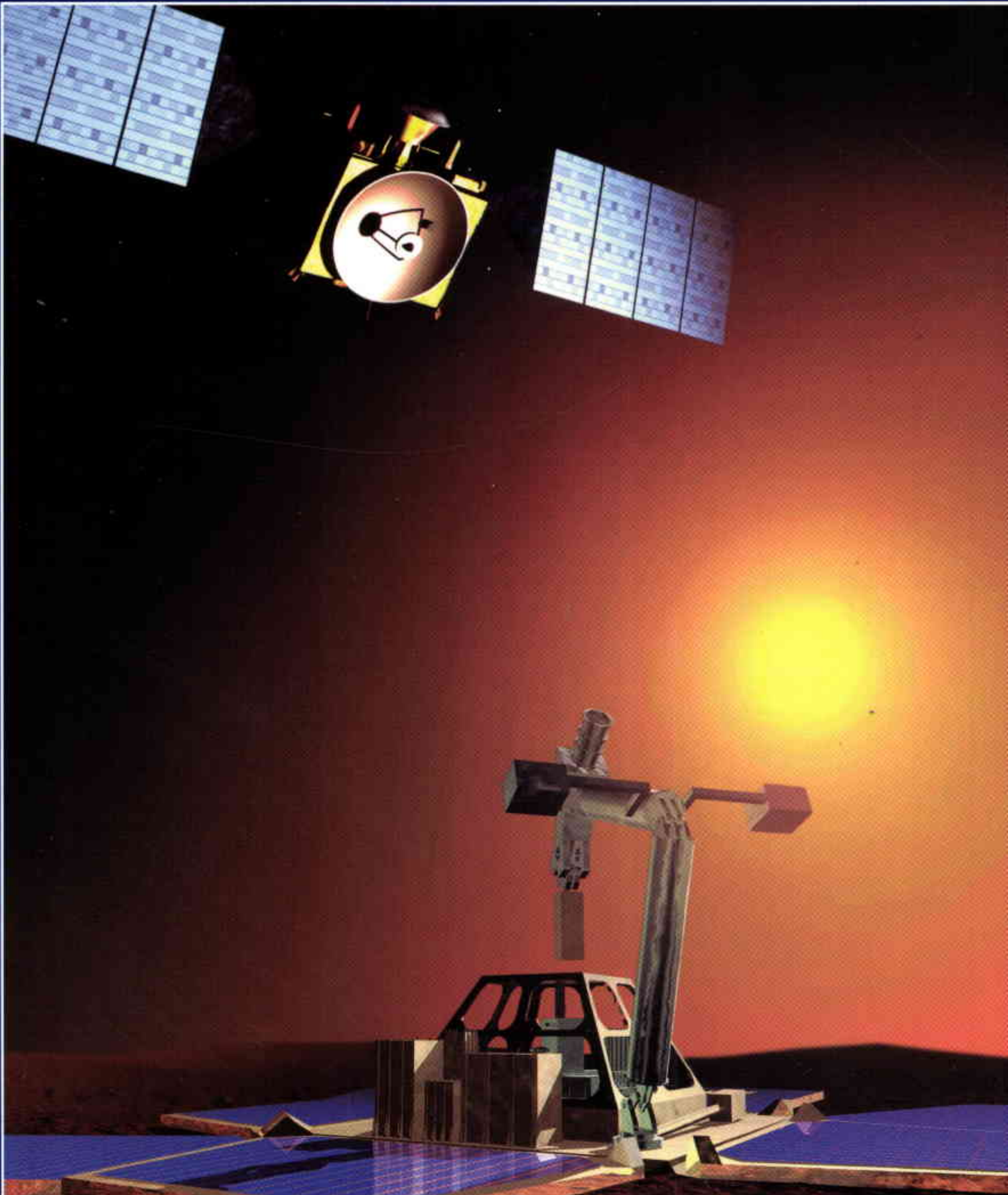
esa bulletin

number 98 - june 1999



European Space Agency
Agence spatiale européenne

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, Finland, France, Germany, Ireland, Italy, Netherlands, Norway, Spain, Sweden, Switzerland and the United Kingdom. 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 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: H. Parr

Director General: A. Rodotà.

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 Finlande, la France, l'Irlande, l'Italie, la Norvège, les Pays-Bas, le Royaume-Uni, la Suède et la Suisse. Le Canada bénéficie d'un statut d'Etat coopérant.

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

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

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

Le SIEGE de l'Agence est à Paris.

Les principaux Etablissements de l'Agence sont:

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

LE CENTRE EUROPEEN D'OPERATIONS SPATIALES (ESOC), Darmstadt, Allemagne.

ESRIN, Frascati, Italie

Président du Conseil: H. Parr

Directeur général: A. Rodotà.

