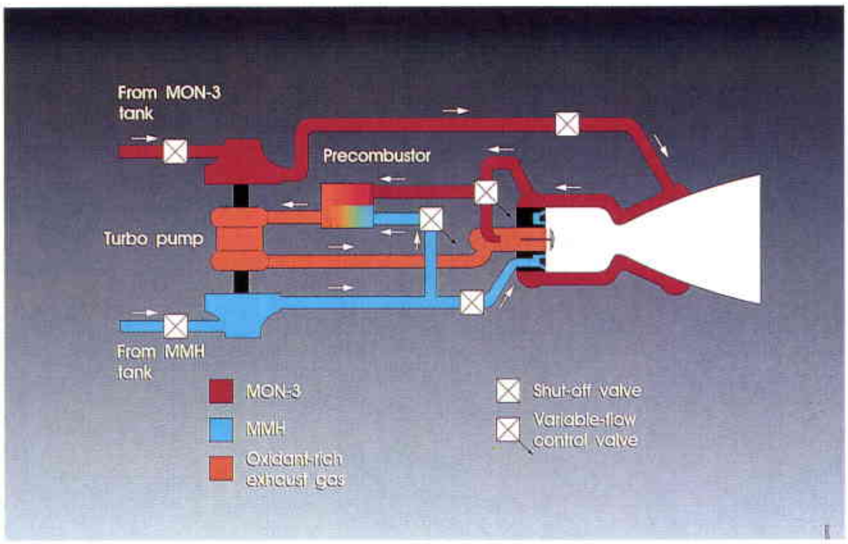


Figure 4. The ATE engine pre-combustion cycle

ATE engine characteristics

Thrust	20 kN
Specific Impulse (I_{sp})	>3383 m/s (>345 s)
Mixture Ratio (MON/MMH)	1.86
Expansion Ratio (A_e/A_t)	400
Pump Inlet Pressure	0.4 MPa
MMH Pump Exit Pressure	18.1 MPa
NTO Pump Exit Pressure	19.5 MPa
Chamber Pressure	9 MPa
Injector	Central pintle or swirl with annular fuel sheet and fuel cooling
Dry Engine Mass*	74.2 kg
Length (Total)	1720 mm
Diameter (Maximum)	760 mm
Turbopump Rotation Speed	8000 rad/s

* In the SEP variant, which uses a ceramic combustion chamber and nozzle extension, the engine mass reduces to 57.9 kg and moreover cooling with supercritical NTO is then not necessary.

Such mission demands translate into significant mass penalties when the propulsion system has low performance. Increasing the specific impulse from the present 309 s to 345 s by using an ATE increases the useful mass for a GTO–GEO transfer by 208 kg, and for a LEO–GEO transfer by 615 kg. This in turn translates into a substantially longer spacecraft lifetime and hence into dramatically increased revenue earning.

The ATE concept

Four European contractors have been working on detailed design and trade-off studies for such an engine: FIAT Aviazione (I), Royal Ordnance (UK) with British Aerospace (UK) as subcontractor, SEP (F) and Volvo (S). The engine that has emerged is a high-performance turbopump-fed pre-combustion cycle engine (Fig. 4). Its thrust chamber and part of the nozzle are cooled with supercritical NTO.

The ATE's propellants are stored in lightweight tanks at 0.5 MPa. Part of the NTO flows at supercritical pressure through small channels to cool part of the nozzle and the combustion chamber. Part of the heated NTO flows to the injector, but most goes to the pre-combustor. The MMH is partly fed to the precombustor, but the larger part is injected into the combustion chamber. Some MMH is used as a film coolant to keep the combustion chamber and nozzle wall temperatures sufficiently low. The pre-combustor drives the turbine which, rotating at 8000 rad/s and delivering 190 kW, directly drives the two propellant pumps on either side of it. The oxidiser-rich exhaust products from the turbine are fed to the pintle or swirl injector to be injected into the combustion chamber.

The combustion chamber itself is made from Narloy-Z or a similar copper alloy with a high heat conductivity, into which 122 small coolant channels have been milled. The cool outside of the combustion chamber liner is closed by an electro-deposited metal transition layer and a lightweight fibre overwrap. A variant studied by SEP simplifies the design by using a ceramic combustion chamber and nozzle, which only require film cooling.

The present estimates are that it will take about 8 to 10 years to develop the ATE up to and including ground qualification.

Mission scenarios

Large spacecraft launched by Ariane-5 would benefit from having an ATE as a boost motor for high-delta-V missions. The ATE's high specific impulse (345 s compared to 309 s for today's NTO/MMH engines and 316 s for the L7) leads to a significant increase in useful payload. In addition, the high thrust level (20 kN versus 400–500 N for the present LAE) reduces gravity losses and also simplifies operations in that the number of burns may be reduced from six to three or less for a LEO–GEO mission.

A more advantageous option is to inject a stack of satellites by means of an Orbital Propulsion Module (OPM). In this case, two or three spacecraft could be injected by a single OPM with one ATE. However, this would require a major change in design philosophy for the spacecraft, as presently all telecommunications satellites are designed with a built-in liquid apogee engine.

Table 2 compares the gains in useful payload with the ATE with other possible candidates.

The mass benefits may be translated into:

- the simultaneous launch of more spacecraft, thereby reducing the launch cost per spacecraft
- increased mass of revenue-earning payload onboard the spacecraft
- increased mass of propellant onboard the spacecraft, thereby increasing mission lifetime.

The last option seems the most attractive from a commercial point of view. If one assumes that two spacecraft are launched simultaneously, each may be 85 kg heavier. If one assumes that 60 kg were additional control-system propellant (the other 25 kg being needed for larger tanks, etc.), mission life would be extended by three to four years, representing a large increase in revenue for the satellite system owner, perhaps even equating with the replacement cost of the satellite itself.

Table 3. Useful mass in orbit using different upper stages*

	GTO	GEO
Ariane-5 + L7	6004	2735
Ariane-5 + ATE	6796	3529
Titan IV + 2 Star 63F**	4028	-
Titan IV + ATE	6456	2788
Titan IV + 2 Star 75**	5616	-

* Based upon Ariane-5 lifting 18 000 kg to LEO.
** Solid perigee stages fitted directly to the spacecraft in a dual-launch stack.

Table 2. ATE performance gains for Ariane-5 launches (incl. effects of gravity loses)

Mission	Engine	Firing Duration (min)	Delivered* Mass (kg)	Mass benefit for ATE (kg/%)
LEO–GEO	ATE	29	4797	
	3 kN	187	4256	541/13
GTO–GEO	ATE	5	3335	
	3 kN	35	3221	114/4
	400 N	260	3157	178/6
LEO–GTO	ATE	21	7376	
	3 kN	145	6658	718/11

* Based upon Ariane-5 lifting 15 000 kg to LEO.

Another scenario has also been investigated in which different Ariane-5 and Titan IV upper stages have been considered. The results are summarised in Table 3, which shows that using the ATE gives a useful mass benefit of almost 800 kg, most of which may be translated into revenue-earning payload and/or an increase in satellite operational lifetime.

The future

No decision has yet been taken to develop an ATE. The engine layout and concept has been, and is still being studied in detail by four of the major European propulsion companies. Technological difficulties that will have to be solved have been identified and there is strong confidence that such an engine could be developed within eight to ten years. Such an ATE would have to compete on the World market with the American XLR 132 engine, which is in a more advanced state of development but offers lower performance.

The other, extremely important advantage of the ATE is that it would boost European technology in the rocket-propulsion area. This in turn could have very important spin-offs for other technology areas, including future launcher developments and the overall European technology domain.

The Solid End-Burning Motor

Presently, BPD (I) is developing an improved IRIS solid-rocket motor. Although called an 'end-burning' motor, it is in fact spherical (Fig. 7). The HTPB/Al/AP solid propellant delivers a specific impulse of 291 s. The epoxy-aramide fibre wound case, produced by MAN (D), weighs approximately 47 kg, and the nozzle is phenolic-resin based, with a carbon/carbon throat insert.

Figure 5. The Royal Ordnance (UK) version of the ATE

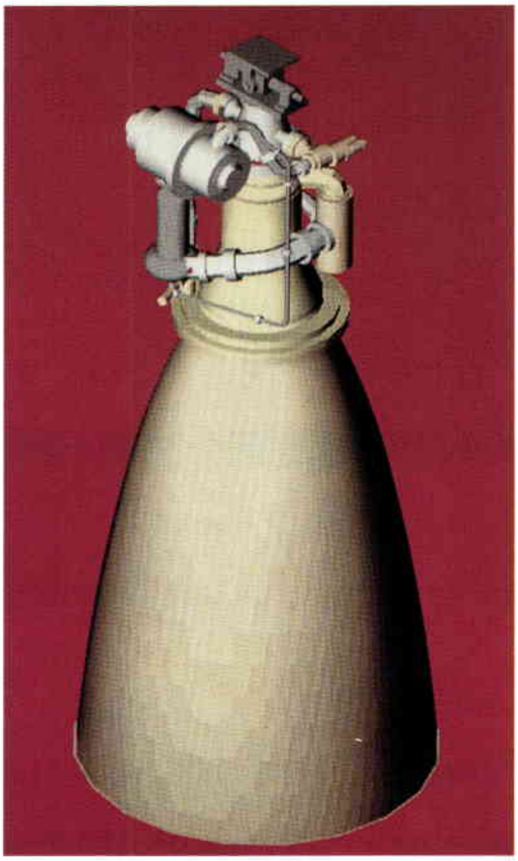


Figure 6. The Fiat-Aviazione (I) version of the ATE

A particular feature of the solid motor is its consumable igniter. Until now igniters for rocket motors have been heavy as they have had to remain integer during engine operation. BPD has developed a 'consumable' igniter based on carbon-fibre/epoxy. It is spherical in shape and the inside is covered with a fast-burning propellant, which is ignited by a pyrotechnic charge. After ignition of the igniter, which is bonded to the head-end of the propellant grain, holes on the igniter's equator serve as nozzles and spray hot combustion products onto the propellant grain, thereby achieving rapid ignition. After burnout, all epoxy is consumed, together with much of the carbon fibre. The remainder of the soft fibre cloth is exhausted through the nozzle.

This successful European development of a consumable igniter is regarded as an important technology breakthrough and

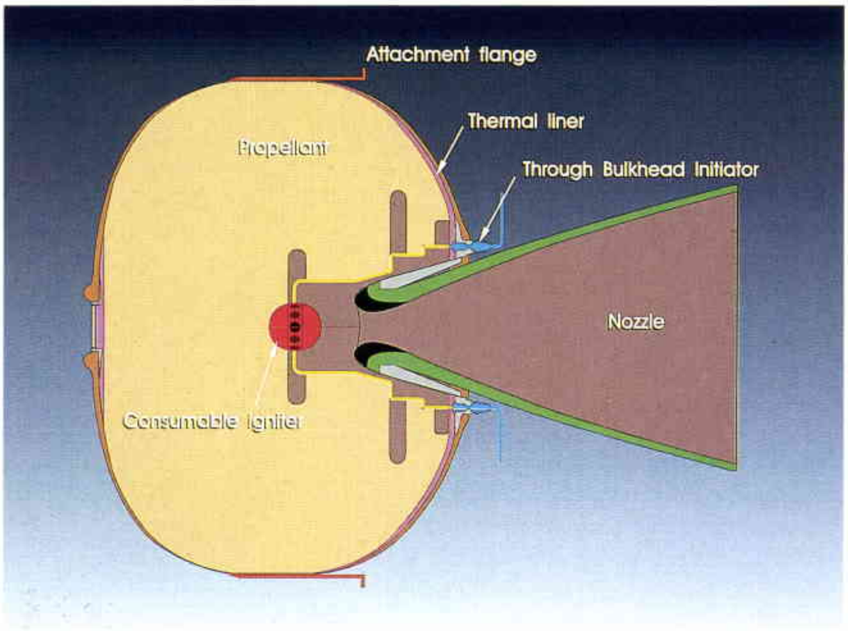


Figure 7. Cross-section of the EBM solid-rocket engine of BPD Difesa e Spazio (I)

EBM Characteristics

Thrust	57 kN
Specific Impulse (I_{sp})	2858 m/s (291.5 s)
Propellant 1811:	
Aluminium	18%
Hydroxy Terminated Poly Butadiene	11%
Ammonium Perchlorate	71%
Expansion Ratio (A_e/A_t)	60
Chamber Pressure (av.)	4 MPa
Propellant Mass	1602 kg
Empty Motor Mass	127 kg
Maximum Diameter	1351 mm
Length	1736 mm
Payload Mass for GTO–GEO	2195 kg

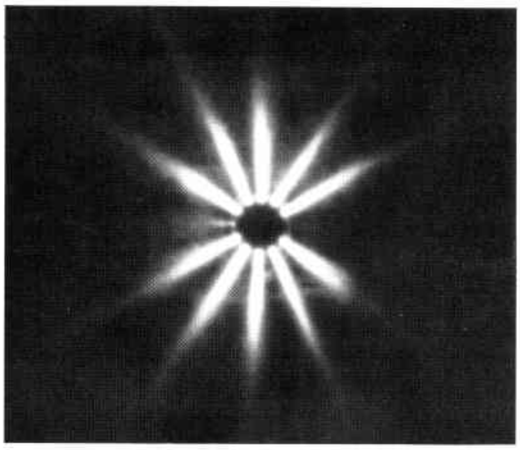


Figure 8a. The EBM's consumable igniter bonded to dummy propellant

Figure 8b. Operation of the EBM consumable igniter (high-speed photo.)

the EBM that it fires could be used for the launch of telecommunications satellites in the 2000 kg class (i.e. 3800 kg incl. EBM).

New storable propellants

The performance of storable propellants has been limited in recent years to a specific impulse of about 293 s for solid propellants, and 310–320 s for liquid propellants at low pressures. As the ATE design studies indicate, by increasing the chamber pressure and nozzle expansion ratio, a maximum of 345–350 s is achievable with storable liquid propellants. Some years ago, the Agency placed a small study contract to investigate whether, with the latest technology, higher-performance propellant combinations might be possible.

The contractor, the Prins Maurits Laboratory/TNO in Rijswijk (NL), has in fact identified a number of new propellant combinations that look extremely promising, in some cases offering dramatic performance improvements: 11% for liquid and 7% for solid propellants.

The Agency is presently further investigating the new liquid-propellant combination (NTO/Pentaborane) via a contract with SEP (F), and the new solid-propellant combination (HNF/GAP/Al) via a contract with APP (NL). The chemicals (Pentaborane, GAP and HNF) involved in these new propellants are not readily available commercially, and many of their chemical and physical properties are not very well known. The procedures for producing good-quality GAP are protected by American patents.

The Hydrazinium Nitro Formate (HNF) must also be in a very pure state if it is to remain stable. It can be produced in various ways, one of which requires very pure hydrazine as a starting material. As it happens, the Agency has already commissioned a plant in Germany, together with MBB/ERNO (D) and Sulzer (CH), to produce purified anhydrous hydrazine for other purposes.

Table 4. New storable-propellant combinations

Mix Ratio		P_c (MPa)	A_e/A_t	I_{sp} (m/s)
LIQUID PROPELLANTS				
Reference Propellants*				
NTO/MMH	1.65	0.7	200	3030
NTO/MMH	1.86	9	400	3383
New Liquid Propellants**				
NTO/B_5H_9	3.17	1	125	3372
NTO/B_5H_9	3.44	10	700	3755
SOLID PROPELLANTS				
Reference Propellant*				
76% NH_4ClO_4 13% Al 11% HTPB		10	100	2946
New Solid Propellant**				
59% Hydrazinium Nitro Formate 21% Al, 20% Glycidyl Azide Polymer		10	100	3161
New Hybrid Propellant**				
55% Hydrazinium Nitro Formate 10% Glycidyl Azide Polymer 35% B_5H_9		1	125	3336

* Based on actual performance or detailed calculations

** Only 92% of theoretical performance (equilibrium flow) to account for 8% losses

While the SEP work has concentrated until now on establishing the physical properties of B_5H_9 in combination with NTO, the work on solid propellants is somewhat more advanced. Ingredients of good quality have been produced on a laboratory scale (GAP and HNF by PML-TNO (NL), and HNF by Univ. of Lyon (F)). The first combustion tests with very small propellant samples have confirmed the theoretical expectations.

Apart from its higher performance, the new solid propellant has another advantage that

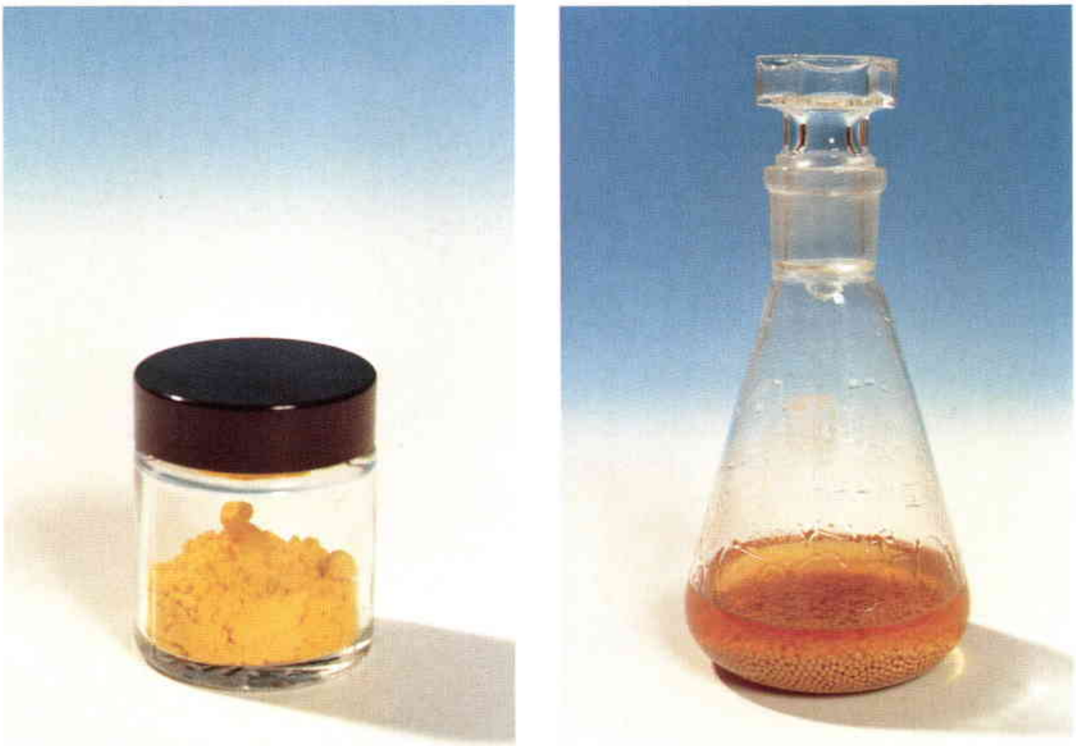


Figure 9. New storable propellants:
(a) Hydrazinium Nitroformate, which is a crystalline material
(b) Glycidyl Azide Polymer (GAP); small spheres are a drying agent

may prove even more important. Some of today's solid boosters for launchers produce hydrochloric acid as a byproduct of the combustion process. The new propellant combination would remove this polluting element, thereby constituting a major contribution from European technology to 'cleaner' spaceflight.

Hydrazine purification

Hydrazine is used for spacecraft propulsion, in monopropellant thrusters for attitude and orbit control, as a fuel for dual-mode engines, and may, as noted above, be the precursor for the production of HNF in new solid propellants. The hydrazine used in the catalytic thrusters has to be of very high purity and at present the only producer is Olin in the USA. The Agency has therefore initiated work with ERNO Raumfahrttechnik GmbH (D) on a plant to produce purified anhydrous hydrazine in Europe for spacecraft-propulsion applications. This highly automated facility, based on a melt-crystallisation system developed by Sulzer (CH), which is a subcontractor to ERNO, can process at least three different feed materials: standard-grade hydrazine, monopropellant-grade hydrazine, and 92% hydrazine concentrate, the first two of which are readily available from stock. The 92% hydrazine concentrate may be obtained using a method developed by Univ. Claude Bernard-Lyon I (F).

The European plant, commissioned in February 1991, will produce up to 30 kg of anhydrous hydrazine per day. It has already produced purified hydrazine for the Craf-Cassini project.

Liquid-gauging techniques (in space)

On Earth, it is relatively simple to determine the amount of liquid in a container, but this simple task becomes highly problematic in a zero-gravity environment. It is mandatory to know how much propellant is left onboard a spacecraft for several operational purposes. For example, geostationary spacecraft need to be boosted into higher 'graveyard' orbits at the ends of their lifetimes, to avoid overcrowding in the geostationary orbit. Putting a spacecraft into its graveyard orbit too early results in a substantial loss of revenue; if it runs out of propellant prematurely, however, it must remain in the geostationary orbit, posing a hazard to other spacecraft.

In orbit, in the absence of gravity, the liquid may be distributed anywhere within the container, and determining the amount remaining is not an easy matter. The Agency is presently exploring two methods that promise high accuracy, both of which rely on determining the volume of gas in the container and subtracting it from the tank volume.

The first method, under development with Techno System (I), uses a small auxiliary volume (about 1% of the total tank volume) which can be varied periodically by a motor-driven piston. By measuring the resulting pressure fluctuations in the container, one obtains a measure of the volume filled with gas.

The second method, being developed by the Technische Universität Hamburg Harburg (D) in cooperation with MBB/ERNO (D), uses a slightly different approach. As propellant tanks are pressurised by helium, stored in high-pressure bottles, a precisely known amount of helium can be admitted to the propellant tank, resulting in a pressure increase that depends directly on the volume admitted to the tank and the gas volume in the tank. The gas volume in the tank can therefore be determined from the measured increase in pressure.

Both methods have yielded good results in laboratory testing, giving accuracies in the order of 1% of total tank volume. The second method has also been tested under weightless conditions during parabolic flights, confirming results obtained on ground.

Such accurate liquid-volume gauging in space will not only allow the Agency to achieve more reliable lifetime monitoring of its spacecraft, but will also have important applications for manned spaceflight, for the Hermes spaceplane and the Columbus Project. The same method may also be used to monitor critical life-support liquids.

NTO chemistry

Nitrogen tetroxide (NTO) is the main storable oxidiser in use today. It is a liquid at room temperature, has a high vapour pressure, and is also extremely toxic. It is never used in a chemically pure form; it usually contains some water, and a small amount of nitrous oxide (NO) is usually added to reduce corrosivity. Onboard spacecraft, it is usually stored in titanium-alloy tanks, because its reactivity with titanium is low. However, these tanks also contain stainless-steel components, and other propulsion-system components are also being manufactured from stainless steel.

It has been found that steel can form insoluable compounds with these Mixed Oxides of Nitrogen, or 'MONs', which may precipitate out in and block small passages, especially the very small injector tubes. This phenomenon, known as 'oxidiser flow decay', may become a serious problem for spacecraft with long operating lifetimes and small bipropellant RCS thrusters.

The causes of the flow decay are still not fully understood, and the Agency has therefore initiated an in-depth research contract with Royal Ordnance (UK) to investigate the various parameters and their effects in detail. It is expected that the results of this work will lead to clear guidelines on how to handle MON/stainless-steel contact, and how to avoid and/or prevent flow decay due to precipitation. It is intended to extend this contract to aluminium and titanium alloys in the near future.

Figure 10. Hydrazine purification plant. To the left is the crystalliser and to the right the five stage vessels

Conclusions

We have examined some of the major new developments in spacecraft chemical propulsion during the last six years. The many innovations reported reflect a growing European competence and competitiveness in spacecraft propulsion, with a logical and continuous expansion of Europe's capabilities. Clearly, without the presence and endeavours of an active and competitive European propulsion industry, the Agency could never have achieved as much as it has.

Two-Phase Heat-Transport Systems for Spacecraft

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Introduction

For satellites with rather low power levels, thermal management can be performed by using passive devices, such as radiators, coatings, heaters and insulation. Early manned missions such as the Mercury, Gemini and Apollo programmes, made use of pumped fluid loops to collect greater amounts of waste heat from distributed sources for rejection by space radiators. Even for higher power levels (e.g. Space Shuttle and Spacelab), these single-phase fluid loops have still been sufficient for successful thermal management.

Due to the increased power dissipations onboard many of today's satellites, more and more two-phase heat-transfer devices such as heat pipes are being employed to enhance heat transportation and to increase radiator efficiency. For future large-scale space applications, such as the International Space Station Freedom, and possibly also Europe's Columbus and Polar Platform Projects, thermal-management systems employing two-phase heat-transfer loops are currently being considered. Compared to today's single-phase loops, they offer several worthwhile advantages, including reduced overall mass, reduced pump power consumption, nearly isothermal behaviour, adjustable working temperature, considerable flexibility in terms of the siting of heat-dissipating components, and high growth potential.

In a conventional closed, single-phase, iquid cooling loop, a working fluid is circulated from the heat-input section to the heat-rejection section and back again by a mechanical pump, as in a domestic heating system. Within the heat-input section, the temperature of the working fluid is increased by absorbing the heat dissipated from the spacecraft components. The warmer fluid is pumped to the heat-rejection section, where the sensible heat is removed and the fluid temperature reduced. The colder fluid is then pumped back again to the heat-input section to close the cycle.

The amount of heat that can be transported in such a loop is proportional to the mass flow, the temperature difference between the hot and cold sides, and the specific heat capacity of the working fluid. As there is a limit to the allowable temperature difference in that most spacecraft components have a rather narrow working-temperature range, control over the amount of heat to be transported has to be exerted by adjusting the mass flow rate.

Quite often the equipment to be cooled undergoes a duty cycle ranging from high power dissipation with all instruments on, to low power dissipation when most instruments are off. Consequently, the possible mass flow in the fluid loop has to cover a wide range. As the pipework and the pump have to be designed for the maximum flow rate, such single-phase liquid loops suffer from a large mass penalty, together with a high demand for electrical energy to drive the pump.

The situation is quite different in a two-phase system (Fig. 1; schematic only). In this case, the working fluid coexists as liquid and vapour inside the hermetically sealed loop. A mechanical pump transports the liquid phase of the working fluid to the evaporator. The heat coming from the spacecraft component to be cooled partially or completely evaporates the liquid entering the evaporator. The two-phase mixture or pure vapour exiting the evaporator then flows along the vapour line to the condenser. Inside this condenser, the latent heat of evaporation is transferred to a radiator, thereby condensing the fluid. The exiting liquid phase of the working fluid flows back along the liquid line to the pump.

The accumulator in the loop is used to adjust the working temperature, by managing the fluid content in the condenser and thereby its thermal resistance. In this way, the operating temperature of the two-phase loop can be adjusted – within limits depending on the actual design and on the working fluid chosen – to the prevailing requirements of the spacecraft.

Because the two-phase loop makes use of the latent heat of evaporation/condensation to transfer heat from evaporator to condenser, the mass flow rate necessary to transport a given heat load is considerably less than in a single-phase loop. To illustrate this effect, Figure 2 shows the ammonia flow rate as a function of the heat load to be transported in the case of a single-phase loop for three temperature differences, and with a two-phase loop. Clearly, the flow rates required for a two-phase loop are much lower than for single-phase heat-transport systems. For a temperature difference between the hot and cold sides of 20 K, the flow rate needed for a single-phase loop is about twelve times higher than for the two-phase loop. An unrealistic temperature difference of 40 K would still result in a flow rate about six times larger than with a two-phase loop.

In a practical spacecraft design, such an increase in flow rate results in larger pipe diameters, and hence an increase in mass. Moreover, to circulate this higher mass, a larger pump is required and the power needed to drive it is increased by at least one order of magnitude.

As the mass of the necessary sensors, valves, etc., is comparable for the two heat-transport systems, and because in nearly all spacecraft designs mass and available power are both critical items, a large reduction in mass flow rate, and thus a considerable reduction in overall system mass, is a clear advantage of two-phase loops.

Mechanically-pumped two-phase loop

The development of a European mechanically pumped two-phase heat-transport system was started in 1983 within the preparatory support technology programme for Space Station/Columbus. An initial study identified the critical components and concluded by recommending a system based on a parallel arrangement of evaporator cold plates and heat exchangers, parallel condenser units and a conventional mechanical pump. The following components were identified as being critical, with a need to start development work:

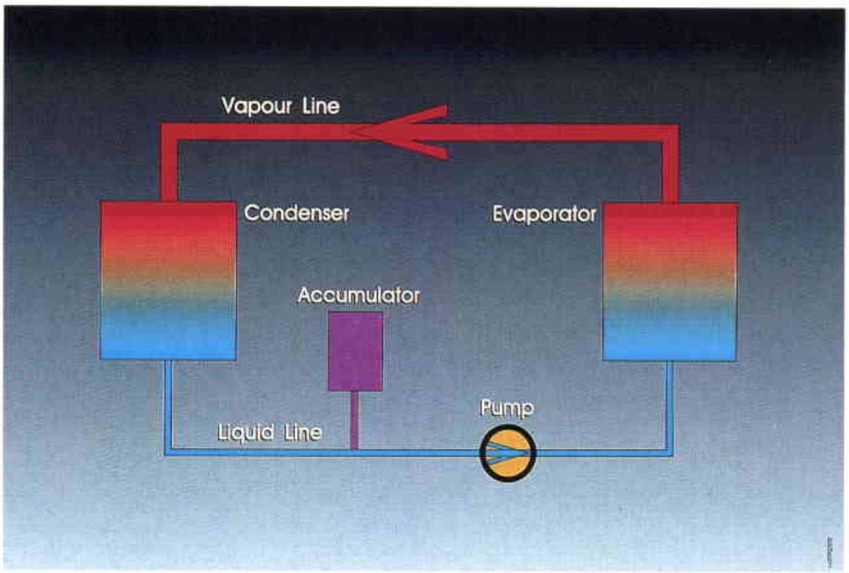


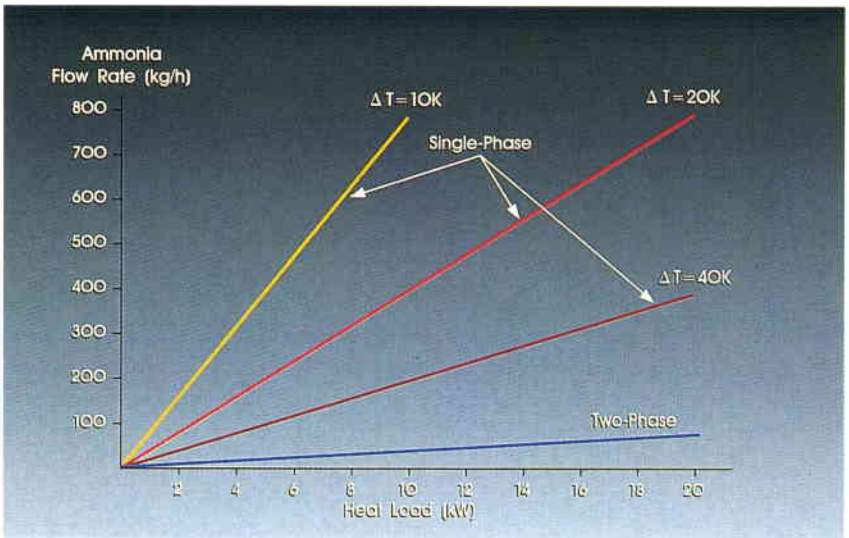
Figure 1. Schematic of a two-phase heat-transfer loop

- evaporator cold plate
- evaporative heat exchanger
- vapour-quality sensor
- heat-rejection interface
- accumulator/control reservoir
- control system
- mechanical pump.

During the course of work performed for ESA by Dornier (D), Aeritalia (I), BAe (UK), Fokker (NL), and NLR (NL), the various components were designed, manufactured, tested individually and integrated into a test bed (Fig. 3), with the exception of the pump, which was the subject of a separate study. Within this test bed the components were submitted to a comprehensive checkout and test programme to demonstrate their performance characteristics and limits.

The test bed provides all necessary sensing, monitoring and control equipment to allow supervision and control of each of the critical components, as well as of the overall system performance. It is designed for a maximum heat load of 10 kW (two 5 kW evaporators) and a cooling (heat-rejection) capability of up to 12 kW. The working fluid is Freon R 114, and the working temperature set-point 20°C.

Figure 2. Ammonia flow rates for single- and two-phase loops



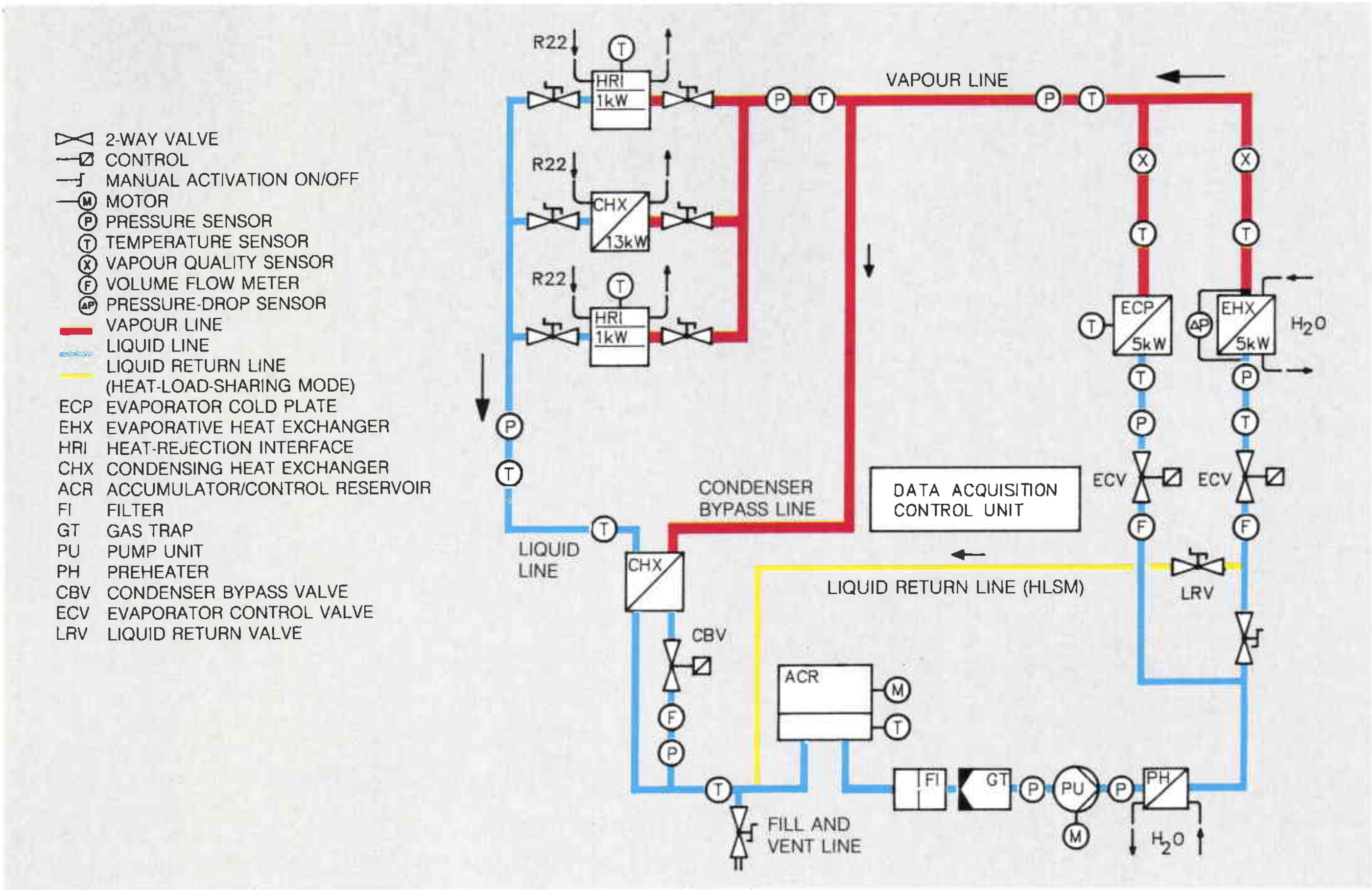


Figure 3. Schematic of the mechanically pumped two-phase test bed

Figure 4 shows the evaporator section of the test bed with an evaporative cold plate and an evaporative heat exchanger in parallel.

A separate technology programme was initiated in 1990 with Reusser (CH) to develop an engineering model of a mechanical pump suitable for the two-phase loop.

Evaporator cold plate

This unit's task is to cool heat-dissipating devices like payloads, instruments or subsystem units which are mounted on top of its cover plate. The liquid entering the capillary-supported cold plate is distributed in an internal reservoir and transported via a porous structure to the internal evaporative surface. At this surface, the heat coming from the attached payload evaporates the liquid. To enhance this evaporation process, the surface has a large number of small grooves. The resulting vapour is collected in larger channels before entering the vapour line.

The cold plate, which has a payload mounting area of 0.33 m^2, has been successfully tested and the maximum heat load achieved was 5 kW.

Evaporative heat exchanger

An evaporative heat exchanger is required when a heat load has to be transferred from one cooling loop to another, such as from the water cooling loop inside a habitable module to the external spacecraft cooling loop using Freon. Its internal design provides for a parallel flow of Freon and water in helicoidal ducts. Energy is exchanged between the two media, causing the water temperature to decrease while the Freon partially evaporates on its way through the unit.

The heat exchanger is cylindrical in shape, with an outside diameter of 350 mm and a height of 540 mm. Tests have shown that the unit can transfer a heat load of up to 6 kW from the water to the Freon loop.

Vapour quality sensor

The local vapour quality in a two-phase system is defined as the relative local vapour mass content of the flowing two-phase mixture. A vapour quality of 0 corresponds to pure liquid, while a value of 1 represents saturated vapour. If in a two-phase system the mass flow rate through an evaporator is constant, a change in heat load will result in a change in vapour quality at the outlet. In order to control the mass flow rate through the individual evaporators, a vapour quality sensor is needed at the outlet of each.

A properly controlled two-phase system is achieved if, for any working condition, the vapour quality at the outlet of the evaporators is kept as close as possible to 1, thereby making maximum use of the latent heat of evaporation of the working fluid. However, operation of cold plates at vapour qualities above 1 has to be avoided to prevent overheating and subsequent failure. To determine the vapour quality, the sensor measures the void fraction (relative volumetric vapour content) in the flow cross-section. The measurement itself is based on the different dielectrical permittivities of the vapour and liquid phases.

Tests with two different types of vapour-quality sensor have given satisfactory results, proving that such sensors can indeed be used to control a mechanically pumped two-phase system.

Heat-rejection interface

The heat-rejection interface, or condenser, is based on a multi-channel design. Two parallel condenser branches, each with a number of small parallel channels, connected by a vapour inlet and a liquid outlet, were chosen for improved thermo-hydraulic performance. The design is intended to allow a coupling of this condenser to a radiator panel via a number of heat pipes.

These condensers, each of which is designed for a heat-rejection capability of 1 kW, have been successfully tested and have proved to be a promising basis for the building of larger condenser arrays.

Accumulator/control reservoir

The task of an accumulator in a two-phase system is to control the system pressure and corresponding system temperature by either flooding the condenser or removing fluid from it. If, for given stable working conditions in a two-phase heat-transport system, part of the condenser is blocked by liquid coming from the accumulator, the efficiency of the condenser will decrease and the system will react via an increase in system pressure and temperature. This effect can be used very advantageously to change the temperature set-point of this type of heat-transport loop, allowing a given heat load to be removed over a range of temperatures, depending on the loop design and the properties of the working fluid used.

The accumulator design is based on a variable-volume reservoir through which the liquid Freon R114 coming from the condenser flows. It consists of a stainless-steel vessel with an integrated metal bellows, the volume of which can be varied mechanically by an electro-motor drive unit. Tests have shown that this design is perfectly capable of controlling the loop pressure set-point and maintaining it to within 0.01 bar.

Control system

For a two-phase heat-transport system to run properly under varying heat-load and heat-

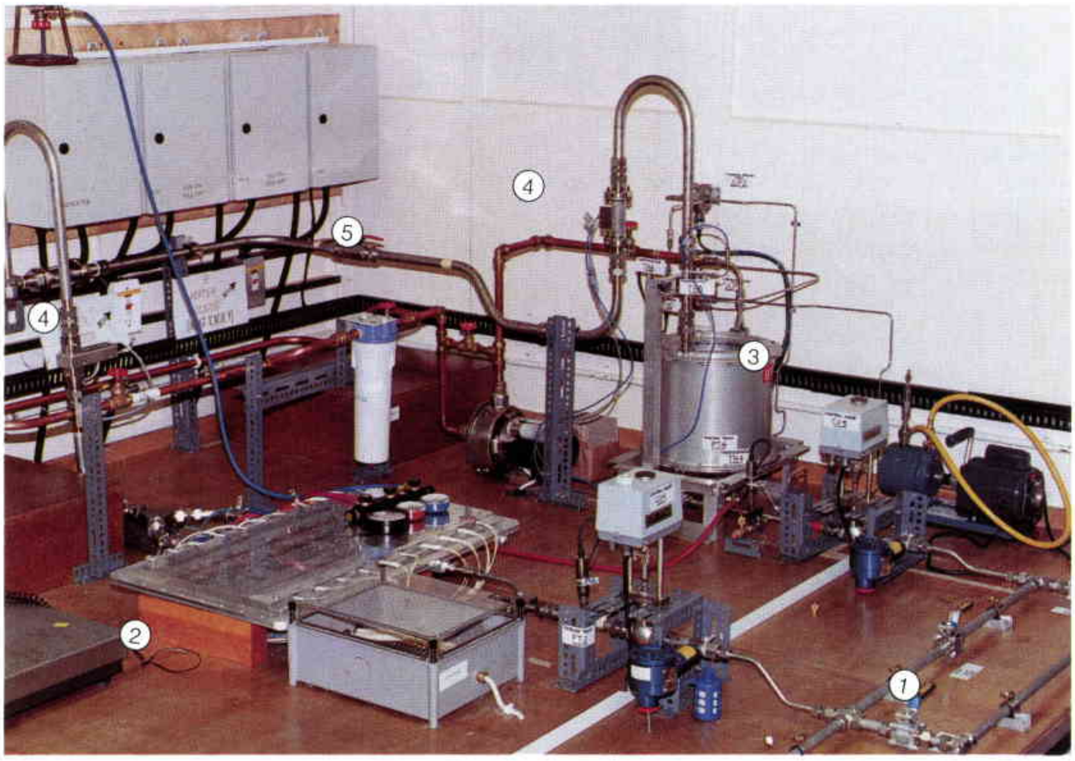


Figure 4. Evaporator section of the two-phase test bed

1. Liquid line
2. Evaporator cold plate
3. Evaporative heat exchanger
4. Vapour-quality sensor
5. Vapour line

sink conditions, an appropriate control system becomes necessary. The amount of liquid flowing into each evaporator has to be adjusted to keep the vapour quality at the outlet at a defined value, the system vapour pressure and hence the system temperature has to be maintained at a preset value, and the temperature of the liquid entering the pump has to be controlled to avoid cavitation inside the pump, for example.

For each of the above-mentioned controls, a separate control loop was designed and implemented in the test-bed computer. The overall control philosophy worked quite well; some instabilities were encountered, but they were partially due to sensor inaccuracies. In a future test series, a more advanced control concept based on adaptive–predictive control philosophy is also to be investigated.

Capillary-pumped two-phase loop

A second, very interesting two-phase heat-transport system is the so-called 'capillary-pumped two-phase loop'. In this case, the mechanical pump in Figure 1 is replaced by a capillary pump, i.e. by a special evaporator capable of producing the pumping force necessary to drive the fluid around the loop.

The working principle of such a loop has its origins in the 'heat-pipe' principle. A simple heat pipe consists of a hermetically sealed, typically metallic tube (e.g. aluminium, stainless steel, copper) containing a certain amount of working fluid (e.g. ammonia, methanol, water), coexisting as liquid and vapour. The tube has a capillary structure running along its entire length, often consisting of simple axial grooves, as in most heat pipes in use in current satellites, arteries made of metallic screens or sintered powder structures. If heat is added to one end of this heat pipe, the working fluid evaporates out of this capillary structure and the resulting vapour flows towards the colder end of the pipe, where it is condensed. The working fluid, now in a liquid phase, is transported back to the evaporator by the capillary forces in the capillary structure.

Because the liquid and vapour move in a counter-flow arrangement within the same container, and because the capillary structure must run the length of the liquid flow path, the maximum length and transportable heat load of conventional heat pipes is limited. In addition to various attempts to overcome these limitations whilst still retaining the basic heat-pipe geometry, a very promising development emerged in the form of the capillary-pumped loop. The latter can be considered as an advanced heat-pipe concept, the main difference being that the vapour and liquid lines are separated and the porous or capillary structure is only present within the evaporator, where it is used to transport the liquid working fluid to the evaporative surface while developing the capillary pressure head to drive the fluid around the loop.

One drawback of a capillary-pumped loop is the limited pressure head available, which means that the design of the loop and its components have to minimise all pressure drops. A major advantage, however, is the lack of moving parts compared with a conventional pump, which substantially reduces noise and vibration levels and makes this type of heat-transfer system particularly suitable for applications where undisturbed microgravity conditions are required.

The development of a two-phase capillary-pumped heat-transport system was started at Sabca (B) and Dornier (D) in 1987 with ESA funding. The system is designed to achieve a heat-transport capability of 5 to 10 kW over a distance of up to 20 m within a controllable temperature range of 0 to 20°C, using ammonia as the working fluid. Further requirements are long-term operation in space, compatibility with microgravity requirements, and minimum power consumption. The development model, which has already been tested, consists of two parallel evaporators each with a maximum heat-transport capability of 5 kW, parallel condenser arrays, a subcooler, a thermal accumulator to control loop system pressure and hence operating temperature, and an additional re-priming tank.

