european space agency

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agence spatiale européenne

number 70

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european space agency

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

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

The Directorate of the Agency consists of the Director General; the Inspector General; the Director of Scientific Programmes; the Director of 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

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

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

ESRIN, Frascati, Italy.

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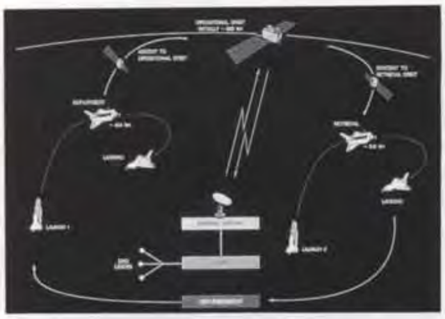

Cover: The Eureca flight-operations scenario (see articles on pages 17 – 39)

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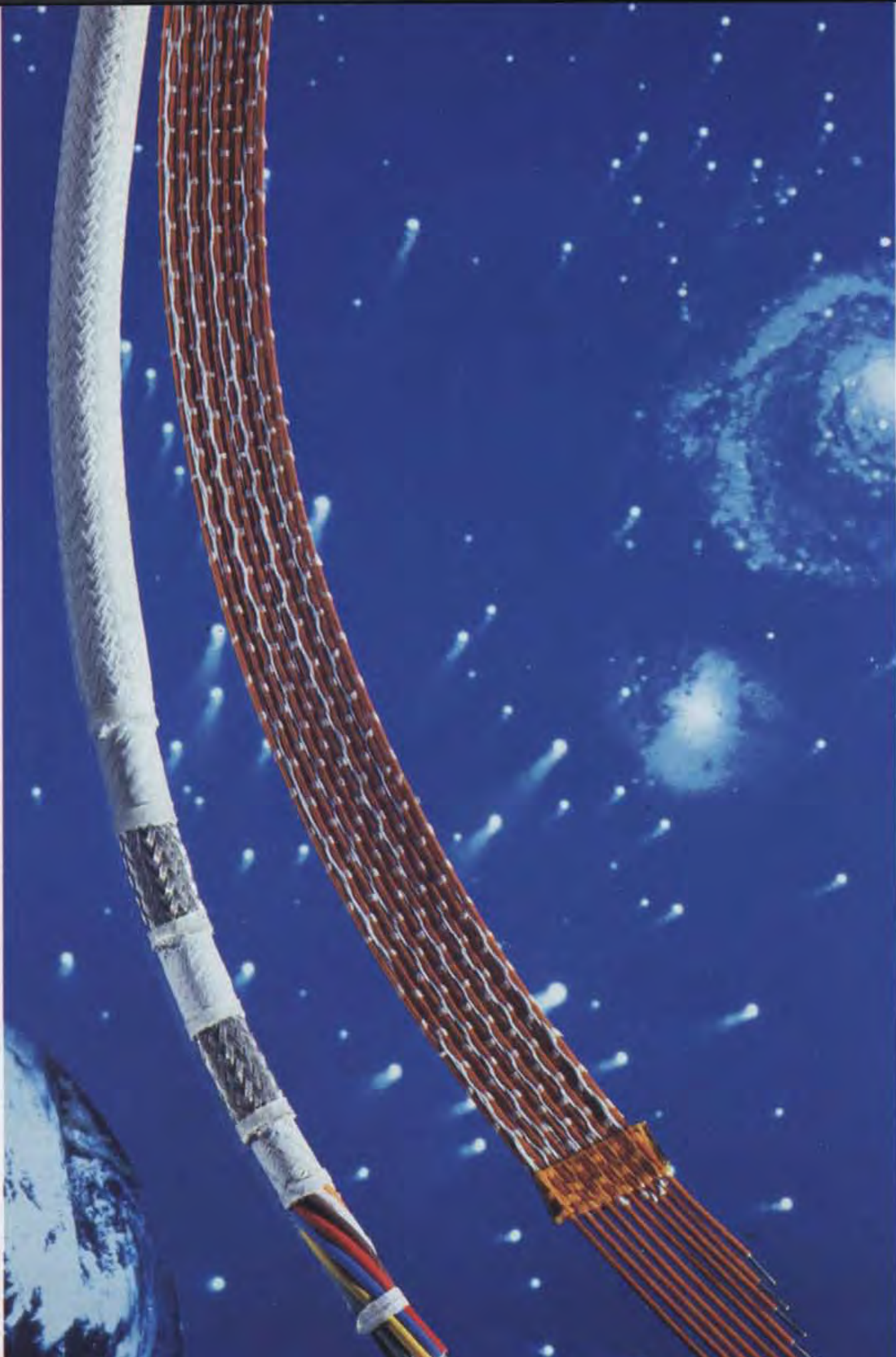


Consequences of the Changing Political Landscape for Future Space Projects*

J.-M. Luton
Director General, European Space Agency, Paris

First let me say how honoured I am to have been invited to this Forum and to have the opportunity of addressing this distinguished audience on the perspectives of European cooperation in space following the ESA Ministerial Conference held last November in Munich.

The Reuschel banking house has been one of the leading banks in the space business in Germany for more than 25 years. It has served as a bridge between the Agency and Industry, thereby ensuring the success of the European space effort. A gathering such as this provides an imporant opportunity to demonstrate the commitment of the various partners to that effort. I therefore very much welcome and support this initiative to bring together representatives from politics, industry and finance who are dealing with space matters in one way or another.

The accompanying speech was given on 29 March 1992 at the 'Munich Space Forum', organised by Bankhaus Reuschel & Co., on the eve of the European International Space Year Conference.

1992 is an important year both for space activities – it is 'International Space Year' – and for Europe itself, with the completion of the Single Market foreseen by the end of the year. We, the European space community, are at the crossroads of both aspects. We are well aware that the European space programme is at a turning point as we re-assess our plans for the future in the light of the new geo-political situation, and consider the right way forward for the European space effort.

In many fields of space activity Europe has, over the last 30 years, developed a remarkable expertise, particularly in the areas of space-science research, satellite communications, launchers and Earth observation from space. Probably the best known of Europe's space-technology capabilities is its Ariane launcher. Another recent example illustrating what European cooperation in space can accomplish is ERS-1, ESA's first remote-sensing satellite, the outstanding results from which have greatly impressed the Earth-observation community throughout the World.

However, successful as these common European efforts in space-research cooperation have been, the challenges of the 1990s mean that Europe must strengthen its capabilities and coordinate and consolidate its long-term space effort if it is to become a fully-fledged player on the World space scene.

One of the Agency's key tasks, as laid down in its Convention, is to draw up and implement a long-term European space policy, by recommending space goals to the Member States vis-a-vis other national and international organisations and institutions.

The Agency's path to the future was set out in Rome in 1985 and in The Hague in 1987 when Ministers endorsed a wide-ranging and vigorous Long-Term Space Plan for Europe extending to the year 2000. The principal objectives of that plan, which remain valid today and which were confirmed here in Munich, are firstly to maintain and enhance Europe's competitiveness in all sectors of space and strengthen the position of European Industry as a partner for international cooperation; and secondly, Europe should strive to master all areas of space technology, including the development of a European manned space capability.

In the field of manned operations, Europe set itself the objective of autonomy in order to be able, in subsequent phases, either to conduct purely European programmes, or to cooperate with other space-faring nations whilst starting from a position of strength.

Hence, partnership with the United States in the International Space Station Programme through the Columbus Programme was seen as a means of gaining early access to space for manned operations. This was to be balanced by the development of the Ariane-5 launcher and the Hermes spaceplane. Co-operation with the former Soviet Union – although not excluded – was perceived to be limited by the political situation at that time.

However, since the Hague Meeting, the World has changed dramatically. Events in Central and Eastern Europe, especially in the former Soviet Union, have transformed the political landscape in undreamed of ways. German reunification, and the intense demands for economic reconstruction in Germany's new Länder, has affected European affairs, including space activities.

Furthermore, the European Community's drive for economic and political unity has regained momentum following the Maastricht Summit. Given the global challenges facing Europe, the European Community is also determined to become a more powerful force in World affairs, and is taking on a more assertive role in such areas as deregulation, removal of trade barriers, and protection of the environment.

The perception of Earth observation from space has also changed since the Hague Meeting. Ensuring the protection of the environment in which we live is now accepted as a matter of paramount importance, requiring attention at the highest political level on an international scale. Green issues now feature strongly on the agendas of political meetings, such as that of the Group of Seven. Earth-observation data are needed for policy decisions and for a better understanding of the impact of man's activities on such phenomena as global change. Hence, Earth observation from space must now become a central element of the Agency's future strategy.

The affordability of the space objectives set out in The Hague has become of major concern to some Member States, particularly in the present fiscal and budgetary climate. Given the political, technical and budgetary evolution facing us, some Member States are reluctant to make commitments that would be binding far into the future, without the necessary flexibiiity to adjust plans to the new global realities.

Having sketched out the political environment as it evolved before the last Ministerial Conference, let me now turn to the major decisions taken in Munich. Ministers adopted two specific Resolutions. Firstly, they endorsed the Long-Term Space Plan as the strategic planning framework for the Agency's future activities, and reaffirmed the objectives set out in The Hague. At the same time, Ministers asked whether our vision of the future could be improved taking into account this new World order. Accordingly, they instructed the Agency to re-examine the path to the goals established in The Hague in the new political context.

Mr Jean-Marie Luton

They felt that World politics was at a turning point, which would also have a profound impact on space policy. We are no longer in a space race where a primary motivation for space activities is to try to establish a technological upper hand over the opposite side.

The new geo-political constellation offered, so they stressed, a unique opportunity for all the space-faring nations to combine their capabilities and to share the benefits of space research and applications worldwide.

It was emphasised that, as the international space situation was changing with the rest of World politics, we should place our space programme in a more contemporary context. Our work has a wider context and, like other European institutions, the Agency's activities must fit into a larger framework. The new environment offered us an opportunity to forge closer ties with the countries that make up the former Soviet Union and to build up a more cooperative relationship with the new states, thus contributing to their integration into the international community.

Therefore, we have to look for new ideas and possibilities for wider international cooperation, in the first instance in Europe, with a view to using urgently such capacities as exist in non-Member countries and progressively developing long-term common links with them. This could also involve expanded space cooperation with the United States and cooperative ventures with Japan.

The second important decision taken in Munich reflecting the unanimous view of Member States as to where they wanted to advance quickly, concerned Earth observation. Consequently, an Enabling Resolution on the observation of the Earth and its environment was passed and the development of the first polar Earth-observation mission, which will provide data continuity with ERS-1 and ERS-2 from 1998 onwards, was approved. The Ministers also emphasised that the Agency should examine the way in which Earth-observation activities are coordinated worldwide, so that the contribution that ESA makes meshes to best effect with what is being done elsewhere.

I can tell you that, at this stage, major efforts are under way in the various fields of activity of the Agency to find new potential partnerships and to look for areas where there might be possibilities for enhanced international cooperation, using existing space capabilities elsewhere. These range from the procurement of equipment, to the use of test or training facilities, and technology transfer to joint developments. I myself have recently been to Russia, the United States and Japan to present this new ESA initiative.

In parallel with this activity, we are currently working on a strategy that addresses the concerns expressed by the Ministers in Munich. It is based on a realistic appraisal of what our Member States can afford over the next 3–4 years. Hence, this revised strategy will allow the programmes to proceed at a pace more consistent with the funding likely to be available from the Member States.

The strategy will also be designed for flexibility, to allow a range of choices without foreclosing on options that we may want to pursue in the future.

This strategic plan will also provide an evolutionary approach to developing Europe's space capabilities in various steps, providing affordable missions that will show an earlier return on investment than originally foreseen. It will take careful account of the balance between utilisation and infrastructure, and between science, applications and launchers.

We live in a society that is dependent on science and technology. As Europe prepares for its place in the highly competitive World of tomorrow, science and technology will play an increasingly important role. The exploration of space and the challenging space projects undertaken jointly by European States within the framework of the European Space Agency can be seen to be a truly essential element in Europe's technological success.

Space research is also an area in which two of Europe's strongest aspirations come together: European integration and the promotion of advanced technology. Space research and development is a major area in which Europe can consolidate its unity and develop a common identity.

Cooperation within Europe is no simple matter, as past experience has shown. ESA has demonstrated and continues to demonstrate that scientists and engineers, in partnership with Industry and Government, can overcome national and institutional interests and ambitions to join in a cooperative venture that has secured Europe a prominent position in space. ESA's achievements are a reminder that successful cooperation can be realised even in an area of growing economic importance.

The next step involves the question of future cooperation and of our future links in space with the States of the former Soviet Union. We have to meet this new challenge with the same spirit that has made us successful in all of our preceding steps in the building of our European cooperative effort.

Problems on Earth – Solutions from Space?

Space Technology's Contribution to Promoting Global Change

E. Reuter
Chief Executive Officer, Daimler-Benz AG, Stuttgart

Just twenty-three years ago, hundreds of millions of people the World over sat glued to their televisions and radios, watching and listening in fascination as the 'Eagle' landed on the Moon and Neil Armstrong spoke his famous words. Do you remember our enthusiasm, our excitement at having finally taken a step closer to fulfilling one of humanity's age-old dreams?

The accompanying speech was given on 29 March 1992 at the 'Munich Space Forum', organised by Bankhaus Reuschel & Co., on the eve of the European International Space Year Conference.

Well, times certainly seem to have changed. Just one look at the media, for instance, and you get the impression, at least in this country, that everybody views the Columbus/Space Station, the Hermes spaceplane – in fact the whole caboodle of manned and even some unmanned space travel – as nothing more than a luxury, a costly playground for those living in the past.

What might be the reasons for this attitude?

I think recent history provides some clues. Back in the days of the Cold War, the thrilling vision of space technology and space travel degenerated into a nightmare spectacle of various countries flexing the muscles of their technological prowess and national might. The upshot was that the original concepts took a back seat as arms races gobbled up unheard-of sums of money. As a consequence, for much of the general public, space technology and research no longer means exploring new frontiers, but rather wasting huge sums of taxpayers' money – money that is direly needed elsewhere – on arming oneself to death.

There's a further key factor at work here: in the past few years, many have increasingly taken for granted the benefits of aerospace technology. New knowledge and new products we have gained through aerospace research have become household terms and everyday wares, and nobody stops to think about just where they came from. I don't know how else to account for the fairy tale that the only good thing that came of those adventures out in space was the Teflon-coated frying pan.

And what about those popular articles on an outer space full of scrap metal floating around – stories with headlines like 'At 23 000 Miles Up, Space is at a Premium?' Aren't these indicators that we have long felt entitled to count our Earth's surroundings among our natural possessions? After all, the inherent meaning of taking something for granted is to not fully appreciate it.

That's why it is all the more imperative for us to lend an ear to those people who do not play to the populist gallery, but who instead follow a rational, responsible approach in shaping their thoughts and actions.

Unlike small-minded would-be experts who in some cases even puposely overlook the benefits of unhindered access to the cosmos and who clamour for us to drop out of space research, the rationalist looks forward to the wealth of opportunities it presents for improving our present quality of life and for solving the problems of today and of future generations.

Indeed, one such benefit we have gained from aerospace technology – one which the nay-sayers often conveniently forget – is the discovery of the ozone hole, which was the work of orbiting satellites and not of Earth-bound researchers scanning the skies. And let's not forget those first pictures of the Earth transmitted back from space that made us see just how unique and delicate our planet is. Those overwhelming images enabled us to recognise contexts and connections we must observe increasingly as we seek new ways to protect our environment.

We can now investigate and evaluate climatic change and environmental damage, predict the weather accurately, and sound early warnings of impending catastrophes. We can now obtain invaluable data on desert expansion, forecast crop yields, discover new mineral deposits, and monitor compliance with disarmament treaties or environmental-protection agreements.

Mr Edzard Reuter

Satellites help guide traffic, transmit telephone calls and television broadcasts, and give us access to knowledge stored in databanks around the World. Without satellites, it would take us decades to establish communications links with the successor nations to the previous Soviet Union – again, one of those not so petty plus points that many so conveniently overlook.

Significant as all of these achievements are, aerospace research and technology is achieving other breakthroughs of even greater importance. For example, the type of fuel cells that are to supply the Hermes spaceplane with power can later be used to build environmentally-sound power plants on Earth. Another promising project is the collaboration of Deutsche Aerospace and Tupolev on a hydrogen-powered airplane whose fuel supply is based on low-temperature concepts. As soon as the technique for storing liquid hydrogen in orbit has been perfected, we will gain a major tool for dealing with the environmental strain associated with aviation. Finally, the question of how to transfer to Earth solar energy 'captured' in outer space is no longer merely fantasy.

The list even includes basic research on new medicines or materials in nearly gravity-free surroundings. Moreover, the experience gained in working on international aerospace projects gives rise to new management methods and organisational methods that are crucial for staying on the competitive edge, and without which we could never master the global challenges of tomorrow's World economic order.

To be sure, progress has sometimes occurred at less than the speed of light, causing disappointments and refuting proclamations of the initial heady days. But perhaps that's par for the course, seeing as how we live in the age of 'instant gratification'. An acute example of the devastating consequences of this approach is provided by the field of memory-chip technology. Cases like this should make us ask if we are not perhaps wrong in using the short-term, or at most mid-term, yardstick to measure the cost/use ratio of projects reaching far into the next millenium.

You can also pose the question in another way: Can we even afford not to make use of the potentials of aerospace research and its associated technologies? In other words, wouldn't it be presumptuous of us to assume that we alone can set limits today to thought and action, and thereby draw the boundaries for tomorrow's knowledge and skills? And wouldn't this simply prove that these professional doom-mongers had been right all along in tirelessly railing against our lack of responsibility towards future generations?

I think the answer to all of these questions is crystal-clear.

If that is the case, then let us have the courage to candidly admit that no one can predict with complete accuracy just what shape the solutions offered by aerospace technology will take. Even Kepler could not have imagined that his curiosity about the courses of the planets would lead to findings that would one day form the foundation for rocket-flight calculations. But one thing we **do** know is that today's international aerospace cooperation can be a major contributor to safeguarding peace.

The Spacelab years, for example, have gone down in the annals of ERNO, the Prime Contractor for the European Spacelab Programme, and thus in the annals of our company too, as a symbol of a partnership crossing national and even continental borders. In this respect, the work of ESA is a shining example of just how successful collaboration in Europe can be.

Both of these examples underline how aerospace technology is poised to become a key factor in the integration of Europe.

Today,. in a World no longer ravaged by the East–West conflict, there are novel options beyond those I have already mentioned. Anyone can learn, for instance, all about the previous Soviet Union's pioneering work in aerospace research and technology. Nonetheless, these accomplishments seem to be slipping into obscurity. Nowadays, the only thing managing to attract much attention is the Mir Space Station, and even there people's curiosity revolves primarily around the nationalities of new visitors or around the Russian astronaut who has been orbiting the Earth for months and who will come home to an unrecognisable World.

Regardless of the compassion we feel for such situations in the Commonwealth of Independent States, it is essential for us to do some soul-searching about how mutually to make the best use of the scientific and technological potential there. I am aware that many humanitarian steps have already been taken. But wouldn't we provide a much more crucial contribution towards stabilising these countries if we offered concrete programmes for integrating them as partners in international cooperation, and in projects that could certainly be financed by the Western nations?

In my opinion, that would not only do a great service to a large number of individuals, but to all of mankind, because there's no getting around the fact that today, global economic cooperation – and thus interdependencies as well – are inescapable in many sectors. Indeed, for the industries affected, they have become vital. If we accept this as a given, then we should easily be able to summon the resolve to create the appropriate conditions and institutions to support worldwide economic networks.

From there, would it be more than just a small step for us to incorporate space technology and travel into our efforts to help maintain global political stability?

Synthetic-Aperture Radar image of southern Germany and northern Switzerland taken by ESA's ERS-1 remote-sensing satellite


EURECA
MBB ERNO
THE EUROPEAN RETRIEVABLE CARRIER
esa
SENER
FWD
+ X

The Eureca Project – From Concept to Launch

W. Nellessen
Eureca Project, ESA Directorate for Space Station and Microgravity, ESTEC, Noordwijk, The Netherlands

The European Retrievable Carrier, to be placed into orbit in July 1992 by the Space Shuttle 'Atlantis', is an unique, re-usable, user-oriented space facility that has been developed to meet the needs of both scientific and applications-oriented users in the coming years. At the same time, Eureca is also very much a step towards European autonomy in the space field, which was one of the goals laid down at the ESA Council Meeting at Ministerial Level, in The Hague, in November 1987.

Introduction

The first concepts for an autonomously operating 'European Retrievable Carrier', now more familiarly known as 'Eureca', originated in 1978 when ESA was engaged in the study of a Spacelab follow-on development programme. At that time, the development of Spacelab and its utilisation by ESA astronauts represented Europe's first undertaking in the field of manned spaceflight systems. However, many scientists and politicians in Europe were undecided at that time about the merits of continued engagement in the field of manned space-flight beyond Spacelab's development and utilisation as part of the agreed cooperative manned space programme with the United States.

The reluctant attitude of several ESA Member States towards substantial investment in the development of autonomous manned spaceflight systems was further aggravated by the general economic situation in the late seventies, which suggested that ESA's budget would be constrained in the future within a ceiling of about 700 MAU per year. This in itself would not have allowed for further substantial European engagement in the development of autonomous manned spaceflight systems.

On the other hand, there was also a fear that Europe would loose out in the longer term if it did pass up any further engagement in manned space activities, and that it would eventually be unable to participate in the development of commercially attractive products in the near-Earth environment.

Member States were therefore responsive at that time to ESA's proposal to consider a modest but evolutionary Spacelab follow-on development scenario, illustrated in Figure 1, that would allow Europe, with moderate annual expenditures, to:

- contribute, on the basis of its experience gained with Spacelab, to the development of a man-operated module as part of a continued cooperative programme with the United States for the construction of an International Space Station
- develop an automated and retrievable carrier system, using the Spacelab pallet-only configuration as a basis.

These two elements would then allow the development of the basic technologies and operating principles that would eventually be required for the construction and operation of larger and autonomously operated European space complexes, be they in the form of

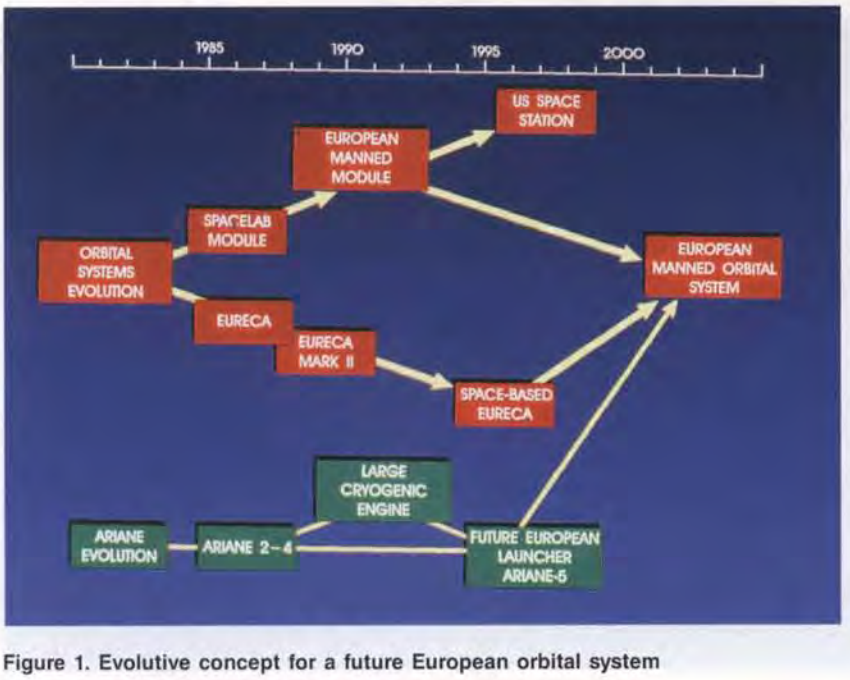


Figure 1. Evolutive concept for a future European orbital system

space-based manned laboratories or factory-type, unmanned and automated processing plants.

This idea of a moderate but continuing and evolutionary development of a future autonomous European space system was appealing to most of the ESA Member States, leading to the decision by the Agency's Council in December 1981 to undertake the development of an automated and retrievable Carrier as a first step in this direction.

This decision by the ESA Council was very much welcomed by the scientific community, as a space platform of this type would ideally supplement the research capabilities offered by Spacelab. It would allow longer-duration flights, which a number of experiments specifically required, and would also provide a 'quieter' microgravity environment because the man-made disturbances that could affect Spacelab's payloads would be excluded.

Having completed the detailed definition of the Carrier and its experiments, the development of Eureca was contracted in 1984 to the German company ERNO as Prime Contractor, leading the consortium of European companies shown in Figure 2.

At the time of writing, the fully integrated Eureca platform (see frontispiece) is being prepared for transportation into space aboard Space Shuttle 'Atlantis' in July 1992.

The overall Eureca system concept

The Eureca system design was based on the following essential objectives:

- that Eureca should be capable of being carried into orbit by the Space Shuttle, separated from it, operated in a free-flying mode under the control of ESA's European Space Operations Centre (ESOC) in Darmstadt (D), and later retrieved again by the Shuttle and returned to Earth;
- that the Carrier should be capable of making five flights in a ten-year period;
- that users should have certain of the advantages of both Spacelab and a conventional free-flying satellite, namely adequate mass and power, up to six months of operating time, orbital altitudes up to 600 km, an unpolluted environment, adequate pointing accuracy and attitude stabilisation, and very low residual onboard accelerations;
- that the Carrier's design should accommodate the size of payload that can be developed economically in Europe;
- that transportation and operating costs should be as low as possible;
- that development costs should be kept as low as possible by using hardware already developed and readily accessible in Europe;
- that the basic design should be adaptable to carry instruments for research and applications in the life- and material-sciences, astrophysics, geophysics, meteorology and advanced technology.

The spacecraft design concept

The resulting design concept for the Eureca platform is shown in Figure 3. This configuration has been designed to:

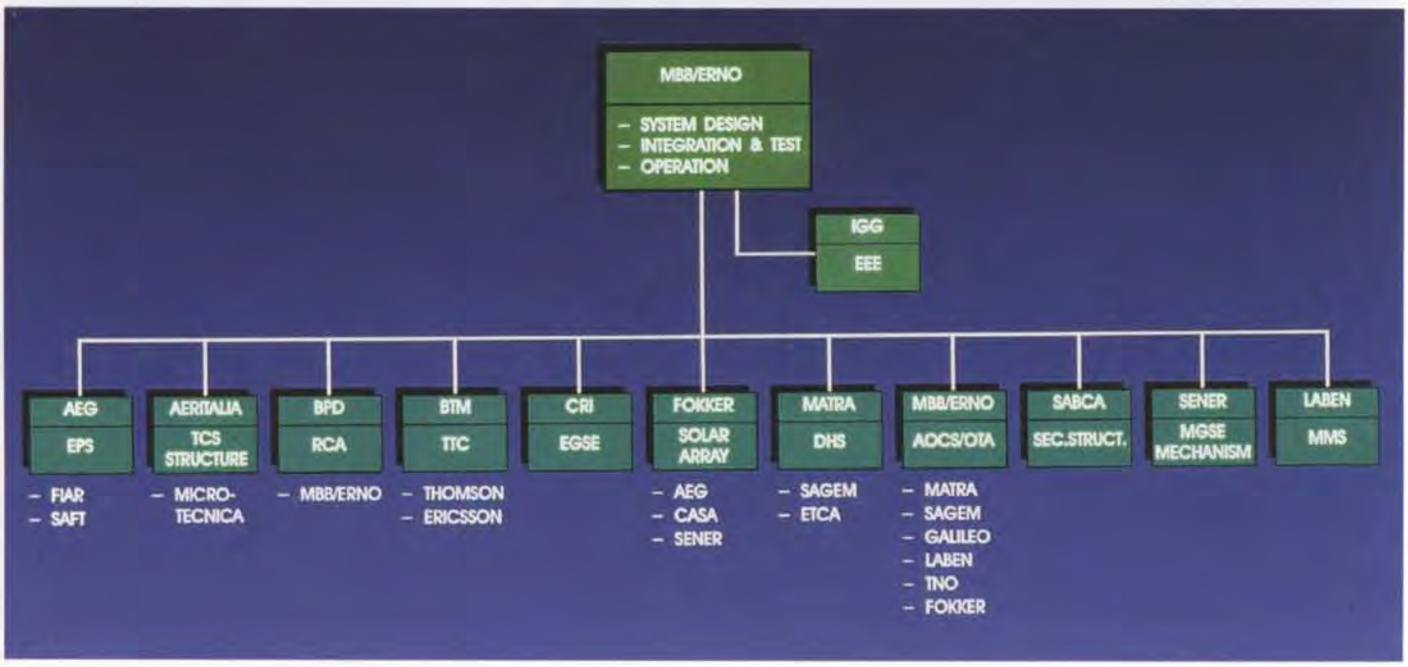


Figure 2. General industrial task distribution for the development of Eureca

- maximise the volume available for payloads on the Carrier's upper deck;
- optimise its length-to-mass ratio to minimise launch charges;
- attach directly in the Space Shuttle's cargo bay via a simple three-point attachment system;
- facilitate platform and payload maintenance on the ground between flights.

To facilitate both the initial integration of payloads into the Carrier and their subsequent exchange, Eureca provides both standardised structural attachments and standardised power and data interfaces. The data-handling system is a decentralised facility which allows the users to process data internally in their own instruments using their own software and then link to the onboard data bus for the transmission of telemetry data and the reception of commands.

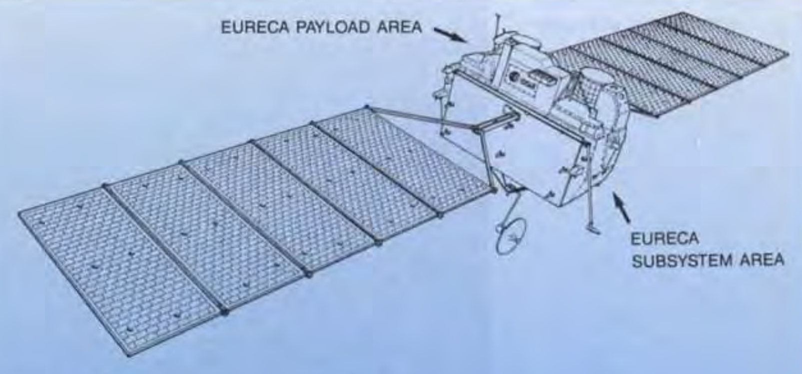
Compared to Spacelab with its centralised computer system, Eureca's Data-Handling System (DHS) has greatly simplified the payload-integration effort, leading to significant cost reductions for both the Eureca platform itself and its users.

Since Eureca's DHS interfaces are largely compatible with the industrial bus standard (IEEE 488), the users can employ commercially available checkout equipment and reuse their software at system-integration level without the need for reprogramming. This too has helped to reduce the costs of experiment development, system integration and operations.

When attached to the Space Shuttle, Eureca requires only a minimum of Shuttle interface and safety verifications during launch preparations. In flight, the Shuttle will only control deployment and retrieval operations in the immediate vicinity of the Orbiter. During all other flight phases, Eureca's flight will be controlled from ESA's European Space Operations Centre (ESOC) in Darmstadt (D).

Because during routine flight operations the intervals between ground-station contacts with Eureca can be as long as 18 h, the Carrier's onboard attitude, data-handling, power-supply and thermal-control subsystems have been designed such that they can function autonomously, i.e. without ground-control intervention, for up to 48 h at a time.

In addition, the system has been designed to survive another 10 to 12 months in orbit beyond the nominal mission lifetime of six



MASS	TOTAL	4500 kg
	FUEL LOADING	750 kg
	AVAILABLE TO PAYLOAD	1000 kg
VOLUME	AVAILABLE TO PAYLOAD	8.5 m^3
POWER	SOLAR ARRAY OUTPUT	5000 W
	AVAILABLE TO PAYLOAD	1000 W
	PEAK	1500 W
THERMAL CONTROL	LIQUID FREON LOOP (1200 W) AND MULTI-LAYER INSULATION	
DATA MANAGEMENT	HIGH SPEED	256 kbps DOWN LINK (S-BAND)
	LOW SPEED	2 kbps UP LINK (S-BAND)
	MEMORY CAPACITY	128 Mbits
	AVERAGE P/L BUS CAPABILITY	1.5 kbps
ATTITUDE POINTING ACCURACY		$\pm 1°$ (3 SIGMA)
MICROGRAVITY		10^{-5}g < 1 Hz
		10^{-3}g > 100 Hz
ORBIT		525 km ; 28.5°
MISSION DURATION		6 MONTHS OPERATIONAL AND 3 MONTHS DORMANT
DESIGN LIFE		5 MISSIONS OR 10 YEARS
TURN AROUND TIME BASELINE		2 YEARS BETWEEN RETRIEVAL AND NEXT LAUNCH

Figure 3. Eureca system capabilities and resources

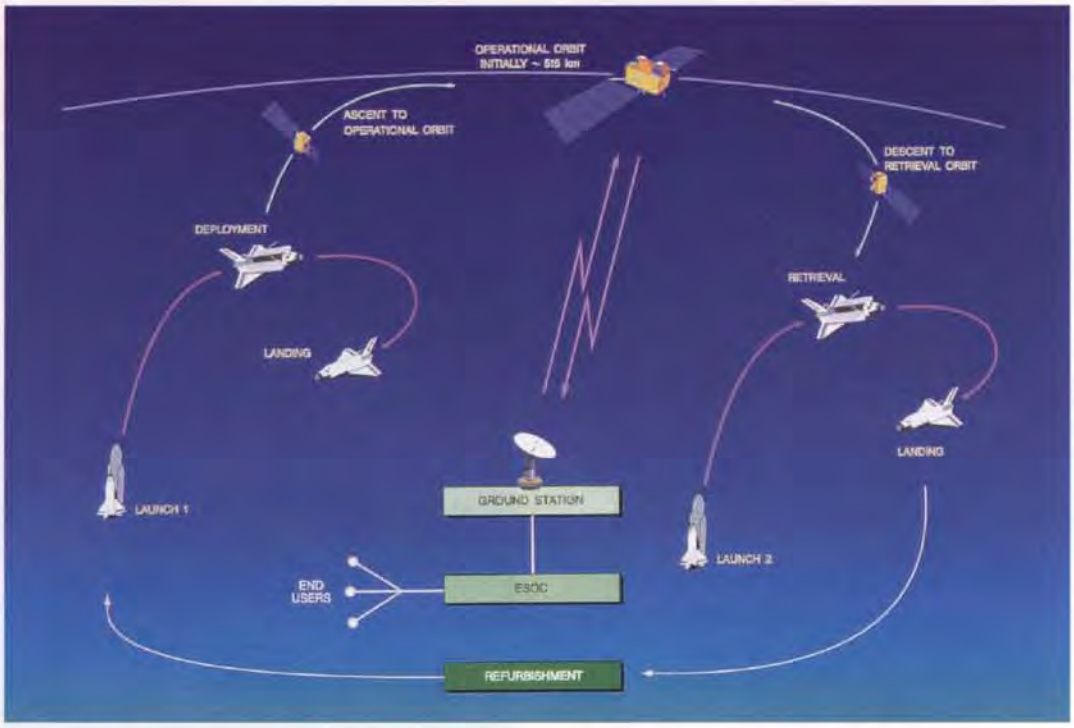
months, in case the first planned rendezvous for collection by the Space Shuttle should fail.

The flight-operations concept

The Eureca flight-operations scenario is summarised in Figure 4. Once the Space Shuttle has reached an altitude of about 400 km, it will deploy Eureca using its remote manipulator arm. During this deployment process, ESOC will check-out the Carrier's state of health whilst it is still being held by the Shuttle arm. After a successful check-out, ESOC will take over full control of Eureca flight operations.

As a first step after deployment, Eureca will use its own propulsion system to climb to an altitude of about 500 km, where it will remain for the next six months or more. Upon completion of its mission, Eureca will again descend under its own power to rendezvous with the Space Shuttle for its return journey. Once back on Earth, Eureca will be shipped back to its home base in Bremen (D) to be prepared for its next flight.

Figure 4. Eureca flight-operations scenario



During the Eureca deployment and retrieval operations, three ground stations will be used by ESOC for control purposes – Perth (Australia), Maspalomas (Canary Islands) and Kourou (French Guiana). During routine in-flight operations, only the first two of these ground stations will be required.

The user accommodation concept

In the course of a study of the 'user friendliness' of the Spacelab system, questioning of FSLP (First Spacelab Payload) and D1 mission (First German Spacelab Mission) investigators resulted in a strong recommendation from the user community to simplify access to future facility-type spacecraft like Eureca by:

- simplifying the documentation requirements
- simplifying the payload-integration and interface-verification operations
- providing skilled project personnel to assist the users in resolving interface, safety and operational problems
- minimising bureaucracy and the need for frequent and costly meetings.

Having taken these desires of the user community into account, it can be fairly claimed now, at the culmination of the Carrier's development, that the Eureca payload-integration process represents a major step forward compared with previous procedures.

User-friendly documentation

For Eureca, a significant effort has been invested in achieving a user-friendly mission environment, because the typical user will not necessarily be an experienced investigator already familiar with the management procedures of complex multinational space projects. In fact, substantial gaps have existed in the past between the documentation standards set for the industrial consortia responsible for space-vehicle development, and the documentation provided by relatively small investigator teams with limited budgets and more hardware-oriented personnel.

This gap was exacerbated by the normal practices of industry, which usually tends to define system requirements by referring to documents of general validity and not ones specific to the current project. As a consequence, 'untrained' users have sometimes had to devote substantial resources to reading and understanding reference documents only minor parts of which were relevant to their own particular instruments.

On the contrary, the Eureca documentation approach is based on a set of payload-specific documents dedicated to (modular) familiarisation with Eureca payload management, with the Carrier's interfacing systems, and with the external interfaces imposed by firm mission-assurance and operational requirements.

The major user effort is now limited to the preparation – in response to an ESA Announcement of Opportunity – of a single interface document, the Instrument Interface Proposal (IIP). In the IIP, the candidate user is presented with a number of suites of interface-relevant information, essential for the definition of his or her own instrument.

Each section of the IIP summarises the essential aspects of the Eureca subsystems, e.g. mechanical, thermal, electrical, etc. At the end of each section, the user is expected to answer to few specific questions, in a pre-defined format, sufficient to define the extent of the Carrier resources needed to conduct the mission.

During an accommodation study based on these user-prepared IIPs, ESA, together with the Carrier integrator, assesses the IIP's compatibility with the Eureca system and checks the feasibility of instrument requirements potentially in conflict with the standard Eureca capabilities. Finally, after an interface review process lasting approximately three months, ESA converts the IIP into an 'Instrument Interface Agreement' (IIA).

The release of the IIA is then completed by the issue of a few IIA Annexes, each dealing with technical details for different disciplines, which are agreed individually at a later stage, but not later than the Eureca Critical Design Review, depending on the particular instrument's design maturity. This step completes the essential requirements as far as user-provided documentation is concerned.

During the period of actual payload development and integration, the user needs to prepare the following essential documents:
- the safety data package to obtain NASA flight clearance
- the instrument user manual for the training of the ESOC flight controllers, and
- the interface test procedure for the integration onto the Carrier.

End-to-end data communication
The Eureca data-management system consists of the Data-Handling Subsystem (DHS) – the 'space segment' – and the Overall Check-out Equipment (OCOE) and the Operations Control Centre (OCC) with the Data Disposition System (DDS) – the'ground segment'.

During ground operations (assembly, integration, test and verification), the data-management system provides end-to-end data transfer from an instrument to its relevant Instrument Test Equipment (ITE). In this two-way data communication, the entire data-handling equipment chain between the two end points is transparent: the data arrive in exactly the same format and with the same content as they were sent.

During orbital operations (nominal mission phase), the data-management system relays information from the subsystem/instrument via the DHS, the Telemetry and Telecommand Subsystem (TTC), the ground station, the OCC, and finally the DDS, to the user's home establishment, and vice versa. Again, the links are entirely transparent to the messages conveyed.

The user defining and supplying both hardware and software for the instrument, for the ITE, and for the instrument data evaluation system, can employ the same software for stand-alone testing of the instrument, for the system-integration and check-out phase, and for the instrument in-orbit operational phase, even though entirely different (but transparent) transmission links are being used for the different phases.

The benefit of this end-to-end system is twofold:
(a) the user incurs reduced hardware, software, and manpower needs and the time required for system compatibility testing is minimised, and
(b) the carrier/payload system is extremely flexible with respect to the interchanging of different instruments, e.g. refurbishment for new Eureca missions.

In effect, the overall payload concept of Eureca is therefore based on a 'plug-in/plug-out' philosophy, requiring only a minimum of integration and verification effort.

The end-to-end data communication outlined above can take the form of a work station (the user's ITE or home establishment), connected via a transparent network to the 'equipment' (the instrument or subsystem) . From this work station, the equipment can be accessed remotely to operate it and to send and receive data. The type of network used for the various operational phases (stand-alone configuration, system integration, flight operations) is irrelevant as far as the work station's and the instrument's operating software is concerned.

Figure 5 illustrates the various steps involved in integrating and operating instruments on Eureca.

The data transferred in the network needs to be of a standardised format. This is the only restriction on the user's software, the data contents and representations being entirely

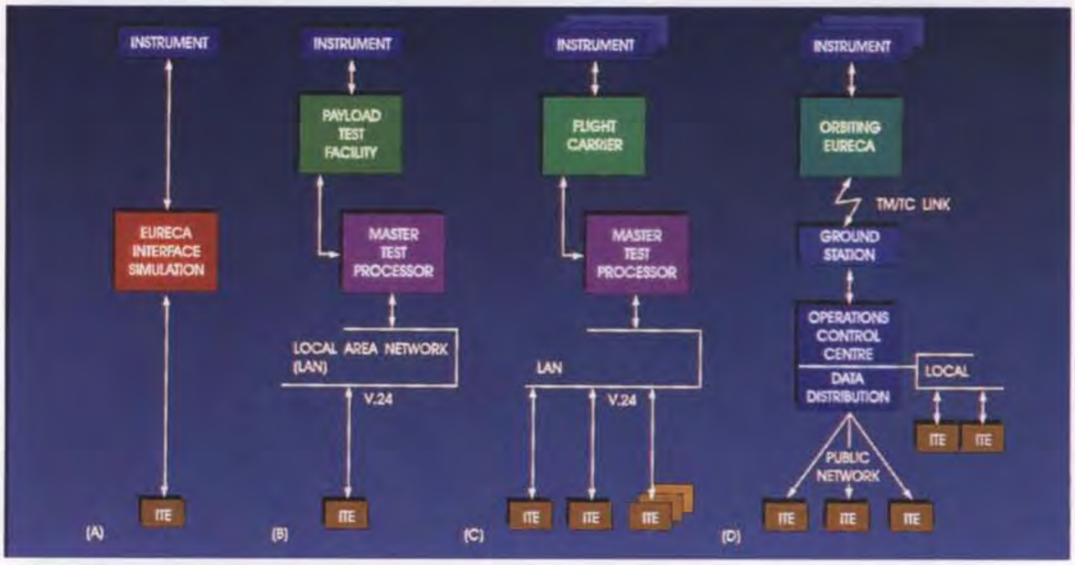


Figure 5. Integration of Eureca payloads into the end-to-end communications scenario

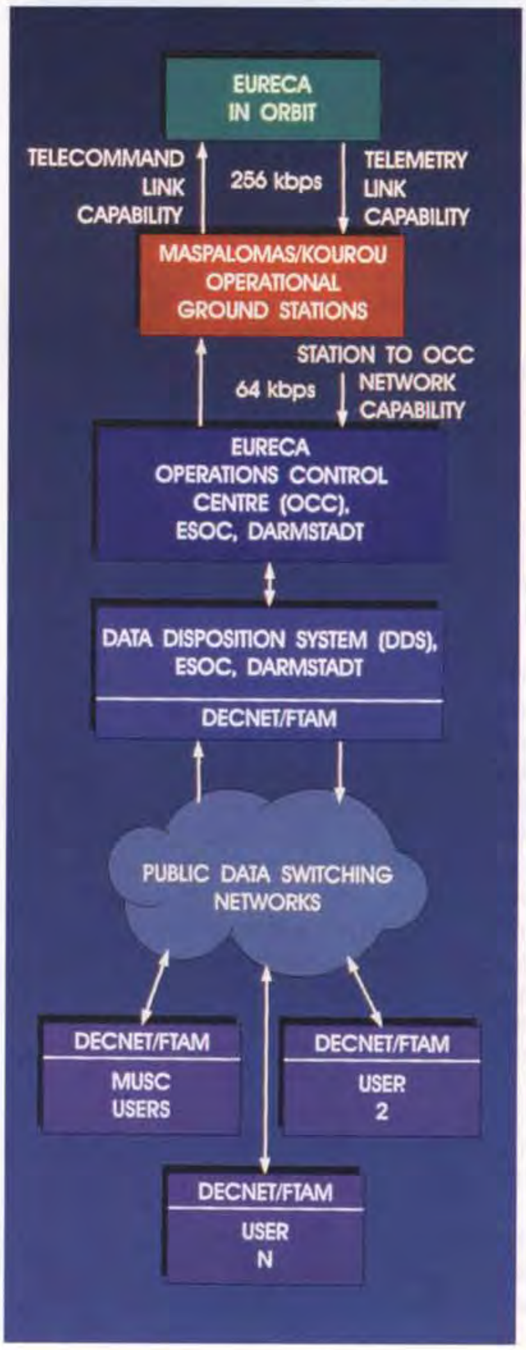


Figure 6. Eureca mission-operations data flows for the routine mission phase

the user's choice. The formal architecture for such a network application is the packetised telecommand/telemetry, providing a 'standard envelope' for the data: a header containing type, length, and address information, followed by the user's data field.

Using this information in the packet header, the data-management system can process and forward the messages (commands, housekeeping data, and science data) between the end points without altering their format or content. Software overheads incurred due to the packetisation are typically only a few percent.

With the availability of this packetised treatment for the scientific data, the previous approach of pre-processing such data at ESOC has been replaced by a data-dissemination system (called DDS) which transfers the scientists' 'private' data directly to their respective institutes for further processing.

Figure 6 summarises the data flow and functional structure of the DDS system at ESOC.

The MUSC: an interactive operations concept for user support

An important feature of future payload operations in space will be the decentralisation of both the real-time operations and the mission-preparation functions, leading to greater involvement of the participating scientists' home institutes.

This concept is already being implemented for the first Eureca mission via the creation of the Microgravity User Support Centre, or MUSC. This Centre, located at the German national space centre at DLR near Cologne, is supporting both scientific and commercial users in preparing and performing their space experiments. It is presently focussing on the microgravity, materials-science and life-sciences disciplines, the three participating institutes that make up the MUSC being: the DLR Institute for Space Simulation, the DLR Institute for Aerospace Medicine, and the DLR Institute for Materials Research (Fig. 7).

The major tasks of the MUSC are to support the user in the following three areas:

(a) experiment preparation and qualification, by supporting experiment development tests, facility validation tests, sample qualification tests, experiment verification tests, and 1-g reference tests (where applicable)
(b) experiment operation, by supporting experiment monitoring, command generation and experiment optimisation
(c) scientific experiment evaluation, by providing: a microgravity information centre with a specialised microgravity library and access to literature databanks; a databank providing microgravity experiment data and technical data for experiment facilities; and a scientific support programme with access to the knowhow and the scientific/technical infrastructure of the three participating DLR research institutes.

The first scientific mission of Eureca
In response to the most urgent needs of the microgravity science community at the time of payload selection, the first Eureca mission is devoted primarily to materials-science experiments requiring minimal gravitational disturbance (low-frequency disturbance less than 10^{-5}g) for periods of more than a week.

The Call for Experiments for this first Eureca mission resulted in 129 experiment proposals, 93 of which came from the microgravity disciplines, and the remainder from space-science, applications and technology-demonstration programmes.

In view of this high response from the microgravity science community, ESA decided to also undertake the development the following multi-user facilities as part of the Eureca Programme:

- an Automatic Mirror Furnace Facility (AMF), to study semiconductor materials
- a Multi-Furnace Assembly (MFA), to study the wettability, migration sintering and growth characteristics of materials
- a Solution Growth Facility (SGF), to study organic crystal growth
- a Protein Crystallisation Facility (PCF), and
- an Exobiological Radiation Assembly, to study the exposure of biological materials to the space environment.

These facilities have allowed the accommodation of thirty-seven experiments, originating from eight ESA Member States, on the first Eureca flight.

In addition to the above so-called 'core facilities', two other microgravity instruments were selected:
- a High-Precision Thermostat (proposed from Germany), and
- a Surface Force Adhesion Facility (from Italy).

Figure 7. The Eureca experiment payload facility at the Microgravity User Support Centre (MUSC), at DLR, in Germany

The multi-user facilities and these two additional instruments together make up about 80% of the payload complement for the first Eureca mission. However, in order to demonstrate already on this first mission the broad utilisation potential of Eureca, the remaining 20% of the payload complement has been reserved for space-science and technology experiments, which are represented by the following instruments:
- a Solar Spectrum Measurement Assembly
- a Solar Variation Measurement Assembly
- an Occulation Radiometer
- a Wide-Angle X-ray Telescope
- a Time Band Capture Cell, to measure micro-particles
- a Radio-Frequency Ionisation Thruster Assembly (RITA), to qualify advanced propulsion techniques in space
- an Inter-Orbit Communication (IOC) Assembly, to relay Eureca data via the Olympus satellite to the ground
- a Gallium Arsenide Solar-Cell Assembly, to explore the development of solar cells.

The instruments embarked on Eureca will allow a total of 55 individual experiments to be conducted. More detailed descriptions of the 15 instrument packages to be flowm on this first mission and their individual experiment objectives can be found in the next article in this Bulletin, by L. Innocenti.

Future utilisation potential of Eureca

Based on the large number of experiment proposals that were received for the first Eureca mission and subsequent proposals from the astrophysics scientific community, numerous payload studies have been undertaken which have clearly demonstrated Eureca's flexibility for adaptation to carry different payload complements, provided the new requirements do not overstrain the inherent extension capabilities and operating principles of the basic Eureca design.

As a first extension of Eureca system capabilities, it is anticipated that the Inter-Orbit Communications (IOC) instrument package currently being flown as a communications experiment from Eureca via the European Olympus communications satellite to a central ground facility (Fig. 8), will evolve into an operational capability of Eureca, thereby facilitating future quasi-real-time interactive involvement of ground-based experimenters with their on-board experiments.

Aside from the fact that the development of the autonomously operating Carrier already encompasses many of the design techniques and operating principles required for future free-flying Colùmbus systems, Eureca is also very well suited in its present form for advanced in-flight demonstrations of the technologies that will be needed in the future for in-orbit assembly and payload-exchange activities, as well as for in-flight refuelling and rendezvous demonstrations.

To explore these possibilities, the Eureca Project and various ESTEC Departments have conducted numerous studies to verify Eureca's potential to demonstrate such technologies in space under realistic

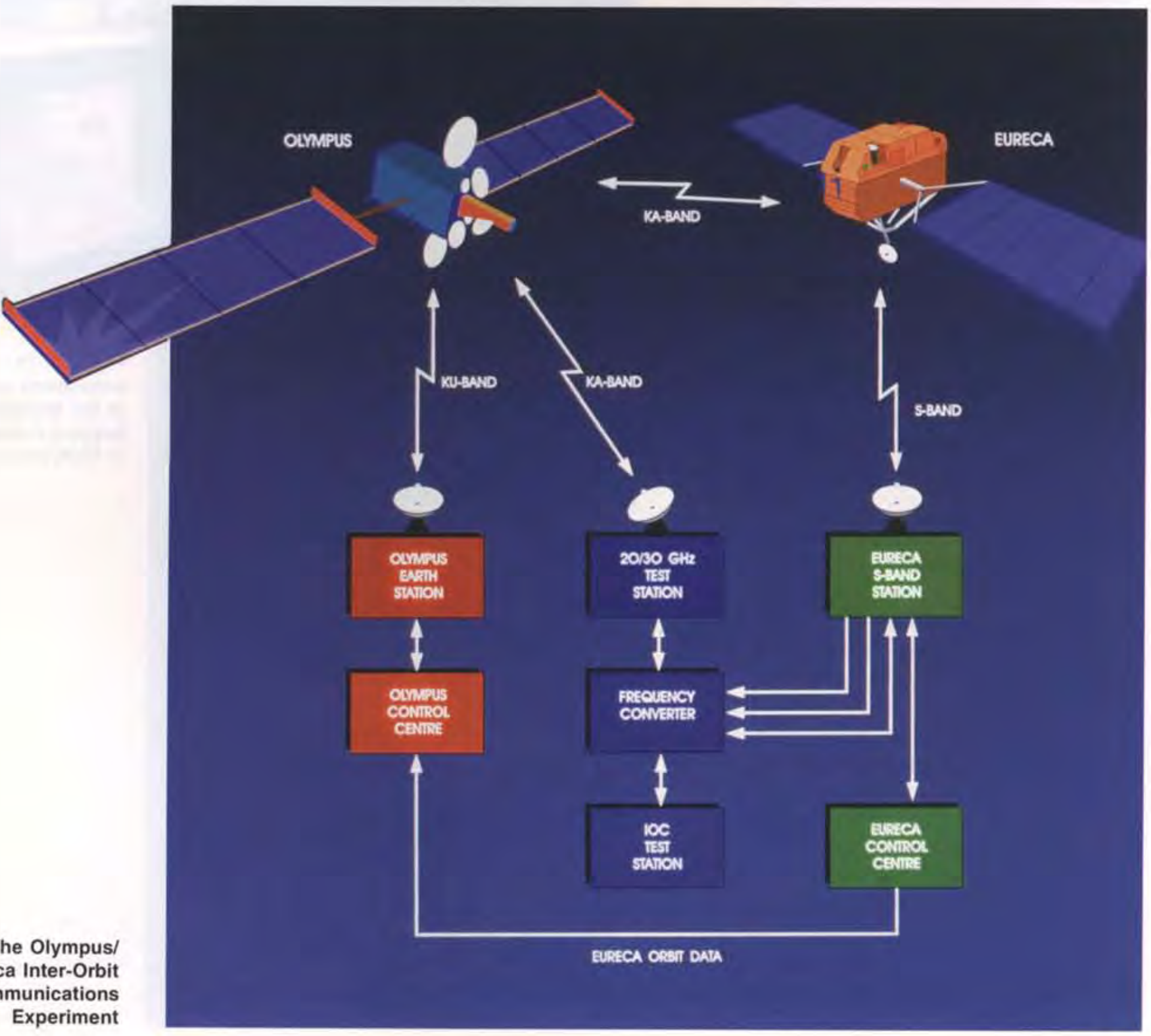


Figure 8. The Olympus/Eureca Inter-Orbit Communications Experiment

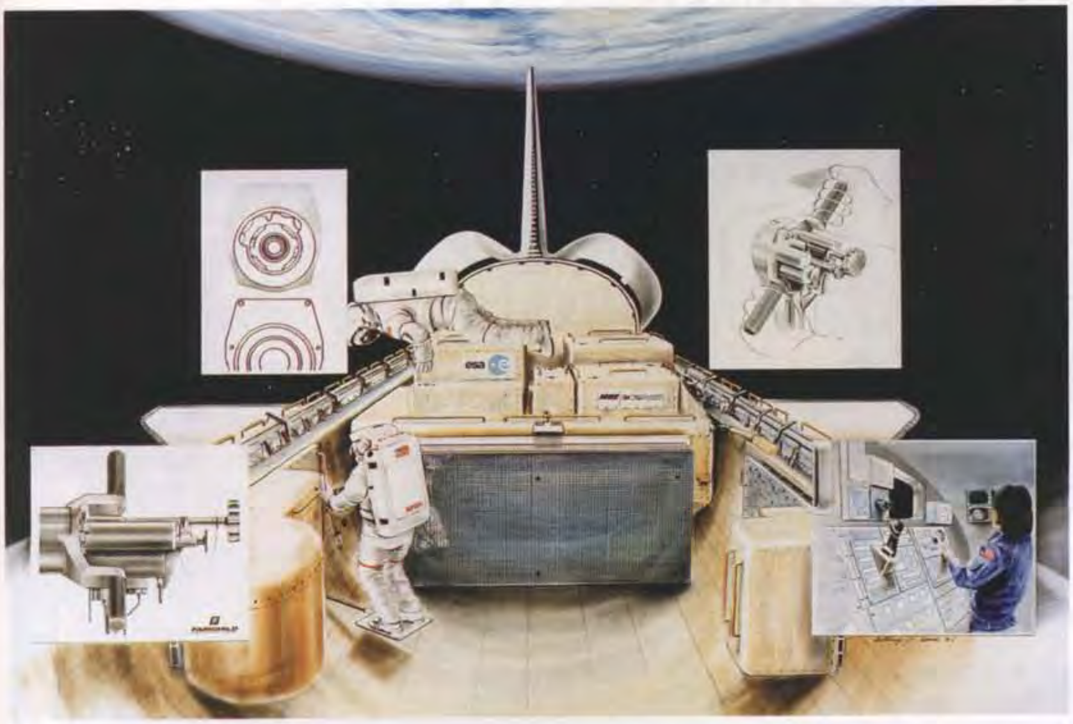


Figure 9. In-Orbit Refuelling and Payload Exchange Experiment onboard the Space Shuttle

conditions, well in advance of their operational use in the Columbus and Hermes scenarios (Fig. 9).