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2200 AG The Netherlands
Tel.: (31) 71.5653400

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Printed in the Netherlands ISSN 0376-4265

European Space Agency
Agence spatiale européenne


Payload Interface Unit


Antenna Pointing Electronic

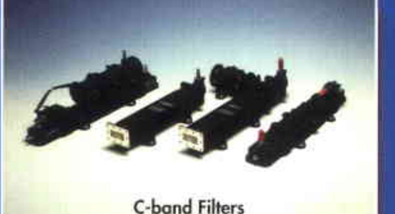

Remote Terminal Unit


BPSK Modulator


ASIC-Technology


S-band digital Transponder

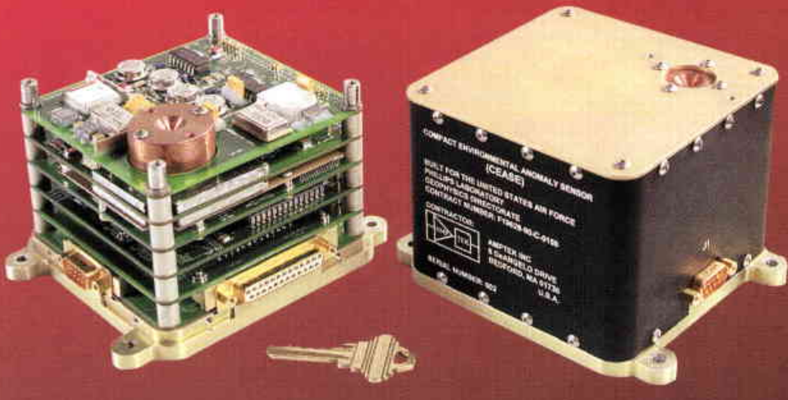

Ku-band input Multiplexer


C-band Filters

Space Radiation Alarm

"CEASE"

COMPACT ENVIRONMENTAL ANOMALY SENSOR



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- On-board determination of hazardous conditions

CEASE is a compact, radiation hard, low power, space "weather" hazard sensor developed to monitor the local radiation environment and to provide autonomous real-time warnings of:

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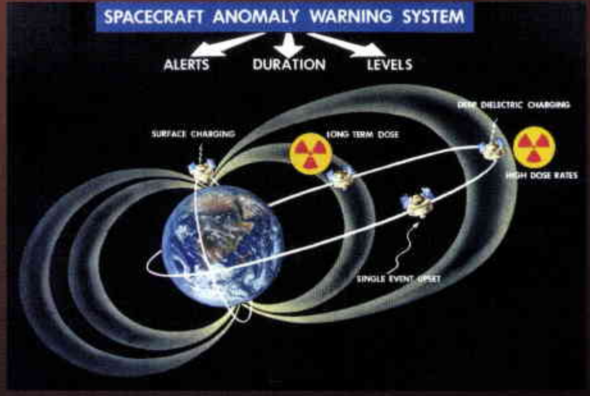
CEASE detailed radiation data is used to pinpoint causes of spacecraft anomalies, and to forecast hazardous conditions before they affect the mission. The spacecraft, in turn, can re-prioritize its operations, inhibit any anomaly sensitive tasks such as attitude control adjustments, or initiate other prudent actions as indicated by the **CEASE** warning flags. Device degradation mechanisms and radiation tolerance of components can also be monitored.

The US Department of Defense has selected **CEASE** for several missions, including:

- **TSX-5**
- **STRV-1C**
- **SBIRS LADS**

and the **DSP** operational spacecraft.



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Current off-the-shelf Amptek sensors measure spacecraft charging, thermal and suprathermal, and high energy particles.

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The Brussels Council at Ministerial Level

The 141st meeting of the Council of the European Space Agency, and the eighth at Ministerial Level, took place on 11 and 12 May at the Palais d'Egmont in Brussels. Belgium hosted the meeting at the invitation of Mr Yvan Ylieff, the Belgian Minister for Science Policy and Chairman of the previous Council Meeting at Ministerial Level. During the opening session, Mr Ylieff handed over the Chair to Lord David Sainsbury, the UK Minister responsible for space. In addition to the 13 European Ministers and representatives of the Irish and Canadian Ministers present, representatives from Portugal, the European Commission, Eutelsat, Eumetsat and the European Space Science Committee attended as observers. Three European Commissioners – for Industry, Research and Transport – also participated in the meeting.

The main objective of this Ministerial Council was to shape a space policy that will allow Europe to continue to play a major role in space activities on the world stage. The Ministers responsible for space activities in the Agency's Member States were asked to endorse ESA's new strategy and its role in working with national players, intergovernmental organisations, European Union institutions and industry in order to respond to the challenges of the next millennium. They were also asked to decide, in the context of ESA's Long-Term Plan for the period 1999-2006, on new programmes spanning the fields of space science, access to space (launchers), space applications (Earth observation, telecommunications and navigation), exploitation of the International Space Station and advanced technology. They were also called upon to decide on a Level of Resources for the period 1999-2003 for the Agency's Mandatory Activities.


Lord Sainsbury

In the event, the Ministers approved the Level of Resources for the period 1999-2002 (essentially the General Budget and the Science Programme budget) to a total of 2103.2 MEuro (at 1998 economic conditions). This should hopefully enable ESA to implement all of its planned scientific missions.