The evaporator itself is a square aluminium box (510 mm sides and 42 mm thick) with liquid inlet and vapour outlet tubes (Fig. 5; schematic only). It contains a wick structure made of a porous plastic material (pore size about 30 micron) with a number of liquid distribution channels. The subcooled liquid entering the evaporator is distributed in these channels within the wick and transported via capillary action to the evaporative metal surface, which has a large number of very fine grooves to enhance the heat transfer. There the liquid is evaporated and the resulting saturated vapour is fed via larger vapour collecting ducts to the vapour outlet. The pumping pressure head, required to drive the fluid around the loop, is generated at the interface between the evaporative

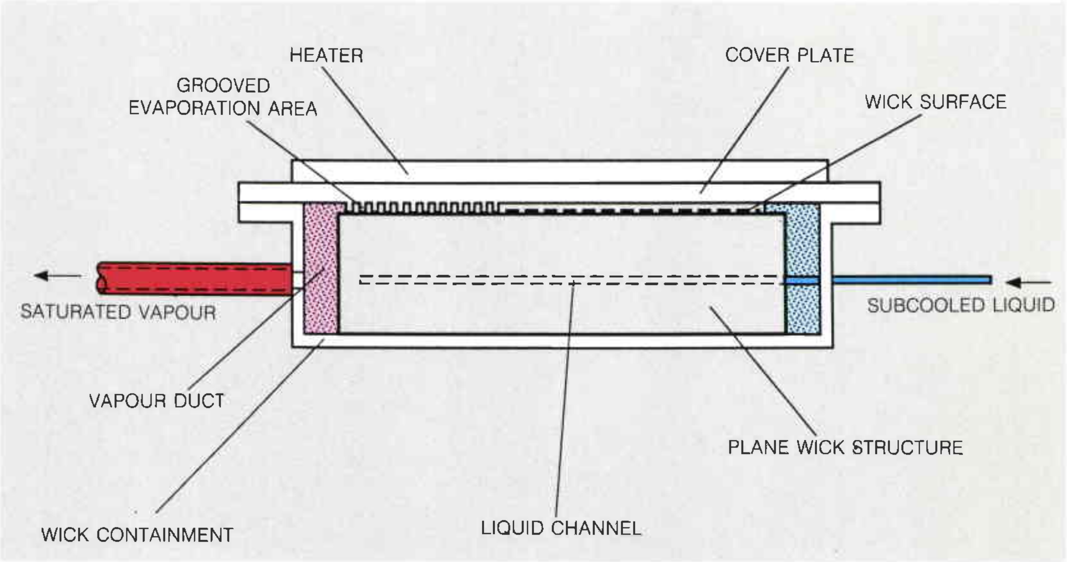


Figure 5. Schematic of a capillary-pumped evaporator

surface grooves and the surface of the wick. After flowing through the vapour line, the vapour is condensed in the two parallel condenser arrays. Downstream from the main condensers, a special subcooler unit reduces the liquid temperature to a few degrees below the saturation temperature, to avoid vapour generation inside the porous structure instead of at the evaporative surface. Such vapour generation would block the evaporator and lead to interruption of the liquid flow within the wick structure.

To start the evaporator, the capillary structure must be primed by pushing cold, subcooled liquid into the porous material. The loop is therefore provided with a re-priming tank containing sub-cooled liquid, which is pushed into the evaporator. During normal operation of the loop, this tank is slowly refilled.

To control the loop pressure and hence the temperature, a thermal accumulator which contains liquid and vapour in equilibrium is used. If an increase in loop temperature is requested, a heating element inside the accumulator is activated to increase the existing vapour bubble and thereby push liquid into the loop. This additional liquid blocks off part of the condenser, increasing its thermal resistance. If the applied heat load on the loop and the heat-sink conditions are not changed, this increase in thermal resistance will result in an increase in loop operating temperature. To reduce the loop temperature, the heating element is switched off, the volume of the vapour bubble decreases, and liquid is drawn from the condensers into the accumulator.

Initial tests using Freon, and the main tests with ammonia as the working fluid both proved successful. During these system tests, the capillary-pumped loop proved to be a viable tool for transporting up to 7.5 kW of heat over a distance of more than 10 m, with a range of 0 to 20°C for the system temperature. It also provided very good temperature control, and temperature stability of the order of 1 K, for widely changing heat-load and heat-sink conditions. Heat-load sharing, i.e. transfer of heat from an active evaporator to a non-active one acting as a condenser, has also been successfully demonstrated. This feature is extremely useful in cases where a switched-off payload attached to an evaporator has to be kept at a certain temperature.

Two-phase-loop flight experiments

As two-phase flow and heat transfer differ in their behaviour when subjected to a 1-g or a low-gravity environment, the technology of two-phase heat-transport systems and their components has to be demonstrated in orbit. Development of a two-phase loop experiment was therefore proposed last year by NLR (NL) and Sabca (B) as part of ESA's In-Orbit Technology Demonstration Programme. The experiment is intended to be integrated into a Get-Away Special (GAS) container, to be flown aboard the US Space Shuttle. The experiment will be running autonomously, providing its own power supply, data handling and experiment control once the switch-on command has been sent by the Shuttle's crew.

The experiment, which is a joint NLR (NL), Sabca (B), Bradford Engineering (NL), Fokker (NL) and Stork (NL) activity, consists of a capillary-pumped two-phase ammonia system, including two parallel evaporators, a multi-channel condenser in two sections, two

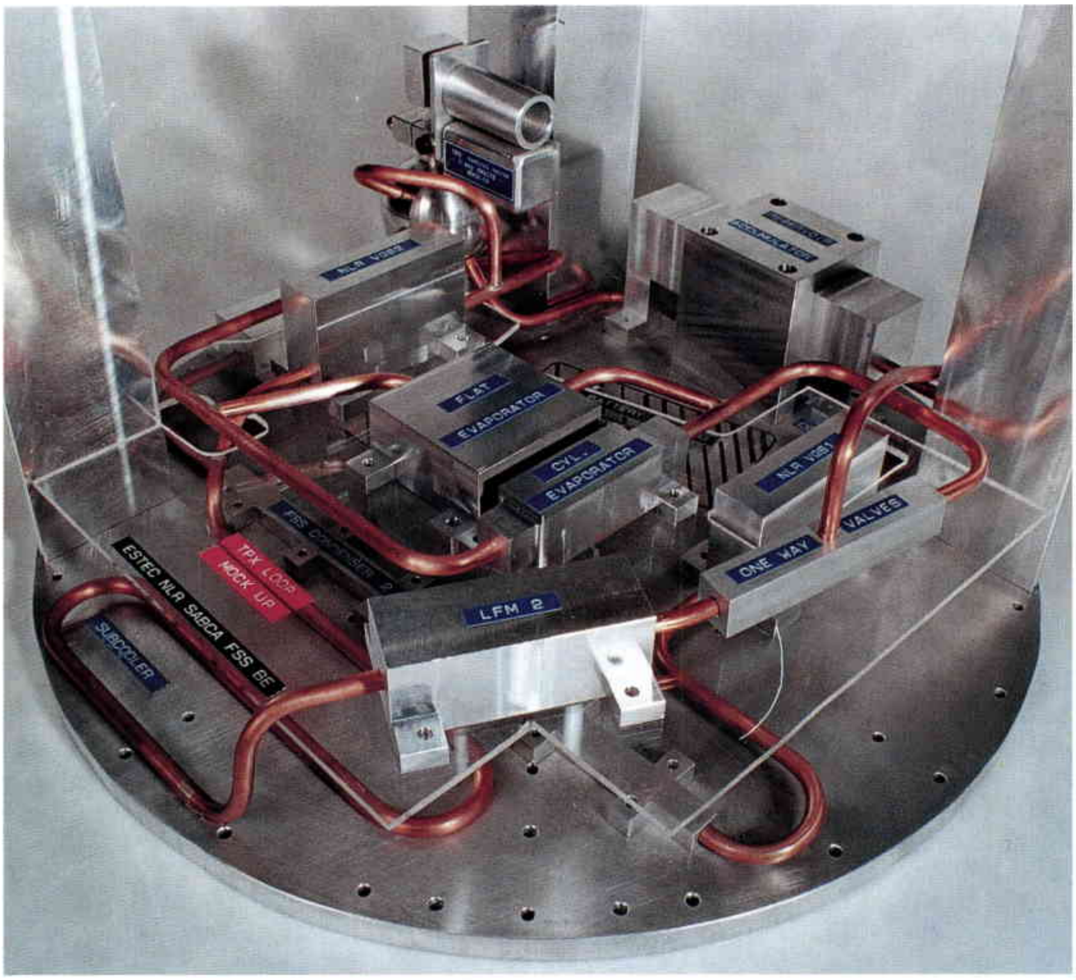


Figure 6. Mock-up of two-phase experiment

vapour-quality sensors, a sub-cooler and an accumulator. Figure 6 shows a mock-up of the two-phase experiment.

The main objectives of this in-orbit demonstration are:

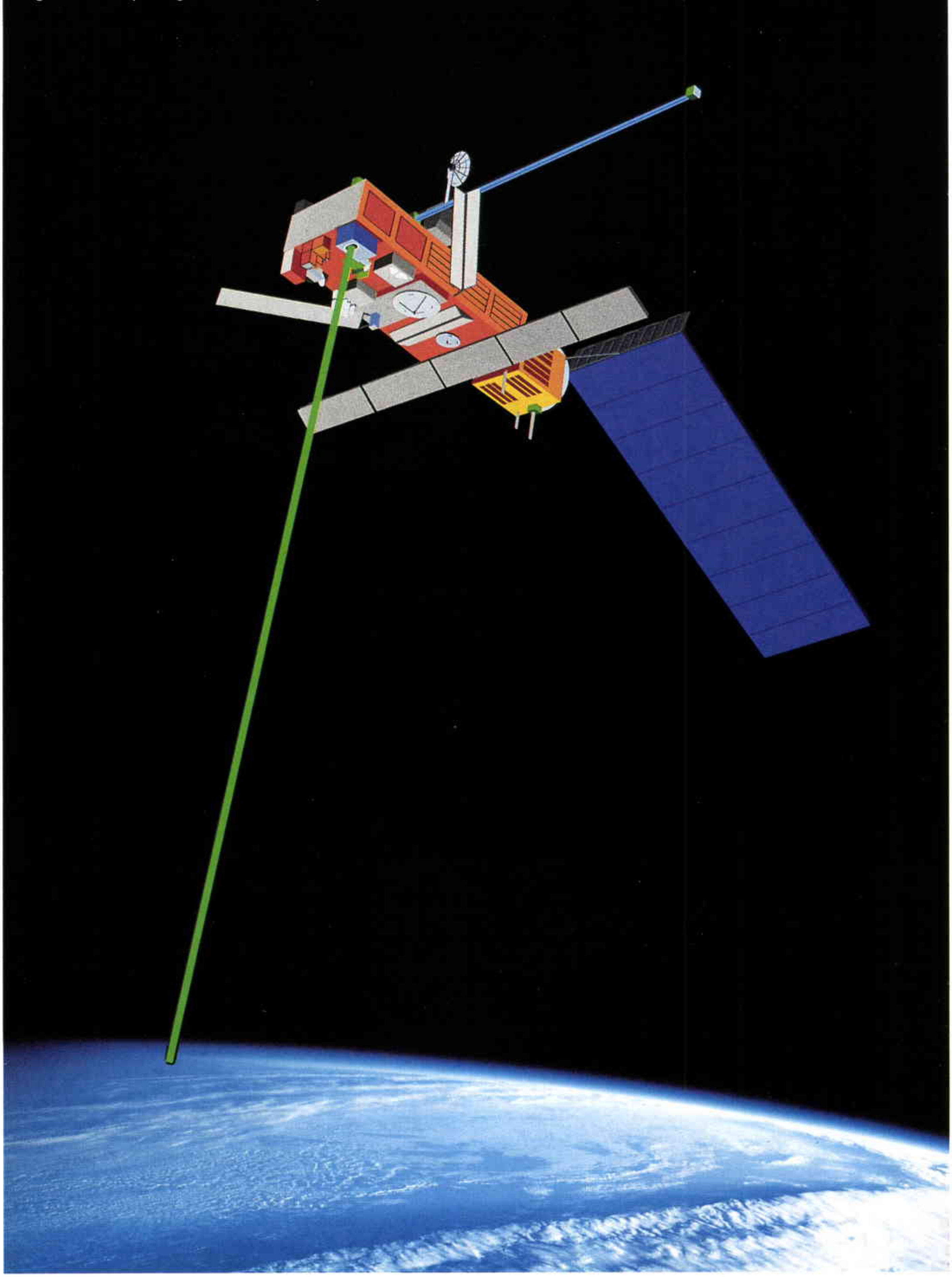
for the capillary-pumped loop:
- to demonstrate its heat-transfer potential under different heat-load and heat-sink conditions
- to prime and start up under different starting conditions
- to adjust and maintain the loop working temperature under different (varying) heat-load and condenser conditions

for the vapour-quality sensor:
- to prove concept feasibility under space conditions
- to compare the performance of two sensors in order to assess the influence of location within a loop
- to perform calibration and to assess the differences between low-gravity and 1-g sensor performance
- to demonstrate the sensor's capability for control tasks

for the condenser design:
- to demonstrate and verify the working principle and to determine performance limits in a low-gravity environment.

The results expected from this in-orbit demonstration, together with their comparison with predictions and with ground-based results, will provide extremely valuable information for the design of two-phase heat-transport systems for future spacecraft and space vehicles.

Figure 1. Lidar probing the Earth's atmosphere from the Polar Platform



Laser-Based Remote Sensing from Space

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Introduction

Since the late 1970s, ESA has been engaged in an R&D programme to apply lasers for the remote sensing of the Earth's atmosphere from space. Plans are also in place to develop lidar instruments for flight on the Agency's polar-orbit missions. Active laser remote sensing from space is regarded as an important step forward in our capability to understand weather and climate processes, and to assess threats and changes to the Earth's environment.

At a time of increasing public awareness of the potential vulnerability of the Earth's climate to man's activities, ESA is stepping up efforts to develop space-borne instrumentation for the efficient monitoring of the Earth's atmosphere. New space techniques for the provision of global data must be developed if further significant advances are to be made in operational meteorology, climate studies and environmental research. One of the most exciting of the new approaches being considered is active sensing with laser instruments, which use short light pulses to obtain depth-resolved information on the composition and physical state of the atmosphere. Key atmospheric observables such as aerosol layers, humidity profiles and winds can be observed with unprecedented horizontal and vertical resolution, remedying many of the deficiencies of current passive sensor systems.

Laser-based remote sensing is often referred to as 'Lidar' (acronym from Light Detection and Ranging). Lidars are based on the principle of a laser-light pulse being sent into the atmosphere to probe the distance, physical state or chemical composition of the backscattering layers. The excellent vertical resolution of Lidar measurements allows accurate height assignments to be made for atmospheric features, complementing the data obtained from passive sounders and imagers, which generally have poor height resolution.

Since Lidars provide their own light source, they can operate both in the dark side of a satellite's orbit as well as in the sunlit portion, increasing the useful coverage of observation. By viewing the atmosphere from space, satellite-borne Lidars have the advantage of being able to probe the upper troposphere and the stratosphere without the signal being masked by optically thick layers in the lower atmosphere. The result is vast data coverage, in terms of both areal extent and depth of measurement.

The last few decades have seen significant advances in laser technologies, to the point where it now seems feasible to consider the deployment of Lidars in space. Many ground-based and airborne Lidar systems have already been built and operated, clearly demonstrating their measuring capabilities and potential. A strong scientific, technological and industrial base is now available in Europe from which space Lidar systems can be developed. There has also been a steady evolution of the means by which active instruments can be carried into orbit.

The planned launching into polar orbit in the late 1990s of a series of large platforms will offer new possibilities for operating laser remote-sensing systems in space. On these large platforms, Lidar instruments could be operated jointly with other advanced sensors, producing a continuous stream of data that could provide almost complete insight into the prevailing state of the atmosphere.

The provision of such data will be one of the most challenging tasks for the future, as the continuous updating, completeness of coverage and highest accuracy of meteorological databases will be of greatest importance in improving the power of weather-forecasting and climate-prediction models in the coming decades.

Space Lidar concepts

Lidar is a generic term associated with a wide variety of instruments that can differ profoundly in type, complexity and power

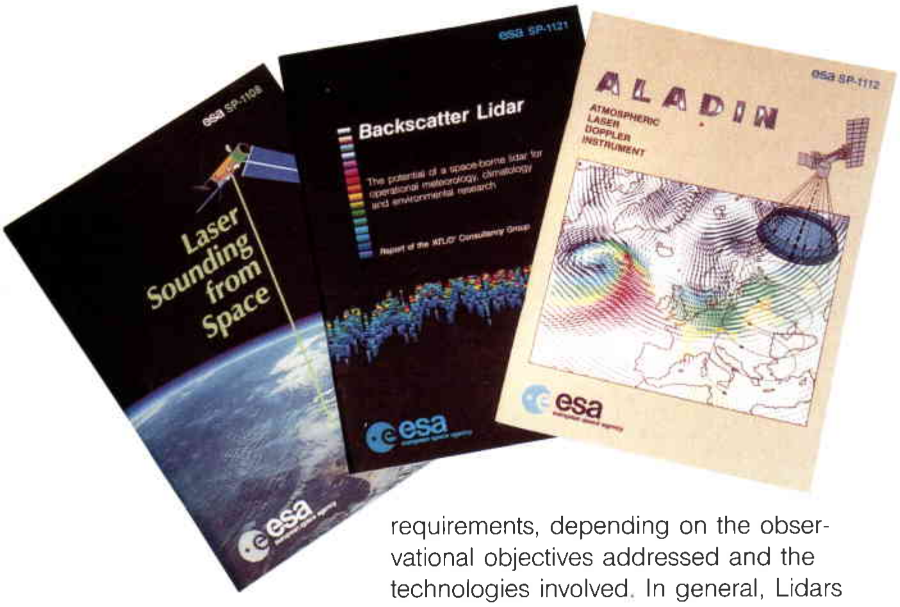


Figure 2. ESA Lidar study group reports, including 'Laser Sounding from Space' (ESA SP-1108), 'Backscatter Lidar' (ESA SP-1121), and 'ALADIN - Atmospheric Laser Doppler Instrument' (ESA SP-1112)

requirements, depending on the observational objectives addressed and the technologies involved. In general, Lidars are quite demanding instruments, in terms of both the developmental effort and spacecraft resources required. For spaceborne systems, clearly, a suitable balance between development cost and operational utility must be found.

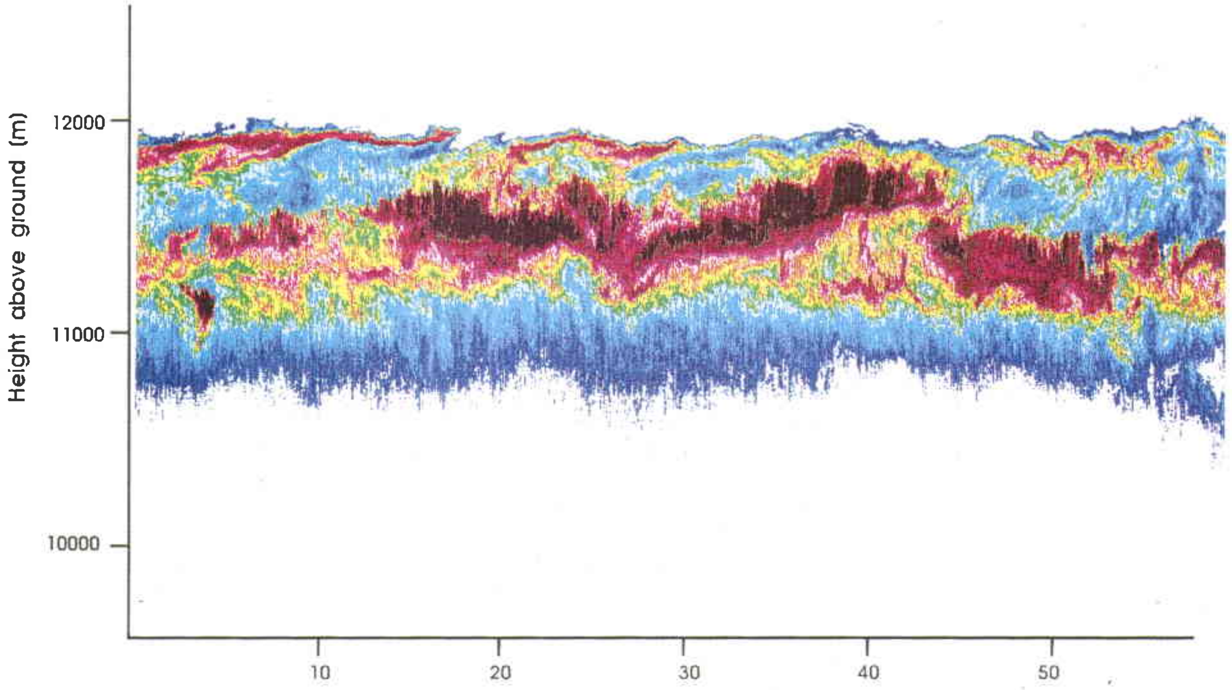
The question of selecting the most appropriate Lidar systems for use in space has been the subject of continuous debate in the past few years. In this context, ESA has set up a number of external consultancy groups composed of users, scientists and laser-instrumentation specialists in order to obtain advice on suitable instrument concepts and development priorities in this field. Three Lidar concepts emerged from these discussions as being the most suitable candidates for spaceborne use, namely the Backscatter Lidar, the Differential Absorption Lidar (Dial), and the Doppler Wind Lidar.

Backscatter Lidar

This is the least demanding of the possible space Lidar concepts in terms of technology risk and development effort, yet it can provide very important atmospheric data. The Backscatter Lidar basically relies on a strong, but not necessarily coherent, pulsed light source illuminating the atmosphere, combined with a receiving telescope serving as a simple photon collector.

A spaceborne Backscatter Lidar can provide global information on the scattering and extinction coefficients of the various atmospheric layers, e.g. on the extent, height distribution and optical thickness of aerosol and cloud layers. Knowledge of these factors could prove invaluable for climatic research, given their vital role in the global radiation balance. Weather forecasters could benefit from Backscatter Lidar data either indirectly to improve passive-sensor measurements (e.g. by correcting remotely-sensed ocean-surface temperatures, cloud radiative properties, or vertical water and temperature profiles), or directly to obtain information on cloud distribution and air mass discontinuities. Such data would be particularly useful at night and over the oceans, where other observations are scarce. Measurements from an orbiting Backscatter Lidar could also prove useful for studying the long-range transport of natural aerosols and air pollutants.

Figure 3. Typical Backscatter Lidar profile, of cirrus layer measured in this case from an aircraft



Differential Absorption Lidar (Dial)

Dial can be seen as a possible evolution of the Backscatter Lidar. Dial systems can measure atmospheric parameters of high meteorological interest by tuning the laser wavelength to the specific absorption features of atmospheric trace constituents. The method generally uses two adjacent laser wavelengths, one centred on a molecular absorption line, the other off any absorption line, to obtain range-resolved density profiles of a specific atmospheric constituent. Using suitable oxygen and water-vapour absorption lines, the technique permits the measurement of such important meteorological variables as temperature, pressure and humidity profiles.

Ground and aircraft experiments have demonstrated the power of Dial systems in obtaining unprecedented measurements of atmospheric trace species and meteorological parameters. The systems themselves, however, are rather complex as they require precisely tunable, multiple-wavelength laser systems along with highly sensitive, wavelength-selective detector devices.

Doppler Wind Lidar

This instrument can determine global wind fields, thereby leading to a considerable improvement in weather-forecasting skills. It is based on the principle of measuring the Doppler shift of the light backscattered from aerosol particles transported by the wind. Such an instrument generally needs a highly coherent and powerful pulsed laser beam, combined with a complex receiver and Doppler processor. This instrument is therefore considerably more complex and demanding than the Backscatter Lidar in terms of technology development and platform resources, but it is certainly the Lidar instrument that would make the largest contribution to operational meteorology, given the importance of global wind fields in weather-prediction models.

Much experience has already been gained from terrestrial and aircraft-borne Doppler Wind Lidars, most of them based on the carbon-dioxide (CO_2) gas laser. Many systems are currently in operational use, for example for wind-shear and local-turbulence monitoring on airport-runway approaches.

Whereas the Backscatter Lidar clearly appears to be a high-priority, first-generation candidate for early space implementation, given the limited technology risks involved, the realisation of spaceborne Doppler Wind Lidar and Dial systems constitute major technological challenges. Compared to terrestrial systems, a whole range of fundamental problems would have to be solved. The stringent spectral emission characteristics of the transmitter laser would have to be achieved at a much higher output power in order to obtain accurate measurements over the large probing distances involved from orbit. Similarly, detector devices become very complex, as they have to accommodate the dynamic frequency variations and angular displacements caused by the spacecraft's motion and Lidar beam scanning.

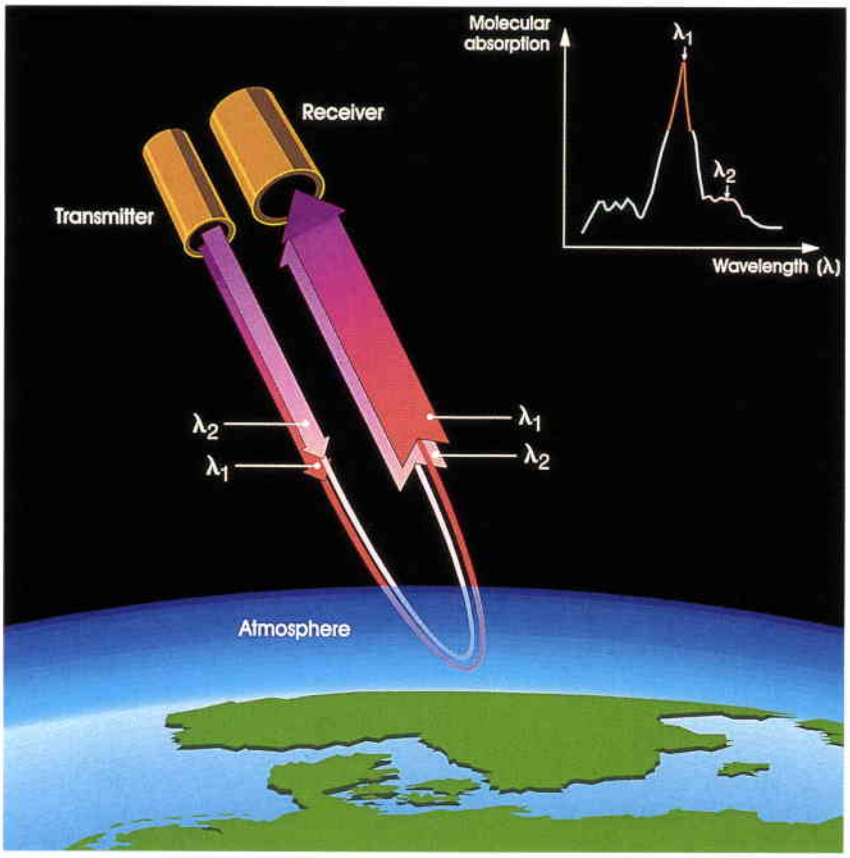


Figure 4. Principle of Differential Absorption Lidar (Dial)

Preparing the technology

Recognising the potential importance of Lidars for Earth remote sensing, ESA has carried out a number of development activities within its basic Technology Research Programme (TRP) in order to foster the requisite technological advances. Critical to the successful use of Lidars in space is the achievement of efficient and powerful laser sources with the necessary levels of beam quality, reliability and lifetime.

Initially, ESA opted for the Alexandrite (chromium-doped chrysoberyl, $Cr^{+3}:Al_2 BeO_4$) crystal laser as the prime candidate for space Lidar applications. This laser emits in a spectral region where backscattering

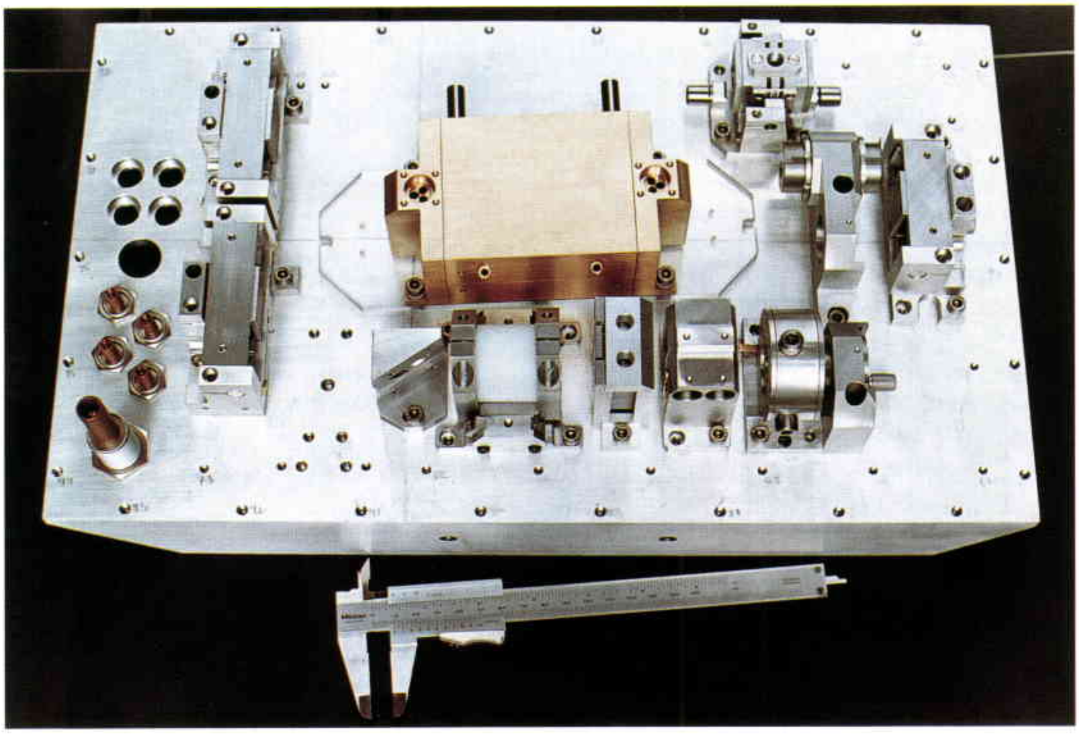


Figure 5. Breadboard model of flash-lamp-pumped Nd-YAG laser, showing the laser head located inside the optical resonator

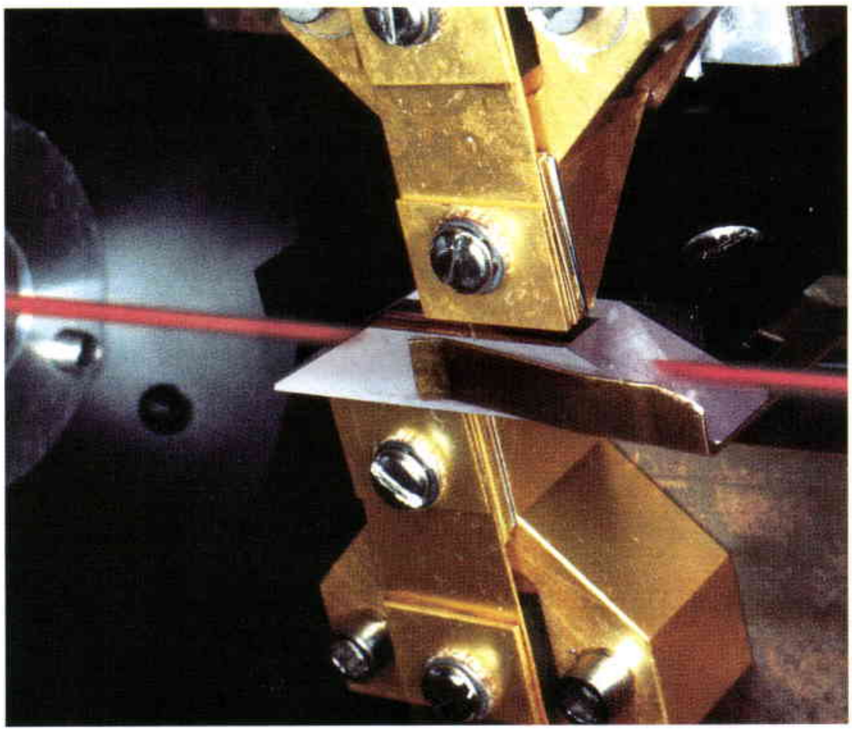
efficiency from aerosols is very high. The laser can be tuned to the absorption lines of oxygen and water vapour, and it also offers the potential to perform incoherent Doppler wind measurements. Initial progress with Alexandrite crystal quality, however, levelled off rapidly, indicating potential limitations for high-power, long-life applications. ESA therefore redirected its development emphasis to the more established and more reliable Nd-YAG (neodymium-doped yttrium-aluminium garnet, Nd^{3+}: $Y_3 Al_5 O_{12}$) laser.

In solid-state crystal lasers, flash lamps are normally used to excite (optically pump) the active laser material. ESA has applied this approach to develop a technology demonstrator for a high-energy, flash-lamp-pumped Nd-YAG laser for Backscatter Lidar applications. Recent advances in GaAlAs semiconductor laser arrays, however, are pointing to the opportunity for replacing the flash lamps in the laser architecture by laser-diode arrays to optically pump the active material. The resulting all-solid-state laser source is compact, rugged and highly power-efficient, due to the good spectral overlap between the laser-diode emission and laser-material absorption. Following up this progress in technology, ESA recently initiated a programme to develop a diode-laser-pumped Nd-YAG laser for use in spaceborne Backscatter Lidars.

For the Doppler Wind Lidar, the carbon-dioxide (CO_2) laser appears at present to be the best technological choice for a spaceborne instrument, considering the maturity of this laser and the worldwide experience in the development and use of coherent CO_2 laser-radar and Doppler wind instruments. ESA is currently funding the development of a 10 J pulsed CO_2 laser as part of its spaceborne Doppler wind technology effort.

At the same time, however, the Agency is also looking into the possibility of using all-solid-state laser sources in the mid-infrared for Doppler wind applications. These new types of crystal laser use certain long-lived

Figure 6. Nd-YAG laser crystal, optically pumped by two diode-laser arrays (red beam is a helium-neon alignment laser)



metastable states of rare-earth ions such as Erbium (Er), Holmium (Ho), and Thulium (Tm) in conjunction with diode-laser pumping to achieve laser emission in the eye-safe region above 1.5 micron. The mid-infrared range of the electromagnetic spectrum covered by these lasers is extremely rich in infrared absorption lines of atmospheric trace gases. ESA is therefore also looking into these lasers for potential Dial applications.

Apart from laser-transmitter technology, ESA is also focussing its attention on other critical Lidar technologies, such as beam-scanning and receiver technologies. Space-borne Lidars must include means to scan the probing laser beam across the ground track to achieve the desired areal coverage.

Beam scanning and spacecraft orbital motion cause an angular offset between the transmit and receive beams, which must be dynamically compensated by special lag-angle compensation devices. This problem is further aggravated in coherent Doppler Wind Lidar and Dial applications where spacecraft motion and beam scanning also cause dynamic Doppler shifts in the received beam, which have to be taken care of in the receiver systems.

A considerable part of ESA's Lidar technology effort is currently devoted to finding technical solutions to these problems.

Development strategy

Given the cost and complexity associated with Lidar instrumentation, it is considered over-ambitious for Europe to undertake development of all of the Lidar sensors described above on its own. A balanced and gradual implementation of the various possible systems is indicated.

Presently, ESA is giving priority to the Backscatter Lidar in view of the favourable relation between scientific return and development cost. Such a Backscatter Lidar, the so-called 'Atmospheric Lidar' (Atlid), has been put forward as the prime candidate to be flown on Europe's polar-orbiting Earth-observation missions. Atlid is complementary to current US endeavours, which concentrate on the definition of a Doppler Wind Lidar (LAWS – Laser Atmospheric Wind Sounder) and Dial system (LASA – Lidar Atmospheric Sounder and Altimeter) as part of NASA's Earth-Observing System (EOS) effort.

For the Doppler Wind Lidar, the effort required to develop a spaceborne instrument currently exceeds the capabilities available to ESA in this field. It is more appropriate to consider this instrument as part of a wider international venture, e.g. in the context of the US LAWS programme. Related ESA technology-development activities are therefore primarily intended to strengthen the Agency's position in any future international undertaking in this field. For Dial, the Agency's effort will largely depend on the further evolution of both the Atlid programme and its true scientific/application utility, which still needs to be further assessed.

Lidars for ESA's polar-orbiting missions

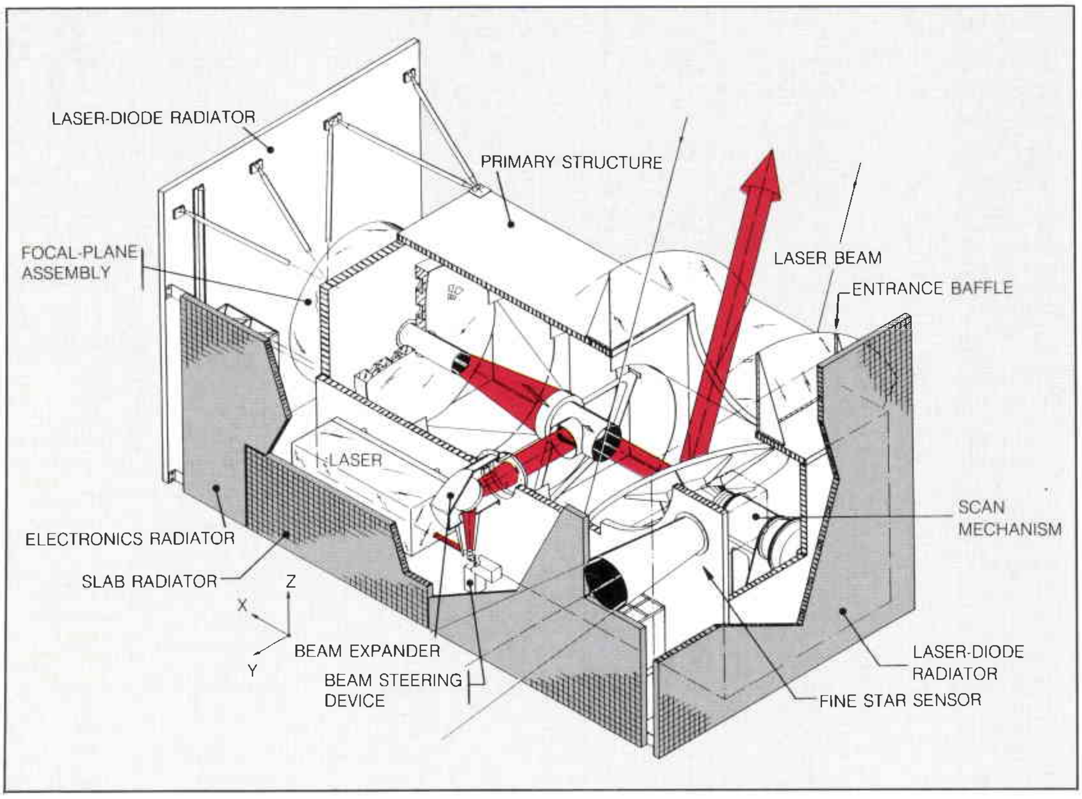
When the Agency started to prepare for the Polar-Platform Earth-observation missions, a number of Lidar instrument-definition studies were carried out, assisted by an external Lidar consultancy group. An initial, pre-Phase-A study led to the Atlid being conceived as a pre-operational core-instrument for the Polar Platform. It will be operated during a three-year mission to satisfy the needs of meteorologists and climatologists, by measuring the heights, strengths and depolarisation properties of scattering layers (clouds and aerosols) in the lower atmosphere.

The Atlid pre-Phase-A study investigated two possible modes of operation, one primarily for cloud and planetary boundary-layer studies, requiring a high-repetition-rate/low-energy (100 Hz, 100 mJ) laser, and a second mode for stratospheric and tropospheric aerosol studies, requiring a low-repetition-rate, but high-energy laser (20 Hz, 500 mJ). The former requirement could be fulfilled by a diode-pumped Nd-YAG laser and the latter by a flash-lamp-pumped Nd-YAG laser. The study indicated, however, that the overall power requirements of the high-energy mode were well above the allocated power budget of 400 W on the Polar Platform. It was therefore decided to drop the high-energy mode of operation, i.e. to exclude the flash-lamp-pumped Nd-YAG laser option.

Following the Atlid pre-Phase-A study, two parallel Phase-A studies were performed, by Matra and Battelle Europe. Both studies confirmed the basic feasibility of Atlid, but identified some critical technology areas which require further development before it can be employed on the Polar Platform. For this reason, it was decided not to include Atlid in the First Polar-Platform Mission, but to assign it a high priority on the second one.

Atlid will have to operate from an orbital height of 800 km, with a swath width of ± 700 km, in order to provide global data

Figure 7. Atlid instrument concept proposed by Matra



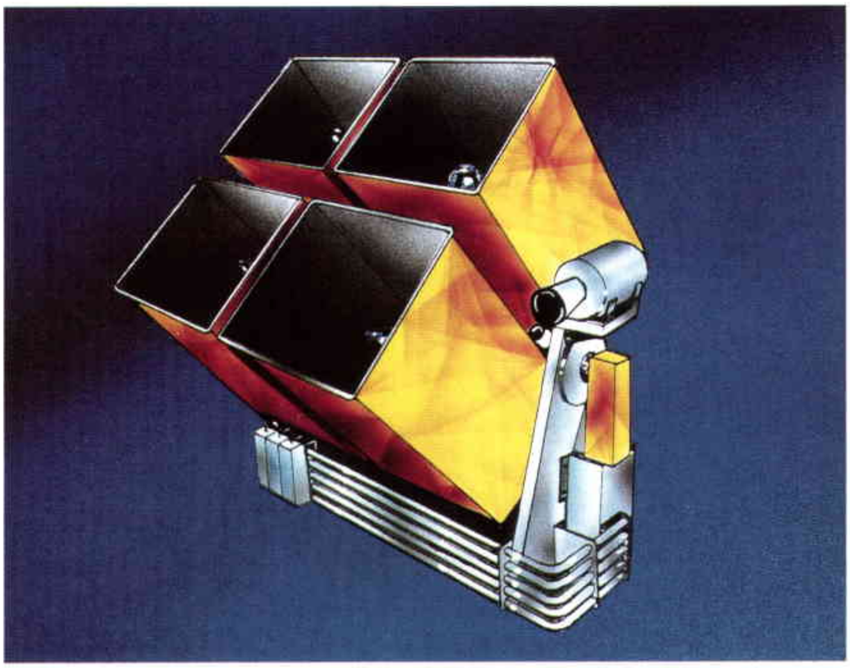


Figure 8. Atlid instrument concept proposed by Battelle

coverage. This requires scanning of the Lidar across the ground track over ± 40°. To achieve this wide scan, the Matra instrument concept foresees a 45°-tilted, elliptical mirror, rotating around the telescope's optical axis. The concept proposed by Battelle, on the other hand, uses a scanning receiver telescope assembly to achieve the desired scan. To reduce the size and moment of inertia of the scanning assembly, a set of four small rectangular-shaped telescopes is proposed instead of a single large telescope. The collected optical signal is then coupled by optical fibre to the detection package mounted on the stationary Atlid structure, thereby avoiding the need for critical alignment tolerances between telescopes and signal detectors.

During the course of this year, ESA will issue a Call for Tender for a comprehensive technology pre-development programme that should lead to the realisation of a complete demonstration model of the Atlid instrument. This pre-development effort is necessary both to provide confidence in the space applicability of the new technologies involved, and to arrive at a sound design for the future spaceborne instrument.

ESA plans to carry out this pre-development effort in two stages: a first R&D-oriented stage, addressing overall instrument design and the breadboarding of critical technologies, and a second engineering stage during which the various subsystems of the Atlid demonstration model will be developed, assembled and tested. The first stage is intended to last two years; it will deal with the critical areas identified in the two Atlid Phase-A studies and investigate them further with a view to refining the overall instrument design by validating new technology concepts for critical components. The second stage is planned to last until 1995, at which time Phase-C/D activities could start with a view to a possible flight of Atlid on a Polar-Orbit Mission in the year 2000.