Near-term Eureca mission planning

As part of the Columbus precursor flight programme, it is now planned to refly Eureca twice more, perhaps in 1995 and 1997. The microgravity payload for the first reflight will be largely the same as for the maiden flight. The payload-definition process for the second reflight is not expected to be finalised until late 1993.

Further details can be found in the article on future Eureca missions elsewhere in this issue of the Bulletin.

Conclusion

From the experience accumulated so far during the development of Eureca, and from the various studies discussed above, the following conclusions can be drawn:

- The Eureca design responds successfully to the original programme objectives of developing a retrievable and re-usable carrier system, adaptable to various mission requirements, and offering a cost-effective utilisation programme compared with other systems.
- The Eureca system is attracting growing user interest.
- The Eureca system has good potential for serving as a test-bed for demonstrating essential Columbus technologies in flight, such as rendezvous-and-docking and in-orbit servicing.
- The user-friendly nature of the Eureca Programme is reinforced both by documentation aimed at making the system transparent and easy to access, and the transparent end-to-end data communication.
- The possibility of re-using experiment facilities on several flights minimises the cost to the Eureca user, thereby attracting a larger user community, which is potentially also to the benefit of the Columbus Utilisation Programme.
- The first Eureca mission will exploit decentralised real-time ground operations for the first time, with a User Support Centre working on-line in an interactive mode with ESA's Mission Control Centre.

In summary, therefore, it may be concluded that the Eureca system is not only a viable system in itself, but it can also be regarded as a major potential stimulant and contributor to the preparations for the International Space Station and its utilisation programme.

Scientific Utilisation of Eureca-1

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The European Retrievable Carrier (Eureca) is the first space platform that will be retrieved from orbit and launched again two years later carrying a different payload. It has been designed to undertake scientific investigations under microgravity conditions, i.e. very low gravity. Eighty percent of the payload on the first mission will be devoted to microgravity experiments.

In addition, Eureca's long mission duration (six to nine months), its retrievability, its altitude outside the Earth's atmosphere, and the fact that it is always pointing toward the Sun, make it a unique tool for research in space.

Introduction

The European Retrievable Carrier (Eureca) is the first space platform that has been designed to be launched into space, retrieved, and launched again two years later carrying a different payload.

The first Eureca mission (Eureca-1) will be launched with the Space Shuttle 'Atlantis' (STS 46) on 11 July 1992. After deployment from the Space Shuttle, Eureca will be transferred to its operational orbit of 515 km, using its own propulsion system. Once the system has been commissioned, Eureca will begin its operational phase. The spacecraft, which has been specially designed for scientific investigations in a very low gravity or microgravity environment, is able to carry a payload of 1000 kg in Low Earth Orbit (LEO), and supply the payload with 1000 W of power. In its first mission, Eureca will carry a payload consisting of five multi-user facilities in which 26 experiments will be performed, and ten individual instruments which will serve experiments in space science, space technology and microgravity (Fig.1).

The nominal operation phase of the mission will last six months. During that period, all the platform services and resources, such as attitude and thermal control, data handling and the power supply, will be continuously available. At the end of the mission, Eureca will descend to meet the retrieving Shuttle. Presently, retrieval of Eureca has been scheduled to be performed with the Space Shuttle 'Atlantis' (STS 54) on 22 April 1993.

Flight operations

Flight operations will be conducted from the Eureca Operation Control Centre (OCC) at ESOC in Darmstadt, Germany (a detailed description of the operation appeared in ESA Bulletin No. 60).

During routine operations, the main ground station will be in Maspalomas, Gran Canaria. (A second ground station in Kourou, French Guiana, will also be used. The ground station in Perth, Western Australia, will be the back-up station.) Eureca will pass over Maspalomas in sequences of five or six consecutive orbits a day (Fig. 2) and each station pass will last less than ten minutes. There will be five or six passes everyday, separated by 90 minutes, and then Eureca will not be visible for a period of 16 to 18 hours. Overall, the platform will only be visible from the ground for about 3% of the duration of the mission.

This limited period of visibility has a significant effect on the flight operations concept, and on the system and payload design. To carry out all system and payload activities, a 'Master Schedule' containing a list of up to 1000 time-tagged commands, i.e. commands to be executed at a specified time, will be uplinked daily. Real-time interactions from ground to the spacecraft, i.e. the sending of telecommands for immediate execution, will be limited to special operations that have to be monitored in real-time from the ground. For this reason, an advanced level of automation and on-board checkout has been included in the design of both the system and the payload.

The Eureca OCC will also prepare the payload timeline for the mission, based on the requirements of each Principal Investigator in

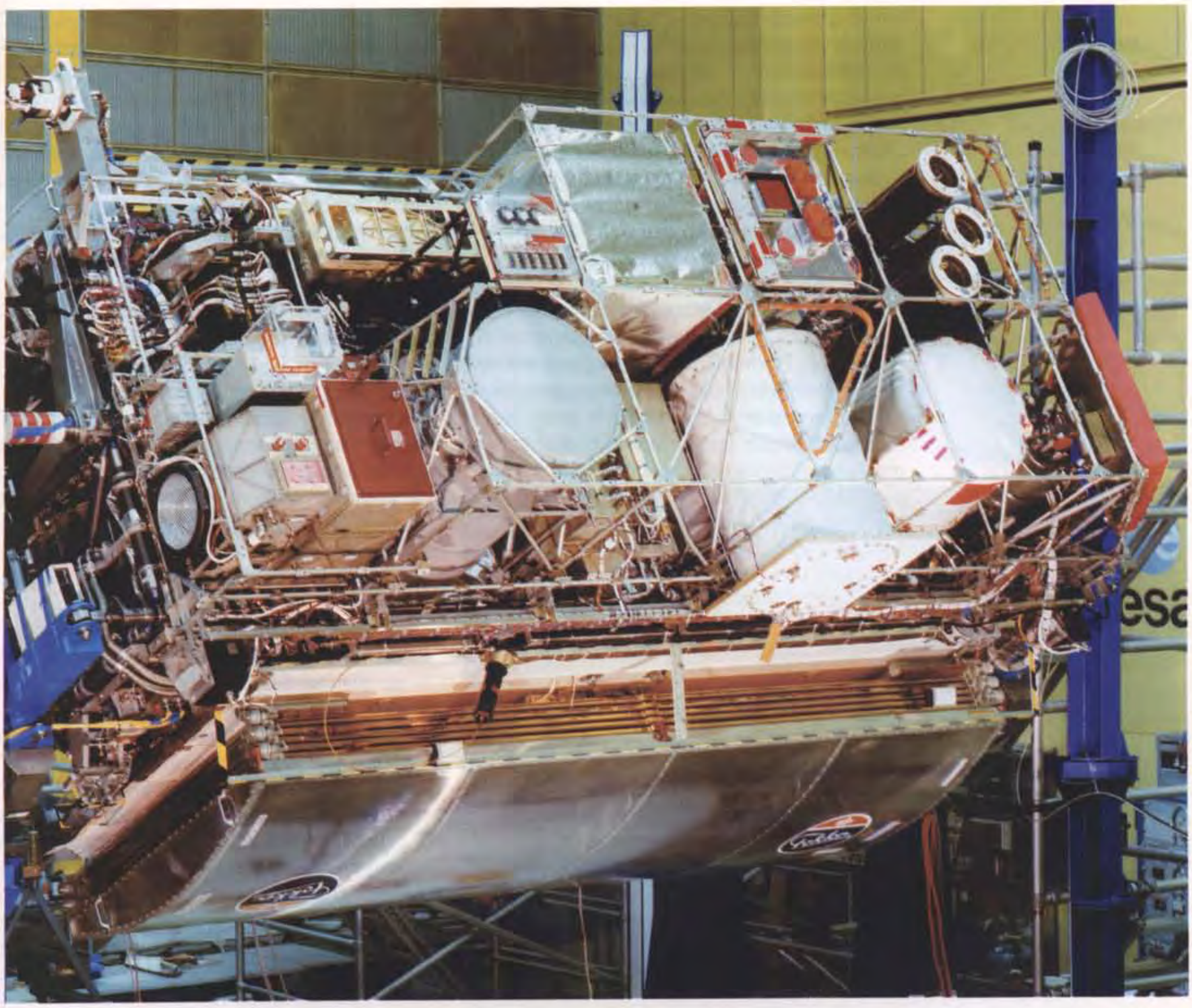

Figure 1. Upper deck of Eureca with all facilities and instruments integrated, before installation of the thermal cover

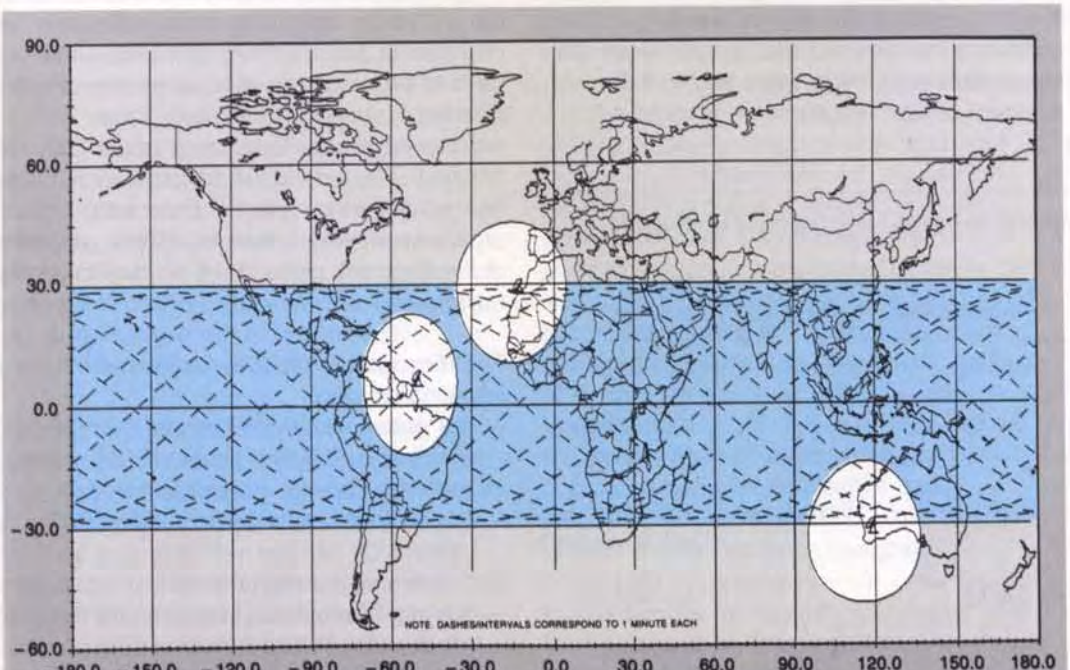

Figure 2. Eureca's ground track and station coverage

terms of the amount of time and power required to perform each experiment. During the mission, ESOC will collect all system and payload data, pre-process it and make it available to the users. For the first time, an electronic system, the Data Disposition System (DDS), will be used to store the data. Users will be able to dial into this computer system from their home site and retrieve the required data.

For this mission, a Microgravity User Support Centre (MUSC) has also been established in Porz-Wahn, Germany, to support users in their mission preparation and mission operations. The support is primarily aimed at the scientists with an experiment in one of the multi-user facilities. In particular, the MUSC is assisting the scientists in the preparation of the flight parameters. During the mission itself, the MUSC will be responsible for operating the multi-user facilities. Furthermore, the MUSC will collect appropriate data from the DDS, translate it into engineering values, and distribute it to the scientists.

Special features of the mission

With its six-month mission, Eureca will significantly increase the number of hours devoted to microgravity experiments that have been spent in space. Until now, European microgravity research has been carried out only during Spacelab missions, sounding rocket and parabolic flights, and most recently, Russian missions. As shown in Table 1, Eureca offers a much longer experiment time than any of the other missions.

Since Eureca has been designed for microgravity experiments, special attention has been paid at the design level to achieving the required microgravity levels. All subsystems and the payload had to fulfil stringent design requirements in order not to introduce disturbances on board. In microgravity, experiments are more sensitive to low frequency disturbances. The acceptable levels for disturbances are indicated in Figure 3. Tests on the ground have proven that the residual acceleration is as specified in Figure 3, and the final verification will be made during the mission when the Microgravity Measurement Subsystem will measure the accelerations on board. The high mission altitude of 515 km has been selected to minimise the air drag acceleration.

But Eureca is not only suitable for microgravity research; its long mission period and its retrievability are particularly appealing for technology demonstration experiments, i.e. to demonstrate new technology that might be useful in space in the future. Furthermore, the Eureca mission is also suited for space science experiments because of the following features:
— its mission duration of six to nine months provides a long observation period
— its altitude of 515 to 480 km (after 10 months in orbit) is well outside the Earth's atmosphere (the residual pressure at 500 km is about 3^{-7} Pa)
— Eureca is always pointing to the Sun which makes it a very suitable platform for solar-observation experiments
— experiments are retrieved for analysis upon returning to Earth.

Eureca-1 will carry five instruments dedicated to space science.

The payload

In the first mission, the payload will consist of five multi-user facilities and ten individual instruments. Each multi-user facility will be used to process several samples provided by different European universities. Those facilities have been developed under ESA contract. The ten individual instruments have been provided by different European organisations and industries. Eighty percent of the Eureca-1 payload will be dedicated to microgravity experiments.

The microgravity payload consists of the following facilities:
— the Automatic Mirror Furnace (AMF)
— the Solution Growth Facility (SGF)
— the Multi-Furnace Assembly (MFA)
— the Protein Crystallisation Facility (PCF)

and of two single instruments:
— the High Precision Thermostat (HPT)
— the Surface Forces Adhesion (SFA) instrument.

Table 1. Characteristics of missions carrying microgravity experiments

Mission		Payload mass	Power supply	Mission duration
Spacelab missions		4500 kg	3500 W	7—9 days
Sounding rocket flights	Texus/Maser	350 kg	—	6—7 minutes
	Maxus	700 kg	—	14 minutes
Parabolic flights		3200 kg max	15000 W max	100 parabolas with 25 μg each
Photon spacecraft		500 kg	—	14—30 days
Eureca		1000 kg	1000 W	6 months

The space radiation payload consists of:
- the Exobiology and Radiation Assembly (ERA)
- the radiation dosimeters.

Five instruments are dedicated to space-science research:
- the Solar Spectrum (SOSP) instrument
- the Solar Constant and Variability (SOVA) instrument
- the Occultation Radiometer (ORA)
- the Wide Angle Telescope (WATCH)
- the Timeband Capture Cell Experiment (TICCE).

Three instruments are dedicated to the demonstration of space-technology:
- the Radio Frequency Ion Thruster Assembly (RITA)
- the Inter-Orbit Communication (IOC) instrument
- the Advanced Solar Gallium Arsenide Array (ASGA).

Each facility and instrument is briefly described in the following paragraphs.

Microgravity experiments

The Automatic Mirror Furnace

The Automatic Mirror Furnace (AMF) is an optical radiation furnace designed for the growth of single, uniform crystals from the fluid phase. Gravity markedly influences the growth of crystals from the fluid phase. In particular, it is linked to the generation of defects caused by the unhomogeneous incorporation of impurities and inclusions. Gravity-driven convection influences the growth kinetics, compositional homogeneity, impurity distribution, morphological stability and nucleation of crystals. Microgravity conditions allow the growth of single and better structured crystals.

The AMF facility consists of an ellipsoidal mirror with a halogen lamp located at one focus and the sample to be heated at the other (Fig. 4). The focusing of the lamp's radiation results in the heating and melting of a transverse section of the sample. By slowly pulling the sample out of the furnace, directional solidification is achieved.

Most of the crystals will be grown using this Travelling Heater Method (THM), a technique which has proven to be a very important one for metallic solution growth of electronic materials in space. This method potentially enables the growth of crystals with a large diameter, under clearly defined and steady state conditions. Using the THM, the solvent zone is placed between a solid seed and the polycrystalline feed material. By moving the sample with respect to the lamp focus, steady crystallisation at the advancing seed-solvent interface is achieved. Simultaneously, feed material is dissolved at the feed—solvent phase boundary. The solute transport in the liquid zone is established by diffusion. The crystals formed will be mainly II-VI and III-V semiconductors, such as cadmium telluride or indium phosphate, which are of great technical interest because of their widespread use in the electronic industry.

The Solution Growth Facility

The Solution Growth Facility (SGF) is dedicated to the growth of monocrystals with low solubility. Many kinds of crystals can be grown by a process in which liquid reactant solutions diffuse into pure solvent and react chemically to form single crystals that are relatively insoluble. Such a process is usually referred to as the 'double diffusion technique'.

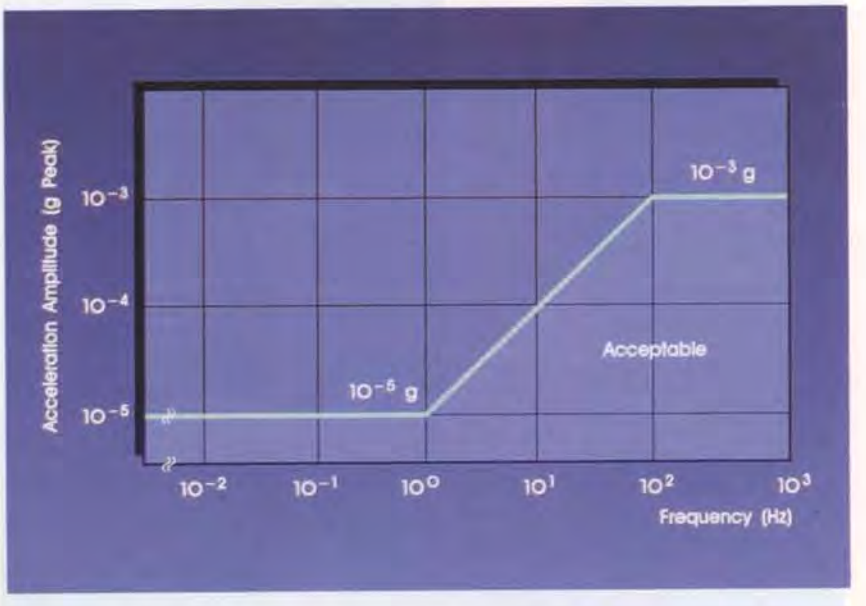

Figure 3. Acceptable levels for disturbances under microgravity conditions for Eureca missions

On Earth, gravity-driven phenomena such as buoyancy, sedimentation, and convection, hinder the formation of single and well-ordered crystals. The effects of these phenomena can be overcome by using gels, which slow the process, but this gel method has limitations due to the few substances available to properly gel the growth solution. Moreover, the gel introduces impurities into the growing crystals. These drawbacks should be avoided under microgravity conditions because convection and sedimentation are eliminated. The Solution Growth Facility has been designed specifically for this purpose, to grow crystals in liquid under microgravity conditions. The facility consists of three isothermal reactors and a gradient thermal reactor.

Each of the three isothermal reactors is made up of three chambers. The central chamber is filled with pure solvent; a different reactant is dissolved in each of the two adjacent chambers. When the valves that separate the chambers are opened, the two reactants are allowed to diffuse towards the central, buffer chamber. When the two diffusion fronts meet, a chemical reaction occurs and leads to crystallisation. During the Eureca-1 mission, crystals of calcium carbonate, zeolite and amorphous tricalcium phosphate will be grown from solutions.

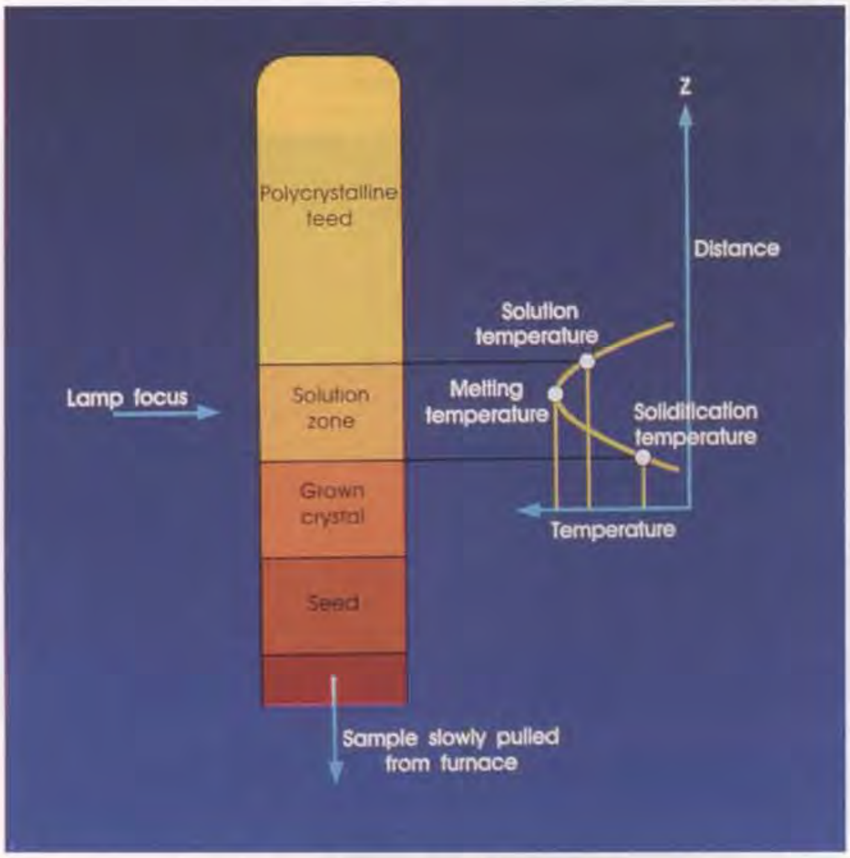

Figure 4. Principle of the Travelling Heater Method

The other reactor, the gradient reactor, is dedicated to the study of thermo-migration, or the Soret effect, in aqueous solutions. Thermo-migration is the process whereby mass transport is induced by a temperature gradient. This process leads to the separation of the components of the liquid-phase mixture. On Earth, such mass transport is disturbed immediately by gravity-driven convection flows. This prohibits the proper measurement of the effects of thermo-migration. The gradient reactor is expected to allow the measurement of those effects, using the Soret coefficient, i.e. the ratio between the thermal diffusion coefficient and the isothermal diffusion coefficient. In addition, since thermo-migration requires a long time for equilibration, the long-duration Eureca mission offers an ideal opportunity to measure the Soret coefficient.

The Solution Growth Facility experiment involves 20 tubes containing a binary mixture, maintained with a temperature gradient of 8°C, i.e. a difference of 8°C between the two ends of the tube. Toward the end of the experiment, a sample of 1.5 mL will be isolated at each end of each tube. The composition of these samples will then be analysed on the ground.

The Multi-Furnace Assembly

The Multi-Furnace Assembly (MFA) is a collection of furnaces designed for research into material solidification, crystal growth and diffusion, using high temperatures. It will be used to investigate different aspects of material science in the absence of gravity-driven flows.

For the first Eureca flight, the facility will consist of eight isothermal furnaces and four gradient furnaces. Each furnace will contain one sample which will be processed at high temperature. Unlike in the Automatic Mirror Furnace where only a part of the sample will be heated, in the Multi-Furnace Assembly the whole sample will be heated.

In one of the 12 experiments, the high temperatures that can be reached in the MFA furnaces will be used to grow large crystals of lead-tin-telluride ($Pb_{1-x}Sn_xTe$) and gallium arsenide (GaAs) from the vapour phase. In another experiment, tungsten-carbide and cobalt will be sintered in microgravity. On Earth, gravity segregation prevents the production of hard metals with a high binder content which are, in fact, highly interesting from a technical point of view.

Experiments that are concerned with interfacial phenomena in liquid alloys can also benefit from the microgravity environment. Monotectic alloys do not mix under terrestrial conditions since gravity separates the two liquids almost immediately due to their difference in density. Microgravity allows detailed studies of the diffusion processes, i.e. the growth of droplets (known as Ostwald ripening), and the investigation of surface properties.

As in the Solution Growth Facility, one experiment will study the thermo-migration effect. The MFA thermo-migration experiment consists of a cartridge containing tin and gold which will be maintained at a temperature gradient of 200°C for ten days. Just before the end of this period, the sample will be divided into several parts, while it is still in the liquid phase. After the flight, the relative concentration in each part will be measured.

The Protein Crystallisation Facility
Based on the successes achieved in experiments on earlier flights, growth of protein crystals in space has become a high-priority microgravity activity. Sufficiently large and perfect crystals are required to allow the molecular structure of proteins to be determined. That knowledge of the protein's molecular structure is a prerequisite for the understanding of biological processes on the molecular level.

Protein crystallisation is a multi-parameter problem involving the optimisation of the purity of the biological material, and its pH level, temperature, concentration, additives and solvent. One of the most common problems found with the growth of proteins on Earth is the formation of many, very small crystals: instead of the few, large crystals that are desired (measuring at least 0.3 mm in each dimension), numerous small crystals, which are unsuitable for X-ray analysis, form. Experiments have shown that this undesirable effect is mainly due to convection and thus may be overcome in space.

The Protein Crystallisation Facility has been designed for the investigation of protein growth under well-defined conditions. The facility is made up of 12 reactors which are designed to be used with the double diffusion technique. Each reactor consists of four chambers: two salt chambers, one protein chamber, and one buffer chamber. All chambers are filled bubble-free with the appropriate solution and, when microgravity conditions are reached, the protein chamber, the buffer chamber and one of the salt chambers are connected. The diffusion of protein molecules and salt ions across the buffer zone induces the protein molecule to crystallise. Just before the end of the mission, the second salt chamber will be connected to increase the salt concentration in the buffer chamber and thus to stabilise the protein crystals.

During the Eureca-1 mission, crystals of lysozyme, β-galactosidase, rhodopsin, α-crustacyanin, and bacteriorhodopsin will be grown. Transfer RNA complex, essential for the cellular translation of genes into proteins, will also be grown.

The High Precision Thermostat
The critical point is the highest possible temperature and pressure at which the gas and liquid states are separated by a discontinuity in density. At that point, the delicate balance between the liquid and gas states leads to unusual properties: the heat capacity greatly increases, clear fluids become cloudy due to spontaneous density fluctuations, and the fluid becomes extremely susceptible to temperature gradients and gravity.

On Earth, convection begins at a temperature difference of only a few milli-Kelvin, and fluids near the critical point are so compressible that a 1 mm-high sample will be 10% denser at the bottom than at the top. To better understand the processes at the critical point, new experiments that are free from the complications resulting from buoyancy-driven convection or density stratification induced by gravity, are necessary. The microgravity environment offers a suitable environment to run these critical point experiments. Furthermore, because of its long mission, Eureca-1 is particularly suited to such experiments since equilibration at the critical point is a slow process, requiring a long experimentation time. The High Precision Thermostat (HPT) provides a uniform temperature and a stability of the order of 100 μK.

All pure fluids exhibit similar behaviour near their gas—liquid critical points, i.e. the essential physics near the critical point is independent of the molecular species. Thus, any fluid would satisfy the scientific requirements of such an investigation. Sulphur hexafluoride (SF_6) has been universally chosen as a test fluid because it is non-toxic, non-flammable and has a convenient critical point (45.5°C and 38 bars). During the Eureca mission, the adsorption of a pure fluid (SF_6) at a solid surface (graphitised carbon) at the critical point will be measured.

The Surface Forces Adhesion instrument
Surface forces govern phenomena such as adhesion, friction, cold welding and sintering, and a deeper understanding of their behaviour is necessary both from a theoretical and a practical point of view. On the ground, these forces are masked by the force of gravity which is several orders of magnitude greater than the surface forces. The only type of surface-force experiment that is possible on the ground is a static experiment. Usually two bodies are put into contact under a defined load. The load is then removed and the force required to separate the two bodies is measured. However, these Earth-bound measuring techniques have not yielded reliable quantitative data.

Dynamic experiments, such as launching a body against a fixed target, cannot be performed on the ground because gravity would be the prevailing force. However, this experiment is possible in microgravity, with residual accelerations of 10^{-4} to 10^{-5} g. In the experiment on Eureca, small metal hemispheres will be projected against the metallic surface of a force transducer. The rebound will be investigated as a function of the roughness and the mechanical characteristics of the colliding bodies. In particular, the conditions under which the projectile and the target adhere will be studied.

Space radiation experiments

The Exobiology and Radiation Assembly

The principles leading to the emergence of life from inanimate matter, evolution and the distribution of life on Earth, are still relatively unknown. Exobiological research may add many new pieces of information to our concept of 'life' by expanding research beyond the Earth, to space, the planets, the comets and the meteorites of our solar system.

The space environment has generally been viewed as extremely hostile to all forms of life, due to several of its characteristics:

- the high vacuum, with pressure as low as 10^{-14} Pa;
- the solar electromagnetic radiation, extending from wavelengths of 2×10^{-12} to 10^{2} m;
- the solar corpuscular radiation emitted in the solar wind and during the solar flares;
- the galactic cosmic radiation, consisting of approximately 86% protons, 12.7% He-ions, 1.3% heavy ions with charge Z greater than two, and electrons;
- the extreme temperatures determined by the deep-space temperatures of 4 K and by the position of a body relative to the Sun.

While this extreme environment represents a definite barrier to active biological growth, metabolism and reproduction, some living organisms such as the spores of bacteria and fungi have the capacity to survive harsh conditions in a dormant mode. However, the complex action of the factors found in space cannot be fully reproduced in laboratories. Until now, all theories have been based on results from laboratory experiments and a few short-duration space experiments. (The experiments performed on NASA's Long Duration Exposure Facility (LDEF) are still being analysed.)

The Exobiology Radiation Assembly (ERA) was developed to allow such investigations. The ERA is a multi-user facility that houses biological experiment samples for exposure to the solar, space-vacuum and deep-space environments. It also provides scientists with the opportunity to conduct experiments in space for a relatively long period of time.

The survival of whole organisms, such as bacterial spores, exposed to solar ultraviolet radiation for different lengths of time, will be studied. The effects on DNA molecules, and the possible protective effect that would be provided if the biomaterials were buried in a meteorite, will also be investigated. The results of these studies may provide clues as to whether biological molecules could have survived travel through space from extraterrestrial sources.

The radiation dosimeters

The prediction and measurement of the flow density of cosmic radiation and its spectral composition with respect to charge, energy and linear energy transfer, and as a function of orbit parameters and mass shielding, is of fundamental importance to all experiments conducted in space. Because of the complexity of the radiation environment and of its interaction with matter, it is very difficult to calculate the radiation inside an orbiting spacecraft and therefore actual measurements are still preferable. Several dosimeters have been placed on-board Eureca-1; they will provide a characterisation of the actual nature and distribution of radiation on-board Eureca. The dosimetric data will be compared with that of other spaceflights and with theoretical predictions.

Space science experiments

Two instruments on-board Eureca will be dedicated to measuring the solar constant, the total incoming solar radiation which is the primary external source of energy for the Earth's atmosphere. Any change in that value directly affects the Earth's radiation budget and, consequently, the climate. A change of approximately 0.5% per century would be sufficient to explain the minor ice age of the 16th and 17th centuries. However, the variability of the solar constant remains uncertain: because the standard deviation of all solar constant determinations since 1966 is 1%, no conclusion concerning the variability of the solar constant can be based on experimental data currently available. In addition, the values of the solar constant show dispersions due to atmospheric attenuation. The measurements made from Eureca will therefore provide important new data.

The Solar Spectrum instrument

The Solar Spectrum (SOSP) instrument will measure the absolute spectral irradiance of the Sun between 170 and 3200 nm, its possible variation with the solar cycle, and the wavelength range responsible for the variations of the solar constant that are observed simultaneously using other instruments. To achieve this objective, measurements must be taken over a very long period, i.e. ten years, and this requires that the same instrument fly on future Shuttle missions. The instrument has already flown on the Atlas-1 mission, in March 1992.

It is important to know which wavelength ranges of the solar spectrum are involved in the variability of the solar constant. In fact, consequences of changes in the solar irradiation flux are directly related to the wavelength range involved. The range of 170 to 3200 nm of the solar spectrum will be studied using three spectrometers: one spectrometer will cover the ultraviolet region, one the visible region, and another the near infrared region.

The Solar Constant and Variability instrument

The main objective of the Solar Constant and Variability (SOVA) instrument is the determination of the solar constant, its variability and its spectral distribution, with high resolution at five different wavelengths. The aim is to measure:

- very short-term variations, with periods ranging from a few minutes to several hours. These results may improve the understanding of the gravity modes of solar oscillations.
- short-term variations, with periods ranging from hours to months. These variations are associated with the solar activity and the energy redistribution mechanisms in the solar convection zone.
- long-term variations, with periods of years (i.e. the solar cycle), for comparison with earlier and future measurements on board Spacelab and others vehicles, as a reference for climatic research.

The second objective is to measure the total irradiance, i.e. the radiation integrated over the whole solar spectrum, in space. Two types of absolute radiometers with an absolute accuracy estimated to be of the order of ±0.1 % and a sensitivity better than 0.05%, will be used. Using two different types of radiometers that have been removed from the effects of the atmosphere and with some of their characteristics tested in situ, is the only way in which a truly accurate measurement of the total irradiance of the Sun can be made. Before Eureca is launched and after its retrieval, those radiometers will be compared to a set of ground-maintained radiometers in order to ascertain the required long-term stability. The radiometers have also flown on the ATLAS-1 mission.

The Occultation Radiometer

The Occultation Radiometer (ORA) is an instrument designed to measure aerosol and trace-gas densities in the Earth's atmosphere. The attenuation of the various spectral components of the solar radiation as it passes through the Earth's atmosphere enables vertical abundance profiles for ozone, nitrogen dioxide, water vapour, carbon dioxide, and background and volcanic aerosols to be determined for altitudes between 20 km and 100 km.

The ORA instrument uses the Sun occultation technique, i.e. it measures the intensity of the solar radiation during the sunrise and sunset phases of each orbit. It takes advantage of the Sun-pointing capabilities of the Eureca carrier itself and measures the solar radiation in ten narrow wavelength domains spanning the ultraviolet, visible and infrared portions of the spectrum.

The Wide Angle Telescope

The X-ray sky has a very variable appearance. New X-ray stars appear and fade away, lasting from milliseconds to years. Cosmic gamma-ray bursts provide an extreme example of rapid and unpredictable variability. These bursts rise and decay within seconds but, during their active life, they outshine the combined flux from all other sources of celestial X-rays and gamma rays by factors of tens, hundreds or even thousands. X-ray novae are much less conspicuous but more predictable. They flare regularly, typically with intervals of a few years. In the extragalactic sky, the Active Galactic Nuclei show apparently erratic fluctuations in their X-ray luminosity with time scales of days to weeks.

The Wide Angle Telescope for Cosmic Hard X-rays (WATCH) is designed to detect and locate such events. The data gathered can be used in two overlapping ways. Firstly, it can be used in its own right to provide light curves and energy spectra for the brighter persistent sources and for X-ray transients and gamma ray bursts. This data may be searched for regularities in the time variations related to orbital movements or rotation, or for spectral features due to cyclotron resonances in strong magnetic fields or characteristic atomic or nuclear X-ray lines. Secondly, the data can be used to alert other, more powerful instruments on the ground or in space to study the objects that WATCH has detected to be in an unusual state of activity.

The Timeband Capture Cell Experiment
The objectives of the Timeband Capture Cell Experiment (TICCE) are:
— to study the microparticle population in near-Earth space by establishing the penetration of thin foils (measured in microns)
— to retrieve samples of impacting micro-particles by the capture cell technique, for laboratory analysis
— to determine the impact rate and epoch of such capture products relative to seasonal changes throughout Eureca's six to nine months of exposure
— to study the incidence direction of dust relative to the exposure geometry of TICCE.

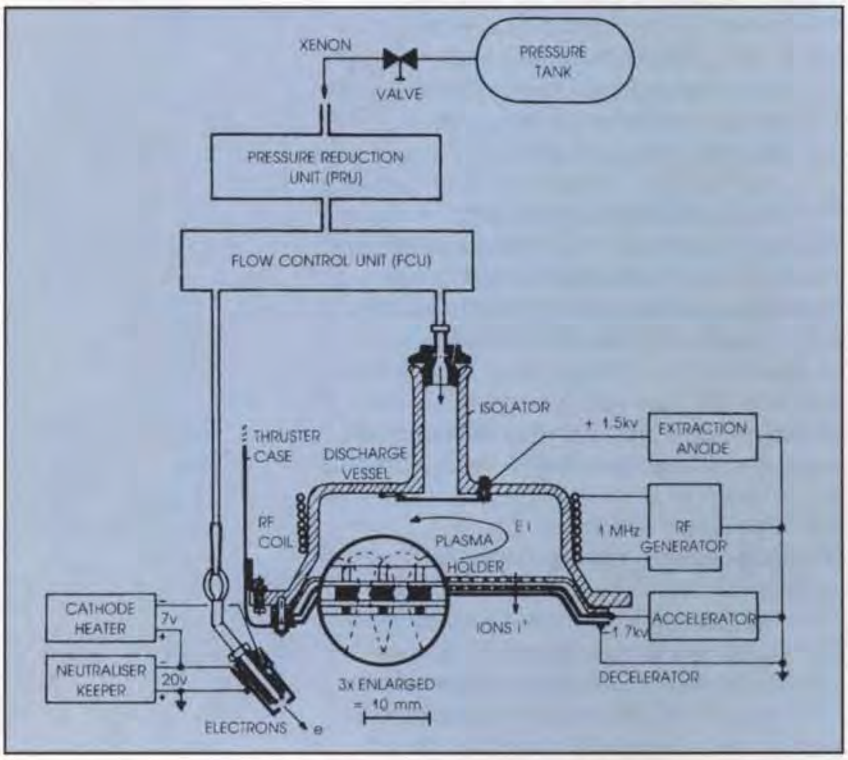

Figure 5. The Radiofrequency Ion Thruster Assembly (RITA)

The achievement of these objectives and, in particular, the direct association of particle chemistry and the time of collection (to within a number of days), will assist in determining the source of particles such as Earth debris, cometary dust, meteoroids and streams, which are currently thought to make up the microparticle population.

Particles will pass through a foil and into a collector surface below the foil. To obtain time information, the foil on the capture cell will be moved at pre-set intervals during the mission. The phase shift between the perforation in the foil and the particle will enable the particle's arrival timeband to be determined. A total movement of approximately 15 cm over six months will yield 20 timebands of six days each.

Space technology demonstration instruments

Eureca-1 will also house three instruments that will demonstrate space technology that could be extremely useful for future space applications.

The Radiofrequency Ion Thruster Assembly
The Radiofrequency Ion Thruster Assembly (RITA) is an ion thruster system which generates a variable thrust level of 5 to 10 mN by acceleration of xenon ions in an electrostatic field. The system consists of a propulsion unit which contains the ion thruster and the neutraliser, a propellant storage and flow control unit, a power conditioning unit which contains the electric power conversion, and a digital automatic control unit. Figure 5 shows the general method of functioning of the thruster, the neutraliser, and its connections to the electronic components.

Eureca is particularly suited to this electric propulsion experiment because the spacecraft will be retrieved and returned to Earth after mission. This provides the invaluable opportunity to examine the hardware after use. Successful demonstration of RITA's operation in space may lead to the use of the device for the orbital control of commercial geosynchronous satellites. As the specific impulse of RITA is a factor 10 higher than that of the chemical thrusters currently used, the satellite's launch mass can be decreased and its payload and/or lifetime increased.

The Inter-Orbit Communication instrument
The Inter-Orbit Communication (IOC) links provide the means for time-extended radio-frequency contact between spacecraft operating in low Earth orbit and one or more Earth stations, via a geostationary relay satellite.

This data communication link may prove to be one of the most valuable resources on Eureca. During a mission, experiments generate a large amount of data that has to be either stored on-board or downlinked to a ground station. With the data communications systems that are currently being used, this

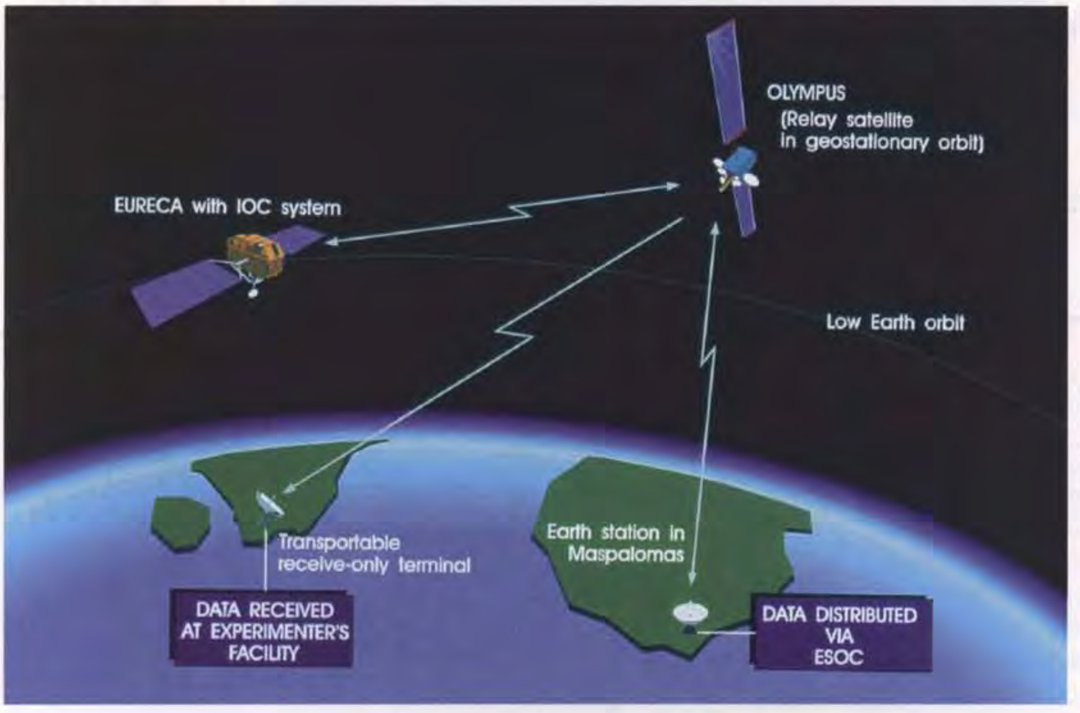

Figure 6. The Inter-Orbit Communication (IOC) links

can cause a bottleneck for simultaneous payload operations.

Before the IOC system can be used operationally, it must first be tested under operational conditions. The primary purpose of the IOC experiment is, therefore, to test and evaluate the potential overall system characteristics associated with an IOC service in the 20/30 GHz frequency bands, and to demonstrate to future users the potential benefits and low risk of such a system, whereby, in particular, telemetry data can be relayed directly to a ground station.

The fixed Earth station, which will maintain two-way communication with Eureca via ESA's geostationary Olympus satellite, is located in Maspalomas. It will be supplemented by a 1.2 m diameter Transportable Receive-Only Terminal, as shown in Figure 6.

The Advanced Solar Gallium Arsenide Array
The power demanded from space solar arrays is expected to grow drastically in the future, not least because of space station requirements. It is foreseen that new generations of solar cells will replace the present photovoltaic devices. Gallium arsenide (GaAs) solar cells are the most likely to be used in future applications owing to their high conversion efficiency and resistance to harsh environmental conditions.

The Advanced Solar GaAs Array (ASGA), a technology demonstration experiment on advanced gallium arsenide solar cells, consists of two solar panels equipped with different strings of cells. One panel is devoted to the optical concentrators and cells, while the other is dedicated to different kinds of planar cells. The aim of the ASGA experiment is to obtain real-time measurements for different kinds of GaAs cells during six months of operation in low Earth orbit to allow their performance trend to be monitored.

Conclusion
As shown by the various disciplines represented on board Eureca-1 — microgravity science, space science, as well as space technology demonstration — Eureca's versatility is one of its most appealing features.

The low level of residual acceleration on board and the long mission duration offered by Eureca promise exciting results in microgravity science. Coupled with Eureca's retrievability and reusability, these features make it a unique tool for research in space. In fact, as reported elsewhere in this Bulletin, the second and third Eureca missions are already being planned. The Inter-Orbit Communication experiment will be used operationally, provided that its testing on the first mission is successful. Its availability will greatly improve data communication between Eureca and the ground.

The Eureca-2 and Eureca-3 Missions

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As part of the Columbus Precursor Flights Programme, the Spacelab-E1 mission and two Eureca-reflight missions are planned. Eureca-2 and Eureca-3 will be cooperative flights with NASA, which will provide the Shuttle launches and retrievals free of charge in return for a share of the payload resources.

Future Eureca missions
The Carrier configuration and overall mission scenario for the Eureca-2 and Eureca-3 flights will be basically the same as those for Eureca-1. New features are an additional payload-accommodation panel on the bottom of the Carrier and an enhanced payload data-link capability via IOC/Artemis and/or a second ground station for Eureca-3.

The schedule for the second and third flights depends on the final timing of Eureca-1's retrieval and the minimum ground turn-around time of 25 months. The payload instrument delivery window is from 18 to 12 months before launch, i.e. new instruments must be delivered 18 months before launch for check-out and integration and refurbished instruments not later than 12 months before launch. The nominal mission duration for Eureca-2 and -3 will be 7 months.

The 'Call for Proposals and Ideas – Research Opportunities on Space Columbus Precursor Flights' was issued in November 1990, and more than 500 experiments and instruments have been proposed for these flights (including Spacelab-E1).

Table 1. Eureca-2 and Eureca-3 schedules

Eureca-1	Scheduled for retrieval 21 April 1993
Eureca-2	
Payload delivery	01/12/93 to 31/05/94
Mission	31/05/95 to 31/12/95
Eureca-3	
Payload delivery	01/08/96 to 31/01/97
Mission	31/01/98 to 31/08/98

This wealth of proposals has been reviewed by scientific peer groups and by inter-disciplinary ESA review teams in the case of technological experiments. This has resulted in a shortlist of experiments for Eureca-2 and -3 with emphasis on the following scientific and technological fields:

Life Sciences
- cosmic radiation
- long-term experiments on the response of biological organisms to microgravity.

Materials Science
- solidification physics and crystal growth under microgravity conditions
- surface forces and interfacial tension.

Space Science
- background-ultraviolet and radiation monitoring
- solar observation
- space environment, including dust and micro-meteorite investigation.

Earth Observation
- optical and thermal surface exposure to space.

Technology
- materials exposure to space
- long-term in-orbit-operation demonstration of new technologies (i.e. maser clock, plasma contactors, arc-jet propulsion, etc.)

The Eureca-2 payload
Table 2 shows the Eureca-2 payload-candidate shortlist, from which the final selection will be made mid-1992.

The instruments on the shortlist exceed the overall Eureca payload carrying capability of 1000 kg. As all of the payloads shortlisted are scientifically well supported, major criteria in the final selection process will be the availability of funding and the feasibility of meeting the tight schedule in the cases where new instruments need to be developed.

Figure 1. The elements of the Eureca-2 Costing Reference Payload

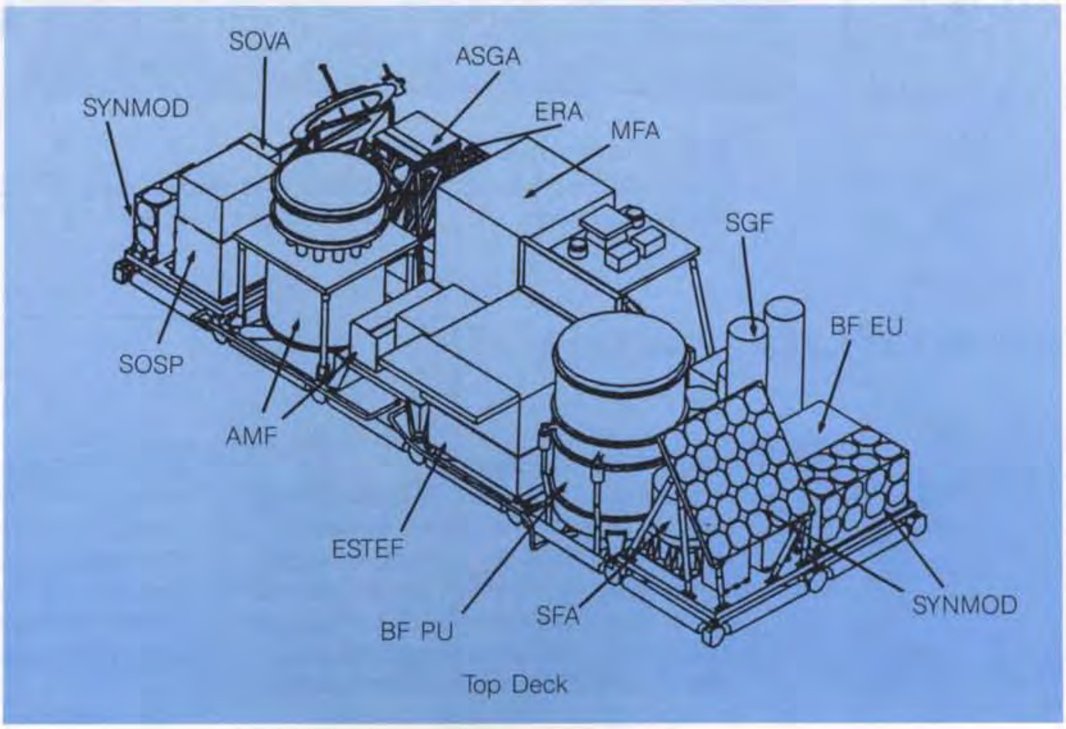


Table 2. Eureca-2 payload shortlist

Discipline	Instrument		Comment
Materials & Fluid Sciences	AMF	Automated Mirror Furnace	Reflight
	MFA	Multi-Furnace Assembly	Reflight
	SGF	Solution Growth Facility	Reflight
	76 SFA	Surface Adhesion Forces	Reflight
	PCF	Protein-Crystallisation Facility	Reflight
Life Sciences	Botany Facility	For plant growth	New payload
	ERA	Exobiology & Radiation Assembly	Reflight
	SPICE	Space Particle Intact Capture Experiment	NASA payload candidate
Space Science	105* SOVIM	Solar Variability & Irradiate Monitor	SOVA Reflight
	154* SYNMOD	Synoptic Monitoring of Orbital Debris	New payload
	275* SOLSPEC	Solar Spectral Irradiance & Its Variability	SOSP reflight
	377* IDES	International Diffuse EUV Spectrometer	New payload, bottom deck
	310* MAM	Measurement of Orbit Atoms and Molecules	New payload
Technology	4,473,479* ASGA	Advanced Solar Arsenide Array	Reflight
	124* PLEGPAY	Plasma Electron Gun Payload	New payload
	346*	Optical Fibres in Space	Exposure experiment
Columbus Technology	ESTEF	European Science & Exposure Facility	Small platform for a variety of exposure experiments

* Reference numbers assigned to the proposals during the 'Call for Proposals and Ideas' evaluation process.

Figure 1 shows two views of the so-called Eureca-2 'Costing Reference Payload', which is a model payload being used for programmatics planning purposes until the finally selected payload is known.

The Eureca-3 payload

The payload for the Eureca-3 mission is the subject of a revised Announcement of Opportunity to be issued in 1993, which will ask for updates of the proposals made in response to the initial 'Call for Proposals and Ideas' in November 1990. Like Eureca-1 and -2, Eureca-3 will be a multi-disciplinary mission also, but with greater emphasis on technology and space science.

The Eureca-3 core payload will consist of the NASA Optical Properties Monitor (OPM), Maser Clock and potentially a reflight of SPICE, as well as possible reflights of Eureca-2 instruments and facilities. The core payload will be determined at the beginning of 1993 as a basis for the revised Announcement of Opportunity. The selection will take into account the Eureca-1 experience and results. The core payload will then be complemented by updated proposals from the responses to the 1993 Announcement of Opportunity. The new candidates presently recommended by the scientific/technical evaluation panels are shown in Table 3.