There is an urgent need to ensure strategic independence for Europe in the field of satellite navigation. The Ministers therefore decided to commit 58.4 MEuro until end-2001 for the definition phase of the Galileo programme being developed in cooperation with the European Union, and even indicated the availability of 178 MEuro for the subsequent development phase (until end-2006). As a result, aircraft, ships, trucks, trains, cars and ambulances will soon be guided and easily located via a constellation of European satellites. Most importantly, Europe will now be able to access the huge markets for navigation-related ground equipment and services.

The Ministers also recognised that European industry needs to increase its share of the worldwide telecommunications market. They therefore allocated 260 MEuro (for the period 1999-2002) to the development of multimedia and information systems, and 30 MEuro for preliminary studies of future systems in the period 2000-2005. Tele-medicine and tele-education are but two examples of the new fields in which space can help improve our quality of life.

Because space offers Europe a unique opportunity for contributing to worldwide efforts towards understanding our environment and managing the natural resources of our planet, the Ministers decided to fund the Living Planet programme, with a commitment of 593 MEuro through to the end of 2002.

Europe also wants to be a strong and valued partner in the International Space Station. The Ministers therefore allocated 298.5 MEuro to the Station's exploitation for the period 2000-2001. Moreover, the Ministers recognised the importance of continuity in the European Microgravity Research Programme and approved the extension of the EMIR-2 programme for the period 1999-2003, allocating 48 MEuro.

To safeguard Europe's independent access to space and its leading position in the

Ministers and Senior Representatives of the ESA Member States, in Brussels

First row (from left to right):
Mr Antonio Rodotà (ESA Director General), Mr Mattie McCabe (Ireland), Mr Josep Piqué (Spain), Mrs Edelgard Bulmahn (Germany), Lord David Sainsbury (United Kingdom), Mr Claude Allègre (France), Mr Yvan Ylieff (Belgium), Mrs Mona Sahlin (Sweden)

Second row (from left to right):
Mr Hugo Parr (ESA Council Chairman), Mr Ortensio Zecchino (Italy), Mrs Annemarie Jorritsma-Lebbink (Netherlands), Mr W.M(Mac) Evans (President, Canadian Space Agency), Mr Caspar Einem (Austria), Mr Jan Trøborg (Denmark), Mr Lars Sponheim (Norway), Mr Kimmo Sasi (Finland), Mr Charles Kleiber (Switzerland)

commercial launcher market, the Ministers decided to fund the Ariane-5 Plus programme, aimed at enhancing the performance of Europe's heavy launcher, with a total of 533 MEuro until 2001. The Ministers allocated 25 MEuro for the extension of the Ariane-5 Infrastructure programme for 2001 and 134 MEuro to Ariane-5 ARTA for the period 2001-2002, so as to place Ariane-5 on a competitive footing and to consolidate its reliability. Moreover, the Future Launcher Technologies Programme received an allocation of 54 MEuro until end-2001. Finally, subject to further studies to be completed by October 1999, it was agreed to revisit funding of the second step for the development of Vega, the new small launcher.

The statement made by ESA's Director General, Antonio Rodotà, to the assembled Ministers on the opening morning, the three key Resolutions passed by the Ministerial Council, and the Press Release issued to the media at the close of the meeting on 12 May are all contained in the following pages. esa

Ministers &


AUSTRIA


FINLAND


BELGIUM


DENMARK


NETHERLANDS


IRELAND


CANADA

Delegations

Statement to the Ministerial Council by ESA's Director General

Antonio Rodotà

Ministers, Delegates, Ladies and Gentlemen,

It is a real honour for me to have the opportunity to address you today at this Ministerial Council meeting, at which you will discuss subjects that are crucial to the future of the Agency and the entire space sector in Europe.

This meeting is taking place at a strategic moment when space is also at the centre of debate in the United States, for various reasons:

- the new Commercial Space Act, which is creating a new potential barrier between the USA and the rest of the world
- the large increase in the US budget for research, and for some defence activities with substantial spin-off for the commercial sector
- the serious problems that the US launcher industry is suffering, with the recent series of failures.

At this Ministerial Council, Europe is addressing strategic problems of vital importance to our future and I sincerely hope that the conclusions that you will reach are going to lend fresh impetus to European space activities.

You have already received our proposal. I would like in a moment to convey some figures which will, I hope, give you even more confidence in the decisions you are invited to take in order to shape the future of the space sector in Europe, a process made all the more difficult by the budgetary constraints currently prevailing in most Member States.

You all know that space is a fast-expanding sector, in which Europe is playing an important role. The total turnover for world space activities, including related services, is today estimated at 90 billion US dollars, with the commercial sector expanding at about 20% a year and employing around 1 million people worldwide.

Although investment in Europe is 15% of the world total, Europe presently has more than 40% of the commercial launcher market, and around 20% of the commercial satellite market. However, competition is becoming fiercer and massive investment is needed to maintain the position that we have achieved and possibly to build on it by taking our share of the fast-growing information market.

The scientific sector has been a pillar of space activity in Europe and it is still leading world research in many areas.