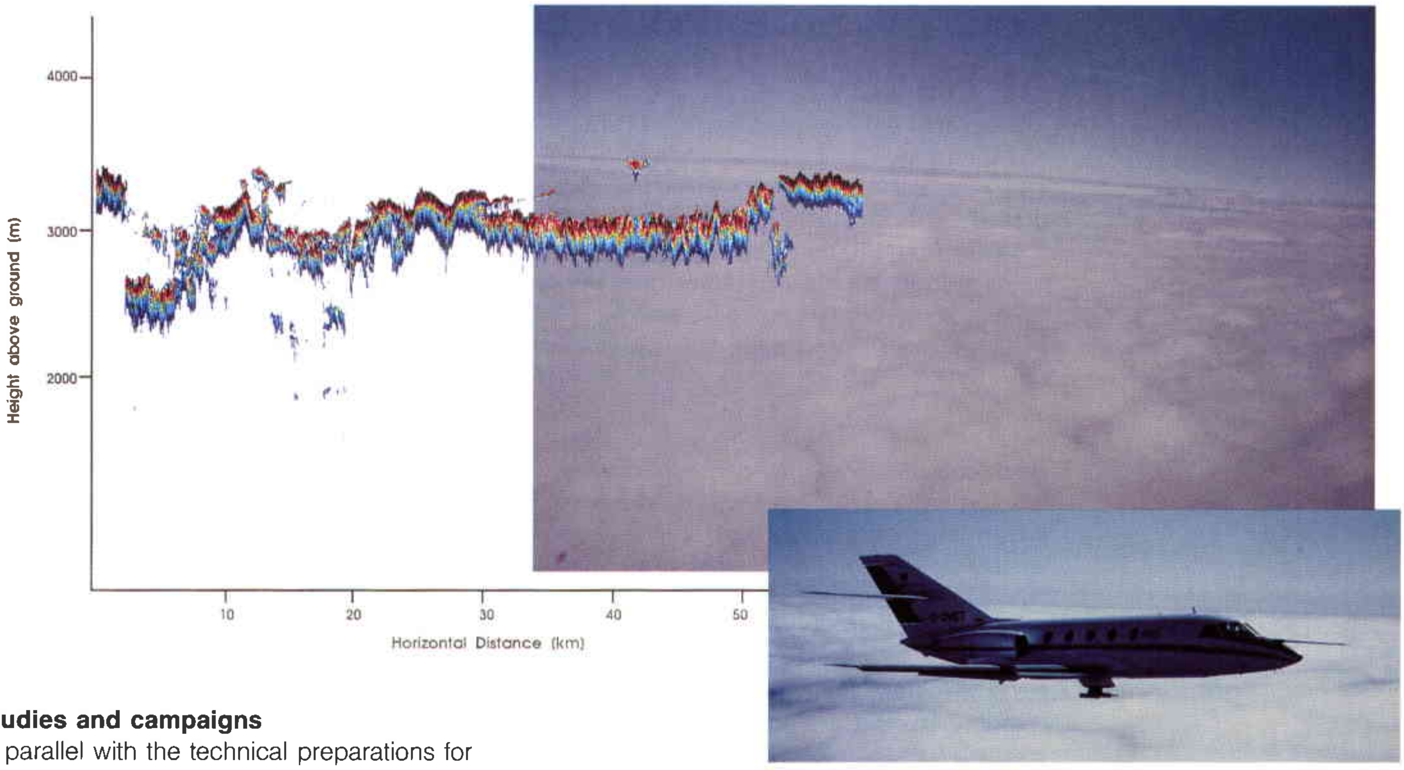


Figure 9. The European Lidar Airborne Campaign (ELAC'90). Backscatter Lidar profile of strato-cumulus measured over the sea (Photo. courtesy of DLR)

Studies and campaigns

In parallel with the technical preparations for Atlid, ESA is conducting a programme of user-oriented studies to examine the impact of Atlid data on meteorology, climatology and environmental research. There is a need to develop algorithms to transform spaceborne Backscatter Lidar data into meteorologically meaningful information. These studies are also playing a major role in the further Atlid instrument definition, as they will help to define optimal sampling strategies, processing levels and data formats.

A prime focus of these user-oriented studies is to determine the extent of the improvement that can be achieved in atmospheric-parameter retrievals from passive sensor observations using Backscatter Lidar data. One of the major drawbacks of passive vertical infrared and microwave sounders is their poor vertical resolution of atmospheric temperature and water-vapour profiles, and the resulting inability to resolve small-scale vertical features of meteorological interest.

Atlid would provide accurate global information on the height, strength and polarisation properties of scattering layers in the lower atmosphere, features that are poorly detected by passive infrared techniques. The studies are examining how active Lidar data can be introduced into the retrieval process for better use of the passive data, leading to quantifiable improvements due to the synergistic exploitation of Atlid in combination with passive soundings.

The studies of improvements in meteorology and climatology due to spaceborne Backscatter-Lidar measurements are also hampered by a lack of experimental evidence. To obtain representative samples of Lidar signals produced in real meteorological situations, an airborne campaign was carried out in October 1990 – The European Lidar Airborne Campaign 1990 (ELAC'90). Using two airborne Lidar systems, provided by the French National Space Centre (CNES) on a Fokker F27 and the German DLR on a Falcon aircraft, typical cloud and aerosol distributions were monitored over selected areas in Europe.

The airborne Lidar systems were combined with infrared radiometers and supplementary meteorological measurement equipment, allowing realistic modelling of the sampling problems of future Atlid data for climatologically relevant sets of atmospheric situations.

The data have been gathered and recorded and are now in the process of being evaluated. An important outcome of this campaign will be the availability of a realistic assessment of the achievable height accuracy for real cloud fields. The results of ELAC'90 will contribute to the design of an optimal scan geometry for Atlid, because this is closely related to the measured variability of clouds and aerosols. The same is true for the pulse-repetition frequency and the field of view. Moreover, the strength of Lidar signals measured during ELAC'90 will constitute an excellent basis for achieving accurate signal-to-noise-ratio simulations for Atlid.

Twenty Satellite Years of ECS Operations at Redu

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By February 1991, the ECS Control Centre at Redu had accumulated twenty years of in-orbit experience with the ECS satellites, which it operates on behalf of Eutelsat. The start of this effort began in June 1983 with the launch of ECS-1, and was greatly expanded with the launches of ECS-2 in 1984, ECS-4 in 1987 and ECS-5 in 1988 (ECS-3 was lost as a result of a launcher failure). The operational support required of Redu for the ECS missions has been demanding, with the need to maintain the satellites within a 0.1° stationkeeping box, continuing demands from Eutelsat to increase the number of transponders used for communications, and several in-orbit relocation operations.

Background

It is surprising how many people believe that, when a satellite has been successfully launched, there is nothing more to be done than to use it for meteological, telecommunication or scientific purposes. However, as those in the business of satellite operations are only too aware, there remains the responsibility and demanding workload of ensuring the day-to-day continuity of the mission. The satellite operations engineers, working quietly and anonomously in the depths of space technology, can very quickly find themselves propelled into the spotlight if European communications services or international maritime telephone calls are interrupted!

Satellite missions vary in their complexity with, of course, a corresponding impact on the ground-support facilities and operations staff needed. In general, the more ground intervention that is required, the higher is the risk of something going wrong, particularly where satellite dynamics are concerned. The ECS satellites, with their stringent stationkeeping requirements, are good examples of such a demanding mission. Their good availability record during the twenty satellite years accumulated to date reflects favourably on the efforts of the ECS project team, the industrial consortium who constructed the satellites, and the operations team who have nursed them throughout their years in orbit.

The ground-support facilities for the ECS mission, including the in-orbit test facilities, were described in some detail in ESA Bulletin No. 54. As explained there, the dedicated ECS Control Centre was installed at Redu, in Belgium, together with the telemetry, tracking, command and in-orbit test facilities. Apart from the so-called 'Launch and Early-Operations Phase', or LEOP, for each satellite, which has been supported from the Operations Control Centre (OCC) at ESOC in Darmstadt (D), and periodic ranging support from ESA's Villafranca Station near Madrid (E), Redu works autonomously in supporting the four ECS missions on behalf of Eutelsat, including routine orbit determination and prediction and manoeuvre planning. Eutelsat itself is responsible for the leasing of the communications payloads and the subsequent traffic management. With Eutelsat's cooperative participation, the day-to-day operational interface with Redu has run very smoothly.

Table 1. Accumulated ECS operational lifetime

Satellite	Launch	Years in orbit (to end Feb. 91)
ECS-1	June 1983	7.70
ECS-2	August 1984	6.57
ECS-4	September 1987	3.45
ECS-5	July 1988	2.61
	Total years	20.33

Facilities and staffing

The Redu Control Centre

The first computer system installed at Redu was designed to support three satellites in orbit. It was based on two Siemens computers similar to those still in use at the Meteosat Control Centre at ESOC. When the decision was taken in 1986 to control four satellites in orbit, the system was replaced by a Multi-Satellite Support System configuration based on Gould computers of the type used at ESOC for LEOP operations and the routine Marecs and OTS operations. Thus it was goodbye to black and white screens, multiplexers, strip-chart recorders, cabled links and removable disks – in their place came colour screens, work stations, laser writers, virtual circuits and dual-port-access fixed disks! The system gained in both flexibility and redundancy.

A team of Operations Controllers works a two-position 24 h shift to monitor and control the four satellites and their dedicated ground facilities (antenna configuration and Control Centre computers). The operations themselves are planned and supervised by a small team of spacecraft engineers.

Telemetry, tracking and command

The ECS mission continues to use the VHF band (now obsolete) for telecommanding but it has the advantage of being able to transmit to all four spacecraft, regardless of spacecraft attitude, with one fixed antenna.

The TC1 antenna (Fig. 1) is dedicated to ECS, and TC2, which is part of the general shared network facilities, acts as a backup facility. The command antenna that used to be dedicated to Geos at Redu was moved to the Agency's Odenwald station to provide site redundancy.

The ECS telemetry also uses the VHF band during the LEOP and special operations such as orbit manoeuvres, but SHF is normally used during the on-station phase. The number of SHF antennas has therefore grown with the number of ECS satellites in orbit, i.e. one 4.5 m telemetry antenna per satellite plus one ranging antenna (which can also act as a telemetry backup).

In-orbit testing

Test and monitoring earth-station facilities have been constructed at Redu to make in-orbit performance measurements for both the ECS and Olympus satellites. There are four fixed earth stations dedicated to ECS and Olympus:

- TMS-1: a 13.5 m antenna system covering the 14–11 GHz band, used for the ECS baseline payload
- TMS-4: a 9 m antenna system covering the 14–12 GHz band, used for the ECS and Olympus specialised services payloads
- TMS-5: a 9 m antenna system covering the 18–12 GHz band, used for the Olympus TV broadcast payload

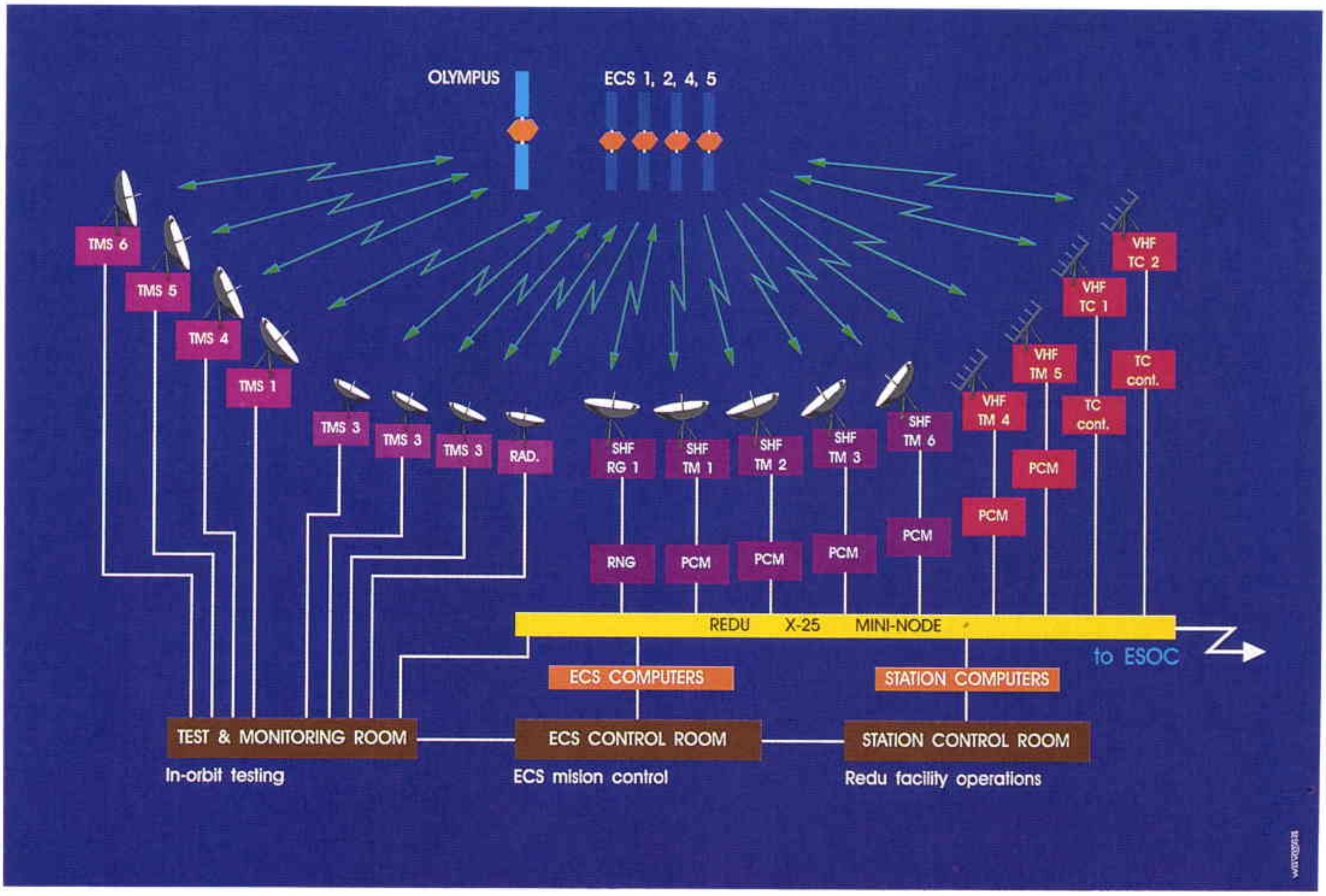


Figure 1. Redu site facilities

- TMS-6: a 4 m antenna system covering the 30–20 GHz band, used for the Olympus communications payload.

Three TMS-3 air-transportable stations dedicated to the measurement of coverage-dependant parameters are used to establish the performances of payloads operating in the 14–12/11 GHz bands at the edge of the beam contours.

All of the above stations took part in the ECS and Olympus in-orbit testing (and also that of the second-generation Eutelsat-II F1 and F2 satellites).

The Redu in-orbit test facilities are under the responsibility of an ESA engineer, assisted by two contract engineers and the maintenance personnel. During the acceptance testing of a satellite, however, comprehensive support is provided by staff from ESA's Telecommunications Directorate at ESTEC (NL). Representatives from Eutelsat and the satellite prime contractor (BAe) are also present at the station during such testing.

Spacecraft operations

Operating a satellite in orbit is a 24 h per day task. Although many of the activities are of a routine nature, they are all essential to its continued well-being. Following the demanding launch and early-orbit phase, which is supported by a full mission control team, the burden falls on the small team of engineers and technicians who must attend to: battery reconditioning, battery recharging after eclipses, thermal control, inhibition of the spacecraft's Earth sensors against Sun and Moon blinding, payload reconfiguration, periodic exercising of certain onboard units, etc., as well as the more demanding operations described below.

Table 2. ECS stationkeeping manoeuvres — status January 1991

	ECS-1	ECS-2	ECS-4	ECS-5
Number of East manoeuvres	207	153	81	53
Number of West manoeuvres	11	9	8	4
Number of North manoeuvres	54	51	17	18
Number of South manoeuvres	51	24	12	
Total number of manoeuvres	323	237	118	75
Total speed increment (m/s)	323	319	190	132
Hydrazine mass at launch (kg)	107	117	116	122
Current hydrazine mass	6.1	3.5	51.3	77.2

Launch and early-orbit phase

The LEOP activities for each ECS satellite – during which it was repointed in transfer orbit prior to firing the apogee motor, and then despun, its solar arrays deployed, the Earth acquired, and the drift towards final orbital location initiated – all took place from the Main Operations Control Centre at ESOC, supported by VHF stations at Malindi, Carnarvon, Ibaraki, Kourou and Redu. These activities generally proceeded very smoothly, helped by the experience acquired with earlier missions of a similar type (OTS, Marecs-A and B, and each subsequent ECS), the high level of training of the operations team, and good preparation of the necessary operational documents. The platform commissioning tests were also conducted from ESOC.

Thereafter, however, operations were transferred to Redu for the all-important acceptance and commissioning tests on the various payloads.

Stationkeeping

All of the spacecraft in the ECS series have a design lifetime of seven years. Within this, 5.9 years of north-south stationkeeping was foreseen for ECS-1, and 4.9 years on the subsequent satellites. This reduced stationkeeping lifetime is due to the heavier payloads and full eclipse capability of the later spacecraft, which have two additional channels and larger batteries.

The last inclination manoeuvres for ECS-1 and on ECS-2 were performed in August 1989 and October 1990, respectively, and since then the remaining hydrazine has been used solely for attitude and longitudal control.

Table 2 provides an indication of the multitude of stationkeeping operations that keep the Redu control team busy!

Orbital positions

The youngest take the place of the oldest – a fact of life that applies equally well to satellites as to humans! This replacement scenario began with the launch of ECS-5, which was placed at the position previously occupied by ECS-4, which in turn replaced ECS-1 – a chain of events known in technical jargon as 'spacecraft re-location and co-location'. It continues with the upcoming satellites of the Eutelsat-II generation. Extensive use is made of the 'Portable ESOC Package for Synchronous Orbit Control' (PEPSOC) in planning the multiple start, stop or avoidance burns involved in executing this satellite 'ballet' in geostationary orbit, in cooperation with ESOC's Flight Dynamics Division.

Figure 2 shows the various relocations that took place between 1988 and 1991.

Number of transponders in use

The communications payload of ECS-1 has 12 channels, nine of which are designed to be operated simultaneously when the satellite is in sunlight, and five during eclipse. These constraints were subsequently relaxed to increase the channels available in eclipse to six and finally to seven. Subsequent ECS satellites have a total of 14 channels, with the addition of two specialised-service channels, nine of which are designed to be operated during both the sunlit and eclipse phases. This was uprated later to a total of 10 channels operating simultaneously in both sunlight and eclipse, and more recently as many as 11 channels have been used simultaneously in certain cases.

Originally, the ECS system was designed to provide intra-European communications and Eurovision television. It has rapidly become a system not only for telephony traffic, but is even more in demand from television, radio and business companies (Fig. 3).

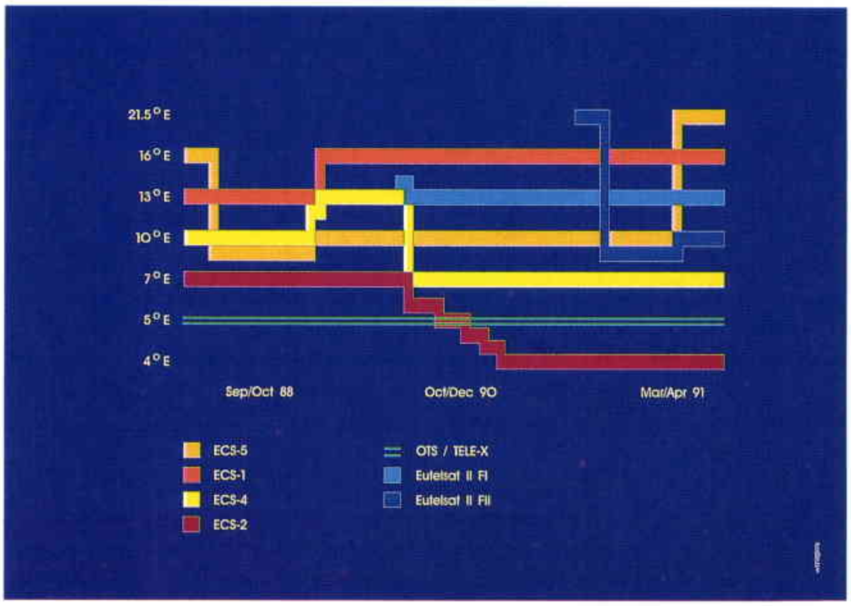
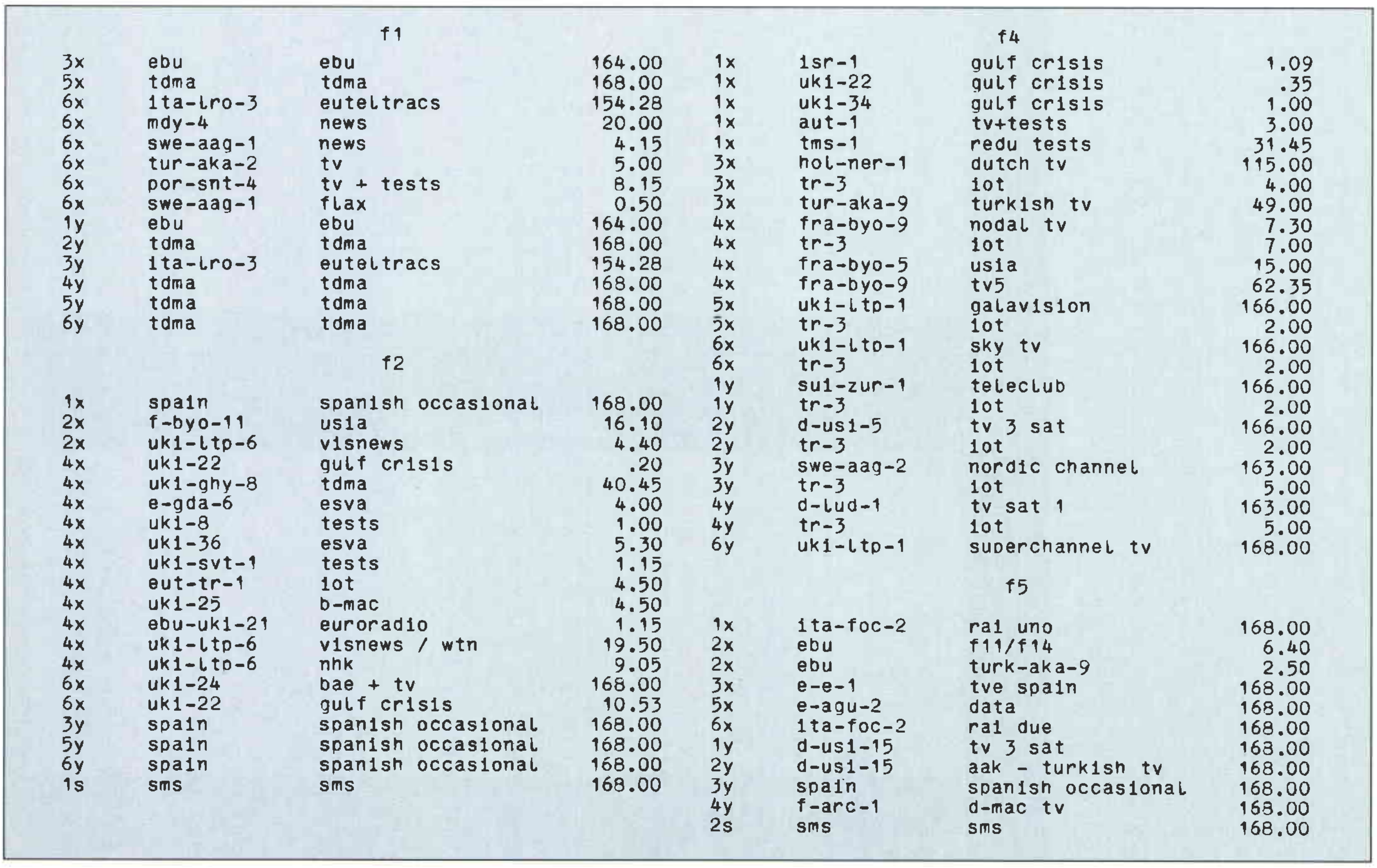


Figure 2. Chart showing the various locations of the ECS satellites between 1988 and 1991

Outages

It is rather difficult when writing about operations not to mention those contingencies that could disturb an otherwise peaceful existence! Over the past years, the Redu contol team has enjoyed the dubious pleasures of the effects of electrostatic discharges, of unexpected automatic reconfigurations occurring, of course, at night and during the weekends, of bubbles in the hydrazine, of thruster clogging, of spurious channel switch-offs, of an emergency Sun-

Figure 3. A weekly status report on ECS utilisation (included by kind permission of Eutelsat)



```
                              f1
3x     ebu          ebu                     164.00
5x     tdma         tdma                    168.00
6x     ita-lro-3    euteltracs              154.28
6x     mdy-4        news                     20.00
6x     swe-aag-1    news                      4.15
6x     tur-aka-2    tv                        5.00
6x     por-snt-4    tv + tests                8.15
6x     swe-aag-1    flax                      0.50
1y     ebu          ebu                     164.00
2y     tdma         tdma                    168.00
3y     ita-lro-3    euteltracs              154.28
4y     tdma         tdma                    168.00
5y     tdma         tdma                    168.00
6y     tdma         tdma                    168.00

                              f2

1x     spain        spanish occasional      168.00
2x     f-byo-11     usia                     16.10
2x     uki-ltp-6    visnews                   4.40
4x     uki-22       gulf crisis                .20
4x     uki-ghy-8    tdma                     40.45
4x     e-gda-6      esva                      4.00
4x     uki-8        tests                     1.00
4x     uki-36       esva                      5.30
4x     uki-svt-1    tests                     1.15
4x     eut-tr-1     iot                       4.50
4x     uki-25       b-mac                     4.50
4x     ebu-uki-21   euroradio                 1.15
4x     uki-ltp-6    visnews / wtn            19.50
4x     uki-ltp-6    nhk                       9.05
6x     uki-24       bae + tv                168.00
6x     uki-22       gulf crisis              10.53
3y     spain        spanish occasional      168.00
5y     spain        spanish occasional      168.00
6y     spain        spanish occasional      168.00
1s     sms          sms                     168.00

                              f4
1x     isr-1        gulf crisis               1.09
1x     uki-22       gulf crisis                .35
1x     uki-34       gulf crisis               1.00
1x     aut-1        tv+tests                  3.00
1x     tms-1        redu tests               31.45
3x     hol-ner-1    dutch tv                115.00
3x     tr-3         iot                       4.00
3x     tur-aka-9    turkish tv               49.00
4x     fra-byo-9    nodal tv                  7.30
4x     tr-3         iot                       7.00
4x     fra-byo-5    usia                     15.00
4x     fra-byo-9    tv5                      62.35
5x     uki-ltp-1    galavision              166.00
5x     tr-3         iot                       2.00
6x     uki-lto-1    sky tv                  166.00
6x     tr-3         iot                       2.00
1y     sui-zur-1    teleclub                166.00
1y     tr-3         iot                       2.00
2y     d-usi-5      tv 3 sat                166.00
2y     tr-3         iot                       2.00
3y     swe-aag-2    nordic channel          163.00
3y     tr-3         iot                       5.00
4y     d-lud-1      tv sat 1                163.00
4y     tr-3         iot                       5.00
6y     uki-ltp-1    superchannel tv         168.00

                              f5

1x     ita-foc-2    rai uno                 168.00
2x     ebu          f11/f14                   6.40
2x     ebu          turk-aka-9                2.50
3x     e-e-1        tve spain               168.00
5x     e-agu-2      data                    168.00
6x     ita-foc-2    rai due                 168.00
1y     d-usi-15     tv 3 sat                168.00
2y     d-usi-15     aak - turkish tv        168.00
3y     spain        spanish occasional      168.00
4y     f-arc-1      d-mac tv                168.00
2s     sms          sms                     168.00
```

reacquisition on ECS-1 in 1985, of a complete payload switch-off and so on, not to mention the more mundane troubles that can affect the ground segment itself, such as transmitter failures, disk crashes, power failures due to lightning, etc.

Table 3. Total transponder operating hours

	ECS-1	ECS-2	ECS-4	ECS-5
Total no. of hours of operating tubes	558 559	496 006	256 509	188 458
Number of spurious switch-off events	47	161	11	23

Despite all such events, however, the ECS mission has been providing, and will continue to provide, an extremely high degree of reliability, to the obvious satisfaction of the users! Table 3 summarises the transponder operating history and the spurious switch-off events (typically lasting some 3 to 6 min) that have occurred over the years.

In-orbit testing

The in-orbit testing of the ECS satellites is a long process which begins with the release of the satellite payload specification and ceases at end of the satellite's lifetime.

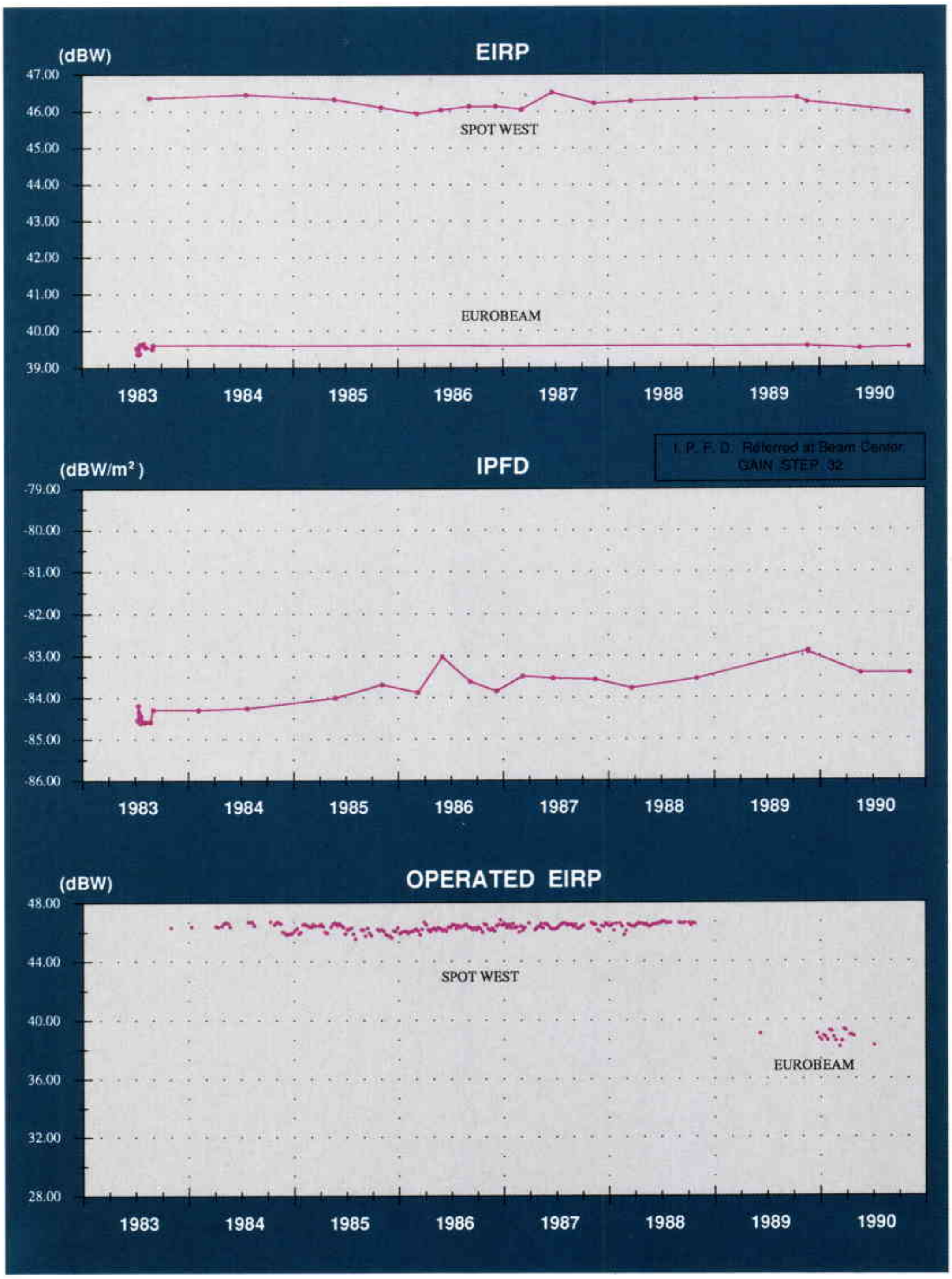


Figure 4. ECS-1 channel performance over a seven-year period (Channel 1Y)

Five phases can be clearly identified:
- definition of test methods and procurement of facilities
- commissioning and acceptance testing
- routine monitoring
- periodic testing
- anomaly investigation.

Definition of test methods and procurement of facilities

The main objective of the in-orbit testing of a telecommunications satellite is to verify that the payload specifications are met in orbit. It is therefore necessary to establish test methods compatible with such a requirement. For each payload specification, a test method is derived and the appropriate earth-station equipment identified. Once the overall test methods have been defined, the procurement of the in-orbit test facilities is initiated. This task is the responsibility of ESA's Telecommunications Directorate, with the collaboration of ESOC for the earth-station infrastructure interfaces.

Commissioning and acceptance testing

The in-orbit testing of the ECS communications satellites has been performed according to procedures and a test plan established and agreed with Eutelsat and the ECS Prime Contractor (BAe). The in-orbit testing activities at Redu start as soon as the launch is declared a success, with intensive rehearsals being conducted whilst the satellite is drifting to its final orbital position. These rehearsals allow the Redu staff and facilities to achieve a high degree of operational readiness for the commencement of the in-orbit tests proper.

The in-orbit testing of ECS-1 lasted three months, that of ECS-2 tooks five weeks, and that of ECS-4 and 5 three weeks each. Olympus has so far been the most demanding in terms of time and resources, with 2.5 months being required to complete the in-orbit-test activities.

Routine monitoring and periodic testing

Once the satellite has been put into service, daily routine monitoring of the active repeaters is performed from Redu. The periodic testing consists of the rechecking during the satellite's lifetime of the evolution of key parameters on active repeaters and redundant units in order to establish a trend analysis for repeater performance (Fig. 4).

Anomaly investigations

Should anomalous behaviour occur in an operational repeater, key parameters are checked without delay to arrive at a first analysis of the failure. A testing strategy is then established by the ECS Project, industry and IOT experts for conducting an in-depth investigation using the Redu facilities.

This testing is necessary to help the payload engineers to understand and analyse the mechanism of the failure.

Earth-station verification and acceptance

The Redu in-orbit testing facilities are also used occasionally for Eutelsat ESVA tests to ensure that new stations entering the Eutelsat system comply with the specifications. So far, fourteen earth stations have been checked by Redu on behalf of Eutelsat.

Conclusion

With twenty satellite years of operations with ECS now achieved, Redu is probably at about two thirds of the probable eventual total of thirty. The future projects that will be controlled from Redu will not permit an accumulation of this magnitude, but the advanced technology to be employed on such missions as Artemis, the next ESA project to call upon Redu's expertise, will nonetheless place new and challenging demands on the operations support team. Redu looks forward to its involvement in the satellite control, telemetry, tracking and commanding operations, and in-orbit testing and mission operations first for Artemis, and later for the DRS mission. Both missions will allow the Redu team to build further on its already long experience, and permit it to continue to live up to its local name of 'Centre Spatial de Redu'.

Powering the ESA Network

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The quality and availability of power supply required by the Agency's ground-station-network facilities cannot be provided by public networks. Power plants have therefore been developed specifically for that purpose by the Station and Communication Engineering Department at ESOC in Darmstadt, and these have been implemented at a number of ESA sites.

Introduction

The ground stations that provide the interface between the satellites in orbit and the ground house the equipment needed to perform the critical tracking, telemetry, telecommand, data processing and ground communication tasks. This equipment and the ancillary facilities must therefore be served by a highly reliable electrical power supply, since any perturbation in that supply can present a serious hazard for spacecraft operations.

The ESA ground stations are often located at isolated sites, chosen both to maximise station coverage and minimise local radio-frequency interference. Given these two constraints, the power available locally to the stations via the public network is often of poor quality and unsuitable for meeting satellite operational requirements. It has therefore become customary ground-station practice to reinforce the local public network with emergency backup power systems.

The high reliability required for ESA's S/X-band communications network, and the substantial increase in power demand compared to past implementations, have promoted a 'global' approach to ESA ground-station-network power facilities. The standard power plant configuration developed by ESOC has therefore already been installed at the Agency's Redu (Belgium), Salmijaervi (Sweden) and Maspalomas (Spain) stations.

User characteristics and requirements

ESA's satellite ground stations generally include the following facilities:

- Main Equipment Room (MER), including telemetry, telecommand, data-processing and ground-communications equipment
- Antenna Equipment Room (AER), including tracking, downlink/uplink conversion equipment, and high-power amplifiers
- antenna servo-system, including the antenna driving equipment (thyristor AC/DC converters, DC motors)
- the MER and AER air-conditioning systems, including blowers and compressors to maintain appropriate temperature and humidity conditions inside the electronic equipment
- ancillary facilities (lighting, sockets, etc.)

The electrical requirements of each of these facilities must be considered differently, depending on their level of involvement in the operational tasks.

Power-supply continuity

The electronic equipment performing the data processing and the link with the satellite need to be protected against electrical-supply disturbances or interruptions, which might seriously affect operations (i.e. hardware or software failures).

The servo-system equipment ensuring the antenna's motion during normal satellite tracking can tolerate short interruptions (max. 30 s) without jeopardising the mission. For critical operations, however, guaranteed continuity of supply may be required.

The power supply of the air-conditioning equipment can tolerate short interruptions (10 to 20 min), during which system inertia alone will maintain a reasonable temperature and humidity inside the electronic equipment.

Power-supply cleanliness

Some ground-station facilities can generate perturbations that have an adverse effect on the station's power supply, as shown in Figures 1 and 2.

Heavy mechanical structures like the 15 m S/X-band antennas moving at high speed can also result in perturbations in the electrical distribution. During fast movements, the power peak can reach 180 kVA in less than 1 s (Fig. 3).

Air-conditioning system compressors driven by electrical motors based on an on/off cycling procedure can also cause transient perturbations in the electrical distribution.

Power-supply tolerance

The role of the power plant is to maintain the electrical-supply parameters of voltage, frequency and harmonic content within pre-set limits compatible with both the operational requirements and station-equipment manufacturer's specifications. Typical limits for 'general' and 'sensitive' users are shown in Table 1.

Table 1

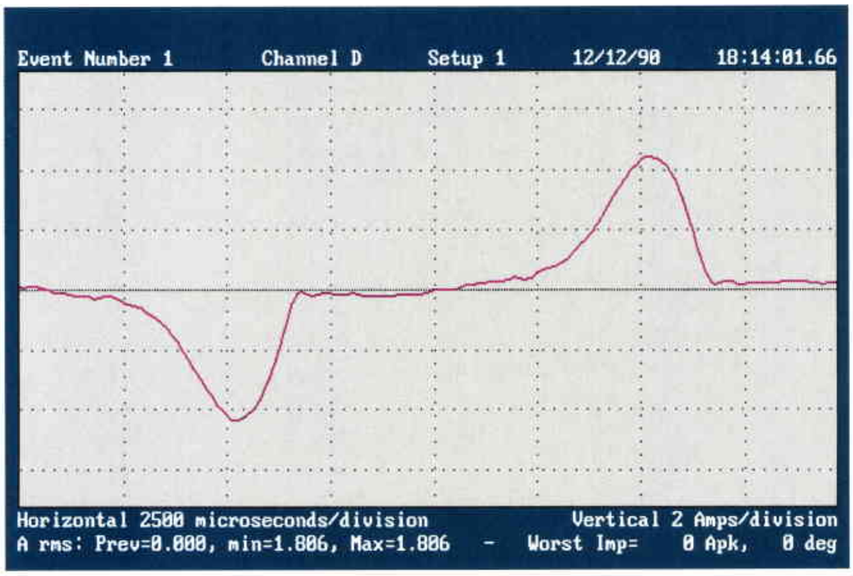
Sensitive users	
Voltage:	±5%
Frequency:	±2%
Harmonic content:	less than 3%
Interruption max.:	0 s
General users	
Voltage:	±10%
Frequency:	±4%
Harmonic contents:	less than 5%
Interruption max.:	30 s

Supply configuration

To avoid any interaction between the so-called 'sensitive' and 'general' users, it is necessary to foresee a separate supply for each. To optimise the power-system configuration and minimise cost, it has been decided to combine supply continuity and cleanliness. The continuous/clean supply provides power to the sensitive users (electronic/safety equipment), and the interruptible/dirty supply serves the general users (thyristor loads, motors, heaters, ancillary facilities).

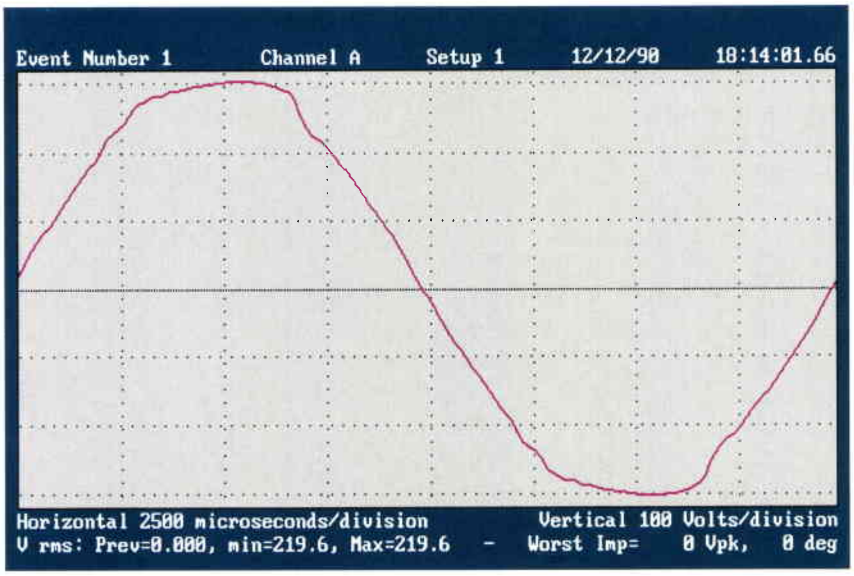
Figure 4 shows the standard ESA ground-station power-plant configuration with:

- two medium-voltage feeders
- two transformers
- two diesel generator sets
- two AC/DC–DC/AC converter sets.



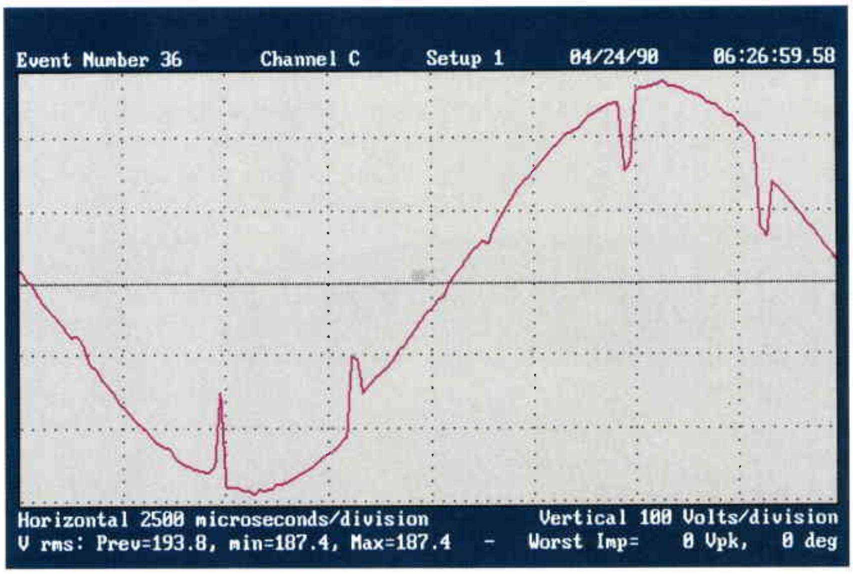
```
Event Number 1        Channel D      Setup 1       12/12/90       18:14:01.66
Horizontal 2500 microseconds/division                Vertical 2 Amps/division
A rms: Prev=0.000, min=1.006, Max=1.006    -    Worst Imp=     0 Apk,     0 deg
```

Figure 1. Main Equipment Room nonlinear load



```
Event Number 1        Channel A      Setup 1       12/12/90       18:14:01.66
Horizontal 2500 microseconds/division              Vertical 100 Volts/division
V rms: Prev=0.000, min=219.6, Max=219.6    -    Worst Imp=     0 Vpk,     0 deg
```

Figure 2. Main Equipment Room voltage distortion



```
Event Number 36       Channel C      Setup 1       04/24/90       06:26:59.58
Horizontal 2500 microseconds/division              Vertical 100 Volts/division
V rms: Prev=193.8, min=187.4, Max=187.4    -    Worst Imp=     0 Vpk,     0 deg
```

Figure 3. Typical perturbations caused by a 15 m-diameter antenna's servo-system

The medium-voltage feeders connect the station to the 10–20 kV public network. The medium/low-voltage transformers convert the 10–20 kV supply to a 380/220 V supply. The diesel generator sets, which are the so-called 'short-break systems', are standard diesel engines driving AC alternators, providing 380/220 V of backup power to the station. The AC/DC–DC/AC converter sets with battery backup, known as 'no-break systems', provide the 380/220 V clean and continuous supply to the sensitive users. The redundant battery sets are designed for 4 min of autonomy under full load.

To minimise interference, stations have been provided in the past with dynamic no-break systems. However, the low levels of interference recorded during recent radio-frequency measurements on transistorised no-break systems qualify them for future implementation in this role.

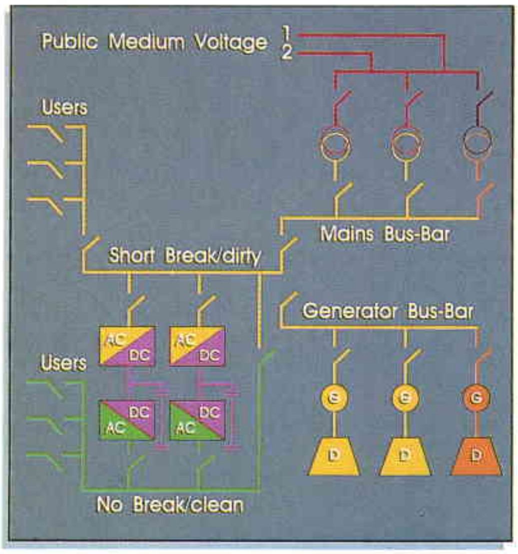


Figure 4. Power-plant configuration

Figure 5. Redu ground-station power-plant building

The power equipment is housed in a dedicated, sound-damped building with a concrete anti-vibration base. Electrical power is distributed to the users (antennas, operations building, etc.) via cables routed in conduits across the site. In order to accommodate future developments and extensions as a result of the various projects assigned to the ground stations, the power-system configuration and related infrastructure are both modular in concept. The power is provided to the users on two different buses:
- the first, called the 'short-break/dirty bus' supplies the general users
- the second, called the 'no-break/clean bus' supplying the sensitive users.

During normal operations, the public grid supplies the short-break bus-bar and the no-break systems, which supply continuous, clean power to the no-break bus-bar. In the event of a failure in the public grid:
- the redundant diesel generator sets start automatically and take over from the public supply with a delay of not more than 30 s
- the redundant DC/AC no-break converters continue to supply the no-break users without interruption.

During the 30 s bridging time, the DC/AC converters are supplied by the batteries.