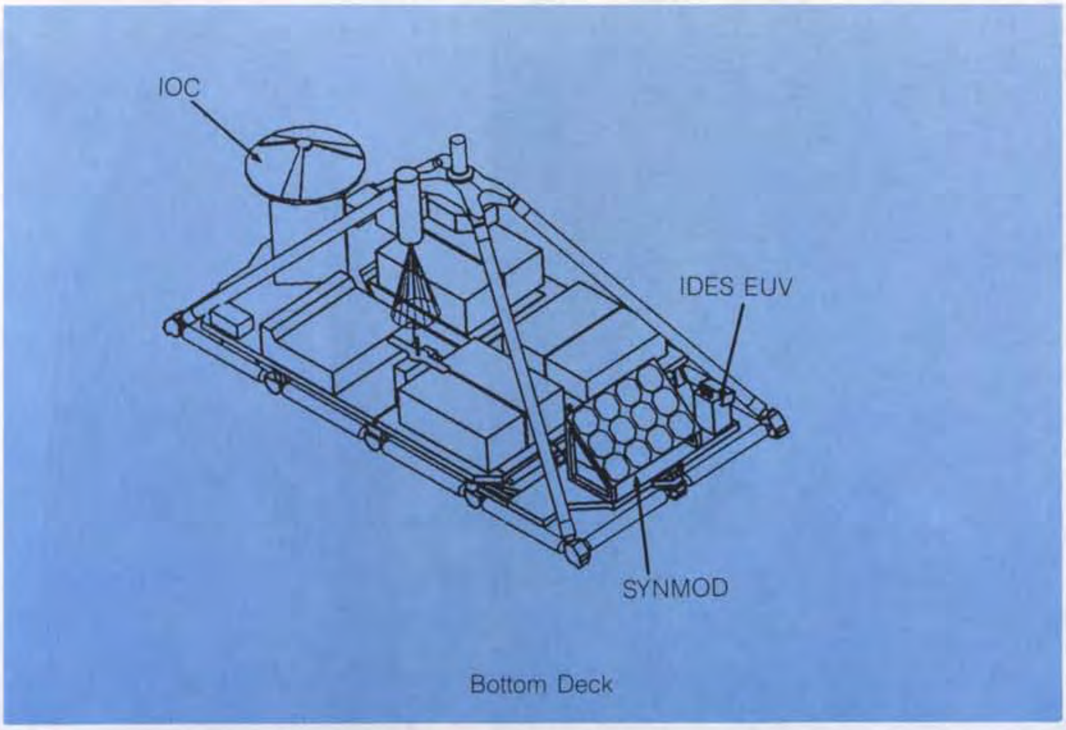
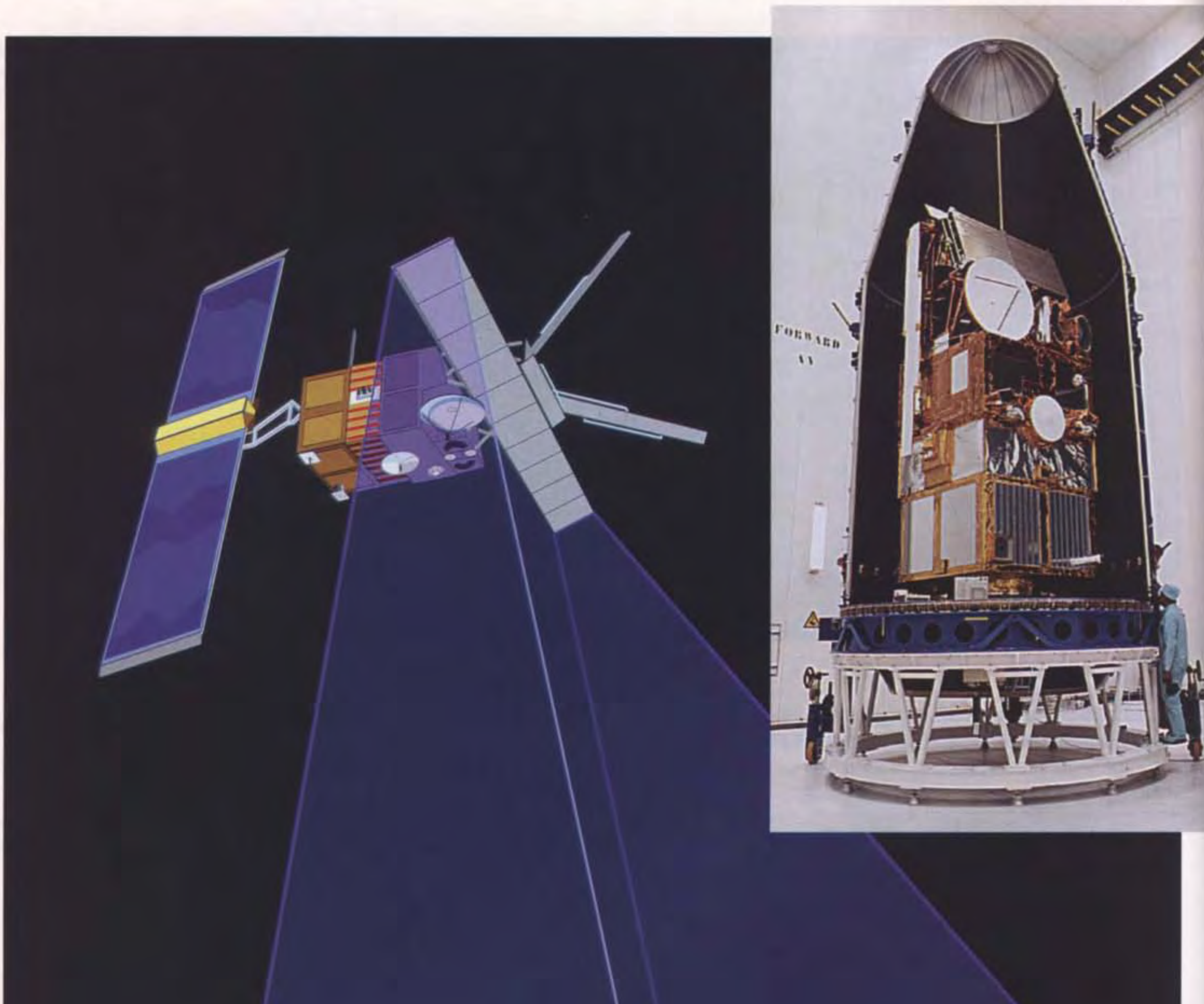


Table 3. Possible new payload elements for Eureca-3*

Discipline	Instrument	
Materials/Fluid Sciences	LTVGF	Low-Temperature Vapour Growth Facility
	258	Forced Convention
	313 AGF	Automated Gradient Furnace
	467 Sesame	Dedicated furnace for the growth of semi-conducting ternary compounds
Life Sciences	274 RAMOS	Radiation Monitoring in Space
Earth Observation	134 Vexuvio	Visible Explorer and Ultraviolet Infrared Observer
	357	Occulation Spectrometer
Space Science	30 MGS	Multi-Layer Grating Spectrometer, Sun observation
	55 ARMS	Absolute Radiometric Measurements in Space
	180 EUDOSSO	Experiment for Measuring Long-Term Solar Diameter Variations
	382	Maser Clock (European instrument)
Technology	447 Diva	Flight Demonstration of an Arcjet Propulsion System
	496	Arcjet Test
	47	Evaporator Test
	22	Microwave Radar
	348	Eureca-Based Tether Initiated Re-Entry Demonstration
	49 Diff. GPS	Global Positioning System
NASA Candidates	OPM SPICE	Optical Properties Monitor Space Particle Intact Capture Experiment
	Maser Clock	

* Preliminary list pending updating based on the revised Announcement of Opportunity in early 1993


FORWARD

ERS-1: The First Months in Orbit*

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This article reports on the ERS-1 activities during the early-orbit and commissioning phases of the mission, addressing in particular the calibration/validation activities and the mechanisms set up during the commissioning phase to validate basic products delivered in near-real-time to users.

The Launch and Early-Orbit Phase (LEOP)

ERS-1, the first European Remote-Sensing Satellite, was launched from Kourou, in French Guiana, on 17 July 1991. The countdown for the Ariane launch (V44) proceeded perfectly, with lift-off at the opening of the launch window (1:46:31 UT) and delivery of the satellite to the required orbit some 18 minutes later, within contact of the Wallops Island ground station (Fig. 1).

On separation from the launcher, the ERS-1 spacecraft started to execute the pre-programmed automatic sequence of attitude acquisition and initial deployments, which was completed in half an orbit, the solar-array deployment being monitored by the ESA ground station near Perth, in Western Australia.

* Both ERS-1's payload complement and the mission objectives were extensively described in ESA Bulletin No. 65.

Deployment of the spacecraft's large Synthetic Aperture Radar (SAR) antenna took place as planned while ERS was being monitored from the Santiago and Wallops stations. The fore-antenna of the Wind Scatterometer required the use of its redundant motor to achieve full deployment. The satellite deployment sequence was completed with that of the aft antenna, which deployed nominally.

A few difficulties were initially experienced with the convergence of the spacecraft's attitude control in fine-pointing mode, but these problems were circumvented within three days and the drift manoeuvre to take ERS-1 towards the so-called 'Venice Orbit' for the Commissioning Phase was initiated.

The payload switch-on and initial checks were initiated on 23 July, with the IDHT (X-band Instrument Data Handling and Transmission System). For all subsequent operations, systematic recording was performed throughout 10 orbits per day, and the on-board recorder played back whilst the satellite was over the Kiruna station, in Northern Sweden. This allowed the good tracking performance of the Radar Altimeter (RA), over land, ocean and ice, to be observed on 25 July, the first day this instrument was switched on.

On 26 July, the Along-Track Scanning Radiometer (ATSR) was switched on and the Venice Orbit phase acquired.

On 27 July, all Active Microwave Instrument (AMI) modes – wind, wave and image – were successfully tested. The first images over Spitzbergen, Norway, were acquired

Figure 1. The station network supporting the Launch and Early Orbit Phase (LEOP) operations of ERS-1

and processed at Kiruna; those over the Flevoland Polders in The Netherlands were acquired at the Fucino ground station near Rome, and processed at ESRIN in Frascati, near Rome (see pages 104–107, ESA Bulletin No. 67). Near real-time processing of the Wind Scatterometer mode data at Kiruna also provided very realistic derived wind fields.

The PRARE instrument was also switched on successfully. Unfortunately, after a few days of nominal operation, it had to be shut down following a major failure, which has so far not been circumvented.

Two weeks after launch, nominal playback operations were routinely performed, with the four stations of Kiruna (Sweden), Maspalomas (Canary Islands, Spain), Gatineau (Canada) and Prince Albert (Canada) acquiring the global dataset from the low-bit-rate instrumentation, while SAR image-mode data were regularly received at Kiruna, Fucino and Maspalomas.

Thanks to the comfortable energy situation prevailing on-board the spacecraft, it was decided to increase the SAR imaging-mode duty cycle to 12 min per orbit (including 4 min in eclipse), as well as to confirm global operation and recording of the low-bit-rate instrumentation (Radar Altimeter, AMI Wind-Wave Mode and ATSR).

These challenging and complex early in-orbit operations were conducted successfully in 18 days, so that the satellite was ready to enter its Commissioning Phase on 3 August. This success can be attributed to a combination of three complementary factors:
- The very good satellite design and the comprehensive testing of both the satellite and its deployment mechanisms performed during the integration/test phase.
- The very comprehensive simulation programme conducted at the ESOC Mission Management Control Centre (MMCC), in Darmstadt, Germany, where no less than 54 simulations were performed in the six months prior to launch.
- The very effective cooperation established between the Industrial, ESTEC Project and ESOC Control Teams who were based at ESOC during the mission's critical Launch and Early-Orbit Phase.

Figure 2a. SAR image of the Flevoland area, in The Netherlands

Figure 2b-d. Map showing the three transponder locations, with a zoom of the echo of the transponder and target response

Table 1. ERS-1 SAR receiving stations phased-in during the Commissioning Phase

ESA	Fucino (I) Kiruna (S) Maspalomas (E)	Canada	Prince Albert Gatineau	Japan	Hatoyama Kuamoto
Alaska	Fairbanks	Ecuador	Cotopaxi	Norway	Tromsø
Antarctica	O'Higgins (D) Syowa (J)	France	Aussaguel	UK	West Freugh
Australia	Alice Springs	India	Hyderabad		
Brazil	Cuiaba				

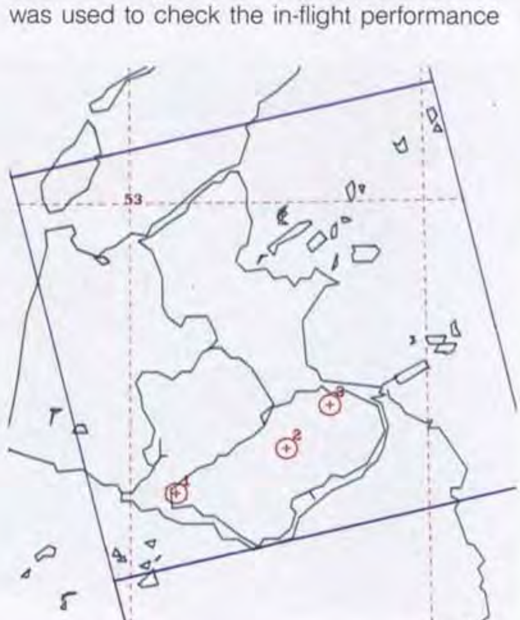
The commissioning activities

In order to conduct these activities, a 3-day orbit-repeat cycle was selected and controlled within a ± 1 km longitudinal deadband. This so-called 'Venice Orbit' allowed the calibration sites to be revisited every 3 days, and in particular the Venice site selected for the Radar Altimeter's calibration.

The main goals during the Commissioning Phase were to:
- calibrate/validate the on-board instrumentation and associated main user products, and support the associated campaigns
- phase-in and commission the near-real-time ground-segment components
- support the scientific projects being conducted during this phase.

AMI SAR imaging

It was quickly established that excellent and stable performance was being obtained from this instrument and this was confirmed by the outstanding quality of the SAR images produced. This instrument, being very sensitive to spacecraft attitude performance, was used to check the in-flight performance



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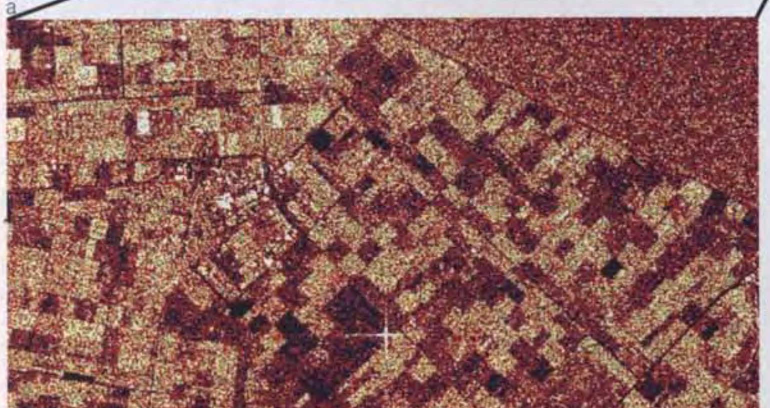


c

d

of the attitude-control system, which proved to be better than specified.

The main calibration site used was in the Flevoland area of The Netherlands. Three active transponders and numerous corner reflectors were deployed, permitting repetitive observations at three-day intervals. The data set acquired permitted calibration of both the instrument itself and the processing chains.

The transponders and corner reflectors are targets of known backscatter cross-section. They are used as references to establish the SAR antenna gain stability through the swath as well as a function of time, to characterise the complete chain (SAR instrument and on-ground SAR processor), and also permit radiometric/geometric calibration of these images.

By comparing the on-board calibration with the external calibration, it has been possible to assess the stability of the instrument during the Commissioning Phase: in fact, all parameters have proved to be extremely stable and no degradation has been observable during the first five months of the mission. The combination of high image quality observed, together with the constant product quality that can be offered with the SAR images, including those produced in near-real-time, bears witness to the high stability of the overall system.

SAR data acquisition and summer Arctic projects

A very extensive data acquisition campaign was conducted during the Commissioning Phase, including acquisitions over Antarctica, by the O'Higgins and Syowa stations, and over the Arctic, where extensive coverage is provided by the Kiruna, Tromsø, Gatineau, Prince Albert and Fairbanks stations.

Four projects were carried out in the Arctic during the months of August and September 1991, using ERS-1 SAR images. One of these was in support of the 'Astrolable' expedition from Europe to Japan via the Arctic route (i.e. the North-East Passage). The 'Astrolable' is the first West European vessel since 1940 to be permitted to sail this route, which has various potential economic benefits, but at present requires the assistance of ice-breakers. The 'Astrolable' was integrated into a convoy following a Russian ice-breaker, the route of which is clearly visible on an ERS-1 SAR image taken on 16 August 1991 (Fig. 3).

Throughout the voyage, numerous ERS-1 SAR images (compressed before transmission) and ice-density maps, derived by a scientist from the Nansen Remote Sensing Centre (NRSC) in Bergen, Norway, were transmitted to the 'Astrolable' by Inmarsat. For the first half of the route, SAR images received and processed by the Kiruna station in Northern Sweden were transmitted in near-

Figure 3a. The 'Astrolable' research vessel

Figure 3b. SAR image of the Russian ice-breaker's route through the Northwest Passage.

real-time. For the second half, the Fairbanks station in Alaska provided the same service (Fig. 4).

The 'Astrolable' project demonstrated conclusively the potential benefits of access to the near-real-time SAR images in a harsh and therefore costly operating environment, which is of vital interest for the future development and exploitation of the Arctic region.

Figure 4. The 'Astrolable's' route from Europe to Japan

Near-real-time dissemination of ERS-1 SAR images over Europe

The ERS-1 mission includes the setting-up and exploitation of a near-real-time SAR image dissemination system across Europe. In practice, the ERS-1 Broadband Data Dissemination Network (BDDN) uses the SMS transponder of Eutelsat-2 to disseminate SAR images from the ESA stations at Kiruna and Fucino to 14 receiving centres distributed throughout Europe. The network operates with a data rate of 2 Mbit/s.

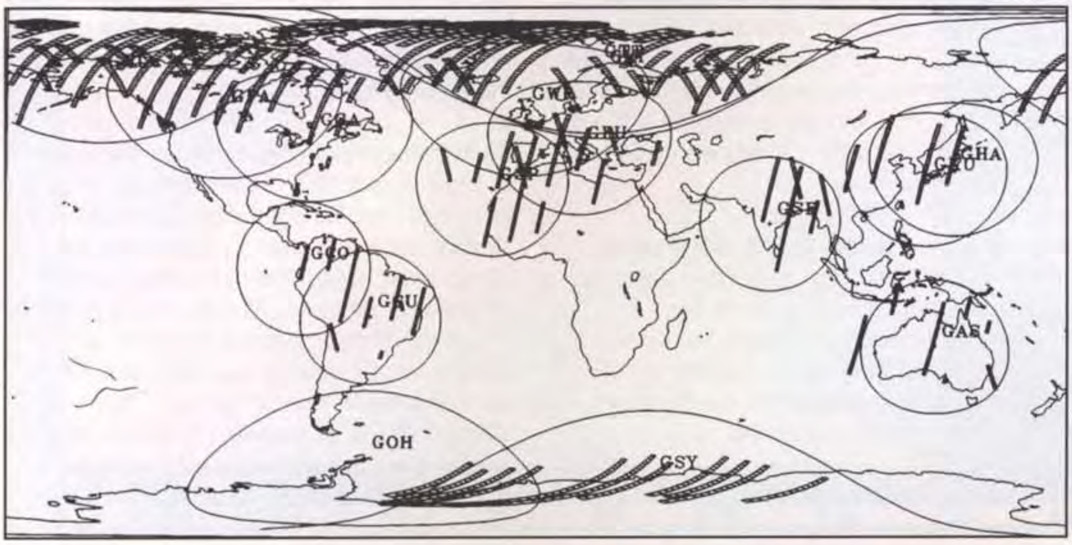


Figure 5. Typical 3-day SAR acquisition cycle with the phased-in SAR acquisition station network in the background

The BDDN operations were initiated on an experimental basis from Kiruna shortly after ERS-1's launch, permitting the first ERS-1 SAR images taken over Spitzbergen on 27 July to be transmitted to ESTEC with only a few hours delay. The network itself was implemented progressively during the summer and autumn months of 1991. At present, both the Kiruna and Fucino stations are transmitting SAR images daily, and ten receiving stations are already operating, with the others in the process of installation.

Since early January 1992, both Kiruna and Fucino have been distributing daily SAR images to the BDDN receiving stations, supporting in particular the Ice-Phase experiment and pilot projects.

Figure 6. The Broadband Data Dissemination Network (BDDN)

Figure 7. Locations of the three wind-scatterometer transponders, at Arenasillo, Malaga and Adra (Southern Spain)

Figure 8. A wind transponder installed at Adra, in Southern Spain

AMI Wind Scatterometer

The role of the AMI wind mode, which operates only when the SAR imaging mode is not being used, is to measure surface wind fields. The Wind Scatterometer provides three measurements per cell through its three beams (fore, mid and aft) across the 500 km swath width. The cells are defined as 50 km by 50 km squares.

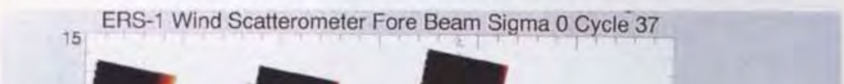
The calibration/validation of this instrument mode requires two complementary activities:
- engineering calibration, to obtain calibrated backscatter measurements
- geophysical validation to confirm the C-band model and permit wind vectors to be derived for each cell.

Engineering calibration

This calibration is being performed using three transponders installed in Southern Spain, permitting two observations every three days – one descending pass and one ascending pass – with the three beams. The three transponders have been positioned so as to provide good sampling of the swath (Fig. 7).

Each transponder (Fig. 8) tracks the satellite to provide calibration return echoes to the fore-, mid- and aft-beams, in sequence as the satellite approaches and passes over the transponder array. The data are processed on site and retrieved via data links to ESTEC, where the final processing is performed using both the satellite telemetry data and the transponder calibration data. The combination of descending and ascending passes provides six calibration points for each beam every three days.

Figure 9. Map of the Amazonian Rain Forest obtained with the ERS-1 fore-beam.



The calibration points are complemented by a verification of stability through the swath while overflying large well-known homogeneous natural targets. The Amazon Rain Forest is one such area that has been extensively used (Fig. 9).

The results of this complex calibration are extremely good, providing an absolute calibration through the beam swaths and inter-beams within about 0.3 dB at the end of the Commissioning Phase.

Wind-wave geophysical validation

The geophysical validation permits the C-band model (establishing the relation between measured sea backscatter and surface wind) to be confirmed and fine-tuned. This model (C-Mod 2) was established before launch based on measurement campaigns using aircraft, ship and buoys, and has been used as reference for product generation since the start of the ERS-1 mission. The tuning of this model has been a major objective of the wind–wave validation campaign during the Commissioning Phase.

In performing the geophysical validation of the wind and wave products derived from the ERS-1 AMI and Radar Altimeter instruments, two approaches have been followed in parallel:

- Comparison of ERS-1 wind/wave products with prediction models on a regional or global basis. This activity was initiated on 14 August with four European meteorological centres, including the European Centre for Medium-Range Weather Forecast (ECMWF).
- Comparison of ERS-1 wind/wave products with in-situ measurements.

Haltenbanken campaign
A major campaign coordinated by ESA was conducted in the Haltenbanken area, off the west coast of Norway, between 17 September and 10 December 1991.

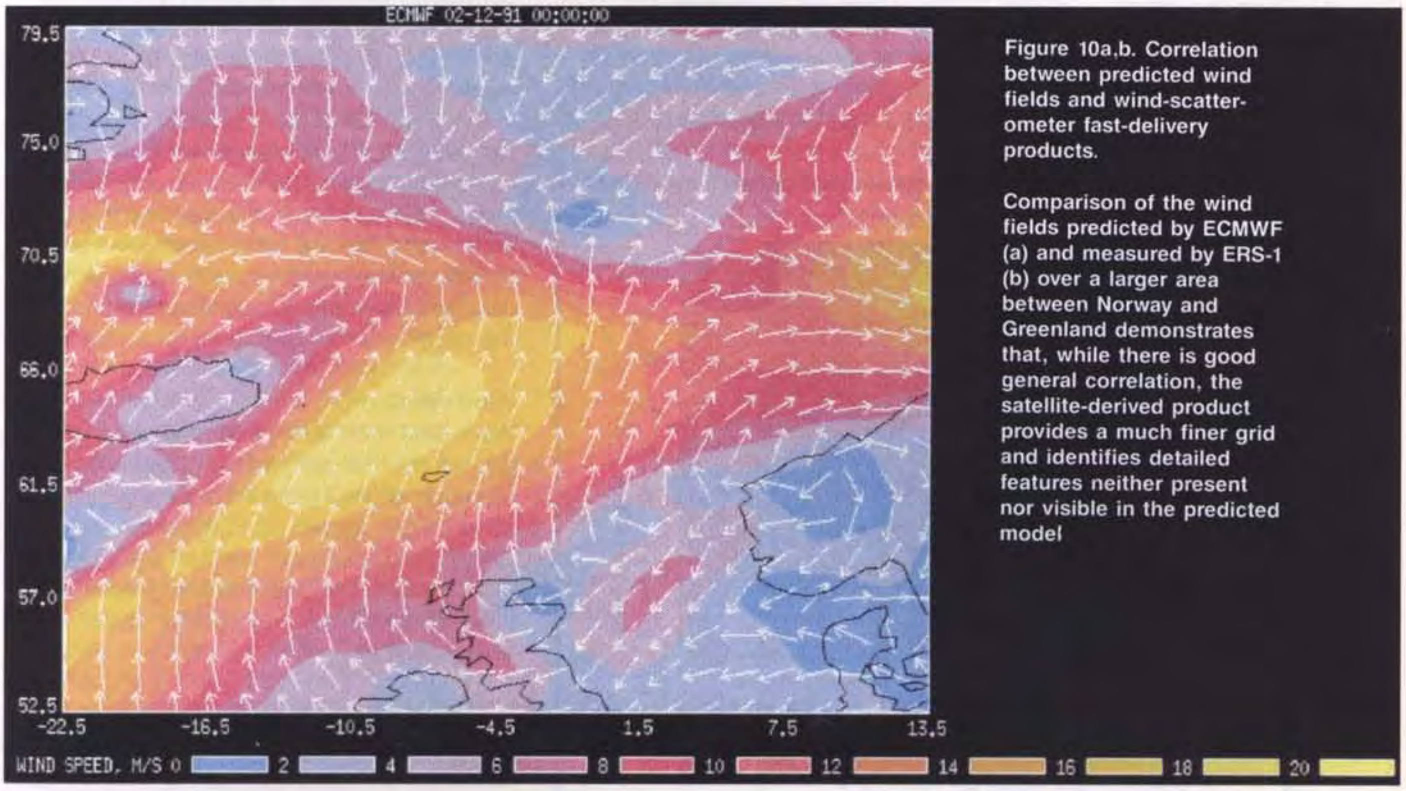


Figure 10a,b. Correlation between predicted wind fields and wind-scatterometer fast-delivery products.

Comparison of the wind fields predicted by ECMWF (a) and measured by ERS-1 (b) over a larger area between Norway and Greenland demonstrates that, while there is good general correlation, the satellite-derived product provides a much finer grid and identifies detailed features neither present nor visible in the predicted model

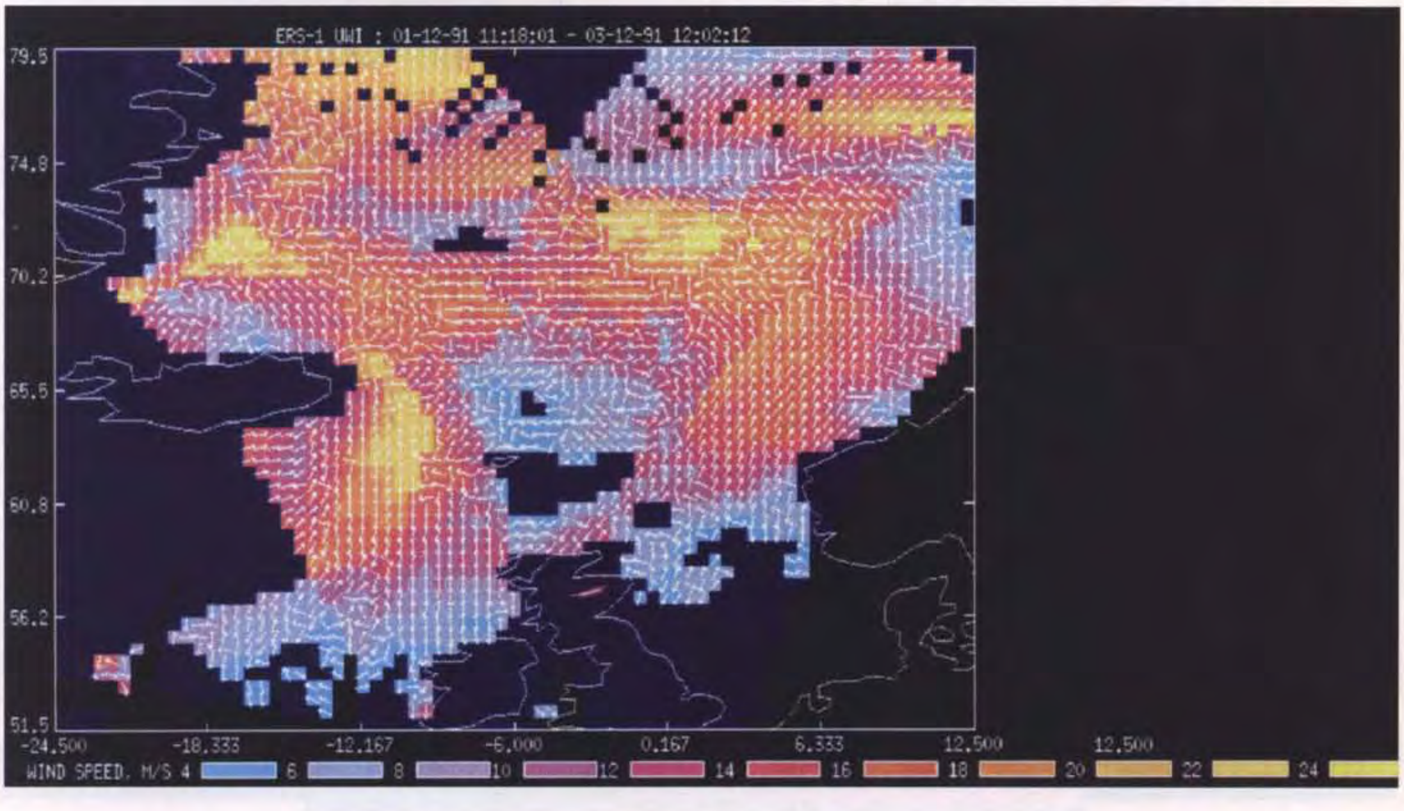


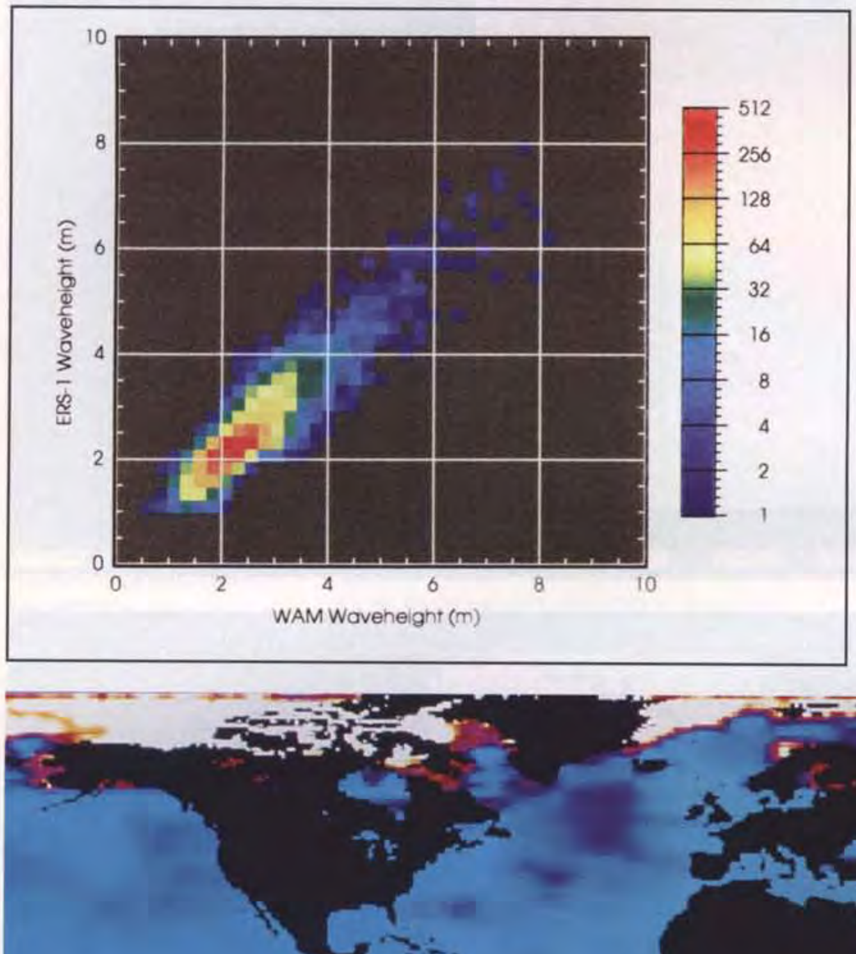
Figure 11. Comparison of significant-wave-height measurements with the ECMWF WAM model over a 7 day period in early December 1991.

Figure 12. Global averaged significant wave height measured by the ERS-1 Radar Altimeter during the period 20–27 October 1991. The colour code represents the number of entries per bit

A buoy network was deployed over this area and several specially equipped ships and aircraft supported the campaign with wind/wave measurements and some other complementary observations.

A total of 95 sorties were made by three aircraft acquiring wind/wave data during overflights of the buoy network by the satellite. These were complemented with SAR aircraft missions and the in-situ data set collected by three research vessels and the buoy network, including ten wind/wave buoys specially developed and deployed by Oceanor (Norway) for this project.

A campaign operational centre was set up at Trondheim, where all the data from the campaign were acquired with no more than a 24 to 48 h delay, and correlated with weather predictions from meteorological centres and ERS-1 fast-delivery products acquired and processed at ESA's Kiruna station.



The near-real-time correlation performed during the campaign permitted a very good correlation between the in-situ and satellite wind measurements to be verified. While confirming the general validity of the C-band model established before launch and used in the wind fast-delivery product generation, the co-location files established during this campaign confirm the need to update this model. By April 1992, the new model will be available for use for product generation, thereby enhancing the quality of the wind-field fast-delivery products disseminated to the users.

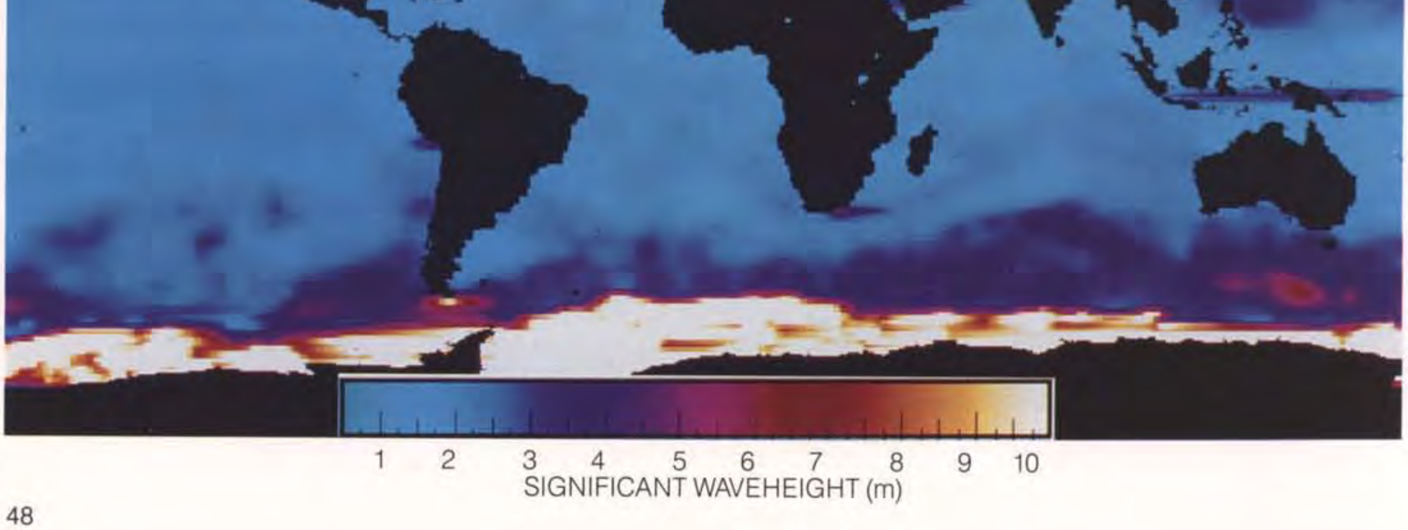
Wave validation

Wave data have also been acquired throughout this campaign to support the validation of the Radar Altimeter's significant wave height, as well as to evaluate the wave-imaging capabilities of the AMI SAR and wave modes, the objective being to validate the transfer function from image spectra to wave spectra.

In the meantime, fast-delivery image spectra are being systematically produced from the ERS-1 wave mode.

Radar Altimeter

The ERS-1 Radar Altimeter (RA) has been



making measurements since 25 July 1991. During the early weeks of the mission, the on-board operating parameters were fine-tuned to optimise its performance. While good performances were quickly achieved in ocean-tracking mode, the fine tuning of the tracking parameters over ice and sea-ice areas, as well as the optimisation of signal reacquisition following loss of tracking criteria, proved to be more difficult.

The fast-delivery processing system became operational very early on in the commissioning phase. By 14 August 1991, fast-delivery products were being routinely sent to four meteorological centres, which passed back reports on the quality of the results. In addition, the RA height measurements (satellite height above the Earth's surface beneath) were being routinely ingested into the orbit determination. For the significant-wave-height and wind-speed products, a comparison database was quickly established, largely with the help of the ECMWF. With the help of these comparative data, a number of anomalies in the fast-delivery products were identified and gradually removed.

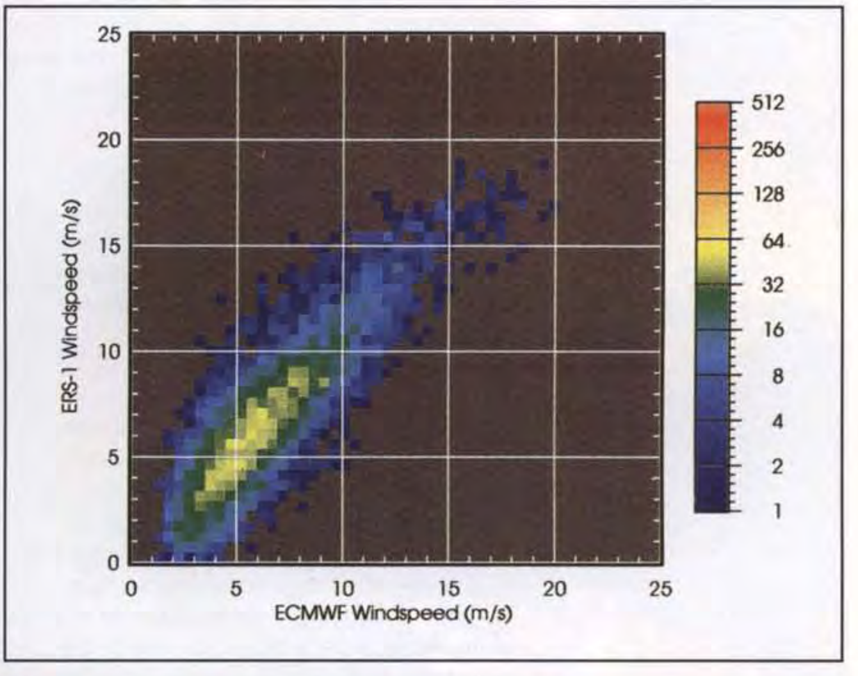
The RA has been running with simple theory-based wave-height processing, with no special correction factors. The results, presented as a two-dimensional histogram comparison with the ECMWF Wave Model, are shown in Figure 11. Clearly, the RA wave heights are in good agreement for a wide range of wave heights all over the globe. A global map of the Significant Wave Heights (SWH) obtained during one three-day cycle is shown in Figure 12, where the data have been interpolated across-track, and then globally smoothed.

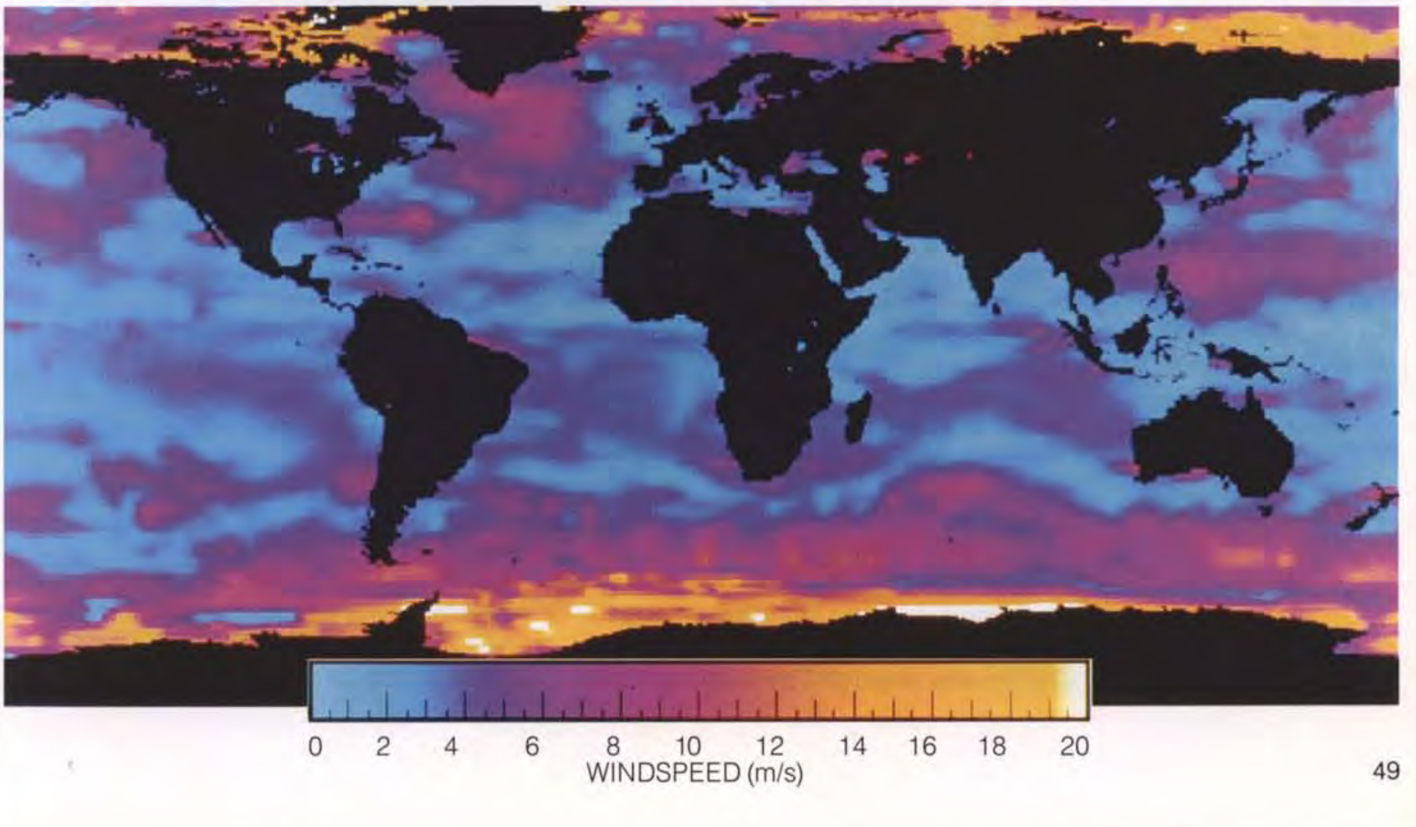
The wind-speed measurements are based on pre-launch calibration of the instrument and use of the wind model. There is still a need for further analysis, as the comparison with the ECMWF model is good but not perfect (Fig. 13). A similar global map averaged over three days is shown in Figure 14.

Analysis of the correlation data file obtained during the Haltenbanken campaign has been initiated to support the fine-tuning validation of significant wave height and wind-speed derived from the Radar Altimeter.

Figure 13. Comparison of wind-speed measurements with the ECMWF wind model over a 7 day period in early December 1991.

Figure 14. Global averaged wind speed measured by the ERS-1 Radar Altimeter during the period 20–27 October 1991.





The height calibration took place over a series of orbital arcs in the vicinity of Venice, Italy, where a dedicated campaign was conducted from 31 July to 17 September 1991. Nine arcs were considered to be valid for height calibration, using multiple laser coverage of the arc as well as good in-situ and RA data as criteria. Sufficient measurements were obtained to allow a high-quality calibration of the height bias. The analysis is now almost complete and indicates a small bias with respect to on ground characterisation of about 20 cm and an absolute height calibration accuracy of ± 5 cm.

Height measurements with the Radar Altimeter have been examined by several groups in an effort to quantify its performance. The emerging picture is that the basic height noise of the instrument is about 2—3 cm, but this requires additional processing for extraction.

One of the entirely new areas in altimetry which the ERS-1 instrument has been able to explore is measurements over ice, for which it has shown itself able to deliver meaningful data over severe terrain, thereby offering promising opportunities for scientific research.

ATSR microwave and infrared radiometer
The ATSR microwave radiometer is being calibrated by the Centre de Recherche de Physique de l'Environnement (CRPE) in France, which developed and delivered this ERS instrument. Very good engineering calibration results are being obtained and the data will soon be available for use in the correction of the Radar Altimeter precision altitude product (wet atmospheric component correction).

The ATSR infrared radiometer commissioning has also been conducted by the instrument's provider, Rutherford Appleton Laboratories (RAL, UK). This instrument, including its mechanical cooler, has been behaving very well since launch and the calibration efforts – in particular Sea Surface Temperature (SST) measurements – have been supported by several in-situ campaigns.

By the end of the Commissioning Phase, RAL was reporting its processing chain as operational and ready to undertake routine processing of all ATSR data.

ATSR products
The image presented in Figure 15 shows the brightness temperature of a 512 km by 512 km area covering Central Italy and part of the Mediterranean. This image, acquired at night on 28 November 1991, shows the Earth's surface radiance in the 3.7 μm band, calibrated and geocoded but not corrected for atmospheric effects.

The image has been processed with false colour to show the range of brightness temperatures (deg K) indicated in the key. As with most night-time images, the land surfaces, appearing green/brown/grey, are cooler than the sea, which appears in blue with the warmest areas in red. On land, the higher regions are of course cooler, and the green areas generally correspond to low-lying areas, valleys and 'urban heat islands'. Cooler areas, including lakes and estuarial outflows, appears dark blue. Near the top of the image, Lago di Bracciano (dark blue) can be seen, and further south the Rome conurbation (green). The Tiber valley and its estuarial outflow can be seen to the west of the city.

Further south, the Bay of Naples can be picked out, and the islands of Capri and Ischia can be discerned. Mount Vesuvius appears as a cooler (brown) circular feature just inland from the Bay. In the ocean, surface-temperature gradients are clearly visible. In the northeast corner of the image a concentration of small clouds can be seen, presumably created down-wind of the land mass as cool air from the land meets the warmer moist air over the Adriatic.

Ground-segment phase-in
Whilst the calibration/validation activities were in progress, a very effective phase-in process for the ground segment was conducted in parallel. The MMCC at ESOC quickly proved to be very effective in the operational scheduling of the satellite, using the ESA station at Kiruna as a reference, acquiring 9 to 10 orbits a day out of 14, and providing most of the data necessary for the verification of both satellite and instrument performances.

From early August 1991 onwards, systematic acquisition and processing of global low-bit-rate data has been possible at ESA's Kiruna, Gatineau and Maspalomas stations, and acquisition only at the Prince Albert station.

The near-real-time distribution (within 3 h of data take) of the global fast-delivery products was widened at the end of November 1991 from the original four meteorological centres involved in the validation, to all centres nominated by the programme participants. Off-line distribution of the global fast-delivery

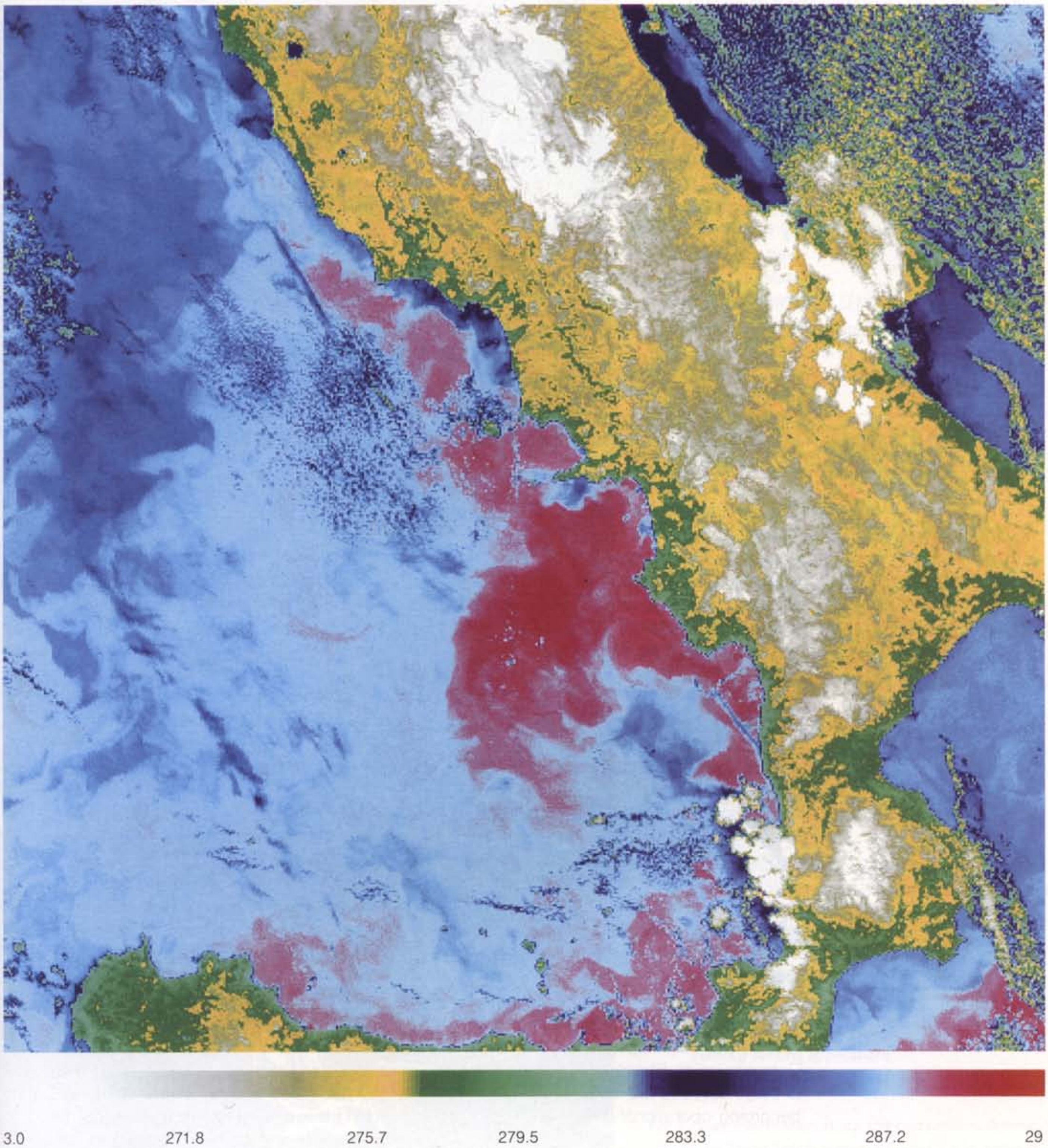


Figure 15. Along-Track Scanning Radiometer (ATSR) brightness-temperature image of Central Italy.

products has also been initiated from the French Processing and Archiving Facility (F-PAF).

The SAR coverage and associated SAR fast-delivery processing provided by the three ESA stations in Kiruna, Fucino and Maspalomas has been very quickly enhanced by the phase-in, begun in early August 1991, of national and foreign SAR receiving stations. The ESA SAR fast-delivery product was declared validated and ready for distribution by mid-October 1991. SAR processing was also certified by ESA at four national/foreign stations – Tromsø, Gatineau, Prince Albert and Fairbanks – before the end of the Commissioning Phase.

Delivery of SAR images to users was therefore in progress from several stations before the end of Commissioning Phase, as well as from the German Processing and Archiving Facility (D-PAF).

The functions of the Central User Service located at ESRIN, in Frascati (I), were phased-in step-by-step during the commissioning phase (MMCC interfacing and station scheduling, SAR mission scheduling, user-request handling, product control and distribution, and interfacing to the PAFs).

Several of the basic PAF services were operational before the end of the Commissioning Phase, not only permitting archiving and cataloguing of the data and products, but also supporting some initial product distribution. The D-PAF was capable early in the Commissioning Phase of organising laser tracking of ERS-1 by a large number of laser stations around the world, and of retrieving these data for the generation of a precise reconstituted orbit, which will subsequently be used for offline Radar Altimeter precision processing.

The phasing-in of the PAF services was not intended to be completed by end of the Commissioning Phase, and therefore some of these services are still in the process of becoming operational.

Conclusion

The activities carried out during the Commissioning Phase have clearly demonstratted the viability of the ERS-1 satellite in a realistic operational context.

All of the calibration and verification activities that have been performed have confirmed both the excellent performances of the instruments and their stability, enabling the delivery

of calibrated products that meet or even exceed the original specifications, thereby marking the successful completion of the Commissioning Phase.

These good results allowed ESA to release fast-delivery products to the user community before end of the Commissioning Phase, thereby feeding the operational meteorological centres with the global low-rate products and affording early data access to the scientific community, with SAR images being distributed to users either in near-real-time or via offline processing and distribution.

Transfer of ERS-1 to the 'Ice Phase' orbit was initiated in mid-December. By 1 January, the satellite was already operating nominally in its new orbit, which is still a 3-day repeat orbit, but with a longitudinal phasing selected specifically for the ice experiments.

By mid-April 1992, ERS-1 will acquire a 35-day repeat-cycle orbit in which the SAR will be capable of imaging any part of the world within station coverage while preserving all objectives of the global low-rate mission.

Less than six months after launch, the ERS-1 satellite system has been declared operational and ready to serve the scientific, research and application user communities. At the end of January, a consortium of three companies – Eurimage, Radarsat International and Spotimage – signed a contract with the Agency entrusting them with the marketing of ERS-1 data, thereby initiating the commercial distribution of the products from ESA's first European remote-sensing satellite.

Acknowledgement
The success of the early in-orbit operation and commissioning of ERS-1 is the result of the dedicated work of a large team drawn from the various ESA establishments, the ERS stations, national institutes and industry. This article is the direct result of their work. It is also the result of the efforts of the much larger team in industry, ESTEC and the national institutes who contributed over many years to the production and delivery of the ERS-1 satellite and its instrumentation, which has proved to work so well in orbit.

Figure 1. The Giotto spacecraft

Giotto — The Second Encounter

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On 4 May 1992 the Giotto spacecraft was successfully reactivated after its second period of hibernation and is currently being prepared for its encounter with Comet P/Grigg-Skjellerup on 10 July 1992. The elements of the scientific payload that survived the earlier encounter with Comet Halley are expected to make a further important contribution to our understanding of cometary phenomena.

The reactivation

The second reactivation of the Giotto spacecraft had been scheduled for 4 May 1992. At 16.:55 h local time, the first commands were sent from the European Space Operations Centre (ESOC) in Darmstadt, Germany, via NASA's Jet Propulsion Laboratory in Pasadena (Calif.), to the 70 m Deep-Space Network (DSN) ground station in Madrid, Spain, for uplinking to Giotto. At that time, the space probe was 219 million kilometres from Earth.

The commands sent were the first in an extensive series designed to awaken Giotto from its hibernation configuration. To ensure reception of the signals by the tiny omni-directional antenna on the top of the spacecraft, the DSN's most powerful 95 kW transmitter had to be used.

The spacecraft was configured to allow the transmitter connected to the Low-Gain Antenna to be turned on. At 18:14 h local time, the Madrid ground station reported the reception of a downlink carrier with a signal strength of −171 dBm, as predicted by the ESOC Operations Team. Giotto was back, again at the first attempt, just as in 1990 after its first period of hibernation! Once again, Giotto had lived up to the confidence that the Project and Operations Teams had placed in it. Only the waiting required was a little nerve-racking, because the remoteness of the spacecraft from Earth meant that one had to wait nearly half an hour for the spacecraft's response to a command to be seen on the ground!

A series of 'blind' manoeuvres were subsequently performed to orient Giotto so that its High-Gain Antenna (HGA) pointed towards Earth and telemetry could be received. This was accomplished on 7 May 1992, when good telemetry was received continuously. At this point, the Giotto reactivation effort could be truly declared a success!

With this first, most important phase completed, we can look ahead with keen anticipation to the encounter with Comet P/Grigg-Skjellerup.

Comet Grigg-Skjellerup

P/Grigg-Skjellerup, Giotto's second target for a close flyby, has the second shortest orbital period, just 5.09 yr, of any known comet except P/Encke, which has a period of 3.31 yr. P/Grigg-Skjellerup has an aphelion of 4.94 AU and a perihelion 0.99 AU, and was first discovered by John Grigg (1838–1920) from New Zealand and rediscovered in 1922 by John Francis (Frank) Skjellerup, an Australian working in South Africa.

Giotto will encounter Grigg-Skjellerup just 12 days before the comet passes perihelion, when it should be showing close to peak activity. However, if one compares the water-molecule production rate measured for Comet Halley ($7 \times 10^{29}\ s^{-1}$) with the best predictions for Grigg-Skjellerup based on IUE-spacecraft and ground-based photometry (about $2-3 \times 10^{27}\ s^{-1}$), one realises immediately that the new target is much less productive than Halley.

Comet P/Giacobini-Zinner, the target of the International Comet Explorer spacecraft flyby in late 1985, lies somewhere in between the two in activity terms (production rate of $2 \times 10^{28}\ s^{-1}$).

This variation in activity underlies the prime scientific objective of the Giotto Extended

Mission (GEM), namely to compare a comet with a low gas production rate, P/Grigg-Skjellerup, with the very active and 'fresh' Comet Halley.

If we compare the actual mass losses per second for these comets, the variations are perhaps even more readily apparent. At the time of the Giotto encounter on 14 March 1986, Comet Halley was losing a total of 30 tons of gas and dust per second, whereas for Grigg-Skjellerup this figure will be of the order of only a few tens to a few hundreds of kilogrammes of material per second, i.e. a large truck load from Halley compared with something one could transport in a family car. Any dependence of the measured cometary phenomena on the dust and gas production rate is therefore expected to be highlighted by the comparison between Comets Halley, Grigg-Skjellerup and Giacobini-Zinner.

The payload

Eight of the eleven experiments making up the original Giotto payload survived the first encounter without being damaged at all, or only to the extent that they can still be used to carry out meaningful investigations at Comet Grigg-Skjellerup. The current status of the payload for the Giotto Extended Mission is summarised in Table 1.