I think we have reason to be proud of what Europe has achieved so far. I would like just to emphasise the point with a few more figures:

- In 1998, the insurance companies paid out 640 million US dollars in claims for launch failures, none of them European launcher failures; in the same year they paid out 1.15 billion US dollars for satellite failures in orbit, of which only 67 million - less than 7% - was for European satellites.
- I would like to share with you the pride of Arianespace in its record of 44 consecutive perfect Ariane-4 launches and ESA's pride in the qualification of Ariane-5, which will open up new market opportunities.
- I would like to draw your attention to the fact that 43 of the 46 satellites launched by ESA have operated on average of 2.5 times as long as originally planned, and only three have not lasted for their planned lifetime. This equates to greater value for money. For instance, one of these ESA satellites, ECS, is now part of the Eutelsat fleet and after 11 years of service (it was planned for 4) is being used over the Atlantic to start a brand new Internet service between the USA and Europe. These new services will provide new opportunities for Eutelsat, which was created around some former ESA satellites and has since signed contracts with European companies valued at 3 billion Euros.
- Other ESA satellites that have greatly exceeded their planned operational lifetimes are Marecs and the Meteosats. The latter are operated today by Eumetsat, the organisation that was born out of an ESA development programme and is now a pillar of the international operational meteorology sector. According to analyses performed by Eumetsat itself, the financial benefits to the user community are around 15 times the corresponding investment costs.

- Finally, and with particular pride, I would like to stress the remarkable competence of the people controlling and operating our European satellites - in particular the scientific satellites - and to point once again to the incredible recovery of SOHO, thanks to which the world-wide science community will be able to continue to explore the Sun and its all-important interaction with our planet. This satellite too is already exceeding its planned lifetime.

It is fine to have nice slogans, but we feel that it is much more important to have solid results. But we cannot just take satisfaction in past achievements - we have to set challenging objectives for the future. We have to set challenging objectives for ourselves (ESA) and we also have to set challenging objectives for European industry, and we have already started to do so.

Even though the Agency's activities have remained at a practically constant level from 1996 to 1999, we have trimmed our staff by more than 20% (from more than 2100 to 1700) and we have reduced the General Budget by more than 20% (from 440 billion Euros in 1996 to 350 million in 1999). In addition, the Science Directorate has been able to accommodate a replacement Cluster mission within the existing budgetary framework. Against this 20% improvement, the general productivity increase in Europe over the same period has been around 2% per year. Even more significantly, the internal costs of the Agency account for just 15% of its total budget and we have made the commitment to reduce programme overruns from 15% (the 1996 figure) to zero, and this has been the status quo since 1997. This is the most challenging objective for ESA and the European space industry because we have to strive to maintain it without detracting from the quality and performance of our programmes.

In addition to what has been achieved already, we have agreed to further reduce the internal costs of the Agency over the next two years to arrive at a final figure of 335 million Euros, without affecting the research activities. Depending on your decisions at this Ministerial Council, other actions are also planned. In fact, most of the programmes we are proposing for your attention require a different type of interaction with industry. Most of them call for risk-sharing with industry, and we intend to pursue this approach wherever the market allows. We intend to make extensive use of industry's expertise, assigning it more responsibility for the definition and operation of programmes, in particular in the application sectors (telecommunications, navigation, Earth observation), but also for the exploitation of the Space Station. This trend, together with the profound changes underway in industry itself, will require a reshaping of ESA. This reshaping must take into account the competences of ESA's partners: the European Union and the national space agencies.

The relationship between ESA and the European Union has been growing in recent years. This growth was marked last year at the political level when the two Councils passed the same Resolution calling for synergy and complementarity between their respective organisations. This relationship will bear fruit today with the decision on Galileosat.

We will propose modifications in due course to the existing organisation of ESA, which whilst respecting the rules laid down in the Convention will give the Agency a more streamlined structure, able at the same time to interface with the new large companies and to maintain access to the competence and technologies available from Europe's network of small and medium-sized enterprises. Competition is becoming an increasingly distinctive feature of the space sector, and ESA has to use it more extensively, both directly and indirectly, maintaining fairness and transparency.

We understand that all of these themes - competition, transparency and efficiency - require a lot of effort, clear objectives and motivated people. We are working on all aspects of our personnel policy - career paths, salaries and technical competence - so that we may continue, as in the past, to count on a motivated and efficient staff able to contribute to the evolution of the entire space sector in Europe.

We are sure that you, the Ministers, will set us clear and challenging objectives for the future of the Agency. We commit ourselves to reshaping the Agency in accordance with such objectives, and we are counting on the support of all of our Member States.