In the event of system overloading due to engine failure or accidental extra loading, priority is given to the no-break users. The short-break users will be disconnected using a management system that groups loads into four different levels of priority according to operational requirements:

- Priority 1: antenna servo-system and air-conditioning blowers
- Priority 2: air-conditioning compressors
- Priority 3: light, MER (short-break)
- Priority 4: ancillary facilities.

During critical satellite operations, continuity of the short-break supply can also be required. In this case, there is the possibility to supply the station with the redundant diesel generators using the public grid as a backup. The changeover from the diesel supply to the public grid can be made in less than 1 s.

Electronic remote monitoring

Due to the complexity of the power plants, it is necessary to assist the operators with their operation and maintenance tasks by providing an electronic remote monitoring system. This system, based on 'mimic displays', shows power-plant status, operating ranges, maintenance status and alarms, together with first-level failure diagnosis.

Power-plant working conditions are also monitored automatically, including the logging of system events (alarm, status) and the recording of electrical parameters (voltage, frequency, current, power).

System reliability and maintainability

The basic power-plant configuration is designed with adequate redundancy to ensure the necessary availability of supply.

The general idea is ultimately to use identical electrical equipment throughout the ESA ground-station network, thereby keeping the spare parts that have to be stocked to a minimum and allowing exchanges of experience between sites. Global maintenance support is planned, with a standardised maintenance and system-performance evaluation approach. Remote electronic diagnosis of power-plant problems from the manufacturer's premises can then be employed to reduce repair time and further assist station staff in their day-to-day tasks.

Current implementation

At this stage, three stations have been fitted with the standard power-plant configuration:

- the Redu power plant, implemented in 1986, replacing the previous defective emergency power system
- the Salmijaervi power plant, implemented in 1989, combined with the new ground-station implementation
- the Maspalomas power plant, also implemented in 1989, replacing the old NASA power system installed for the Apollo Project.

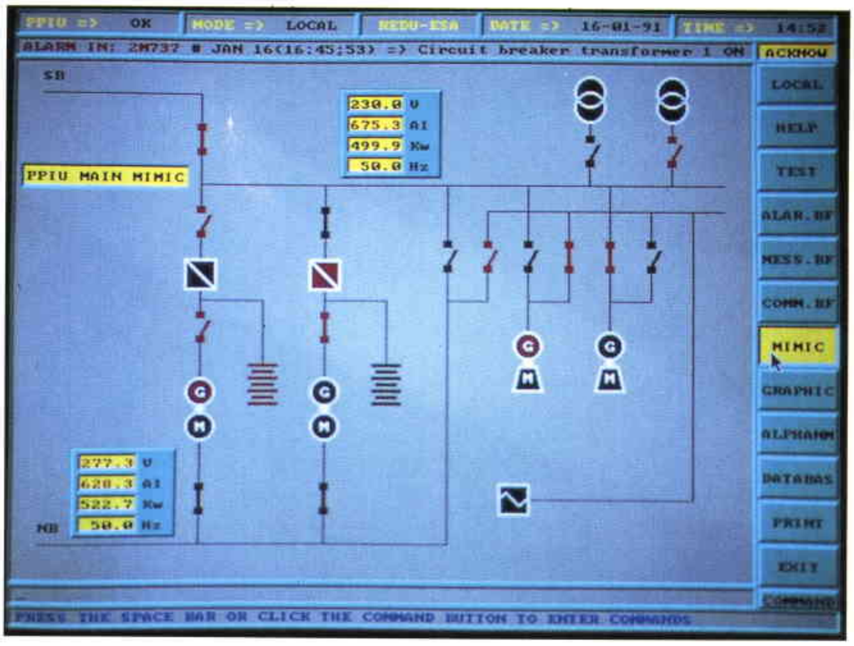
A reduced configuration has also been implemented, again in 1990, at the Kourou station, replacing the old CNES power system.

Conclusion

Contrary to the common view, support facilities like the electrical power supply or electronic equipment cooling are vital for spacecraft operations and need to be considered very carefully considered.

The standard ESA ground-station power-plant configuration that has been outlined here has been achieved by taking a global approach to ESA's network power-supply facilities. It is based on a modular concept capable both of meeting current operational requirements and of being adaptable to the various constraints encountered in satellite ground-station implementation.

Four years after the first system implementation, and with three such systems now in operation around the World, a high degree of success can be claimed for this endeavour in pursuit of power-system reliability and standardisation.



PPIU => OK | MODE => LOCAL | REDU-ESA | DATE => 16-01-91 | TIME => 14:52

ALARM IN: 2M737 # JAN 16(16:45:53) => Circuit breaker transformer 1 ON

230.0 V
675.3 AI
499.9 Kw
50.0 Hz

277.3 V
628.3 AI
522.7 Kw
50.0 Hz

PRESS THE SPACE BAR OR CLICK THE COMMAND BUTTON TO ENTER COMMANDS

Figure 6. Power-plant remote-monitoring 'mimic displays'

Figure 7. Power-plant control panel


RTurino 89

The Eurostep Distance-Learning Experiment with Olympus – Laying the Foundations for Success*

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The achievements of Eurostep up to the end of its first year of operations have pleased both its members and its sponsors. The challenge now is to develop it into a self-supporting organisation that can continue to contribute to the development of satellite distance-learning and satisfy the needs of its members.

1989 – A year of preparation

After the launch of Olympus on 12 July 1989, the major objective of the Programme became to demonstrate a range of new applications for satellite communications. For the Eurostep distance-learning experiment itself, there were a number of important milestones in 1989. In April in Vienna, during the Olympus Utilisation Conference, came the unanimous decision of the participants in the experiment to set up a cooperative association. The following month, the name Eurostep was chosen for this body, which was subsequently given legal status under Dutch law.

In July, Olympus was launched by Ariane flight V32. In September, Eurostep made formal proposals to ESA to manage the experiment, and guide the efforts of some 80 founder members. In November, Eurostep hired an experienced Canadian to set up and run the London operations. In the December, ESA took the formal step of signing the Agreement to give Eurostep right of access to up to nine hours of transmission time on the Olympus European DBS channel (ESA Bulletin 60 gave details of this Agreement).

During 1989, the British Broadcasting Corporation (BBC) had agreed to support Eurostep by providing tape play-out services with the same facility that was to be used for its own 'Enterprise Channel'. Eurostep would transmit between 0900 and 1700 h CET (Central European Time), and BBC Enterprises itself from 1700 to 0100 h CET daily. The BBC also organised a terrestrial feeder link to the uplink earth station loaned by ESA to the British National Space Centre (BNSC), who provided the direct funding for the manning of the facility by BBC staff. There was another link provided by 'London University Livenet', which allowed live transmissions to be made from a number of university colleges and teaching hospitals.

Thus, 1989 was a year of busy preparations during which the imminent and long-awaited launch of Olympus drove all before it.

1990 – A year of achievement

Much as 1989 was the final year of preparation, so 1990 was the first year of achievement of the results of all of this preparation. The very first transmissions from Eurostep and BBC Enterprises went out on 8 January. During this first year of operations, there were initially six hours of daily transmissions by Eurostep, and this was increased to seven hours daily after the summer-holiday period. The total Eurostep transmission time up to the end of 1990 was 1743 hours. Of these, 1065 hours were first transmissions of programmes, and there were 678 hours of repeat transmissions.

Although there were 89 founder members at the start of the venture, only about 46 transmitted programmes during 1990. A list of these pioneers is given in Table 1. By the end of 1990, there were about 120 members of Eurostep.

The use of Olympus by Eurostep has not all been limited to videotaped television programmes. In 1990, three projects contributed 76 h of live programming, with audience interaction via the telephone. These projects were the UK Training Agency Starnet programmes, a series of English-language learning programmes from Kings College London, and Captive, also from London. The proportion of live transmissions is expected to increase in the future.

Aside from television, other projects have

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* The origins of this story were described in ESA Bulletins Nos. 56 and 60, which covered the five years from 1984 to 1989, when the Agreement between ESA and Eurostep on the use of Olympus was drawn up. A brief report on the 1989 Eurostep Conference appeared in Bulletin No. 63, and an article on the overall Olympus Utilisation Programme in Bulletin No. 64.

been making use of the Olympus satellite for the broadcasting of data associated with the programmes, in particular text courseware. The Oxford University language-learning series was a pioneer in this respect. Eurostep also provides a teletext programme guide and news bulletin.

All in all, Eurostep has succeeded in providing an experimental framework in which a variety of tests and demonstrations of distance-learning services can be made, with 80 different programme series going out in 1990. This volume of programming has attracted the attention of channel operators, and it is hoped that programmes from Eurostep will soon be carried on other channels besides the Olympus Italian channel, which already features four to five hours of educational and training programmes daily. This shows that at least one public-service broadcaster (RAI) judges the Eurostep programmes to be of sufficiently high quality to be shown on its channel. It is hoped that further collaboration between Eurostep and leading broadcasters will develop.

Table 1. Transmissions in 1990

Institution	City	Hrs/yr	Programmes
Training Commission	Sheffield	83	Adult Education
Open University	Milton Keynes	60	Tertiary Education
Educational TV Assoc.	York	84	Group
SCET	Glasgow	76	Mixed
University College	Dublin	60	Group
Fern Universiteit	Hagen	106	Adult Education
Univ. of Glasgow	Glasgow	15	Language Learning
Brighton Polytechnic	Brighton	9	Language Learning
TVE1 Centre	Clwyd	47	Schools Productions
Univ. of East Anglia	Norwich	57	Tertiary/Adult Educ.
Univ. of London	London	41	Group
Rights and Humanity	London	28	Sociology
Kings College	London	11	Language Learning
Captive	London	6	Technology
Gwynedd County Council	Gwynedd	97	Mixed
Oxford University	Oxford	114	Language Learning
Coventry Lanch. Poly.	Coventry	10	Mixed
Greensat	London	18	Ecology
Post-Grad. Medic. School	Exeter	26	Medicine
European Parliament	Luxembourg	48	Adult Education
Univ. Thessaloniki	Thessaloniki	106	Mixed
IASPA	Brussels	50	The Arts
Aston University	Birmingham	58	Adult Education
Elec. Univ. Norway	Stavanger	3	Adult Education
TV-Inter	Stockholm	35	Religion
Generalitat de Catalunya	Barcelona	65	Culture
Min. of Ed. and Science	Madrid	15	Language Learning
Tekel	Bilbao	9	Technology
Trans World Radio	Hilversum	108	Religious Educ.
University of Navarre	Pamplona	12	Culture
Nat. Inst. Higher Educ.	Limerick	18	Umbrella
CNDP	Paris	100	Cult. and Lang.
VIDEOSCOP	Nancy	20	Medicine
CNED	Rennes	16	Secondary Educ.
Min Affaires Etrangeres	Paris	10	Culture
ENS	St. Cloud	13	Mixed
Univ. de Nantes	Nantes	16	Training trainers
Univ.P.et M. Curie	Paris	4	Maths
CLEMI	Paris	11	Culture
IFACE	Paris	13	Management
Univ. de Poitiers	Poitiers	3	Mixed
CFI	France	8	
Belgian Bldg. Research	Brussels	2	Training
Escovision (ASLK-CGER)	Brussels	12	Banking
Europa Nostra	Brussels	5	Secondary Educ.

TOTAL TRANSMISSION TIME (1990) = 1743 hours

Another way to view these developments is to realise that distance-learning has not featured previously in the European satellite-broadcasting landscape. Consequently, the Eurostep experiment has played a major part in the emergence of distance-learning as an established element of broadcasting.

Eurostep has also created opportunities for cooperation between different countries in programme production and experimentation. The British Olympus User Group (OSBUG) held a seminar in December 1990 at which ten projects were presented. Although all were British-led, every one featured international collaboration in its planning and execution. Internationalisation of the Eurostep staff itself has also become established with a Greek Acting Chief Executive working with the Dutch Headquarters staff in Leiden, an Irish Transmission Scheduling Centre in Dublin, and an operations office in London with Canadian, French and British staff. Up to the end of 1990, Eurostep was also served by member liaison offices in the UK, France, Belgium, Spain, Italy and Ireland. Sadly, the limited funding currently available means that Eurostep has not been able to maintain these national offices.

Eurostep has attracted attention in the USA and Canada, where distance-learning by satellite has become something routine. Eurostep has been keen to learn from their experience, but the North Americans have been equally interested in the novel approach to the organisation of the Eurostep experiment. There is much more to do in terms of this two-way transfer of distance-learning knowhow across the Atlantic.

Eurostep as an experiment

Eurostep is both a framework for experiments and an experiment in itself, seeing how it can find the means to develop, in terms of the form in which it might best develop, how it can be managed by the members (who are educators), and the extent to which funds can be found to make this possible.

Eurostep was conceived as a framework in which to carry out a much wider range of experimental projects than can be devised or executed by any one person or organisation. I and my colleagues at ESA have had the privilege of playing a part in this venture, being able to watch the progress of the group, and sharing in the enthusiasm of its members. The word 'experiment' has been used by the Agency to describe all Olympus utilisation activities and is clearly appropriate to the many technical tests carried out with the satellite. It has also become an appropriate term to describe Eurostep itself, in two respects.

Eurostep supports a large group of projects, each 'experimenting' in its own particular way. Some are studying the effectiveness of a new distance-teaching technique. Others are using a long-established technique, but need to know if there is an interest in their material further afield, and hence a market for their programmes. What will people pay? How many people? Is the material appropriate for learners in another country? Some projects are working in the area of authoring, investigating new ways of preparing educational material. Others seek simply to inform and hope that someone out there is learning something by watching. The key to success for all of these projects is to find funds to continue, either with more of the same, or a development of earlier ideas, perhaps simply to find learners who will pay. But commercial or government sponsorship is just as effective. Some projects are seeking to find out if money can be saved in existing educational and training endeavours. If the saving is something more than the commercial satellite distribution cost, then longer-term viability may be assured.

The search for a development strategy

If a continuing stream of projects comes forward, then Olympus could continue to be used by Eurostep experiments in distance-learning for the remainder of the satellite's lifetime. The ESA Agreement with Eurostep demands that there be at least 20% annual turnover in projects, to make room for new members and new ideas. In this model, Eurostep is a test bed for experimentation, and this is its original concept and the minimum that ESA hoped was achievable. However, ESA is not able to fund Eurostep indefinitely and the available Agency budget will be adequate only until the end of 1992. Thus Eurostep needs to find other sources of funding to extend its life beyond the end of the third year of Olympus operations. Income due direct from Eurostep members was less than 15% of all receipts in 1990/91, and so some increases are likely to be proposed for future years.

The need for alternative funding was evident before the end of 1989 and has never been doubted. Eurostep commissioned studies of the implications of this challenge and identified some ideas for the development of the organisation. Besides remaining a 'gatekeeper' of an experimental test bed, there appeared to be two possibilities. Firstly, Eurostep could grow into a 'controlled access channel' which provided more elaborate services for members (or paying users) to transmit programmes of their own choice. Secondly, Eurostep could continue to develop into a full 'educational channel', choosing, commissioning and paying for a supply of programmes. Advice was received that in any case, some degree of continuing public funding was likely to be unavoidable.

EUR●STEP

The Educational Channel for Europe

Eurostep had planned to hold its annual conference in Barcelona (E) in April this year, but concerns about security forced a postponement until October. Such gatherings offer a good opportunity for Eurostep to present itself to outsiders and for debate between its existing members regarding the association's development. The six-month postponement has therefore been something of an anticlimax.

Contrasts with Channel-e and Europace

There are two other European satellite distance-learning projects that have come into existance at about the same time as Eurostep, and some comparisons may provide guidance as to how Eurostep should proceed. They are examples of what Eurostep might wish to become, but satellite distribution of distance-learning material is the only element that the three enterprises have in common.

Channel-e could be called an 'experimental controlled-access channel'. With European Commission funding as an experiment for a year within the Delta Programme, it invited producers of programmes in five chosen categories to pay for the services that are provided. Some 200 h of programmes were transmitted up to March 1991, aimed at a mass audience. Up to forty thousand homes were reportedly tuned to Channel-e on any given day. Live transmissions with audience interaction had not been made up to the end of January 1991. The budget appears to be about half that of Eurostep.

Table 2. Satellite distance-learning projects in Europe

	Eurostep	Channel-e	Europace
Nature	Experiment	Experiment	Operational Channel
Drivers	Programme Providers	European Inst. for the Media	Subscribers
Selection of Prog. Providers	Eurostep but open to all	By EIM	By experts
Educ. Sector	Many fields	Selected fields	Professional training
Subject areas	A wide range	Selected fields	Advancing technology
Funding			
– programmes	Providers	Providers	Subscribers
– channel	ESA, etc.	CEC, etc.	"
Motivation	Study D-L by satellite	Study D-L by satellite	Follow state of the art
Reception	Potentially 10 to 10 K sites	Potentially 20 M homes	150 to 200 sites
Live Programmes	Some	No	Some
Satellite	Olympus	Astra	Eutelsat
Transmit Hours (1990)	1743	200	400

Europace is a fully-operational industrial training channel which commissions programming currently oriented to a few target subject areas in advanced technology. Initially, about twenty organisations were subscribing members of Europace, which has some similarities to the National Technological University in the USA. There are more than 150 receiving sites. Programme producers are organisations chosen because of their expertise in the target fields. Selections from these programme sources are made by advisory boards in each area of specialisation. Much care is thus taken with the selection of programme producers who must have a proven track record. About 400 h of programmes are broadcast each year and the budget is believed to be about four times that of Eurostep.

Table 2 compares the features of the three projects.

Summary of current status and some conclusions

Eurostep has recently secured the services of a permanent Chief Executive who can lead the association steadily forward. The first task of this person will be to tap a number of funding sources, so that Eurostep can be independent of the influence of any single sponsor. An independent Eurostep will be best able to maintain a steady course in this new field.

At present the membership includes large British and French groups, and ESA would like to see more participation by other countries. ESA has long wished to establish a second uplink near Brussels, and it is intended that this should become the main centre for Eurostep transmissions. Further uplinks in other countries look feasible, and this would improve the accessibility of Olympus and encourage a more balanced participation.

Meanwhile, operations with Olympus and other satellites must continue meeting the needs of its members and their individual projects, thereby placing continuing demands on Eurostep's budget. The group has already shown it can do pioneering work of global interest, but collaboration with world leaders in this field needs to continue.

There are some uncertainties concerning the future of satellite broadcasting in Europe, but Eurostep has certainly helped distance-learning by satellite to become a part of the scene.

Accessing the Mobile Communication System 'Prodat' from Very Small Satellite Terminals

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'Prodat' has been developed as part of the Agency's Prosat Programme. The latter embraces three main activities in the field of satellite communications with mobiles: a link evaluation and measurement phase; 'Promar', a maritime voice experiment; and 'Prodat', a data-messaging system.

Prodat

'Prodat' is a demonstration system for satellite communication between small mobile terminals installed on trucks, aircraft and small ships, and stationary (fixed) stations connected to the system by means of various public terrestrial networks (Fig. 1).

Prodat operates in the L-band (1.5–1.6 GHz) frequency range for the link between the satellite and the mobile terminal. The feeder link between the earth station and the satellite is in the C-band (6 GHz). The use of C-band and the power constraints of available satellites necessitate the use of a rather large antenna and a powerful transmitter at the hub station. Therefore, a single hub station is used, and the fixed terminals are connected to it by means of public communication networks.

The Prodat system is organised around a Prodat Network Management System (NMS), co-located with the hub station. The primary functions of the NMS are to:

- control the communication-link protocol used on the satellite link with the mobile stations
- control the protocols used for the fixed terminals via the various terrestrial networks
- perform the message-switching function between mobile stations and fixed terminals.

Prodat provides the following services:
- transmission of messages from fixed- to mobile-terminal users, from mobile- to fixed-terminal users, and from mobile- to mobile-terminal users
- transmission of requests from fixed-terminal users to a mobile terminal, followed automatically by a reply supplying information, such as the position of the mobile, from the mobile equipment
- broadcasting of messages to a fleet of mobile-terminal users
- automatic periodic polling of mobile-terminal positions, this function currently only being available for aircraft within the framework of an air-traffic-control experiment.

Until December 1990, Prodat was operated using the Marecs-B2 satellite, then in geostationary orbit at 26°W. The NMS was located at ESA's Villafranca earth station in Spain. This satellite has recently been moved to 55°W, making the elevation from Europe to the satellite too low for reliable mobile communications. The NMS has therefore been moved to Fucino, in Italy, in order to access an Inmarsat-2 satellite over the Atlantic Ocean.

Terrestrial access to Prodat

Prodat users based at fixed locations are able to access the system via various terrestrial networks:
- the public telex network, using a telex machine or a PC-based telex system
- the public Packet-Switched Data Network (PSDN) based on the X.25 protocol (the user must have a computer and suitable software)
- the Public Telephone Network (PSTN) using a modem and a PC with suitable software
- the international airlines network SITA (only for airlines participating in the experiment).

The use of the telex and PSDN networks requires the installation of specialised,

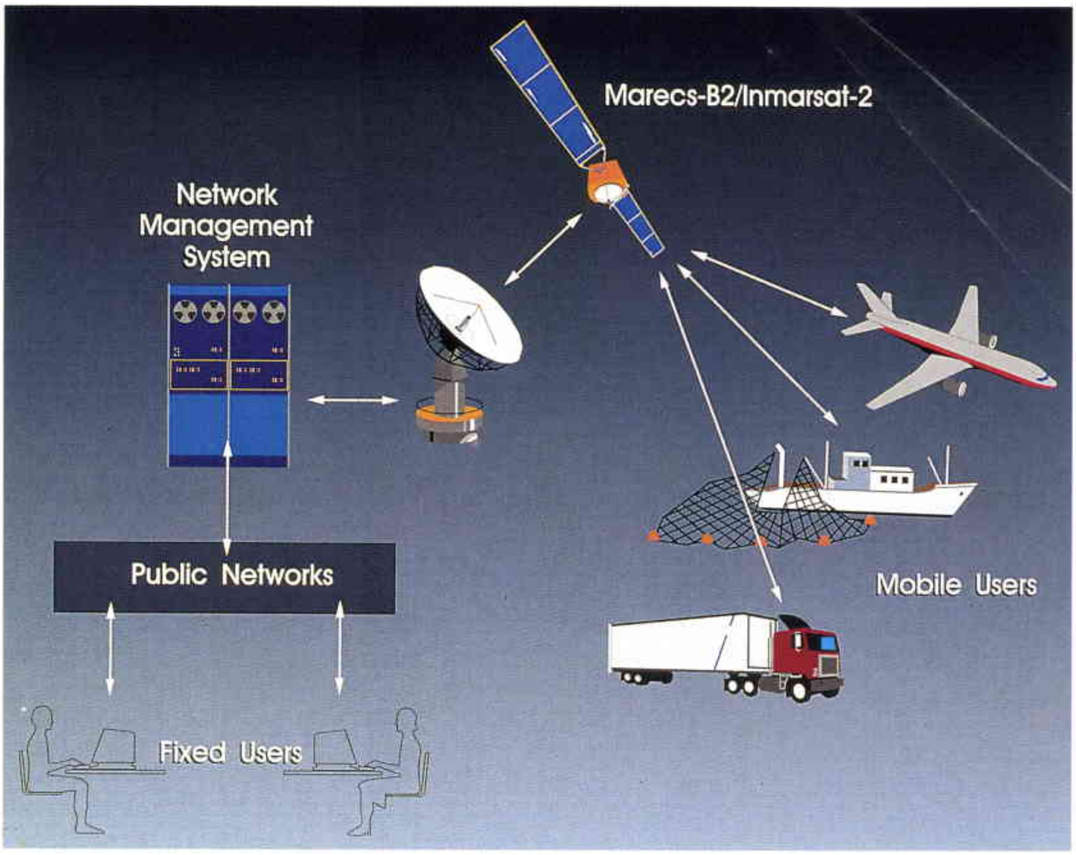


Figure 1. The Prodat system

dedicated lines from the public network operator to the user's premises, making this type of link ideal for regular users. However, these networks are unsuitable for casual use, such as demonstrations at exhibitions or at the sites of interested organisations or companies, because suitable lines are normally not easily available.

A telephone, on the other hand, is normally readily available almost anywhere, and so the PSTN access seems an easy solution for Prodat demonstrations. However, the quality of international telephone connections is often such that it may take several attempts before a line of sufficient quality for modem operation is obtained. Moreover, during busy periods numerous attempts may be necessary to achieve a connection at all.

The telephone connection is nearly always the weakest link in the communication. This is unfortunate, particularly for demonstration purposes, because it makes Prodat appear less impressive than it really is. The uninitiated spectator is only able to experience the overall performance and cannot normally be expected to appreciate the contribution of various parts of the system to that perceived performance.

VSAT access to Prodat

Prodat has been demonstrated, together with a Very Small Aperture Terminal (VSAT) satellite communication system, at a number of recent exhibitions. With the telephone-line problems at other demonstrations in mind, the idea of linking the two satellite communication systems, thereby enabling the VSAT demonstration system to be used as an access link to Prodat, was born (Fig. 2).

One of the current experiments in the demonstration programme associated with the Agency's Olympus telecommunications satellite connects computers by means of a high-speed satellite link, using a hub station and a VSAT station operating at 20/30 GHz (described in detail in ESA Bulletin No. 64, pp. 98–101). At present, a single VSAT station communicates with the hub station, using dedicated carriers for hub-to-VSAT and VSAT-to-hub communications. Enhancements are currently being made to extend the system to several VSAT stations, time-sharing the VSAT-to-hub frequency under the control of the hub station.

The computer configurations at the hub and the VSAT station are similar. At each site, an Ethernet Local Area Network (LAN) connects the computer, or computers, and the satellite communication equipment. If required, several computers, including desktop work stations, personal computers and minicomputers, may be connected simultaneously to the LAN.

The satellite communication equipment, in addition to the antennas and the radio-frequency front-ends, consists of a pair of modems and a pair of Ethernet routers. The function of a router is to link two or more LANs by means of a long-distance line, normally operating at a lower data rate than the LAN itself. In this case, the long-distance line is the satellite link. The router is able to determine which computers are on the same LAN as the router, and which are on a remote LAN. Only the traffic to the remote computers is transmitted over the satellite link, at the data rate supported by this link. The speed of local traffic is not reduced by the router.

This configuration has been realised completely with commercially available equipment. It is, in fact, not very different from conventional wide-area networks established by connecting LANs by means of land lines. The main difference is in the speed of the satellite link, namely 2 Mbit/s, which is considerably greater than the rate normally available on long-distance lines. At this data rate, the propagation delay of approximately 270 ms becomes significant and may limit the throughput of some applications.

The routers, in conjunction with the satellite link, effectively establish a transparent bridge between the two LANs, and any application that can run between two computers on a single LAN can run across the satellite link, though in most cases at a reduced speed.

Accessing Prodat via the VSAT link

For the purpose of demonstrating the feasibility of accessing Prodat via the VSAT link, it was decided to use, as far as possible, existing facilities and interfaces. This has led to a very simple implementation of a system that is both useful and very easy to use. The complete configuration is shown in Figure 3.

Since the VSAT hub station was located at ESTEC, in The Netherlands, and the Prodat NMS in Villafranca, near Madrid in Spain, a method of interconnecting the two had to be found. The existing inter-establishment network of the Agency, Esanet, was found to be suitable for this purpose. The NMS was already connected to Esanet to carry out remote testing from ESTEC. A connection to Esanet was also available on a work station at ESTEC which is accessible via the LAN connected to the hub station of the VSAT system. Finally, a PC was connected to a work station of the VSAT.

The reason for using a PC rather than the work station itself was twofold:

- A software package for a PC was available which could easily be modified to provide a reasonably good user interface for Prodat access.
- The work station was already being used for other demonstrations, and so it was convenient to separate the Prodat user interface from those other applications.

Setting up the VSAT connection

Once the VSAT system is operational, the user starts a Prodat-specific application program on the PC. This application program incorporates terminal-emulator software (i.e. a program that enables the PC to behave like a computer terminal). Everything the user types is sent to the work station, and data from that work station is displayed on the screen. Further processing of the data is unnecessary.

Using the terminal emulator, the user logs into the local work station, which runs under the Unix operating system. From there, remote log-in to the Unix work station at the hub is possible, passing through the routers and the satellite link through Olympus. The PC then appears to be linked directly to the remote work station, with data passing

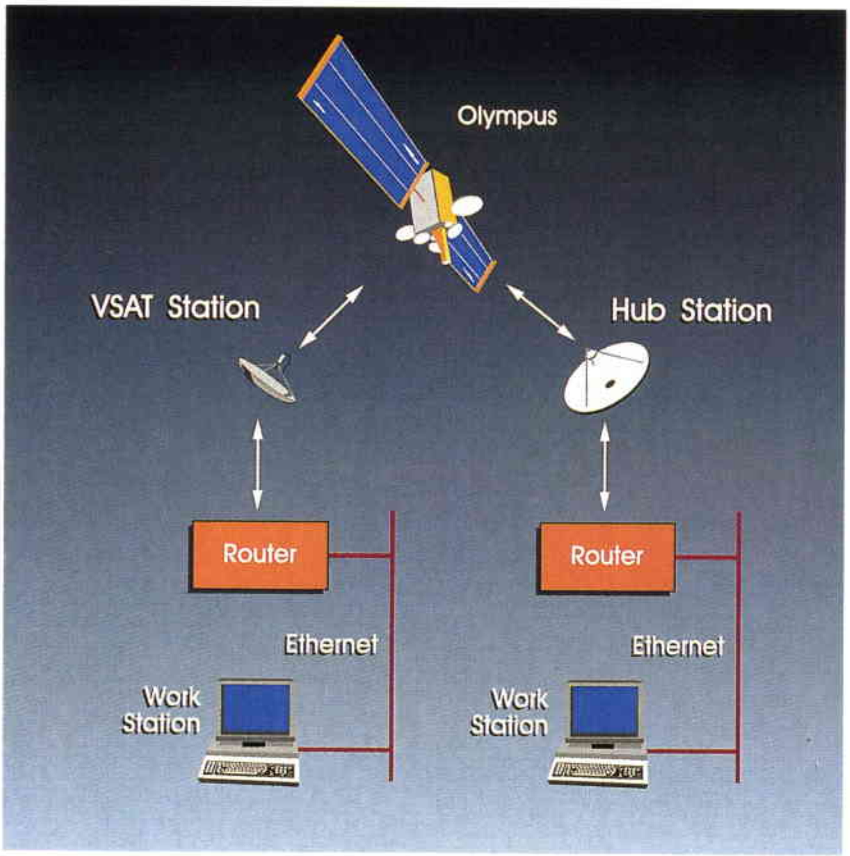


Figure 2. The Very Small Aperture Terminal, or 'VSAT', communication system

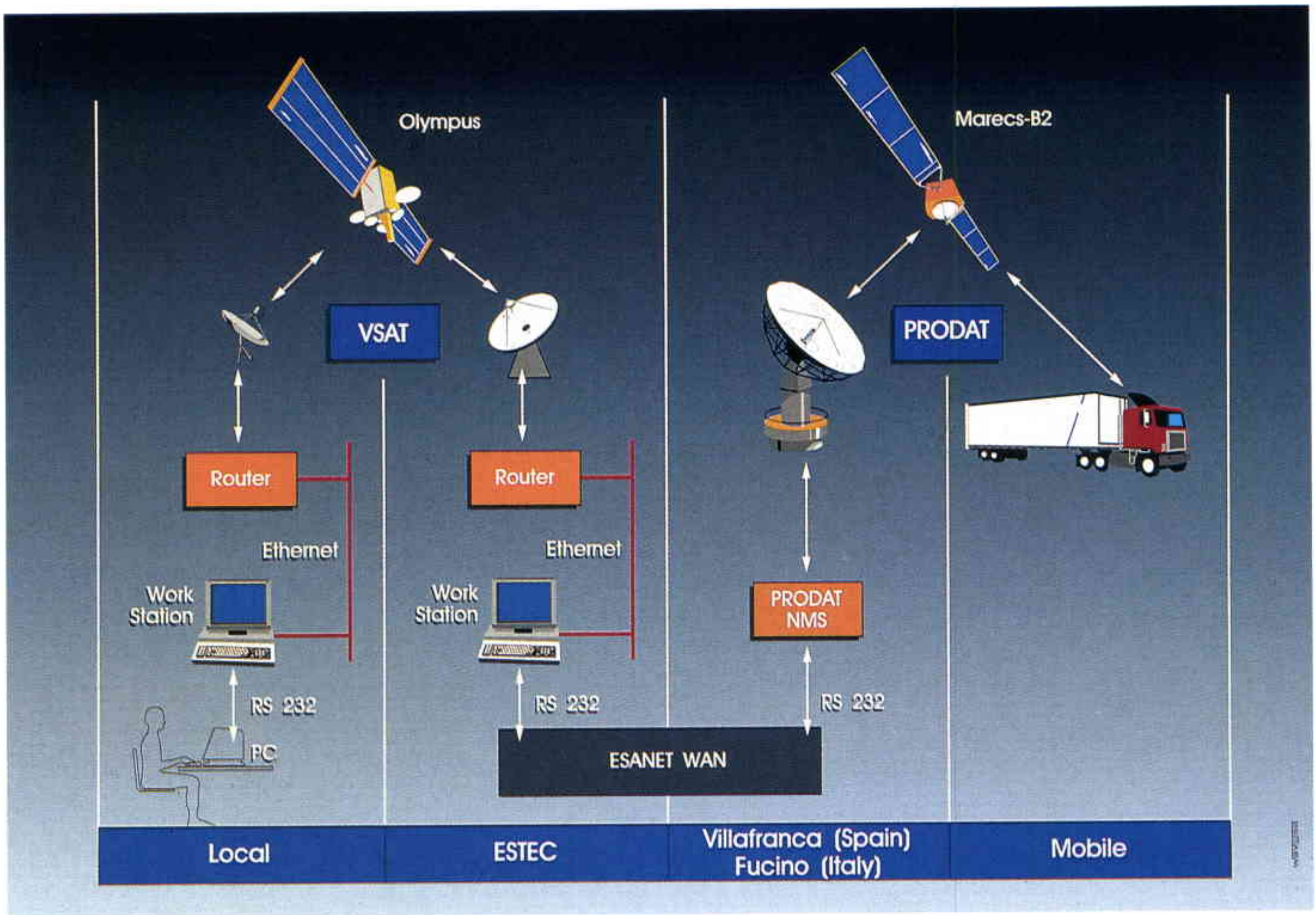


Figure 3. Access to Prodat via the VSAT system

transparently through the local work station.

Next, a Unix terminal-emulator program called TIP is started on the work station at the hub. This program communicates with a serial port on the work station connected to the ESTEC general-purpose LAN. A transparent connection has now been set up from the PC to the ESTEC LAN.

Finally, the necessary commands are issued to the LAN Network Control Centre computer to establish the connection, via the LAN and the Esanet wide-area network, to the Prodat NMS at Villafranca, or later, at Fucino. The PC at the VSAT site is now transparently connected to the NMS, passing through two computers, three LANs, one wide-area network, and one high-speed satellite link via Olympus. The PC now switches from the terminal-emulation software mode to the message transmission/reception mode.

Sending and receiving Prodat messages

Once the connection between the PC and the Prodat NMS has been established, Prodat is ready to use. As previously stated, Prodat is a messaging system supporting the transmission of messages from fixed stations to mobile-terminal users, and vice versa.

To send a message from the PC to a mobile, the user composes his or her message by means of a text editor, which forms part of the messaging software on the PC. A message header containing the identifications of the sender and recipient of the message is also constructed.

When the user is satisfied with the message, the PC is instructed to send it. The message is sent through the established link to the NMS which, in turn, sends it to the mobile terminal via the mobile satellite link. Unless the so-called 'delivery report option' has been suppressed, the NMS returns a message to the PC informing the user whether the delivery of the message to the mobile was successful.

Conversely, when a mobile-terminal user sends a message addressed to the port to which the VSAT link is connected, that message is first sent via the mobile satellite link to the NMS. The NMS then sends it via the VSAT link to the PC, which displays and optionally prints the message. A delivery report to the mobile terminal is generated by the NMS, but a shortcoming of the present configuration is that the NMS cannot always reliably determine whether the message was actually received by the PC.

The Prodat system, in addition to handling user-to-user messages, also provides a facility for automatically accessing data which may be available on the mobile terminal. For example, a truck may be equipped with an automatic position-determination device, such as a GPS or Loran-C system. The data output of such a device may be connected to the Prodat mobile terminal, and may be read out through the Prodat system at the request of the fixed-terminal user. The position data can be displayed automatically on a map by the PC software.

Experience to date

The system described above was first used for demonstrations at the 41st International Astronautical Congress (IAF), held in Dresden (D), on 3–13 October 1990, and later at the VSAT European Satellite User's Conference in Luxembourg, on 13–14 November 1990. In both cases it functioned very well.

Compared with access via a telephone line, it showed a tremendous improvement in the speed of access to Prodat, the response time typically being reduced from several minutes to a few seconds. The performance of Prodat – as opposed to that of Prodat plus a telephone line – was thereby successfully demonstrated.

Future developments

Further work is in progress on several fronts:

- Extension of the VSAT connection to multiple VSAT stations connected to a single hub is being studied, starting with a simple system incorporating a few VSAT stations, each with a reserved frequency for the inbound link. Later, schemes for the time-sharing of frequencies will be studied.

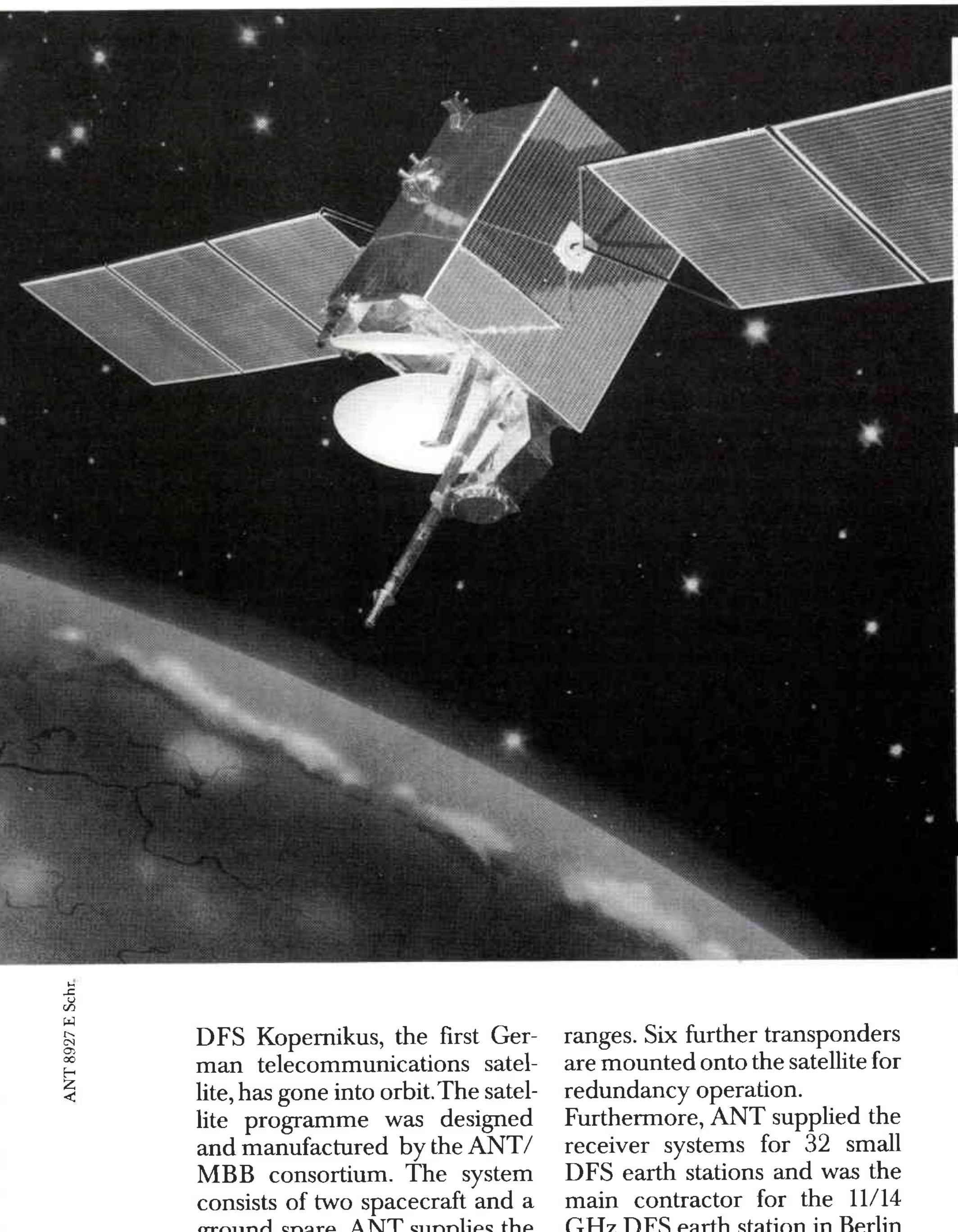
- A connection between the Unix Electronic Mail system and Prodat is being studied. This would be more coherent than the present solution, and would present many other interconnection possibilities for Prodat.

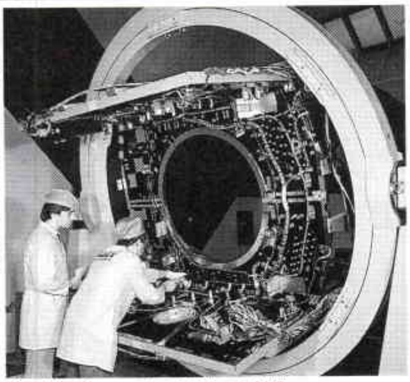
- The second generation of Prodat, Prodat-2, is currently under development. This system will have a more unified approach to the access for a fixed-terminal user. The access network will be based on the CCITT X.400 series of recommendations, and will present many interesting network options, such as local access nodes, e.g. for a country or for a single large user. Connecting such local nodes by means of VSAT links, thereby providing direct access to VSAT terminals at certain users' sites, is undoubtedly an interesting possibility.

- The preparatory work for the European Mobile System (EMS) payload has started. One of the services foreseen as a result of this work is direct access to the mobile satellite link via VSATs at the users' sites, intended for private mobile satellite business networks.

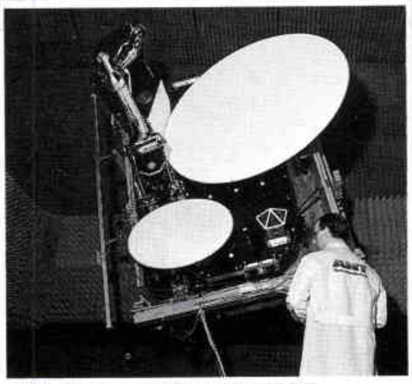
Satellite Technology from ANT:

DFS Kopernikus – The German Telecommunications Satellite

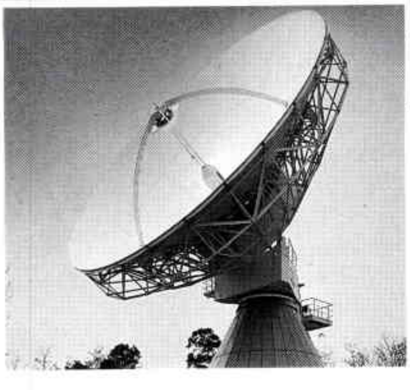




Satellite integration hall at ANT



DFS antenna module measurement



ANT 8927 E Schr.

DFS Kopernikus, the first German telecommunications satellite, has gone into orbit. The satellite programme was designed and manufactured by the ANT/MBB consortium. The system consists of two spacecraft and a ground spare. ANT supplies the entire telecommunications payload.

Kopernikus is equipped with eleven transponders which can be simultaneously operated for the transmission of speech, text, data and TV programmes in the 11/14, 12/14 and 20/30 GHz frequency ranges. Six further transponders are mounted onto the satellite for redundancy operation.

Furthermore, ANT supplied the receiver systems for 32 small DFS earth stations and was the main contractor for the 11/14 GHz DFS earth station in Berlin as well as for the conversion to DFS operation of an earth station in Usingen.

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Dynamic Development of Space Business – A Study of German Space Industry

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'Per aspera ad astra' (through difficulties to the stars) is probably an appropriate description of past and future developments in the space business. With public opinion alternating between euphoria and disenchantment, the space business has developed into an interesting field of operation even for companies outside the sector.

This article is a summary of an empirical study of the German space industry, commissioned by the Federal Ministry for Reseach and Technology (BMFT)/DFVLR and performed by the Kienbaum Institute. It is based on data from BMFT and ESA databases, together with primary data collected from industry, i.e. BMFT and ESA contractors in Germany and their suppliers.

The difficulties involved in gaining access to space have always been underlined by problems and accidents. Nevertheless, the high-technology projects in the civil space industry have always had sensational successes, giving prestige to those nations and companies involved.

In the expectation of increasing industrial utilisation of space, political decisions concerning the continuation and expansion of German space activities were taken at an early stage and with the necessary foresight. Starting with transport systems, which have been developed to a stage where they are exploited in full-scale production, some areas of satellite technology, such as communications, are today being used on a commercial basis as a matter of course. In addition to opening up further customer segments and fields of application for satellites (e.g. earth observation, navigation), the still inadequate levels of industrial involvement in exploiting the reduced-gravity conditions available in space need to be increased.

The European Ministers of Research and Technology intend to achieve the objectives that have been set, in cooperation with their European partner nations, by adopting the supply-oriented approach that has proved so valuable in the past. In the hope that a supply of research and production capacities in space, tailored to suit all user requirements, will generate increased private demand, the existing infrastructure is to be considerably improved and expanded with the aid of public funds.

In the period 1976–1985 the German Ministry for Research and Technology made the largest contribution, namely 80%, to public space funds. As a result of the capability achieved, both in industry and research, the Federal Post Ministry (BMP) was able to take advantage of existing expertise in the field of satellite technology. The BMP is the second largest national contributor (approximately 17% of total funds) within the space business.