The performances to be expected from the Rème Plasma Analyser (RPA) and the University of Bern's Ion Mass-Spectrometer (IMS) are still somewhat uncertain. The RPA will have to be checked out again just prior to the encounter to ensure that the EESA sensor can be operated nominally to provide the electron spatial density close to the comet. The IMS–HIS sensor, on the other hand, is working nominally, but was designed to function optimally for the very high relative encounter velocity of 68 km/s at Halley, rather than the 14 km/s at Grigg-Skjellerup, which will make the interpretation of any mass-spectra extremely difficult.

Science at Comet Grigg-Skjellerup

The functioning payload complement listed in Table 1 drives the two main scientific areas

Table 1 — The Giotto experiment complement (original specifications)

Experiment	Measurement	Technique
HMC	Colour imaging of cometary nucleus and inner coma	Narrow-angle CCD camera with Ritchey-Chrétien telescope
NMS	Energy and mass of neutrals M-analyser: 1–36 amu E-analyser: 10–1410 eV (1–57 amu) 210–2180 eV (9–89 amu)	Ionisation by electron beam Electrostatic energy and magnetic sector field momentum analyser Parallel-plate electrostatic analyser
IMS	Energy and mass of ions HERS: 20–8000 eV and 1–35 amu/q HIS: 100–1400 eV and 12–57 amu/q	Sector magnet and electrostatic deflector Two quadrispherical analysers with magnetic deflection
PIA	Mass (3×10^{-16}–5×10^{-10}g) and composition (1–110 amu) of individual dust particles	Impact ionisation, time-of-flight tube (1m) in which the ions are separated according to their masses
DID	Determination of mass spectrum of dust particles from 10^{-17} to 10^{-3} g with three different detectors	MSM/RSM: 3+1 piezoelectric elements for large masses CIS: capacitor for medium masses IPM: impact charge measurements for small masses
JPA	FIS: solar wind and cometary ions from 10 eV to 20 keV IIS: cometary ions from 90 eV to 70 keV and 1–45 amu	Hemispherical electrostatic analyser with subsequent quadrispherical sector Five electrostatic analysers, each followed by a time-of-flight tube
RPA	EESA: solar wind and cometary electrons from 10 eV to 30 eV PICCA: cometary ions from 1 to 200 amu	Quadrispherical electrostatic analyser with 4π viewing Hemispherical electrostatic analyser
EPA	3-D measurement of protons from 15 keV to 20 MeV, electrons from 15 keV to 140 keV, alpha particles from 140 keV to 12.5 MeV	Three telescopes, each with two solid-state detectors
MAG	Interplanetary and cometary magnetic field Experiment range: 0.004–65536nT	Outboard sensor: triaxial ring-core fluxgate magnetometer Inboard sensor: biaxial
OPE	Coma brightness in four continuum (dust) bands and at four discrete wavelengths (gaseous emissions of OH, CN, CO^+, C_2)	Rearward-looking photopolarimeter with eight interference filters
GRE	Cometary electron content & mass fluence	Phase differences between S- and X-band RF signals

that can be addressed during the Grigg-Skjellerup encounter: the particle and field instruments have the potential to provide significant new results pertaining to the field of cometary plasma physics. The Optical Probe Experiment and the Dust-Impact Detection System (DID) will complement our knowledge of dust-production rates and size distributions for a low-activity comet.

The dust measurements can also provide important data to support future European and international space programmes. Future missions to comets, for example, will need engineering models of the cometary dust environment for low-activity comets, which the GEM mission should help to improve.

Cometary plasma physics is part of a broader domain of space plasma physics dealing with the interaction between a planetary atmosphere and a flow of magnetised plasma. Examples include comets, Venus, the Saturnian satellite Titan in the solar wind, and Io, Titan and Triton in their planetary magnetospheres. Physically, comets are distinguished from the other planetary bodies by their characteristic of possessing a non-gravitationally-bound atmosphere.

Three instruments that will be especially useful for the Grigg-Skjellerup encounter survived the dust impacts unscathed during Giotto's encounter with Comet Halley. Of these, the Implanted Ion Sensor (IIS) of the Johnstone Plasma Analyser (JPA) provides the full pitch-angle distribution for each chemical species in a range of energies from 100 eV/q to 86 keV/q. Its time resolution is rather good, with just 128 s required for a full set of observations. This corresponds to a spatial resolution of approx. 14 km/s x 128s = ±1700 km in the cometary frame of reference.

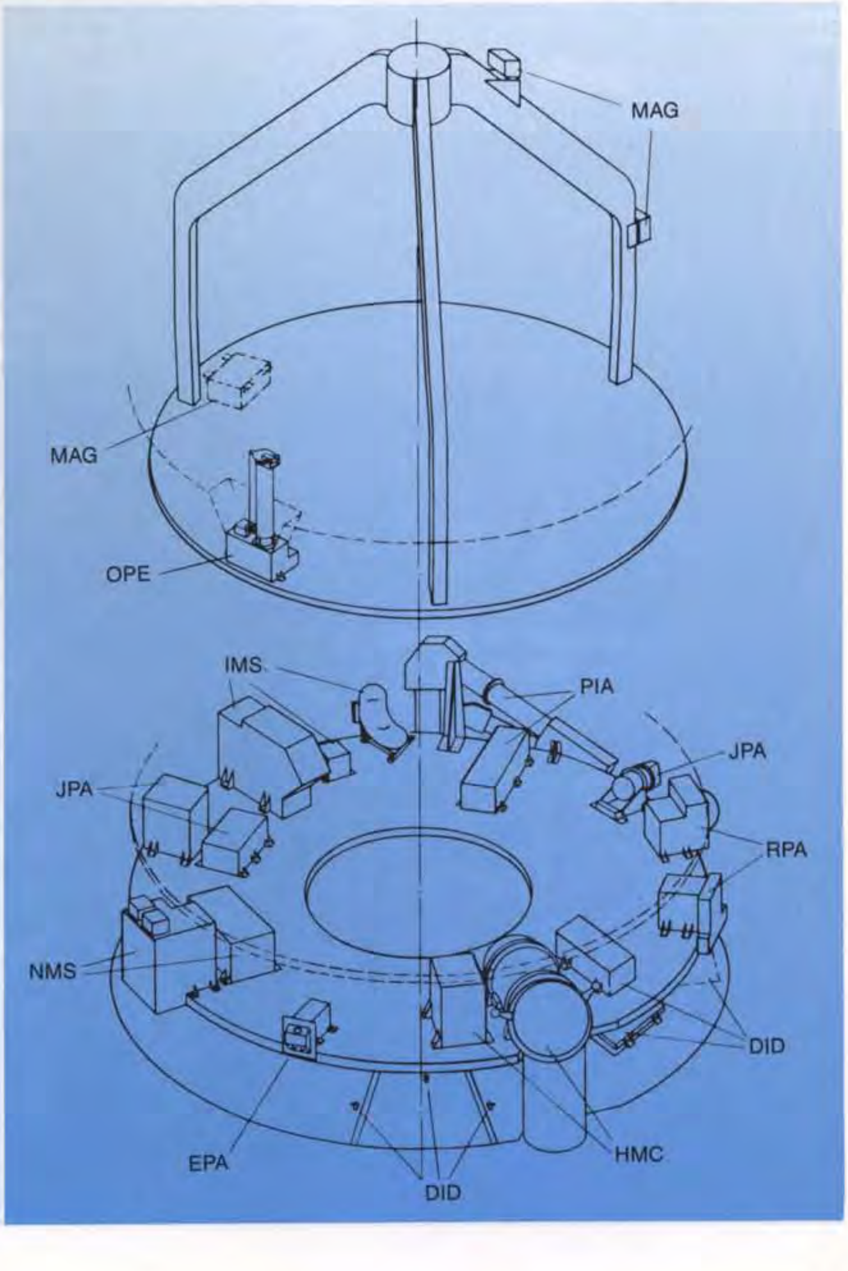
The Magnetometer (MAG) is also fully operational with 35.4 ms resolution, corresponding to 0.5 km spatial resolution. The Magnetometer results can be processed and evaluated much more easily for Comet Grigg-Skjellerup than for Halley because of the absence of magnetic disturbances produced by the motors of the Halley Multicolour Camera (HMC), which is no longer functioning.

In addition, the fully operational Energetic Particle Analyser (EPA) contains three semiconductor telescopes, each incorporating two totally depleted silicon surface barrier detectors. Electrons, protons, alpha particles and heavier ions can be measured in eight channels covering an energy range extending from approximately 30 keV to several tens of MeV. High spatial and temporal (0.5 s) resolution is available.

Finally, although the Rème Plasma Analyser (RPA) is severely crippled by dust damage, it may still provide some information on low-energy electrons.

The complement of operational instruments described above provides a particularly fortunate combination, since they potentially provide reasonably complete coverage of the cometary magneto-plasma. Although, compared with the Halley flyby, very low energy ions and electrons will be, at very best, only partially recorded and some spatial resolution will also be lost, the surviving payload elements promise excellent particle and field measurements.

Figure 2. Locations of the ten Giotto experiments onboard the spacecraft (see Table 1 also)

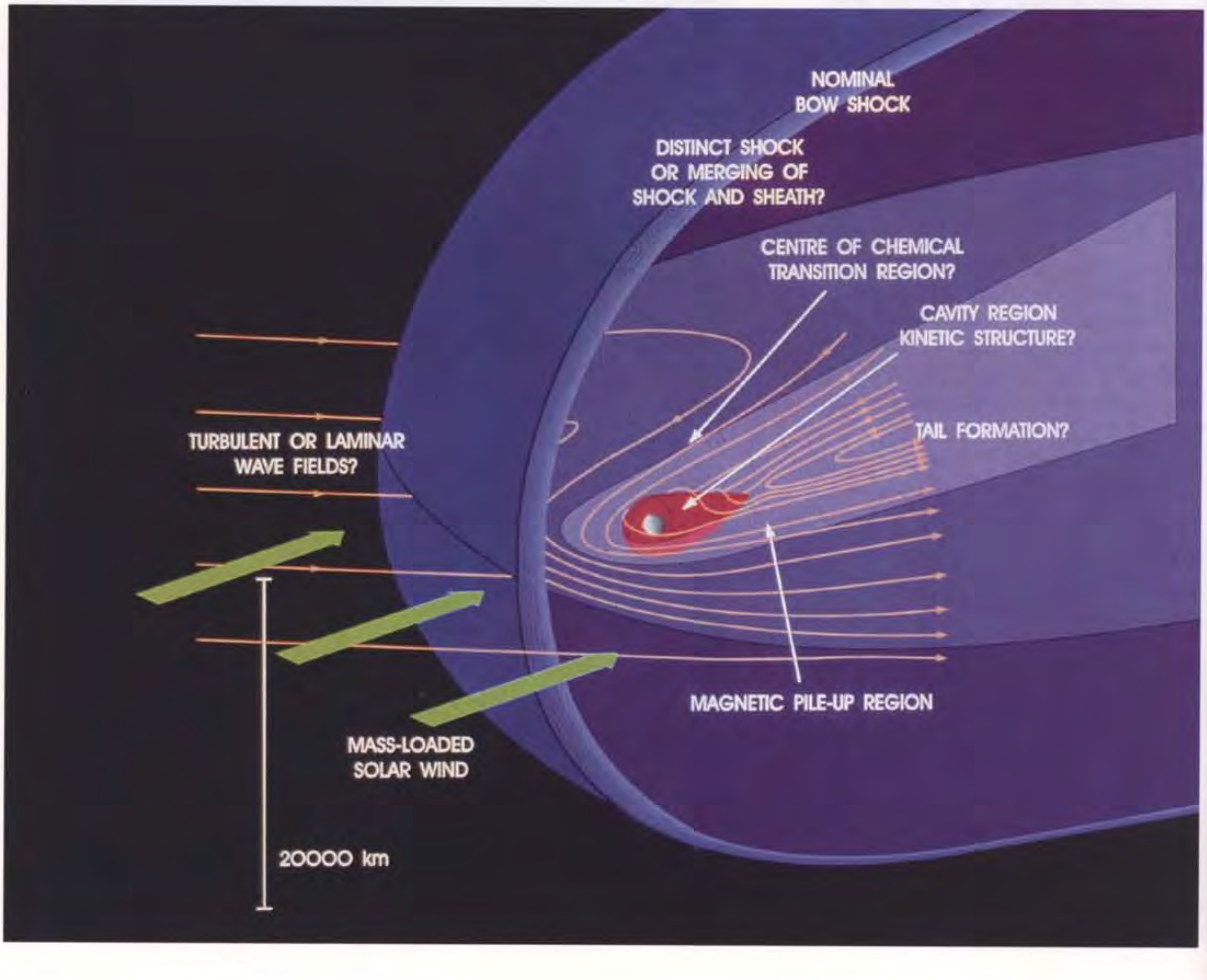


Basic physical considerations show that the comet/solar-wind interaction depends: on the characteristics of the solar-wind plasma and magnetic field; on the Sun's photon radiation, on the production rate and outflow velocity of the cometary gas; and on certain atomic parameters such as cross-sections, etc. Physical theories can be tested by comparing the predictions with observational measurements. Since all three encounters, at Comets Giacobini-Zinner, Halley and Grigg-Skjellerup, share approximately the same Sun–comet separation at the time of flyby, the relative effects of radial variation in the solar wind and in the solar radiation can be essentially disregarded. Temporal variations may, however, be significant. The largest predictable variation is in the gas production rate as discussed earlier.

The parameters mentioned above enter into the computation of characteristic length scales, which represent the physics involved in a particularly illustrative way. For constant solar-wind and solar-radiation conditions (e.g. at 1 AU), these characteristic scales vary quite differently as a function of the comet's gas production rate (Q). The ionisation length scale given by the product of the neutral particle velocity and the ionisation lifetime (approx. 10 s for hydrogen) does not vary as a function of Q. On the other hand, the distance at which the neutral gas flux equates with the solar-wind flux is approximately proportional to the square root of Q. The latter two length scales can be combined to yield the expected stand-off distance of a cometary bow shock.

A length scale that is important for the kinetic structure is the gyro radius of a suitable charged particle. Except in the presence of major solar-wind deviations from the average, the gyro radii are not expected to change, since the magnetic-field magnitude and the velocities remain the same. Variations in these and other important characteristic length scales with Q show that the plasma interaction with large and small comets is not due to their representing reduced or

Figure 3. Possible scenario for solar-wind interaction with the comet P/Grigg-Skjellerup and some unresolved questions



amplified versions of each other. Rather, the dependence on Q is much more complex and is hence of appreciable diagnostic value.

The specific scientific objectives of the Giottó Extended Mission can be summarised as follows (see also Fig. 3):
- characterisation of the changing features of the solar-wind flow and observations of cometary pick-up ions and anomalous acceleration
- determination of electron densities
- observation of upstream waves, and determination of the locations of the various boundaries (bow shock, ionopause, etc.)
- observation of the magnetic pile-up region and cavity
- determination of dust spatial density and size distribution, and the optical properties of the dust grains
- discrete gaseous emissions
- combined dust and gas densities.

The encounter

Owing to the limited power available onboard the spacecraft (20% less than for the Halley encounter due to the larger heliocentric distance of 1.01 AU, compared with 0.9 AU at Halley), payload operation will nominally start on 1 July 1992 with the switching on of the Magnetometer, followed by the Energetic Particle Analyser (EPA) and the other experiments during the subsequent days. A short checkout of the Halley Multicolour Camera (HMC) has been scheduled for 3 July to see if any unexpected improvements have occurred.

After the last orbit and attitude correction manoeuvres scheduled for 8 July, the full complement of operational instruments will be switched on in the morning of 9 July and operated throughout the period of closest encounter, which will occur between 17:20 and 17:25 h ESOC local time on 10 July 1992.

The bow-shock crossing at Comet Grigg-Skjellerup is expected to be observed at a distance of 23 000 km, or about 26 min before the closest encounter. The relative encounter speed of 14 km/s translates into a closing speed of 50 000 km/h between the spacecraft and the comet. The first dust particles are expected to be detected between 1 and 5 min before closest approach, depending on the actual encounter distances. We know with a high degree of confidence that Comet Grigg-Skjellerup releases dust, because there is a meteoroid stream, the Sigma Puppids, related to it. All in all, these factors dictate that the spacecraft should be aimed as close to the nucleus as possible for the flyby.

Figure 4. Image of Comet Grigg-Skjellerup taken on 25 May 1987 with the 3.5 m telescope at Calar Alto Observatory, Spain (Courtesy of the Max-Planck Institute for Astronomy, Heidelberg, Germany)

There is a lot of scope for surprises during the Grigg-Skjellerup encounter. The Giotto spacecraft has so far performed beyond all expectations, which is already an achievement in itself.Let us hope that the science conducted at Grigg-Skjellerup will make a further substantial contribution to the overall success of the mission, in the tradition of the encounter with Comet Halley, which provided us with such a wealth of new results.

Acknowledgement

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Data Archiving for the International Ultraviolet Explorer (IUE) Satellite

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This article examines the ways in which the International Ultraviolet Explorer (IUE) Project has solved the problems associated with the access and exploitation of vast volumes of archived astronomical data. The lessons learnt are relevant to the planning and implementation of other high-volume scientific data archives.

Introduction

Space observatories like IUE have been pushed into the front line of astronomical data archiving in recent years for two reasons:

- Their data rates are extremely high compared with those from ground-based astronomical observation. The total observing time provided by IUE during the 14 years of orbital operations to date corresponds to roughly 70 years of observations from a ground-based observatory at a good site. Consequently, no infrastructure existed previously within the astronomical user community that was capable of handling such a quantum leap in data-archival needs.
- The data-reduction requirements of a satellite observatory are usually such that it is extremely difficult for individual scientists to handle the basic data-reduction task (i.e. the transformation of instrumental values into physical values) themselves and therefore this usually has to be tackled by the Project rather than the individual user.

The IUE spacecraft is a three-axis-stabilised observing platform carrying a 45 cm telescope. It is a joint NASA/ESA/SERC venture for which ESA has supplied the solar arrays and operates the satellite from its IUE Observatory at Villafranca, near Madrid (Spain). NASA, which supplied the spacecraft and the launch, operates the IUE Observatory at Goddard Spaceflight Center in Maryland (USA). SERC (UK Science and Engineering Research Council) supplied the IUE scientific instruments.

Launched in January 1978, IUE was one of the first true space observatories accessible to the astronomy community at large, the IUE team had to address the many new problems associated with a large astronomical data archive. For more than 14 years now, the IUE satellite has been collecting spectral data on a wide variety of astronomical objects in the 115 to 320 nm wavelength region. Currently, the IUE Archive contains more than 85 000 observations (210 Gbyte of data; see Table 1).

Since the data from IUE enter the public domain after six months, the need for an archive of some type (which at that time was unspecified) was already foreseen at the time of original programme definition. In practice, the archival development effort has managed more or less to keep pace with the data collected, so that the experience with the IUE Archive can serve as an interesting yardstick when evaluating future archival projects at the conceptual and planning stages.

Why build astronomical archives?

The creation and subsequent collection and organisation of written records is thought to have started about 5000 years ago. Aside from the important task of maintaining the significant photographic plate sets taken by ground-based observatories, the 20th century has brought an urgent need, driven by space projects in particular, for the creation of more easily managed and accessed astronomical archives for consultation during the coming decades.

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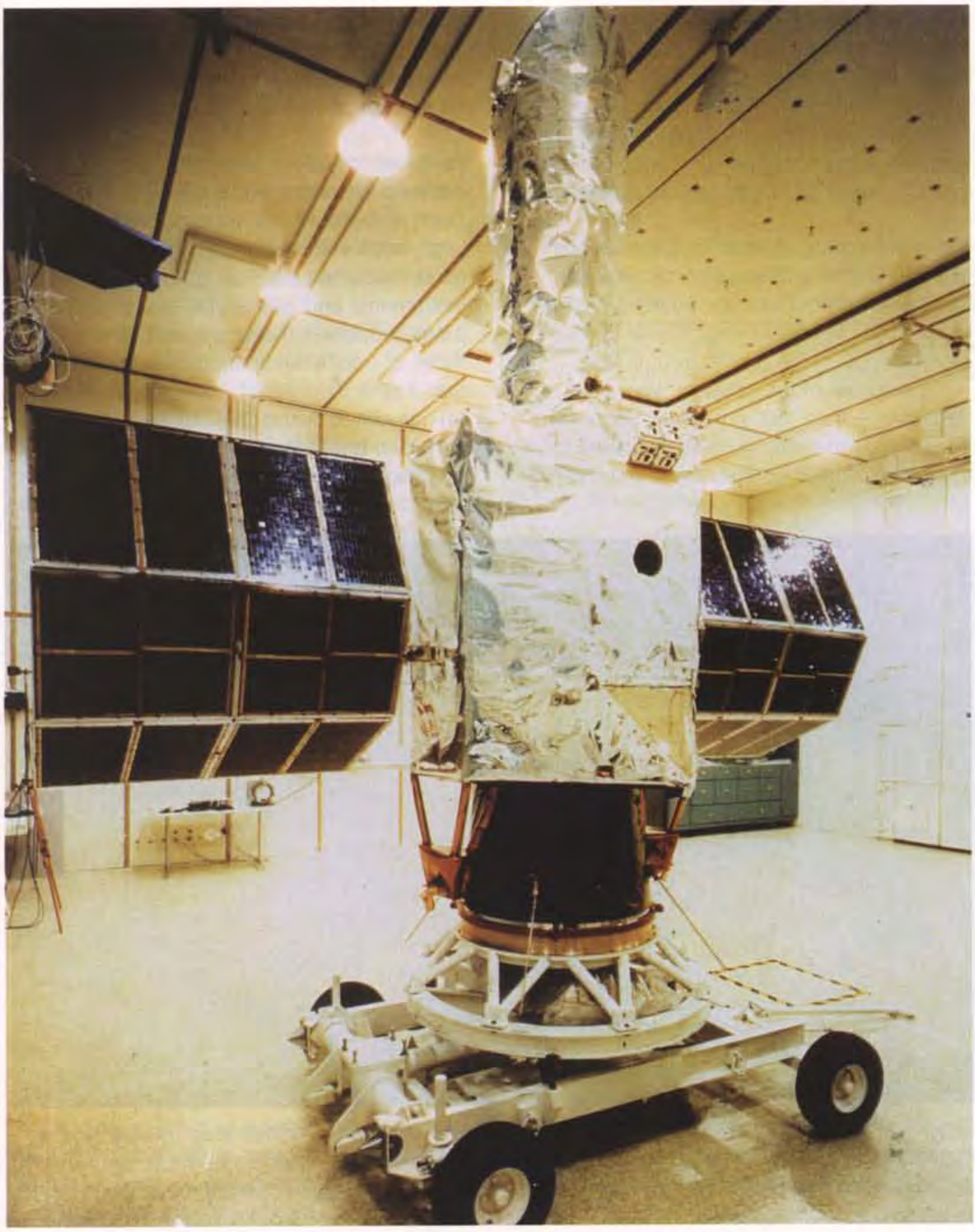

Figure 1. The IUE spacecraft before launch, with its solar panels in their extended in-orbit configuration. The three-segment panel arrangement was chosen in preference to moveable panels to ensure sufficient power over the wide range of solar aspect angles experienced during IUE's operations

From the astronomer's viewpoint, we know that astronomical observations are the building blocks of astrophysics. The accumulation of observational data across the presently accessible electromagnetic spectrum has enabled the development of an apparently consistent theory of stellar evolution within the framework of fundamental physics. This has encouraged the formulation of cosmological theories not only to interpret cosmological observations, but also to make the bridge between general astrophysics and high-energy physics.

These cosmological and theoretical considerations suggest that there was an interval of some 15 billion years between the present state of the Universe and its

Table 1. Contents of IUE Tape Archive (March 1992)

All data		Number of items	Total
Raw image	0.59 Mbyte	85 096	50.2 Gbyte
Photometric	1.18 Mbyte	85 096	100.4 Gbyte
Label info.,	0.009 Mbyte	85 096	0.8 Gbyte
Low resolution			
ELBL	0.67 Mbyte	56 915	38.1 Gbyte
Merged	0.015 Mbyte	56 915	0.8 Gbyte
High resolution			
Merged SW	0.66 Mbyte	14 264	9.4 Gbyte
Merged LW	0.74 Mbyte	13 917	10.3 Gbyte
Total		85 096	210.0 Gbyte

beginnings, which has to be spanned by theory. At the foundation of this theoretical bridge is the concept that the Universe is relatively static, and that variations take place in two modes only: secular ones, on time-scales comparable with those of stellar evolution itself, or strictly periodic ones.

The combination of modern observations with the limited archival records available has demonstrated that the power spectrum of variability in astrophysics contains much more energy in the higher frequencies – time-scales of the order of weeks to decades – than was previously suspected. This implies that the foundations of the theoretical bridge connecting the current epoch with the early stages of the Universe might contain serious errors. The size of this gap could be reduced empirically by one to two orders of magnitude if access to past observations via well-defined archiving procedures were an everyday possibility.

Providing this capability at the same time that powerful new instruments are pushing the limits to the observable Universe outwards, i.e. closer to the early phases, allows a two-pronged attack on furthering our understanding of the Universe, in that:
(i) we will accumulate the fundamental observational evidence needed to support our current concepts of the Universe, and
(ii) we will have a major tool available for maintaining consistency between high-energy physics and cosmology in the future.

For these reasons alone the archiving of astrophysical observations takes on an importance that merits urgent international attention, along with the associated issues of access to and dissemination of this information.

As far as the information content of such archives is concerned, it has already been recognised that information per se is an economic resource on a par with other resources such as labour, materials, instruments and capital. On the other hand, it has properties that are quite different from those of traditional economic resources, in that it is:
(a) naturally diffusive
(b) grows rather than wears out through usage
(c) expansion is limited only by time and human cognitive capabilities, and
(d) transactions involving the exchange of information will not result in a loss for the original owner.

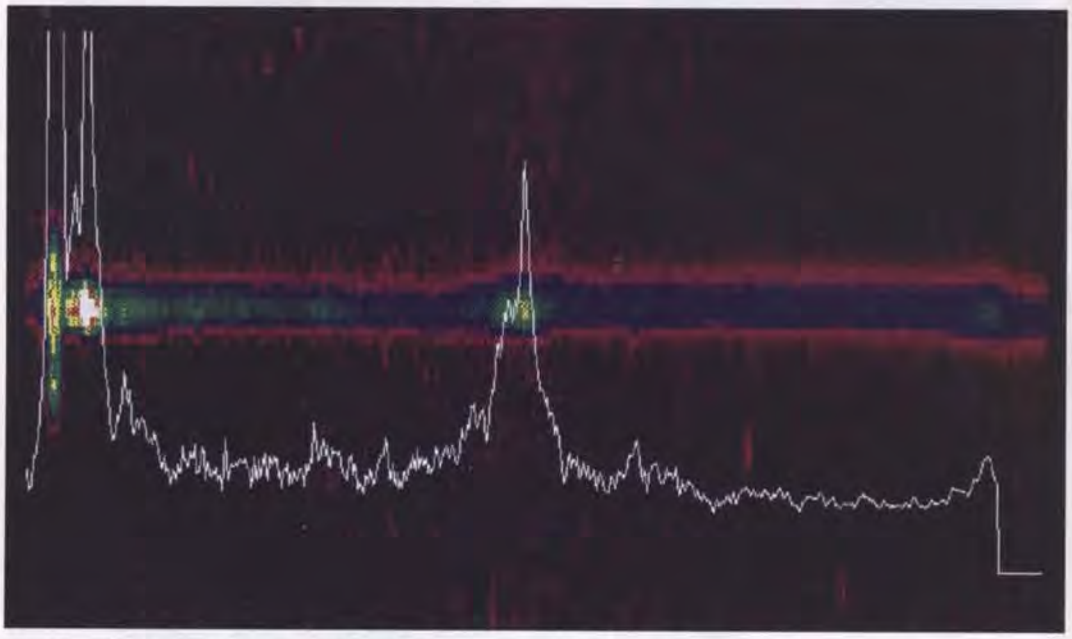

Figure 2. The last two stages in the IUE data-reduction process. The extended line-by-line spectrum is a spatially resolved spectral linearised image of the object observed – in this case the Seyfert-1 galaxy NGC 5548 – while the overplotted line is its integrated spectrum, in physical units, extracted from the ULDA.

Experience from the retrieval of more than 300 000 data sets from the IUE Archive has shown that this last form of archival data is an order of magnitude more useful to the community (judging by the demand) than the earlier stages of processing.

The IUE Archive over the years

No detailed maintenance and archival support was foreseen as part of the original mission plan and the IUE Archive, which now holds more than 200 Gbyte of data, has served to foster recognition of the importance of efficient data archival to the scientific value of space missions – not least through the massive use made of the data that it contains (Fig. 3 and Table 2).

Each of the three agencies involved in the IUE Project has an 'archival centre' serving the IUE user community: NASA's is at the National Space Sciences Data Center (NSSDC) at GSFC; ESA's is at the IUE Observatory at Villafranca, in Spain; and the SERC's is at Rutherford Appleton Laboratories (RAL), near Oxford (UK). Each of these centres maintains a complete up-to-date copy of the IUE Archive.

The IUE Archive is currently still defined as the contents of the archive tapes, which are copies of the data products supplied to the Guest Observers. Magnetic tapes, which are the earliest form of magnetic storage device, have two major drawbacks:
(i) data retrieval is slow and labour-intensive
(ii) data degradation occurs after a comparatively short time (5–10 years).

The NSSDC has made some efforts to forestall this data degradation by rewriting archive tapes. In the future, the IUE Archive, in the form of the IUE Final Archive (IUEFA), will be stored on the more permanent medium of optical disks.

Production of the IUEFA will involve complete reprocessing of the IUE data via the application of new image-processing techniques and will exploit today's greater understanding of the IUE instrument characteristics. All of the experience acquired during the past 14 years in data distribution and archival maintenance will be applied to build upon the already high level of user satisfaction with the Archive's usage.

Table 2 illustrates the current use being made of the IUE Archive by the astronomy community via the three archive access points and the different modes of retrieval available.

The original method of retrieving data from the IUE Archive was to forward a written data request by normal mail to one of the centres. Tape copies of the appropriate section(s) of the original archived data were then made and sent to the astronomer, again via regular mail. Over the years, the number and scope of the demands increased proportionally with the size of the Archive, and it became apparent that this approach was insufficient to maintain the data set and to serve customer demand in an efficient manner. Consequently, each of the IUE archival sites has developed its own archive support structure in order to cope.

The most important innovations at ESA's IUE Archive at Villafranca over the years have been:
(i) The putting on-line of the IUE Catalogue (IUE Merged Log) as early as 1982, using a commercially available database management system to provide remote-

Table 2. Usage statistics for the IUE Archives (August 1990)

		Total*	Annual* rate	% annual	% total
12 yr	VILSPA – Tape	34 600	2880	6.8	15.5
2 yr	VILSPA – ULDA/USSP	49 000	24 500	58.3	21.9
12 yr	NSSDC – Tape	21 825	1820	4.3	9.8
3 yr	NSSDC – Network	6025	2010	4.8	2.7
12 yr	RAL	19 800	1650	3.9	8.9
10 yr	RDAF	72 000	7200	17.1	32.3
10 yr	CURDAF	20 000	2000	4.8	9.0

* These columns give the number of spectra delivered from the IUE Archive (direct delivery to Guest Observers is not included; this implies that each IUE spectrum has already been delivered 4.7 times).

Key to Table 2

The different modes of access available to the IUE users indicated in Table 2 signify (archive retrieval rates indicated as spectra/day):

ULDA/USSP (68 spectra/day)
- Distributed (National Hosts) low-resolution corrected data-set (in physical units).
- Data storage: highly compacted, disk-resident; remotely accessible only.
- Data transfer: triggered directly by the user via special distributed software package.

RDAF (34 spectra/day)
- NASA special arrangements at data-analysis facilities.
- Data storage: mass disk storage with partial archive.
- Data transfer: none, data delivery locally to user disk for use at the Regional Data-Analysis Facility at GSFC.

CURDAF (11 spectra/day)
- NASA special as RDAF in Boulder.
- Data storage: tapes with partial archive.

NSSDC (10 spectra/day)
- NASA, normal de-archiving.
- Data storage: tapes and mass-storage device.
- Data transfer: tape mailing and retrieval from online disks for copying by the user within a time limit from NSSDC to user institute.

VILSPA (10 spectra/day): ESA normal de-archiving.
- Data storage: tapes.
- Data transfer: tapes by mail.

RAL (5 spectra/day): SERC normal de-archiving.
- Data storage: tapes.
- Data transfer: tapes and sometimes electronic-mail delivery (UK only).

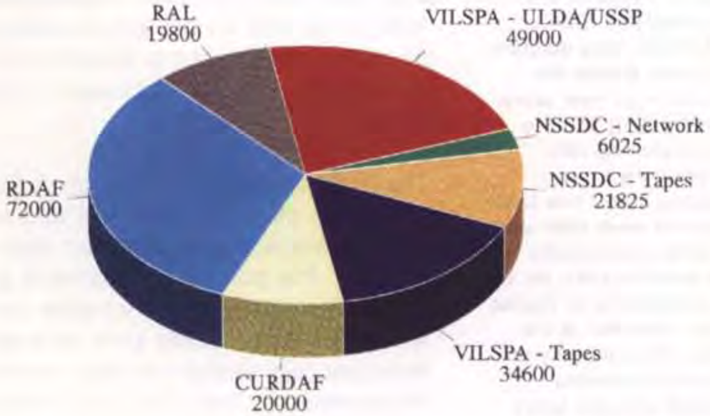

Figure 3. IUE data retrievals supported by the three Agencies up until August 1990, reflecting the much greater than expected usage of archived data (see also Table 2). Note that the more modern data-retrieval schemes – ULDA, RDAFs and NSSDC Network – have already supported more de-archival activities than the original procedures (tapes).

interrogation and other typical archive functions.

(ii) The creation and organisation of a distributed-host system, known as the Uniform Low-Dispersion Archive (ULDA), and its Software Support Package* (USSP), for the low-dispersion data. This has proved to be an extremely efficient archive-usage support mechanism, as Table 2 confirms.

(iii) The latest innovation at Villafranca is the implementation of a Structured Query Language (SQL) for interrogating the IUE Merged Log with complex queries, even from remote sites.

Although, as Table 2 reflects, all three distribution centres have developed similar procedures for coping with the growing pressures from archive users, a major fraction of the de-archiving in recent years has been supported by two mechanisms.

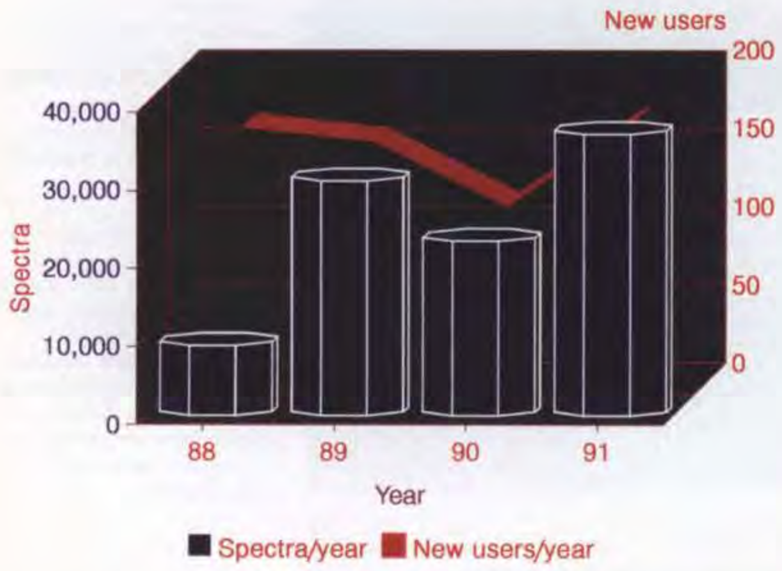

Figure 4. Usage of the ESA-developed IUE ULDA/USSP. This diagram, which also shows the registration of new users (currently 600) and the total de-archival rate supported each year, illustrates that it has taken somewhat more than one year (first installations were made in 1987) for the user community to realise the full potential of the facility. The similarity of the trend in spectra retrieved and new users registered illustrates that first time users are generally retrieving more data that they can practically handle (see Fig. 5 also).

The ULDA and the RDAFs together support 80% of the total annual data requests for the IUE Archive, and it is interesting to note the different approaches followed in the two cases.

The RDAFs (Regional Data-Analysis Facilities) have been developed by NASA and support data retrieval and analysis at two sites in the USA. The scientist is required to go physically to the site, where he/she can work with specialised analysis tools, although a remote-access service has also recently been implemented. In the USA, data retrieval without visiting the archival site was only previously supported by the NSSDC, which has served to maintain the strongly centralised nature of the archives whilst complicating data access for those scientists not directly supported by the Agency responsible for the Project.

On the other hand, the ESA solution of providing the ULDA/USSP represents a diametrically opposite approach to servicing the high degree of interest in the data. By exploiting the fact that the national communications infrastructure is frequently of better quality and always considerably less costly to use than international communications services or personal travel to the Archive centre, the ULDA/USSP represents a low-cost solution for both user and supplier. The main interest of the scientist is in acquiring the data in a convenient physical-unit format, often preferring to use their own tools for the detailed scientific data analysis at their home institutes.

The compact IUE Low-Resolution Data Set (ULDA) has now been delivered to 17 national hosts, which serve the astronomical communities of 22 countries, extending well beyond the borders of the thirteen ESA Member States. The modular structure of the ULDA has made it possible to adapt the archival support to the particular facilities available in each country. The total amount of support required at each national host is limited to disk space and connection to national networks for data retrieval. Data selection and delivery are controlled by the interested scientist, without interference from either the host or the IUE Project.

The Villafranca IUE Observatory, as the principal centre, limits its role to the release of new (controlled) versions of the ULDA (last issue version 3.0), the collection and redistribution of usage information, which is collected automatically (also available to the users themselves), and trouble-shooting for the national-host installations.

The ULDA's modular structure and strict software-development controls have allowed host-specific data formats to be introduced with minimal effort, as well as the development of new versions of the USSP suited to more modern operating systems, such as UNIX (the original USSP was designed to operate primarily under VMS) without major problems.

The major strength in the concept underlying the IUE ULDA/USSP is the fact that it is not

* The USSP was developed by the ESA IUE Observatory, in collaboration with Trieste Observatory, Rutherford-Appleton Laboratories, and the Space Telescope European Coordinating Facility (ECF).

a monolithic structure requiring a complex learning process by the user: it is essentially maintenance free, since all file-handling is arranged by the software; it has been shown to be sufficiently flexible that major operating-system changes can be handled with relative ease; it does not require a large staff to support the extremely high data-retrieval rates (68 spectra per day; Table 2); it does not impose a particular data format; it allows scientists in the Developing Countries to have access to modern scientific data in a way that is well matched to the local conditions at a time when their own resources would make this very difficult.

The ULDA/USSP example demonstrates the advantages of distributed systems. The many computers of a distributed system can be exploited for increased performance (overlapping execution). Strategic copies of critical components can be made to increase availability and improve fault tolerance. To balance the load and reduce access times, components can migrate in a distributed system, so that new operational needs can be satisfied more easily and rare expertise can be duplicated.

Like ESA establishments and national centres, the ULDA/USSP National Hosts are geographically distributed. The considerable advances in telecommunications, software for computer sharing, and the widespread availability of networking interfaces make distributed systems a cost-effective resource by utilising both the local expertise and infrastructure which, in the case of IUE, have been built up over more than a decade.

The high usage figures certainly suggest that the concept has fulfilled a latent need in the scientific user community in general, and in the astronomical community in particular.

Conclusion
In examining the need to preserve astronomical data and to them more readily accessible to the scientific community, it has been shown that the IUE Project has played a pioneering role in striving to meet these requirements. Some differences in approach between the solutions adopted by various agencies involved in the IUE Project have also been highlighted. Other ESA missions have faced and will face similar problems in the future.

The major lessons with IUE of:
(i) the extreme importance of reduced data in physical units, compared to raw data sets
(ii) minimum project interference with the actual retrieval process
(iii) careful quality control over the output products
(iv) maintenance of scientific expertise in the form of direct use of the data by scientific staff for up-to-date research, and
(v) close contact with the scientific user community
should not be overlooked.

Distributed systems are now firmly part of the computer and communications industry, facilitating widespread availability of archives through high-performance communication networks. Even though the IUE experience has shown that major activities can be undertaken without excessive cost, it has to be realised that no data archive can be exploited effectively today without a good network facility, and that adequate financial support is required to supply and maintain such a service.

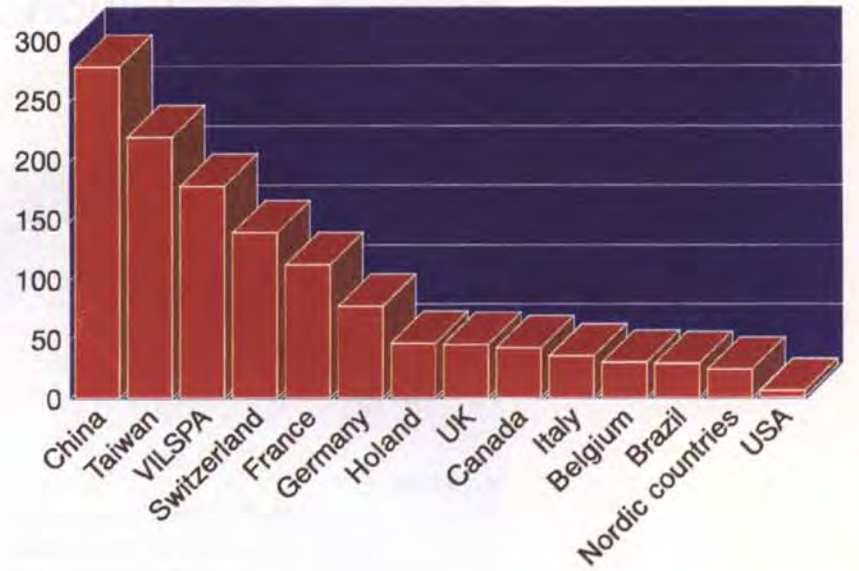

Figure 5. Histogram of the number of spectra de-archived per user per year from the ULDA/USSP. For clarification of the apparent trend, it must be noted that in China, user access is via floppy disk and visits to the National Host rather than via networks. The installation in Taiwan is very recent and is heavily used for education, while Villafranca is host to the ESA IUE Observatory. The remarkably similar rate of some 45 spectra per user per year for the other countries probably reflects the research capacities of the individual astronomers. This rate is therefore probably fairly representative of the way in which astronomical archives can be expected to be used in future.

Electric-Propulsion Activities in Europe

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Electric Propulsion in Europe has reached a strong level of maturity but considerable effort is needed to maintain competitiveness with the rest of the World. The USA and Japan have been flight testing various electric-propulsion technologies for several years and are about to use some of them operationally on their satellites, while the USSR already has some ten years of in-orbit experience with these kinds of devices. In Europe the first flight test opportunity for electric propulsion will occur later this year, and the coming years will be crucial if Europe is to remain competitive in this challenging technology.

Introduction

The principal attraction of electric thrusters for the propulsion of spacecraft lies in their high exhaust velocity, which is normally one order of magnitude or more greater than that of chemical thrusters. The corresponding reduction in the propellant mass that must be carried by the spacecraft permits the inclusion of a greater portion of useful payload, and/or the extension of mission durations, or even the achievement of space missions inaccessible with conventional chemical rockets.

We can define electric propulsion as 'the acceleration of a propellant by electrical heating and/or by electric and magnetic body forces'. This definition may be further subdivided empirically into three distinct, but not necessarily isolated, concepts:
- electrostatic propulsion (ion thrusters, FEEP)
- electrothermal propulsion (resistojets, arcjets), and
- electromagnetic propulsion (MPD thrusters).

The operating range of electric-propulsion thrusters is illustrated in Figure 1, while Table 1 shows typical specific-impulse, thrust and power-consumption values for both chemical and electrical propulsion.

Table 1. Operating range of electric-propulsion thrusters

Specific Impulse and Exhaust Velocity		
Chemical Propulsion		
Monopropellant Hydrazine	230 s	(2256 m/s)
Storable Bipropellants	310 s	(3041 m/s)
Cryogenic Propellants	450 s	(4414 m/s)
Electric Propulsion		
Electrostatic (electron bombardment)	3000 s	(29430 m/s)
Electrostatic (radio frequency)	3200 s	(31392 m/s)
Electrostatic (field emission)	6000 s	(58860 m/s)
Electrothermal (multi-propellant resistojets)	130 ÷ 150 s	(1275 ÷ 4905 m/s)
Electrothermal (hydrazine PACT)	300 s	(2943 m/s)
Electrothermal (pure arcjet)	600 s	(5886 m/s)
Electromagnetic	3000 s	(29430 m/s)

Thrust	
Chemical Propulsion:	0.5 N to thousands of Newtons
Electric Propulsion:	0.1 mN to 2 N
Electrical Power Consumption	
Chemical Propulsion:	Negligible (a few watts for valve actuation)
Electric Propulsion:	1 to 60 W per mN of thrust

Although the benefits offered by electric propulsion have long been recognised, the technology's history has been always been punctuated by ups and downs, with mission managers often quite reluctant to entrust their mission's success to this new technology.

During the sixties and until the mid-seventies, several European laboratories were actively investigating different electric-propulsion concepts, but this effort did not result in any flight experiments and so, largely as a result of budgetary restrictions, most of the development programmes in Europe were de-scoped or terminated. Electric propulsion failed then to achieve operational status and to break the vicious 'no flight/no development – no development/no flight' circle.

The situation only started to improve in the mid-eighties, when the increased masses and lifetimes of the satellites being developed, together with the greater powers available on-board, made the use of electric propulsion even more attractive. Work on ion

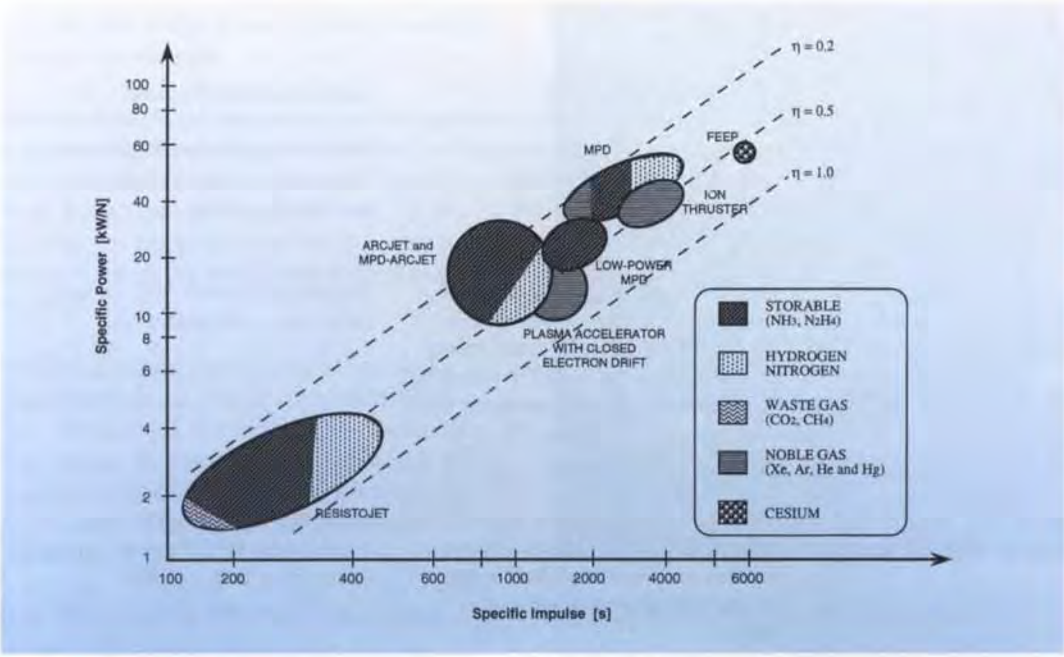


Figure 1. Operating ranges of electric-propulsion thrusters

engines and arc jets intensified, the use of 'safer' propellants (like noble gases) was pursued, and R&D and testing efforts gained momentum in Germany, the UK, Italy and France.

The current situation in terms of the most important European electric-propulsion activities is as follows:

- One flight opportunity has already been secured, with the RITA experiment on the Eureca-1 mission, to be launched this summer.
- An operational Ion Propulsion Package will be flown aboard ESA's Artemis satellite, to be launched in 1995, for which the RITA and the UK systems will perform the north–south station-keeping manoeuvres.
- Several development programmes are underway for ion engines (UK and Germany), arc jets and MPD (Italy and Germany), and the FEEP system (France and Italy).

The state of the activities in the rest of the World shows that there too electric propulsion is highly rated as a very promising propulsion technology. Electric-propulsion systems have been used in the USSR for something like ten years (plasma accelerators with closed electron drift) and will very soon become operational on American (Rocket Research Low-Power Arcjet, Hughes 13 cm Ion Thruster) and Japanese satellites (Melco Corporation Kaufman-type Thruster, Low-Power Arcjets and MPD).

Table 2 provides an overview of the principal electric-propulsion programmes presently being developed worldwide. Clearly, European industry needs to take appropriate action if it is not to be left behind by the strong international competition.

Electrostatic propulsion

In electrostatic propulsion, electric energy is used to ionise a propellant (nowadays usually xenon). The ions are then expelled at high velocity by an electric field. An electron emitter, called 'neutraliser,' is used to neutralise the ion beam.

Ion Propulsion Assembly for Eureca

The RIT-10 thruster, developed by MBB (D), is characterised by a discharge chamber diameter of 10 cm and is able to produce a thrust of up to 15 mN. This thrust level is ideal for north–south stationkeeping of geostationary satellites with an in-orbit mass of up to 2000 kg.

The RIT Assembly (RITA) is going to be tested as one of the payloads aboard Eureca-1, which will be put into orbit by the Space Shuttle 'Atlantis' next July. About 2000 h of operations at different thrust levels are planned, the exact operating cycles being determined by the availability of power, which must be shared with the other payloads. The flight hardware (Fig. 2) consists of the thruster, the neutralizer, the power supply and control unit, the radio-frequency generator, the xenon propellant tank and the flow-control unit. Due to the short contact periods between Eureca and the ground station, the RITA experiment is designed to operate fully automatically (Table 3). It was ground-qualified and delivered by MBB (D) to the Eureca prime contractor in 1989.

Table 2. Overview of principal electric-propulsion programmes

	Electrostatic Thrusters	Electrothermal Thrusters	Electromagnetic Thrusters
Europe	**RITA-10 ready for flight test on Eureca-1 (1992).** RITA and UK-10 ion thrusters operational on Artemis satellite.	Development of low-power-arcjet systems in Italy and Germany. Flight tests proposed for the Eureca-3 mission (1987).	Different power-level MPD thrusters developed at laboratory level in Germany and Italy.
USA	Two qualification models of the Hughes 13 cm ion thruster ready to begin the ground qualification phase.	**1.8 kW hydrazine thruster (Rocket Research Co.) built for use on the GE Astro Space Series 7000. Ready for flight in 1993 on AT&T's Telstar-4.** 26 kW ammonia arcjet developed for a flight experiment on the P91-2 spacecraft (Phillips Lab.)	Different power-level MPD thrusters developed at laboratory level.
Japan	**20 mN ion thruster test on the Engineering Test Satellite (ETS) VI, in 1993.**	Development of low-power-arcjet systems for NSSK of geosynchronous satellites and reaction-control systems for platforms and spin-stabilised satellites.	**EPEX flight test of 1 kW class quasi-steady MPD thruster, onboard Space Flyer Unit 1 (1994).**
Russia	Development of ion thrusters with surface ionisation, with volume ionisation and colloid thrusters.	Electric-heating thrusters tested on Meteor-Priroda and Resurs-0 satellites.	**Stationary plasma thrusters with closed electron drift used for more than 10 yr onboard Soviet satellite (Meteor).**

Figure 2. RITA flight hardware (MBB/ERNO) mounted on the standard support plate of Eureca

Table 3. Characteristics of the RITA engine for Eureca-1

Thrust Level (mN)	5	10	12.5	15
Beam Accelerating Voltage (V)	1600	1550	1530	1500
Total Mass Flow Rate (mg/s)	0.18	0.32	0.38	0.44
Total Specific Impulse (s)	2780	3130	3290	3410
Power Input (W)	220	390	478	586

Ion Propulsion Package for Artemis

The Advanced Relay and Technology Mission, Artemis (previously known as Sat-2), is a communications technology demonstration satellite for advanced data-relay and land-mobile applications which is currently being developed by ESA within the Data Relay and Technology Mission (DRTM) Programme.

The Artemis baseline programme element consists of the development and in-orbit operation of a single geostationary satellite (Fig. 3), with launch currently planned for 1995.

The Ion Propulsion Subsystem (IPS) for Artemis has been conceived and sized to support the full 10 years of North/South Station-Keeping (NSSK) that is required for commercial telecommunications missions. This is being achieved by the introduction of both functional and technological redundancy, allowing the subsystem to execute daily station-keeping firings of up to 3 h at both orbital nodes, for a period of 10 years excluding eclipse seasons (equinox).

Both ion propulsion technologies developed in Europe – the UK-10 and the RIT – are planned to be used on Artemis as a fully operational and redundant system. One RIT and one UK-10 will be mounted side-by-side on the north and south faces of the satellite and operated alternately. The design for

Artemis can subsequently be used on any commercial satellite.

For the Artemis application, the RITA as designed for the Eureca Platform will be simplified and its mass reduced. The thrust level is also being increased, from 10 to 15 mN, the expected total input power for this level of thrust being less than 600 W (Fig. 4).

The breadboard-model phase has been completed at the end of 1990 and MBB is now working on the fabrication of engineering models for lifetime tests, which will be performed at ESTEC, and on engineering qualification models for the qualification of the units.

The British UK-10 IPS (Fig. 5) has been developed for two thrust levels, namely 10 and 25 mN. The lower thrust is appropriate to drag compensation on large remote-sensing spacecraft, whereas the latter is suitable for NSSK on communications satellites such as Intelsat-VII, and has been chosen for the Artemis application (thrust level 18 mN).

The engineering models of UK-10 thrusters under test were manufactured by RAE (UK), but transfer of this process to Matra-Marconi (UK) is now taking place.

In the same time frame, a separate RAE mission demonstrating orbit-raising or inclination changing is now under consideration. An in-depth study is also underway at RAE into an atmospheric-drag compensation application, and at Culham a small upper stage using the UK-10 IPS (the Argos concept) is being designed.

Figure 3. Artist's impression of the Artemis satellite (Courtesy of Alenia)

Figure 4. RIT-10 thrusters being fired (Courtesy of MBB/ERNO)

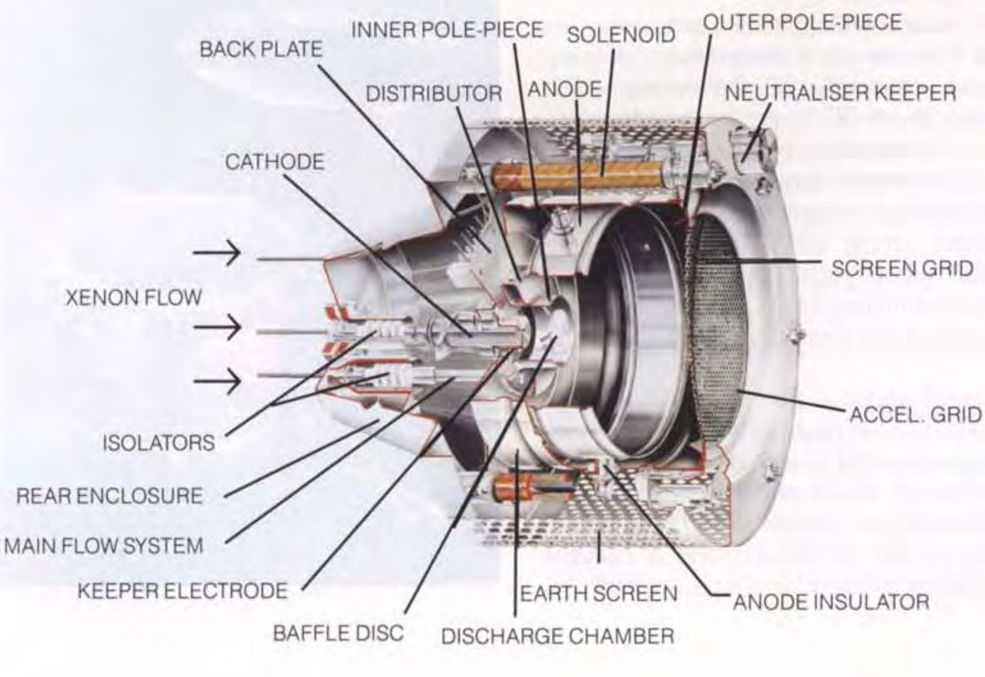


Figure 5. Schematic of UK-10 ion thruster (Courtesy of RAE and Matra-Marconi)

Figure 6. RIT neutraliser (Proel) undergoing life-testing

Elsewhere, Proel (I) has developed a hollow-cathode neutraliser capable of operating with the German RIT-10 ion thruster. This device, which is undergoing lifetime testing at ESTEC, has presently logged more than 10 000 h of operation (Fig. 6). Following the breadboard phase, Proel has been given a contract in the context of the Artemis reference mission to undertake a qualification programme on this neutraliser.