Antonio Rodotà

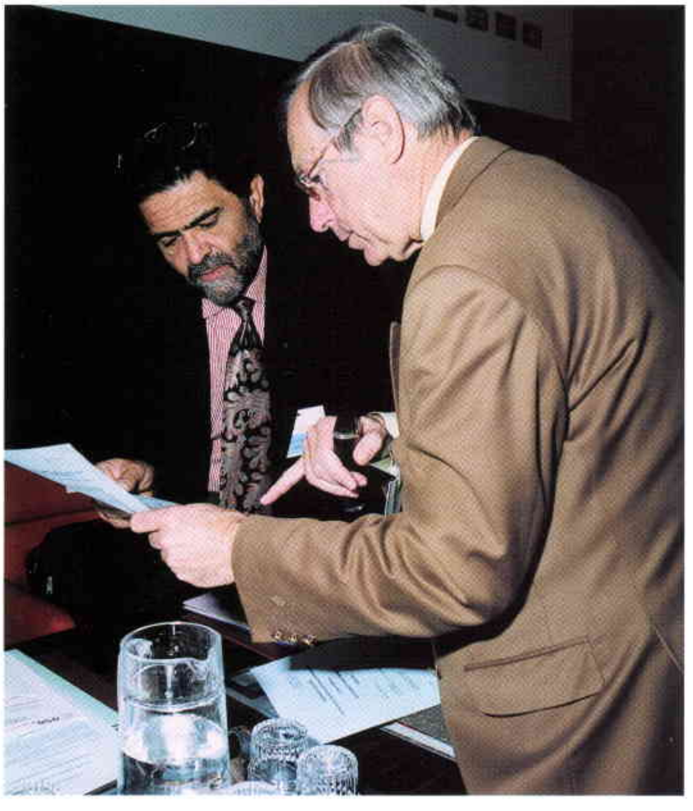
Council in Session

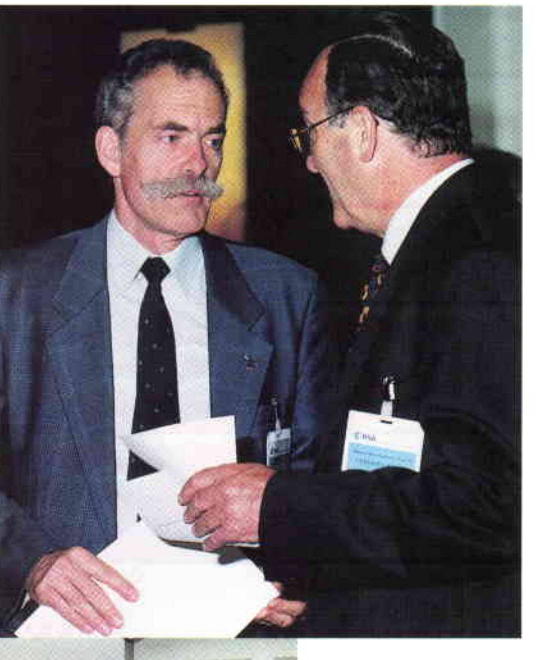
Opening by Mr Yvan Ylieff (left), host for the meeting

The ESA Executive and Ministerial Chairman Lord David Sainsbury (right, seated centre)

Behind th

e Scenes





Press Release, 12 May 1999

Ministers Shape the Future of European Space Activities

Ministers of the Member States of the European Space Agency (ESA) today set challenging objectives for the future of European space activities and approved major new programmes to achieve them.

Meeting in Brussels on 11 and 12 May, the 14 member countries of ESA, together with Canada, which has a co-operation agreement with the Agency, approved investments in new space-related development programmes. Newly elected ESA Ministerial Council Chairman Lord Sainsbury, the UK Space Minister, told waiting international journalists:

"The ESA Member States have given a great boost to the whole European space community. The new investments agreed will underpin the development of new jobs in multi-billion Euro, knowledge-based industries in the next decade".

Highlighting the adoption of the first phase in a long-term programme of environmental science, he continued:

"The agreement to embark on the Living Planet Programme is the first step towards providing an assured long-term programme of research which looks at the Earth and its environment from space. We are putting Earth Sciences on a more equal footing with ESA's traditional strengths in scientific research".

Other programmes to receive approval from the Ministers included further enhancements of Europe's highly successful launcher industry, new developments in satellite navigation, satellite communications, particularly multimedia systems, and further preparations for providing Europe's contribution to the International Space Station in its early years of operation. The Ministers also agreed the budgets for the ESA Science Programme allocating 1460.8 MEuro for the period 1999-2002.

The new programmes were endorsed against a background of agreement among the Ministers on four broad objectives for the Agency:
- achieving and maintaining the highest quality science
- developing technologies for world-competitive space industries throughout the Member States
- developing an integrated network of specialised technical centres belonging to ESA and national organisations, and
- achieving and maintaining world-class standards in the management of the Agency and its programmes.

The Ministers emphasised the need to adopt new ways of managing programmes, transferring greater responsibility to industry and engaging in a range of partnerships. This approach was demonstrated most clearly in the decision to proceed with a full programme definition for the Galileo global navigation satellite system. This will be undertaken initially in partnership with the European Union, which is expected to decide on the programme in June, but the Ministers have instructed the Director General to bring in user and other commercial interests early in the development phase.

Closer co-operation between ESA and the EU in developing a unified European space strategy was evidenced by the presence during the meeting of the European Commissioners for Industry, Research and Transport. Mr Kinnock, the Transport Commissioner, welcomed the commitment to the Galileo Programme and said:

"I am very pleased by the enthusiasm which the space and research ministers of Europe have shown for the Galileo concept. The space interests of the EU and ESA are largely complementary and we are developing highly effective ways of working closely with each other. Navigation in land, sea and air transport is an excellent example of that – and the potential benefits for users and producers in Europe are massive. I am sure that there will be more examples in other areas of development in the coming year".