Between 1976 and 1985, approximately 8000 million DM of public funds were provided in Germany for setting up an adequate structure for space activities (Fig. 1). Because Germany's activities are integrated into European space policy, approximately 46% of the budget was initially directed towards the European Space Agency (ESA) during this ten-year period. ESA was then responsible for redirecting funds to Germany by allocating appropriate orders to German space companies and institutes.

Approximately 26% of the total German public funds were allocated to space companies and institutes by means of direct project subsidy: 74% in the form of orders and 26% in the form of grants. A further 11% of public space funds were used for the institutional subsidy of the German Aerospace Establishment, DLR (formerly DFVLR).

It also became apparent from the Kienbaum study that, during the ten-year period, the space business was concentrated In a small number of companies and research

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*Managing Director of The Wyatt Company GmbH, Germany, since 1 October 1990 institutes. Public funds were initially directed almost entirely to a total of only 17 companies and 40 research institutes. When these figures are being assessed, it must be borne in mind that the annual business volume in the space sector, amounting on average to DM 800 million and approximately .1500 million in 1985 (Fig.2), is still relatively low in comparison with the turnover in other sectors. Furthermore, the proportion of space-related turnover amounted to only 7% of overall corporate turnover in the companies, and 22% in the institutes.

It would appear that, in terms of business volume, space activities have not yet achieved major significance, either in terms of macro-economic or micro-economic considerations. An analysis of the number of people employed in this sector provides a comparable image. In 1985, the 17 companies employed approximately 5000 employees in their space divisions, representing less than 4% of their total workforce. The 40 research institutes employed approximately 1000 people in the space sector, representing only 11% of the total personnel employed. In the ten-year period under review, the number of employees engaged in space activities rose by approximately 70% in the companies, whereas a slight decline was recorded in the research institutes.

In addition to the generation of more private demand for space systems, the increase in the level of technological expertise within industry can itself contribute to further market development. As a result of greater work-sharing and specialisation, the importance of sub-contracts has increased in recent years. In 1985 German space companies covered only 60% of their business volume by means of direct funds from ESA, the Federal Ministry for Research and Technology (BMFT) and other Ministries. A total of 40% of overall business volume relied on sub-contracts, mainly from abroad. Although these orders could also have been publicly financed and have originated as a result of geographical-distribution factors, they are still an indicator of the international capability of the German space industry.

In-house work was responsible for 60% of the approximately 1500 million DM turnover generated by German space companies in 1985, and 40% of the total turnover was generated by sub-contracts. More than 500 of these sub-contracts remained within the Federal Republic of Germany, and most of them presumably still remained within the same restricted circle of companies (mostly prime or system contractors).

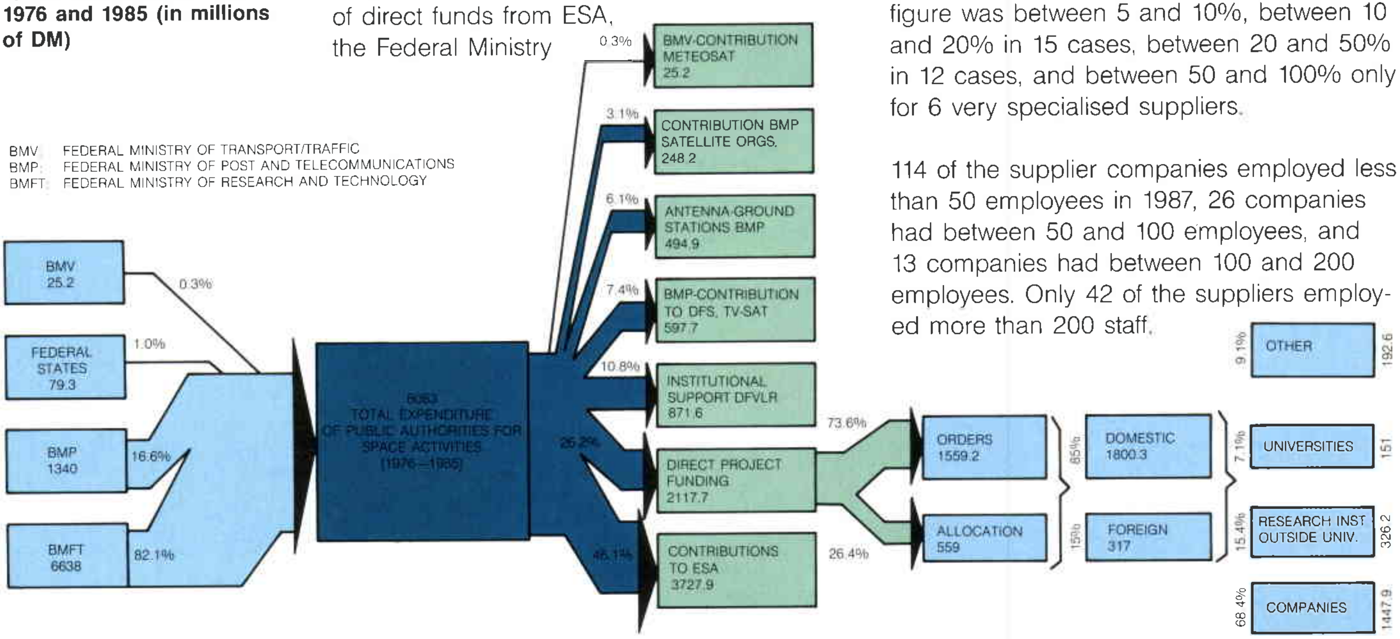
However, international cooperation between space companies, as well as the assignment of sub-contracts to suppliers, has led to a gradual increase in the level of space expertise. Although the proportion of funds received by suppliers is still relatively small in relation to the overall space budgets, the number of small- and medium-size suppliers has expanded from approximately 40 to approximately 200 companies in the period 1974–1987.

The approximately 200 suppliers surveyed by Kienbaum achieved a space-related business volume of approximately 100 million DM in 1987.

The significance of the space business in terms of total turnover generated for suppliers is still relatively small. In 1987, for 94 of the 200 suppliers, space activities generated less than 5% of total sales. In 19 companies, this figure was between 5 and 10%, between 10 and 20% in 15 cases, between 20 and 50% in 12 cases, and between 50 and 100% only for 6 very specialised suppliers.

114 of the supplier companies employed less than 50 employees in 1987, 26 companies had between 50 and 100 employees, and 13 companies had between 100 and 200 employees. Only 42 of the suppliers employed more than 200 staff.

Figure 1. Total public-authority expenditure on space activities between 1976 and 1985 (in millions of DM)



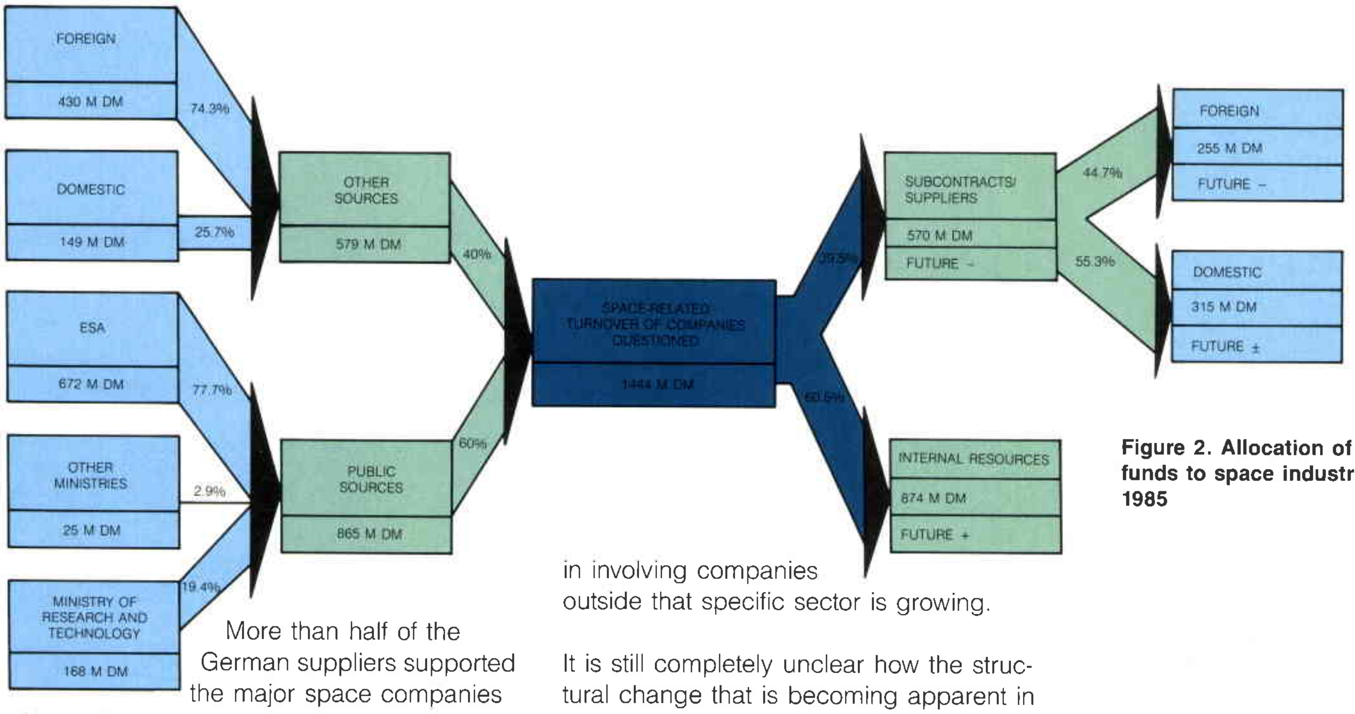


Figure 2. Allocation of funds to space industry in 1985

More than half of the German suppliers supported the major space companies with products in the fields of electronics, mechanical engineering and machine building. The other deliveries covered basic materials, software and products in the fields of electrical engineering, chemistry and synthetic products. Furthermore, work was primarily performed in the fields of consultancy, research and development, the provision of equipment and contract labour.

In terms of regional concentration, the Kienbaum study illustrated that deliveries came mainly from a particular area, namely Bavaria, Baden-Württemberg and Northrhine Westphalia.

The political scene has been set for the strategic expansion of the civil space business irrespective of the current low economic significance of space activities. The programmes and systems planned at European level will lead to an increase in major projects. At the same time, competing macro-economic problems, e.g. in the environmental sector, in conjunction with limited public budgets, will lead to an increasing need to justify space activities. Consequently, increasingly stringent requirements will be placed on the efficiency of space projects as well as the mechanisms for reducing their costs. Furthermore, greater private involvement in the financing of the planned orbital infrastructure is required.

Because the international space industry is still characterised by relatively little competition as a result of a reduction in the number of competitive tenders, and in view of marketing agreements, mutual holdings and mergers of competitors, political interest in involving companies outside that specific sector is growing.

It is still completely unclear how the structural change that is becoming apparent in the space industry can be handled both politically and industrially. This shift away from 'development and set-up projects' towards the future tasks of 'operating the orbital infrastructure' will require completely new qualifications on the part of companies involved in the market. The setting-up of a European orbital infrastructure will initially lead to growth particularly in the staffing levels in space companies. However, the personnel involved in the operating phase will require significantly different qualifications. The problem will be to counter the expected discontinuities by timely strategic planning for the companies' own development.

From the political point of view, it will not be a matter of leaving market development in the space industry completely to its own devices, i.e. abandoning such development to internal market forces. In view of the still insufficient private demand for industrial activities in space, as well as the less restricted distribution of public funds by some European space nations, the German path to the stars will certainly be somewhat difficult in the foreseeable future.

However, as one of the leading industrial nations, Germany cannot afford not to tread this path. On the contrary, Germany will have to assume leadership tasks on the way to the stars and will have to foster more industrial companies willing to participate in this journey in order to be able to undertake commercial operations in space at a later date.

Speeding Payments to Industry – The ESA Solution

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ESA payment conditions for prime contracts are designed to provide a reasonable and contractually justified cash flow to Industry. Nevertheless, payments to lower-tier contractors have often been very much delayed due to the many levels of invoice approval required within the Industrial Consortia. Investigation of complaints concerning these delays has shown that the Agency almost invariably has paid within the due period, i.e. 30 days after receipt of the invoice from Industry. By the time the invoice has reached the Agency, however, a long period has generally elapsed since it was originally raised by the lower-tier contractor.

The problem

Apart from cases in which an invoice has been disputed as not properly due, two prime reasons have been identified for the delays that have occurred in the past in the transmission of payments to lower-tier contractors in Industry:

a. The transmission and certification of an invoice through each contractual tier, even if done in a reasonable time (say 30 days), implies that a subcontractor with five levels above him may only be paid six months after the milestone has been achieved. This structural effect can be, and is, to some extent, compensated for by the payment of generous advances, but this has its limitations.

b. Investigations show that delays can be more than structural, resulting from higher-tier contractors not handling invoices with due expedition. In many cases the delays occur in the administrative departments within the company, because a low order of priority is applied to subcontractor invoices, sometimes to the detriment of the project's progress.

The firms which are most subject to a poor clash flow as a result of this situation are those that, due to their size and financial resources, suffer the most, and can in some cases find difficulty in meeting their own obligations. The Agency, which relies on the participation of these smaller, often highly skilled, firms in its projects, has no wish to see them disadvantaged in this way, and perhaps even discouraged from working in the space field at all. ESA has therefore been actively seeking a solution.

The contractual framework

The Agency's current contractual rules for making payments are as follows:

a. Payments can be made as *advance payments* at the beginning of the work, as *progress payments* in the course of the work, and as *final payments* after acceptance of the total result. Each contract specifies what payments are due upon what events. In the case of *fixed-price contracts*, progress payments are made against successful completion of milestones. For *cost-reimbursement contracts*, progress payments are made against cost reports of expenditure incurred, and sometimes against a development cost plan, with adjustments as actual cost reports are received. Procedures have been adopted to permit the payment of cost escalations early against provisional indices.

b. Where the contract is with a prime contractor which itself has co- and/or subcontractors, specific provisions are made. While the Agency only has a contractual relationship with the prime, payments are usually made directly to the co- or subcontractors when due. This is done to avoid the time involved in money circulating through the banking system before reaching the ultimate payee, and to minimise currency exchanges. Although the payment is made directly to the ultimate recipient, the proper legal construction is that it is in satisfaction of an obligation due from the Agency to the prime contractor (which has its own, separate, obligations downwards). Invoices raised by the subcontractors are submitted through, and certified as due by, higher-tier contractors, and finally by the prime. This certification should indicate that the work that is the subject of the payment has been satisfactorily performed, and that the invoice is correct, both in form and arithmetic.

The preferred solution

The late receipt of payments by the lower-tier contractors is clearly a situation that should not and cannot be ignored. It is in nobody's interest that firms should run into financial difficulties for reasons unrelated to their own technical or managerial competence. Moreover, as already noted, the firms which suffer most are those that are least able to bear the consequences.

At the same time, it must be recognised that the system used for the making of payments, the contractual obligations involved, and the practical manner of disbursement, have a profound effect on the way in which a project is run. The proper control of payments against satisfactory performance remains a significant management tool. Any solution has to steer a well-defined course between accelerating the receipt of money and the long-established and proven procedures of ESA Programmes.

The solution that the Agency has agreed with Industry meets these requirements satisfactorily. In essence, it is that invoices from lower-tier contractors will be submitted *simultaneously* to the higher-tier partners and to the Agency. This replaces the current procedure of linear invoice progression and approvals. If the intermediate levels do not object within a contractually specified time, the Agency will effect the payment to the subcontractor concerned.

In principle, this approach can be introduced using existing paper communications. However, the amount of paper involved, the potential problems of postal delays, and the difficulty, in the case of a dispute, of objectively confirming receipt of a document, leads the Agency to base its proposals, and the detailed implementing procedures, on the electronic ESA Tele-Invoicing System (ETIS). It has the facilities for the rapid transmission of invoices, and comments thereon, to more than one recipient in parallel, and provides the necessary visibility to those concerned, without outsiders having access.

ETIS – The vehicle for improvement

ETIS is currently used for the transmission of invoices from Industry to ESA. As an integral part of the Agency's strategy for using electronic techniques for the speeding up of administrative tasks, it is adaptable, with a change of philosophy, to encompass also invoice transfer between contractors.

ETIS was introduced in 1987 with the aim of linking Industry to ESA for the transmission of invoices electronically. After trials with one of the Agency's prime contractors, Dornier GmbH, the system was considered proven and was introduced on a wider scale. A brochure on ETIS (ESA BR-53) was subsequently distributed throughout European space-related industry and, in the course of 1990, 135 MAU had been paid to contractors by the Agency against 2500 invoices received electronically. The present system, called 'ETIS Mark 1', is therefore clearly working very well.

At a seminar held on 26 and 27 April 1990 in Florence (I), the Agency proposed a new procedure to Industry, and one that found general favour with the major space companies represented. This procedure is as follows:

a. A subcontractor, having achieved a milestone, raises an invoice using ETIS. This invoice is addressed to his next higher-tier contractor and *all* intermediate contractual parties up to the prime contractor.

b. The Agency pays the invoice directly, within a specified period, unless objections have been raised by any intermediate-tier party, and if it has itself no reason to believe that the payment is not due.

c. Objections to payments by intermediate parties must be made, with reasons, via ETIS, so that the subcontractor concerned, all intermediate parties, and the Agency have visibility. ETIS will ensure that such objections will not be visible to those who have no legitimate interest, e.g. subcontractors below the level of the firm raising the challenged invoice. If objections are raised, payment will not be made until the matter is resolved through the normal contractual/project channels.

d. The period allowed for objections must give the firms adequate time to consider the invoice and the work covered, but at the same time not induce undue delay in the receipt of payment. Given the speed of information transmission possible with ETIS, the Agency considers one month from the date on which the invoice is registered in ETIS to be suitable.

e. Payment by the Agency will be regarded as a provisional payment, and does not imply any formal acceptance or certification of the work performed. Equally, lack of objection by any intermediate tier does not constitute formal acceptance of the work. The existing provisions for testing, verifying, and accepting the work formally remain applicable. Delays and costs due to failure to carry this out in good time will not be allowable against the Agency.

f. Most subcontractors are under fixed-price contract. For those cases where a subcontractor is on cost-reimbursement, and as means do not exist for submitting cost reports within the same time scale as invoices via ETIS, the Agency is prepared to agree, on a case-by-case basis, a payments scheme whereby a significant portion of the foreseen costs, according to a development cost plan, is paid so as to assure a reasonable cash flow.

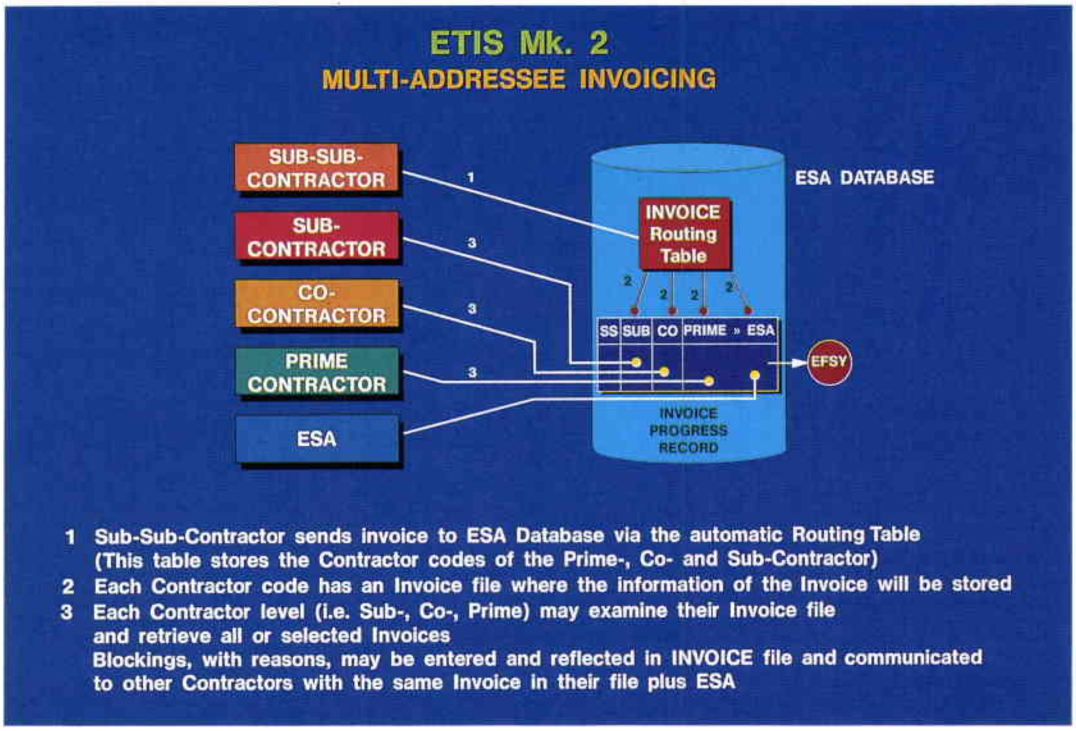
g. The agreement of advance payments will take account of the expedited cash flow made possible by the above procedures.

ETIS Mark 2 – The technical requirements

The change in philosophy from ETIS Mark 1, which encompasses electronic invoicing from Industry to the Agency, to Mark 2, which will also enable invoices to be transmitted between companies as well as to and from ESA, requires changes in the technical approach. The present system is based on the transmission of invoices from an Industry-based personal computer, or PC, via either General Electric's Quik-Comm Network (PC-to-PC via General Electric's mainframe computer in Amsterdam) or ESANET (PC-to-company mainframe and thence to the ESA mainframe with downloading to ESA Finance Department PCs). The introduction of several hundred more contractors into ETIS necessitates a more standard approach. ETIS Mark 2 must be able to:

- facilitate the creation, modification and management of standard invoices on remote stations
- manage the electronic transfer of invoices to ESA and status messages from ESA by means of the public data network (X.25)
- allow monitoring by contractors involved in the approval chain of the reception, blocking or deblocking of their invoices
- allow intermediate contractual approval levels to introduce blockings and comments on invoices within a given time frame
- transfer the accepted invoices to EFSY, the Agency's financial system, after control.

This new approach is illustrated in Figure 1.



1 Sub-Sub-Contractor sends invoice to ESA Database via the automatic Routing Table (This table stores the Contractor codes of the Prime-, Co- and Sub-Contractor)
2 Each Contractor code has an Invoice file where the information of the Invoice will be stored
3 Each Contractor level (i.e. Sub-, Co-, Prime) may examine their Invoice file and retrieve all or selected Invoices
Blockings, with reasons, may be entered and reflected in INVOICE file and communicated to other Contractors with the same Invoice in their file plus ESA

Figure 1. ETIS Mark 2 multi-addressee invoicing

ETIS Mark 2 – The main concepts

Supplier

Suppliers working as contractors on ESA obligations (contracts) can join the ETIS system. For each obligation a 'route' defines the relationship between the contractors working together on that contract:

- Prime contractor (Level 1)
  - Co-contractor (Level 2)
    - Subcontractor (Level 3)
      - Sub-subcontractor (Level 4), etc.

ETIS Local Station (ETIS-L)

ETIS suppliers work with the ETIS Local Station. The latter is a remote terminal that allows management of the suppliers' invoices and their related data. The invoices can then be sent to the ETIS Central System (ETIS-C).

The ETIS-L also allows reception of the messages concerning the contractor sent by the Central System or the other contractors. Those messages can be invoices, invoice status messages, error messages, or fixed data.

A Local Station is physically located at the supplier's premises. It communicates with the ETIS-C by means of the public X.25 services. If a supplier works at several different locations, each location will be defined by a different supplier code and have its own ETIS-L station.

ETIS Central System (ETIS-C)

The Central System controls the invoices and loads them into the relevant contractors' mailboxes. After a certain time interval (the so-called 'X interval'), currently defined as 30 days from the invoice's inception, those invoices implicitly accepted by Industry, i.e. those that have not been explicitly blocked, will be transferred to EFSY, the Agency's Financial System, for further processing within ESA and eventual payment.

Each supplier working with the ETIS system will have a mailbox allocated at ETIS-C in which messages will be temporarily stored before transfer to and from the database.

Route

Suppliers can work on any number of obligations. For a specific obligation, the contractor can appear a number of times on the same or on different levels. Within each obligation, the supplier is defined by a route number, which is a key to trace the supplier's level and that of the organisation above him to whom he is contractually linked.

All invoices emanating from the contractor are 'mailed' to the contractors above him in the route. Within the defined 'X interval', they can control this invoice. If necessary, they can send a blocking message to ETIS-C. This will stop the 'X interval' countdown, as long as the invoice is not unblocked by the blocking contractor after settlement of the problem.

All messages concerning invoice status evolution are mailed to the ETIS-L stations concerned (i.e. those higher in the route).

Fixed data

A set of data is shared by all participants to the system:
- Currencies
- Countries
- System Messages
- Suppliers
- Supplier's Bank
- Route.

This data is kept up to date by ETIS-C. Upgrades are loaded into the mailboxes of the ETIS-L stations. For suppliers' banks and route, only a data subset specific to the ETIS-L supplier is loaded. Only ETIS-C has a complete set of all data.

Invoices

Invoices are created on the ETIS-L stations by the suppliers. These will be in a fixed, standard format. One ETIS-L can enter invoices for all obligations it is working with (and for which a route number has been downloaded onto its system by ETIS-C). It can also enter invoices for non-ETIS suppliers (without a route) under its own route number.

The ETIS-L stations can also enter invoices for ETIS suppliers which do not have an ETIS-L station, but which are defined in the route. In this case, the ETIS-L enters the invoice for the subroute number.

Status of ETIS Mark 2

Current planning foresees an operational system being available by the middle of 1991. Figure 2 gives an overview of the elements that will then be in place.

Changes to contract terms

Some changes will be made to the terms of tender and of contract to accommodate the new procedure. As payments made under the scheme are to be treated contractually as advances, the changes to the terms need be neither extensive nor dramatic.

a. The *Conditions of Tender* lay down the principles against which payment is made, and ask the bidder to submit proposed payment plans for the individual price elements that meet these requirements. The principle will stay the same, but the payments plans themselves, which after negotiation become part of the contract, may differ somewhat from previous ones.

b. The payment clauses of the *General Terms and Conditions for ESA Contracts (Clauses 20 to 22)* remain unchanged.

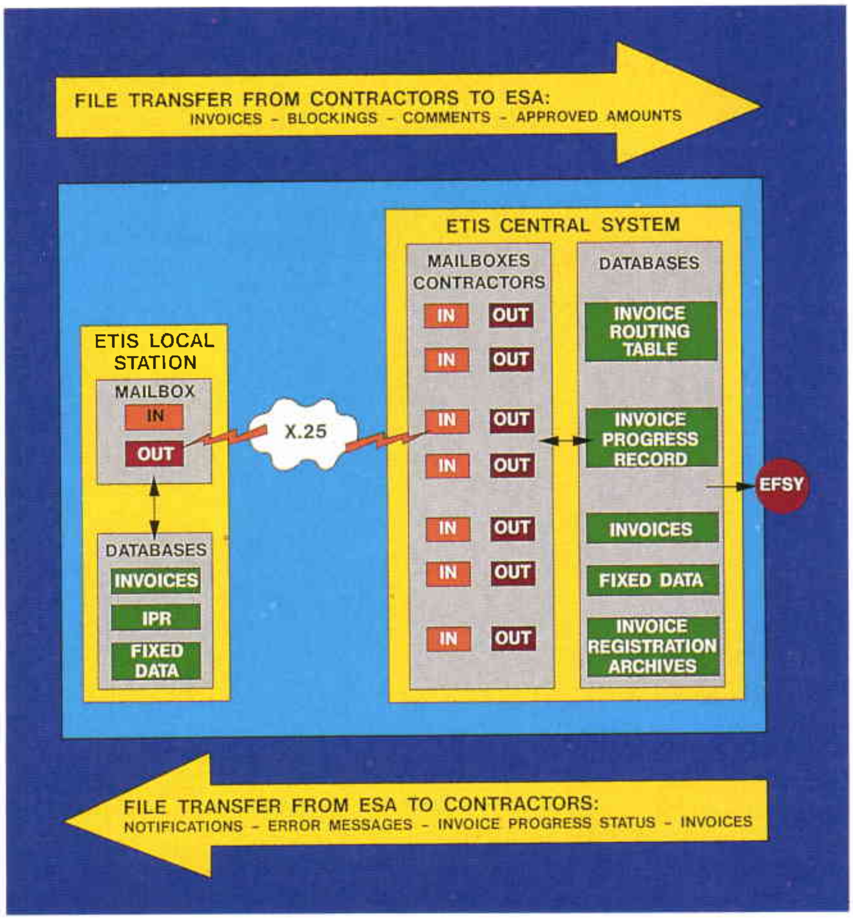


Figure 2. ETIS Mark 2 system overview

The implementing clauses in the specific contract text will require some additional text:

– incorporating the ETIS procedure (this already applies in some contracts), while the requirement for five paper copies can be eradicated

– stating the principles given above

– indicating that payments made thus are advance payments in the case of fixed-price contracts, and partial progress payments (actually also advances) in the case of cost-reimbursement contracts

– stating the contractual effect of a payment objection made within the specified period

– providing, in the case of both price types, a mechanism for periodic formal approval by the prime contractor of work done by lower-tier contractors, and thus enabling the advance payments to be converted to final payments for that element. In the case of fixed prices, this would occur for specified milestones. For cost-plus contracts, reports will of course still be required and will, as at present, be used for periodic settlement at regular intervals (e.g. yearly) with adjustment and audit provisions.

It is normal practice for major projects to include the basic formal rules for payment in the contract and then to describe the detailed implementation in a financial appendix and perhaps in the management plan. Specific text for the operation of ETIS and the means for raising objections to payments and for clearing them will be generated.

ETIS Mark 2 – Part of a strategy

The development of electronic invoicing by the Agency is not a 'stand-alone' project. It is part of a strategy, conceived by the Agency's Administration, to use electronic communications right across the board, with the subsequent elimination of paper and its inherent postal delays, queries arising from unclear information, and so on. The obvious benefits of instant communication have been linked to other, less visible but more tangible improvements such as automatic transfer between systems by using standard formats; the elimination of queries by installing validation checks at points of entry; the use of electronic signatures for internal approvals; and many more.

The ETIS Tele-Invoicing System should therefore be seen as part of a chain, which starts with Industry receiving Invitations to Tender via EMITS (ESA Electronic Mailing of Invitations to Tender), submitting cost proposals utilising ECOS (ESA Costing Software), and then sending its bills via ETIS. The Agency then obtains all internal technical, contractual and financial approvals via electronic signatures. The final act is to transfer the associated payment instructions to the Agency's banks via Telebanking, thereby making the electronic circuit complete.

Recent Developments in ESA's Information and Data Policy

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As the Agency's role developed over the last two decades, it became apparent that the detailed provisions of its original information and data policy would require a combination of modernisation and expansion. A major step forward in this respect was made with the Council's approval of a new ESA document entitled 'Rules Concerning Information and Data'.

Introduction

In December 1989, after considerable preparation and discussion by a special Working Group of the Agency's Administrative and Finance Committee (AFC), the ESA Council approved a document (ESA/C(89)95, Rev. 1) entitled 'Rules Concerning Information and Data'.

The objectives of the document are:

> '*to describe in a comprehensive way the policy and practice of the European Space Agency with respect to information and data and to give guidelines for negotiations with third parties*'

and

> '*to enlarge on the basic principles contained in the Convention*'.

Information and data is not a legal expression. For the purposes of the said 'Rules', it should be understood as comprising any recorded results directly or indirectly generated by ESA in the execution of its tasks. Information and data, in this sense, would cover such widely varying items as a Contract Study Report, an invention or a software programme developed under contract to ESA, a scientific publication by an ESA staff member, or a stream of data relayed back to Earth from an experimental payload aboard an ESA-provided spacecraft.

The basic principles in respect of information and data are summarised in global terms in Article III of the ESA Convention, where it states that the Agency shall:

> '*...... facilitate the exchange of scientific and technical information pertaining to the fields of space research and technology and their space applications....*'

> '*...... ensure that any scientific results shall be published or otherwise made widely available after prior use by the scientists responsible for the experiments .....*'

and

> '*...... with regard to the resulting inventions and technical data, secure such rights as may be appropriate for the protection of its interests ....*'

These lofty statements have, in the past, been elaborated into more detailed and practical provisions, in particular the Guidelines ESA/C(77)47 and the Rules ESRO/76. Hardly surprisingly, however, these detailed provisions have not always kept pace with the role and position of the Agency as it has developed over the last two decades. In the very significant field of information and data generated by industry, the 'General Clauses and Conditions for ESA Contracts' provide the detailed interpretation of Article III of the Convention. Also here there was felt to be a need to have a fresh look at certain contractual provisions in the light of recent developments in the law, or changes in contractual practice.

It was, therefore, the need to modernise and expand the existing policy, coupled with the desire to express in a single document all aspects of this policy, that has resulted finally in the formulation of the 'Rules on Information and Data', hereinafter referred to as 'The Rules'.

The Rules have a total of five chapters:

I. In-House-Developed Information and Data
II. Contractor-Developed Information and Data
III. Information and Data Relating to Payloads Flown on Space Vehicles
IV. Transfer of Information and Data or Other Assets Outside the Member States
V. Protection Covering Information and Data Held by the Agency.

It should be noted that the Rules do not apply directly to Contractors or Third Parties in general. The Rules establish guidelines for the policy of the Agency on the subject of information and data. Insofar as these guidelines deviate from the current policy as defined for example in the 'General Clauses and Conditions for ESA Contracts', or in the 'ESA Staff Rules', the latter documents will have to be brought in line with the Rules in order for the new policy to become effective.

It is not the intention of this article to present a complete resumé of the contents of the Rules, but rather to draw attention to some new and interesting developments, particularly those relating to Chapters II, III and IV. Chapters I and V deal with in-house aspects of ESA data policy and will not be further addressed here.

Contractor-developed information and data

Contracts placed by ESA are normally governed by the ESA 'General Clauses and Conditions', a standard document designed to cover all types of procurement from small studies to complete satellite systems. Part II of the General Conditions contains 'Special Conditions concerning Intellectual Property Rights, Disclosure of Information and Rights of Reproduction'.

Although Part II has seen a number of revisions during the past twenty years – the current terms are included in document ESA/C/290/Rev. 4 – the underlying principle of a 'licence policy' has always remained unchanged. This policy entitles a Contractor to retain rights on all Contractor-developed information, inventions and technical data, whereas the Agency and the Member States (or, in the case of optional programmes, the Participating States) will acquire a non-exclusive, free-of-charge, right to use such inventions and proprietary information for their own requirements in the field of space research and technology and their space applications.

There are, with one exception, no fundamental restrictions on the Contractor's freedom to exploit the results of the contract. The exception concerns sales or licence-agreements for non-space applications or outside Member States; these, in principle, are subject to royalty.

In the Chapter 'Contractor-Developed Information and Data', the Rules confirm the principle of the licence policy and add a number of new clauses.

In order to maintain the consistency between the General Conditions and the Rules, it has been necessary to modify Part II. This exercise, which has been done in close consultation with representatives from industry participating in 'Eurospace', has recently been completed. The resulting Revision 5 of ESA/C/290 is expected to be approved by the ESA Council shortly. The main modifications with respect to Revision 4 are outlined below.

Revision 5 makes a general distinction between:

- forms of legal protection for which application is required (i.e. patents and other industrial property rights), and
- protection of information other than through patent: this, in turn, is subdivided into sections dealing with copyright, protection of background information, and protection of computer software.

The latter provision, which is the equivalent of the clause on Technical Data in Revision 4, no longer uses the definition of proprietary technical data as data 'giving a lead over the competition' (all other data being non-proprietary). Under this scheme, the Agency could freely disseminate the non-proprietary information, whereas the distribution of the more interesting results of a contract was limited to either the purpose of the contract itself or for the exercise of the reproduction right.

In practice, these definitions have been causing difficulty. In the new Clause 38, the degree of protection allowed to the Contractor and, conversely, the rights of the Agency, are determined by the answer to the question: 'Has the information been developed under the contract ?'. If the answer is 'No', the information is protectable through the new provisions introduced for 'background information'. If the answer is 'Yes', the information produced by the Contractor will be protected by copyright.

However, notwithstanding the Contractor's copyright, the Agency and the Member States (or Participating States) are entitled to a

'free-of-charge, non-exclusive, irrevocable right to use, copy and disseminate the information for their own requirements in the field of space research and technology and their space applications'.

It is realised that there are limitations inherent in copyright protection of high-technology products. There may, furthermore, be good grounds to afford additional protection to competitive positions which do not rely entirely on Agency funding. The new clause allows for such protection on a case-by-case basis and restricts the dissemination if it is established that 'justified interests' of a Contractor would otherwise be prejudiced.

A new clause introducing the concept of 'background information' emphasises the requirement for the tenderer to identify such non-ESA-funded information at an early stage in the procurement process. If, in the course of the contract, a Contractor claims to have provided 'additional' background information, the burden of proof is with him to demonstrate that the information is not a product of the contract. The protection afforded to background information is identical to that provided by the copyright clause in the case of 'justified interests', described above.

The definition in Revision 4 of software as 'technical data ... not being capable of protection other than by secrecy or contractual undertakings' is incompatible with legal developments in the field of software protection. Although it would have sufficed to refer to the provisions on copyright protection, the principles of which apply equally to software, a specific clause was nevertheless introduced in order to avoid ambiguity. Having confirmed the Contractor's 'right to apply for and enjoy protection in accordance with applicable laws' and the Agency's (and the Member States') right to use and copy the software for their own requirements.........., the new clause proceeds to identify a specific type of software referred to as 'operational software'. The definition of 'operational software' given is:

'Software required for essential spacecraft check-out or space operation purposes and which has been developed with a fundamental intellectual contribution by the Agency's staff (the development, operation and maintenance of this software will normally be performed under contract to the Agency at its facilities and under its technical supervision and responsibility)'.

This is clearly not the standard type of software developed under contract to ESA, but rather the exceptional case of large and complex software programmes. Typically, these are developed over long periods of time, involving different Contractors as well as in-house efforts, and are designed for use by several projects. In order to avoid inextricably entangled situations of ownership and rights of use, the new clause foresees that for this particular software the Agency may reserve to itself ownership of intellectual property rights; the Contractor shall, in such a case, be entitled to a right of use of this software.

The present clause on 'Modifications and Improvements' will give way to a wholly new provision entitled 'Evaluation of Technology'. This clause aims at promoting cross-fertilisation between space and non-space industry. It is in the interests of ESA to stimulate the widest possible transfer of technology for peaceful purposes, thereby increasing the return on capital invested in space efforts. The clause reads:

'On request by the Agency and on conditions to be agreed with the Contractor including the reimbursement of reasonable costs, the Contractor shall assist the Agency, or a third party nominated by the Agency, in assessing the commercial applications for space and non-space purposes of the results of his work performed under contract to the Agency. Such assessment shall be performed with due regard to the intellectual property rights owned by the Contractor and his intended use of the results of the work'.

Finally, a new clause will be inserted in the General Conditions in order to define the procedures to be followed in the case of export of contract results outside the Member States. This question, which is the subject of Chapter IV of the Rules, will be addressed later in this article.

Information and data relating to payloads flown on space vehicles

As mentioned above, the need for a fresh approach in particular in the area of information and data relating to payload data, was one of the reasons for the drafting of the 1989 Rules. The policy followed by ESA in this respect had been laid down as early as 1965 in the so-called 'Rules

ESRO/76'. In those early days, all ESA Programmes were mandatory, and most were Scientific Programmes. Today, Scientific Programmes are still mandatory, but there are also a multitude of non-mandatory or 'Optional Programmes', which cover a wide range of technology applications or demonstrations, as well as serving (pre-)operational purposes.

The basic principles guiding the data policy in respect of the mandatory Scientific Programme can be summarised as follows:

- After a relatively brief period during which access to the experiment data is reserved exclusively to the experimenter, the data become available to ESA and, via ESA, to the general scientific community.
- During this period of 'prior access', the experimenter is entitled to protect the scientific results of his experiment by whatever legal means are available to him, provided he reserves to ESA a free-of-charge licence to use any inventions or data for purposes of space research and technology and their space applications.
- The experimenter is obliged to publish the results of his experiment within a reasonably short period; failing this, the Agency shall have the right to do so.

This approach, having worked satisfactorily for previous scientific missions, has been preserved in Chapter IIIA of the Rules, entitled 'Information and data relating to payloads flown free of charge to an experimenter as part of an Agency Programme'. This type of flight opportunity can, however, also include ESA-funded flight opportunities of commercial-type payloads provided by a Third Party. In such a case, a more conservative approach towards the distribution of the flight results could be appropriate. It is, accordingly, stipulated that:

> '*The conditions on which Third Parties may be given access to the data resulting from the in-flight operation of the payload, shall be determined by the relevant delegate body, taking into account any views expressed by the experimenter. Unless there are specific reasons of commercial interest, acceptable to the relevant delegate body, such conditions should normally provide for unrestricted access by Third Parties.*'

Chapter IIIB is concerned with (information and data resulting from) 'payloads .... flown on board a space vehicle provided by the Agency at the request of a customer who reimburses the flight charge, or his apportioned share thereof, in accordance with the Agency's charging policy'.

In exchange for his reimbursement of the flight cost, the user of the flight opportunity (who is, appropriately, called the 'customer') is guaranteed full confidentiality of the flight data. Insofar as the rights in data resulting from the payload are concerned, the Rules state unambiguously that:

> '*all rights in inventions or proprietary technical data, directly or indirectly resulting from a payload flown onboard a space vehicle, shall be vested in the customer ...*'.

Chapter IIIC is an umbrella provision, giving guidelines for all those cases which do not fall under Chapters IIIA or B above. The following cases are mentioned as examples:

1. A payload developed under contract to the Agency, the flight and operation of which is also financed by an Agency programme.
2. A payload developed with, or without, Agency involvement, the flight of which is jointly funded by the Agency and another party.
3. A payload developed with Agency involvement, the flight of which is funded solely by another party.

Typical examples of case 1 are the Olympus payload and the ESA funded elements of the ERS-1 payload.

Given the funding conditions of Case 1, it appears equitable that:

> '*any data, inventions, or proprietary technical data resulting from the in-flight operation of the payload shall belong to the Agency on behalf of the Participating States*'.

Concerning the exploitation of the data transmitted by the payload, the Rules recognise the commercial opportunities offered by the Optional Programmes and stipulate that:

> '*(the exploitation of the data) ..... may be allocated by the Agency to Third Parties, on conditions to be approved by the relevant Programme Board*'.

Some guidance is given to Programme Boards by providing that such conditions shall take account of any investments by the Third Party and must protect intellectual property rights created by the Third Party at its own expense.

Examples 2 and 3 describe more complex forms of cooperation for flight opportunities where the funding for the flight is provided either jointly by ESA and its partner(s) or supplied entirely by the partner(s).

The Rules do not attempt to provide solutions for all possible situations that can arise. They merely provide the boundaries within which the partners will have to negotiate fair arrangements doing justice to the circumstances of the case. Insofar as the rights of ESA are concerned, the possibilities offered by the Rules include a general waiver of rights for the benefit of the partner funding the flight cost, or a licence providing limited rights of use to ESA without the right to give sublicences, as well as ESA ownership of rights combined with licence rights acquired by the partner. The criterion to be applied in all cases remains the actual contribution of each party 'to the development, or the development cost, of the payload and to the cost of the flight and operation thereof'.

It is obvious that the approach given by the Rules is still rather rudimentary and will have to elaborated in more detail based on the experience to be gained in future programmes. The Rules recognise this in that it is foreseen to review their application after a period of three years.

Transfer of information, data or other assets outside the Member States

The inclusion of this Chapter reflects the growing and justified concern that the results of activities conducted by ESA and its Contractors should not be misused for purposes other than those sanctioned by the Convention.

Exports to non-Member States can be undesirable on two counts:

- non-peaceful uses of the results of ESA Programmes are in violation of the Agency's Convention

- the Convention expects ESA to protect the competitivity of European space industry: a contrario, actions which can jeopardise Europe's position in this respect must be prevented.

We have seen in the discussion relating to Chapter 2 above that it is a fundamental characteristic of ESA policy to leave the ownership of intellectual property rights and their exploitation to Industry. ESA Contractors are, in principle, free to dispose of the information, data and other assets generated under contract to ESA.

In the deliberations on the question of how to control the export of ESA products, it was felt that the principle of the licence policy should be preserved and that duplication of national rules should be avoided. Firms wishing to export technology must abide by national rules and procedures, as well as multilateral arrangements controlling the export of sensitive technology. The Agency itself cannot be party to such multilateral agreements and is not governed by national rules. The solution that emerged, in the end, from these considerations is one of trustful consultation rather than coercion.

It is clear that, for such a policy to work successfully, a number of conditions must be fulfilled:

- The common interest of the Member States to abide by the Convention must prevail over the individual interests of any State or its subjects.

- The procedure must guarantee the absolute confidentiality of the information being supplied: it must also be fast.

- It requires the willingness of all parties to cooperate in good faith.

In this spirit, the Rules foresee that the delegate meetings convened from time to time to consider intended transfers:

> '....... *shall be governed by extraordinary rules of procedure guaranteeing strict confidentiality of documents and deliberations. These rules shall be approved by Council'.*

Without going into the detail of the Rules or the procedures, which will be presented to Council shortly, the main features of the scheme, insofar as applicable to industry, can be summarised as follows:

- Subject to the review procedure are information, technical data or other assets belonging to an ESA Contractor by virtue of a contract with ESA, which are intended for export to a non-member State, persons under the jurisdiction of such States or to other international organisations.

- The request for transfer takes the form of a standard document to be completed by the Contractor containing, inter alia, particulars on the customer, the final destination, the intended use of the subject of the transfer, the programme under which it was developed, the nature of the benefit to be obtained in exchange for the transfer (i.e. financial, cross-licence arrangement, etc.).