Ion Thrusters for Primary Propulsion Applications

As opposed to the concept of 'secondary' electric propulsion with applications like NSSK and thrust levels of the order of 10–30 mN, 'primary' electric propulsion requires thrusts one order of magnitude higher, i.e. 200–300 mN. The goal is to use these thrusters on missions with extremely high delta-V (several km/s), such as interplanetary missions.

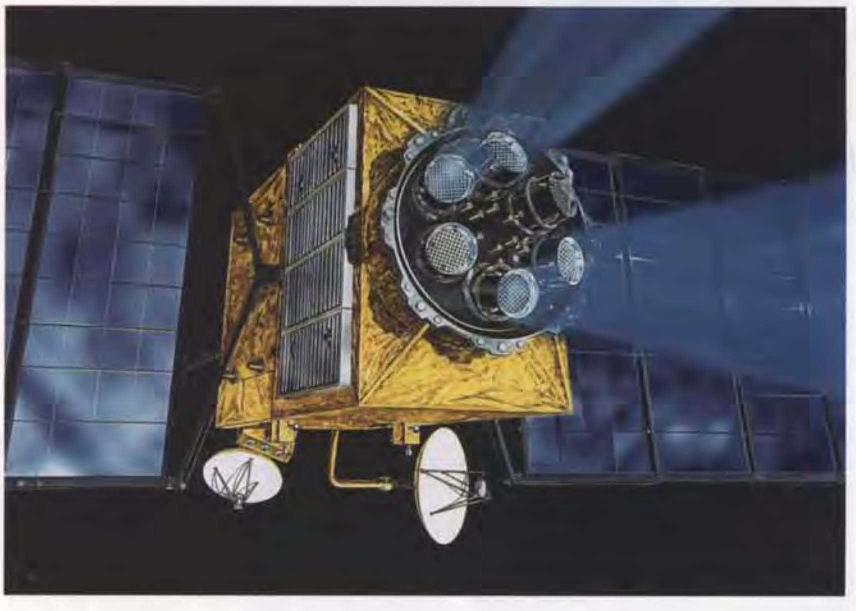


Figure 7. Primary propulsion by means of ion thrusters; the Agora mission

In 1983, when primary electric propulsion entered ESA mission considerations (for the 'Agora' project; Fig. 7), the already optimised 35-cm RIT-35 engine (which used mercury as propellant) had been redesigned, built as a laboratory prototype, and later equipped with an enginering-model dished-grid system. Under ESA/ESTEC funding and MBB subcontracts, the engine was performance-mapped with mercury, argon and xenon at Giessen University (D).

In the same period in the United Kingdom, in parallel with the development of the UK-10 IPS, it was decided to embark on the design of a scaled-up version of the thruster, for primary-propulsion applications. The initial aim was to meet the requirements of possible interplanetary missions and so a nominal thrust level of 200 mN was selected, using xenon propellant, leading to a thruster diameter of 25 cm. The laboratory version performed exactly as predicted and so an engineering model was then designed and manufactured (Fig. 8).

The activities on primary propulsion were then left 'pending' for about two years, but it has recently been agreed to continue this work on the basis of European cooperation involving Germany, the United Kingdom and Italy. A new thruster is being developed under ESA funding. The so-called 'ESA-XX' will be the design product of both German and British experience accumulated in this field, the idea being to make use of the radio-frequency electrodeless discharge of the RIT concept together with the simple and reliable grid system developed for the UK-25, and Italy providing the high-power electronics.

Field-Emission Electric Propulsion (FEEP)

In 1972, ESA began the development of an advanced concept of electric thruster, based on the field-emission principle. Under the action of an electric field, the free surface of a liquid conductor is distorted into a series of cones (Taylor cones). If the electric field is sufficiently strong, ions are spontaneously created at the tips of the cones and accelerated away, thereby producing an ion beam directly from the liquid phase with a very high power efficiency (98–99 %).

Since 1972, FEEP has evolved from the simple pin emitter, through linear arrays of stacked needles, to high-efficiency solid-slit emitter. The liquid metal most commonly

Figure 8. Engineering model of UK-25 for primary propulsion (Courtesy of RAE)

used is caesium, but several other metals and alloys have also been tested. Emitter modules 1, 3, 5 and 8 cm long have been successfully tested. Table 4 summarises the characteristics and performance of a typical FEEP emitter module (Fig. 9).

With FEEP, the thrust can be switched on or off instantaneously and can be throttled continously from 0 to 120% of its nominal value. Any desired thrust level can be provided by simply stacking single emitter modules in parallel. Recently, the ability to operate with FEEP in pulsed mode has been demonstrated, opening up the possibility of using this system for new domains of applications, such as extremely fine pointing or positioning of spacecraft (space interferometry, gravitational-wave research missions, etc.).

In 1984, the system was given for industrialisation to SEP (F). In recent years, the same company and Centrospazio (I), acting as a subcontractor, have been working on the system under ESA contract (TRP). Testing with both operational modes – continuous and pulsed – are continuing with the aim of conducting a space test in the 1990s.

Table 4. Performance data for a typical FEEP emitter module

Emitter Length	8.0 cm
Emitter Depth	2.4 cm
Emitter Thickness	0.8 cm
Slit Width	1.1 μm
Thrust per Unit Length	0.3 mN/cm
Power-to-Thrust Ratio	55 W/mN
Specific Impulse	60000 Ns/kg
Mass Efficiency	60%
Transmission Efficiency	99%
Power Efficiency	98%

Figure 9. FEEP emitter being fired

Electrothermal propulsion

In electrothermal propulsion, electrical energy is used to heat a propellant gas, which is then accelerated by gas-dynamic expansion in a nozzle. The propellant flow may be heated in different ways: by passing it over an electrically heated solid surface ('resistojets'), by passing through an arc discharge ('arcjets'), by high-frequency excitation, and also by other methods.

Resistojet Technology

Working under ESA contract, MBB/ERNO (D) has developed a multi-propellant resistojet, using GN_2, CH_4 and CO_2. The goal of the study was to design and develop a long-life resistojet and to conduct about 300 h of firing tests. The power control unit used to regulate and control the platinum–rhodium heater element showed excellent operational behaviour. Focal points for further development activities in this field were also highlighted in the contract.

Arcjet Thruster Technology

In 1986, ESA started a comprehensive programme for the development of arcjet systems. The first activity undertaken as a part of this programme was the development of a 15 kW arcjet, which was assigned to BPD (Colleferro, I), with IRS (Stuttgart, D) acting as a subcontractor. Moderate power arcjets are being developed as a potential advanced technology upgrade for the Columbus Free-Flying Laboratory's propulsion system for orbit-change and orbit-maintenance purposes.

More recently, a new project has been set up for the development of a low-power arcjet in the 1 kW class for European communications satellite station-keeping and other auxiliary propulsion uses (Table 5). The use of decomposed hydrazine arcjets may permit very efficient use of propellant onboard future spacecraft, particularly in combination with 'dual-mode' propulsion systems, in which a single feed system (tank, pipes and valves) can be shared by all of the satellite's propulsion systems (upper-stage engine, attitude and orbit control monopropellant

Table 5. Typical characteristics of a low-power arcjet for the north-south stationkeeping of geostationary satellites

Power	1.80 W (input to PCU) 1.62 W (input to thruster)
Specific Impulse	520 s (mission average)
Thrust	18 mN
Feed Pressure	20 ÷ 15 bar, blowdown mode
Total Weight	3 kg (approximate)

Figure 10. The two low-power arcjet thrusters being investigated at BPD and Centrospazio, in Italy

thrusters, NSSK low-power arcjets), thereby making possible very large mass savings.

The ESA contract for the development of the low-power arcjet was initially awarded to BPD, within the Agency's ASTP Programme, with Centrospazio (I) acting as a subcontractor. Test activities included parametric performance mapping using nitrogen, hydrogen, ammonia and mixtures of these gases, but were focussed on testing catalytically decomposed hydrazine and on endurance testing (Fig. 10). The power level selected for the propulsion system was determined by considering mission opportunities and related power constraints existing within the European programmes, including the proposed in-flight arcjet demonstration (DIVA).

The DIVA experiment (Fig. 11) has been proposed as one of the ESA Columbus Precursor Flight experiments and could be scheduled for launch on the Eureca-3 platform in 1997. It involves a flight test of a 1 kW-class arcjet system to demostrate its readiness for flight applications and will serve as a precursor to a mission currently under study. The experiment is expected to: demonstrate the operational capability and on/off cycling characteristics needed for NSSK; verify system operating procedures; measure and characterise propulsion system/spacecraft interactions; and validate ground-test data.

Figure 11. The Italian-developed low-power arcjet proposed for a flight test on Eureca-3, (the Diva experiment)

The development of the system for the low-power arcjet has begun this year as a continuation of the earlier ASTP activity, and will be funded by the Italian Space Agency as part of its national programme. Phase-1 of the programme will last 18 months and will include a system study to define missions first applications in detail, mission requirements, and propulsion system configuration and subsystem requirements.

Power levels are expected to be between 0.5 and 1.5 kW, and the components to be considered include the arcjet, gas generator, power-conditioning unit (PCU), connecting cable, propellant storage and feed system, propulsion-system controller and diagnostics. The design, fabrication and testing of a breadboard model PCU is also included in this programme. Finally, the planning for the engineering model and qualification phase will be established.

In Germany also, since the early seventies, a broad spectrum of arcjets has been studied, principally at the University of Stuttgart's Institute of Space Systems (IRS). Within the framework of a national development programme, it has designed and built a 1–2 kW arcjet for hydrazine propellant, working together with MBB/ERNO (D).
A prototype thruster (Fig. 12) and dedicated gas generator are being investigated with an H_2/N_2 gas mixture. Hydrazine testing will be performed at an MBB/ERNO facility in Trauen (D).

Two flight opportunities are envisaged for the German low-power arcjets. One such flight test, called Artemis (Arcjet Test Mission), is proposed for a Columbus Precursor Flight on the Eureca Platform, and is currently being contemplated by ESA for the Eureca-3 mission. It offers the possibility to demonstrate the effectiveness of an arcjet engine in the 1 kW-class range. In addition, one of AMSAT's OSCAR (Orbital Satellite Carrying Amateur Radio) satellites (P3-D), which will be launched on the second Ariane-5 test flight in 1996, should carry an IRS thermal arcjet for station-keeping. Ammonia will be used as the propellant for this 700–800 W arcjet. A diagnostic package is also foreseen, to observe and control thruster performance.

For the medium power level (1 N, 15 kW-class thrusters), a water-cooled laboratory model and a thrust stand have been built at IRS under subcontract to BPD, with ESA funding, and completed last year. For the 10–30 kW range, various versions of a modular water-cooled laboratory model have been tested with various propellants for basic research purposes, and as prototypes for the radiation-cooled thermal arcjet which is shown in Figure 13 (optimisation of the arc conditions within the nozzle region is of great importance for the development of a thermal arcjet).

In the past, little experience had been accumulated with thermal arcjets in the power range above 30 kW. A development programme has therefore been started, in 1989, to investigate in a first step the possibility of achieving higher exhaust

Figure 12. The German low-power arcjet thruster (Courtesy of MBB/ERNO and IRS)

velocities by raising the power level. A first water-cooled experimental model of a high-power thermal arcjet has been built and tested at IRS in Stuttgart. It could be demonstrated that even with a water-cooled model, high exhaust velocities of up to nearly 15 000 m/s are achievable with hydrogen propellant. Sufficiently high efficiencies are also expected with a radiation-cooled device, which is foreseen as the next step.

Electromagnetic propulsion

In electromagnetic propulsion, electrical energy is used to create a neutral plasma in an arc discharge. The plasma is then expelled at high velocity by the interaction of the discharge current with the magnetic field. A typical application of this principle is Magneto-Plasma-Dynamic (MPD) thrusters.

MPD Thruster Technology

In Germany, high-power self-field MPD thrusters delivering from 50 kW to 1 MW have been developed at IRS under USAF cooperation grants and with additional German funding. The MPD-thruster development programme has been continued at IRS in order to provide the basis for future thruster type selection.

Nozzle-type MPD thrusters of various throat diameters have been studied experimentally

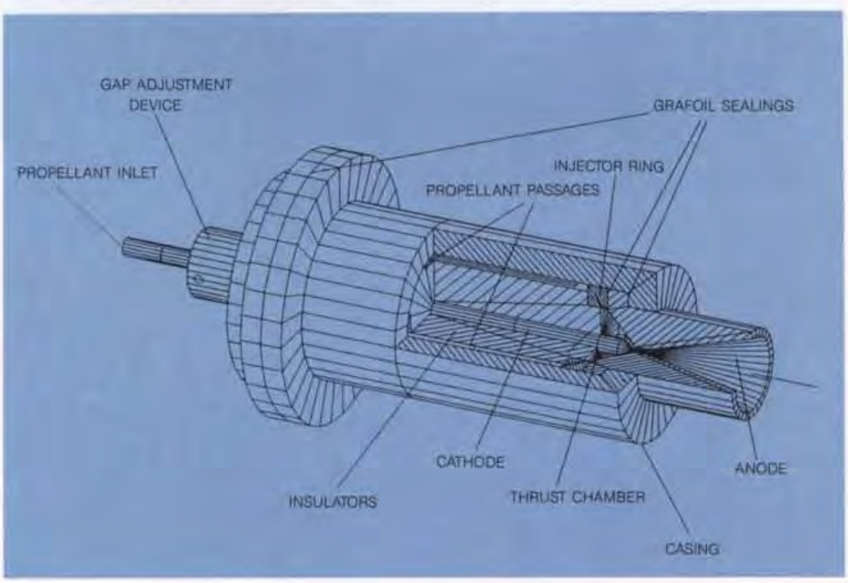


Figure 13. Medium-power radiation-cooled arcjet (Courtesy of IRS)

and theoretically during the last years. To investigate the influence of anode temperature on thruster performance, a so-called 'Hot-Anode Thruster' (HAT) has been built at IRS, with a radiation-cooled tungsten anode (Fig. 14). Cylindrical MPD thrusters have been developed to increase the current level at low voltages and thus achieve high exhaust velocities at megawatt power levels.

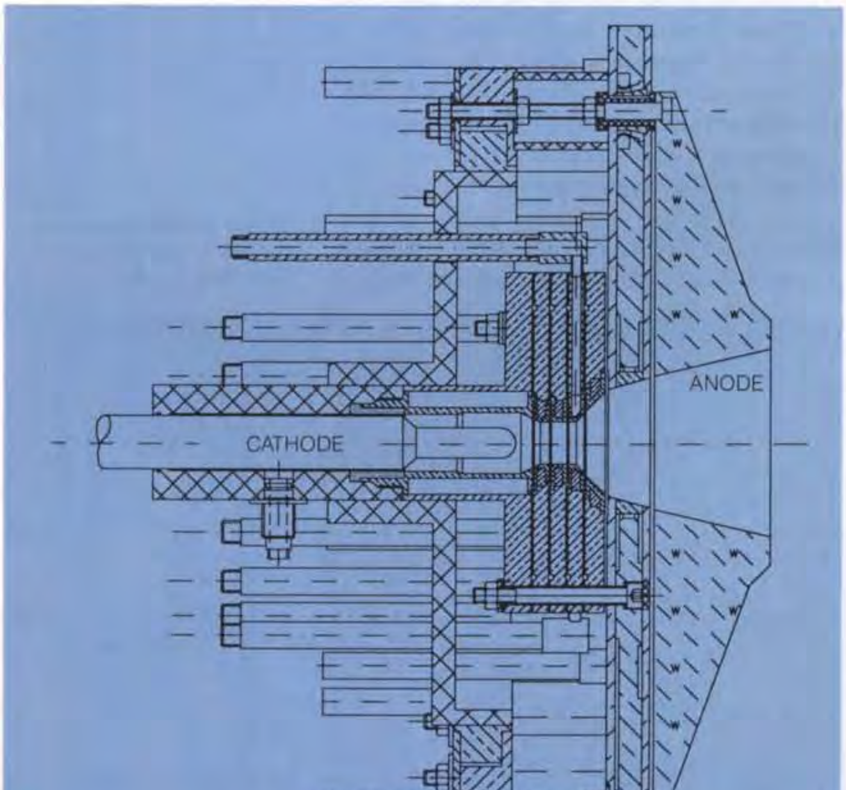
In Italy, ESA-sponsored activities on MPD propulsion were initiated in the early 1980s. BPD took over the role of prime contractor, with the Universities of Pisa and Rome serving as subcontractors. In subsequent years, the focus of industrial development gradually shifted towards shorter-term concepts, such as arcjets, and as a result responsibility for this line now lies entirely with the group in Pisa (Centrospazio). The University of Rome provides support in diagnostic development for solid-propellant MPD thrusters operating in the range of few megawatts of instantaneous power.

Current MPD activities at Centrospazio involve a series of tests on a family of gaseous-propellant devices. This type of device is intended for quasi-steady operation, simulating continuous operation at multi-megawatt power levels over periods of a few milliseconds. The principal objective of this research is to improve understanding of the basic physical phenomena involved in pure magneto-plasmadynamic acceleration and to provide information relevant to the future development of high-power steady-state MPD thrusters. Tests are currently being carried out in a quasi-steady discharge mode, also with artificially heated electrodes, to reproduce the thermal conditions characterising a steady-state thruster.

This project is presently funded under the ESA/ASTP-3 programme.

In the framework of a collaboration with the Electric Propulsion Laboratory of the University La Sapienza of Rome, with the sponsorship of the Italian Space Agency, diagnostic studies of the plume using intrusive techniques started last year (Fig. 15).

Figure 14. Schematic and test of the hot-anode MPD thruster (HAT) developed at IRS



Non-propulsive applications

As a spin-off of the experience gained with plasma thrusters, two plasma wind tunnels have been built at IRS for the qualification of thermal-protection materials for re-entry vehicles. Several plasma generators are under development for this application. At present, both wind tunnels are equipped with magneto-plasmadynamic sources (Fig. 16). With a wind tunnel equipped with an MPD generator, the first phase of re-entry – high specific enthalpy and low stagnation pressure – can be simulated.

Most of the qualification experiments for the thermal-protection system for Europe's Hermes spaceplane, for German capsule projects, and for the Huygens probe's entry into the atmosphere of Titan have been performed in these plasma wind tunnels. A development programme for a plasma source that can be used for the simulation of Martian atmospheric conditions is foreseen.

Between 1978 and 1985, three RIT engines were used for materials- processing experiments at Giessen (D). Between 1986 and 1988, the University built six 10 cm 'RIM-10' engines for their own test purposes and for selling to industry.

Figure 15. Diagnostic study of the plume in a ring anode MPD thruster at Centrospazio

Since 1988, the Pfeiffer/Balzers company in Wetzlar (D) has been responsible for RIM engine industrialisation, manufacture, and sales. The main advantage of radio-frequency ion sources for materials processing is their ease of operation, even with reactive gases.

From 1977 until 1986, several neutral-particle injector generators were investigated, optimised, and performance-mapped at Giessen University (D), for nuclear-research applications. Due to the high reliability and the very simple discharge power supply of the largest generator, namely the 25 x 50 cm hexagonal ion surce 'RIG-HEX', the MPI fusion centre in Garching, near Munich (D), decided to equip its new tokamak machine 'Asdex-Upgrade', with five of these generators; another three are planned for the KFA nuclear center at Jülich (D).

In the UK, a 1 cm-long FEEP emitter manufactured by ESTEC is being used as the emitting core of an ion machine produced commercially for surface analysis.

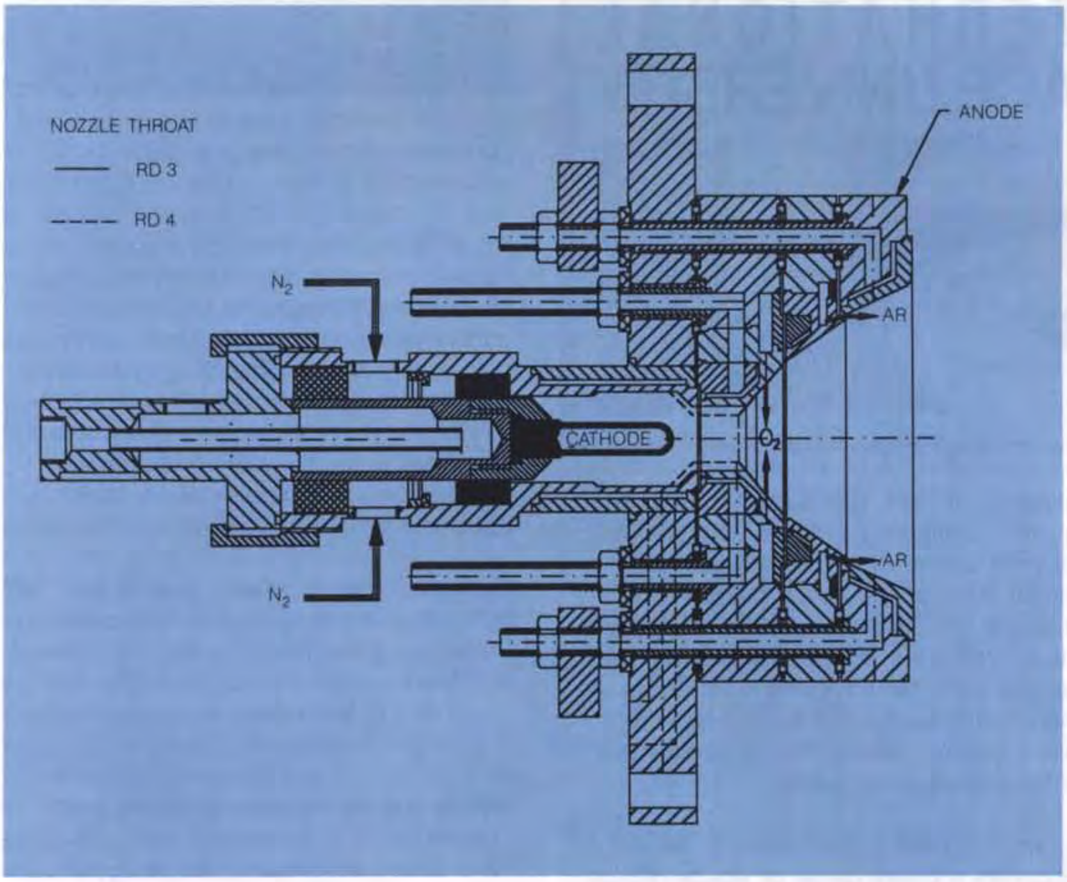


Figure 16. Schematic of a plasma source for wind-tunnel applications at IRS

ESA and the International Space University (ISU)

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The International Space University, or ISU, was set up in 1987 by a group of young American and Canadian graduates with the aim of providing an international programme of higher education devoted to research and development in the space field. A non-profit-making body, the ISU is the first institution of its kind and is intended particularly for young graduates who are already in the early stages of their professional careers. They may come from technical, scientific or administrative backgrounds, but have in common an excellent academic record, managerial potential, and above all an exceptionally strong interest in space.

The intensive teaching programme offered to students in the course of summer sessions covers a broad range of space-related disciplines. This multidisciplinary approach is one of the key features of the ISU, helping students to fully appreciate the complexities of managing large space projects, especially in an international context.

This international approach is another key feature of the ISU. While the students selected usually come from about thirty countries, the teaching staff is also made up of leading experts – academics, researchers and industrialists – from the international space community. This professional and cultural diversity represents a considerable challenge in terms of the creation of an educational programme, but is also doubtless one of the reasons for the ISU's considerable success.

How is the University organised?
The ISU was set up and operates largely thanks to sponsoring, with various levels of financial support for its development coming from a number of private and public-sector industrial undertakings and also government bodies, space agencies and academic institutions.

To define and implement ISU policy, a Board of Directors (representing a number of sponsors) manages the University's administrative and financial affairs, with the help of specialised committees. The Board also determines basic strategy for the ISU as well as future development plans, and is supported in this by a Board of Advisors made up of senior representatives of governments, industry and research bodies.

Finally, the ISU has a team of executive staff, whose offices are currently located in Cambridge (near Boston) in the USA. This team is responsible for implementing ISU policy and for administrative arrangements.

Where are the summer sessions held?
The first ISU summer session was held at the Massachusetts Institute of Technology (MIT) in Cambridge (USA). It was attended by 104 students from 21 countries. Since then, the ISU's reputation has grown and its geographical spread has widened.

In 1989, the ISU was the guest of the Université Louis Pasteur in Strasbourg, France. That year, 124 students from 25 countries attended.

The 1990 summer session, attended by 130 students from 30 countries, was held in Toronto (Canada) at the Institute for Space and Terrestrial Science, University of York.

In 1991, the Moscow Aviation Institute was to have hosted the session, with some 137 students, but that plan had to be postponed due to the prevailing uncertainties. Finallly, it was decided that the Ecole Nationale de l'Aviation Civile (ENAC), in association with the Groupement des Industries Françaises de l'Aéronautique et du Spatial (GIFAS), would host the 1991 session in Toulouse, France.

The 1992 summer session is to be held in Kitakyushu in Japan.

The ISU has thus, year by year, built up its reputation worldwide, thanks to a determination on the part of its management to increasingly internationalise its sessions, combined with a concern to adapt and rearrange its educational programmes in the light of experience.

What does a summer session consist of?
ISU summer sessions last ten weeks and fall into three parts: a core programme, advanced classes, and a study project. The core programme basically takes up the first month. Teaching is multidisciplinary in nature, which means that all students are required to attend all the classes in the ISU's nine curriculum areas. These are:

- Architecture: The design of inhabited structures in space.
- Business and Management: The funding and administrative organisation of space projects.
- Engineering: Design of the mechanical structures and systems for satellites, launchers and space platforms.
- Life Sciences: The medical and human aspects of life on-board a space vehicle.
- Physical Sciences: The areas covered include astronomy, astrophysics and planetary science.
- Policy and Law: This curriculum focuses on the policies and laws relating to space programmes, including discussion of the relevant international treaties.
- Resources and Manufacturing: Study of microgravity and of the non-terrestrial resources that could be used for the development of space projects.
- Satellites and their Applications: The design of satellites and their use in telecommunications and Earth observation.
- The Humanities: Study of philosophy, art, journalism and literature, as they relate to space.

At the end of the core programme, students sit an examination to monitor their progress.

During the second month, students take an advanced course in their chosen curriculum area. They are required to complete a number of assignments, such as writing professional articles or presenting research topics.

The third part of the course is the study project, to which all students contribute (sometimes in two groups if two projects are undertaken in one session). This gives students an opportunity to work in their field of interest as part of a 'project team'. They are divided into study groups, devoted to such topics as quality assurance, cost analysis, telecommunications problems, etc. The study project generally gives rise to a report that runs to several hundred pages.

Study projects undertaken by the ISU to date have been:

1988 Lunar Base
1989 Variable Gravity Research Facility and Lunar Polar Orbiter
1990 Earth Observation and Asteroid Mission
1991 International Mars Mission.

Two projects are planned for 1992. The first is to design a satellite to harness solar energy collected in orbit, the second to design a network of telecommunications satellites and computers to link the major international space centres and build an associated ground station.

Students have access at the ISU to a variety of resources. These include a library of books and research articles on all the subjects taught at the ISU, as well as substantial computer facilities. Some fifty networked computers and several work stations provide access to space databases, powerful calculating tools, virtual environment programs, simulators, etc.

Who are the lecturers?

The teaching staff can be divided into three categories. A core of some thirty lecturers give classes at the ISU for several weeks, and in some cases throughout a session. Most are space professionals working in space agencies, commercial companies and research institutes. The second group consists of visiting lecturers who come to the ISU for a few hours, or sometimes a few days, to teach in their specialised fields. Finally, these lecturers are supported by assistants, who are generally former ISU students.

Each of the three groups includes ESA staff members.

How are the students selected?

There are a number of different selection criteria. The main requirement is that the student should already be studying for a Master's Degree or a Doctorate, or to be in the early stages of a professional space career. In addition, students are expected to have a good knowledge of English, the working language of the ISU.

In drawing up their applications, candidates are also required to write several essays on why they wish to attend the ISU. Specifically, all students are asked to imagine what shape their future careers in the space field might take.

Arrangements for selecting students vary depending on the country from which they come. The ISU has set up liaison units in a number of countries which deal with candidate selection locally. This is the case in Japan and Canada in particular. In other cases, the space agencies themselves select and sponsor candidates. ESA and NASA fall into this last category. The remaining ISU students are selected directly by the University's central administration.

Relationship between the ISU and ESA

Aware as it is that the success of ever more ambitious and complex space programmes demands substantial advances in technology and increased international cooperation, ESA welcomes the advent of the International Space University. For this reason, and also in order to establish and consolidate European participation in the ISU, the Agency has sought to contribute to its work at various levels.

ESA has, since 1988, allowed an average of two staff members per year to attend ISU summer sessions, as part of its professional training arrangements.

The Agency has also been asked to assist by providing teaching in certain disciplines, by helping to shape research projects, or by monitoring the work of the students. Depending on the particular year, between 5 and 20 ESA staff members have been called upon to share their knowledge and experience in this way with ISU students.

The 'Mars Exploration Task Group' at ISU'91 in Toulouse (F)

In addition, since 1990 – with the approval of the Agency's Delegations – it has been ESA policy to make available, each year if possible, to one person from each of its Member States and Associated States, a grant covering the cost of attendance at ISU summer sessions.

Since 1990, the Agency has also contributed about 50 000 US$ per year to help fund certain programme elements, especially research projects.

The future of the ISU

Although the summer sessions will be maintained in the years to come, the ISU has wider long-term aims. The University wishes to develop a permanent academic establishment, study at which would lead to a post-graduate 'Master's in Space Studies'. This degree would be awarded after a year's study involving a combination of multi-disciplinary and specialised teaching, and participation in individual and group research projects. It is also intended that, by means of a grant structure, a number of students should be able to continue their studies beyond the ISU Master's level.

The idea of the 'permanent campus' is to set up a network of separate, linked campuses, each with its own specific function. A central campus will receive students working for the Master's Degree (some 120 a year) and will provide the basic multi-disciplinary teaching. Research projects forming part of the Master's programme and post-Master's grant-supported studies will be pursued at existing universities, which will be the 'affiliated' and 'advanced' campuses.

Work has already begun on selecting the various campuses, the ISU having in April 1991 invited all of the major universities, institutes, philanthropic organisations and governments to partner the University. In proposing partnerships of this kind, the ISU is genuinely seeking to share with other leading institutions around the World not only its students, teaching staff and research activities, but also its reputation and its future projects.

In principle, the results of this 'Call for Partners' will be announced this year, with the permanent campus receiving its first students in 1995.

Conclusion

To have studied at the ISU is clearly an asset to a young space professional. In addition to the academic value of the courses taught and the project studies, ISU students rub shoulders, in a highly international environment, with other students from the most varied professional backgrounds. For example, European space engineers learn to work with American lawyers, Japanese doctors and Russian scientists. This aspect of the ISU is certainly unique and is very enriching.

The ISU also encourages a great many social activities with a view to creating a network of friendship among students. These include cultural evenings (when students from particular regions or countries present their local cultures), group outings, not to mention the masked ball at which all members of the ISU community are expected to appear in disguise.....the theme chosen being, naturally enough, 'Space'!

Space projects increasingly depend on cooperation among nations. Thanks to the network of 'professional comradeship' in the international space field created by the ISU, its students will go on to work together on the international projects of tomorrow.

M-HEO: The Optimal Satellite System for the Most Highly-Populated Regions of the Northern Hemisphere

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In February 1992, the World Administrative Radio Conference (WARC) recognised the importance of direct satellite radio broadcasting (DBS-R) services, by assigning a worldwide frequency band to it. DBS-R will offer international radio services with unprecedented high-quality digital sound, extended coverage and reliable reception.

The ESA Archimedes project is planning to develop the technology to enable the provision of DBS-R services on a experimental basis to both Western and Eastern Europe by means of highly-inclined elliptical orbits (HEOs). By selecting particular classes of HEOs, i.e. 'multiregional' HEOs (M-HEOs), an operational DBS-R system can be designed such that services could be extended beyond Europe to the Far East and North America while using a minimum number of satellites per region served. Mobile communication services are also envisaged for demonstration under the Archimedes project; such services could also be included in a later operational system.

In addition to telecommunication applications, the M-HEO system concept can be used in meteorology. Unlike other satellite systems, M-HEO offers continuous coverage of the northern regions of the Earth, which undergo important and very rapidly changing meteorological phenomena.

Direct satellite radio broadcasting

Radio broadcasting can be subdivided into two broad categories: international or national services that provide news and commentary, and local stations that provide mainly music and entertainment.

International services typically use shortwave (SW) frequencies for long distance broadcasting and medium wave (MW) for national services. As every radio listener has experienced, international services operated using SW and MW are generally characterised by poor quality and unreliable reception conditions. International SW services have gained particular popularity during international crisis, expecially in those countries where free dissemination of information has not been permitted. SW services still play a fundamental role in developing countries, but a significant drop in SW and MW radio audiences is being experienced in more industrialised regions. In the latter, in fact, the growing number of local FM stations, and the enormous diffusion of digital audio (compact disc players and digital tape recorders), has educated users. They now demand higher quality sound: consumers in industrialised countries are becoming less accepting of low quality listening and unpredictable reception conditions.

Many important international broadcasters are planning to improve the quality, reliability and coverage of their SW and MW transmissions by offering services to worldwide audiences that are comparable to or even better than those offered by local FM radio stations. The only viable way to provide such vast scale, high-quality audio broadcasting is to use satellites. Satellite-based radio offers the opportunity to upgrade and expand the concept of worldwide SW broadcasting, by offering digital audio transmission and reliable reception to an audience of hundreds of millions of listeners. Direct satellite radio broadcasting (DBS-R) has been under study for the last twenty years, but is only now becoming a viable and interesting option, in view of the consumer electronics industry's current capability of producing low cost, miniaturised digital receivers.

DBS-R services have the potential of capturing millions of users, and thus becoming, together with television broadcasting, one of the dominant applications for satellite communications. Satellite radio broadcasting can offer two distinct services that cannot be made

available over a large area using terrestrial means:
- International news and commentary services with a quality comparable to that offered by local FM stations.
- Music and entertainment with a quality indistinguishable from compact discs or digital audio tapes.

Unlike with TV satellite broadcasting which is based on fixed installations, the feasibility and success of DBS-R is based on the ability to receive the satellite signal anywhere using a small personal or mobile receiver. Easy signal reception and high availability from all outdoor locations gives DBS-R most of its commercial appeal.

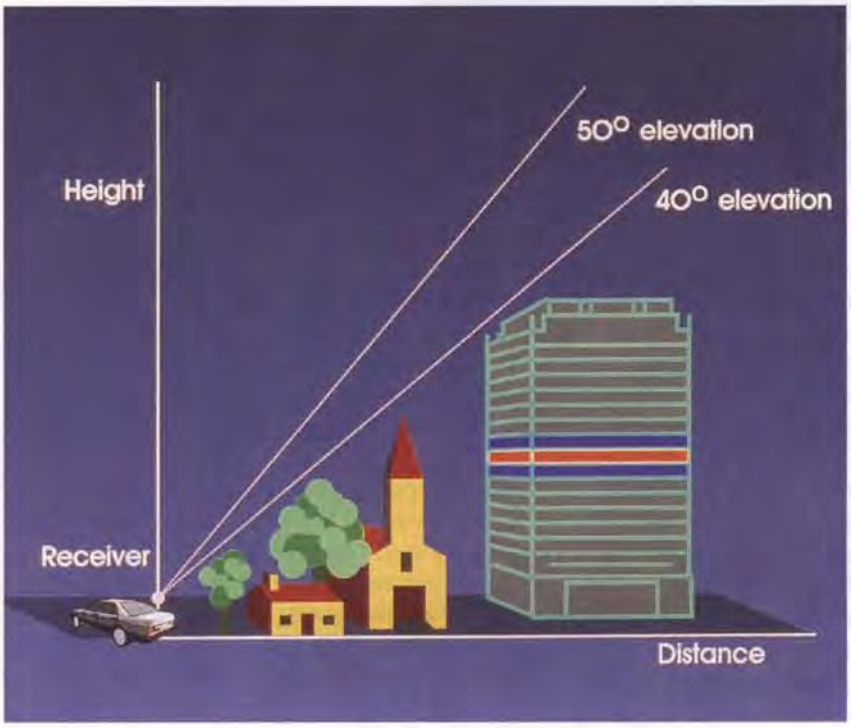

Figure 1. Importance of high elevation angles for satellite radio broadcasting

Establishment of worldwide frequency for DBS-R

At its recent meeting in Spain in February 1992, the World Administrative Radio Conference (WARC), the regulating body for international frequency allocation, recognised the socio-economic benefits of DBS-R by assigning a worldwide frequency allocation to satellite-based radio broadcasting services. The frequency band allocated is around 1.5 GHz. This region of the spectrum is presently occupied by terrestrial radio links, but WARC-92 has established criteria for a gradual build-up of DBS-R services in the 1.5 GHz frequency band. As usual in the case of totally new services, there will be regional differences in the implementation of the WARC-92 allocation, but the worldwide interest in establishing satellite-based radio services has been clearly demonstrated.

Non-GEO systems: the solution for high-latitude regions

To provide DBS-R services to small personal receivers equipped with simple antennas, the satellite must provide a high power flux density (pfd) in the service area. This required pfd will be prohibitive if the satellite is not visible from high elevation angles. The effect of high elevation angles is shown in Figure 1. If the satellite is not visible, even an increase of 20 dB in the satellite's radiated power (100 times more than the required power) would not be sufficient to compensate for signal fading due to buildings and other obstacles. In addition, such an increase would result in an unacceptably high cost for a satellite radio broadcasting transmission. On the other hand, limiting the signal availability, and thereby accepting frequent loss of signal due to obstacles, would not be acceptable to listeners or to broadcasters.

Geostationary (GEO) satellites, which orbit the Earth's equatorial plane (Fig. 2), are able to cover a vast area but provide low elevation angles at latitudes above 30°, i.e. in most regions of the northern hemisphere. Therefore, a GEO-based DBS-R service would not be able to provide the signal availability to personal or mobile receivers located in almost all regions of the northern hemisphere unless both a high-powered spacecraft and a large and complicated antenna system are used. Operational GEO DBS-R services are conceivable only in low latitude regions; in the northern regions, operational DBS-R services based on GEO satellites are not economically viable.

The use of non-GEO orbits has therefore been considered for DBS-R and mobile satellite communications in high latitude zones. Highly-inclined elliptical orbits (HEOs) have been studied as an alternative for regional satellite services. A satellite in the HEO considered lies on an orbital plane inclined approximately 63° with respect to the equatorial plane (Fig. 2). This gives the satellite the advantage of being viewed in high latitudes at very high elevation angles. A satellite in HEO is not geostationary but can be used at the points in the orbit where the satellite moves very slowly presenting, from a telecommunications point of view, a quasi-stationary behaviour.

Under the framework of its Archimedes project, the European Space Agency is examining a DBS-R mission in HEO. The HEO systems that have been considered so far are those based on Molniya or Tundra orbits (Fig. 2) that have orbital periods of

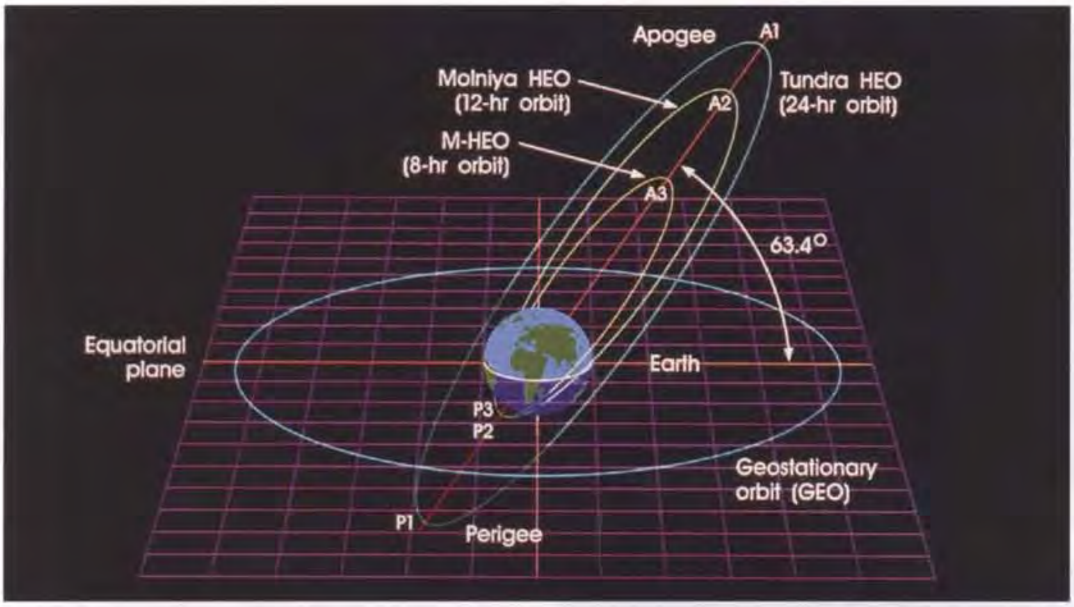

Figure 2. GEO and HEO orbits

12 and 24 hours respectively and apogees at 39 000 and 47 000 kilometres.

When Molniya or Tundra orbits are optimised for European coverage, no other densely populated region of the Earth can be served with the same satellite system. To satisfactorily cover Europe 24-hours a day, four satellites in the Molniya orbit or three in the Tundra orbit have been considered as the baseline for an operational outgrowth of the Archimedes DBS-R system. Such a system would correspond to a deployment cost that could not be shared with other service areas outside Europe. In the case of a totally new service, such as DBS-R, this development cost might represent a barrier to establishing an operational service.

In order to reduce the cost per radio channel of DBS-R, ESA has been examining other HEOs that offer the advantage of providing the same European services as using satellites in the Molniya or Tundra orbit while providing radio broadcasting to other densely populated regions of the Earth.

Multiregional HEO DBS-R services

Basic orbit theory and simple geometrical considerations suggest various alternative HEO orbits that are suitable for providing broadcasting services to several regions, i.e. 'multiregional' HEOs or M-HEOs. Attention has been focused on the use of eight-hour elliptical orbits. Table 1 compares such a M-HEO system with the Molniya and Tundra concepts. When it is carefully optimised, the eight-hour M-HEO can in fact offer:

— Three apogee loops, corresponding to three well-separated service areas, i.e. Europe (including both Eastern and Western Europe), the Far East and North America.

— A lower apogee altitude, and thus increased in-orbit mass margins and considerable power savings in comparison with the more distant Molniya and Tundra orbits.

— A minimum number of satellites (six) for continuous service to the given coverage areas.

Therefore, the three major service areas (Europe, the Far East, and a large part of North America) could be served with elevation angles greater than 50°. In comparison with the Molniya orbit, the number of satellites required to provide such coverage would increase by 50% (from 4 to 6), while the areas served would increase by 300% (from 1 to 3). In addition, given the lower apogee altitude, the required power for M-HEO services would be reduced by a factor of 2.5.

Using M-HEO offers a good opportunity to both share the deployment costs among three major service areas and, considering the lower power required, reduce the satellite unit cost with respect to Molniya and Tundra systems.

Table 1 — Comparison of HEO systems

	M-HEO	Molniya	Tundra
Orbital period (hours)	8	12	24
Altitude at apogee (km)	27 000	39 000	47 000
Altitude at perigee (km)	1 000	1 000	24 000
No. of satellites required*	6	12 (4 for coverage of Europe only)	9 (3 for coverage of Europe only)

* For around-the-clock simultaneous coverage of Europe, the Far East and North America.

M-HEO satellite constellation

In its basic configuration, the space segment of the M-HEO is composed of six satellites in elliptical orbit around the Earth. The constellation parameters are summarised in Table 2.

The orbital period and the eccentricity have been selected such that a minimum number of spacecraft (six) can provide continuous, high elevation angle coverage in three geographical areas that are spaced 120° apart around the Earth's equator (Europe, the Far East, and North America).

Every 24 hours, each spacecraft in the six-satellite configuration is operational for a period of four hours over each of the three apogee-loops in the relevant service area (Fig. 3). After four hours, it 'hands over' its functions in the service area to the next satellite in the configuration, which is following the same ground-track. Each day, the same satellite covers the three different service areas at the same local time but this time slowly drifts during the course of the year (by about four minutes per day, due to sidereal shift).

The perigee altitude must be maintained above 1000 km to avoid aerodynamic drag from the atmosphere. The selection of orbit inclination for M-HEO is driven by the propellant requirements for the orbit-keeping manoeuvres. The 'stable' orbit inclination of 63.45° has been selected. A small decrease from this inclination, although beneficial in terms of elevation angles in the service areas, would result in very demanding propellant requirements for counteracting the argument of perigee drift due to the Earth's oblateness (known as the J_2 effect). In the proposed system, the selection of the argument of perigee is critical for maximising the coverage width over the three service areas. For best coverage, the argument of perigee is set to 270°.

The six-satellite M-HEO constellation enables a user to receive radio-signals from an elevation better than 50° over both Eastern and Western Europe, the Far East and most of continental North America. The service areas depicted in Figures 4 and 5 are determined by overlapping the 50° coverage at apogee and 'handover' points. An additional market, which includes Taiwan, Hong Kong, the U.S. East Coast, and most of the Commonwealth of Independent States, can still be captured at a minimum elevation of 40°.

Table 2 — Parameters of M-HEO satellite constellation

No. of satellites	6
Altitude at apogee	27 000 km
Altitude at perigee	1 000 km
Orbital period	8 hours
Inclination	63.435°
Argument of perigee	270°
Ascending node	60° apart
Mean anomaly	180° apart
Useful orbit time	4 hours
Handover condition	2 satellites visible at altitude of 20 500 km

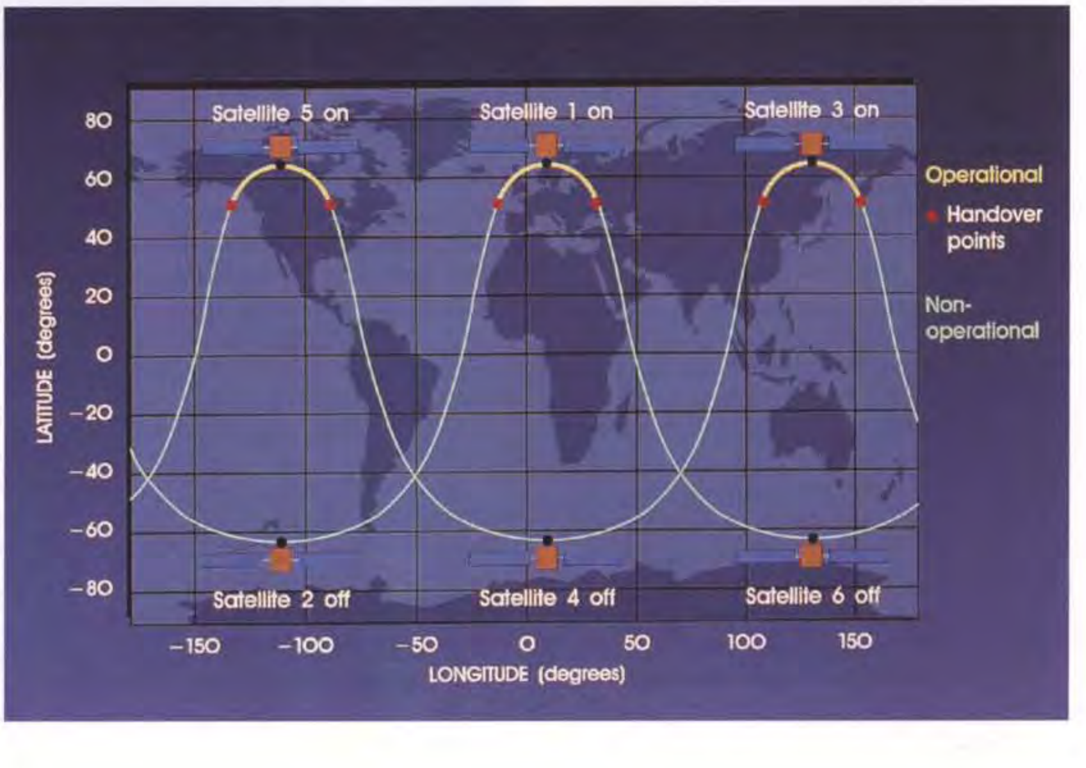

Figure 3. M-HEO satellite constellation ground-track

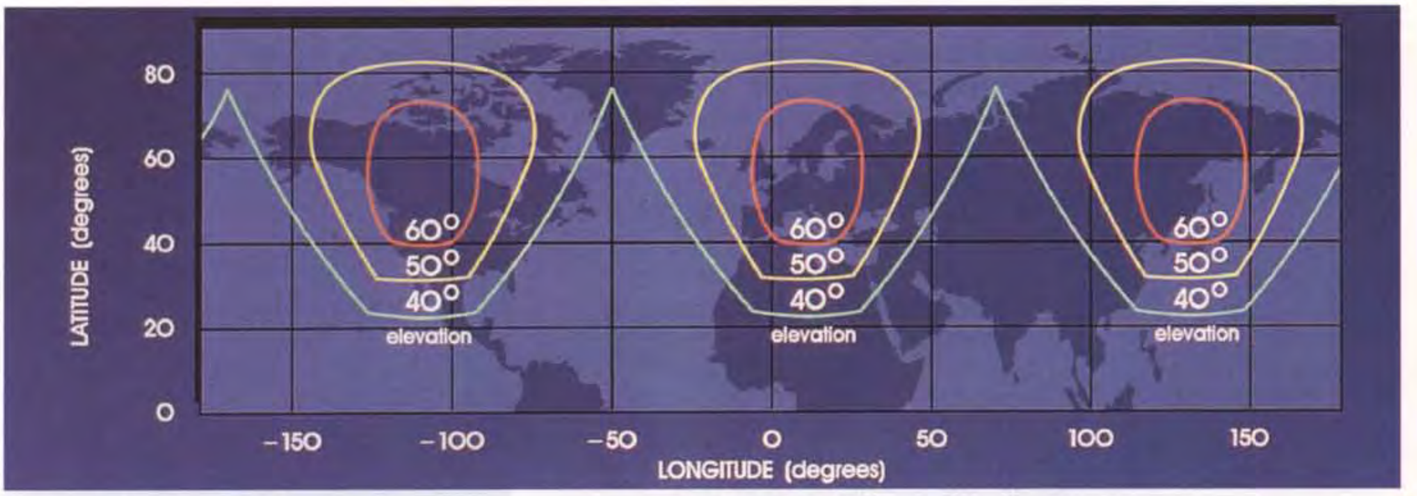

Figure 4. Coverage contours based on a minimum guaranteed elevation

The M-HEO system also presents an interesting feature to broadcasters. Figure 6 shows the regions of the Earth, all above 58° N latitude, from where the European, Far Eastern, and North American loops can be seen at the same time. This means that a broadcaster can simultaneously uplink radio programmes to the three satellites that are covering the three service areas at that moment, from a single location above 58° N.

Spacecraft design is constrained by in-orbit launcher capability. M-HEO offers a considerable advantage over similar HEO systems, such as systems in the Molniya and Tundra orbits and other possible multiregional HEOs, due to its lower operating altitude (i.e. it is closer to Earth), and the consequent increase in the spacecraft mass that can be delivered to orbit. The relatively low operating

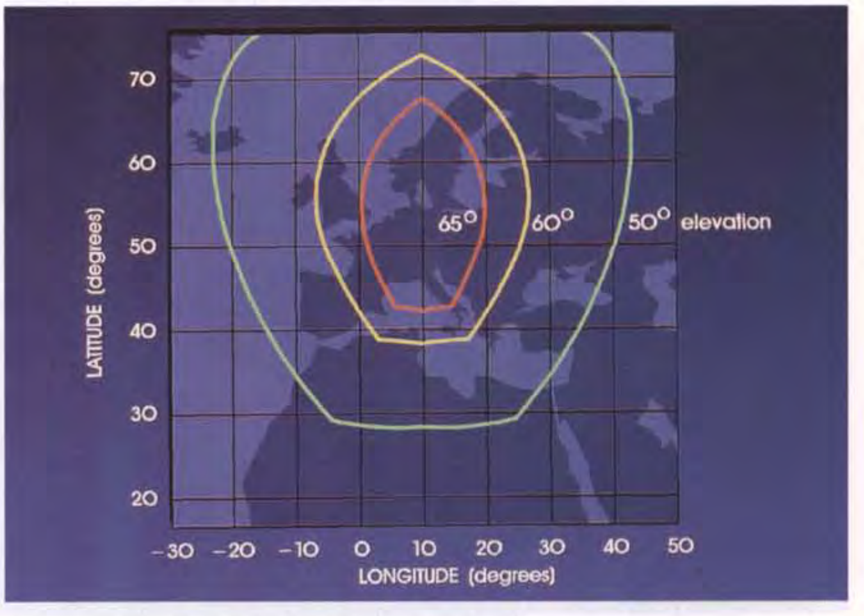

Figure 5. Coverage contours over Europe, based on a minimum guaranteed elevation

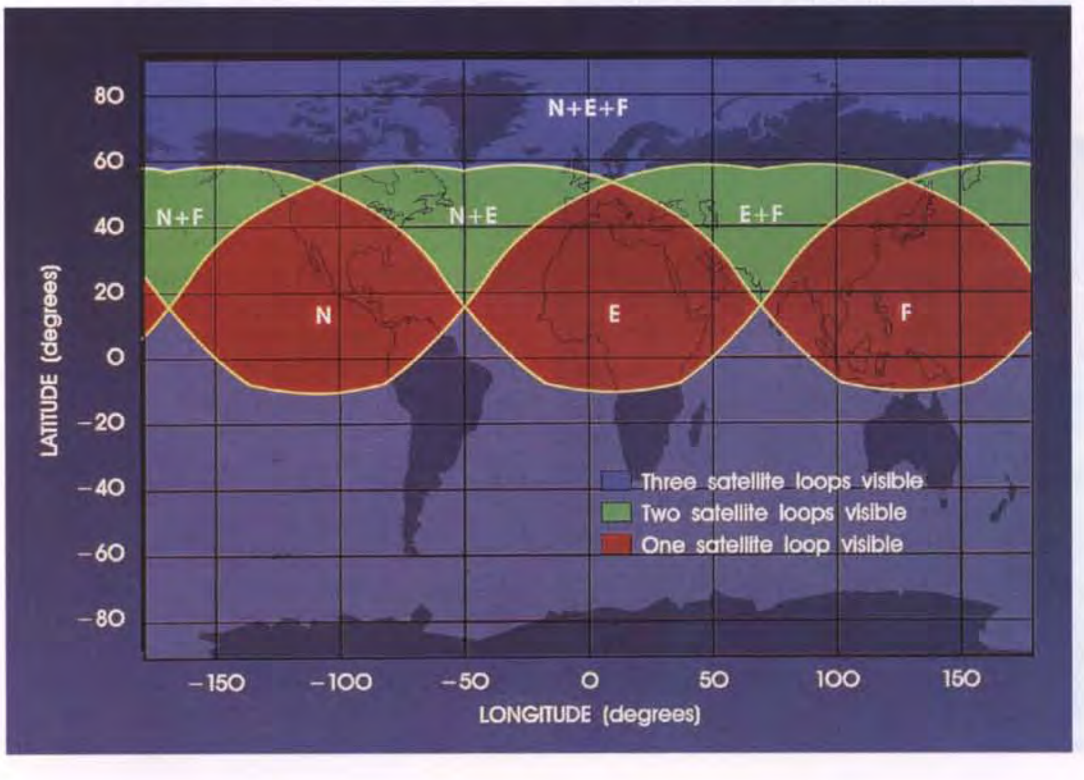

Figure 6. Regions above 5° elevation from which the apogee loops are visible around-the-clock

N = North American loop
E = European loop
F = Far Eastern loop

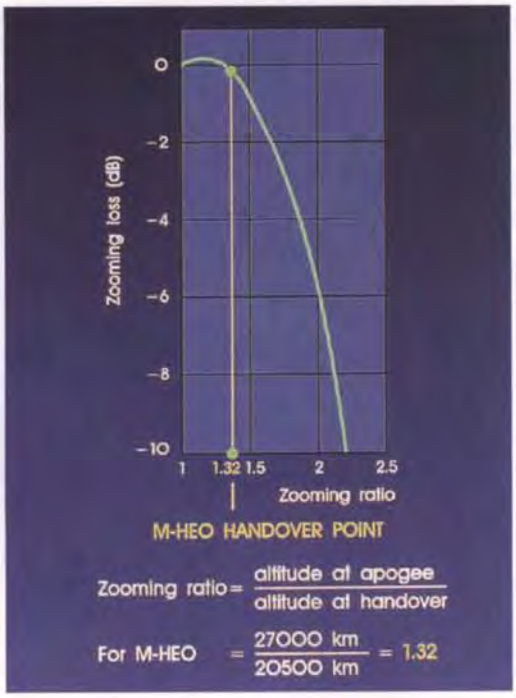

Figure 7. Effect of zooming ratio on zooming loss

altitude is also attractive in terms of transmitting power requirements for the spacecraft; path losses at 1.5 GHz are in fact around 4 dB less than Molniya orbit and 5 dB less than Tundra orbit (along the nadir direction). Therefore, considering the increased in-orbit mass launch and the lower power required, significant spacecraft simplifications are expected when compared to the design proposed for Molniya and Tundra orbits.