With a keen eye on Europe's future space policy, the Ministers welcomed the Report and Action Plan of the Long-term Space Policy Committee (LSPC): "*Investing in Space: The Challenge for Europe*". This report identifies three major challenges that Europe will have to face as it enters the new millennium – strategic independence, planetary management and expansion beyond present horizons. It also includes an Action Plan of 20 proposed initiatives as a first response for Europe to these three challenges in order to secure a leading position in the face of fierce international competition.

The Agency's Director General, Antonio Rodotà, was happy with the outcome of the meeting, noting that:

"The decisions taken here in Brussels will set the direction for the Agency for the next five years and beyond. We have made considerable changes in our working methods in the past four years, since the Ministerial Council in Toulouse in 1995. We have set in train a system of continuous improvement, and Ministers have rewarded us with a resounding vote of confidence. Most importantly, they have shown their determination to maintain a world-class European space industry in selected strategic sectors, and to continue their support for Europe's renowned scientific community. There will be many people in companies both large and small, throughout Europe and in Canada, who will respond positively to this exciting vision of Europe's future in space".

The Press Conference on 12 May

ESA/C-M/CXLI/Rés. 1 (final)

RÉSOLUTION SUR L'AVENIR DE L'EUROPE SPATIALE

(adoptée le 11 mai 1999)

Nous, Ministres représentant les Gouvernements des 14 États membres de l'Agence spatiale européenne (ESA), réunis le 11 mai 1999 à Bruxelles pour la session du Conseil,

ATTIRONS L'ATTENTION sur l'importance stratégique de l'espace et sur les résultats remarquables obtenus durant les trente années d'efforts conjoints de l'Europe dans ce domaine, en particulier les contributions exceptionnelles qui ont été apportées à la connaissance scientifique de l'Univers et de la Terre, la création réussie d'un secteur industriel en ce qui concerne les lanceurs, la fabrication des satellites et l'offre de services, ainsi que l'engagement des jeunes générations dans cette nouvelle conquête.

PRENONS NOTE du fait que les activités spatiales européennes sont soumises à une évolution de plus en plus rapide à mesure que de nouveaux services toujours plus nombreux sont mis à la disposition du grand public et qu'apparaissent ainsi de nouvelles possibilités en matière de croissance et d'emploi. Ceci nécessite que l'industrie et le soutien institutionnel public fassent l'objet d'une adaptation correspondante. Un regroupement industriel optimal et un approfondissement des relations entre l'ESA et l'Union européenne en seront des éléments clés.

DÉCLARONS que les défis nouveaux et difficiles du XXI$^{\text{ème}}$ siècle exigent une politique européenne concertée, de façon à ce que l'Europe puisse tirer pleinement parti de ses potentialités sur le plan de la coopération internationale et de la compétitivité sur le marché mondial. Ceci nécessite que l'ESA s'engage davantage en vue de satisfaire les besoins du public et de réaliser de nouvelles conquêtes, et

ESA/C-M/CXLI/Res. 1 (Final)

RESOLUTION ON
SHAPING THE FUTURE OF EUROPE IN SPACE

(adopted on 11 May 1999)

We, the Ministers representing the Governments of the 14 Member States of the European Space Agency (ESA), assembled in Council at Brussels on 11 May 1999,

CALL ATTENTION to the strategic importance of Space and to the remarkable results achieved during thirty years of common European endeavour in this field, in particular the outstanding contributions that have been made to the scientific understanding of the Universe and the Earth, the establishment of successful launcher, satellite manufacturing and service industries and the engagement of our young people in the opening up of this new frontier.

NOTE that European space is undergoing accelerating change, as more and more new services become publicly available and new opportunities for growth and employment open. This necessitates corresponding adaptation in industry and in public institutional support. Optimum industrial grouping and a deepening relationship between ESA and the European Union will be key elements.

DECLARE that the new and demanding challenges of the 21st Century call for a concerted European effort, so that Europe achieves its fullest potential in international cooperation and world market competition. This requires increased ESA efforts, towards serving public needs and conquering new frontiers, and a new approach coordinated by ESA, to pooling human, technical and financial resources to achieve our objectives.

ESA/C-M/CXLI/Rés. 1 (final)
Page 2

qu'elle coordonne une nouvelle méthode visant à mettre en commun les ressources humaines, techniques et financières permettant d'atteindre nos objectifs.

DÉCIDONS de valoriser les activités spatiales européennes auprès des citoyens en assignant à l'ESA, conformément aux dispositions de sa Convention, les objectifs spécifiques suivants:

- Poursuivre des recherches scientifiques de la plus haute qualité en ce qui concerne l'exploration du système solaire, l'astronomie, l'observation de la Terre, les sciences de la vie et les sciences physiques, en accord avec les priorités établies au terme des revues scientifiques de pairs.

- Mener les activités de recherche et développement les plus judicieuses afin d'améliorer la compétitivité, la croissance et l'emploi et de favoriser un environnement au sein duquel les petites et moyennes entreprises (PME) européennes pourront prospérer, en accord avec les objectifs convenus en partenariat avec l'industrie relativement aux parts de marché à conquérir dans tous les secteurs commerciaux, y compris les télécommunications, les lanceurs commerciaux, l'observation de la Terre, les activités de navigation et de localisation par satellite. Les actions appropriées de l'ESA devraient faire l'objet d'une concertation approfondie avec l'Union européenne et les autres organisations européennes concernées.