- The Agency transmits the request to 'Points of Contact', appointed by Member States (or Participating States in the case of Optional Programmes) for receiving the information under conditions of confidentiality.

- If no request for the case to be examined by a delegate meeting has been received by the Agency within six weeks from the notification by the Agency, the latter will inform the Contractor that there are no objections to the transfer.

- If a request for examination by a delegate meeting has been received within the six-week time frame, the Agency will convene a meeting within eight weeks from the original date of notification of the proposed transfer.

- The criteria to be applied for arriving at a recommendation on the transfer, shall include the potential effect on the objectives of the Convention, in particular the exclusively peaceful purposes of the Agency and the interests of the Member States as a whole, including the protection of their competitive position.

- If more than one third of the Member States are not in favour of the proposed transaction, this shall be considered as a negative position having been taken. The Contractor and the State under whose jurisdiction the Contractor is placed, shall be informed of the results of the meeting.

- The Contractor shall not enter into a binding commitment with respect to the transfer without having received the meeting's opinion and the agreement of the State under the jurisdiction of which he is placed. The Contractor shall use best endeavours to meet comments or objections raised by the meeting.

Revision 5 of the General Conditions will contain those provisions, derived from Chapter IV of the Rules, which are directly relevant to ESA Contractors.

It is foreseen that the above scheme will become operational as soon as the Council has approved the detailed procedures governing the conduct of the delegate meetings.

Conclusion

By grouping together and in some instances reformulating the main aspects of ESA's policy in respect of information and data, the Rules will hopefully contribute to a greater clarity and cohesion of application in this complex field. Obviously, only the test of time will prove if certain new procedures as outlined above will meet with expectations. The Rules themselves foresee a trial period of three years, after which they will be reviewed. Ultimately, it is only in discussion and negotiation with the 'users' that shortcomings can be identified and, where necessary, new approaches developed.

'Hyperline': The Information Browser

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ESA Information Retrieval Service (IRS), ESRIN, Frascati, Italy

State of the art information is vital to managers and engineers involved in complex projects. The already large and ever-growing volume of that information and the complexity of the computer query languages has made the accessing and retrieval process a cumbersome task. One of the natural ways in which humans acquire information is by 'browsing' – 'Hyperline' is a new information-retrieval tool that allows both 'concept' and 'reference' browsing, as well as providing the all-important semantic association between the users' concepts and those contained in the information-retrieval system itself.

Introduction

Scientists, engineers, managers and administrators are especially in need of information at the beginning of a new project, task or responsibility. This thirst for information is usually satisfied by going to the library, discussing with the librarian, and scanning journals, books or conference proceedings. Another method, and one that is being used more and more, is to enlist the help to an on-line information-retrieval system, like ESA's IRS. Alas, even after acquiring a password and gaining access to the system, there often remains one more hurdle: the command language necessary to formulate requests and searches for information.

To make access easier, IRS has developed Hyperline, a facility whose use does not require any formal training and via which the retrieval and browsing of information can be conducted within a user-friendly menu-driven environment.

Hyperline integrates two basic information-retrieval elements under a single unique user interface: 'document browsing' and 'navigation through concepts'. It has been developed in the framework of a model able to unify classical information-retrieval searching and the latest hypertext browsing approaches to information processing. It adapts the computer interfacing to the pattern of browsing and concept-to-concept association that seems particularly suited to the workings of the human mind.

Information to be browsed

On the ESA-IRS database, close to fifty-million bibliographic references are grouped into more than eighty 'collections', covering an immense range of scientific and technical information topics, including: Aerospace, Astronautics, Astrophysics, Agriculture, Biology, Chemistry, Physics, Engineering, Geology, Mathematics, Medicine, Building and Construction, Materials Sciences, Information Sciences, Meteorology, etc. The individual collections can each contain millions of bibliographic references. Several of the largest collections have auxiliary data structures that classify the references according to topic and subject, i.e 'conceptually'.

Concept association has been widely accepted in psychology as the most basic unit of thinking. Moreover, the intrinsic interdisciplinary nature of information itself elicits concept association. This is particularly true of aerospace information. Until now, computerised information systems have relied on scarcely interactive modes of working that have made this task very cumbersome. With Hyperline, such associations are immediate and clear. Hyperline shows easily, for example, that the concept of 'zero-gravity experiments' can be associated with 'crystal growth', and that 'locust monitoring' can be conducted via 'satellite remote-sensing' and 'geographical information systems'.

Current IRS users

The user population is rather heterogeneous in its interests and level of knowledge of the IRS system and its query language. It is spread across several tens of countries, and there are large differences in the types of equipment being used to connect to the ESA-IRS computer in Frascati (I) and perform the on-line searching (ranging from teletypes to personal computers and mainframes).

In order to make Hyperline available to all existing ESA-IRS users, the first implementation has been designed with a character-oriented interface to provide access to the service even from 'dumb' terminals. A second implementation, with a window interface, for access via PC is being prepared.

Hyperline is specifically aimed at users who are not familiar with the ESA-IRS query language and have perhaps never even used an information-retrieval system before. It has been designed to support those managers, engineers and scientists who know the 'concepts' of their interest, but who wish to be relieved of the burden of learning the intricate details of a specialist query language.

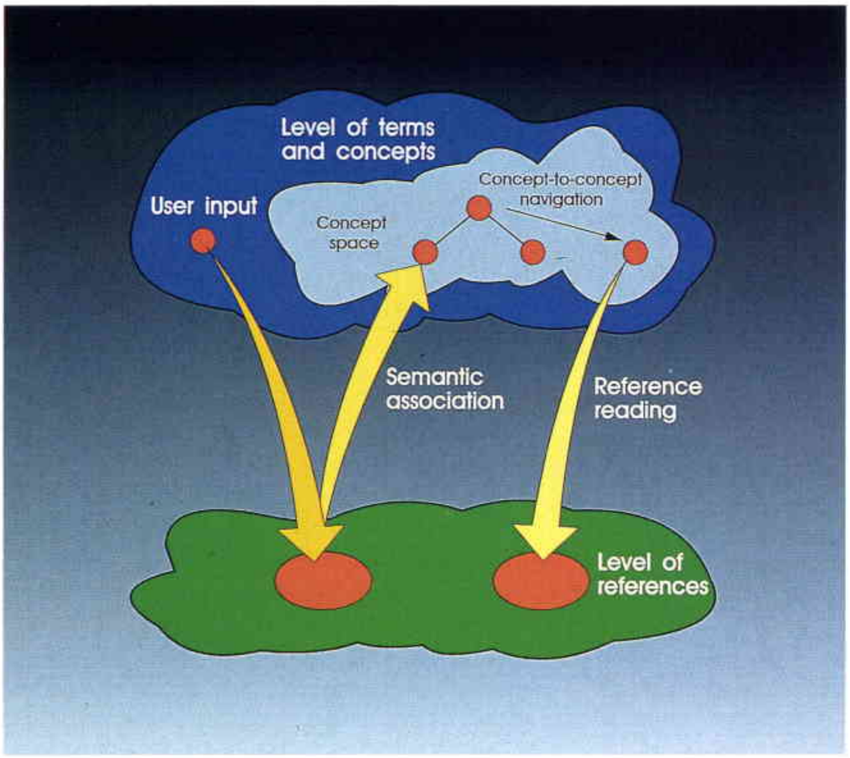


Figure 1. Architecture of the basic model of Hyperline

The browse capability

The facility

Computerised information for retrieval systems consists mainly of 'bibliographic references', usually with a title, an abstract, author name(s), publication medium and date. The information 'references' to journal articles, reports, books, dissertations, conference papers and the like. The references are usually prepared for the computer by information specialists, who classify the documents by identifying topics, subject areas and even individual concepts. In parallel with the classification of single documents, a knowledge base is built up from the concepts involved and their interrelationships. This knowledge base is then loaded into the computer together with the bibliographic references, thereby providing an enormous store of knowledge.

This knowledge can now be used and explored via the Hyperline facility, permitting 'navigation' through the concepts in the thesaurus, as well as the browsing and reading of references at any point in the navigation.

The implementation of the new facility has required the development of a new information-retrieval model to overcome the limitations of current information-system architectures. The database managed by an operational information-retrieval system is usually made up of two elements:

- the collection of bibliographic references
- the auxiliary data.

As mentioned above, the auxiliary data can be associated with each reference in order to represent its semantic content, and is also used to select and retrieve the references from the database in response to the user's queries. The new model is based on a two-level architecture. At the first level lies the collection of references of interest. The second level can be identified as that of concepts, i.e. the conceptual space in which semantically related concepts are placed.

The first level of the architecture, the plane of the collection of references, is managed by the information-retrieval system. The second level has been designed and implemented as a conceptual interface between the user and that collection. Hyperline implements the interactive use of the auxiliary data conceptual structure and the relationships between the level of documents and that of concepts, and vice versa. At the first level, the Hyperline interface makes the underlying handling of Boolean logic completely transparent to the user.

The architecture of the basic model is shown in Figure 1, while Figure 2 sketches the relationship between Hyperline and the more traditional ESA-Quest environment. It is important to note that Hyperline is domain-independent and therefore works for a wide variety of topics, ranging from aerospace to engineering and materials science. At present, it can be used with ten different, large bibliographic collections.

The results of a study on human/computer interaction with hypertext information-retrieval systems show that, for efficient information transfer and support and effective user/system interaction, the following functions have to be included in the interface (Fig. 3):

- semantic association
- concept navigation and back-navigation
- sequential and associative reading of references
- history
- support to query formulation.

Semantic association

The aim of the semantic-association function is to provide the user with the appropriate entry point into the concept network (knowledge base) stored in the system. In this way, the user does not have to have advance knowledge of the concepts in the knowledge base, because Hyperline suggests them. The user can formulate the concept of interest in normal words (natural language). The user-expressed concept is then mapped by the system into a list of semantically related concepts that form part of the knowledge-base managed by the system. This system-generated list of semantically related concepts serves as an entry point for the user to the auxiliary data structure. Via this entry point, the user can then start to interact with the system in order to acquire the information being sought via concept-to-concept navigation and document browsing.

In the example shown in Figure 4, the user is interested in the meaning of, and information about, the acronym 'SGML' (Standard Generalized Markup Language). SGML is not a stored concept in the knowledge base (the bibliographic file used in this example is INSPEC), which means that the user could not know which concepts are associated with SGML without having an in-depth knowledge of the query language. What Hyperline does is to provide the user with a list of suggested concepts that are semantically related to 'SGML', like 'Standards' and 'Electronic Publishing'. This semantic association is made using the knowledge stored in the auxiliary data of the bibliographic file. An inference mechanism, based on statistical analysis, has been implemented to perform the association between the user terms that appear in the bibliographic file and the concepts stored in the knowledge base.

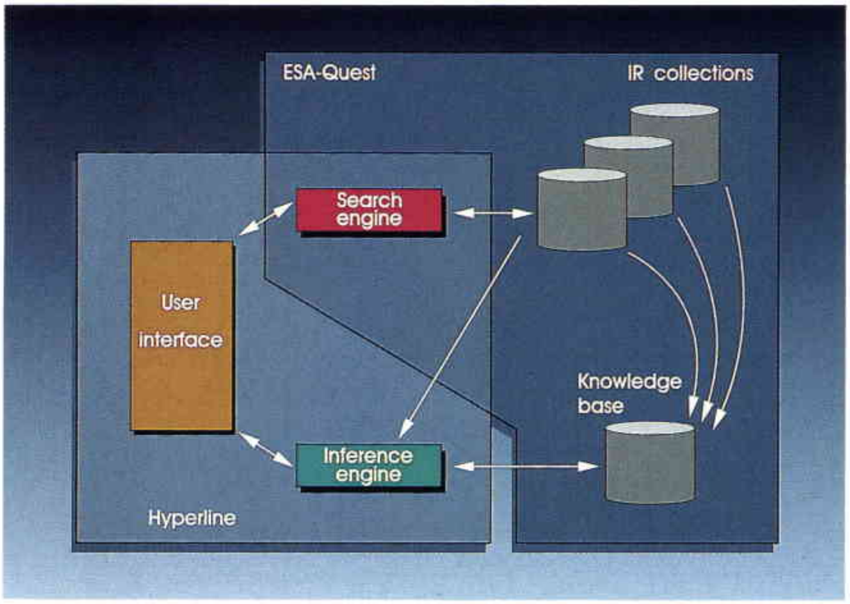


Figure 2. Hyperline relationships with the ESA-Quest environment

Navigation

The navigation function then gives the user the possibility to browse through the structure of the semantic concepts representing the information content of the collection of bibliographic references. In the example of Figure 4, the user can navigate the concept network by choosing, for example, the term 'Electronic Data Exchange' to get the semantic structure around this term, as shown in Figure 5.

Reference reading

At any time during the auxiliary-data-structure navigation, the user can choose the the option of showing bibliographic references. This option allows the references

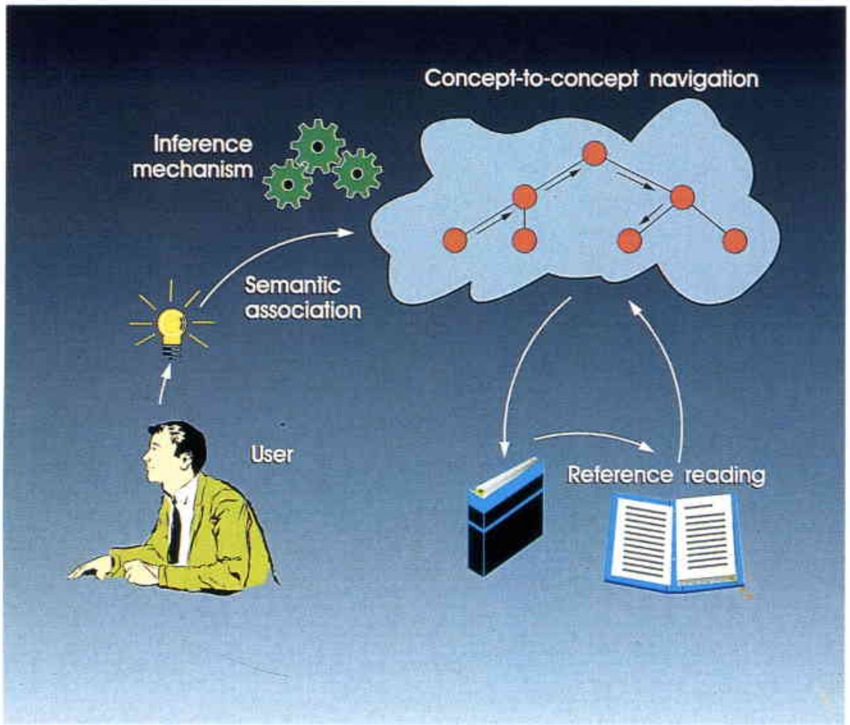


Figure 3. Functional schematic of Hyperline

containing the actual term or concept in the network (see Fig. 6) to be read. Again, with the application of the inference mechanism, it is possible to jump to semantically related references also.

The history function

The history function keeps track of the user/system interaction during any Hyperline session, displaying all functions executed during the navigation process. Because Hyperline's semantic-association feature allows the user to jump from concept to concept, and even from topic to topic, the history function has been designed to support the users if they should begin to lose their sense of context.

Support to query formulation

At any time during concept browsing, concepts can be selected and put aside for subsequent use in Boolean query formulation. The support to query formulation has been implemented with the idea of preparing the way for a hybrid information-retrieval system. In such a system the two elements of classical Boolean searching and hypertext browsing should be more intimately inter-connected. From a functional point of view, hypertext and retrieval functions should always be available at the same time. The use of menus makes the coexistence of hypertext and search functions difficult, and a new graphical interface will therefore be required to integrate hypertext and information-retrieval capabilities.

Conclusions

Hyperline, the new ESA-IRS hypertext environment, supports the browsing of and concept navigation through large collections of bibliographic information. It has been specifically designed to support access to large amounts of multi-disciplinary information for engineers and managers. The design supports, suggests and elicits concept associations. The ensuing computer/human interaction evolves according to patterns that emulate the workings of the human mind.

Figure 4. Example of semantic association

```
User Input:

  1 — SGML
________________________________________
Related thesaurus terms:

  2 — ELECTRONIC PUBLISHING
  3 — STANDARDS
  4 — WORD PROCESSING
  5 — DESKTOP PUBLISHING
  6 — ELECTRONIC DATA INTERCHANGE
________________________________________
```

Figure 5. Example of navigation

```
Thesaurus term: ELECTRONIC DATA INTERCHANGE
___________________________________________________
Ref  Items  Term                             Relation
 1     784  ELECTRONIC DATA INTERCHANGE
 2    4994  DATA HANDLING                    Previous
 3     993  EFTS                             Narrower
 4    5974  CAD/CAM                          Related
 5     763  INTEGRATED SOFTWARE              Related
 6   39674  STANDARDS                        Related
 7    4994  DATA HANDLING                    Broader
 8    4994  DATA HANDLING                    Top term
 9      11  DATA PORTABILITY                 Used for
10       6  DATA TRANSFER FORMATS            Used for
11     109  EDIF                             Used for
___________________________________________________
```

Figure 6. Example of reference reading for the 'Electronic Data Interchange' concept

```
Show item 1 of 784
Quest Accession Number: 91035746
  C91010855 INSPEC Conference Paper Issue 9103
  EDI security: A management perspective, Lennox, G.
  Proceedings of Compsec International 1990
  London, UK 10-12 Oct. 1990
  1990, p. 209-14, 0 Refs. Country of Publ.: UK
  Publisher: Elsevier Advanced Technol. Oxford, UK
  Pages: 519
  Treatment: G (GENERAL OR REVIEW)

  EDI electronic data interchange, is the electronic transfer
of commercial or administrative data using an agreed
standard to structure the message data.          —More—
```

Focus Earth

Combining Optical/Infrared and SAR Images for Improved Remote-Sensing Interpretation

J. Lichtenegger, ESA/Earthnet, ESRIN, Frascati, Italy

A series of satellite images is presented to demonstrate the potential, and in some cases the limitations, of different types of spaceborne-sensor data — optical/infrared data from Landsat's Thematic Mapper (TM), and microwave data from Seasat's Synthetic Aperture Radar (SAR) — specifically for land-use and coastal-mapping applications.

The area considered is the northeastern part of the Isle of Anglesey in the Irish Sea, connected to the UK mainland by two bridges (lower right corner) over the Menai Strait. The area consists largely of arable land and some woods. Bangor, the largest town in the area, lies at the entrance to the Strait.

Traditionally, good candidates for this type of application are TM channels 4, 3 and 2 (false-colour infrared) or 3, 2 and 1 (natural colour) images. The latter combination is especially valuable for coastal areas, because of the water-penetration capabilities in the visible part of the spectrum (Fig. 1). It was found, however, that channel 5 also shows detailed features in the tidal flats. The best channel combination was judged to be 5:3:1 for red, green, blue colours assigned in the displayed image (Fig. 2).

Figure 3 shows a Seasat L-band SAR image of the same area. Being a single-band image, the strength of backscatter towards the active microwave sensor is displayed in grey levels. Over the land, strong returns can be observed from woods and fields with high vegetation cover. Settlements also appear bright because of the many vertical and horizontal planes (houses, etc.) acting as corner reflectors. The peculiar appearance of the bridges in the lower left corner of Figure 3 stems from the type of construction used (material, structure and pillar arrangement). In the water, tidal flats and areas sheltered from the wind are black because of their smooth surfaces, whilst wind-swept areas produce greater backscatter and hence appear brighter.

The combined optical/microwave image is shown in Figure 4. The superpositioning was done using common features along the coastline. Making full use of previous experience, a linear combination of the TM channels was computed. The best visual results are obtained for: red, SAR data; green, mean value of channels 1,2 and 3; and blue, channel 5.

In Figure 4, over the land visually bright objects are shown in yellow if the surface is rough (settlements) and cyan (bare soil) if it is smooth. Vegetated areas vary from red (fields) and magenta to blue (woods) because of the higher surface roughness. It is worth noting that using SAR data allows some otherwise cloud-hidden information to be retrieved; this is also true for cloud-shadowed areas (lower left corner).

Over the sea, additional information about water depth is obtained from such an image combination, red areas being deeper than yellow ones because of penetration of the optical wavelengths and rough-water surface detection by the SAR.

The superpositioning of the images was achieved in this case via a global geometric transformation, which clearly has limitations. Whilst the fit seems to be perfect along the coast, mismatches can be observed at higher elevations due to the foreshortening effects of the SAR data. Although elevations in the western (left) part do not exceed 150 m, a rigorous further correction is needed. To-day's established techniques use high-resolution cartographic elevation information to correct SAR data. For the forthcoming ERS-1 data, such geocoding will be done at the ERS Processing and Archiving Facilities (PAFs) in the UK, Germany and Italy on an operational basis.

Focus

Image Data:
- Landsat-5 Thematic-Mapper Frame 205/23 of 22 June 1988, acquired by Earthnet's Kiruna Station in Sweden.
- Seasat/SAR Orbit 633 of 10 August 1978, acquired by Earthnet's Oakhanger Station in the UK, and processed by Earthnet in Frascati, Italy.

Image Processing:
- Earthnet, ESRIN, Frascati (I).

Figure 1. Landsat Thematic-Mapper, channel combination 3:2:1 (RGB) for 15 km x 12 km area of Anglesey in North Wales

Figure 2. Landsat Thematic-Mapper channel combination 5:3:1 for the same area as in Figure 1, optimised for coastal- and land-use mapping applications

ESA Point of Contact

Earthnet User Services
ESRIN
Via Galileo Galilei
00044 Frascati, Italy

Tel. 39 6 9401218/210
Telex 616468 EURIME I
Fax. 39 6 9426285

Figure 3. Seasat/SAR image of the same area as in Figure 1. The bright areas on the sea are due to wind-evoked rougher surfaces which contrast with the smooth surface of the tidal flats or calm water. Over the land, bright areas are settlements (with texture), woods (field-like pattern), or steeper hill slopes (long linear features) facing radar illumination from the southwest

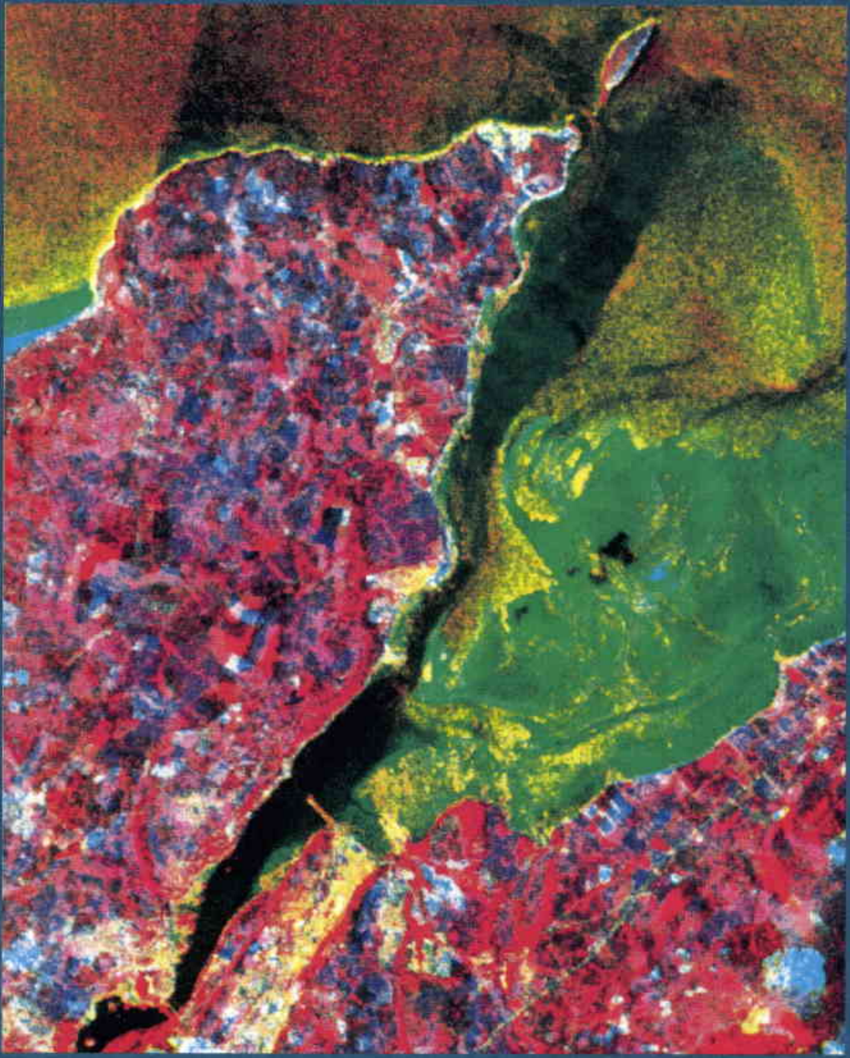


Figure 4. Combination of Seasat/SAR (red), 'optical brightness', i.e. linear combination of channels 1:2:3. (green), and channel 5 (blue), showing potential uses especially in the tidal-zone area. Limitations on data use are apparent in the hilly areas, where mismatches are observed. Geocoding using digital elevation data would fully compensate for this error, and will be operational for ERS-1 SAR data

In Brief

New Earthnet ERS Central Facility Inaugurated in Italy

On 12 April, Mr Jean-Marie Luton, the Agency's Director General, and Senator Learco Saporito, Undersecretary of State at the Italian Ministry for University and Scientific and Technological Research, inaugurated the new Earthnet ERS Central Facility (EECF) at the Agency's ESRIN Establishment in Frascati, near Rome. The EECF is the first element of the Payload Data Coordination Centre planned for the coming years.

Prof. Francesco Carassa, Chairman of the ESA Council, Prof. Luciano Guerriero, President of the Italian Space Agency, and many other high-ranking officials from both Government and industry attended the inauguration.

The Agency's ERS-1 satellite, with its unique microwave radar instrumentation able to 'see' through clouds and darkness, is designed to gather vast amounts of data of the Earth and its environment. ERS-2, and the Polar-Orbit Earth Observation Missions (POEMs) that will follow in the late 1990s will provide the necessary long-term continuity of data flow, and will thereby help to give us a better understanding of evolution patterns and statistics, complementing available data from non-radar missions.

The ground segment that receives and processes this information and makes it available to the user communities will be of paramount importance to the success of both the ERS and the subsequent Earth-observation missions. Earthnet's experience in acquiring, processing, archiving and distributing remote-sensing data from non-ESA missions since 1978 has provided the basis for the setting-up of the EECF, ready to ensure efficient exploitation of ERS-1 payload data.

The EECF has round-the-clock telecommunications links: with the Mission Management and Control Centre at ESOC, in Darmstadt (D), which executes the mission operation plan prepared by the EECF; with the ERS ground stations, for the scheduling of near-real-time distribution of Fast-Delivery (FD) products; with the Processing and Archiving Facilities for data-product orders; and with the users themselves, in order to provide access to the online worldwide catalogue of ERS data and to exchange messages.

The EECF will therefore be ESA's prime interface not only with the established Earth-observation user communities around the World — meteorological services, research centres, geophysical and oceanographic institutes, universities, national space agencies, etc. — but also with the many commercial entities that are now beginning to exploit remote-sensing satellite data for better management of their activities.

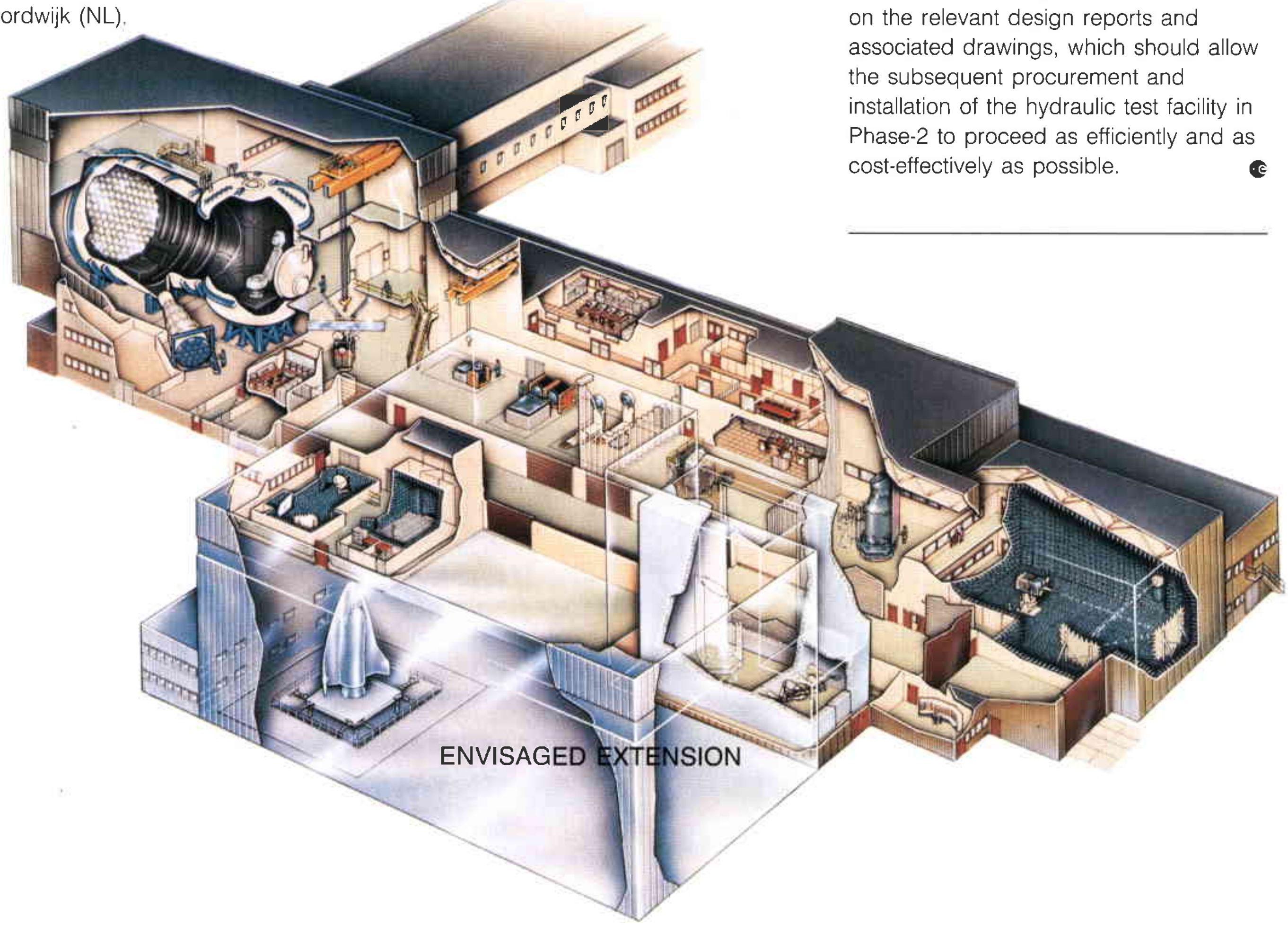
Mr J-M. Luton, ESA's Director General, addresses the assembled dignitaries: seated in the first row, from right to left, are: Monsignor Matarrese (Bishop of Frascati), Signor Romani (Mayor of Frascati), Prof. Carassa (Chairman of ESA Council), Prof. Guerriero (President of the Italian Space Agency), Ing. Pucci (Chief Executive of Alenia Spazio), and Ing. Mazzuca (Director of the Office for Space Affairs at the Italian Ministry of Science and Technology)

Additional Test Facility to be built at ESTEC

During its meeting on 12 and 13 March, ESA's Industrial Policy Committee approved the procurement proposal for Phase 1 of the Hydraulic-Shaker Test Facility to be constructed at ESTEC, in Noordwijk (NL).

This Hydraulic Shaker will be an essential element for the testing of large Ariane-4 and Ariane-5 payloads, such as XMM, the Polar Platform, Hermes, etc. and must therefore be operational not later than 1996, according to present programme schedules.

During this first phase, the mechanical and hydraulic configuration and the electronic hardware and software layout will be defined, and it will be possible to adapt the facility's performance to evolving programme requirements, without major cost impact. This result will be a detailed specification based on the relevant design reports and associated drawings, which should allow the subsequent procurement and installation of the hydraulic test facility in Phase-2 to proceed as efficiently and as cost-effectively as possible.



ESA's Director General, Mr J-M. Luton, presenting Senator Saporito with a 1:30 scale model of ERS-1 during the Press Conference following the ERS EECF Inauguration

MOP-2 Launched by Ariane

With yet another successful Ariane launch (V42) on the night of 2 March, Meteosat MOP-2 was placed into an elliptical transfer orbit. Early telemetry received at the European Space Operations Centre (ESOC) in Darmstadt (D) showed the spacecraft to be in excellent condition.

On Monday 4 March, at 13.34 h UT, the spacecraft's Apogee Boost Motor was fired to place it into geostationary orbit. This manoeuvre was also completed successfully and the motor ejected, as foreseen, shortly after burn-out at 13.39 h.

The spacecraft then drifted towards its intended geostationary position at 0°, where, as 'Meteosat-5', it will replace Meteosat-4, which will then become the in-orbit back-up spacecraft. (See next item for further details).

MOP-2's companion spacecraft on the dual launch was the Astra-1B direct-broadcast satellite owned by Société Européenne des Satellites. After three firings of its bi-propellant Apogee Boost Motor, on 3, 6 and 8 March, this satellite was also placed safely into geostationary orbit. Its solar panels and communications antenna were then deployed successfully and the satellite began drifting slowly towards its final operating position at 19.2°E, which it should reach by 23 March 1991.

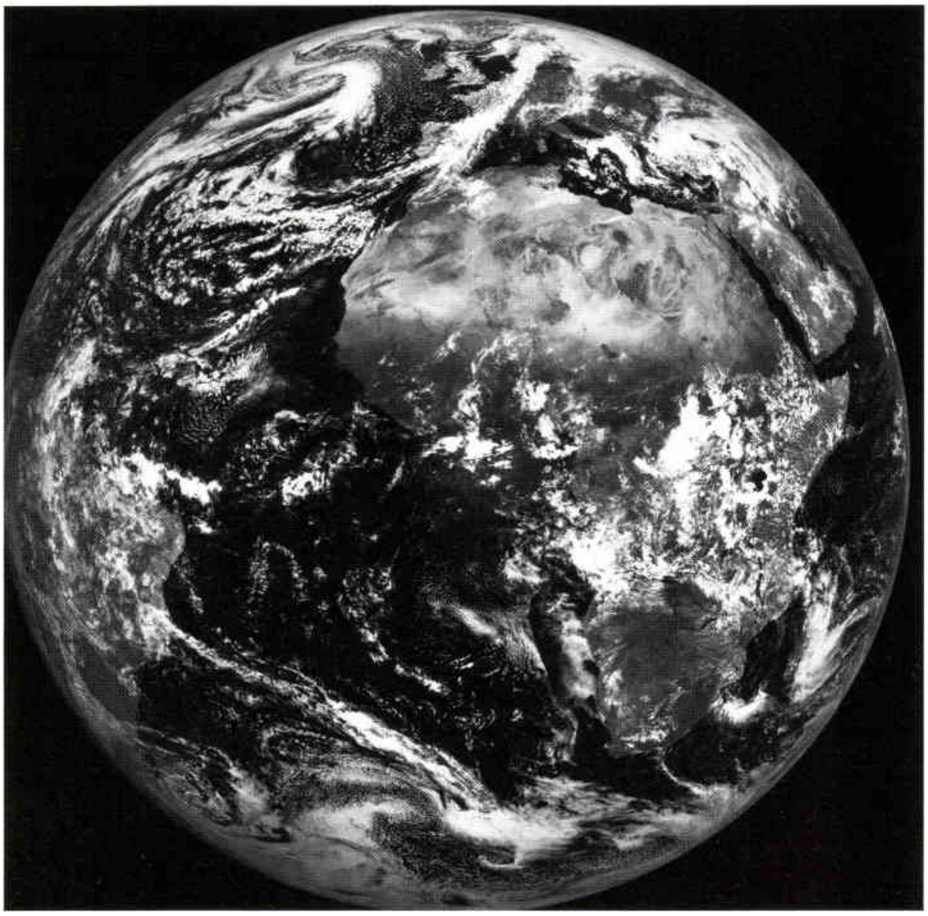
First Images Aquired by MOP-2 Satellite

ESA resumed its commissioning of MOP-2 (second Meteosat Operational Programme satellite) on 3 April 1991, at the end of a period of eclipses in orbit. On the same day, the spacecraft, launched on 2 March by an Ariane 44LP vehicle, acquired its first image.

The sequence of commissioning events, controlled from the European Space Operations Centre (ESOC) in Darmstadt, Germany, started with the removal, using pyrotechnics, of all instrument protection items: ejection of the radiometer baffle cover, release of the radiometer bearings to allow scanning, and ejection of the radiometer cooler cover. MOP-2 was then ready to acquire its first image in the 'visible' part of the electromagnetic spectrum.

On 4 April, the spacecraft's other imaging channels were activated and the first images in the thermal-infrared and water-vapour regions of the spectrum acquired.

This very important milestone having been successfully passed, the spacecraft is now being prepared for entry into operational service, currently scheduled for 2 May. MOP-2 will later be officially handed over to its new owner, the European Meteorological Satellite Organisation (Eumetsat), and will be re-designated 'Meteosat-5'.



First image acquired by MOP-2/Meteosat-5, in the visible part of the spectrum, at 11.55 GMT on 3 April 1991

US Aerospace Award Goes to ESOC

Kurt Heftman, Director of the European Space Operations Centre (ESOC) and David Wilkins, Flight Operations Director at ESOC for many ESA missions, were honoured by the American magazine Aviation Week & Space Technology at ceremonies in Washington in April this year.

The magazine's annual Aerospace Laureate awards are presented to individuals and teams who have made significant contributions in the global field of aerospace in the past year or during a lifetime of service. Honourees are selected from nominations by Aviation Week's editors in six categories: Commercial Air Transport, Operations, Electronics, Space/(Missiles, Aeronautics/Propulsion and Government/ Military.

The distinction in the Space/Missiles category 1990 was awarded to Kurt Heftman and David Wilkins for leadership that enabled the European Space Agency to successfully launch, and in a number of cases salvage, a series of deep space probes and Earth orbital missions throughout the 1980s and in 1990.

From left to right, Mr Kurt Heftman, Mr Donald Fink, Editor in Chief, Aviation Week and Space Technology, and Mr David Wilkins

ESA and the Canadian Space Agency Sign Five New Agreements

At the ESA Council Meeting in Paris on 20 and 21 March 1991, the Agency's Director General, Mr. Jean-Marie Luton, and Dr. Larkin Kerwin, Director General of the Canadian Space Agency, signed five Agreements covering Canada's participation in future ESA Programmes.

As a result, Canada will be taking part in:

— the Hermes Development Programme
— the development and exploitation phases of the ERS-2 Programme (Canada already participates in the ERS-1 Programme)
— the first Polar-Orbit Earth-observation Mission (POEM-1) using the Columbus Polar Platform
— Phase-4 of the Agency's Advanced Systems and Technology Programme (ASTP-4), and
— the Data Relay and Technology Mission (DRTM) Programme.

Canada's links with ESA date back to the mid-1970s, when it was first granted 'Observer Status'. Since 1979 it has maintained even closer ties with ESA, under the terms of three successive Cooperation Agreements. Canada is also a long-standing contributor to ESA's Telecommunications Programme and has been heavily involved in the large Olympus communications satellite programme.

With these new Agreements, almost twenty years of close cooperation between Canada and ESA and its Member States will be strengthened still further.

Dr. Larkin Kerwin (seated left) and Mr Jean-Marie Luton

ESA Signs Cooperation Agreement with Hungary

On 10 April 1991, in Venice (Italy), Mr Philip Goldsmith, the Agency's Director for Earth Observation and Microgravity, acting on behalf of ESA's Director General, signed an Agreement covering cooperation in the exploration and use of outer space for peaceful purposes with the Hungarian Minister for Research and Technology, Mr Ernö Püngor.

This Agreement – the first of its kind to be signed by ESA with an Eastern European Country – is a result of a visit to the Agency by a Hungarian Delegation in May last year, and a reciprocal visit by an ESA Delegation to Hungary two months later.

It is a first step towards cooperation between ESA and Hungary in the areas of: space science; Earth observation, and environmental protection in particular; and fundamental research in the fields of microgravity and telecommunications. Joint projects in these sectors should follow, as well as fellowships and exchanges of experts, training courses or joint symposia and conferences, and access by Hungary to the Agency's European Space Information System (ESIS).


Mr Ernö Püngor (right) and Mr Philip Goldsmith signing the cooperation Agreement

Rumanian Delegation Visits ESA

On Wednesday 13 March 1991, the Agency received a Delegation from Rumania led by Prof. Stefan Ispas, Rector of the Bucharest Academy of Technology. The aim of the talks was to establish formal contacts and to discuss the prospects for future cooperation in the space-science, remote-sensing, microgravity, and telecommunications domains.

During the meeting, ESA was invited to send a Delegation of its own to Rumania to visit the various bodies and institutes there involved in space activities.

Bucharest was recently the venue for 'Satelcomm '91', a pan-European satellite-telecommunications conference and exhibition (24—26 April 1991) organised by ESA in conjunction with the European Broadcasting Union (EBU) and Eutelsat.


Mr M. Häkkänen (left), Finland's Ambassador to France, and Mr J.-M. Luton, Director General of ESA, at the signing ceremony

Finland Signs Four Agreements with ESA

On 19 January 1991, in Paris, Mr M. Häkkänen, Finland's Ambassador to France, and Mr J.-M. Luton, ESA's Director General, signed four Agreements relating to the Finnish Government's participation in:

(i) the ERS-2 Programme (Phase-E), in the remote-sensing domain

(ii) the Polar-Orbit Earth-Observation Mission (POEM-1) Preparatory Programme, also a remote-sensing endeavour

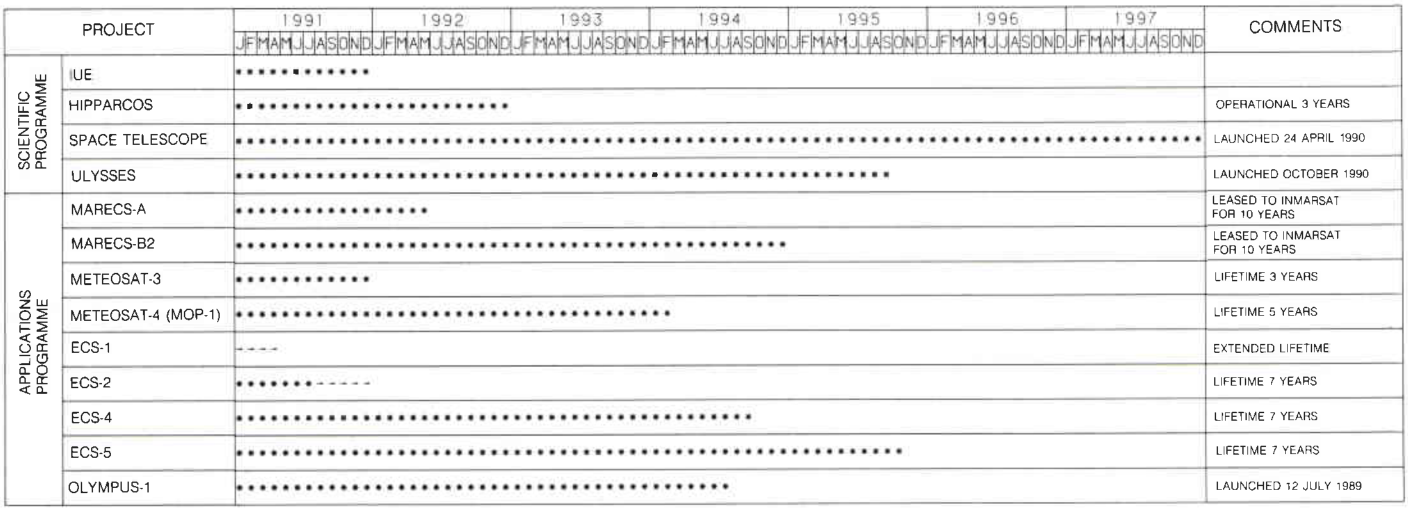
(iii) the Data Relay and Technology Mission (DRTM), a telecommunications programme, and

(iv) Phase-4 of the Agency's Advanced Systems and Technology Programme (ASTP-4).