User segment concept

The user segment is centred around the service area and the receiving terminal concept. In the following, the frequency considered for DBS-R is around 1.5 GHz, the allocation assigned at WARC-92.

Service area design

As previously discussed, the system provides continuous coverage of three distinct service areas. Each service area is defined by the minimum guaranteed elevation, the satellite antenna coverage, and the available power on board the spacecraft.

The satellite antenna must be designed to fulfil the requirements of the three service areas. A very simple antenna concept, i.e. a single beam reflector antenna, is presented to illustrate the basic characteristics of the radiofrequency coverage. The same single beam reflector antenna is used to cover the three service areas. By computer optimisation, it has been found that a good balance between antenna gain and coverage area is obtained with a 2 metre reflector antenna with a 7° halfpower beamwidth at 1.5 GHz. During the dwell time along the operational arc around the orbit apogee, the antenna beam is assumed to be constantly pointed towards a reference location on the Earth's surface.

A critical point of HEO systems is the variable altitude that causes a zooming of the antenna 'footprint' in the service area, i.e. as the altitude decreases, the antenna covers a smaller area. This 'zooming effect' is partially counteracted by the fact that the average slant range and, consequently, the signal path loss diminish from apogee to handover. The net result of these two effects is expressed using the 'zooming loss' factor (Fig. 7). Zooming loss becomes significant when the zooming ratio is above 1.5. In the case of an M-HEO, the zooming ratio is approximately 1.3, thus lowering the altitude compensates for the zooming effect and practically no zooming loss occurs. This zooming compensation effect is taken into account in Figure 8 where, as as example, the European coverage is shown. The area within the boundary indicates where the minimum required pfd is continuously guaranteed, 24-hours per day.

To achieve a greater geographical coverage and a higher antenna gain, a multi-beam antenna could be used.

Receiving terminal concept

The user terminal is composed of a receiving antenna, a radiofrequency part, a baseband demodulator, and a signal decoder. The receiving terminal antenna must be simple, and without the need for tracking devices. It

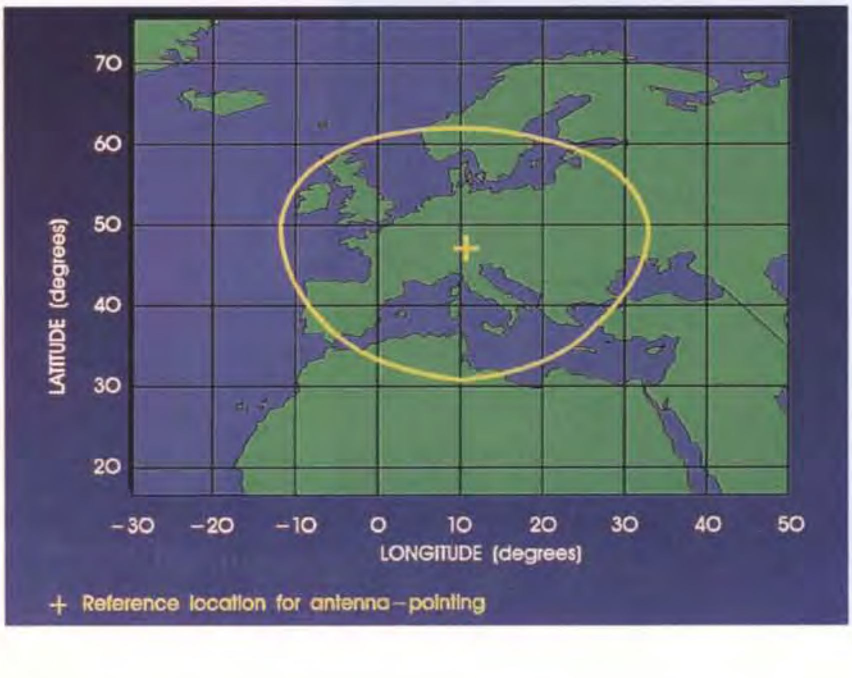

Figure 8. Example of M-DBSR minimum power flux density contour over Europe using a simple 2-metre reflector antenna

must also be able to handle satellite visibility requirements and be easily accommodated in portable and mobile receivers.

The user antenna requirements have been derived by analysing the satellite azimuth and elevation variations in various test points in the three services areas. The results are reported in Figure 9. This figure shows the polar plots of the satellite track on the antenna plane. The antenna plane is considered to be coincident with the local horizontal plane. An antenna with reception capability in its upper hemisphere with a conventional aperture of approximately 100° and azimuthal symmetry, can be used by all listeners located in the three service areas, including those where the satellite is visible at an elevation angle of 40°.

varying meteorological phenomena that affect the major developed countries. GEO weather satellites do not cover the polar cap and cannot provide a good, undistorted view of the high latitude zones. Low Earth orbit (LEO) satellites in sun-synchronous 90° polar orbit can observe the entire globe, but only the polar caps can be observed each orbital period while the rest of the world can only be observed a few times per day.

The M-HEO concept offers clear and continuous visibility of the northern regions, and a significant advantage when observing those phenomena that require high temporal resolution to provide a reliable forecast. In Figure 10, the views from the three M-HEO apogees are compared to what is achievable from three geostationary satellites located at

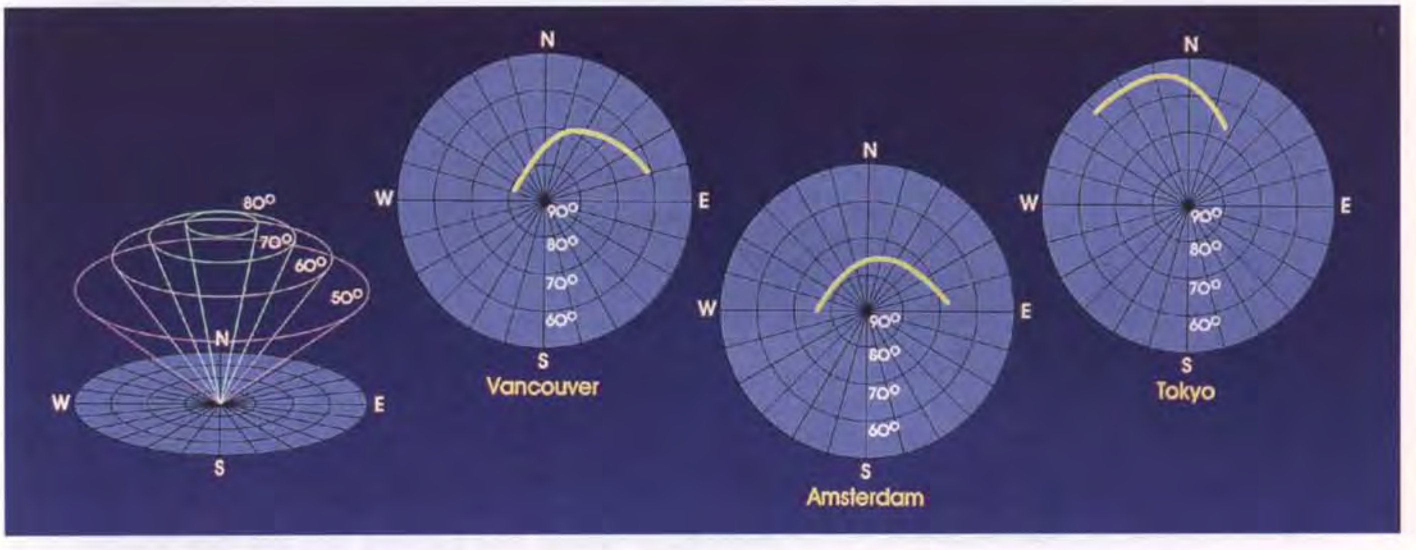

Figure 9. Polar plots of the satellite track on the local horizontal plane

An antenna with the above characteristics can provide a peak gain of approximately 5 dBi at 1.5 GHz. Due to symmetry in azimuth and broad aperture, this antenna can also tolerate the movements that are typical of mobile and portable receivers.

M-HEO: An opportunity for meteorology?

The M-HEO provides an optimal and continuous view of the Earth's northern regions. In addition, the polar cap is simultaneously observed from the three orbital arcs around the apogee. Therefore, although the M-HEO system was initially conceived for telecommunications purposes, it could also offer the opportunity to host a meteorological payload, with significant cost-saving benefits.

Satellites currently in orbit do not provide continuous and high quality coverage of the regions between latitudes of 60° and 80°. However, these regions undergo rapidly

an equivalent longitude. The M-HEO apogees offer a much greater view of the Earth in general, and a clearer, undistorted view of the northern regions in particular.

Conclusion

The novel satellite communication system based on an M-HEO allows low cost, around-the-clock coverage of three different regions of the Earth. By using a suitably selected elliptical orbit, continuous coverage is assured in both Eastern and Western Europe, the Far East, and most of North America. The selected orbit allows a constellation of six satellites to provide service with an elevation of better than 40° over the three service areas from a maximum altitude of 27 000 km. This new concept provides a significant economic and technical advantage when compared to previously proposed systems in GEO or HEO orbit, using the minimum number of satellites per region served.

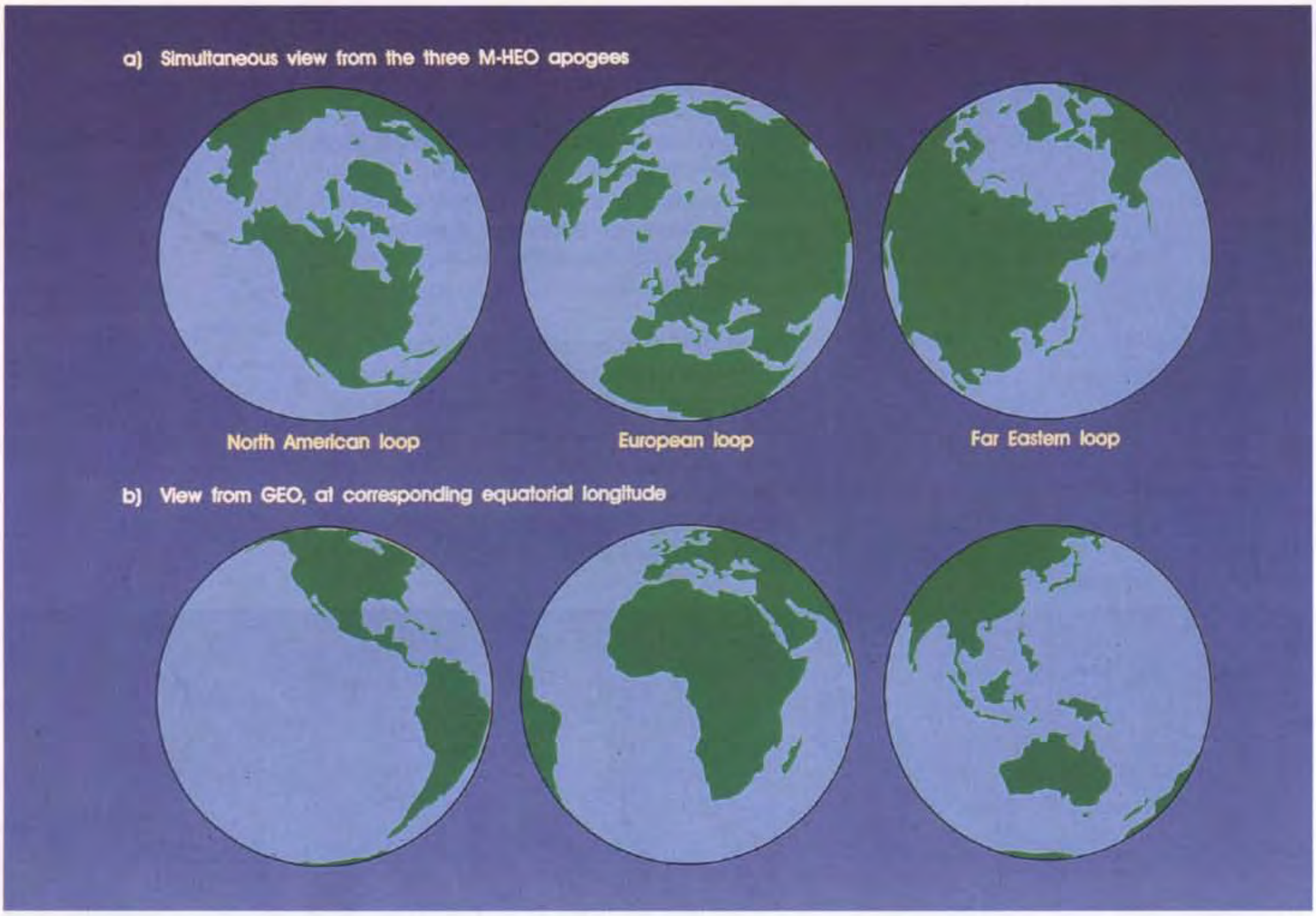

Figure 10. Comparison of M-HEO and GEO views

The M-HEO system is particularly suited to direct satellite radio broadcasting (DBS-R). In February 1992, WARC-92 assigned a worldwide frequency allocation to DBS-R, assuring that DBS-R will become an important satellite communications application. M-HEOs can also be used to provide competitive mobile services in the coverage areas.

The M-HEO system also offers an interesting opportunity for meteorological applications, because of the continuous and undistorted view of the Earth's northern regions that M-HEO provides. The polar cap is continuously and simultaneously observed from the three orbital arcs around the apogee.

ECOS: The Agency's Proposal-Presentation and Cost-Analysis Tool for the 1990s

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Use of the ESA Costing Software (ECOS) is now a mandatory requirement for the Agency major programmes. Since first becoming operational in 1988, ECOS has rapidly become an indispensable tool both for ESA and for Industry, particularly at Prime-Contractor and major-subcontractor or co-contractor level, where there is often a responsibility for large numbers of lower-tier subcontractors. The latest version of the software, ECOS-Clarion, to be released later this year provides both greater functionality and a more user-friendly interface.

Introduction

The process of proposal preparation for large space programmes of a development nature will never be a simple task, given the need to present sufficiently detailed technical, schedule and management information to convince the customer of the credibility of the proposals, the constraints of having to meet budgetary targets or match competitors' prices, in addition to the requirement of having to meet a strict deadline for submission of the proposal.

Figure 1. The ECOS log-on screen

In the context of ESA programmes, whether as part of a mandatory or an optional programme, the Prime Contractor is also obliged to ensure that, apart from having a cost-effective allocation of effort, the work is distributed to industry in the various Member States in accordance with a target geographical distribution that reflects the financial contribution of each Member State to that programme's funding.

European industry has shown itself to be well able to respond to the need to work together with companies in other countries and to minimise the possible impact on costs. It does mean, however, that there is a certain fragmentation in the breakdown of the work to be performed, and the number of companies involved tends to be somewhat higher than would otherwise be the case.

Not much more than two decades ago, proposal cost estimates were being calculated using mechanical desk-top calculators, with data being entered on the costing forms by hand or using a typewriter. Then, about twenty years ago, the larger companies started using mainframe computers to perform cost calculations on the data fed in, and the costing forms were printed automatically.

Whilst it required a large amount of laborious effort to input and integrate the cost data, particularly at Prime-Contractor level, with the smaller programmes at that time and the fewer companies involved, it was an onerous but still manageable task.

Over the years, however, there has been an increase in the number of ESA Member States and a dramatic increase in the size and complexity of the programmes being undertaken, both factors contributing in turn to a substantial increase in the number of companies involved.

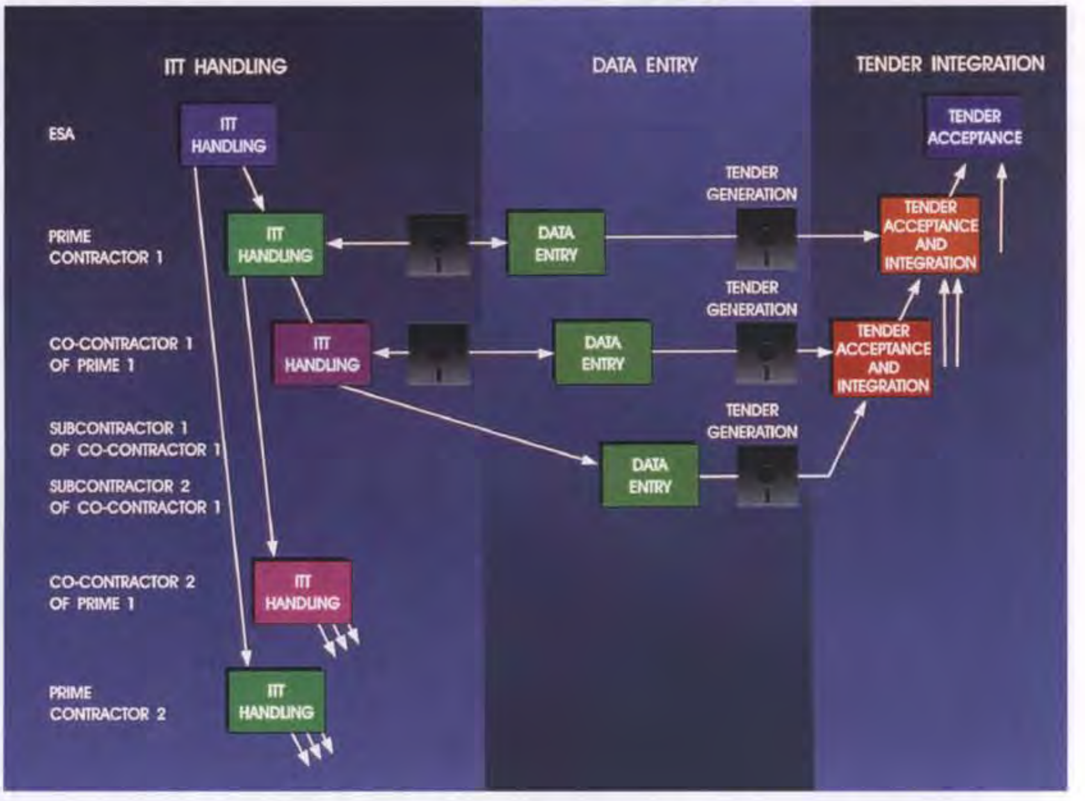


Figure 2. The three stages of cost proposal preparation

In 1970, the annual ESA budget was 63 MAU and the programmes at that time, primarily scientific satellites, typically cost of the order of 20–30 MAU (less than 100 MAU at 1990 price levels). By 1990, the ESA annual budget had risen to some 2000 MAU, while the proposal submitted by MBB/ERNO that year for the Columbus Programme's main development phase was for a total price of approximately 2200 MAU. This proposal involved 225 subcontracts placed with 80 different companies, and there were a total of 3600 separate work packages.

It is clearly an immense task to prepare and submit such a proposal. However, over the years, whilst the size and complexity of proposals has increased dramatically, there has also been a steady improvement in the means available for producing such proposals, with the development of powerful personal computers and word processors, the progress in desk-top publishing, and now the availability of ECOS.

What is ECOS?

ECOS – the ESA Costing Software – is a standardised software package which permits the partition of work down the industrial structure and the electronic submission of cost proposals (via telecommunications links or on diskettes) to higher-level contractors, for ultimate submission to the Agency. The information presented is that required by the ESA costing and pricing requirements as represented by the PSS-A (ESA Procedures, Standards and Specifications) series of forms.

An important feature in this process is the computerised integration of data at successive levels of the contractual hierarchy, this automation avoiding the onerous task of manual integration of data from lower-level contractors, a task that is both time-consuming and prone to the introduction of errors due to repetitive data entry. Thus whilst ECOS can be implemented for the submission of a cost proposal by a single contractor, it is of particular value for large programmes involving many companies, the latter being a dominant feature of the Agency's major programmes.

The aim with ECOS has been to achieve a homogeneity of approach at the different contractual levels of a proposal for a particular programme and between different programmes. This has led to the adoption of a strictly product-oriented breakdown ('Product Tree'), in conjunction with the traditional Work Breakdown Structure (WBS), which tends to be discipline- and organisation-oriented. The example that has commonly been used to illustrate the two different approaches is that of a house (Figs. 2,3).

The advantages of ECOS are that it:
- Ensures consistency of the data.
- Enables computerised tender integration at each contractual level.

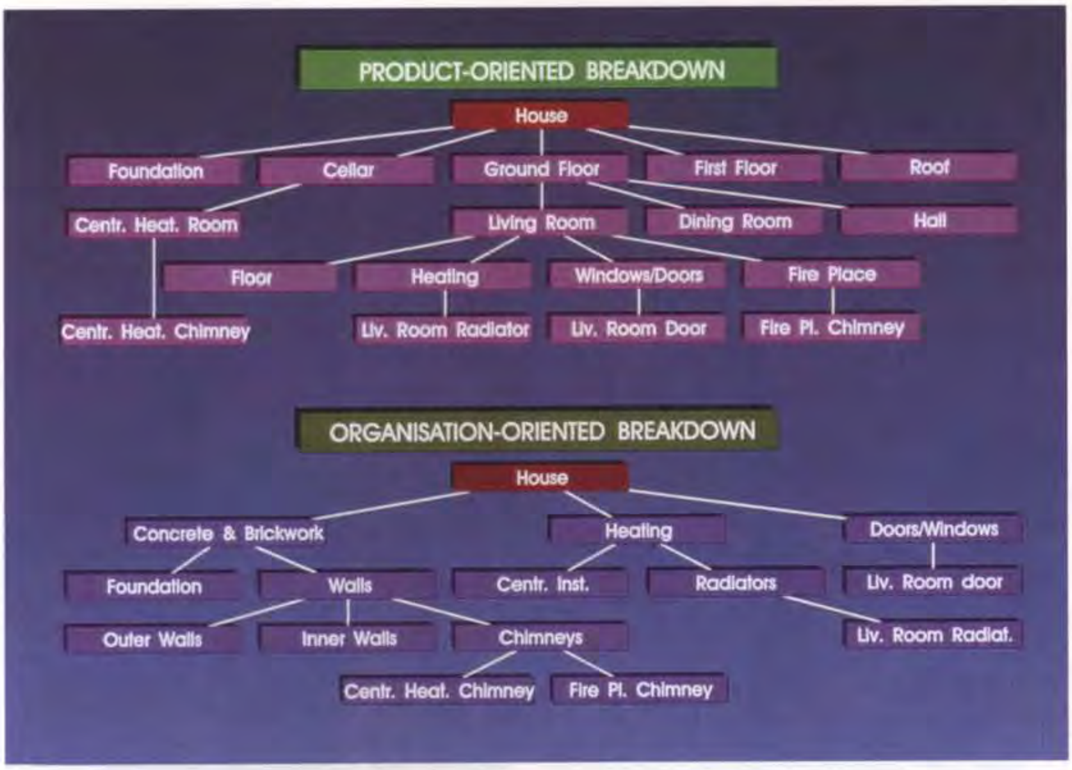


Figure 3a. Product-oriented breakdown, or 'Product Tree', approach

Figure 3b. Industrial organisation/discipline-oriented breakdown, or 'Work-Breakdown Structure', approach

- Enables a clear presentation of information.
- Incorporates information concerning the technical and programmatic baseline relevant to the cost proposal.
- Enables detailed and rapid analysis of tenders at any level.
- Reduces the volume of paper (in principle, all information from the financial proposal can be provided on a diskette, including both narrative text and cost details).
- Provides great flexibility when proposal data needs to be changed at short notice.
- Allows for simulations of change impacts.
- Facilitates updating of proposals to reflect finally negotiated prices.
- Permits transfer of information from ECOS into company or Agency project-control systems.
- Allows for interfacing with internal company computerised costing systems.
- Provides flexibility in input-level detail, and information can be presented or extracted at any level.
- Provides for commercial security. Information may be protected by passwords where appropriate.
- Facilitates the organised collection of cost data from various projects for the derivation of Cost Estimating Relationships (CERs) and for parametric analysis.
- Can be handled on personal computers, which provides ease of access and requires only a relatively small investment.

Returning to the example of the Columbus Phase-C/D proposal mentioned in the Introduction, one can appreciate the benefit of using ECOS where, with all data being input to the system only once by the originating company, it meant that there were approximately 45 work packages per company. Therefore, each company had only to handle a manageable amount of data, although the integrated dataset is enormous.

The development of ECOS

The ECOS approach was conceived by the Agency, jointly with Eurospace, as a means of implementing the revised ESA-standard general costing and pricing requirements (the PSS-A series), the need being perceived as a result of the increasing size and complexity of the ESA programmes.

The original software was developed under the responsibility of the Agency's Cost Analysis Division with the support of external software houses. The development effort itself proved to be more difficult than anticipated, being complicated by the constraint that the software had to run on a PC rather than on a mainframe. This decision had been taken because the ECOS concept requires that lower-level subcontractors, which are often smaller companies, are also required to use the software, and not all of them could be expected to have mainframe systems.

The rapid evolution of PCs in recent years means that this would no longer have been a problem, but in the mid-1980s the limited power of PCs, combined with the much less sophisticated software support tools, made the development effort much more difficult.

Nevertheless, ECOS first became operational in May 1988, when it was used by MBB/ERNO for the submission of the Columbus Programatics Proposal.

The list of programmes in which ECOS has already been implemented, and those future programmes for which its use has already been initiated, is as follows:

Table 1. Programmes for which ECOS has been or will be used

Project	Phase*	Company	Proposal Submission
Performed			
Columbus	Programmatics	MBB/ERNO	May 1988
	Phase-C/D	MBB/ERNO	Aug. 1988
	Phases-C1/C2/C/D	MBB/ERNO	Dec. 1990
Hermes	Programmatics	Aerospatiale	May 1991
HERA	Phase-1	Fokker	Sep. 1988
	Programmatics	Fokker	Sep. 1990
EVA	Phase-1	Dornier	Dec. 1988
	Programmatics	Dornier	Dec. 1990
	Phase-C/D	Dornier	July 1991
Soho	Phase-B	Matra	March 1989
	Phase-C/D	Matra	1991 partial
Cluster	Phase-B	Dornier & MSS	March 1989
Polar Platform	Programmatics	BAe	August 1989
POEM	Phase-B	Dornier	May 1991
Huygens	Phase-B	BAe & Aerospatiale	Oct. 1990
MIMR	Phase-B	Alenia	Aug. 1991
Initiated (included in RFQ requirements)			**RFQ Issued**
Artemis	Phase-C/D	Alenia	Oct. 1991
Hermes	Phase-C/D	Aerospatiale	Nov. 1991
HERA	Phase-C/D	Fokker	Nov. 1991
POEM	Phase-C/D	Dornier	April 1992

* Phase-B = Design Phase Phases-C/D = Main Development Phases

At the present time, more than 160 firms are in possession of the ECOS software and most of them have had one or more of their staff trained in its use by ESA Cost Analysis Division, which periodically runs courses for small groups.

Considering the large number of companies involved and the discipline that it imposes, the implementation of ECOS has proceeded relatively smoothly. For the most part, users both in industry and within ESA have accepted ECOS cautiously at first, but have then become increasingly enthusiastic as its benefits have become apparent. However, as with any major new development, others have been more sceptical about its application and experience has demonstrated that scepticism leading to a half-hearted approach can become a self-fulfilling prophesy. However, there are now very few pockets of resistance to ECOS left as its benefits have become so widely demonstrated.

One of the elements that led to some resistance within industry to the implementation of ECOS is the parallel use of ECOS and of company in-house costing systems. However, the Agency encourages the installation of interface software between ECOS and company-specific costing systems, and also between ECOS and other systems such as work-package description and planning tools. Such interfaces are now being employed in a number of companies with considerable success.

ECOS is used in this interfacing operation to build up the WBS, for which information such as WBS number titles is transferred to the company's own costing system. Data entry is then performed in the same way as for non-ESA projects, and finally cost/schedule information is transferred back into the ECOS system.

ECOS as a cost-analysis/data-collection tool

In addition to ECOS's advantages to industry in the preparation and submission of its proposals, it is also an important data-collection tool when setting up a data bank for cost-analysis and cost-estimating purposes.

In the past, the value of historical cost data for these purposes has been limited by lack of a standardised work-breakdown approach and by the absence of important details such as the main technical parameters, development status, and model philosophy/hardware matrix. Without having such details available when comparing the costs of different programmes, it is impossible to be certain that you are comparing like with like, and invalid conclusions may therefore drawn.

The fact that ECOS imposes a systematic and disciplined approach facilitates the

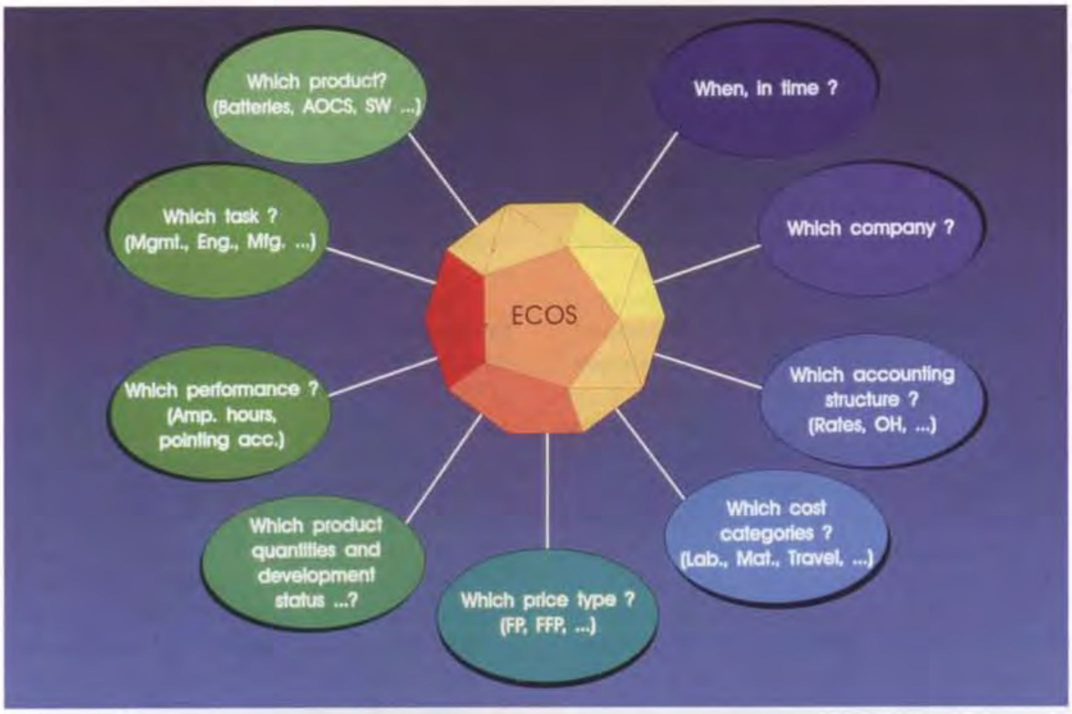


Figure 4. The data-collection role of ECOS

analysis of a particular proposal, due to the consistency in approach at the various levels in the contractual hierarchy. It offers a great many possibilities for making rapid assessments of different aspects of the proposal for any contractor at any level, or any function throughout the proposal. Moreover, information can be extracted to provide a summary view or any detail, as required. It is possible, for instance, to extract immediately all management or travel charges, or all costs relating to a particular model. Whilst such costs cannot necessarily be considered to be stand-alone costs, this does give an immediate basis for a more detailed assessment taking account of other factors.

The degree of consistency makes it easier to simulate the cost impact of possible changes in the work, particularly where it involves the addition or deletion of items, the latter process being quite common with requirements being de-scoped to arrive at a definition of work that can be accommodated within the budgetary limitations.

When a similar approach to the breakdown of work is adopted for different programmes, it facilitates the use of comparative data from other programmes in the analysis of the current proposal costs, and also for the estimation of costs for new programmes, thereby facilitating inter-project comparisons and the derivation of cost-estimation relationships.

With ECOS, information can also be presented in graphical form, as illustrated by Figure 5. This may appear at first sight to be a rather superficial approach, but when faced with an enormously detailed proposal

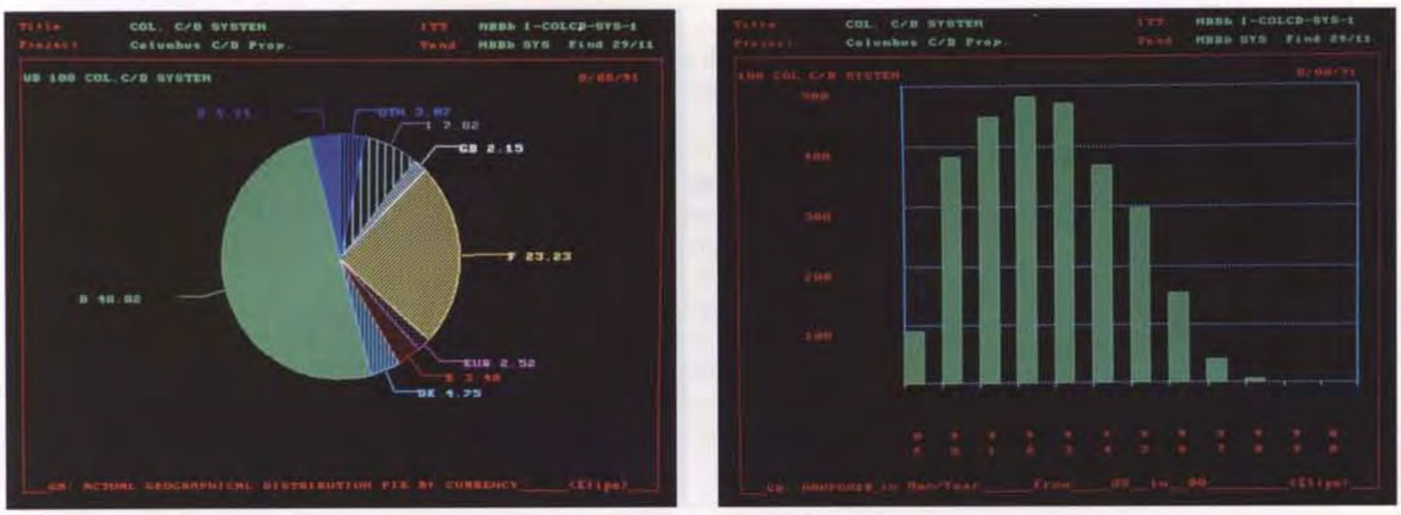


Figure 5. Typical pie-chart and histogram outputs from ECOS

such a capability provides an overview that enables the analyst to remain in control of the exercise and not be overwhelmed by the masses of detail.

The recording of the corresponding technical and programmatic details when assessing costs from different programmes, or when comparing different costs on the same programme at different stages, is of fundamental importance and may therefore seem rather obvious. Nevertheless, it is an aspect that is frequently neglected in the face of day-to-day pressures. The information usually exists, but the technical and cost proposals, which are both usually submitted in great detail, are very often physically separated and the cross-link may not be made.

It is necessary therefore that key technical and programmatic details be extracted from the detailed technical proposal as a special exercise, or that they be presented from the outset together with details of the costs. The second option is clearly preferable and can be readily achieved with ECOS. With the current 'Focus' version of ECOS, there is already a requirement to provide some technical details, and the contractor is also required to provide information regarding the hardware matrix and the development status, as required for by the Agency's General Conditions of Tender (form PSS-A45).

However, the experience has been that, whilst there is a high degree of compliance in meeting the requirements relating to cost details, it is somewhat lower when it comes to the provision of technical/programmatic information in the cost proposal. The next version of ECOS, which will be available shortly, will require the inclusion of more technical detail and the Agency will be placing great emphasis on compliance with requirements in this respect.

The benefits of clear and consistent data presentation and of being able to relate costs readily to a specific technical/programmatic baseline accrue both to the Agency and to industry, who have a mutual interest in establishing a credible cost baseline before embarking on the challenge of contract negotiations and subsequent contract execution.

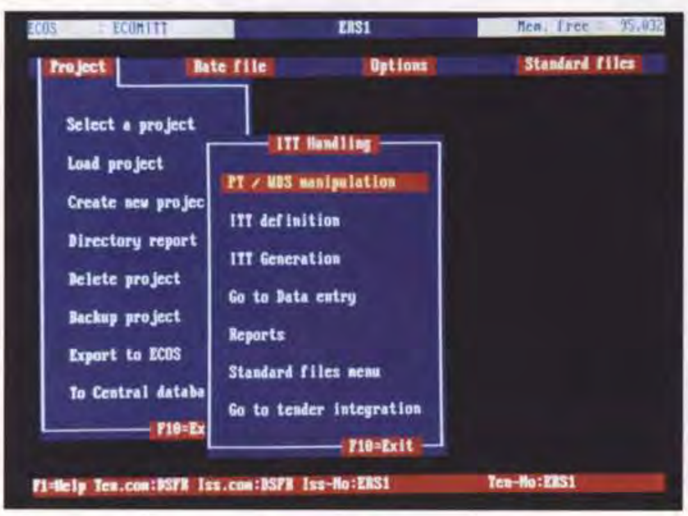
ECOS-Clarion

Despite the successful implementation of the ECOS system, it was felt that the software could be improved and the decision was taken last year to produce a revised version of ECOS based on Clarion rather than Focus.

Some of the major improvements in ECOS-Clarion can be summarised as follows:

- There is an improved user interface and faster execution.
- There is an extended graphics capability.
- A powerful on-line help facility is introduced, considerably reducing the need for training and reference to operating manuals.
- There is more flexibility to allow changes to the WBS at the different stages of proposal preparation.
- There is the possibility of a more detailed breakdown of both the WBS and the cost-centre allocation, for the purposes of internal company resource planning.
- The PC core memory requirement is reduced to less than 500 kbyte (freeing 80 kbyte) and the hard-disk requirement is now only 4 Mbyte for the whole system.
- No commercial database is required.

ECOS-Clarion will become operational in the third quarter of this year, after extensive testing involving industry. Courses will again be organised by the Agency for this updated ECOS, but the additional training needed by



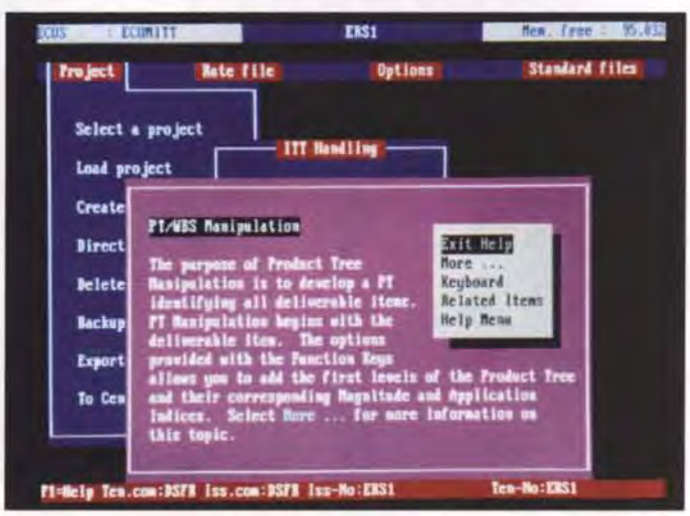


Figure 6. Typical ECOS data entry and manipulation screens

those already working with the existing version will be minimall.

Possible future development of ECOS
The immediate objective is the completion of the development and testing of the ECOS-Clarion version and its release in the second half of 1992, this work being well in hand.

With the exception of those programmes for which Requests for Quotation (RFQs) or Invitations to Tender (ITTs) have already been initiated with the Focus version, the ECOS-Clarion version will then be applied for all new major programmes.

It is planned that, early in 1993, the ESA Information Systems Division (ISD) at ESRIN, in Frascati (I), will take over responsibility for ECOS maintenance from ESA Cost Analysis Division at ESTEC, including provision of a Help Desk facility.

At the present time, ECOS is used primarily for proposal preparation, submission and analysis, and is generally not employed during contract execution. It would certainly be possible to develop ECOS further, step-by-step, into a project-control tool providing the following capabilities:
- Periodic updating of the estimated costs during the lifetime of the project: On a cost-reimbursement programme, the task of such updating is similar to the submission of a new proposal. For this application, ECOS would have to be extended to show the actual costs incurred up to a certain moment, the estimate of costs to be incurred from that time to completion, and the total revised estimate.
- Overview of budget details: ECOS could be expanded to enter budget details, to permit the entry on a regular basis of actual cost details, and to compare actual costs and planned costs. For this application, some data file and report procedures would need to be added.
- Simple schedule-control tool for smaller (lower level) companies. This would entail expanding the data-entry part of ECOS with a scheduling element, but without any integration of schedule data at the higher level. It could also contain an interface for larger companies to their internal schedule-control systems.
- As a final step, integration of actual cost and schedule data, permitting a correlation to be made between the two.

Such project-control facilities might be of particular benefit to those companies not already having their own computerised project-control systems. An alternative approach, which might be more appropriate where there are existing project-control systems in operation, which is certainly the case for most of the major contractors, would be simply to develop interfaces between those existing systems and ECOS.

This has already been achieved in the case of the project-control system (PCMS) for the Columbus Programme and by a number of the major companies working on other programmes.

Finally, whilst ECOS has clear benefits for the implementation for large complex programmes involving many contractors, there is no reason why, as its use becomes more widespread, it should not be used for the submission of relatively small proposals also.

Conclusion
The beauty of ECOS lies in the simplicity of the concept for dealing with the submission and analysis of large and detailed proposals by exploiting the ever-increasing processing power of personal computers. Without such a tool, proposals for major programmes would be almost unmanageable without dedicating large numbers of people to process the masses of detail, whereas with ECOS a relatively small team is able to concentrate on in-depth analysis of the data.

A further major benefit of ECOS is the ability that it provides to build up a database for future analysis and estimating. The data are not only more easily extracted, but also more meaningful as a result of there having been a consistent and disciplined approach to the breakdown of work, and due to the inclusion of the corresponding technical and programmatic details.

ECOS is an excellent example of cooperation between the Agency and Industry to improve the procurement process to their mutual benefit.

Acknowledgement
We would like to take this opportunity to thank the European space industry for its cooperation in developing, and active support in implementing, the ECOS concept, without which the system would certainly not have been such a success.

Electronic Exchange of Information between ESA and Its Partners

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As information is increasingly being handled electronically, the exchanging of that information, for example between different organisations participating in the same project, becomes more and more important.

Electronic Data Interchange (EDI) is a method for the electronic exchange of information, with growing use in industry. It allows organisations to transfer information electronically using an agreed format, and to interpret and use that information as soon as it is received. The information can be exchanged within a few minutes, and the exchange process is independent of the hardware, software or databases used by the participating organisations.

This approach is applicable to some ESA work, in particular communication between ESA and its contractors across Europe. In fact, a group of major industrial contractors has asked ESA to define standards to make the exchange of such information more efficient. The Information Systems Division (ISD) at ESRIN is therefore undertaking a pilot project to demonstrate the feasibility of implementing EDI in ESA work.

Introduction to information exchange

Over the last decade or two and with each successive ESA project, the Agency has automated more tasks. At present, the core of a project, including production of designs, documentation of requirements, and project management and planning, is handled electronically. In fact, the whole satellite and its development process are controlled using information maintained within computerised systems.

As information has been automated, the technical ability to communicate this information has improved, and electronic messages can now be sent to ESA's contractors across Europe in a few minutes. However, exchanging more complex information electronically is far from easy. Every company has different hardware and software, and information created with one suite of software usually cannot be used with another. Documents written by industry often cannot be searched electronically by an ESA engineer, for example, and vice versa.

Even when electronic exchange is possible, each project has a different format for the information exchanged. Therefore, although electronic communication of information between ESA and its partners should be seamless, in practice paper is still the dominant means of communication.

Electronic Data Interchange (EDI) is a method for exchanging electronic information that attempts to address these problems. With EDI, the information is produced to an agreed standard and is then transferred electronically between partners. In that way, the information means the same to both parties, and the partner can use it as soon as it is received, without further manipulation. For example, when one organisation has prepared a plan or a specification, the information can be transmitted electronically to the other party, and then used immediately by the recipient. In that way, EDI also reduces the effect of geographical distance between partners.

Figure 1 shows a simple example of how a document is exchanged using EDI. In this case, ESA is sending a document to a contractor.

EDI effectively 'joins' the partners' computer systems together. The exchange process should therefore be independent of the computer hardware, software or databases used by each organisation involved in the process. The actual communication process can occur by means of public or private communication lines, or can even involve sending a floppy disc by post, as long as the information arrives in time and can be used by the recipient.

Despite the word 'data' in its name, EDI is really about the communication of meaning. Although sending bits and bytes ensures that the other partner receives the information, it does not ensure that the recipient can

Process	Responsibility	Example
ESA application	ESA	Requirements document produced using Framemaker publishing system
Conversion to neutral standard	ESA	Transmission from internal application Document converted to SGML international standard
Communication to EDI system	ESA	Document transmitted from ESTEC to ESRIN Document structure checked & transaction logged at ESRIN
Communication to contractor's system	ESA	Document transmitted from ESRIN to contractor
	Contractor	Acknowledgement of receipt sent to ESRIN
Conversion from neutral standard	Contractor	Document converted to contractor's internal standard Transmission to internal application
Contractor's application	Contractor	Document reviewed and modified using contractor's internal documentation system

Figure 1. Example of document exchange between ESA and a contractor using EDI

properly interpret the information, in the same way as to speak to someone in Japan, you need more than a telephone. Both parties must have a common set of defined terms, and each partner must possess enough cultural understanding to discuss the same concepts. In the same way, the meaning and the format of EDI information has to be defined. Each partner can then retain its hardware, software, standards and procedures, as long as the information being exchanged conforms to the standards.

The use of electronic exchange of information is growing rapidly within industry, and the process is clearly applicable to several aspects of ESA's work. In fact, in March 1992, a group of major industrial contractors asked ESA to define standards to help the contractors exchange information more easily. The Information Systems Division (ISD) at ESRIN has started a pilot project in EDI, using simple, small applications to demonstrate the feasibility of implementing EDI within ESA.

What does EDI mean to an organisation?

Good communication between ESA and its partners is essential to the success of projects. Organisations typically spend 5–15% of their resources on documentation. A large space project, involving contractors in several countries, may spend more because of the large amount of documentation generated. EDI can effectively reduce the 'distance' between partners.

EDI can have a great impact on how an organisation interacts with its partners. It offers several potential advantages to ESA, including:
- Rapid exchange of information between geographically dispersed locations.
- Immediate re-use of information, since no re-typing is required.
- Avoidance of errors usually introduced by the re-typing of information.
- Avoidance of errors introduced by using multiple versions of the information being exchanged.
- Improved structuring of information through standardisation of information.
- Improved productivity through automation and elimination of tasks.
- A single information interface for ESA contractors.
- Exchange of electronic information without intruding upon the contractor's internal computing culture.

However, the costs and benefits of EDI amount to more than saving paper. The costs of implementing EDI lie in:
- Training of staff, including management, to implement and use EDI.
- Management time.
- Reorganisation of internal procedures.
- Software and hardware set-up costs.
- Operations and maintenance costs.

Of these costs, the training and education elements are likely to limit the introduction of EDI. Changing the 'paper culture' will take years rather than months. Both managerial and technical training are required to ensure the success of EDI.

EDI now

EDI is already in common use. Millions of bank transactions, travel information, invoices, and purchase orders, are sent each day using EDI. Each industry tends to have its own EDI system. For example, the automobile industry uses 'Odette', the insurance industry uses 'Limnet', and the retail industry uses 'Tradernet'. The automobile and banking industries have adopted EDI wholeheartedly, and it is impossible to do business with some large companies without using EDI.

ESA is already involved in EDI through electronic mail, invoicing, and the exchange of simple files.

Manufacturing — an example of EDI in use

In industry today, EDI is only one aspect of a modern approach to the quality production of goods. Other aspects include paperless ordering, 'just-in-time' delivery to the point of use, and subcontractors delivering well-made goods every time, on time, and to the proper point.

A visit to a modern computer assembly plant shows EDI at work in a modern quality system. All ordering of computer parts from suppliers and all payments of invoices are done electronically.

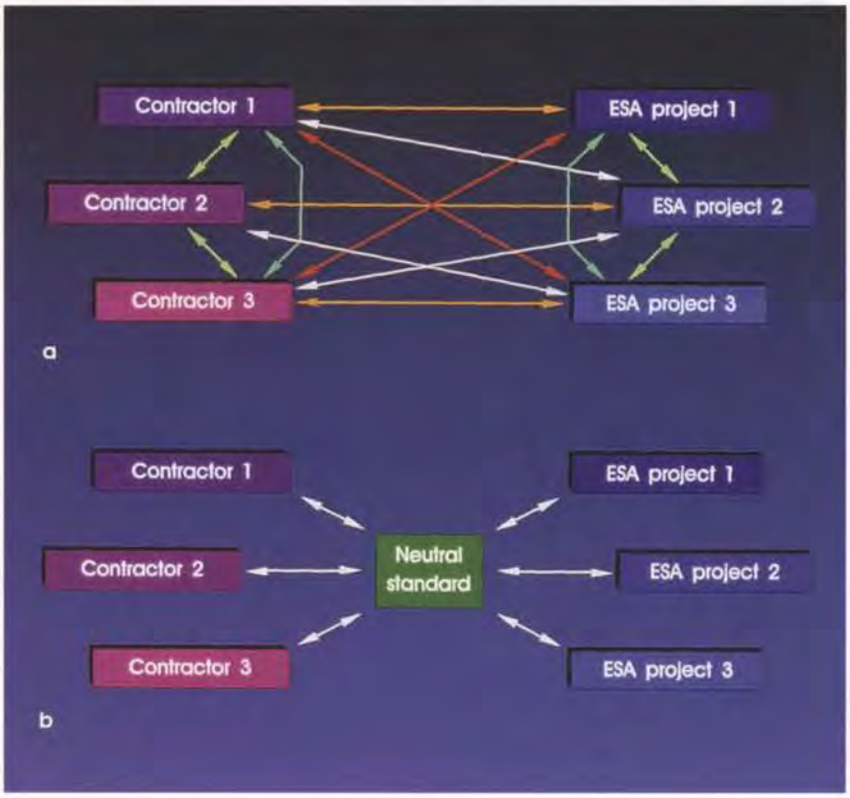


Figure 2a. When each partner defines its own standards for the exchange of information, the latter is often not successful

Figure 2b. Neutral standards are essential for the easy exchange of information

The ordering of computer parts is based on forecasts of the number of computers that customers will order. Each supplier has a standing order which is set for a short period in the future; beyond that time, orders are predicted. When a customer places an order with the computer company, the order is entered into the computer, and the parts needed to fill the order are automatically calculated and entered into the planning system. The orders for the parts needed are then sent electronically to the appropriate suppliers, and the forecasts of orders to the suppliers are changed automatically. No paper orders are ever sent. Using this system, suppliers are better able to schedule the production of the required parts.

Payment to the suppliers is simultaneous with the placement of the order. No invoicing or other human action is required to either send an invoice or acknowledge the receipt of an invoice. In return, the contractors commit to quality and to deliver the proper items on time every time to the right place. Their products are not checked for quality on the production line. Instead, suppliers must guarantee that every part is within the defined quality limits.

By using this approach, the computer company benefits from higher quality assemblies, and reductions in checking time, paperwork and the need for warehousing. This objective, to render the process more efficient, is pursued through a three-year plan with the computer company's major suppliers. EDI is an integral part of this system.

The space industry, which generally builds 'one-off' satellites, cannot completely adopt the same techniques for mass production. However, many principles, tools and techniques of current EDI systems can be modified and used in space-related development. EDI is already used to trim years off the process of vehicle design, for example.

Standards required

Whenever information exchange is discussed, the word 'standards' appears. Ideally, a set of neutral standards, preferably defined by a world organisation, is needed to ensure the successful exchange of information (Fig. 2). There should be a single standard for each type of information being exchanged, wherever feasible. Different types of information include specifications, replies to tenders, and solid models. It would be pointless for different groups or projects within an organisation to develop different

EDI standards for the same type of information. Although each organisation could use its own hardware and software to produce the information, the information must conform to the established international standards if it is to be exchanged efficiently. Indeed, ESA contractors have already requested that ESA's Telematics Board ensure that contradictory standards do not evolve. For some types of information, such as simple documents, such standards exist. However, for other types, such as some aspects of CAD/CAM, the information is more complicated to standardise.

While EDI is only the means to exchange information between different partners, those partners must agree on what will be exchanged, and the format to be used for the exchange. The real, intellectual investment in EDI is therefore the work to establish standards that guarantee that information exchanged electronically can indeed be re-used.

Three established standards which are highly relevant for the EDI pilot are EDIFACT, SGML and X-400. EDIFACT is the de facto standard for EDI in Europe. It was defined by the United Nations to encourage international trading through the containerisation of shipments. Standard Generalised Mark-up Language (SGML) was defined by the International Standards Organisation (ISO) and appears to be becoming the standard for defining documentation. It allows documents to be exchanged between databases or between publishing systems. X-400 is the international standard for the exchange of electronic mail messages.

Better information structuring through EDI
If information must conform to standards, an opportunity exists to make the information more structured and, at the same time, more logical.

Consider an engineer participating in the review of spacecraft proposals submitted to ESA. Over 400 documents had to be evaluated, and approximately 2% of the contents were relevant to one engineer. Imagine if that documentation could have been delivered to ESA electronically, and the engineer could have selected only the relevant material, and concentrated on that information.

Ideally, all documentation could be sent electronically in a neutral, standard format, and the engineer could then search that documentation and print only the relevant information. EDI makes this approach possible.

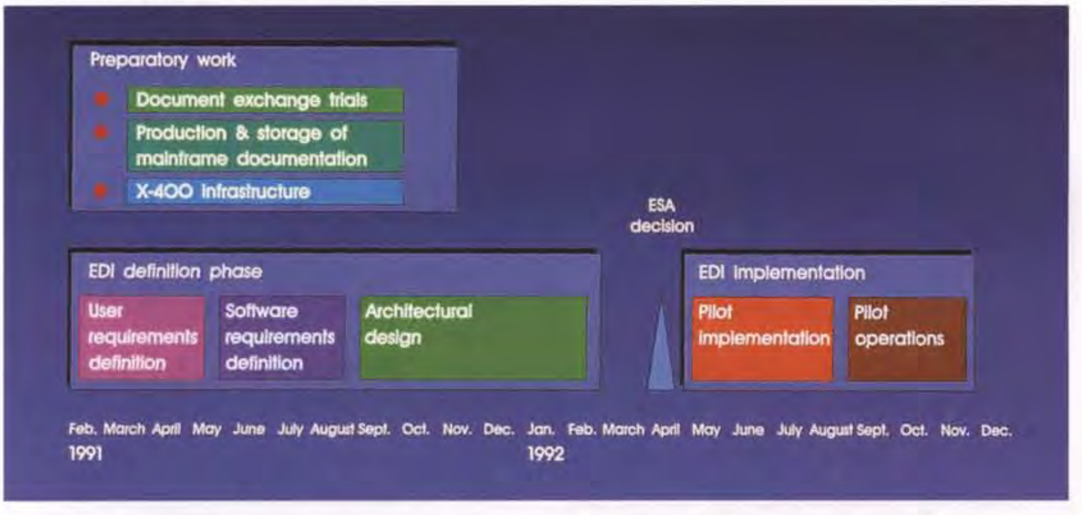


Figure 3. Schedule for the EDI pilot project

What is the EDI pilot project?
In the pilot project being conducted by ISD, six ESA 'customers', i.e. ESA projects or departments, will identify the types of information that they want to transfer electronically, and ISD will determine how this can best be done.