- Favoriser l'émergence d'une communauté d'ingénieurs et de techniciens du secteur spatial européen. Les centres techniques appartenant à l'ESA et aux organisations nationales devraient notamment être regroupés dans un réseau intégré de centres spécialisés, travaillant ensemble dans un esprit de transparence, de complémentarité et de réciprocité, en concertation avec l'ESA, et offrant des possibilités de mobilité beaucoup plus nombreuses. Ce réseau devrait être développé progressivement à mesure que démarreront de nouveaux programmes européens.

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DECIDE to project the value of the European space effort to citizens by setting the following specific objectives for ESA to be pursued in conformity with the provisions of its Convention:

- To pursue the highest quality science in Solar System Exploration, Astronomy, Earth observation, Life and Physical Sciences, in line with the priorities set through scientific peer review;

- To carry out the Research and Development best able to enhance competitiveness, growth and employment, and to nurture an environment in which European Small and Medium-sized Enterprises (SMEs) will flourish in line with targets agreed in partnership with industry for market shares to be achieved in all business sectors, including telecommunications, commercial launchers, Earth observation and navigation and positioning. Relevant ESA action should be concerted in close collaboration with the European Union and other relevant European organisations;

- To foster the development of a community of engineers and technicians of the European space sector. In particular, the technical centres belonging to ESA and to national organisations should be formed into an integrated network of specialised centres, working together in a spirit of transparency, complementarity and reciprocity, concerted by ESA and offering greatly increased opportunities for mobility. This network should be developed progressively as new European programmes are initiated;

- Améliorer les performances de l'ESA en prenant des décisions en temps opportun, décisions pour lesquelles il sera tenu dûment compte des souhaits exprimés par les États membres, de leur état de préparation pour contribuer aux programmes ainsi que des besoins des nouveaux partenaires, et en augmentant la rentabilité de l'ESA. Ceci devrait être mesuré en établissant des indicateurs de performances, en contrôlant et communiquant les résultats obtenus par l'ESA et par les agences spatiales nationales, de façon à permettre une évaluation d'ensemble des activités spatiales menées en Europe.

NOUS FÉLICITONS du travail engagé par le Directeur général et, parallèlement, par la Commission européenne en vue de définir une stratégie spatiale globale pour l'Europe et DEMANDONS que soit préparée une stratégie pleinement élaborée, conformément aux dispositions de la Résolution sur le renforcement de la synergie entre l'ESA et la Communauté européenne adoptée en juin 1998, en consultation avec l'industrie et tous les acteurs engagés dans les activités spatiales européennes, stratégie qui devra être présentée au Conseil avant fin 2000.

FAISONS OBSERVER que, sur un marché arrivant à maturité, l'industrie jouera de plus en plus un rôle prédominant, ENCOURAGEONS l'industrie et le secteur privé, dans le contexte des restructurations de l'industrie en Europe, à assumer une responsabilité stratégique au niveau de la création de nouveaux secteurs commerciaux en exploitant pleinement les potentialités offertes par l'amélioration de l'efficacité économique et le renforcement des synergies, sur la base du concept de partenariat public/privé assorti d'un financement conséquent par l'industrie, et DEMANDONS que l'industrie travaille en partenariat avec l'Agence pour assurer que tous les acteurs aient accès au plus grand nombre de débouchés possible.

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- To enhance ESA's performance through timely decisions, in which due regard is paid to the prevalent wishes of Member States, their preparedness to contribute to programmes and to the needs of new partners, and by increasing the cost effectiveness of ESA. This should be measured by setting performance indicators, monitoring and reporting results achieved by ESA as well as by national space agencies, permitting an overall assessment of the European space effort.

WELCOME the work initiated by the Director General and in parallel by the European Commission towards defining an overall European space strategy and CALL FOR a fully developed strategy to be prepared, in line with the provisions of the Resolution on the reinforcement of the synergy between ESA and the European Community adopted in June 1998, in consultation with industry and all European space interests, and to be put to Council by the end of 2000.

OBSERVE that in a maturing market increased leadership will rest with industry, ENCOURAGE industry and the private sector, taking into account the industrial restructuring in Europe, to assume a strategic responsibility in the opening up of new areas of business with full exploitation of the potential for enhanced cost-effectiveness and synergies, on the basis of the concept of private/public partnership including a significant funding by industry, CALL ON industry to work in partnership with the Agency to ensure that maximum market opportunity is opened to all in the sector.