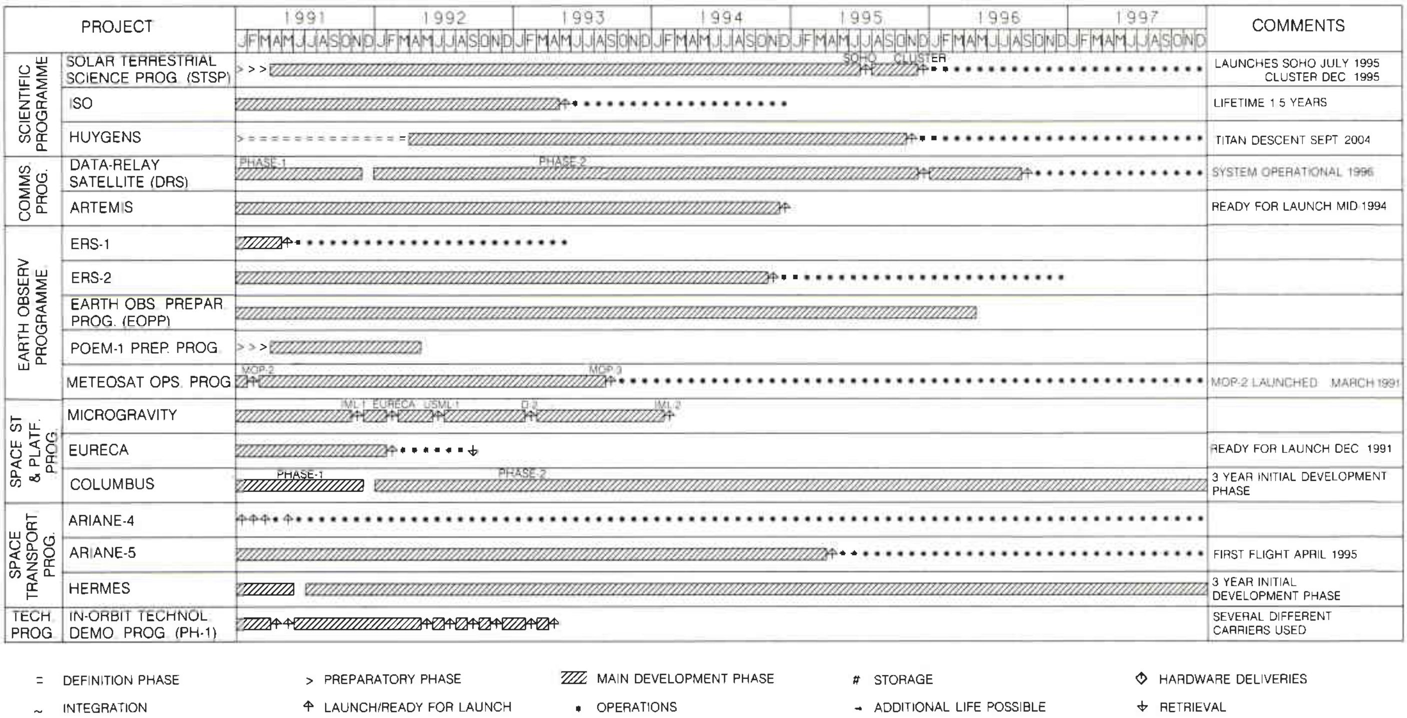
These signings further enhance the involvement of Finland, an Associate Member of ESA, in the European space scene.

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

In Orbit / En orbite



Under Development / En cours de réalisation



Hipparcos

Hipparcos continue de répertorier les positions et les mouvements propres des étoiles. Ce satellite, dont la mission a commencé il y a dix-huit mois, a déjà acquis un volume de données suffisant pour que les équipes chargées de la réduction des données puissent en extraire la position exacte, les parallaxes (distance) et les mouvements propres de chacune des 120 000 étoiles inscrites au programme d'observation. Ces équipes, responsables du traitement des données d'Hipparcos sont parvenues fin 1990 au stade de la toute première 'solution de la sphère' ce qui a conduit aux premières estimations de la position et de la distance d'une petite partie des étoiles observées par Hipparcos.

Ces résultats démontrent déjà que la qualité des données du satellite est exceptionnelle et qu'elles peuvent être réduites de la manière dont on l'avait prévu pendant la phase de préparation de la mission. A partir des réductions de données, on obtient une grande quantité de données photométriques de haute précision ainsi que des informations sur des étoiles doubles dont on ignorait jusqu'ici l'existence.

Ulysse

Après la disparition, à la mi-décembre, de l'effet de nutation qui avait perturbé le véhicule spatial à la suite du déploiement de son mât axial de 7,5 m, l'ensemble du fonctionnement d'Ulysse a été normal, à l'exception d'une anomalie de commande temporaire. Des données scientifiques sont recueillies de façon presque continue et on est parvenu jusqu'ici à une couverture de 98% en moyenne. Un essai du système de radioscience de bord et au sol a été exécuté lors de la première période d'opposition, au début de l'année.

Jusqu'ici, l'évaluation des données s'est fondée dans la plupart des cas sur les fichiers dits 'de visualisation rapide' fournis par le système d'enregistrement de données du JPL. Ces moyens de visualisation rapide ont été mis en place pour permettre aux équipes d'expérimentateurs de transmettre aux instituts auxquels ils appartiennent, via le réseau SPAN/NSI, des séries de données relativement limitées, acquises durant les séquences de poursuite en temps réel. Malgré quelques difficultés de mise en route, la production de bandes de données expérimentales a maintenant commencé et l'arriéré actuel devrait être liquidé sous peu.

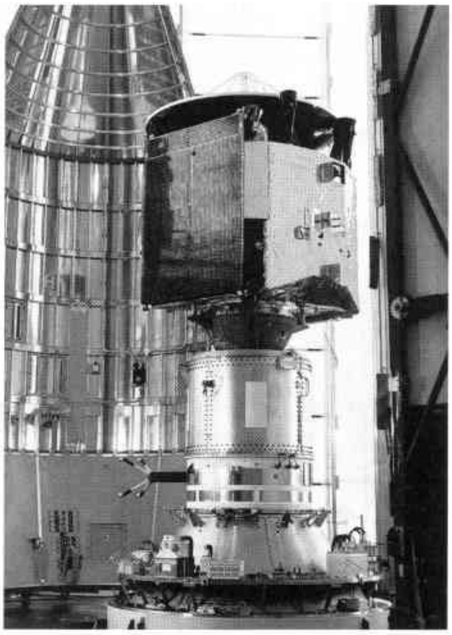
Le potentiel scientifique de la mission a été clairement démontré lors de la récente réunion du groupe de travail scientifique Ulysse qui s'est tenue au JPL à la mi-janvier. Lors de cette réunion, les représentants de chacune des expériences ont été invités à présenter leurs premiers résultats. Les données des deux magnétomètres confirment le très faible champ parasite créé par le véhicule spatial (moins de 0,1 nanotesla), ce qui témoigne du succès du programme de propreté magnétique. Les chercheurs responsables de l'expérience sur les ondes radio et les ondes de plasma, qui fait appel aux antennes du véhicule spatial à monture axiale et sur bras filaire, ont rapporté l'observation de toute une variété de phénomènes dans ce domaine, y compris des sursauts radio solaires de type III, des sursauts d'ondes kilométriques de type auroral et des sursauts radio en provenance de Jupiter. L'expérience sur la composition du vent solaire, la première de son espèce à mesurer en continu la charge ionique du vent solaire, est complémentaire des instruments d'étude des ions et électrons du vent solaire. Les expériences sur le rayonnement cosmique et les particules chargées à haute énergie ont enregistré de nombreux cas dans lesquels l'augmentation du nombre des particules était associée à des éruptions solaires ou à d'aures phénomènes énergétiques solaires. Bien que seule une analyse préliminaire en ait été faite à ce jour, les données de l'instrument sur le rayonnement cosmique de haute énergie démontrent déjà l'excellente résolution isotopique offerte.

Embarquée dans l'espace pour la première fois dans le cadre de la mission d'Ulysse, l'expérience sur le gaz neutre interstellaire a assuré avec succès la détection directe d'atomes d'hélium neutre. L'activité solaire étant proche de son maximum, l'instrument d'étude des sursauts gamma et du rayonnement X solaire a enregistré de nombreuses éruptions solaires dans le rayonnement X dont la corrélation peut être établie avec les observations d'éruptions solaires de plusieurs autres expériences d'Ulysse.

Une caractéristique de base de l'ensemble des données d'Ulysse qui se dégage déjà des résultats limités obtenus à ce jour réside dans la nature complémentaire d'un grand nombre de recherches. C'est ainsi par exemple que les paramètres fondamentaux du vent solaire peuvent être dérivés de plusieurs instruments différents assurant une redondance poussée. Il en va de même pour les différentes expériences sur les particules chargées dont les gammes d'énergie se recouvrent en partie. Les spectres composites d'énergie protonique des éruptions solaires par exemple, qui utilisent des données d'instruments différents, présentent une bonne cohérence. En bref, la haute qualité des résultats scientifiques préliminaires obtenus à ce jour laisse bien augurer du succès de la mission dans son ensemble.

Marecs

Peu avant Noël, Marecs-A en poste à 178° Est au-dessus du Pacifique, est entré dans sa dixième année en orbite. Auparavant, son excellente condition avait permis de pousser la puissance de sortie de l'amplificateur en bande L pour



Marecs-A ready for launch

Lancement de Marecs-A

Hipparcos

The Hipparcos satellite continues its mapping of star positions and motions. 1.5 years into its mission, the satellite has already acquired sufficient data for the data-reduction teams to be able to extract positions, parallaxes (distances) and proper motions for all of the 120 000 stars in the observing programme. The first, very preliminary, 'sphere solution' was completed at the end of 1990 by the data-reduction teams in charge of Hipparcos data processing. This has led to the first position and distance estimates for a small fraction of the Hipparcos stars.

The results already demonstrate that the quality of the satellite data is outstanding, and that the data can be reduced in the manner foreseen throughout the mission-preparation phase. A very substantial quantity of high-precision photometric data, as well as information on previously unknown double stars, is also being generated from the data reductions.

Ulysses

Following the disappearance in mid-December of the nutation-like motion that had disturbed the spacecraft after deployment of the 7.5 m axial boom, all Ulysses operations, with the exception of a temporary commanding anomaly, have been nominal. Scientific data are being collected on a nearly-continuous basis and 98% coverage has been achieved on average so far. A test of the onboard and ground radio-science systems was conducted during the first opposition period early this year.

So far, the majority of the data evaluation has been based on so-called 'quick-look' files provided by the JPL Data Records System. This quick-look facility has been established to enable experiment teams to transfer relatively small blocks of data acquired during real-time tracking passes to their home institutes via the SPAN/NSI network. Despite initial teething troubles, the production of experiment data tapes has now commenced and it is expected that the current backlog will be removed in the near future.

The scientific potential of the mission was clearly demonstrated at the recent Ulysses Science Working Team Meeting, held at Jet Propulsion Laboratory (JPL) in mid-January. At this meeting, representatives from each experiment were invited to present their initial results.

Data from the two magnetometers confirm the very low (less than 0.1 nT) background field due to the spacecraft, testifying to the success of the magnetic-cleanliness programme. Investigators from the Radio and Plasma Wave Experiment that utilises the wire boom and axial spacecraft antennas reported the observation of a wide variety of wave phenomena, including Type-III solar radio bursts, auroral kilometric bursts and radio bursts of Jovian origin. The Solar-Wind Composition Experiment is the first of its kind to make continuous ion charge-state measurements in the solar wind, and is complementary to the Solar-Wind Ion and Electron instruments. The energetic charged-particle and cosmic-ray experiments have recorded a large number of particle increases associated with solar flares and other energetic events on the Sun. Even though only a preliminary analysis has been carried out, data from the high-energy cosmic-ray instrument already demonstrate the excellent isotopic resolution available.

Flown in space for the first time on the Ulysses mission, the Interstellar Neutral Gas experiment has successfully accomplished the direct detection of neutral helium atoms. With the Sun at close to maximum activity, the Gamma Burst and Solar X-ray Instrument has recorded a large number of solar-flare X-ray events that can be correlated with solar-flare observations from a number of other Ulysses experiments.

A key feature of the overall Ulysses data set that is already apparent from the limited results obtained so far is the complementary nature of many of the investigations. For example, fundamental solar-wind parameters can be derived from a number of different instruments, providing a high degree of redundancy. A similar situation exists with the various charged-particle experiments, which have partially overlapping energy ranges. Composite solar-flare proton energy spectra, for example, taking data from different sensors, show good intercalibration.

In summary, the high quality of the preliminary scientific results obtained to date bodes well for the overall success of the mission.

Marecs

Marecs-A, stationed above the Pacific at 178°E, started its tenth year in orbit shortly before Christmas. Due to the spacecraft's continuing good health, it was possible at that time to switch the L-band power amplifier to a higher output level, thus significantly increasing the traffic capacity for the busy holiday season. At the end of January, a reduction in available power, resulting from an anomaly on the solar array, meant a return to the specified capacity.

Marecs-A is now experiencing its nineteenth eclipse season.

Marecs-B2, stationed above the Atlantic Ocean at 55.5°W since the beginning of November, has continued to function in an enhanced-power (high-capacity) mode. Operations have been uneventful and the spacecraft has functioned completely nominally.

OTS

OTS-2 switched off

OTS-2, launched on 11 May 1978, was ESA's first geostationary telecommunications satellite and was developed to provide in-orbit verification of the proposed technology for a future European communications-satellite system. It was experimental in nature, being primarily intended to demonstrate telecommunication techniques, but it also provided a pre-operational service for the Eutelsat organisation. OTS-2's predecessor, OTS-1, had been lost due to failure of its Thor-Delta launch vehicle.

The OTS-2 mission was originally planned to last three years, although sufficient propellant was loaded for five years, and all equipment had a design life of seven years. The satellite was used by Eutelsat until the end of 1983, when the ECS series came into operation. Since then, OTS-2 has continued to be used by ESA for further experimental work.

Throughout its long life, OTS-2 was impeccably controlled and monitored by a dedicated team at ESOC in Darmstadt (D).

répondre à la demande en trafic, en nette augmentation pendant la période des vacances. Fin janvier, un incident de fonctionnement des panneaux solaires a provoqué une réduction de la puissance disponible qui est revenue à sa valeur nominale. Actuellement et pour la dix-neuvième fois, Marecs-A, est en période d'éclipse.

Marecs-B2, en poste au-dessus de l'Atlantique à 55° Ouest depuis début novembre, continue à bien fonctionner à puissance augmentée. Son exploitation se poursuit sans aucun incident et toutes ses fonctions sont normales.

OTS

Fin de service pour OTS-2

OTS-2, premier satellite géostationnaire de télécommunications de l'ESA, a été réalisé pour vérifier en orbite des technologies qui seront utilisées dans les futurs systèmes européens de télécommunications par satellite. Satellite expérimental, sa première mission fut de faire la démonstration de techniques de télécommunications; il assura également un service préopérationnel à Eutelsat. OTS-1, son prédécesseur, avait été perdu par suite du mauvais fonctionnement de son lanceur, une fusée Thor-Delta. OTS-2 fut lancé le 11 mai 1978.

A l'origine, la mission devait durer 3 ans bien que suffisamment d'ergols aient été embarqués pour 5 ans et que tous les équipements aient une durée de vie théorique de 7 ans.

Eutelsat a utilisé ce satellite jusqu'en 1983. Depuis, alors que la série ECS était mise en service, l'ESA a continué à utiliser OTS-2 à d'autres fins expérimentales.

Tout au cours de sa longue vie, OTS-2 a été commandé et suivi de manière remarquable par une équipe de l'ESOC à Darmstadt (Allemagne) spécialement affectée à cette tâche. Les renseignements ainsi obtenus sur la conception des satellites géostationnaires à stabilisation triaxiale sont très précieux tant du point de vue de la charge utile que de celui de la plate-forme. En outre, on a bien entendu acquis une expérience utile en matière d'exploitation de ce type de satellite.

Le dernier des huit ATOP a cessé de fonctionner fin 1990, soit plus de douze ans après le lancement du satellite. OTS-2 ne disposait donc plus de capacité de charge utile et il ne lui restait qu'une quantité limitée d'ergols utilisables. Fidèle à son principe de réduire à un minimum les risques de collisions sur l'orbite géostationnaire, l'Agence a décidé de placer OTS-2 sur une autre orbite.

Le 2 janvier 1991, après une première série d'essais de fin de vie (EOL), la première de quatre impulsions a été déclenchée pour amener le satellite sur son orbite de dégagement. La manoeuvre a réussi et OTS-2, qui gravite désormais à 320 km au dessus de l'orbite des satellites géostationnaires, a été soumis à de nouveaux essais EOL qui ont donné jusqu'à la fin des renseignements précieux.

C'est finalement le 10 janvier qu'OTS-2 a été mis en spin à plat; on a ensuite procédé aux derniers contrôles pour s'assurer que le satellite ne présentait aucun danger. Le 17 janvier, l'émetteur VHF a été définitivement coupé alors qu'OTS-2 continue de dériver de 4° par jour, à 52,3° Ouest, sur une orbite inclinée à 6,9°.

ECS

Voilà près de huit ans que l'Europe a lancé ECS-1, son deuxième satellite opérationnel de télécommunications. L'Agence avait entrepris ce programme en s'appuyant directement sur les résultats convaincants de la mission du satellite préopérationnel OTS-2.

Cinq satellites de la série ECS ont été lancés:
- *ECS-1, juin 1983*
- *ECS-2, août 1984*
- *ECS-3, septembre 1985*
- *ECS-4, septembre 1987*
- *ECS-5, juillet 1988.*

ECS-3 a été perdu par suite d'une défaillance du lanceur mais les quatre autres ont été correctement mis à poste sur orbite géostationnaire.

Tous les satellites de la série ont été fournis par l'ESA pour le compte d'Eutelsat, leur propriétaire et exploitant actuel. Ils sont commandés et suivis par la station sol de l'ESA à Redu (Belgique).

Leurs positions actuelles sont les suivantes:
- *ECS-1, 16°E*
- *ECS-2, 4°E*
- *ECS-4, 7°E*
- *ECS-5, 10°E*

La durée de vie théorique de ces satellites est de sept ans. Les réservoirs d'ECS-1 contenaient suffisamment d'ergols pour qu'il soit maintenu à poste Nord-Sud pendant 5,9 ans; la quantité d'ergols pour ECS-2, ECS-4 et ECS-5 avait été calculée pour un maintien à poste de 4,9 ans. Les manoeuvres Nord-Sud d'ECS-1 et ECS-2 ont maintenant cessé mais elles se sont poursuivies bien au-delà des dates prévues à l'origine.

Les charges utiles des satellites de la série ECS ont aujourd'hui accumulé près d'un million et demi d'heures canaux de fonctionnement et là encore les objectifs devraient être dépassés. Sur les 54 amplificateurs à tubes à ondes progressives (ATOP) montés sur l'ensemble des satellites géostationnaires ECS, 43 sont encore en service.

Eutelsat devrait cesser d'exploiter ECS-1 au cours du premier semestre 1991 bien que, le cas échéant, les réserves en ergols et l'état de la charge utile pourraient autoriser une utilisation beaucoup plus longue. Il en est de même pour ECS-2 qui devrait être exploité bien au-delà de sa durée de vie théorique. Les capacités de charge utile d'ECS-4 et ECS-5 sont actuellement nettement supérieures à celles que visait la conception initiale et continueront à l'être dans un avenir prévisible.

Olympus

Les quatre charges utiles du satellite Olympus-1 continuent de bien fonctionner. En revanche, le 28 janvier à 22.40 h GMT, un incident de fonctionnement du système d'alimentation a fait brusquement chuter la puissance électrique et a obligé les charges utiles à passer automatiquement en mode d'attente. Après soixante secondes, la puissance normale a été rétablie et les charges utiles remises en service ont fonctionné normalement. A la fin de cette période, le panneau solaire sud a cessé d'être pointé sur le Soleil et

The satellite provided valuable information about the design of a three-axis-stabilised satellite in geostationary orbit, both from a payload and a platform viewpoint. In addition, of course, a great deal of useful experience was obtained in the operation of this type of satellite.

More than 12 years after OTS-2's launch, the last of the eight Travelling-Wave-Tube Amplifiers (TWTAs) failed at the end of 1990. OTS-2 then no longer had any payload capacity and also had only a limited amount of usable propellant remaining. Consequently, in keeping with the Agency's policy of minimising the risk of collisions in the geostationary ring, the decision was taken to re-orbit OTS-2.

A series of initial end-of-life (EOL) tests were performed, followed on 2 January by the first of four burns to place OTS-2 into a higher 'graveyard' orbit. This re-orbiting was successfully completed with the resulting altitude 320 km higher than that for the geostationary orbit. Further EOL tests were performed in this new orbit, the satellite still yielding valuable experience to the end.

The satellite was eventually put into a flat spin on 10 January and final checks made to ensure that the system was safe. With the satellite drifting at 4°/day, its inclination at 6.9° and longitude at 52.3°W, the VHF transmitter was finally switched off on 17 January.

ECS

It has been almost eight years since the launch of Europe's second operational communications satellite ECS-1. The Agency's embarkation on this successful programme was a direct result of the convincing performance of its pre-operational predecessor OTS-2, launched in May 1978.

Five spacecraft have been launched in the ECS series:
— ECS-1, June 1983
— ECS-2, August 1984
— ECS-3, September 1985
— ECS-4, September 1987
— ECS-5, July 1988

ECS-3 unfortunately suffered a launch failure, but the other four were successfully placed into geostationary orbit.

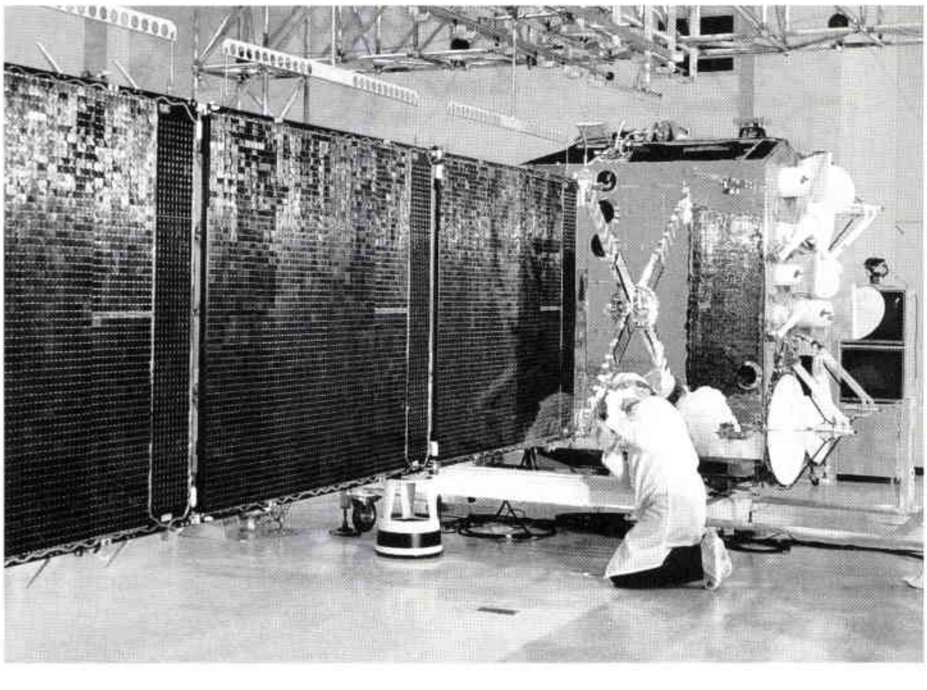
All spacecraft in the series were procured by ESA on behalf of their present owner and operator, namely Eutelsat. The satellites are controlled and monitored from the Agency's Redu ground station in Belgium.

The present spacecraft locations are:
— ECS-1, 16°E
— ECS-2, 4°E
— ECS-4, 7°E
— ECS-5, 10°E

The design lifetime for each spacecraft is seven years, and sufficient propellant was loaded for North-South Station-Keeping (NSSK) for 5.9 yr for ECS-1 and 4.9 yr for each of ECS-2, 4 and 5. NSSK manoeuvres have now ceased on ECS-1 and ECS-2, but both spacecraft were able to support such manoeuvres for far longer than the original target.

The ECS series has now amassed close to 1.5 million channel-hours of payload operation and is on course for further exceeding its original design expectations in this respect. A total of 54 Travelling Wave Tube Amplifiers (TWTAs) were carried into geostationary orbit by the ECS satellites, of which 43 are still fully usable.

It is expected that Eutelsat will terminate operations with ECS-1 in the first half of 1991, although the propellant and payload status would permit considerably longer operation if required. ECS-2 is also expected to continue operation beyond its original design life. ECS-4 and ECS-5 are presently delivering a payload capacity markedly in excess of the original design target and will continue to do so for the foreseeable future.



The ECS-2 spacecraft

Véhicule spatial ECS-2

Olympus

The four payloads of the Olympus-1 satellite have continued to operate correctly. A spacecraft anomaly occurred, however, at 22:40 h GMT on 28 January 1991 when a sudden drop in power resulted in the payloads being automatically configured to their standby modes. Power returned to normal within 60 s and the payloads also functioned normally when they were brought back into operation. At the end of this activity, however, the south solar array ceased to track the Sun and it has subsequently been found to have only a limited angle of travel. The payload configurations have been revised to match the power available, but service is still being provided to all users, with only small power reductions in a few cases. An Agency Board of Enquiry has been set up to investigate the anomaly.

The Direct-Broadcast Payload has continued to carry the RAISAT channel to an extensive audience in Europe, while the RAI has also conducted regular digital High-Definition Television (HDTV) *on a découvert ultérieurement que son angle de déplacement était restreint. Les configurations des charges utiles ont été révisées en fonction de la puissance disponible mais le service continue d'être assuré aux utilisateurs avec, seulement, dans quelques cas, une faible réduction de puissance. L'Agence a constitué une commission d'enquête qui est chargée de rechercher les causes de cette anomalie.*

La charge utile de radiodiffusion directe a continué de diffuser le programme RAISAT à un vaste public en Europe tandis que la RAI procédait régulièrement à des essais de transmission de télévision à haute définition (HDTV). La BBC intensifie sa présence sur le faisceau européen pour devenir BBC TV Europe à partir de mars 1991; à partir d'avril, Eurostep émettra tous les jours sans interruption. European Data Management Services a débuté une période d'essai de radiodiffusion de données de trois mois.

Les stations terriennes en bande Ku ayant été mises en service, la charge utile des Services spécialisés a vu le lancement réussi de quatre nouvelles expériences italiennes. Le collège Polytechnic South West (GB) poursuit la diffusion de ses programmes de télé-enseignement. Un accord a été conclu pour qu'en mai 1991, des chercheurs en microgravité puisse utiliser la capacité de cette charge utile pour observer et conduire leurs expériences embarquées sur des fusées-sondes tirées de Kiruna (Suède) pour des vols de téléscience de courte durée.

On continue d'utiliser la charge utile de télécommunications 20/30 GHz pour les expériences DICE (Visio-conférence) et CODE (Transmission de données). La première implantation industrielle DICE est en place chez Marconi à Portsmouth (GB). Des terminaux V-Sat pour l'expérience CODE sont en cours d'installation au Royaume-Uni et en Autriche. Cette charge utile sera utilisée à l'ESTEC en mars dans le cadre de l'atelier Téléscience pour une démonstration de télécommande d'expériences de téléscience au moyen du système CODE en bande Ka.

Les charges utiles d'Olympus ont servi à la transmission d'autres événements dont une conférence soviéto-canadienne tenue en février à l'Université d'York à Toronto; les débats ont été transmis à Moscou puis rediffusés en URSS par une liaison à deux satellites avec les charges utiles Services spécialisés et Télécommunications 20/30 GHz. A l'occasion de l'exposition Telecom 90 à Harare au Zimbabwe, Olympus a également été utilisé pour une démonstration de télé-enseignement et d'accès à des bases de données qui a été transmise par l'Université du Surrey (GB). Cette opération s'inscrivait dans un programme de démonstrations de l'expérience CODE en Afrique australe au moyen d'une station V-Sat.

Soho

La proposition industrielle relative à la phase principale de réalisation de SOHO (phase C/D), comprenant et prenant en compte les propositions relatives aux sous-systèmes, a été remise dans les délais par Matra. Son évaluation qui a commencé début décembre devrait être achevée début avril.

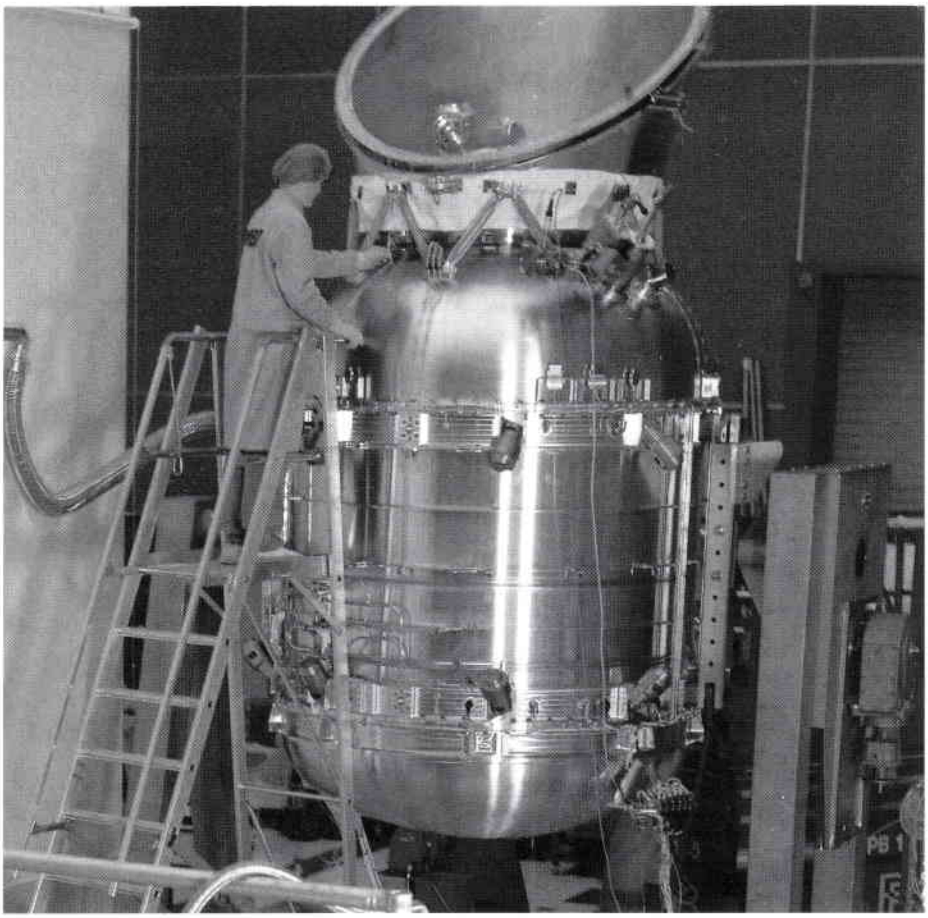
La conception au niveau système et sous-système a avancé conformément aux prévisions durant la phase B sans qu'aucun problème technique risquant de compromettre la mise en oeuvre de la mission ait été identifié. Une attention particulière est apportée au mécanisme de pointage d'antenne (APM) et à certains aspects de la validation du logiciel en raison de leur caractère critique.

La revue de conception système doit avoir lieu les 16 et 17 avril pour le véhicule spatial et les 7 et 8 mai 1991 pour la mission. Tous les éléments constitutifs de la mission véhicule spatial, charge utile, secteur sol et lanceur seront examinés.

Les travaux ont bien avancé pour la charge utile et la définition des interfaces avec les expériences a considérablement progressé. Des revues intermédiaires de la conception des expériences ont été menées à bien, en Europe et aux Etats-Unis, avec la participation de tous les chercheurs principaux.

Filling of the cryostat tank of ISO payload module with helium at IABG, Munich

Remplissage du cryostat à hélium liquide du module de charge utile d'ISO à l'IABG, Munich



test transmissions. On the European beam, the BBC are extending their channel operation to become BBC TV Europe from March 1991, while Eurostep will have uninterrupted daily transmission times from April onwards. European Data Management Services have started a three-month data-broadcast test.

The Specialised-Services Payload has seen the successful launch of four new Italian experiments, following the commissioning of Ku-band earth stations. Polytechnic South West (UK) has continued its educational programme. Agreement has been reached for the payload to provide capacity in May 1991 for microgravity scientists to observe and control their onboard experiments during short flights of 'telescience' sounding rockets from Kiruna, in Sweden.

The 20/30 GHz Communications Payload has continued to be used for DICE video-conferencing and CODE data-transmission experiments. The first industrial DICE site has been completed at Marconi in Portsmouth (UK), while V-Sat terminals for CODE are being installed in the United Kingdom and in Austria. The payload was used at a Telescience Workshop at ESTEC in March to demonstrate the remote control of telescience experiments using the CODE (Ka-band) system.

Other special events for which Olympus payloads have been used have included a Soviet-Canadian Conference at York University, Toronto in February. Sessions were transmitted to Moscow for re-broadcasting in the USSR using the Olympus Specialised-Services and 20/30 GHz Communications Payloads in a double-hop link. Another event covered was a demonstration of distance learning and database accessing by means of transmissions from Surrey University (UK) to Telecom 90 at Harare, in Zimbabwe. This was part of a series of demonstrations in Southern Africa using a CODE V-Sat terminal.

Soho

The industrial proposal for Soho's main development phase (Phase-C/D), including and reflecting the subsystem proposals, was submitted on schedule by Matra. Its evaluation started early in December and is expected to be completed by early April.

System- and subsystem-level design has been progressing as expected during Phase-B, and no technical problems that could jeopardise mission implementation have been identified. The Antenna Pointing Mechanism (APM) and certain aspects of the software validation are receiving increased attention due to their criticality.

The System Design Review at spacecraft level will be held on 16/17 April and the Mission System Design Review on 7/8 May 1991. All the constituent elements of the mission, including spacecraft, payload, ground segment and launch vehicle, will be addressed.

The Soho payload is well advanced and experiment-interface definition has progressed considerably. Experiment Intermediate Design Reviews have been successfully held, both in Europe and the USA, involving all Principal Investigators.

Detailed interface meetings between ESA and NASA, and their respective Contractors, have been taking place and more are planned, in order to adequately control the integrity of the various interfaces. The scientific investigations, launcher, operations and the provision of spacecraft hardware are all covered.

ISO

The flight models of all four scientific instruments are currently being acceptance-tested. They will then be subjected to an extensive programme of performance characterisation and calibration prior to delivery to the Agency in June.

The qualification-model telescope has been delivered for integration into the payload-module cryostat. Payload-module testing will continue until June, when it will be delivered to the prime contractor for system-level testing with the service-module structural/thermal module. Some problems were encountered with the flight-model liquid tank, which both leaked and was found to be too flexible. The leak has since been corrected and reinforcement of the tank is now under way. All electrical-subsystem units are in qualification testing and flight-model manufacture is proceeding well.

The overall project test planning is under review, the aim being to recover delays incurred with the payload module and the attitude-control subsystem. The project schedule is geared to a May 1993 launch date.

The ground-segment detailed design review has been completed and showed good status for the overall design. Efforts made to simplify spacecraft operations have had good results.

Huygens

At its meeting on 21 November, the Agency's Industrial Policy Committee (IPC) endorsed selection of Aerospatiale (Cannes, F) as leader of the consortium to perform the Phase-B detailed definition and design activities for the Huygens probe, ESA's contribution to the joint ESA/NASA (JPL) Cassini/Craf deep-space exploratory mission.

The Phase-B1 activities were formally inaugurated with a contract kick-off meeting at the premises of the prime contractor on 16/17 January as planned, during which significant changes to the original technical baseline on which the contractor's proposal had been based were announced. The most important of these is a complete revision of the overall mission scenario, occasioned by the need to increase power and mass availability for the spacecraft, a scenario that adds a Venus-flyby gravity-assist leg to the already planned Earth and Jupiter gravity-assists.

The new mission profile has brought the launch date forward by six months to November 1995. To meet this new date, the Huygens probe must be delivered earlier, and the planned Huygens/Cassini combined testing significantly reduced. The new mission will increase the flight time by more than 2 years, with Saturn arrival delayed to May 2004 and Huygens probe touchdown on Titan's surface delayed until 25 September 2004.

Intense study and trade-off activities have been performed to evaluate the impact of all changes and to arrive at a clear technical and managerial definition for

Des réunions d'interface détaillée ont eu lieu entre l'ESA et la NASA et leurs contractants respectifs et d'autres sont prévues afin de vérifier comme il convient si les différentes interfaces sont bien complètes. Les éléments couverts englobent les recherches scientifiques, le lanceur, les opérations et la fourniture du matériel du véhicule spatial.

ISO

Les quatre modèles de vol des quatre instruments scientifiques subissent actuellement les essais de recette. Ils seront ensuite soumis à un vaste programme de définition des caractéristiques de fonctionnement et d'étalonnage, avant d'être livrés à l'Agence en juin.

Le modèle de qualification du télescope a été livré en vue de son intégration dans le cryostat du module de charge utile. Les essais de ce module se poursuivront jusqu'en juin, date à laquelle il sera livré au maître d'oeuvre pour les essais du niveau système avec le modèle structurel/thermique du module de servitude. Le modèle de vol du réservoir à hélium liquide a posé des problèmes d'étanchéité et de souplesse excessive. Il a été remédié depuis lors au défaut d'étanchéité, et le renforcement du réservoir est maintenant en cours. Tous les éléments du sous-système électrique subissent actuellement les essais de qualification et leur fabrication aux normes de vol progresse de façon satisfaisante.

Le planning d'ensemble des essais est actuellement revu dans le souci de rattraper les retards qui ont affecté le module de charge utile et le sous-système de commande d'orientation. Le calendrier du projet vise un lancement en mai 1993.

La revue détaillée de la conception du secteur sol a été menée à bien, concluant à un bon état d' avancement de la conception d'ensemble. Les efforts de simplification des opérations du véhicule spatial ont porté leurs fruits.

Huygens

A sa réunion du 21 novembre, le Comité de la politique industrielle de l'Agence a approuvé le choix de l'Aérospatiale (Cannes) à titre de chef de file du consortium chargé de conduire les activités de conception et de définition détaillée (phase B) de la sonde Huygens, contribution de l'ESA à la mission Cassini/Craf d'exploration de l'espace lointain organisée conjointement par l'ESA et la NASA (JPL).

Les activités de phase BI ont officiellement commencé avec la réunion de mise en route du contrat qui s'est tenue comme prévu les 16 et 17 janvier, dans les locaux du contractant principal. Pendant cette réunion ont été annoncés des changements non négligeables par rapport à la base de référence technique initiale sur laquelle était fondée la proposition du contractant. Le plus important consiste en une révision complète du scénario d'ensemble de la mission imposée par la nécessité d'augmenter la puissance du véhicule spatial et la masse qui lui est allouée. Ce scénario prévoit une étape supplémentaire afin de mettre à profit l'effet de fronde gravitationnelle de Vénus en sus de celui de la Terre et de Jupiter comme le prévoyait le scénario initial.

Ce nouveau profil de mission contraint d'avancer de six moix le lancement du véhicule spatial qui doit donc avoir lieu en novembre 1995. Compte tenu de cette nouvelle date de lancement, la sonde Huygens devra être livrée plus tôt et les essais du composite Huygens/Cassini notablement raccourcis. Le nouveau scénario allongera la durée du vol de plus de deux ans, l'arrivée dans le domaine saturnien étant reportée à mai 2004 et la descente de la sonde Huygens sur Titan au 25 septembre 2004.

D'intenses activités d'étude et d'arbitrage ont été menées afin d'évaluer l'incidence de l'ensemble de ces changements et de parvenir à une définition technique et gestionnelle claire du reste de la phase d'étude d'ici à la revue des impératifs du système fixée à la mi-avril 1991.

ERS

ERS-1

A l'issue d'un essai complet du système intégré, le modèle de vol du satellite ERS-1 a été soumis à un essai de validation du système en circuit fermé avec le Centre de contrôle de gestion de la mission. Cet essai a démontré le bon fonctionnement du logiciel de contrôle du satellite installé à l'ESOC (Darmstadt, RFA) et a permis de vérifier les mesures à prendre en cas d'anomalie de fonctionnement à bord.

La revue d'aptitude au vol menée à bien en décembre donne le feu vert pour le lancement du satellite.

L'intégration et l'alignement définitifs des antennes étant terminés, le satellite a été transporté à Kourou début mars en vue de la campagne de lancement.

Les activités relatives au secteur sol ont porté pour l'essentiel sur les essais d'intégration finale et de vérification avant lancement. La revue de recette du secteur sol a eu lieu en mars 1991.

ERS-2

En parallèle à la poursuite des négociations contractuelles, les activités industrielles relatives au satellite ont été mises en route. Plus de 60% des contrats sont conclus.

Les activités de phase B de l'expérience de surveillance de l'ozone à l'échelle du globe ne sont pas encore terminées mais les contrats d'approvisionnement du PRARE-2 et du Radiomètre à hyperfréquence/ATSR ont été signés en décembre 1990 et février 1991 respectivement.

EOPP

Aristoteles

L'étude exploratoire au niveau système que les firmes Aeritalia (aujourd'hui Alenia, Turin) et Matra ont exécutée en vue d'optimiser le profil de la mission Aristoteles sur le solide terrestre et la configuration du satellite correspondant pour un lancement qui lui sera entièrement réservé a été présentée à l'ESTEC en décembre. Elle a démontré la faisabilité du concept révisé, qui permet de conduire des recherches améliorées sur le champ gravitationnel de la Terre pendant six mois, suivies de trois années de fonctionnement à plus haute altitude essentiellement consacrées à la poursuite des mesures du champ magnétique terrestre.

the remainder of the study phase by the time of the System Requirements Review scheduled for mid-April 1991.

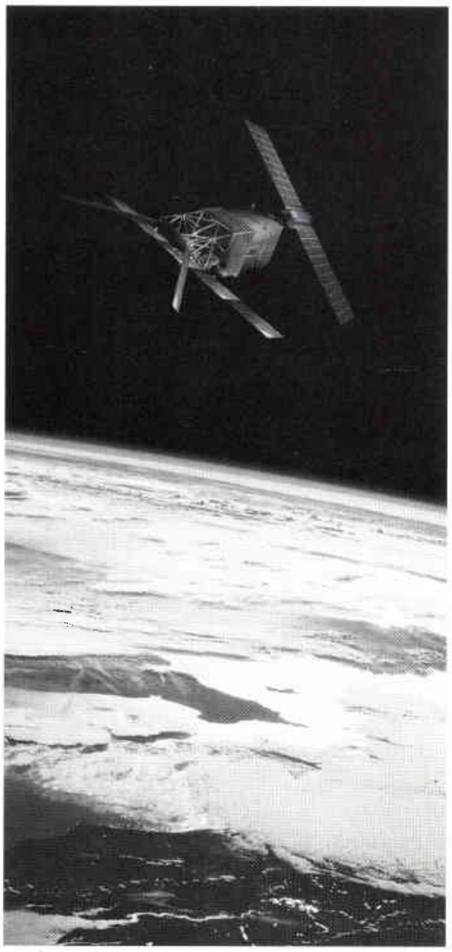
ERS

ERS-1

The ERS-1 flight-model satellite, having successfully passed a full Integrated System Test, was subjected to a System Validation Test in closed loop with the Mission Management Control Centre. This test demonstrated the correctness of the satellite control software at ESOC, in Darmstadt (D), and verified the contingency measures to be taken in the event of onboard irregularities.

The Flight Acceptance Review was completed in December, giving the 'green-light' for the satellite to be launched.

Following completion of the final integration and alignment of antennas, the satellite is awaiting transportation to Kourou in early March for the launch campaign.



Artist's impression of ERS-1 in orbit

ERS-1 en orbite (Vue conceptuelle)

Ground-segment activities have concentrated on final integration and verification testing before launch. The Ground Segment Readiness Review is scheduled for March 1991.

ERS-2

A full startup of industrial activities for the satellite has been achieved in parallel with pursuing contractual negotiations. More than 60% of the contracts have been concluded.

The Phase-B activities for the Global Ozone Monitoring Experiment are not yet completed, but contracts for the procurement of PRARE-2 and the ATSR/Microwave Radiometer were concluded in December 1990 and February 1991, respectively.

EOPP

Aristoteles

The exploratory system study by Aeritalia (now Alenia, Turin) and Matra to optimise the Aristoteles solid-Earth mission profile and the satellite's configuration for a dedicated launch was completed and presented at ESTEC in December. It has demonstrated the feasibility of the revised concept, which allows enhanced gravity research over a six-month period, followed by three years of higher altitude operation, mostly to continue measurements of the Earth's magnetic field.

Pre-development of the gravity-gradiometer accelerometer at Onera (F) has resulted in a new laboratory model that is now ready to be tested. Magnetic testing of an important invar alloy component of the accelerometer has been carried out by Dornier and the University of Braunschweig. It has confirmed compatibility of the gradiometer instrument with high-sensitivity Earth-magnetic-field measurements from the satellite.

The Aristoteles ESA-NASA Workshop scheduled to be held at the end of January in Frascati, Italy, had to be cancelled due to the Gulf crisis. However, a meeting of the European scientists at ESA Headquarters in Paris made very positive recommendations for pursuing the Aristoteles programme, which were subsequently endorsed by the EOSTAG. The Aristoteles Programme Proposal has now been finalised and submitted to EOSTAG (4 February) and to the Agency's Earth-Observation Programme Board (28 Feb.–1 March).

Meteosat Second Generation (MSG)

An assessment study on adding more channels to the baseline imager on a spinning satellite has been successfully completed by Matra, with the final presentation to ESA and Eumetsat being held in mid-December.

A study on 'Data Dissemination Technology' performed by an industrial team led by Computas/Trondheim (N) has also been completed, with its final review meeting being held at ESTEC.

Discussions with Eumetsat and the meteorological user community are continuing in preparation for the envisaged satellite/instrument study phase (Phase-A).

POEM-1

Dornier, the mission prime contractor, has completed the activities of the Phase-A extension contract. They have studied several alternative configurations for the first mission, all of which have proved feasible, although in the case of the most extensive payload complements the resource margins are very slender. The Advanced Synthetic-Aperture Radar (ASAR) and an Advanced Scatterometer have been included in the study instead of AMI-2. The design of these two instruments and of MERIS, MIPAS and the RA-2 has progressed to a level fully consistent with a Phase-A study. It is clear that all five instruments are feasible, although the development schedule for ASAR needs to be carefully investigated.

The declaration for the Preparatory Programme for the First Polar-Orbit Earth-Observation Programme was finalised at the end of 1990. The Member State subscriptions have passed the starting threshold and the new programme is therefore under way.

The Request-for-Proposal package for the mission prime contract (which includes instrument Phase-B's) was released to industry on 15 February. The Requests for Proposal for the MIMR and for the

Les travaux de prédéveloppement à l'ONERA de l'accéléromètre du gradiomètre ont débouché sur un nouveau modèle de laboratoire qui est maintenant prêt pour les essais. Dornier et l'Université de Brunswick ont procédé aux essais magnétiques d'un important composant de l'accéléromètre en alliage invar. Ces essais ont confirmé que le gradiomètre convient pour les mesures de haute sensibilité du champ magnétique terrestre à exécuter du satellite.