The primary objectives of the pilot project are to:

- demonstrate the technical feasibility of EDI
- examine how EDI can fit into the ESA infrastructure
- generate an estimate of the cost of full EDI implementation
- obtain practical experience at relatively low risk and cost.

This pilot project, which began in February 1991 (Fig. 3), has been divided into two parts. In the first part, which was undertaken during 1991, the architecture for the EDI system was defined. The second part of the project, the implementation phase, will start in March 1992.

The development of the system involves more than the development of software. Training materials, guidelines for the EDI implementation, and standardised EDI agreements to define the exchange with ESA contractors, will be produced. Training, test facilities and support will also be offered to the contractors as they convert their internal systems to conform to the EDI standards.

The partners and their roles
Figure 4 shows the responsibilities of the various partners in the pilot project.

The ESA 'customers' participating in the project are the Agency's Coordination and Monitoring Office; Columbus Programme; Microgravity and Columbus Utilisation Department; Hermes Programme; Space Science Department; and Polar Platform Project. They are responsible for defining the types of information that they want to exchange, and the contractor with whom the information is to be exchanged. These ESA customers are also responsible for ensuring that any changes that are required to their internal software to suit the EDI interface are made.

The ESA contractors are the companies or organisations communicating with the ESA customers. They are responsible for agreeing with the ESA customer on the type of information to be exchanged, and on the standard to be used. They will also implement the required changes to their own infrastructure, including their hardware and software, and will make the interfaces to the communications medium and the link to the nearest ESANET node.

The Information Systems Division (ISD) at ESRIN, in Frascati (I), is managing the overall development of the EDI system. The ESA Computer Department (ECD) will implement the changes required to applications software within ESA as a result of the pilot project. In practice, ECD will assist ESA customers and participating contractors with the definition and testing of the software interfaces between their existing applications.

The main contractor for the EDI system is Digital Equipment Corporation (DEC) of France. That contractor will also produce implementation guidelines and standardised EDI agreements to define the exchange with the contractors, and will prepare training material.

User requirements
In the first phase of the pilot project, the ESA customers, in cooperation with their contractors, defined the types of information that they want to exchange; this is primarily complicated information at irregular intervals. This contrasts with current EDI systems where large amounts of relatively simple information, such as electronic mail and invoices, are exchanged. Rather, they want to exchange documentation such as specifications and problem reports, and project-management information such as work-breakdown structures and schedules (Fig. 5). There is also a need for the exchange of information contained in databases, such as non-conformance reports and definitions of experiments.

Partner	Responsibilities
ESA customer	Definition of information to be exchanged Identification of contractor with whom information to be exchanged
ESA contractor	Agreement on information to be exchanged and standards Modifications to own infrastructure Communication to and from internal systems
ESRIN Information Systems Division (ISD)	Development and operation of EDI systems Communication to ESA internal infrastructure Definition of formats for exchange process
ESA Computer Department (ECD)	Changes to internal applications Communication within ESA
ESRIN Technical Operations Division (TOD)	Communication outside ESA

Figure 4. Roles and responsibilities within the EDI pilot project

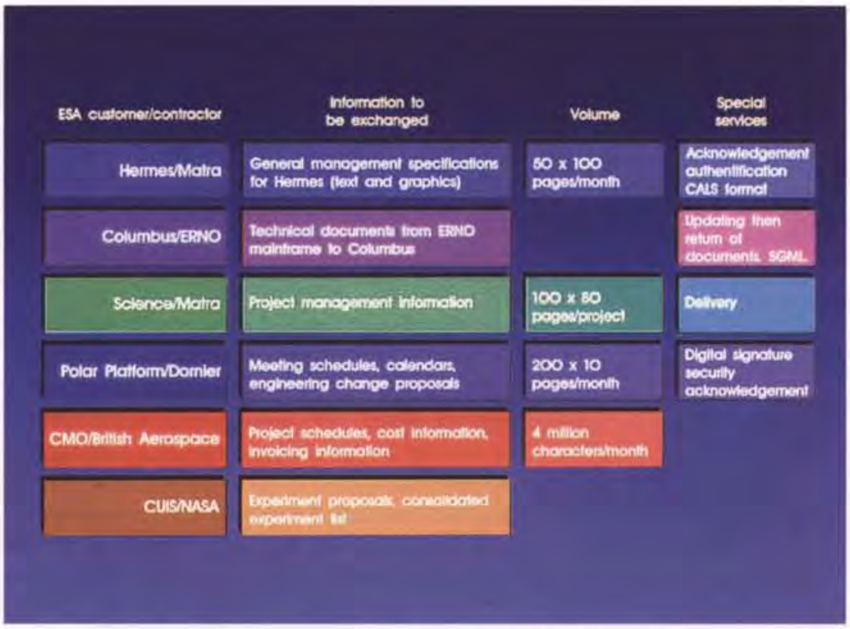


Figure 5. Summary of user requirements for the EDI pilot project

Current status of the pilot project

The architecture for the EDI system has been defined. The implementation phase will start during 1992.

The main software has been chosen. It consists primarily of existing commercial packages which will be installed on a VAX computer at ESRIN in Italy. Later versions of the software will probably be distributed to several ESA sites.

As might be expected, the major difficulty has been handling the large number of interfaces between ESA customers and contractors. In addition, the reaction from industry has been welcoming, but careful. Each contractor has a task similar to ISD's, to make its management more aware of the advantages and disadvantages of EDI. To assist those involved, training material has been generated and presentations given to the major contractors and to participating staff within ESA.

The pilot architecture

The major functions of the pilot project are shown in Figure 6. The on-line EDI system handles the day-to-day transactions between the ESA application and the contractor, and performs the necessary logging and security functions. The system may have some basic 'conformance checks' that ensure that information is structured as it should be.

The communication function moves the information electronically to the appropriate location within ESA or to the contractor.

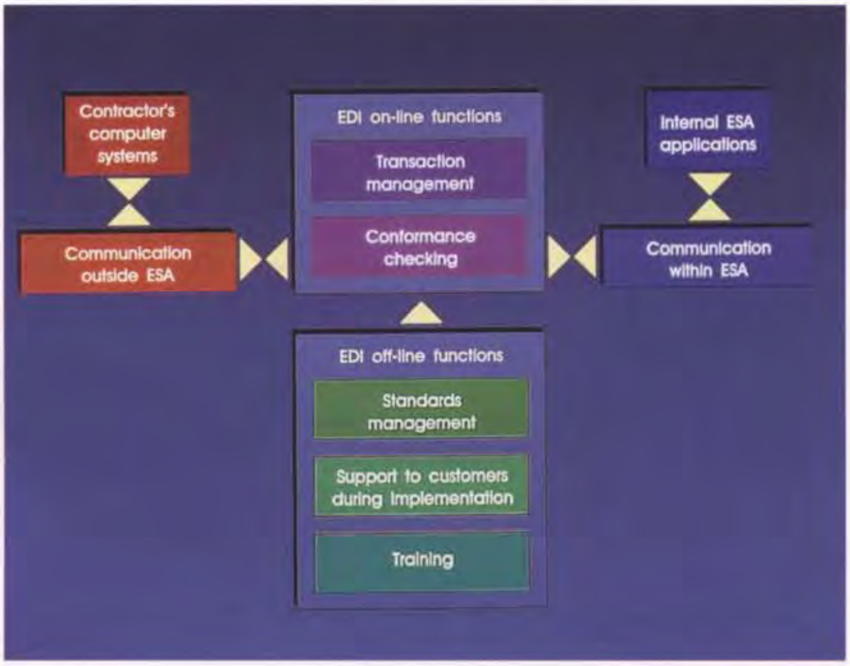
The off-line tasks involve managing the information-exchange standards, introducing new users to the system, assisting contractors in applying the guidelines, interpreting details of the standards, and conducting test exchanges.

Other work in preparation for EDI

EDI is, in fact, only a single component in an organisational information strategy. The EDI pilot builds on the existing ESA computing infrastructure and on the background work undertaken by a variety of ESA establishments. That preparatory work was necessary to ensure that the EDI solutions will function. It primarily involved defining, testing and implementing various international standards.

A standard is being defined for the exchange of project management information. In the past, different ESA projects have implemented several standards for the exchange of project-management information between ESA and its contractors, and also within ESA. However, an ISD analysis showed that a single standard could encapsulate all of the different project-management information sets currently being exchanged. Since an international standard does not yet exist, ISD has asked the organisation that is responsible for the EDIFACT standard to define a project-management information exchange standard. Such a standard will mean that an ESA contractor will need only one interface for its project-management system, no matter how many ESA projects that contractor is participating in. During the pilot project, the Coordination and Monitoring Office in Paris will test that standard.

Figure 6. Functional definition of an EDI system



Other related work undertaken by ESA has involved the definition of common project documents using the international standard SGML. During 1991, ISD ran an SGML trial for the Hermes Programme with the support of Bureau van Dijk (Belgium). The objective was to investigate SGML in a 'real case' situation, which was the creation of a small full-text document repository.

Four standard types of documents (agendas, minutes of meetings, working papers, and technical documents) were structured. Sample documents were encoded with SGML tags. A prototype repository with a text-retrieval system was built and tested. It allowed navigation through the documents and their tables of contents; use of hyperlinks, for example, to produce a glossary; display of graphics and figures; and development of flexible style sheets. Some basic search functions were also available. The system worked well, but it also highlighted practical problems with SGML and the tools used to handle SGML that are currently available.

The ESA Computer Department (ECD) is also conducting trials with SGML standards. Their findings will impact upon the EDI pilot. A study conducted with Brine (Switzerland) concentrated on how to produce uniform documents using a range of different computer systems within ESA, and the storage of SGML documentation in databases. This work enabled ECD to assess the effort involved in developing and using a more structured approach to documentation. ESA has also been developing links between the internal infrastructure and the world standard for communications, X-400. This communication structure will be used during the pilot project.

In late November 1991, ISD sponsored a workshop at ESRIN on the storage of compound documents, to discuss the requirements, standards and methods for handling documentation with industry. More than 70 members of ESA and industry attended the meeting. The EDI pilot was discussed, and the feedback received will shape future EDI developments.

Principles of the pilot project

The basic principles of ESA's approach to EDI are:

- One standard for one type of information.
- Use of commercial products.
- Use of the existing infrastructure.
- No imposition of software on the contractors.
- The users are the experts.
- Training and education are integral to the success of EDI.
- Use of an experimental but structured approach.

Each of these principles is discussed below in more detail.

One standard for one type of information

An ESA contractor should only need a single interface to exchange a single type of information with ESA. In the past, different projects have required that contractors use different information standards.

Use of commercial products

Wherever possible, the EDI development should use commercial software rather than develop software specific to ESA. A market has already emerged for EDI products, and ESA can choose from the best available products.

Use of the current infrastructure

The EDI pilot uses ESA's current infrastructure. For example, as already mentioned, ESA is building a communication 'highway' based on X-400, the ISO standard for electronic messages. This will be used by the EDI system for communication with external parties. The internal connection from X-400 to the ESA electronic mail system (PROFS) is already available at ESA sites.

The EDI pilot also uses existing international EDI standards rather than defining space-specific standards. The United Nations has led in setting standards for EDI, with its EDIFACT standard. This is the obvious standard with which to start because the documentation and software tools already exist. However, all three standards will be tested in the pilot.

No imposition of software on contractors

A contractor may be involved in several dozen different projects, most of which do not involve the space business. ESA accounts for only a small percentage of the business of many of the companies with which it works, and cannot hope to dictate infrastructural decisions such as the choice of EDI software. Past experience shows that such a policy is costly, difficult to maintain, and intrusive upon the contractor's computer culture. However, the pilot project will provide guidelines to help implement the changes necessary at the partners' sites.

The EDI system must concentrate on the information to be exchanged, and the performance of the exchange mechanism. It should interfere as little as possible with how ESA or the partners work internally. Of course, because ISD is primarily using commercial software for the EDI pilot, a contractor is free to use the same software, but this must be that company's own decision.

The users are the experts
The EDI project will be driven by the users' needs. They know best what information will be exchanged, and who it will be exchanged with. If specialists can determine an information standard, that standard should be adopted. Users will exercise the appropriate level of control over the project while leaving ISD with the freedom to develop the system in a professional manner.

Training and education are integral
Training and promotion are an integral part of the EDI pilot project, and not an add-on. The contractor developing the software, DEC, is also providing management and technical lectures, guidelines on implementation for ESA contractors, and manuals for users. As part of the the pilot project, ISD is striving to produce tangible results in small areas in order to develop the commitment necessary for the success of the project.

Use of an experimental but structured approach
EDI is new, still evolving rapidly, and relatively high-risk. In addition, because of the pioneering nature of the work, some partners can be expected to leave the project and there will be some problems with equipment and software.

A prototyping, small-scale approach to the development reduces the risk-to-cost ratio, but discipline is still required. The ESA Software-Engineering Standard (PSS-05) is being followed, and the roles and responsibilities of all participants have been defined carefully and agreed upon in advance. The fulfilment of the user requirements is being emphasised. Compared to a usual software project, there are many more interfaces to be considered, and greater effort must be devoted to training and education.

Each ESA customer will pay towards the pilot project, but the customer's major investment is in tracking the development of the EDI pilot and managing all aspects of their own EDI implementation.

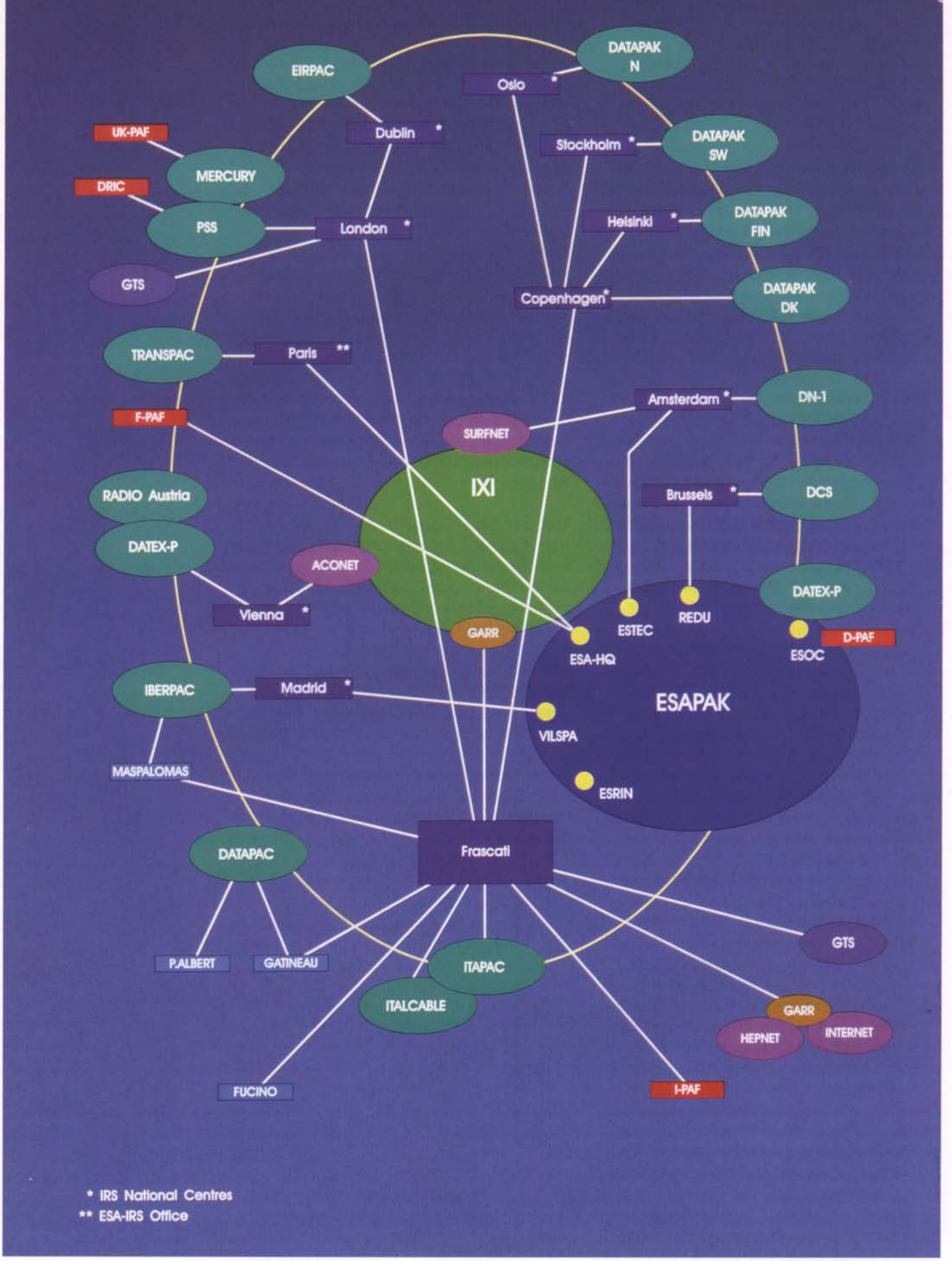
Each contractor will be supported with help, lectures, implementation guidelines and testing facilities, but in turn remains responsible for all necessary changes to their own hardware and software. Each contractor must nominate an internal 'champion' who will convince their own management of the role of EDI and its importance for the company. Although ESA will support the contractor throughout the implementation of EDI, the commitment to the success of the project must come from the contractor. The contractor does not fund the project, nor does ESA fund the contractor.

Conclusion
ISD is using the pilot project to verify the technical aspects of EDI and to prove that information can be exchanged rapidly and effectively across Europe, reducing the effect of geographical distance and national boundaries. The results obtained will support ESA's management decision on how to progress with the technology. ESA is in a natural position to act as a coordinator for information exchange within the space industry.

The pilot project is still in an early phase, but both European industry and the ESA projects have responded positively to EDI. From the managerial viewpoint, EDI has many potential difficulties, none of which are insurmountable, but all of which require attention. Much of the background work required to make the pilot project a success has already been performed. EDI must be pursued incrementally, using international standards and commercial products.

ISD is confident that the success of the pilot project will lead to a more general application of EDI within the space community.

Figure 1. The ESA Data Dissemination Network (DDN)



ESA's Data Dissemination Network Management Centre (DDNMC)

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BIM Information Technology, Everberg, Belgium

The new Data Dissemination Network Management Centre is a modern Network Management System (NMS) that has just been developed by BIM SA (Belgium) for ESRIN to provide improved monitoring of and control over the Agency's data dissemination network. As a very advanced product in the network-management area, the DDNMC concept was exhibited in October 1991 at Telecom'91 in Geneva, the World's premier forum for global telecommunications operators, where it attracted considerable interest.

Introduction

The Data Dissemination Network (DDN) engineered and managed by ESRIN is one of the three major ESA data networks and is dedicated to the support of the services that ESRIN offers mainly to external users, i.e. information-retrieval services (IRS, ESIS, CUIS) and earth-observation-related data dissemination (e.g. ERS-1 products).

The DDN (Fig. 1) is effectively an X.25 private Wide-Area Network covering all of Europe and offering users convenient access to ESRIN's services. DDN Access Points (based on X.25 Satelcom Megapac nodes) in every ESA Member State provide users with local access to the DDN, thus relieving them of the burden of setting up and maintaining international calls. Until now, the DDN has been operated with the help of proprietary heterogenous management tools that had the inconveniences of presenting operators with several different man/machine interfaces and of making the correlation and concatenation of network management data difficult.

It was this need to improve the management of the DDN that triggered the development of the DDNMC. Access to information services at ESRIN has to be reliable, whatever the user's entry point. Good network management guarantees the quality of service that the user requires, namely that of a local connection to the service. This means that faults in the network have to be quickly detected, isolated, corrected and, as far as possible, also prevented by efficient monitoring. It means also that the maintenance and evolution of the network have to be duly controlled. Finally, good network management allows the network manager to keep abreast of the state of the network in terms of both trouble-shooting and maintaining statistics, as well as helping with the planning of the system's future evolution.

Given that high-quality service was becoming difficult to provide with the existing management tools, and no suitable off-the-shelf candidate for their replacement was available, ESRIN decided in 1989 to initiate its own development of the network-management system deemed necessary for more efficient operation of the DDN.

How the DDNMC improves DDN management

Compared to current proprietary network-management systems, the new DDNMC provides substantial improvements in a number of key areas:
- an easy-to-use man/machine interface (MMI)
- a centralised system
- compliance with ISO (CMIP) standards
- an open and scalable system.

Easy-to-use MMI

Based on the AIDA X tool kit, the DDNMC man/machine interface (MMI) provides the operator with a highly sophisticated yet user-friendly means of operating the DDN. Unlike many MMIs, the DDNMC's MMI allows easy customisation of the wide-windowed colour screen.

Independence of the MMI from the management information tree that represents the DDN internally within the DDNMC database allows for any graphic representation of the network; e.g. mixing in a DDN overview of its components at different network levels.

The DDNMC MMI has been built on the concepts of simplicity, consistency and efficiency. Simplicity ensures that no extraneous information invades the screen and that the information that is presented is clearly visible and the icons are easily understandable. Consistency means that: all windows have the same aspect; particular mouse buttons and graphical effects are always used for the same purposes; and menus, error messages, and dialogue boxes are always in the same locations. Efficiency not only means quick response times, but also timely display of relevant information and prompt on-line help.

Such an ideal MMI is obviously consuming in terms of developmental effort, but the result is a DDNMC that is readily acceptable to, and can be used efficiently by, a wide spectrum of operators, leading in turn to substantial gains in productivity.

Centralised system

The modular design of the DDNMC, founded on a common basic software environment, allows the functions currently distributed across separated heterogenous management tools to be centralised.

The ISO concept of 'managed objects' will be fully implemented in the DDNMC to accommodate network components emanating from different manufacturers. These components will be viewed by the DDNMC as belonging to well-identified classes in which a generic object represents each type of component (physical or logical). For non-standardised components, an 'agent' (or 'proxy') either internal or external to the DDNMC presently serves as an interface between the proprietary and the ISO worlds in such a way that the DDNMC sees only standardised objects. For future standardised objects, the 'agent' will be part of their management software, allowing the DDNMC to dialogue directly with them.

Centralisation thus means that screen monitoring and control of all network components will be possible in a standardised way, whatever their specific functions (e.g. a Megapac node will be managed in the same way as a Telematics node offering the same services). Centralisation does not imply, however, that all modules have to be crammed into a single machine. Thanks to the modular design and the capabilities of UNIX, it is possible to distribute the software in as many 'black boxes' as are necessary without loosing the integrated view of the DDN on the operations screen.

The expected gains in productivity derive naturally from the centralisation of operator tasks. Not only will the management of the DDN be easier, it will also be possible to correlate alarms, to perform global inventory control, and to compute statistics from traffic observation and events logging. The complete history of the DDN will also be available thanks to the centralisation of archives.

Compliance with standards

The DDNMC wholly follows the OSI Management Standards (CMIS/CMIP) as specified by the Network Management Forum (NMF) group applying ISO Recommendations. A key issue is whether the DDNMC is to be 'open', in order to manage future standardised network objects and interconnect with other compliant management systems. This also ensures a certain continuity in the DDNMC's future.

Agents will exchange information on managed objects via the CMIS/CMIP protocol. Descriptions of the DDN components/objects (either physical or logical) are maintained in a conceptual repository called the 'Management Information Base' (MIB). The MIB is further subdivided into a 'Management Information Classes' (MIC) database containing a description of all types of DDN objects (the classes) with their properties (attributes) and methods (notifications they can send and actions they can perform), and a 'Management Information Tree' (MIT) containing the actual DDN objects. These standardised fundamental representations of the network ensure that the DDNMC can share its management world with other standardised systems whilst still keeping DDN management consistency. The MIC and MIT implementations also allow for flexibility and evolutivity in the DDN configuration (see below).

Open and scalable system

To cope with the continous change and growth in the DDN, the DDNMC has to be both flexible and scalable. Openness is provided not only by the use of management standards (see above), but also by the careful choice of state-of-the-art hardware and software technology.

The hardware selected for the DDNMC is a SUN Sparc workstation with high-resolution colour graphical display. The basic software includes various industry standards like UNIX and X-Windows. The DDNMC database is the object-oriented database from ONTOS.

The software was developed in C++, making extensive use of the object-oriented approach.

Currently, the DDNMC configuration involves two Sparc work stations, one for the DDNMC itself and one for the Megapac proxy, which is a black box as far as the operator is concerned. The addition of other proxies or of other important modules, such as an expert system for fault isolation (a prototype has been developed for that purpose by ESRIN), is then possible thanks to a distributed processing approach (a special inter-process communications protocol has been devised by BIM for that purpose).

The DDNMC implementation

DDNMC architecture

The DDNMC software architecture is based on local managing processes that communicate with each other through specific protocols based on an IPC mechanism that benefits from the high throughput of UNIX-kernel-based communications facilities (this mechanism also transparently allows some processes to be ported to other machines if necessary). One of those IPC-based protocols offers the same services as the standard OSI CMISE. Parallelism inside the processes themselves is also allowed, thanks to the Sun operating system's 'Light Weight Processes Facility'. Data structures inside processes are C++ object instances and ONTOS C++ objects that can be stored and retrieved in the DDNMC database.

With the exception of the MMI manager, all other processes are running as background servers that respond to requests they receive, and can emit auxiliary requests in order to complete the responses. These processes are triggered by input sources of such events as IPC, CMIP, etc.

The main processes of the DDNMC are the MMI, Start-up and Control, the MIB, Event Analysis and Dispatch, and Event Configuration. Around these kernel processes, the other DDNMC processes are Traffic Observation, Statistics, Trouble Ticketing, DDNMC Agent, Host and Path Testing, the Routing Manager, etc.

DDNMC managing functions

The DDNMC managing functions may traditionally be presented as monitoring and control functions (Fig. 2).

The monitoring functions consist of collecting events (i.e. alarms and other management information), analysing and dispatching them. To collect events occurring in the DDN, the DDNMC either waits passively for their automatic sending by agents of managed objects (in particular the Megapac proxy which forwards the DDN node events) or tries to generate them by launching tests on the network (see below). All events are collected in a unique event-analysis module that receives them from different sources, stores them in a history log, and forwards them to a configurable filtering process. The filtering process can forward, count, update or correlate events. Correlation (currently based on simple pattern matching) may produce new events, which are then forwarded to the event collector (Figs. 3,4).

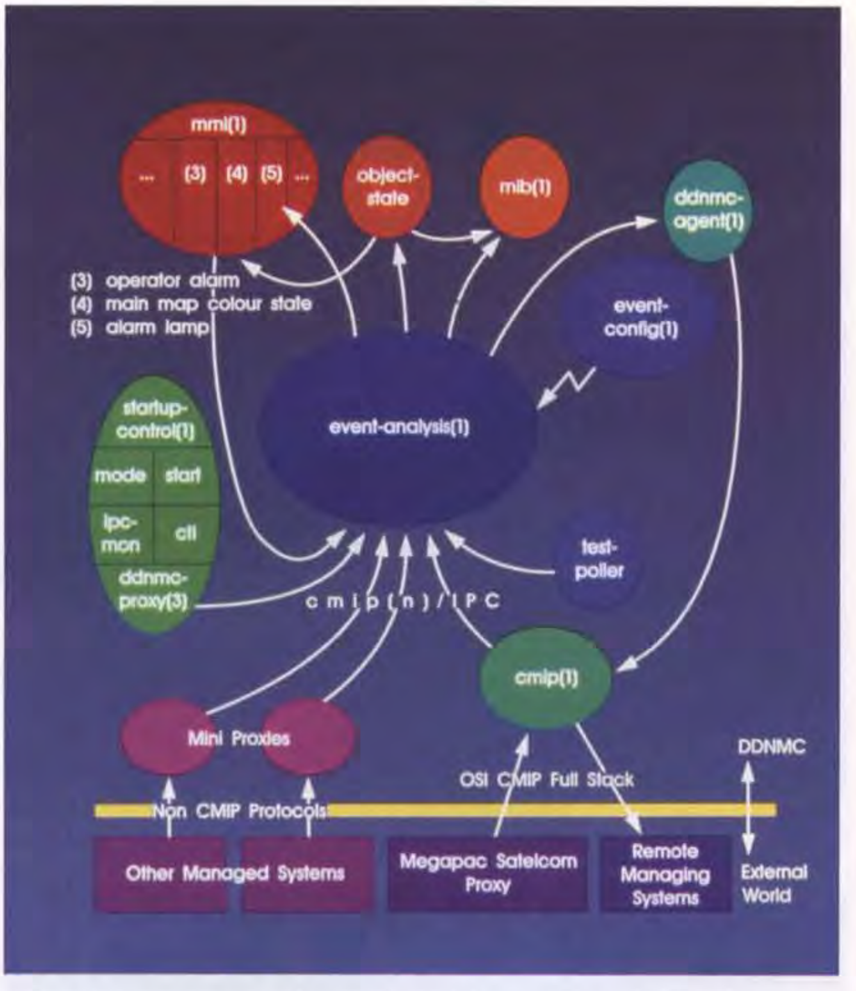


Figure 2. DDNMC event management

Finally, analysed events are dispatched to the various DDNMC modules to trigger some action or to reflect the occurrence of problems (particularly status changes) on the MMI.

Presently, the DDNMC collects events from the DDN X.25 equipment, the ESRIN X.400 central server, the IRS database front-end processors, the ERS-1 dissemination network supervision centre, and the DDNMC itself. It is important to note that no event is ever lost by the DDNMC, but that their utilisation is under the control of the network manager or the operator through the filtering and dispatching facilities. The presence of alarms and the number of outstanding alarms (i.e. those not yet cleared by the operator) are always displayed in the permanent status window (not erasable) of the DDNMC screen.

The DDNMC is also able to launch – either automatically or via operator intervention – tests (based on X.25 calls) on the network to verify the DDN connectivity or the availability of information-service hosts. Calls may be force-routed through given paths of the DDN to ensure that a user connection is possible from local or remote DDN access points to the ESRIN services. Failure of a given connection is reflected on the DDNMC screen up to the last decomposable part of the path that causes problems by repetitive calls circumventing that part. A host test simply checks for the return of the host prompt.

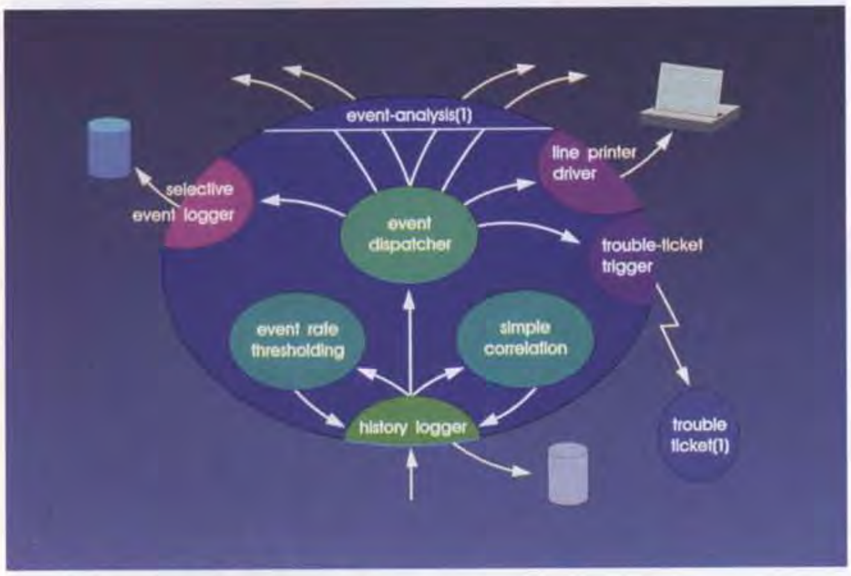


Figure 3. The DDNMC event-analysis process

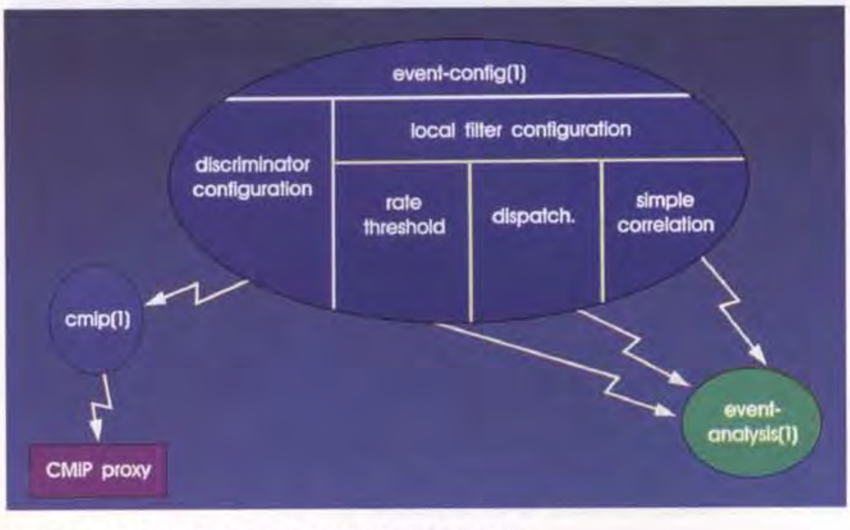


Figure 4. The DDNMC event-configuration process

Control of the network is provided by means of online configuration functions that allow the network manager or the operator to inspect and modify all DDN parameters from a centralised point. Configuration parameters include equipment settings like modem speed, but also more complex objects like the routing tables of the DDN X.25 nodes.

Inventory control is performed via a map showing all equipment, both active and spare, along with the number of operational items and the number of spare components. Thresholds can be set on such numbers to generate an alarm if they are violated.

Finally, the managing functions include traffic observation and statistics that can be tailored for dedicated purposes, e.g. by service providers. Various report templates can be interactively defined and processed either at the operator's specific request or automatically. Libraries of pre-defined statistics will be made available for standard operations.

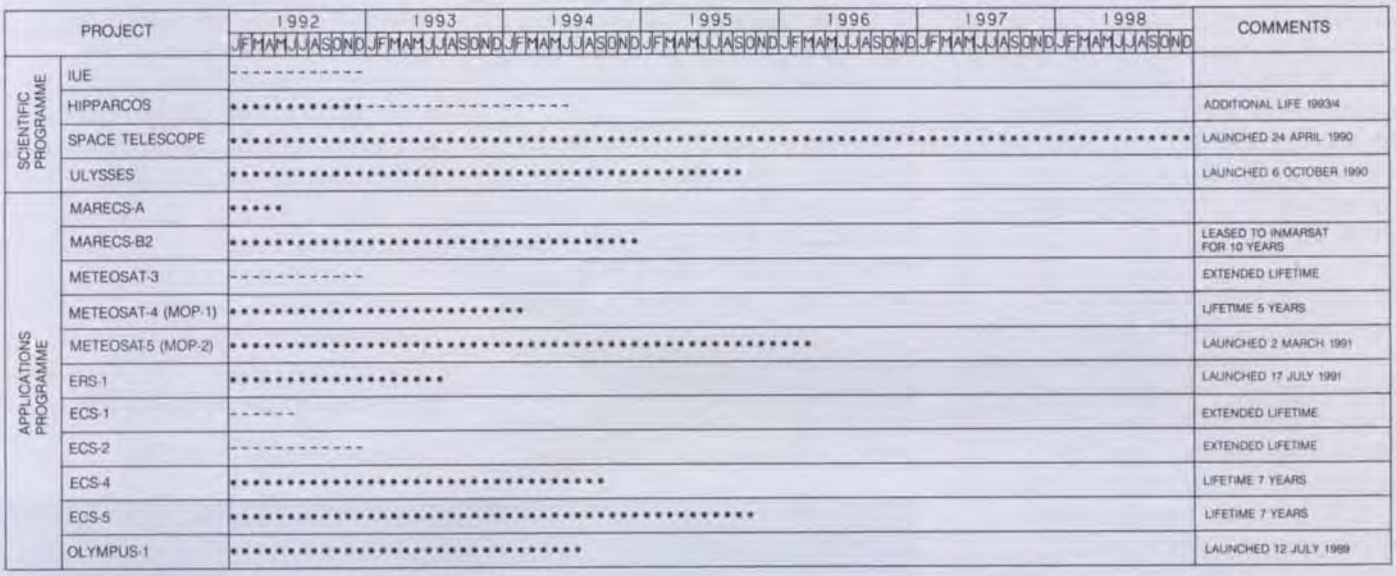
Conclusion

The new DDNMC became operational at ESRIN in March 1992. Its development has taken two years and represents about 100 manmonths of effort, which compares very favourably with the figures usually quoted for developing similar systems.

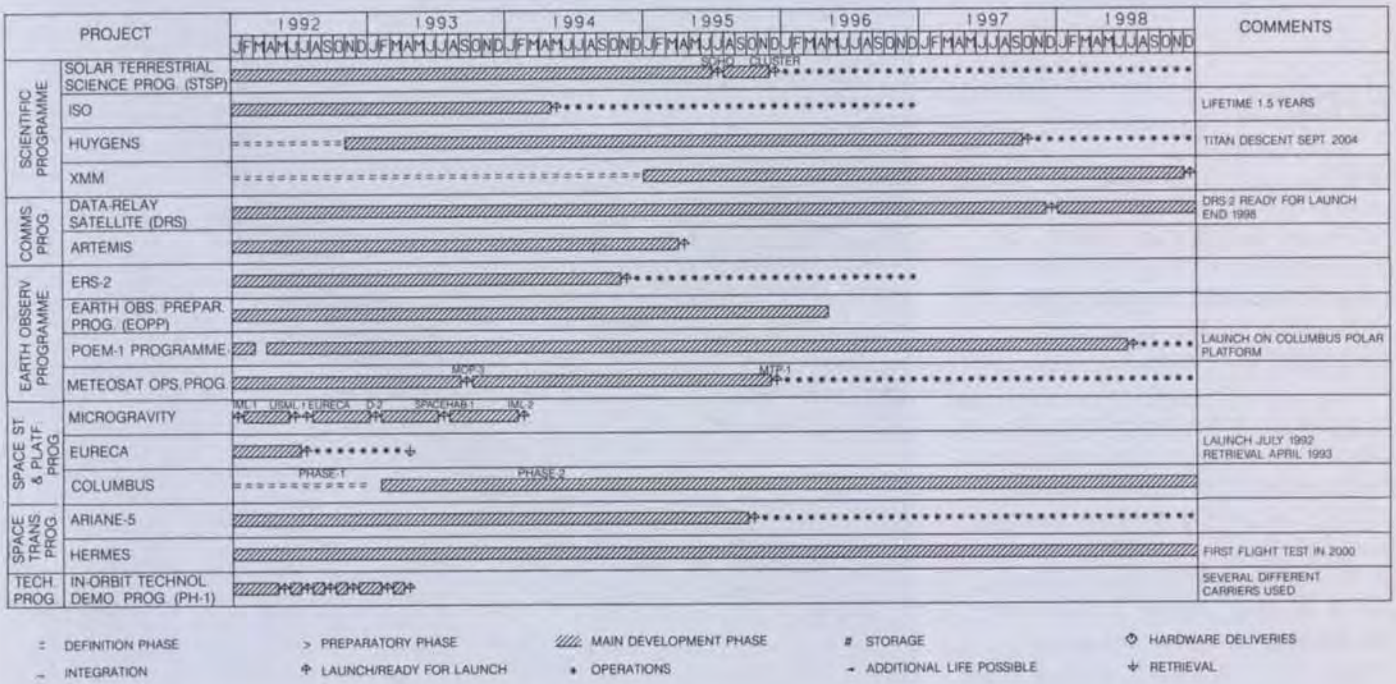
With ESA's commitment to the development of this modern Network Management Centre, ESRIN's users can look forward to the two-fold benefit of a very high quality of service, in combination with reduced DDN operating costs.

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

In Orbit / En orbite



Under Development / En cours de réalisation



Hipparcos

Fin novembre 1991, le satellite d'astrométrie Hipparcos est parvenu au terme de sa deuxième année de collecte de données scientifiques – ce qui est suffisant pour permettre l'établissement d'un catalogue extrêmement précis des positions, mouvements et distances stellaires.

Certains des premiers résultats scientifiques ont fait l'objet d'un article dans le no. 69 du Bulletin de l'ESA. Tous les travaux d'essai et de vérification conduits sur les données astrométriques et photométriques confirment la qualité et la fiabilité de ces résultats. On devrait continuer d'assister à de rapides progrès dans le domaine de l'exploitation des données étant donné que le rythme de traitement de l'énorme volume de données de la mission est en train de rattraper celui de leur production par le satellite.

Pendant les trois derniers mois, l'exploitation du satellite s'est poursuivie comme à l'ordinaire et le véhicule spatial, toujours en bon état, dispose encore d'une charge utile entièrement redondante (détecteur compris). La collecte des données reste supérieure à 60%. La cause scientifique d'une prolongation de l'exploitation du satellite jusqu'à épuisement des fluides disponibles pour la charge utile (vers la mi-1994) sera plaidée devant les groupes consultatifs de science spatiale dans le courant de l'année.

ERS

ERS-1

Le satellite a parfaitement fonctionné sur le plan technique: les résultats de la plate-forme sont tout à fait conformes aux spécifications et tous les modes opérationnels de la charge utile fonctionnent correctement.

La phase de recette en orbite a été menée à bonne fin et s'est achevée à la mi-décembre 1991 par une expérience de deux jours sur le mode de basculement en roulis qui a permis de donner au SAR un angle d'incidence à pente plus forte, particulièrement adapté aux observations terrestres. Le satellite a ensuite été placé sur une nouvelle orbite, avec un cycle de récurrence de trois jours, pour la phase d'étude des glaces qui devrait durer jusqu'à la fin du mois de mars 1992.

L'ensemble des résultats de la phase de recette, y compris les détails de l'étalonnage et l'évaluation du fonctionnement, seront présentés et passés en revue lors de la réunion qui se tiendra à l'ESTEC (NL) en avril 1992 et qui réunira des industriels et des chercheurs.

Le Centre de contrôle et de gestion de la mission (MMCC), installé à l'ESOC, à Darmstadt (D), continue de suivre les activités de la station de Kiruna, de réaliser toutes les manoeuvres nécessaires, de planifier la mission et de manipuler les instruments.

Les revues du MMCC et l'expérience de l'exploitation de la station de Kiruna ont déjà débouché sur un certain nombre de progrès et de mises à niveau qui serviront à améliorer les activités opérationnelles d'ERS-1.

Le secteur sol de la charge utile a donné satisfaction. Il a servi au soutien des phases de 'recette' et 'd'étude des glaces'. On a procédé à des ajustements, des améliorations et à un réglage précis afin d'améliorer le service rendu aux utilisateurs. La communauté scientifique commence déjà à recevoir les données dont elle a besoin pour ses recherches.

L'installation centrale ERS-1 d'Earthnet (EECC), à l'ESRIN (I), continue de traiter les demandes de produits et d'acquisition de données adressées par les utilisateurs et de planifier les activités du satellite et du secteur sol.

Le service de contrôle des produits continue de suivre l'exploitation des stations sol de l'ESA et la qualité des produits à livraison rapide (FD). Il a également contribué à valider les systèmes d'acquisition des stations sol étrangères, ainsi que les produits des installations de traitement et d'archivage (PAF) et des stations étrangères.

ERS-1 image of Southern Holland

Le sud des Pays-Bas vu par ERS-1

Hipparcos

As of the end of November 1991, the astrometry satellite Hipparcos completed two years of scientific data collection — sufficient to allow the construction of a highly accurate star catalogue of positions, motions, and distances.

Some early scientific results were reported in ESA Bulletin 69. All tests and verifications made on the astrometric and photometric data confirm the high quality and reliability of these results. Further rapid progress in the data exploitation is now expected as the 'mass' mission data processing catches up with the satellite data production.

Satellite operations have continued routinely over the last three months, and the spacecraft continues to be in a very healthy state, with full payload (including detector) redundancy still available. Data collection has remained above 60%. The scientific case for extending satellite operations until the end of available payload consumables (around mid-1994) will be presented to the Agency's scientific advisory groups later this year.

ERS

ERS-1

The technical performance of the satellite remains excellent, with platform performance well within specification, and with all core-payload operational modes working correctly.

The in-orbit commissioning phase was successfully concluded by mid-December 1991, with a two-day roll/tilt-mode experiment giving a steeper SAR incidence angle particularly suited for land applications. The satellite was then successfully moved into a new, shifted three-day-repeat orbit cycle for the 'Ice-Phase', which is planned to last until the end of March 1992.

Overall Commissioning-Phase results, including detailed calibration and performance assessments, are to be presented and reviewed, with both industrial and scientific participation, at a meeting in April 1992 at ESTEC (NL).

The Mission Management and Control Centre (MMCC) at ESOC in Darmstadt (D) has continued to control the Kiruna station operations and to execute all necessary spacecraft manoeuvres, mission planning and instrument operations.

Reviews of MMCC and Kiruna station operations experience have already resulted in a number of improvements and upgrades to be implemented in support of ERS-1 operations.

The ERS-1 payload ground segment has operated satisfactorily and supported both the 'Commissioning' and the 'Ice' phases. Adjustments, improvements and fine tuning have been incorporated to improve the service to users. The scientific community has already started to receive the data that it needs for its research endeavours.

The Earthnet ERS-1 Central Facility at ESRIN (I) has continued to handle user requests for data acquisition and products, and to plan the spacecraft and ground-segment operations.

The Product Control Service has continued to monitor the ESA ground-station operations as well as the quality of the Fast-Delivery Products. It has also supported validation of the foreign ground-station acquisition systems and of the Processing and Archiving Facility (PAF) and foreign-station products.

The Fucino (I), Gatineau (Can), Kiruna (S), Maspalomas (E) and Prince Albert (Can) Stations have regularly acquired the scheduled passes. Raw SAR data have been shipped to the PAFs for final archiving. The Low Bit Rate (LBR) data acquired daily from the 14 orits have transmitted to the Fucino station for transcription onto optical disk.

In addition, the LBR and SAR data fast-delivery processing and dissemination to users has continued at Fucino, Gatineau, Kiruna and Maspalomas. Fast-delivery precision and geocoded SAR products have been generated both for distribution and for promotional activities. LBR and SAR sample products have been disseminated to over 200 users to familiarise them with ESA products.

The German PAF has reached full operational status, generating large quantities of SAR products (precision, geocoded, fast-delivery, quick-looks and copies). The French PAF has started routine distribution of copies of Global Radar Altimeter and Windscatterometer fast-delivery data. Operational data archiving has been added to the ongoing development activities and validation capabilities at the British and Italian PAFs.

All national and foreign stations have acquired and archived SAR data within their coverage zones. Products from the Tromsø, Canadian and Alaskan Stations have been validated and their distribution authorised.

The contract with the ERSC (Eurimage, Radarsat International and Spotimage) Consortium for ERS-1 data promotion and distribution has been signed.

Evaluation of the results of the Haltenbanken Wind/Wave Campaign has started, indicating excellent quality in general for the campaign data as well as consistency between the satellite wind/wave and in-situ gathered data.

ERS-2

ERS-2 has continued to progress satisfactorily as regards all the main elements of the payload and the platform.

Following the concluding of the more than 50 subcontracts and the subsequent finalisation of the main contract negotiations, agreement was reached on the Prime Contract with Dornier (D), which was formally signed in February 1992.

Modifications to PRARE-2, as a result of the investigations of the PRARE-1 malfunction on ERS-1, have been defined and are being implemented.

Olympus

The satellite has continued to provide service to users during the 'transition phase' following the in-orbit anomalies encountered during 1991.

Television broadcast channel 24, which is normally assigned to RAI, the Italian broadcasting organisation, has been used on behalf of the European Broadcasting Union (EBU) for the demonstration of HDTV from the Winter

Les stations de Fucino (I), Gatineau (Can), Kiruna (S), Maspalomas (E) et Prince Albert (Can) ont reçu normalement les données du satellite lors des passages prévus. Les données SAR brutes ont été envoyées aux PAF pour archivage final. Les données à faible débit (LBR) acquises chaque jour sur les 14 orbites ont été transmises à la station de Fucino pour qu'elles soient retranscrites sur disque optique.

En outre, Fucino, Gatineau, Kiruna et Maspalomas continuent à traiter les produits FD de données SAR et LBR et à les diffuser auprès des utilisateurs. Des produits SAR FD de précision et géocodés ont été élaborés à des fins de distribution et de promotion. Des échantillons SAR et LBR ont été diffusés auprès de plus de 200 utilisateurs afin de les familiariser avec les produits de l'ESA.

La PAF allemande est maintenant tout à fait opérationnelle et fournit de grandes quantités de produits SAR (de précision, géocodés, à livraison rpide, à visualisation rapide et copies). La PAF française a commencé à distribuer régulièrement des copies des données FD de l'altimètre radar et du diffusiomètre vents. On a ajouté aux activités de développement en cours et aux capacités de validation des PAF britannique et italienne l'archivage des données opérationnelles.

Toutes les stations nationales et étrangères ont acquis et archivé des données SAR prises de leurs zones de couverture. Les produits de la station Tromsø des stations du Canada et de celle de l'Alaska ont été validés et leur distribution a été autorisée.

Un contrat a été signé avec le consortium ERSC (Eurimage, Radarsat International et Spotimage) pour la promotion et la distribution des données d'ERS-1.

L'évaluation des résultats de la campagne vents-vagues d'Haltenbanken a débuté. Dans l'ensemble, les données de la campagne paraissent excellentes et les données vents-vagues du satellite se recoupent bien avec les observations in-situ.

ERS-2

ERS-2 a continué de progresser de façon satisfaisante pour ce qui est des éléments principaux de la charge utile et de la plate-forme.

A la suite de la conclusion de plus de 50 contrats de sous-traitance et de la négociation du contrat principal, on est parvenu à un accord sur le contrat de maîtrise d'oeuvre avec Dornier (D). L'accord a été signé officiellement en février 1992.

Les modifications à faire sur PRARE-2, suite aux recherches sur le malfonctionnement de PRARE-1, installé sur ERS-1, ont été définies et sont en cours.

Olympus

Les utilisateurs ont continué de bénéficier des services du satellite pendant la phase de transition qui a suivi les anomalies de fonctionnement en orbite survenues en 1991.

Le canal de télédiffusion 24, normalement affecté à la radiodiffusion italienne, RAI, a été utilisé pour le compte de l'Union européenne de radiodiffusion (UER) en vue d'une démonstration de retransmission en TVHD des jeux olympiques d'hiver d'Albertville (F). Les signaux télévisés reçus du satellite TDF ont été retransmis en liaison montante via les installations au sol de la station ESA de Redu (B).

La charge utile à 20/30 GHz et celle des services spécialisés ont été utilisées pour procéder à nombre de démonstrations spécifiques. La charge utile à 20/30 GHz a pratiquement été utilisée à pleine capacité, les expérimentateurs nordiques se servant de tout excédent. Des démonstrations ont été conduites à Accra (Ghana), à l'initiative de l'UNESCO, et à Rio (Brésil) à l'occasion de la conférence internationale des Journées spatiales euro–latino-américaines.

Un atelier s'adressant aux utilisateurs de toutes les charges utiles d'Olympus s'est tenu à l'ESTEC (NL) le 30 janvier 1992.

La revue et l'essai des nouvelles procédures d'exploitation relatives au contrôle et à la commande du satellite en orbite se sont poursuivis. Le nouveau mode de correction à gyro et roue à réaction élaboré et mis en oeuvre pendant la phase de transition afin d'économiser des ergols fonctionne de façon satisfaisante. Un modèle d'alimentation électrique informatisé a également été mis au point pour faciliter l'établissement du bilan de l'énergie disponible. L'un des tubes à ondes progressives (TOP) de la charge utile de télédiffusion (TVB) du canal européen étant tombé en panne, ce service ne peut plus être assuré.

Deux revues techniques se sont tenues à la demande de la commission d'enquête afin d'examiner les questions relatives au système et au secteur sol. Ces revues fourniront des informations à la commission pour sa revue officielle de l'aptitude au fonctionnement du satellite qui est fixée à avril 1992.

Soho

La phase de réalisation principale de Soho (phase-C/D) dont Matra assure la maîtrise d'oeuvre, se déroule sans problème majeur. Les négociations contractuelles avec la plupart des sous-traitants se sont achevées dans les délais, fin 1991, et les ultimes négociations devraient se terminer en mars 1992 au plus tard.

Les impératifs techniques ont été épurés et les bilans de masse et de puissance ainsi que ceux des autres systèmes sont passés au crible en permanence de manière à ce que l'on conserve des marges suffisantes.

Une réévaluation des contraintes mécaniques imposées par le lanceur et des marges correspondantes a demandé un renforcement localisé de la structure primaire tant du module de charge utile que du module de service. Les effets de ces modifications en termes de masse et de calendrier ont pu être absorbés dans la limite des marges ménagées au niveau système.

Des problèmes ont surgi en ce qui concerne les dates de livraison du modèle d'identification des structures et des câblages. Les solutions de remplacement qui ont été élaborées seront mises en oeuvre sous peu.

Des gains de masse auxquels il est

Olympic games at Albertville (F). The television signals received from the TDF satellite were uplinked using ESA's Redu (B) earth-station facilities.

The satellite's 20/30 GHz and Specialised Services payloads have been used to provide a number of special demonstrations. The 20/30 GHz payload has been almost fully utilised, with the Nordic experimenters taking up any surplus capacity. Demonstrations have been conducted in Accra, Ghana at the invitation of UNESCO, and in Rio di Janeiro, Brazil, for the International 'Euro-Latin-American Space Days' Conference.

A Utilisation Workshop for the users of all the payloads on Olympus was held at ESTEC (NL) on 30 January 1992.

The review and testing of the new operating procedures for controlling the satellite in orbit have been continuing. The new gyro and reaction-wheel control mode, which was developed and introduced during the 'transition phase' to save fuel, has been working well. A computerised power model has also been developed to help with the budgetting of the available power. Failure of a travelling wave tube (TWT) in the European channel of the television-broadcast (TVB) payload has meant that this service is no longer available.

Two technical reviews, to examine the system and ground-segment aspects, respectively, have been held at the request of the Enquiry Board. These reviews will provide information to the Board for its formal Operational-Readiness Review, which is planned to take place in April 1992.

Soho

Soho's main development phase (Phase-C/D), with Matra as the Prime Contractor, is proceeding without major problem. The contract negotiations with most subcontractors were completed on schedule by the end of 1991, and the remaining negotiations should be completed by March 1992.

The technical requirements have been streamlined and the mass, power and other system budgets are being constantly scrutinised to ensure that sufficient margins are maintained.

A reassessment of the launcher-generated mechanical loads and associated margins has required some local reinforcement of the primary structure, for both the payload and service modules. This had some mass and schedule implications, but these could be absorbed by the margins at system level.

Problems are being experienced with the delivery dates of the engineering-model structures and harness. Work-around solutions have been found and these will be implemented shortly.

Some mass benefits which can be achieved by trading-off injection and orbital parameters have been negotiated with NASA, and the overall outlook is positive.

The work on cleanliness is now concentrated on providing practical training for the experimenter teams.

ESA/NASA cooperation

ESA/NASA cooperation is proceeding satisfactorily. The launcher interfaces with NASA/Lewis, which is procuring the Atlas IIAS from General Dynamics, and with General Dynamics themselves continue to progress. Although most interface parameters are agreed, negotiations on the mechanical interfaces are still in progress.

Soho

The specifications for the tape recorder (Odetics, USA), the high-power amplifier (Cubic, USA) and the fine-pointing Sun sensor (Adcole, USA) have been reviewed as planned and formally agreed. The details of the purchasing procedures and the transfer of responsibility to the European contractors are under discussion.

The work on the flight operations and on the implementation of the ground segment is now in a very advanced stage. Meetings including both industry and experimenters are scheduled at regular intervals to ensure a smooth build up in the space- and ground-segment designs.

Payload

The Soho payload is well ahead in its planned development. All experiments are in an advanced engineering phase and most experimenters have already conducted vibration tests on structural models. The delivery to ESA of these models has been postponed somewhat, taking advantage of the contingencies present in ESA's and in the Contractor's schedules.

Payload status has been reviewed in order to establish fully any associated development risks that could jeopardise timely delivery to ESA. This review was conducted jointly by ESA and NASA, and the outcome presented to the managements of both Agencies.

Most of the experiments are very complex and some problems due to difficulties in overcoming technical, managerial or funding problems are still surfacing.

ISO

Scientific instruments

The flight models of the four scientific instruments are undergoing final testing and calibration. The flight-spare models are being assembled for three scientific instruments. ISOCAM is still investigating the possibilities of modifying its qualification-model focal-plane unit to serve as a flight spare.

Satellite

The satellite development model has completed its mechanical environmental *possible de parvenir en procédant à des arbitrages sur les paramètres d'injection et d'orbite ont été négociés avec la NASA et les perspectives sont positives dans l'ensemble.*

Les travaux relatifs à la propreté sont maintenant axés sur la formation pratique des équipes d'expérimentateurs.

Coopération ESA/NASA
La coopération ESA/NASA progresse de façon satisfaisante. Les interfaces lanceur avec NASA/Lewis, chargé de l'approvisionnement de l'Atlas IIAS auprès de General Dynamics, et avec General Dynamics proprement dit continuent de progresser. Bien qu'il ait été convenu de la plupart des paramètres d'interface, des négociations sur les interfaces mécaniques se poursuivent.

Les spécifications relatives à l'enregistreur sur bande (Odetics, USA), à l'amplificateur grande puissance (Cubic, USA) et au suiveur solaire de précision (Adcole, USA) ont été réexaminées conformément aux prévisions et ont fait l'objet d'un accord officiel. Les détails des procédures d'achat et du transfert de responsabilité aux contractants européens sont à l'examen.

Les travaux sur l'exploitation en vol et sur la mise en oeuvre du secteur sol en sont maintenant à un stade très avancé. Des réunions avec les industriels et les expérimentateurs sont prévues à intervalles réguliers afin de garantir une progression fluide des concepts du secteur spatial et du secteur sol.

Charge utile
Les activités de développement planifiées pour la charge utile de Soho sont bien engagées. Toutes les expériences en sont à des stades techniques poussés et la plupart des expérimentateurs ont déjà exécuté des essais en vibration sur les modèles structurels. On a retardé quelque peu la livraison de ces modèles à l'ESA en profitant des marges prévues dans les calendriers de l'ESA et du contractant.

L'état d'avancement de la charge utile a été réexaminé afin de répertorier la totalité des risques de développement correspondants qui pourraient compromettre une livraison à l'ESA dans les délais. Les résultats de cette revue, conduite conjointement par l'ESA et la NASA, ont été présentés aux responsables des deux Agences.

La plupart des expériences sont très complexes et certains problèmes techniques, de gestion ou de financement difficiles à surmonter continuent de se présenter.

ISO

Instruments scientifiques
Les modèles de vol des quatre instruments scientifiques sont en cours d'essai et d'étalonnage final. Les rechanges de vol de trois instruments scientifiques sont en cours de montage. Pour son instrument au plan focal, l'équipe ISOCAM continue d'étudier la possibilité de modifier son modèle de qualification pour qu'il serve de rechange de vol.

Satellite
Les essais mécaniques d'environnement du modèle de développement du satellite ont été réalisés à Cannes chez le contractant principal, Aérospatiale (F). Le module de charge utile a été séparé du module de service et renvoyé chez MBB à Munich (D) pour inspection et essais de plein cryotechnique à l'intérieur d'une maquette de la coiffe d'Ariane.

Le contractant principal a commencé l'intégration du modèle de vol du module de service. Les sous-systèmes alimentation électrique, RF et traitement des données sont en place et en cours d'essai. Le sous-système de commande d'orientation doit encore être livré.

Les principaux problèmes sont les retards de la livraison des ordinateurs de commande d'orientation, du suiveur stellaire et des gyroscopes. Le problème de la sensibilité excessive à la température du suiveur stellaire a été résolu, comme l'ont confirmé les essais menés sur le modèle d'identification.

L'intégration du modèle de vol du module de charge utile est retardée à cause de problèmes au niveau des vannes d'hélium liquide. Les essais de qualification des vannes modifiées viennent de débuter. Des progrès ont été faits dans la définition des modifications à apporter à la conception pour remédier au problème de l'excès de lumière parasite émise par les parties relativement chaudes du module charge utile qui perturbe les instruments scientifiques. Des modifications de détail sont en cours au niveau matériel.

Secteur sol
Les travaux portant sur le secteur sol progressent de façon satisfaisante.

XMM

Les travaux conduits sur le modèle de développement du miroir (MDM) afin de démontrer le fonctionnement de l'unité de miroirs dans le rayonnement X se déroulent comme prévu. Au total, on a construit trois répliques de miroir en coquille de 40 cm de diamètre, deux d'une épaisseur de 0,4 mm et une de 0,6 mm. Il serviront à établir leurs caractéristiques de fonctionnement dans le rayonnement X avant de passer à la fabrication des miroirs supplémentaires de diamètres différents devant être utilisés dans le MDM. Au total, celui-ci sera équipé de 4 miroirs en coquille de 30 à 60 cm de diamètre. Il est prévu que le MDM soit disponible début 1993 pour des essais dans le rayonnement X.

Deux études de phase-A sont en cours sur XMM, l'une en association avec le projet PRISMA et l'autre avec le projet INTEGRAL. L'une ou l'autre de ces missions pourrait être choisie comme prochaine mission scientifique (M2). Pour ces deux missions, on étudie la possibilité d'utiliser une plate-forme d'observation identique à celle du satellite XMM.

EOPP

Aristoteles
Les études et les activités technologiques relatives à Aristoteles se poursuivent conformément calendrier. Parallèlement, l'Agence a conduit une revue des impératifs 'système' avec le soutien des industriels et de la NASA qui lui ont fourni des données et ont fait des présentations. Le Comité de revue de l'ESA réuni le 11 février a atteint les objectifs qu'il s'était fixé, à l'exception

tests at the facilities of Aerospatiale, the Prime Contractor, in Cannes (F). The payload module has been de-mated from the service module and returned to MBB in Munich (D), for inspection and cryogenic servicing trials inside a mock-up of the Ariane launch-vehicle fairing.

Integration of the flight-model service module has started at the Prime Contractor's facilities. The power, radio-frequency and data-handling subsystems have been installed and testing is underway. The attitude-control subsystem is still to be delivered.

The main problems are delays in the delivery of the attitude-control computers, star tracker and gyroscopes. The problem of excessive temperature sensitivity of the star tracker has been solved, as confirmed by tests on the engineering model.

Integration of the flight-model payload module is held up by the problems with the liquid-helium valves. Qualification testing of the modified valve design has just started. Good progress has been made in identifying the design changes necessary to correct the problem of excessive stray light from relatively warm parts of the payload module affecting the scientific instruments. Detailed hardware changes are being implemented.

Ground segment
The ground-segment effort is progressing satisfactorily.

XMM

Work on the Mirror Development Model (MDM), to demonstrate the X-ray performance of the mirror assembly, is proceeding as planned. A total of three replicated mirror shells of diameter 40 cm, two 0.4 mm thick and one 0.6 mm thick, have been built. These will be used to establish the X-ray performance before proceeding with the buildup of additional mirror shells of different diameters to be used in the MDM. A total of four mirror shells will be fitted, with diameters ranging from 30 to 60 cm. The MDM is planned to be available in early 1993 for X-ray testing.

Two Phase-A studies of XMM are being conducted, one in conjunction with the PRISMA project and the other in conjunction with INTEGRAL. These two missions are candidates for selection as the next scientific mission (M2). Both missions are examining the possibility of using a duplicate of the XMM spacecraft bus as a platform for their observations.

EOPP

Aristoteles
The Aristoteles studies and technology activities are continuing according to plan. In parallel, the Agency has conducted a System Requirements Review, supported by data inputs and presentations from industry and NASA. The ESA Review Board meeting was held on 11 February. Although some technical issues remain to be further addressed, the overall objectives of the review were met.

The Earth Observation Programme Board, at its 27/28 February meeting, approved the Executive's proposed work plan to continue the preparation of Aristoteles through further industrial activities. It also agreed to the initiation of 'Potential Participants' meetings.

Meteosat Second Generation
Phase-A studies of the space segment were begun on 6 February with the prime contractors of two industrial consortia, Aerospatiale (F) and Matra Marconi Space (UK).

A detailed design review of the imager took place on 4 February at Matra.

Meetings have taken place between the Agency and Eumetsat aimed at defining the methodology for future collaboration for the Meteosat Second Generation, including cost-sharing.

Low-Earth Orbit (LEO) missions
Technical, technological and scientific studies have been initiated for a number of possible future LEO instruments such as the HRIS (High-Resolution Imaging Spectrometer), HRTIR (High-Resolution Thermal-Infrared Radiometer), MLS (Microwave Limb Sounder), and Atmospheric Backscatter and Doppler Lidars.

Campaigns
The 1991–96 EOPP Campaign Plan was presented to, and approved by, the Earth Observation Scientific and Technical Advisory Group (EOSTAG) in January.

A Workshop was held at ESTEC on 6/7 February to review the results of the MAESTRO and AGRISCAT campaigns.

Preparations for SAREX 1992 have continued and preparations for ESA's involvement in the Hydrologic Atmospheric Pilot Experiment (HAPEX-SAHEL) have also begun.

POEM-1 Preparatory Programme

POEM-1 system and instrument Phase-B studies
Following the ESA Council Meeting at Ministerial Level in Munich last November, the Prime Contractor was redirected to consider the two imaging-radar instrument alternatives referred to in the Council Resolution.

Instrument design activities are in progress, covering the Advanced Scatterometer (ASCAT), Advanced Synthetic-Aperture Radar (ASAR), Michelson Interferometer for Passive Atmosphere Sounding (MIPAS), Medium-Resolution Imaging Spectrometer (MERIS), Radar Altimeter 2 (RA-2), and Global Ozone Monitoring by Occulation of Stars (GOMOS). The Prime Contractor has finalised instrument-support specifications, which have been distributed to the instrument contractors. In addition, Draft Interface Control Documents (ICDs) are now available for a number of instruments.

Draft ICDs have also been generated for the operational package delivered by Eumetsat and the Announcement of Opportunity (AO) instruments (viz. the Advanced Along-Track Scanning Radiometer (AATSR), Clouds and Earth Radiant Energy System (CERES) Experiment, Precision Range and Range-Rate Equipment – Extended Version (PRAREE) and Scanning Imaging Absorption Spectrometer for Atmospheric Cartography (SCIAMACHY)).

Definition of the interface with the Polar Platform is proceeding. Environmental *de quelques problèmes techniques qui restent à résoudre.*

Lors de sa réunion des 27 et 28 février, le Conseil directeur du Programme d'observation de la Terre a approuvé le plan de travail proposé par l'Exécutif qui porte sur la poursuite de la préparation d'Aristoteles par l'engagement de nouvelles activités industrielles. Il a également donné son accord pour que soient organisées des réunions avec les participants potentiels.

Météosat deuxième génération
Les études de phase-A du secteur spatial confiées aux maîtres d'oeuvre des deux consortiums industriels – Aérospatiale (F) et Matra Marconi Space (GB) – ont commencé le 6 février.

Le 4 février, l'imageur a fait l'objet d'une revue de conception détaillée chez Matra.

L'Agence et Eumetsat se sont réunis à plusieurs occasions pour définir la méthodologie de leur collaboration future au projet Météosat deuxième génération et notamment le partage des coûts.

Missions sur orbites terrestres basses (LEO)
Des études techniques, technologiques et scientifiques ont été engagées pour un certain nombre d'instruments qui pourraient être embarqués lors de missions LEO comme le HRIS (spectromètre imageur haute résolution), le HRTIR (radiomètre thermique dans l'infrarouge haute résolution), le MLS (sondeur du limbe par hyperfréquences) ainsi que les lidars atmosphériques à rétrodiffusion et Doppler.

Campagnes
En janvier, le plan de campagnes EOPP pour 1991-1996 a été présenté au Groupe consultatif scientifique et technique pour l'observation de la Terre (EOSTAG) qui l'a approuvé.

Un atelier a été organisé à l'ESTEC les 6 et 7 février pour passer en revue les résultats des campagnes MAESTRO et AGRISCAT.

Les préparatifs de SAREX 1992 se sont poursuivis et l'ESA a commencé à se préparer à participer à l'expérience pilote hydrologique et atmosphérique HAPEX-SAHEL.

Programme préparatoire POEM-1

Système et instruments POEM-1 Etudes de phase-B
Après la réunion du Conseil en session ministérielle à Munich en novembre dernier, le maître d'oeuvre a été invité à prendre en considération les deux concepts de radars imageurs figurant dans la Résolution du Conseil.

Les activités de conception des instruments progressent; elles intéressent le diffusiomètre de pointe (ASCAT), le radar à synthèse d'ouverture de pointe (ASAR), le sondeur atmosphérique passif à interférométrie de Michelson (MIPAS), le spectromètre imageur à moyenne résolution (MERIS), l'altimètre-radar 2 (RA-2), le spectromètre de surveillance de l'ozone à l'échelle du globe par occultation d'étoiles (GOMOS). Le maître d'oeuvre a achevé la rédaction des spécifications relatives au soutien des instruments; elles ont été distribuées aux contractants des instruments. En outre, les projets de documents de contrôle des interfaces (ICD) sont disponibles pour un certain nombre d'instruments.

Des projets d'ICD ont également été préparés pour les lots opérationnels fournis par Eumetsat et pour les instruments de l'Avis d'offre de participation (AO), à savoir, le radiomètre à balayage le long de la trace de technologie avancée (AATSR), le système d'observation de l'énergie radiative des nuages et de la Terre (CERES), l'expérience de mesure précise de la distance et de la vitesse radiale version améliorée (PRAREE) et le spectromètre d'absorption à balayage et prise d'images pour la cartographie de l'atmosphère (SCIAMACHY).

Les interfaces avec la plate-forme polaire sont toujours en cours de définition. Les impératifs relatifs à l'environnement ont été actualisés et prennent désormais en compte les résultats les plus récents des études prévisionnelles de la plate-forme polaire. La répartition détaillée des responsabilités et la définition précise des limites physiques des interfaces ont été élaborées en vue d'établir les accords d'interface entre POEM-1 et la plate-forme polaire.

Etude de phase-B du MIMR
Les activités de phase-B relatives au Radiomètre imageur hyperfréquences multifréquences ont été engagées. Les revues de conception du montage table sont en cours; celle du mécanisme de balayage est terminée.

Phase-B du secteur sol de POEM
Les industriels ont remis leur proposition portant sur la phase-B du secteur sol; elle est en cours d'évaluation.

Programme POEM-1
Le Conseil de l'ESA réuni en session ministérielle en novembre à Munich, a adopté la Résolution habilitante relative au programme POEM-1 (phases-C/D et E). La Déclaration correspondante a été signée le 27 février 1992 et ouverte à la souscription jusqu'au 16 avril 1992.

Météosat

Après avoir été retiré de l'orbite géostationnaire le 2 décembre 1991, Météosat-2 a finalement été mis hors circuit le 6 décembre. Il aura fonctionné 10 ans et demi. Le satellite est maintenant sur une orbite de dégagement à plus de 300 km au dessus de la zone géostationnaire.

Météosat-4 (MOP-1), stationné à 0°, assure un service opérationnel, tandis que Météosat-3 (P2), à 50°W, assure la couverture de la partie ouest de l'Atlantique.

La propriété de Météosat-5 (MOP-2), qui a été lancé en mars 1991, a été transférée par l'ESA à Eumetsat en janvier 1992.

Le radiomètre de MOP-3 – dont le lancement est prévu pour septembre 1993 – a été modifié de façon à éviter tout phénomène d'adhérence dans le mécanisme d'étalonnage contenant le corps noir. Dans le même temps, on a vérifié la conformité des tolérances du système optique infrarouge. Le radiomètre doit maintenant être soumis aux essais de recette avant d'être livré à l'Aérospatiale (F).

Les activités entreprises par l'ESA pour le compte d'Eumetsat au titre du programme Météosat de transition sont maintenant bien avancées. Une revue requirements have been updated to take account of the latest Polar Platform prediction results. The detailed split of responsibilities and the accurate definition of the physical interface borders have been elaborated in preparation for establishing interface agreements between POEM-1 and the Polar Platform.

MIMR instrument Phase-B study
The MIMR Phase-B activities have been started. Breadboard design reviews are underway and the scanning-mechanism review has been held.

Phase-B of POEM ground segment
The industrial proposal for the ground-segment Phase-B has been received and is being evaluated.

POEM-1 Programme
At the ESA Council at Ministerial Level in Munich in November, the Enabling Resolution was adopted for the POEM-1 Programme (Phases-C/D and -E). The corresponding Declaration was finalised on 27 February 1992 and opened for subscription until 16 April 1992.

Meteosat

After its removal from geostationary orbit on 2 December 1991, Meteosat-2 was finally switched off on 6 December after 10.5 years in orbit. It is now in a 'graveyard orbit', more than 300 km above the geostationary ring.

Meteosat-4 (MOP-1), stationed at 0°, is providing the operational service, while Meteosat-3 (P2) is providing coverage over the Western Atlantic from its position at 50°W.

The ownership of Meteosat-5 (MOP-2), which was launched in March 1991, was transferred by ESA to Eumetsat in January 1992.

For MOP-3, scheduled for launch in September 1993, the radiometer has been modified to avoid adhesion in the black-body calibration mechanism. At the same time, the infrared optics were checked for proper tolerances. The radiometer will now be acceptance-tested before its delivery to Aerospatiale (F).

Activities under the terms of the Meteosat Transition Programme, which ESA is carrying out on behalf of Eumetsat, are now well underway. A Production Baseline Review has been held at MBB (D) for the structure and thermal-protection systems. The launch of this additional Meteosat, MTP-1, is scheduled for the last quarter of 1995.

Earthnet

Data from Landsat-5 and MOS-1a have been regularly acquired at the Fucino (I) and Kiruna (S) stations. Maspalomas (E) has handled the routine acquisition of Spot and MOS-1a data.

The Earthnet TIROS AVHRR coordinated network has continued to acquire and archive HRPT (High-Resolution Picture Transmission) data from NOAA-11 and NOAA-12.

Upgrading activities for Landsat-6 and JERS-1 have continued. Unfortunately, JERS-1, launched by NASDA on 11 February 1992, seems to have a SAR-antenna deployment problem.

The cooperation between Earthnet and the European Commission (CEC) has continued on several projects, including CEC support for: the NOAA AVHRR data archives in Nairobi, Niamey and La Reunion; the OCEAN Project in which CZCS data plus ozone and surface-pressure data continued to be processed and distributed from Frascati; upgrading of the Bangkok station within the ASEAN Project to acquire and preprocess ERS-1 SAR data; the setting up of a regional AVHRR archiving facility in Kuala Lumpur and of additional AVHRR processing facilities in Manila and Jakarta.

The studies and other activities on the Environmental Data Network have continued.

Earthnet's activities on the ERS-1 payload ground segment are reported under ERS-1.

Eureca

Following Eureca's arrival at the Astrotech facilities in Florida (USA), the installation of the Carrier and its associated ground test equipment was accomplished by end of November 1991. By the end of February, all experimental facilities that do not have a critical time constraint before launch had been reintegrated and interface-tested with the flight carrier system. The remaining three instruments are to be installed by the end of April, less than four months before launch. The critical protein samples will be loaded into the Protein Crystallisation Facility just two days before launch.

Interface testing with the Agency's European Space Operations Centre (ESOC) in Darmstadt (D) has also been completed and the Carrier is now being prepared for hand-over to NASA by 6 May, to join the standard integration flow for the Space Shuttle.

Eureca's launch on Space Shuttle 'Atlantis' (STS-46) is planned for 2 or 11 July 1992, and its retrieval by Shuttle flight STS-57 for April 1993.

Space Station Freedom/Columbus

Manned elements
The second Updated Industrial Commitment data package, delivered to ESA at the end of December, has been reviewed. These data provide a concrete basis for the implementation of the Programme.

The Attached Laboratory technical baseline has been the subject of a Configuration Review, which was successfully completed in February, with NASA, NASDA and Canadian Space Agency (CSA) representatives participating in the Board.

Initial activities for the Free-Flyer/Hermes composite optimisation studies have been defined and are reflected in a Statement-of-Work for the Free-Flyer sent to MBB/ERNO (D).

The documents for the submission to the Agency's Industrial Policy Committee (IPC) at the end of March have been prepared and reviewed by the Adjudication Committee.

The third Columbus Industrial Day was held in Turin (I) at the beginning of *de la fabrication du système nominal s'est tenue chez MBB (D) au sujet de la structure et des systèmes de protection thermique. Le lancement de ce Météosat supplémentaire, MTP-1, est prévu pour le dernier trimestre 1995.*

Earthnet

Les stations de Fucino (I) et de Kiruna (S) ont régulièrement acquis les données de Landsat-5 et de MOS-1a. La station de Maspalomas (E) a réalisé l'acquisition de routine des données Spot et MOS-1a.

Le réseau coordonné d'Earthnet de l'instrument AVHRR du satellite Tiros continue d'acquérir et d'archiver les données HRTP de NOAA-11 et NOAA-12.

Les activités de mise à niveau en vue de la réception des données de Landsat-6 et de JERS-1 se poursuivent. Malheureusement, il semble que le déploiement de l'antenne SAR de JERS-1, lancé par la NASA le 11 février 1992, pose problème.

Earthnet et la Commission des Communautés européennes continuent de coopérer sur plusieurs projets. La CCE soutient notamment: l'archivage de données AVHRR de NOAA à Nairobi, Niamey et La Réunion; le projet OCEAN, pour lequel les données CZCS, les données sur l'ozone et sur la pression de surface continuent à être traitées et distribuées par Frascati; la mise à niveau de la station de Bangkok, dans le cadre du projet ASEAN d'acquisition et de prétraitement de données du SAR d'ERS-1; la mise en place d'une installation régionale d'archivage de données AVHRR à Kuala Lumpur et d'installations supplémentaires de traitement des données AVHRR à Manille et à Djakarta.

Les études et autres activités se rapportant au réseau de données sur l'environnement se poursuivent.

En ce qui concerne le secteur sol de la charge utile d'ERS-1, les activités d'Earthnet sont commentées au chapitre ERS-1.

Eureca

Après l'arrivée d'Eureca sur les installations d'Astrotech en Floride (USA), les opérations d'installation du porte-instruments et des équipements associés d'essai au sol se sont terminées fin novembre 1991. Fin février, toutes les installations expérimentales ne présentant pas de contraintes de temps critiques avant le lancement avaient été ré-intégrées et leurs interfaces avec le porte-instruments soumises à des essais. Trois instruments restent à installer d'ici fin avril, soit moins de quatre mois avant le lancement. Les échantillons critiques de protéines ne seront chargés dans leur installation de cristallisation que deux jours avant le lancement.

Les essais d'interface avec le Centre européen d'opérations spatiales (ESOC) de l'Agence à Darmstadt (Allemagne) sont terminés et le porte-instruments est en cours de préparation pour être remis à la NASA le 6 mai et suivre la procédure normale d'intégration à la Navette spatiale.

Eureca devrait être lancé par la Navette Atlantis (vol STS-46) le 2 ou le 11 juillet et être récupéré par la Navette lors du vol STS-57 en avril 1993.

Station spatiale Freedom/Columbus

Elements habités

La revue du deuxième dossier de données sur l'offre ferme actualisée, livré à l'ESA fin décembre, est terminée. Ces données constituent une base solide pour la mise en oeuvre du programme.

Une revue de configuration de la base de référence technique du laboratoire raccordé a été menée à bien en février, avec la participation des représentants de la NASA, de la NASDA et de l'Agence spatiale canadienne.

Les premières activités concernant les études d'optimisation du composite laboratoire autonome/Hermès ont été définies et se retrouvent dans un descriptif des travaux pour le laboratoire autonome qui a été envoyé à MBB/ERNO (D).

Les documents devant être soumis au Comité de la politique industrielle fin mars ont été préparés et revus par le Comité d'Adjudication.

La troisième Journée Columbus des Industriels s'est tenue à Turin (I) début février et a réuni pratiquement tous les contractants participant au programme Columbus.

Les relations ESA/NASA continuent d'être très actives et plusieurs réunions techniques ont eu lieu, notamment une réunion d'échanges techniques sur les concepts de traitement au sol se rapportant au laboratoire raccordé, qui s'est tenue au Centre spatial Kennedy. La quatrième revue de programme conjointe ESA/NASA de niveau 2 s'est également tenue en février; toutes les propositions importantes de l'ESA ont été adoptées.

Depuis leur mise en place officielle par la Commission multilatérale de contrôle, les deux comités stratégiques multilatéraux prévus par le Mémorandum d'accord, à savoir le Comité d'exploitation des systèmes et le Comité d'exploitation des utilisateurs, ont tenu deux réunions communes, en décembre 1991 et en février 1992. Ils se sont mis d'accord sur les modalités – marche à suivre, éléments à fournir et calendrier – de préparation du premier plan d'exploitation et d'utilisation unifié, à publier au 1er janvier 1993, et ils ont commencé l'élaboration des plans de gestion de l'utilisation et de l'exploitation.

Côté utilisateurs, pour faire suite à la résolution du Conseil au niveau ministériel de Munich visant à 'présenter les termes d'une proposition de programme facultatif de vols précurseurs Columbus' et sur la base de la proposition de programme de l'Exécutif, les participants potentiels se sont réunis en janvier et en février 1992. La prochaine réunion est prévue en avril. Le projet de la déclaration a bien avancé.

Les point suivants doivent encore être réglés: le système de gestion, le retour industriel et la mise au point définitive des accords avec l'ASI, le CNES et la DARA au sujet des contributions nationales.

L'évaluation scientifique des propositions

February, involving virtually all contractors working on the Columbus Programme.

Interfaces with NASA have been actively maintained and several technical meetings have been held, including a Technical Interchange Meeting at Kennedy Space Center on ground-processing concepts for the Attached Laboratory. The ESA/NASA Level-2 Joint Programme Review 4 has also been held, in February, with a successful outcome for ESA on all key issues.

Since their formal establishment by the Multilateral Control Board, the System Operations Panel and the User Operations Panel — the two multilateral strategic panels foreseen in the Space Station Memorandum of Understanding (MOU) — have held two joint meetings, in December 1991 and February 1992. They have agreed on the process, inputs and schedule for the development of the first Consolidated Operations and Utilisation Plan (COUP) to be issued on 1 January 1993, and have started developing the Operations and the Utilisation Management Plans.

On the utilisation side, following the Resolution at the Council Meeting at Ministerial Level in Munich to 'present the terms of a proposal for an optional programme of Columbus precursor flights', and on the basis of the programme proposal made by the Executive, two Potential Participants meetings took place in January and February 1992. The next meeting is foreseen for April. Good progress has been made concerning the Draft Declaration. Points still to be resolved are the management scheme, the industrial return and the finalisation of agreements with ASI, CNES and DARA on national contributions.

Scientific evaluation of the proposals for the precursor flights is currently in progress and recommendations on the payload composition for Spacelab-E1 and Eureca-2 are expected in mid-1992.

Among the 'Long-Term Programme' activities, preparation of the EXEMSI experimental campaign is in process, with candidate selection foreseen in March. Sudy of the 'EMSI Long-Term Configuration', again following on from the outcome of the Council at Ministerial Level, has been initiated.

Polar Platform

Following the decision in Munich to postpone the PPF/POEM-1 launch date to mid-1998, a replanning exercise was conducted with industry to adjust the detailed plan of activities, while minimising the financial impact of such changes.

In parallel, the development activities have continued and a number of subsystem and equipment Preliminary Design Reviews (PDRs) have taken place.

In addition, a number of breadboarding activities have been completed, generally with positive results (X-band antenna; high-speed multiplexer; one-third-scale deployment model of the solar array).

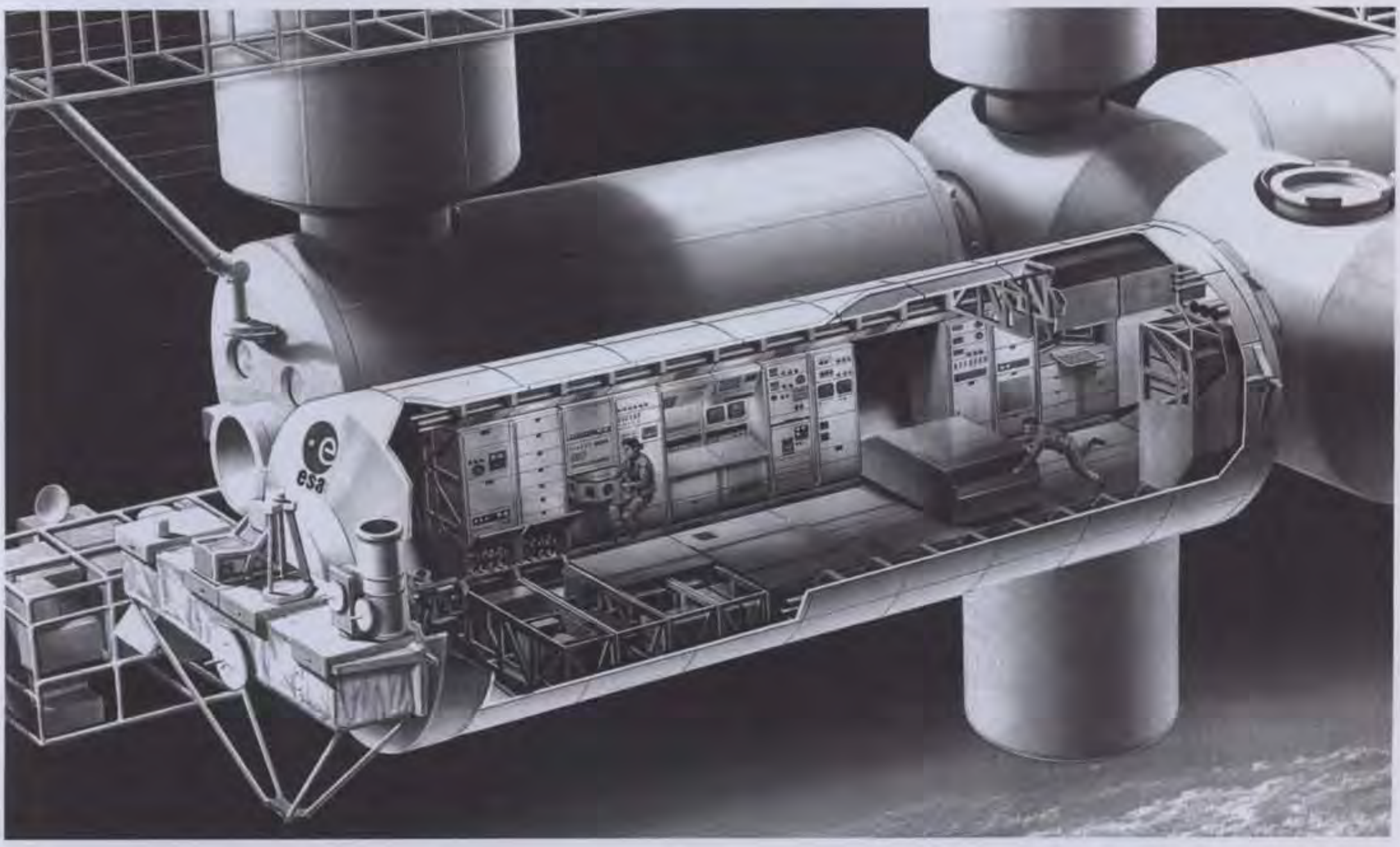
In the MGSE (Mechanical Ground-Support Equipment) area, the manufacture of a number of items has been initiated following successful design reviews.

Component procurement activities are well advanced.

Based on the results of the Ariane-5/Polar-Platform dynamic coupled analysis, the equipment mechanical environment (including that of the payload) has been relaxed somewhat.

The Columbus Attached Laboratory

Le laboratoire raccordé Columbus



de vols précurseurs est en cours et les recommandations sur la composition de la charge utile de Spacelab-E1 et de Eureca-2 sont attendues pour la mi-1992.

Parmi les activités du 'programme à long terme', la préparation de la campagne d'expériences EXEMSI est en cours et la sélection des candidats devrait se faire en mars. L'étude de la 'configuration à long terme d'EMSI' a débuté, également à la suite des résultats du Conseil au niveau ministériel.

Plate-forme polaire

La décision ayant été prise à Munich de reporter la date de lancement de la PPF/POEM-1 à la mi-1998, l'Agence et l'industrie ont entrepris de réaménager le calendrier et d'ajuster en conséquence le plan détaillé des activités tout en s'efforçant de minimiser les incidences financières de ces changements.

Parallèlement, les activités de développement se sont poursuivies et plusieurs revues de conception préliminaire de sous-systèmes et d'équipements ont eu lieu.

En outre, plusieurs montages sur tables ont été exécutés qui ont, dans l'ensemble, donné des résultats positifs (antenne bande X, multiplexeur haute vitesse, maquette au 1:3 du système de déploiement du réseau solaire).

Pour ce qui est du MGSE (Equipement mécanique de soutien sol), les revues de conception ayant été menées à bien, on a lancé la fabrication d'un certain nombre de pièces.

Les approvisionnements de composants sont bien avancés.

En s'appuyant sur les résultats des analyses du couplage dynamique Ariane-5/Plate-forme polaire, les conditions de l'environnement mécanique des équipements (y compris de la charge utile) ont été quelque peu assouplies.

Certains points de détail ont été étudiés en coopération avec l'industrie en soutien des activités actuelles relatives à la phase-B de POEM (installation de la charge utile, cohérence de la documentation, etc.)

Hermès

Secteur spatial

L'effort industriel se concentre sur l'achèvement de la configuration d'étape 2 qui implique: la mise au point définitive de l'architecture des sous-systèmes spationiques, propulsion et réservoirs de stockage, l'optimisation de la disposition des volumes pressurisés et non pressurisés, l'amélioration de la forme aérodynamique pour remédier aux défauts d'équilibre hypersonique, de stabilité latérale subsonique et à certains problèmes locaux. On est parvenu à une forme candidate qui fera l'objet d'une évaluation complète dans le courant de l'année. On continue à travailler à une protection supplémentaire contre les débris spatiaux et à l'incorporation des modifications réduisant la masse proposées par les groupes de travail.

Sur le plan du développement technologique, les premiers essais longue durée (100 h) des piles à combustible ont été menés à bonne fin et on teste maintenant l'ensemble évaporateur d'eau et bouilleur à l'ammoniaque. On se prépare aux essais des échantillons de démonstration de technologie de la structure chaude et de la protection thermique.

The solar array for the Columbus Polar Platform (one-third scale)

Le générateur solaire de la Plate-forme polaire Columbus (échelle 1/3)

Detailed interaction has taken place with industry to support the on-going POEM Phase-B activities (payload accommodation, documentation coherence, etc.).

Hermes

Space-segment

The industrial effort is concentrated on the achievement of the Stage-2 configuration, which requires finalisation of the subsystem architectural design of the propulsion and storage-tank subsystems, the spacionics subsystem, and the optimisation of the layout of the pressurised and un-pressurised volumes, improvement of the aerodynamic shape to mainly overcome shortcomings in hypersonic balance, subsonic lateral stability, and a number of local problems. A candidate shape has been defined which will be fully evaluated in the course of this year. Additional space-debris protection and the incorporation of the mass-saving changes proposed by the task forces are also being pursued.

As far as technology development is concerned, the first long-duration fuel-cell tests (100 h) have been successfully completed, and a water evaporator and ammonia boiler assembly are now under test. Preparations for the testing of the technology-demonstration samples for the hot structure and the thermal protection are in progress.

The results of all of these activities will be reviewed at the Preliminary Design Review in the first quarter of 1993, which constitutes the next major milestone.

Ground segment

An assessment of the status of the ground segment has been performed based on the results obtained from concept and definition studies conducted in this area. The definition of the Flight Control Centre has been further consolidated.

The acceptance-testing of the two large high-enthalpy developmental facilities, F4 and HEG, is currently in progress.

Management aspects

Industrial activity is following the so-called '2002 Scenario', with the goal of advancing system definition, the crucial technologies and the interfaces.

Investigation of alternative development schemes in support of the establishment of the Long-Term Plan is proceeding as an in-house effort.

Following the guidelines of the Council Meeting at Ministerial Level in Munich, possibilities for international cooperation with the Soviet Commonwealth of Independent States, Japan and the USA are currently under investigation. The Hermes industrial participants will become involved only when the framework has been totally defined by ESA.

The inauguration of Euro-Hermesspace took place on 23 January.

Ariane

Ariane-5

The incident that occurred whilst casting the aft segment of the first P230 booster, together with other technical constraints, has led the programme authorities to revise the future sequence of events. One result is that the first flight of Ariane-5 will be deferred by six months.

Main cryogenic stage

Spectacular and very concrete achievements have demonstrated the progress made in the development of the main cryogenic stage, including:

- fitting of thermal protection for the first full-scale tank at Cryospace

- proof pressure testing of the liquid oxygen tank to be used for stage qualification tests in Guiana

- completion of vibration tests on the forward skirt, equipped with its electrical and fluids subsystems, and

- delivery by AMES of the first flight-rated conditioners.

Vulcain engine

The sixth engine in the series, assigned to qualification work, is on the test stand. So far, 84 engine tests have been carried out, involving a total of 8500 s of operation.

The M5 engine has just completed 20 tests and 3800 s of burn time (specified values are 20 for the former and 6000 for the latter).

L9 storable propellant stage

The latest tests on the engine for this stage have allowed the configuration of the injection system to be frozen prior to starting the series of long-duration tests.

Hermes mock-up under test at ESTEC (NL)

La maquette d'Hermès aux essais à l'ESTEC

La prochaine étape importante sera la revue des résultats de toutes ces activités, au premier trimestre 1993, lors de la revue de définition préliminaire.

Secteur sol

L'état d'avancement du secteur sol a été évalué sur la base des résultats des études de conception et de définition menées dans ce domaine. La définition du Centre de contrôle en vol a été consolidée.

Les essais de recette des deux grandes souffleries, F4 et HEG, sont en cours.

Gestion

Les activités industrielles s'inspirent du 'scénario 2002' et on s'attache à améliorer la définition du système, les technologies les plus importantes et les interfaces.

L'étude de procédés de développement de rechange, qui pourront servir à l'établissement du plan spatial à long terme, s'est poursuivie intra-muros.

Dans l'esprit des résolutions du Conseil au niveau ministériel de Munich, on étudie les possibilités de coopération avec la CEI, le Japon et les Etats-Unis. Les participants industriels au programme Hermès ne s'y associeront que lorsque le cadre de cette coopération aura été défini par l'ESA.

Ariane

Ariane-5

L'incident survenu lors de la coulée du segment arrière du premier propulseur d'appoint P230 et d'autres contraintes techniques ont conduit la direction de programme à revoir l'enchaînement des activités futures avec pour conséquence un glissement du premier vol d'Ariane-5 de six mois.

Etage cryotechnique H155

Des réalisations très concrètes et spectaculaires montrent l'état d'avancement des travaux de développement de l'étage H155. Parmi celles-ci l'on peut citer:

- *la pose de la protection thermique du premier réservoir à échelle 1 chez Cryospace*
- *l'essai de timbrage du résevoir d'oxygène liquide destiné aux essais de qualification de l'étage en Guyane*
- *la fin des essais de vibration de la jupe avant, équipée de ses sous-systèmes électriques et fluides*
- *la livraison par AMES des premiers conditionneurs de type vol.*

Moteur Vulcain

Le sixième exemplaire du moteur, destiné à l'exploration du domaine de qualification, est au banc. A ce jour 84 essais moteur ont été réalisés cumulant 8500 s de fonctionnement.

Il faut remarquer que le moteur M5 vient de franchir la barre des 20 essais et des 3800 s (valeurs spécifiées respectivement 20 et 6000).

Etage à ergols stockables L9

Les derniers essais du moteur de cet étage permettent de figer la configuration du système d'injection avant d'engager la série des essais de longue durée.

In Brief

The Spacelab module in the cargo bay of the Space Shuttle Discovery during the International Microgravity Laboratory (IML-1) mission. The Red Sea and part of the Sinai Peninsula are in the background.

Early Report on Two Facilities Aboard IML-1 Mission

The first International Microgravity Laboratory (IML-1) mission was successfully completed on 30 January after nine days in orbit aboard the Space Shuttle Discovery (STS-42). The objective of the mission was to investigate the complex effects of weightlessness in orbit, particularly through experiments in the areas of life sciences, materials sciences and fluid physics.

During the flight, a day was added to the mission and much replanning of scientific activities was required, taking into account the needs of each experiment. The replanning was performed using a specially-developed programme. The revised timeline and procedures were then uplinked to the crew. However, the extra day allowed scientists to prolong their experiments and to take advantage of the scientific results obtained during the previous days of the mission.

The IML-1 payload included two major pieces of hardware provided by ESA, namely the Biorack and the Critical Point Facility. An account of the flight of those two payloads follows.

Biorack

The Biorack is a multi-user facility designed to investigate the effects of microgravity on cells, plants, tissues and other biological samples. It contains three incubators that provide a temperature-controlled environment; a 'glovebox' or enclosed environment which protects samples from contamination; and a cooler/freezer unit. That equipment allows crew members to grow, handle and preserve hundreds of biological samples.

The flight of the Biorack was a great success. The facility performed nominally. The major difficulty encountered during the operation involved the logistics of the Experiment Containers translocations. During the mission, more than 1000 translocations were undertaken both in orbit and on the ground. Of these 2000 translocations, only two were not performed nominally but they were corrected immediately without impact on the scientific results.

Fifteen of the 17 experiments were performed successfully; the other two encountered problems not relating to the Biorack facility. The 1 g reference centrifuges in the Biorack's three incubators provided the scientists with accurate 1 g controls that assisted in discriminating between the effects of microgravity and cosmic radiation. The improved Biorack microscope used in two experiments allowed the Principal Investigators to observe, in real-time, images of their samples transmitted through the microscope's video camera, to monitor the progress of their experiments, and to communicate with the flight crew via the Biorack team on the ground.

Critical Point Facility

The Critical Point Facility (CPF) is a temperature-controlled facility that supports the investigation of fluids at their critical point, where liquid and vapour phases coexist.

The flight of the CPF was also a great success from both a scientific and technical point of view. In particular, the continuous data/video downlink and command systems performed flawlessly, permitting the investigators on the ground to control the experiments. Throughout the mission, downlinked data from video images was received in real-time and, for the first-time, scientists were able to see in real-time their fluid reaching the critical point without the effect of gravity.

Digital video images were also downlinked at the rate of one image per six seconds. That low-rate video system was one of the CPF's original features. It is very suitable for CPF experiments because the dynamics of fluids around the critical point are usually slow, as was confirmed during the mission. The video system provided scientists with on-going information about their sample fluid to enable them to 'feed back' to their experiment by sending commands from the ground.

The scientists used the CPF command capability continuously, with the CPF engineering team sending approximately 1100 commands to the facility. The CPF would first recognise the command, send an acknowledgement message to the ground, and then execute the command. This process took seven seconds.

A commercial photographic camera had been mounted on the CPF to acquire high resolution images of interferometric patterns. It performed perfectly in its different modes and has provided 500 high-quality photographs that will allow accurate and quantitative evaluation of the experimental phenomena.

Both the Biorack and the CPF will also be flown on the second IML flight, planned for the first quarter of 1994.

Astronauts Stephen Oswald (left), pilot, and Norman Thagard (right), payload commander, unload samples from the Biorack facility in the International Microgravity Laboratory (IML) aboard the Space Shuttle Discovery.

Crew of IML-1 Mission Visit ESA Establishments

The complete crew of the IML-1 mission visited Europe between 29 March and 3 April. This proved to be the only opportunity for all crew members to get together because some of the American members have already been assigned to other flights and have begun training.

The group of seven, consisting of shuttle commander Ronald Grabe, pilot Stephen Oswald, mission specialists Norman Thagard, David Hilmers and William Readdy, payload specialists Roberta Bondar (Canadian Space Agency) and Ulf Merbold (ESA), gathered in Munich on 29 March, accompanied by alternate payload specialist Roger Crouch and crew coordinator Julie Sanchez. They attended the International Space Year (ISY) conference and Space Show (see related article).

On the following day, the crew visited ESOC in Darmstadt, Germany, from where numerous IML-1 experiments were carried out with the investigators on the ground involved in real-time. The crew then visited the European Astronauts Centre in Cologne, Germany, and toured the construction site of the new Crew Training Complex. On subsequent days, they were welcomed at ESA Headquarters in Paris and at ESTEC in Noordwijk, the Netherlands.

Crew of IML-1 mission visit Noordwijk Space Expo in the Netherlands

At several of the establishments, the crew presented a slide show which gave highlights of their mission, including in-flight scenes.

ISY Space Show Welcomes Over 20 000 Visitors

Nearly 2000 participants attended 'Space in the Service of a Changing Earth', the international conference held in Munich between 30 March and 4 April. The conference was the first highlight of the International Space Year (ISY), a year-long celebration intended to enhance international cooperation in the use of space technologies for the benefit of mankind, and to stimulate contributions to worldwide scientific research and application activities under the theme 'Mission to Planet Earth'. The year also commemorates the 500th anniversary of Christopher Columbus' discovery of America, and the 35th anniversary of the International Geophysical Year (1957) which initiated many activities of the modern space age.

The European ISY conference was organised by ESA, the German Space Agency (DARA) and the Commission of European Communities. It focused on five topics:

- environment observation and climate modelling
- space-based systems for navigation and mobile communication
- image processing, geo-information systems, and space-assisted modelling
- space sciences
- use of Earth-orbiting laboratories.

The ISY Space Show, which was held in parallel with the conference, welcomed over 20 000 visitors. It provided the general public with a layperson's view of the great range of space operations in Europe and throughout the rest of the world. Exhibits illustrated space history since the Sputnik mission in 1957.

A 'World Space Congress' will also be held in Washington D.C. at the end of August, as part of ISY.

ESA stand at ISY Space Show (photo: A. Walter)

Euroavia Design Contest '92

The European Association of Space Students (Euroavia) has launched its second design contest. Twenty-five students will be selected to participate in a two-week seminar on how to design and build a satellite.

Working in a multinational group, the students will undertake a configuration study of a small, scientific satellite. At present, a small Earth-observation satellite, which could supplement current and future missions such as the Polar Platform, is expected to be the topic for the project. Senior space engineers from sponsoring aerospace companies will guide and advise the students.

The goals of the Euroavia Design Contest (EDC) are to acquaint students in space-related fields with their future working environment, and to strengthen the relations between the European aerospace industry and universities, emphasising the need for European cooperation within these fields.

The workshop will take place during the first two weeks of August 1992, and will be hosted by ESA/ESTEC. The topic of the first EDC was the so-called Ulysses Reference Mission (URM). The contest was followed by a workshop at Dornier in Germany in April 1991.

Students interested in the second EDC should write and submit a technical paper on the space-related subject of their choice (maximum length of 10 pages). An international, technically experienced jury will select the 25 finalists.

For more information or for order-forms for the proceedings of the first EDC, contact:

Euroavia Design Contest Team
Kluyverweg 1
NL-2629 HS Delft
The Netherlands

Tel: (31) 15 - 785366
Fax: (31) 15 - 623096 Attn: VSV/EA

Atlas-1 Mission Successful

The first Atmospheric Laboratory for Applications and Science (Atlas) mission was successfully completed on 2 April, after nine days in orbit aboard the Space Shuttle Atlantis (STS-45).

The purpose of the mission was to investigate how the Earth's atmosphere and climate are affected by the Sun and by human-induced atmospheric changes such as those caused by the products of industrial complexes and agricultural activities. The mission was the first in a series of up to 10 Atlas missions which will gather data throughout an entire 11-year solar cycle, the Sun's regular period of energetic activity. The Atlas missions are part of NASA's Mission to Planet Earth, a large-scale study of the planet Earth as a single, dynamic system.

During the mission, 13 experiments were carried out using 12 scientific instruments provided by Belgium, France, Germany, Japan, the Netherlands, Switzerland, and the United States. Solar radiation, the chemistry of the atmosphere, space plasma physics and ultraviolet astronomy were studied. Many of these experiments will be repeated on later Atlas missions to provide a more detailed, long-term view of the Earth and its environment, and the changes that it is experiencing. The instruments were mounted on two pallets in the Space Shuttle's payload bay, and were exposed directly to space when the Shuttle's bay doors were opened. The Shuttle's altitude (300 km), its orbital inclination to the equator (57°), and its changing orientation with respect to Earth placed the instruments in advantageous orbiting locations for observing the atmosphere, the Sun and astronomical targets.

ESA provided operational support for the European investigations. For one of the experiments, the Measurement of the Solar Constant (Solcon) experiment, the scientists used a work station to provide a direct operational link with the payload on board the Shuttle from ESTEC in the Netherlands. This allowed both ESA and the scientists to prepare to handle long-running experiments directly from their laboratory, in anticipation of the forthcoming era of the International Space Station.

Dirk Frimout, payload specialist, at work during the Atlas-1 mission

The next Atlas flight, Atlas-2, is scheduled for launch in the spring of 1993. After Atlas-1 landed, the science teams for instruments to be flown on Atlas-2 began recalibrating and preparing their instruments for reflight, while analysing and interpreting the data collected during Atlas-1.

European Astronaut Returns From Space

After nine days in space aboard the Space Shuttle Atlantis (STS-45) and more than five months of training in the United States, Dirk Frimout has returned to ESTEC in Noordwijk, The Netherlands. He was one of two payload specialists on the mission. He has become the first Belgian astronaut.

Frimout will resume his position in the Microgravity and Columbus Utilisation Department at ESTEC. He has been responsible for ESA's support of four of the twelve experiments that flew on the Atlas-1 mission since 1984. He was also co-investigator for one of those four experiments, the Grille Spectrometer.

Astronaut Dirk Frimout receives an award from M. Le Fèvre, Director of ESTEC

50th Ariane Launched

The 50th Ariane vehicle was successfully launched on 15 April from the Kourou Space Centre in French Guiana. It placed the Telecom 2B and Inmarsat-2 F4 satellites in orbit. Of the 50 launches, 45 have been successful, placing 85 satellites in space for clients from around the world.

The French government's Telecom 2B satellite will be used for telephone and television coverage in France and in the French overseas departments.

The Inmarsat-2 F4 satellite, launched for the International Maritime Satellite Organization (Inmarsat), will provide global mobile communications for ships, for aircraft, and for mobile users on land over an area reaching from western Europe and western Africa to South America and the east coast of North America. The satellite will begin operations in late May. It will take over the communications traffic in the Atlantic Ocean West region which is currently carried by Inmarsat's first generation spacecraft, Marecs B2. That older satellite will become a spare for that region. Inmarsat-2 F4 is the fourth and final Inmarsat-2 mobile communications satellite to be launched.

The 50th Ariane is also the first vehicle to be launched of a series of fifty Ariane-4 launchers that the international space transportation company, Arianespace, will be using between 1992 and 1998.

Satellite System to Provide Earlier Warning of Food Crises in Africa

The United Nations' Food and Agriculture Organisation (FAO) will use a satellite telecommunication system to provide earlier warning of food crises and natural disasters in Africa.

The system, the Direct Information Access Network for Africa (DIANA), will use an Intelsat satellite to link the FAO headquarters in Rome with its regional office for Africa in Accra, Ghana, the Regional Centre for Services in Surveying, Mapping and Remote Sensing in Nairobi, Kenya, and the Department of Meteorological Services of Zimbabwe in Harare.

High-volume data and images will be transmitted to provide information on precipitation and vegetation conditions in Africa. That information will be drawn from environmental satellites and processed by another FAO system, Artemis, which monitors crop conditions and provides early warning of adverse weather and natural disasters in Africa and Asia. The DIANA system's transmission rate is 64 kbit/s which allows, for example, the transmission of a full image of Africa (consisting of 1.3 million data points) from the Artemis system in approximately four minutes.

The DIANA system consists of a hub station in Rome and a remote station in each of Accra, Nairobi and Harare. Transmissions will mainly be unidirectional, from Rome to Africa, but the remote stations will be able to transmit short messages and computer files to the central terminal in Rome. ESA developed the system, and the FAO and ESA will demonstrate and test it for one year, beginning in July 1992. In the future, the system is expected to be expanded to include other FAO country and regional offices around the world.

ESA Selects Candidate Astronauts

ESA has selected six candidates for its European Astronaut Corps. They were selected from among several thousand applicants from all 13 ESA Member States. Each Member State had been invited to propose up to five candidates following screening on a national level. Fifty-nine applicants then underwent thorough professional, psychological and medical evaluations, and their task-oriented skills and capabilities were assessed. (An extensive article on the selection process will appear in the next issue of the ESA Bulletin.)

The six candidates will begin their training on 1 June with an intensive eight-week introduction to ESA activities at the European Astronauts Centre (EAC) in Cologne, Germany. Four of the candidates will then work in Europe, supporting ESA's manned space flight programmes. They will complete their basic training at EAC after one year. The other two candidates will take up Mission Specialist training, including basic training, at NASA in Houston on 1 August.

The candidates who successfully complete the basic training will then become members of the European Astronaut Corps. The Corps is central to Europe's plans for manned space flight, including joint missions with the United States and the Commonwealth of Independent States.

Candidate astronauts for the European Astronaut Corps. First row (from left to right): Maurizio Cheli, Italy (Age 33), Marianne Merchez, Belgium (Age 31), Jean-François Clervoy, France (Age 33). Second row (from left to right): Christer Fuglesang, Sweden (Age 35), Thomas Reiter, Germany (Age 33), Pedro Duque, Spain (Age 29).

Publications

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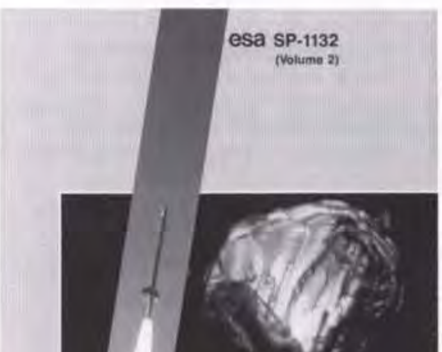

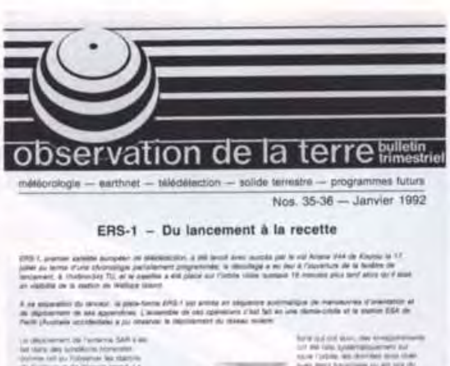

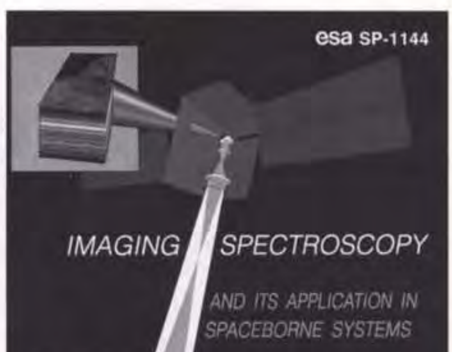

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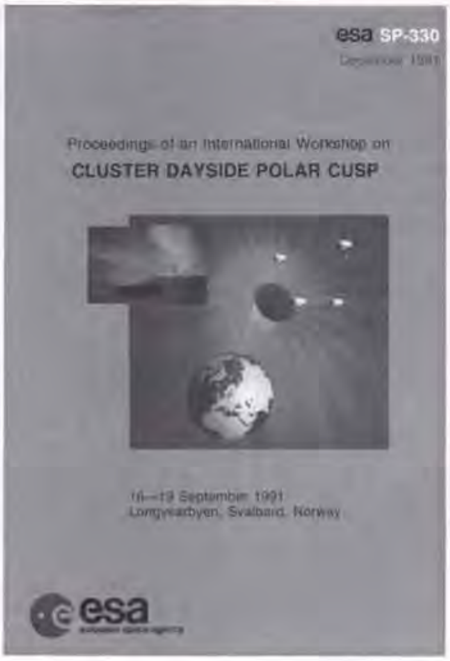

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