La crise du Golfe a obligé à annuler l'atelier ESA-NASA sur Aristoteles dont les travaux devaient se dérouler fin janvier à Frascati, en Italie. Des scientifiques européens réunis au siège de l'ESA à Paris ont toutefois formulé des recommandations très favorables à la poursuite du programme Aristoteles, que l'EOSTAG a ensuite entérinées. La proposition de programme Aristoteles a été définitivement mise au point puis soumise à l'EOSTAG (4 février) et au Conseil directeur du programme d'observation de la Terre de l'Agence (28 février - 1er mars).

Météosat de deuxième génération (MSG)

L'installation de canaux supplémentaires sur l'imageur de référence embarqué sur un satellite stabilisé par rotation a fait l'objet d'une étude d'évaluation dont Matra a fait la présentation finale à l'ESA et à Eumetsat à la mi-décembre.

Une étude sur la technologie de la dissémination des données a également été exécutée par une équipe industrielle placée sous la conduite de Computas/Trondheim (N), avec revue finale à l'ESTEC. Les discussions se poursuivent avec Eumetsat et les services de météorologie pour préparer la phase d'étude envisagée (phase A) sur le satellite et les instruments.

POEM-1

Dornier, maître d'oeuvre de la mission, a terminé les activités relevant du contrat relatif à l'extension de la phase A. La firme a étudié différentes configurations envisageables pour la première mission; toutes se sont avérées réalisables, malgré des marges de ressources très amenuisées pour les dotations de charge utile les plus développées. Le radar à synthèse d'ouverture de pointe (ASAR) et un diffusiomètre de haute technologie ont été inclus dans l'étude à la place de l'AMI-2. La conception de ces deux instruments ainsi que celle du MERIS, du MIPAS et du RA-2 ont progressé de façon tout à fait satisfaisante pour une étude de phase A. Il est clair que les cinq instruments sont réalisables, bien que le calendrier de développement de l'ASAR demande à être examiné avec attention.

La Déclaration relative au programme préparatoire de la première mission d'observation de la Terre sur orbite polaire a été définitivement établie à la fin de 1990. Les souscriptions des Etats membres ayant dépassé le seuil de déclenchement prévu pour le passage à exécution, le nouveau programme est en cours.

Le dossier de demande de proposition pour la maîtrise d'oeuvre de la mission comprenant les phases B des instruments a été communiqué à l'industrie le 15 février. Les demandes de propositions relatives au MIMR et au secteur sol sont en préparation.

Prolongation de l'EOPP

La Déclaration révisée relative à la prolongation de l'EOPP jusqu'en 1996 a été définitivement établie. Les souscriptions ont déjà franchi le seuil des 80% et la prolongation correspondante est donc en cours.

Météosat

Préparation du lancement de MOP-2

MOP-2 sera lancé lors du vol Ariane V42. La campagne de lancement a commencé début décembre par l'expédition de Cannes à Cayenne du véhicule spatial et de l'ensemble des équipements de soutien. Au mois de décembre, les sous-systèmes ont été vérifiés. La campagne s'est interrompue pendant la période des fêtes et a repris début janvier avec les essais au niveau système. Ces essais ont été menés à bien sans aucun problème et, au vu des résultats de la revue d'aptitude au vol, le véhicule spatial a été transporté sur l'aire de lancement et intégré au moteur d'apogée (ABM) entreposé sur le champ de tir depuis le lancement de MOP-1.

L'intégration à l'ABM a eu lieu début février et le véhicule spatial ainsi que l'autre passager d'Ariane ont été montés sur le lanceur le 13 février.

Plusieurs essais, exécutés avec l'ESOC via la liaison ombilicale et par télémesure, ont démontré la pleine compatibilité des installations. Le lancement était initialement programmé pour le 21 février. En raison d'une anomalie décelée lors d'un essai en Europe, Arianespace a décidé de le reporter au ler mars.

Lancement de MOP-2

Le lancement de MOP-2 a eu lieu le jour suivant, 2 mars, à l'ouverture de la fenêtre de lancement. Sa trajectoire a été nominale et l'ESOC a pris le contrôle du véhicule spatial inmédiatement après sa séparation du lanceur. Toutes les fonctions de maintenance sont assurées de façon nominale à bord du véhicule spatial. La mise à feu de l'ABM a eu lieu au moment prévu et a permis de placer MOP-2 sur l' orbite géostationnaire.

Lasso

L'expérience de synchronisation par échos laser à partir de l'orbite géostationnaire (Lasso) embarquée sur Météosat 3 (P2) est utilisée par les stations sol européennes depuis le lancement du satellite. Fin 1990, deux stations sol — l'observatoire de la Côte d'Azur (OCA) et la station de l'Université technique de Graz (A) — ont réussi à se transmettre des signaux d'horloge via le satellite, démontrant ainsi la validité du principe et le bon fonctionnement de l'expérience Lasso qui se poursuit.

Earthnet

Les données transmises par les satellites Landsat, Spot, MOS et Tiros sont régulièrement acquises, archivées, traitées et distribuées.

En 1990, Earthnet a distribué environ 1200 produits numériques Landsat (provenant pour la plupart de l'instrument de cartographie thématique) et quelque 2900 produits photographiques (produits à visualisation rapide compris). Pendant cette période, les travaux de mise à hauteur de la station ont commencé pour l'adapter au nouvel instrument de cartographie thématique de Landsat-6 qui doit être lancé en 1992.

ground segment are in preparation.

EOPP extension

The revised Declaration to extend the EOPP until 1996 has been finalised. Subscriptions have already passed the 80% threshold and that extension is also under way.

Meteosat

Preparation for MOP-2 launch

The MOP-2 launch campaign for Ariane flight V42 started at the beginning of December with the shipment of the spacecraft and all support equipment from Cannes to Cayenne. During December the subsystems were checked out. The campaign was interrupted due to the holidays and recommenced in early January, when system-level tests were started. These were completed without any problem, and a Flight-Readiness Review cleared the spacecraft for transport to the launch area and integration with the Apogee Boost Motor (ABM), which had been stored at the range since the MOP-1 launch.

Integration with the ABM took place during early February, and the spacecraft and its co-passenger were mounted on the launcher on 13 February.

Several tests were conducted with ESOC, both via the umbilical link and via telemetry, which verified full compatibility. The launch was initially scheduled for 21 February. Due to an anomaly during a test in Europe, Arianespace decided to postpone it until 1 March.

MOP-2 launch

The MOP-2 launch eventually took place a day later on 2 March at the opening of the launch window. The trajectory was nominal and ESOC took control of the spacecraft immediately after its separation from the launcher. All house-keeping functions aboard the spacecraft were found to be nominal. ABM firing took place as scheduled and successfully placed MOP-2 into its geostationary orbit.

Lasso

The Laser Synchronisation from Stationary Orbit (Lasso) experiment installed on Meteosat-3 (P2) has been used by European ground stations since launch. Late in 1990 two ground stations — at Observatoire de Cote D'Azur and the Technical University of Graz (A) — succeeded with time transfer via the spacecraft, thereby demonstrating both the principle and the proper operation of the Lasso onboard package. The experiment is continuing.

Earthnet

Data from Landsat, Spot, MOS and Tiros have been regularly acquired, archived, processed and distributed.

About 1200 Landsat digital products (mostly Thematic Mapper) and about 2900 photo-products (including quick-looks) were distributed in the course of 1990. Meanwhile station upgrading to adapt to the Landsat-6 Enhanced Thematic Mapper has been started in preparation for the satellite's launch in 1992.

The Earthnet-coordinated Tiros network stations of Maspalomas, Tromsø and Oberpfaffenhofen have regularly acquired and archived NOAA-10 and NOAA-11 data. The Dundee (UK) facility will also become operational in March.

Tiros data from the Niamey-Agrhymet station have been routinely transferred to Frascati (I) for archiving and redistribution. Discussions have been initiated with the Kenyan Meteorological Office regarding data archiving at and redistribution from Frascati.

The SHARK (Standard HRTP Archiving and Retrieving Kernel) system has also been installed at the La Reunion (France) station. Inclusion of this station in the Earthnet coordinated network is under discussion with the French institute ORSTOM.

The Italian Antarctica facility (Terra Nova Bay) is now operational in accordance with ESA standards. Data collected there will be made available to Earthnet at the end of the Antarctica summer campaign.

In the framework of ESA-EEC cooperation, archiving of CZCS data on optical disk is well in hand in Frascati (with considerable data already archived at Frascati and JRC). Similar operations will take place at Maspalomas, in the Canary Islands.

ERS-1

The Central User Service (CUS) of the Earthnet ERS-1 Central Facility (EECF) in Frascati is being used to familiarise operators with the system and to prepare the operational procedures. Integration of the various subsystems of the Interface Sub-Set (ISS) has been completed and is undergoing acceptance testing. The ERS-1 Help and Order Desk function at Earthnet is now in operation.

Development work for modification of the Fast-Delivery Processing Chain for Gatineau has been completed. It is now ready for shipment and will be installed at the station in early March.

Implementation of the Low-Bit-Rate (LBR) Data Transcription Facility, required to store the ERS-1 LBR raw data on optical disk for long-term archiving at the Brest (F) and Farnborough (UK) Processing and Archiving Facilities (PAFs), has been completed and acceptance tests successfully carried out. The majority of the acceptance tests for the French PAF have also been completed.

The acceptance tests for the SAR geocoding subsystem and for the Radar Altimetry and Tracking System have been successfully completed at the Oberpfaffenhofen (D) PAF.

As far as LBR Fast-Delivery Dissemination is concerned, an agreement with ECMWF, ITAV and the UK Meteorological Office (representing the other meteorological entities) has been reached on the technical implementation, definition of responsibilities, and detailed test plan. The latter foresees tests on the EECF-Bracknell and EECF-ITAV links and end-to-end load tests, all to be completed by the beginning of April. The first test (connection with Bracknell) has already been successfully completed.

Microgravity

Preparations for the IML-1 Spacelab mission, now scheduled for launch in November 1991, are fully under way. On this mission, the Biorack (first reflight) and the Critical-Point Facility (CPF) will be flown.

The Biorack flight model is already integrated into Spacelab, as is the CPF.

Les stations de Maspalomas, Tromsö et Oberpfaffenhofen du réseau Tiros coordonné par Earthnet ont régulièrement acquis et archivé des données des satelites NOAA-10 et NOAA-11. Les installations de Dundee (GB) deviendront opérationnelles en mars.

Les données Tiros transmises par la station Agrhymet de Niamey (Niger) sont régulièrement transférées à Frascati (Italie) où elles sont achivées et redistribuées. Earthnet a entamé avec l'Office kényan de météorologie des négociations sur l'archivage et la distribution de données de Frascati.

Le système SHARK (Standard HRTP Archiving and Retrieving Kernel) a été installé à la station de l'Ile de La Réunion. Le rattachement de cette station au réseau coordonné d'Earthnet est à l'étude avec l'Office de la Recherche Scientifique et Technique d'Outre-Mer (France).

La base italienne en Antarctique (Terra Nova Bay) est maintenant opérationnelle selon les normes de l'ESA. Les données qui y sont recueillies seront mises à la disposition d'Earthnet à la fin de la campagne d'été en Antarctique

Dans le cadre de la coopération ESA/CEE, l'archivage des données CZCS sur disques optiques se poursuit normalement à Frascati (un important volume de données est déjà archivé à Frascati et au JRC). Des opérations similaires auront lieu à Maspalomas dans les Iles Canaries.

ERS-1

Le Service central des utilisateurs de l'Installation centrale ERS-1 d'Earthnet (EECF) à Frascati est fréquenté par les opérateurs qui doivent se familiariser avec le système et préparer les procédures d'exploitation. Les divers sous-systèmes du sous-ensemble d'interface sont maintenant intégrés et sont en cours d'essai de recette. Le Bureau d'aide et de commande ERS-1 d'Earthnet est opérationnel.

Les travaux de modification de la chaîne de traitement des produits à livraison rapide pour la station de Gatineau sont achevés. Les équipements, prêts à être expédiés, sont installés début mars.

On a également terminé la mise en oeuvre de l'installation de transcription de données à faible cadence (LBR) nécessaire au stockage sur disques optiques des données brutes LBR d'ERS-1 en vue de leur archivage à long terme dans les installations de traitement et d'archivage (PAF) de Brest (F) et Farnborough (GB); les essais de recette ont été menés à bonne fin.

Dans l'ensemble, les essais de recette de la PAF de Brest sont terminés.

Les essais de recette du sous-système de géocodage du SAR et du système de poursuite et d'altimètrie radar ont été menés à bien à Oberpfaffenhofen.

En matière de dissémination de produits à livraison rapide LBR, un accord sur la mise en oeuvre technique, la définition des responsabilités et un plan d'essais détaillé a été conclu avec le CEPMMT, ITAV et l'office britannique de la météorologie (représentant les autres organisations météorologiques). Il est prévu de procéder à des essais sur les liaisons EECF-Bracknell et EECF-ITAV et à des essais de charge de bout en bout qui devront tous être terminés pour début avril. Le premier essai (connexion avec Bracknell) a déjà été fait et a donné toute satisfaction.

Microgravité

La mission Spacelab IML-1, dont le lancement est désormais prévu pour novembre 1991, est en pleins préparatifs. A bord du Spacelab, prendront place le Biorack, pour son deuxième vol, et le Dispositif d'étude des phénomènes au point critique (CPF).

Le modèle de vol du Biorack et le CPF sont déjà intégrés au Spacelab. Le modèle d'entraînement du Biorack qui servira au soutien des mesures de référence au sol en temps quasi-réel est installé dans le hangar L du Centre spatial Kennedy (KSC). Avec le chercheurs, on a procédé à une dernière vérification des paramètres de vol des expériences du CPF en utilisant le modèle d'identification du Dispositif. Les essais officiels de la séquence de la mission destinés à vérifier l'aptitude au lancement commenceront au KSC en avril.

Les essais en vibrations du modèle d'identification de la Boîte à gants qui doit être intégrée au Spacelab pour la mission USML-1 (juin 1992) ont été menés à bonne fin.

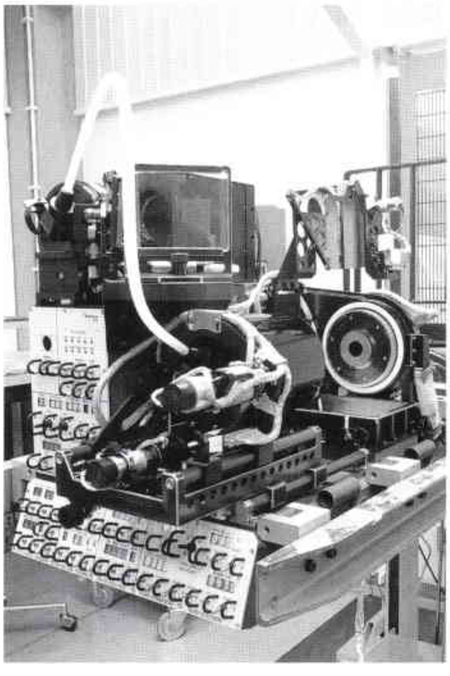
Le modèle de vol du Module avancé de physique des fluides qui doit participer à la mission D-2 (février 1993) a été repris à l'ESTEC; les essais de recette ont été menés à bien. L'intégration du modèle d'entraînement de l'Anthrorack a bien progressé; il devrait être livré en mars au Centre de soutien des utilisateurs de la microgravité au DLR.

En novembre 1990, lancement réussi de la fusée-sonde Texus-27 avec à son bord deux expériences de l'ESA.

En octobre 1990 et en février 1991, la Caravelle du CNES/CEV a fait deux campagnes de vols paraboliques.

Eureca

Les travaux de réparation et de réétalonnage de quelques-uns des équipements du porte-instruments et de



Flight model of the AFPM during testing at ESTEC

Modèle de vol du module avancé de physique des fluides aux essais à l'ESTEC

The Biorack training model to support near-real-time ground-reference measurements is installed in Hangar-L at Kennedy Space Center (KSC). A last verification of the experiment flight parameters for the CPF was performed with the investigators using the CPF engineering model. The formal mission sequence test at KSC will start in April, leading up to launch readiness.

The engineering model of the Glove Box, to be flown on the USML-1 Spacelab mission (June 1992), has successfully completed vibration testing.

The flight model of the Advanced Fluid-Physics Module (AFPM) for the Spacelab D-2 mission (February 1993) has been reworked at ESTEC and acceptance testing has been successfully performed. Integration of the Anthrorack training model has made good progress and delivery to the Microgravity User Support Centre (MUSC) at DLR is foreseen for March.

Two ESA experiments were launched successfully in November 1990 aboard the sounding rocket Texus-27.

Two parabolic-flight campaigns have been conducted with the CNES/CEV Caravelle aircraft, in October 1990 and February 1991, respectively.

Eureca

Having completed repair and recalibration work on some of the Carrier and payload equipment, the whole Eureca flight unit was reassembled in February 1991. The final test phase started in March and will be completed with an ESOC-to-Carrier compatibility test in mid-April.

The third Eureca safety review has been successfully performed at NASA. However, some additional safety data have to be elaborated to provide further evidence to NASA that Eureca has a leak-proof hydrazine subsystem, does not constitute a flammability hazard in its overall configuration, and that the attachments of some of its experimental facilities are not fracture-critical.

Given the flexibility of Eureca's thermal design and in view of the programmatic implications of such an additional test, it was decided not to perform an additional thermal-balance/vacuum test at this late stage in the Programme.

The current project planning foresees the first part of the Flight-Unit Acceptance Review by the end of April, with shipment of Eureca to the USA in the middle of this year for a launch in February 1992.

Space Station Freedom/Columbus

Manned laboratories

The main event of these past months was the delivery, at the end of November 1990, of the revalidated Proposal for the Attached Laboratory and the Free-Flying Laboratory. Since then, the members of the evaluation panels and teams (involving more than a hundred ESA staff) have reviewed the Proposal and issued their report as the basic input to the Tender Evaluation Board, which met on 20/21 February. Work in industry has continued in parallel in order to be able to maintain the overall programme schedule and technical team activity.

ESA has participated, successfully defending the ESA position, in the Level-1 and -2 meetings of the 'Space Station Freedom Programme Restructuring Assessment' exercise, initiated by NASA in early November 1990 and completed at the end of February. Of the many options presented and analysed, the one retained to be formally presented to the US Congress includes, as key features, a shorter, pre-integrated truss, and US laboratory and habitation modules smaller than in the previous baseline, but with the potential for upgrading in a later phase. The launch of this configuration of the Attached Laboratory is planned for the second half of 1998.

For the Columbus ground segment, the major events recently have been the Mid-Term Review for the System Architecture Support Contract, as well as the results of the Detailed Definition of the Centralised Facilities, the Manned Space Laboratories Control Centre and the Columbus Element centres.

On the utilisation side, the first phase of the initial Columbus Utilisation Information System's (CUIS) development has been completed.

The 'Call for Proposals and Ideas' for the Columbus Precursor Flights (two Spacelab and two Eureca) has been issued, and more than 500 notifications of interest had been received by the end of February.

Among the 'Long Term Programme' activities, processing of the data coming from the ISEMSI experiment (one-month-duration isolation experiment, in which six men spent four weeks in hyperbaric chambers) is under way, and a feasibility study of a Logistics Vehicle has started.

Polar Platform

The updated Phase-C/D Proposal for the Columbus Polar Platform (PPF), received in October 1990, has been evaluated (in October/November) by an ESA review team operating under the authority of a Tender Evaluation Board (TEB).

In December, the Polar Platform TEB concluded, on the basis of the evaluation performed, that the Phase-C/D proposal constituted a good basis for proceeding with Polar Platform development and for negotiating a contract with the Platform consortium.

Ariane

Preliminary Design Reviews of Ariane-5 launcher components continued throughout 1990, and the month of December saw some very significant tests and the first deliveries of hardware.

The main events in the development of the H155 cryogenic stage can be summarised as follows:

— construction of the first prototype tank
— delivery and start of assembly of the structural elements (bulkheads and panels) of the qualification tank
— delivery of the first thrust frame
— testing of two Vulcain engines beyond nominal thrust, one test being with a flight-type divergent.

Work on the P230 solid-booster stage is also far advanced, the main events being:

— delivery of the structure of the first B1 booster prior to application of thermal protection *la charge utile ayant été menés à bien, l'ensemble du modèle de vol d'Eureca a été de nouveau assemblé en février 1991. Les derniers essais ont commencé en mars et s'achèveront à la mi-avril avec un essai de compatibilité d'Eureca avec les installations de l'ESOC.*

La troisième revue de sécurité d'Eureca a eu lieu à la NASA. Il reste toutefois à élaborer quelques données de sécurité supplémentaires pour prouver à la NASA que le sous-système d'hydrazine d'Eureca ne peut pas fuir, que le porte-instruments ne constitue pas un danger d'inflammabilité dans sa configuration d'ensemble et que les fixations de certaines de ses installations expérimentales sont protégées contre les risques de fracture.

Compte tenu de la souplesse de la conception thermique d'Eureca et des incidences sur le programme d'un essai additionnel dans ce domaine, il a été décidé de ne pas faire d'autre essai d'équilibrage thermique sous vide à ce stade avancé du programme.

Selon le calendrier actuel du projet, la première partie de la revue de recette du modèle de vol aura lieu fin avril; Eureca sera transporté aux Etats-Unis au milieu de l'année et son lancement est prévu pour février 1992.

Station spatiale Freedom/Columbus

Laboratoires habités

Le fait marquant de ces derniers mois a été la remise, fin novembre 1990, de la proposition revalidée se rapportant au laboratoire raccordé et au laboratoire autonome. Depuis lors, les membres des groupes et équipes chargés de l'évaluation (à laquelle ont participé plus d'une centaine d'agents de l'ESA) ont examiné la proposition et remis leur rapport, apportant les éléments d'appréciation de base, à la Commission d'évaluation qui s'est réunie les 20 et 21 février. Les travaux se sont poursuivis en parallèle dans l'industrie en vue d'assurer le respect du calendrier d'ensemble du programme et d'éviter l'interruption des activités des équipes techniques.

L'ESA a participé aux réunions de niveau 1 et 2, où elle a défendu avec succès sa position, de l'opération de restructuration du programme de la Station spatiale Freedom lancée par la NASA début novembre 1990 et achevée fin février 1991. Parmi les nombreuses options présentées et analysées, celle qui a été retenue pour être officiellement présentée au Congrès des Etats-Unis se caractérise par une poutre centrale plus courte, pré-intégrée, et des modules américains de laboratoire et d'habitation plus petits que dans la conception de référence antérieure, mais offrant un potentiel de croissance pour plus tard. Le lancement du Laboratoire raccordé correspondant à cette configuration est prévu pour le second semestre 1998.

En ce qui concerne le secteur sol Columbus, on citera parmi les principaux événements récents la revue à mi-parcours du contrat de soutien d'architecte système ainsi que les résultats de la définition détaillée des installations centralisées, du centre de contrôle des laboratoires spatiaux habités et des centres spécifiques pour les différents éléments.

Dans le domaine de l'utilisation, la première phase du développement initial du système d'information sur l'utilisation de Columbus (CUIS) a été menée à son terme.

L'appel de propositions et d'idées qui a été lancé pour les vols précurseurs de Columbus (deux vols Spacelab et deux vols Eureca) avait donné lieu à fin février à plus de 500 déclarations d'intérêt.

Dans les activités du programme à long terme, le traitement des données apportées par l'expérience ISEMSI (portant sur un mois d'isolement passé par six hommes en enceinte hyperbare) est en cours, et le coup d'envoi a été donné à l'étude de faisabilité d'un véhicule logistique.

Plate-forme polaire

La proposition actualisée de phase C/D relative à la plate-forme polaire Columbus (PPF), reçue en octobre 1990, a été évaluée (en octobre-novembre) par une équipe de l'ESA placée sous l'autorité d'une Commission d'évaluation. En décembre, au vu de l'évaluation effectuée, la Commission d'évaluation a conclu que la proposition de phase C/D constituait une bonne base pour passer au développement de la PPF et négocier un contrat avec le consortium responsable.

Ariane

Les revues de définition préliminaire des composants du lanceur Ariane-5 se sont tenues tout au long de l'année 1990 et dès le mois de décembre, des essais très significatifs et les livraisons des premiers matériels sont intervenues.

Les principales étapes du développement de l'étage cryotechnique H155 peuvent être résumées ainsi:

- *fabrication du 1er réservoir prototype*
- *livraison des éléments structuraux (fonds et panneaux) du réservoir de qualification et début d'assemblage de ces éléments*
- *livraison du premier bâti-moteur*
- *exécution sur deux moteurs Vulcain d'essais au delà de la poussée nominale, dont un essai avec un divergent de type vol.*

L'avancement des travaux de l'étage à poudre P230 est également très important, il faut signaler les principaux événements suivants:

- *livraison de la structure du premier booster B1 avant la pose de la protection thermique*
- *livraison à Kourou de la maquette qui sera utilisée pour valider l'ensemble des procédés industriels prévus dans la nouvelle usine (notamment coulée et contrôle non destructif).*

Concernant le nouvel ensemble de lancement en Guyane (ELA-3), les étapes les plus importantes dernièrement réalisées sont:

- *mise à disposition de l'industriel du Bâtiment d'intégration des propulseurs à poudre*
- *début d'assemblage de la première table de lancement*
- *exécution des premiers essais de recette du banc des propulseurs P230*
- *mise à disposition des premiers bâtiments de la nouvelle usine de poudre.*

— delivery to Kourou of the mockup to be used to validate all industrial processes planned at the new plant (notably casting and nondestructive testing).

At the Kourou launch site in French Guiana (ELA-3), the most important recent developments have been:
— the handing over of the booster integration building
— the start of assembly of the first launch table
— the performance of the first acceptance tests on the P230 booster test stand
— the handing over of the first propellant-grain manufacturing facilities.

Hermes

Spaceplane

With the completion of the third year of Phase-1 activity, the space vehicle has achieved stage 1 of its definition. The process of consolidating the configuration and the internal and external interfaces continues. The internal layout has been confirmed in studies related to the operational aspects and the accommodation constraints. This work has also established margins in the balancing of the spaceplane.

The vehicle budgets have been revised, taking into account updated subsystem performances and a refined analysis of the mission profiles. At the subsystem level, audits have been continued to establish critical performance parameters and the subsystem mass. This activity has also established the sensitivity of equipment mass to performance and interface requirements.

Work on the aerothermal design, technology and facilities has progressed as planned. The database for the so-called 'Shape 1' has been completed. Several problems concerning fuel-cell power plant technology have delayed the demonstration of the selected design concept and have required remedial action.

The Hermes System Concept Review (SCR), which covered some 90 Hermes documents, has been conducted and recommendations completed for approval by the Board.

In preparation for the complementary space-vehicle review (RDP-A), scheduled to start in April, industry has finalised the definition and justification files.

Ground segment and operations

Further definition of ground-segment elements and the development of cost models for integration into the Programme Proposal has continued. Evaluation of the re-use of the ELA-2 building in Kourou for Hermes preparation and the definition of landing-site installations have progressed, the latter supported by meteorological studies. The candidate European landing site, Almeria, in Spain, is under detailed evaluation.

Management

The technical part of the Phase-1 report has been submitted to the Participating States, in preparation for the decision on Phase-2. The experience gained after five months of joint ESA/CNES Hermes Programme Team operation has been evaluated prior to finalisation of the Agreement between the two Agencies.

Industry has further elaborated the Prime Contractor organisation for Phase-2 and decided to create 'Euro Hermespace', based on participation by Aerospatiale, Dassault Aviation, DASA and Alenia. Details of the industrial organisation are still under evaluation. To ensure continuity of the industrial work from the end of Phase-1 to the beginning of Phase-2, a transition phase has been established (Phase-C2).

In all areas, the industrial short-term activities for the transition phase and definition of the development-phase tasks have been elaborated and negotiated for implementation into the industrial proposals. Industrial manpower deployment on Hermes has reached 1600 staff.

Submission of Industry's proposal for space-vehicle development is scheduled to be completed in March.

TDP

Experiments

The Gallium Arsenide Solar Array (GaAs) experiment, consisting of two patches (2 cm×4 cm) of solar cells with soldered interconnectors, has been integrated onboard the Tubsat micro-satellite. The Critical Design Review for a complete solar-array panel of 4 cm×4 cm cells with welded interconnectors is foreseen for May.

The Solid-State Micro-Accelerometer flight unit has been shipped to Kennedy Space Center (KSC) and was integrated on a GAS bridge in February.

The manufacturing of the Attitude-Sensor Package flight unit is in progress. A flight-representative mock-up to be used to tailor the thermal blanket has been manufactured.

A successful thermal-balance and thermal-cycling test was carried out on a flight-representative model of the Collapsible-Tube Mast in February to confirm its feasibility.

The final design for the Deposition In-Orbit experiment has been completed. The detailed design effort is in progress for the Two-Phase Flow experiment. The Critical Design Review for the Atomic Oxygen Detector is planned for March/April.

Next flight opportunities

Launch of the GAS experiment (Solid-State Microaccelerometer, G-21) onboard Space Shuttle STS-40 is now set for May 1991.

The Tubsat microsatellite carrying the GaAs patches will be launched as a piggy-back payload to ERS-1.

Launch of the Hitchhiker-G experiment (attitude-sensor package) is now foreseen for the second half of 1992, onboard Space Shuttle STS-50. The STRV-1 launch, carrying the Gallium-Arsenide Solar Array Panel, is foreseen for June 1992, while the Bremsat microsatellite carrying the Atomic Oxygen Detector is scheduled for lift-off by the end of 1992 onboard the Spacelab D-2 mission. Other flight opportunities will follow.

TDP next phase

The Final Programme content has been finalised and the subscription period will open in March.

Hermès

Avion spatial

La troisième année d'activité de la phase 1 s'achève avec la première étape de la définition du véhicule. Les travaux se poursuivent sur sa configuration et sur les interfaces internes et externes. Des études portant sur les aspects opérationnels et les contraintes d'aménagement ont confirmé l'implantation interne de l'avion et ont également permis de calculer des marges d'équilibrage.

Les bilans du véhicule ont été révisés sur la base des caractéristiques de fonctionnement actualisées des sous-systèmes et d'une analyse affinée des profils des missions. Les contrôles pratiqués au niveau des sous-systèmes se sont poursuivis pour déterminer les paramètres de fonctionnement critiques et la masse des sous-systèmes et pour mesurer la sensibilité de la masse des équipements aux impératifs de fonctionnement et d'interfaces.

Les travaux sur la conception, la technologie et les installations aérothermiques ont avancé comme il était inscrit au calendrier. La base de données de la 'Forme 1' est achevée. Un certain nombre de problèmes relatifs à la technologie des piles à combustible et auxquels il a fallu trouver une solution ont retardé la démonstration du concept retenu.

La Revue de conception du système Hermes, qui portait sur quelque 90 documents, a été menée à bien et on a élaboré les recommandations que le Conseil directeur devra approuver.

En vue de la revue complémentaire 'avion spatial' qui devrait commencer en avril, l'industrie a bouclé ses dossiers de définition et de justification.

Secteur sol et opérations

La définition d'éléments du secteur sol et l'élaboration de modèles de coûts à intégrer dans la Proposition de programme se sont poursuivies. On continue d'évaluer la reprise de l'utilisation du bâtiment ELA-2 de Kourou où Hermès pourrait être préparé et de définir les installations du site d'atterrissage; ces derniers travaux sont appuyés par des études météorologiques. La base d'Almeria (Espagne) proposée comme site européen d'atterrissage fait l'objet d'une évaluation détaillée.

Gestion

La partie technique du rapport sur la phase 1 a été soumise aux Etats participants qui se préparent à prendre une décision sur la phase 2. L'expérience acquise à l'issue de cinq mois de travail de l'équipe intégrée ESA/CNES a été évaluée avant que soit conclu définitivement l'Accord entre les deux agences.

L'industrie a continué de travailler à l'organisation de la maîtrise d'oeuvre pour la phase 2 et a décidé de créer Euro-Hermespace qui regroupe Aérospatiale, Dassault Aviation, DASA et Alenia. Les détails de l'organisation industrielle sont toujours en cours d'évaluation. Pour garantir la continuité des travaux industriels entre la fin de la phase 1 et le début de la phase 2, on a prévu une phase C-2 dite de transition.

Dans tous les domaines, les activités industrielles à court terme de la phase de transition et la définition des tâches de la phase de développement ont été préparées et négociées en vue de leur intégration dans les propositions industrielles. Les effectifs industriels affectés à Hermes comptent aujourd'hui 1600 personnes.

La proposition industrielle relative aux travaux de développement du véhicule spatial doit être présentée en mars.

Développement technologique (TDP)

Expériences

L'expérience de réseau solaire à l'arséniure de gallium (GaAs) comprenant deux groupes de photopiles de 2 x 4 cm à interconnecteurs soudés, a été intégrée au microsatellite Tubsat. La revue critique de définition, qui portera sur un panneau solaire complet à interconnecteurs soudés, doit se dérouler en mai.

L'unité de vol du micro-accéléromètre à état solide a été expédiée au Centre spatial Kennedy et a été intégrée dans un conteneur 'Get away-special' en février.

La fabrication de l'ensemble de détecteurs d'orientation se poursuit. On a fabriqué une maquette représentative du modèle de vol qui sera utilisée pour la confection de la protection thermique.

Un essai de bilan et de cyclage thermiques a été mené à bien en février sur un modèle représentatif du modèle de vol du mât à tube enroulable afin de confirmer la faisabilité de ce matériel.

La conception finale de l'expérience de dépôt de métaux en orbite est achevée.

En ce qui concerne l'expérience de flux diphasique, les activités de conception détaillée se poursuivent.

La revue de conception critique du détecteur d'oxygène atomique est fixée à mars/avril.

Nouvelles occasions de vol

Le lancement de l'expérience GAS de micro-accéléromètre à état solide (G-21) qui doit faire l'objet d'un vol spécial sur STS-40 est maintenant fixé à mai 1991.

Le microsatellite Tubsat emportant les éléments GaAs sera lancé comme passager auxiliaire d'ERS-1.

Le lancement Hitchhiker-G de l'ensemble de détecteurs d'orientation est maintenant prévu pour le second semestre 1992, à bord de STS-50. Le lancement du panneau solaire à l'arséniure de gallium sur STRV-1 est prévu en juin 1992 tandis que le microsatellite Bremsat, qui emportera le détecteur d'oxygène atomique doit être lancé fin 1992 dans le cadre de la mission D2. D'autres occasions de vol suivront.

Phase suivante du TDP

Le contenu du programme a été définitivement fixé et le programme sera ouvert à la souscription en mars.

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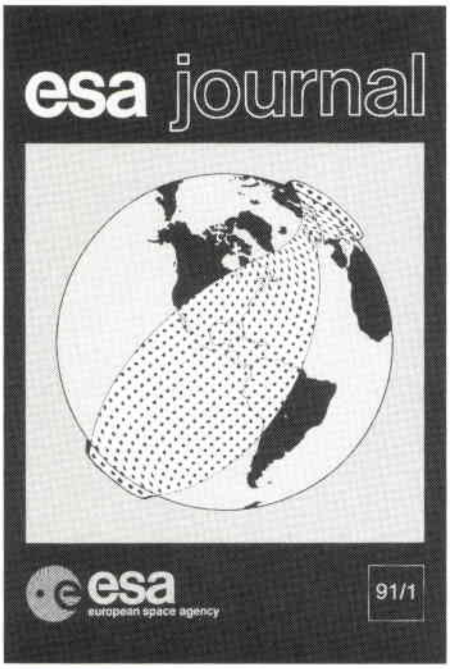

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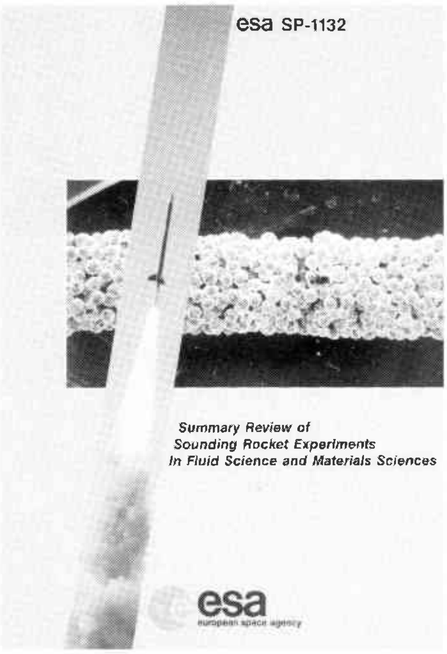

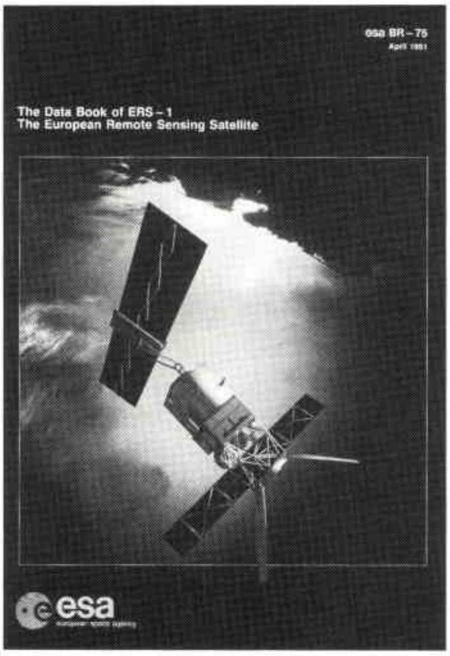

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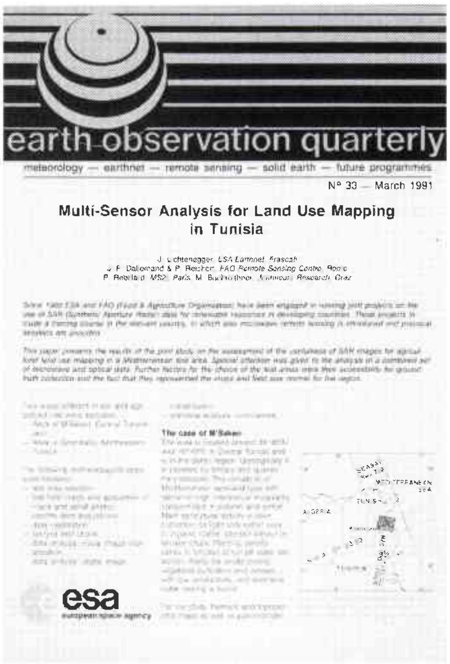

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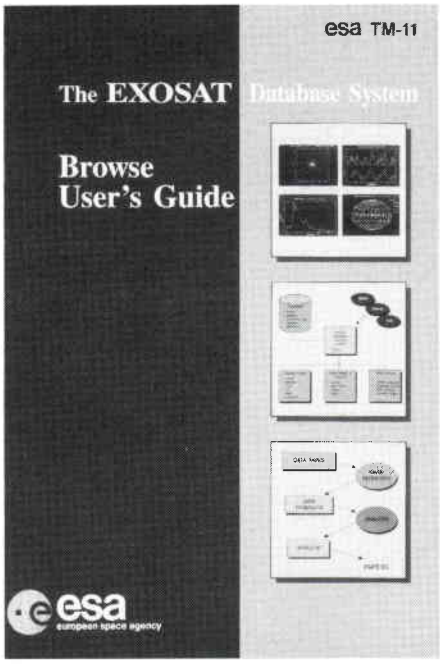

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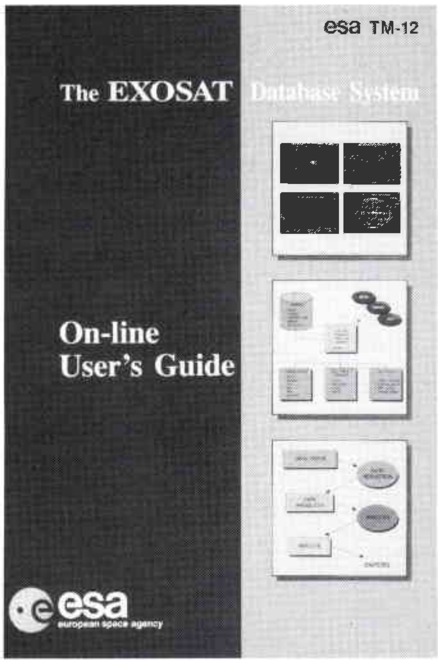

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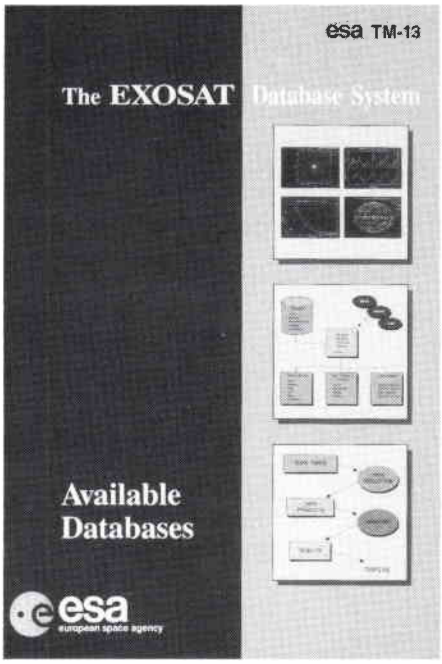

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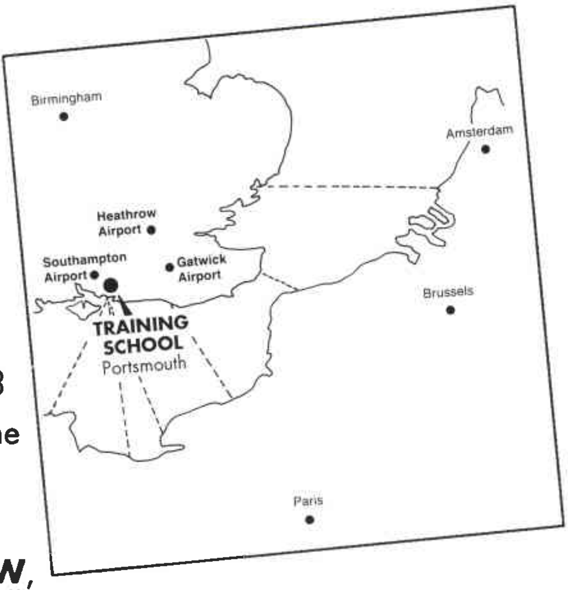
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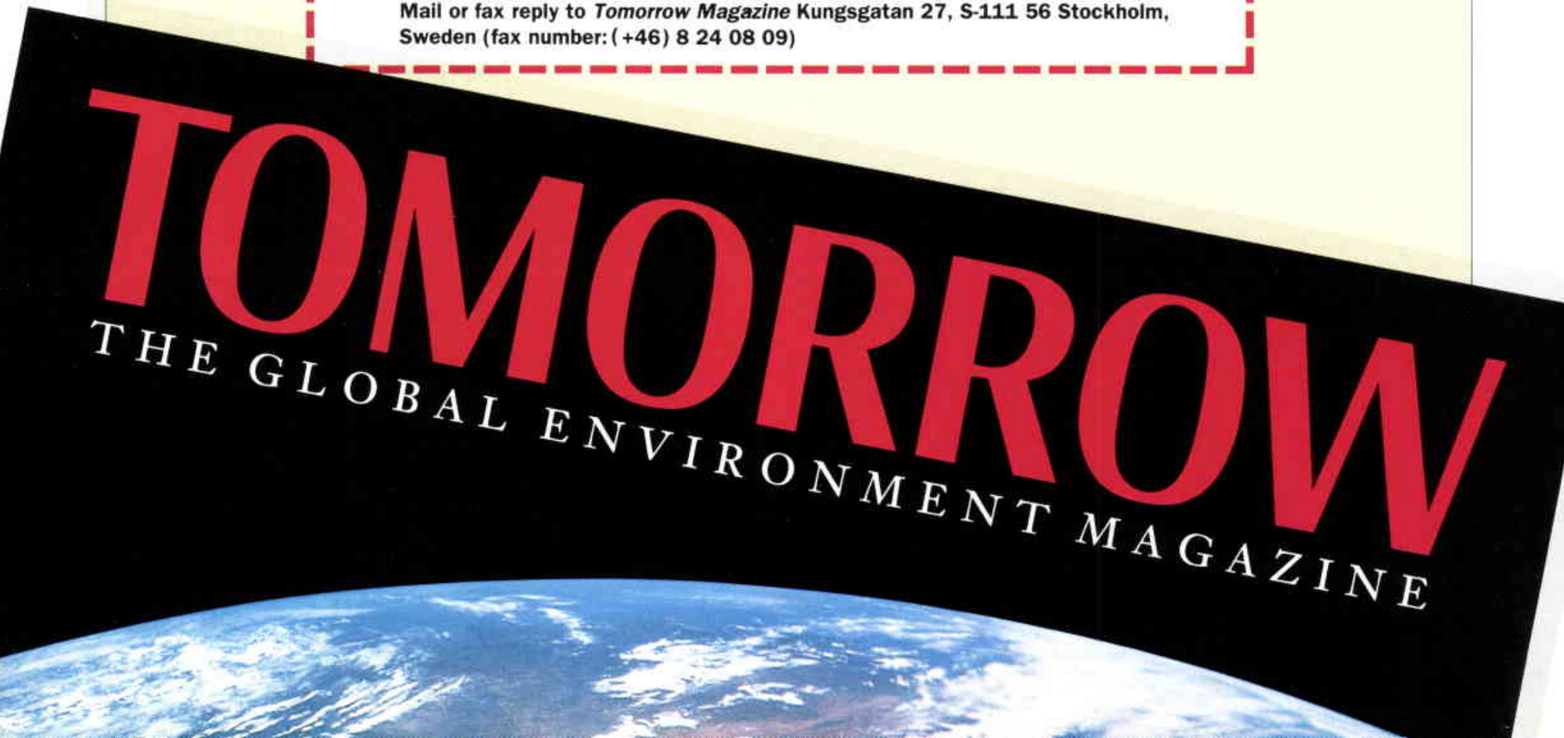
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