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PROJET DE
RESOLUTION SUR L'EVOLUTION DE L'AGENCE
ET SES PROGRAMMES

(adoptée le 12 mai 1999)

Le Conseil siégeant au niveau ministériel,

VU la Convention de l'Agence,

VU la Résolution sur les mesures à prendre dans l'immédiat et sur les préparatifs à mettre en œuvre en vue de la session du Conseil au niveau ministériel relative aux nouveaux programmes et à l'évolution de l'Agence, adoptée le 24 juin 1998 (ESA/C/CXXXVI/Rés.3 (final)),

VU la Résolution sur le renforcement de la synergie entre l'Agence spatiale européenne et la Communauté européenne, adoptée le 23 juin 1998 (ESA/C/CXXXVI/Rés.1 (final)),

VU la Résolution sur l'avenir de l'Europe spatiale, adoptée au niveau ministériel le 11 mai 1999 (ESA/C-M/CXLI/Rés.1 (final)),

VU la proposition du Directeur général relative à une politique spatiale européenne et aux programmes de l'ESA (ESA/C-M(99)4),

ESA/C-M/CXLI/Res. 2 (Final)

RESOLUTION ON THE AGENCY'S EVOLUTION AND PROGRAMMES

(adopted on 12 May 1999)

Council, meeting at Ministerial Level,

HAVING REGARD to the ESA Convention,

HAVING REGARD to the Resolution on immediate measures and preparatory steps towards the Council meeting at Ministerial Level related to the Agency's new programmes and its evolution, adopted on 24 June 1998 (ESA/C/CXXXVI/Res. 3 (Final)),

HAVING REGARD to the Resolution on the reinforcement of the synergy between the European Space Agency and the European Community, adopted on 23 June 1998 (ESA/C/CXXXVI/Res.1 (Final)),

HAVING REGARD to the Resolution on shaping the future of Europe in space, adopted at Ministerial Level on 11 May 1999 (ESA/C-M/CXLI/Res.1 (Final)),

HAVING REGARD to the Director General's proposal for a European space policy and ESA programmes (ESA/C-M(99)4),

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CHAPITRE PREMIER

CONSTRUIRE L'AVENIR DE L'EUROPE SPATIALE

1. RECONNAIT que les objectifs à long terme exposés dans la Résolution ESA/C-M/CXLI/Rés.1 (final) nécessitent une évolution de l'Agence et de sa politique ainsi qu'un ensemble de programmes tel qu'ils sont présentés dans la proposition du Directeur général et exigent le renforcement de la coopération entre l'Agence et d'autres entités concernées par les applications des technologies et des systèmes spatiaux, tout en préservant les programmes consacrés à la science et aux infrastructures.

2. APPUIE une stratégie de l'ESA reposant sur les quatre grands axes suivants: amélioration des connaissances scientifiques, amélioration de la qualité de la vie, renforcement des capacités de l'Europe et développement d'une industrie européenne innovante offrant des services à forte valeur ajoutée, de façon à permettre à l'Agence d'atteindre ces objectifs à long terme.

3. RECONNAIT que la communauté scientifique européenne doit rester à l'avant-garde de la recherche spatiale.

4. CONSIDÈRE indispensable de sensibiliser davantage le public à l'intérêt et à l'importance des activités spatiales et d'inciter les jeunes générations à entreprendre des études et à faire carrière dans le domaine spatial.

CHAPITRE II

EVOLUTION ET POLITIQUE DE L'AGENCE

1. RECONNAIT que, tout en conservant son rôle traditionnel d'élaboration et de mise en œuvre des programmes spatiaux dans les conditions les plus efficaces, l'ESA jouera un rôle central dans la mise sur pied d'une stratégie

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CHAPTER I

IMPLEMENTING THE FUTURE OF EUROPE IN SPACE

1. RECOGNISES that the long-term objectives outlined in ESA/C-M/CXLI/Res.1 (Final) require an evolution of the Agency and its policies as well as a set of programmes outlined in the Director General's proposal and call for an enhanced cooperation between the Agency and other entities concerned with applications of space systems and technologies while preserving programmes dedicated to science and infrastructure.

2. SUPPORTS an ESA strategy built around the following four main axes: improvement of scientific knowledge, improvement of quality of life, reinforcement of Europe's capabilities and development of a European industry of innovation and added-value services, as a proper response to these long-term objectives.

3. RECOGNISES the need to keep the European scientific community in the vanguard of space research.

4. CONSIDERS it essential to heighten public awareness of the benefits and relevancy of space activities and to attract rising generations into space-related studies and careers.

CHAPTER II

THE EVOLUTION OF THE AGENCY AND ITS POLICIES

1. RECOGNISES that, while continuing in its traditional role of setting up and implementing space programmes under the most efficient conditions, ESA will play a central role in putting together a concerted space strategy for Europe, in close cooperation with the European Union, and INVITES the Director General to submit to Council before the end of 1999 a report

concertée de l'Europe dans le domaine spatial, en étroite coopération avec l'Union européenne, et INVITE le Directeur général à soumettre au Conseil avant fin 1999 un rapport répertoriant les mesures visant à adapter les règles et procédures de l'Agence de façon à faciliter les initiatives nationales, de l'Union européenne et du secteur privé, ainsi que son cadre juridique, l'objectif étant de prendre notamment en compte la souplesse de financement de tous les programmes et activités de l'ESA facultatifs ou obligatoires, la participation de l'Agence à de nouveaux domaines d'applications ainsi que la participation aux programmes de l'Agence de contributeurs autres que les États membres, les États associés et les États coopérants.

2. APPRECIE les actions déjà entreprises par le Directeur général pour :

(a) améliorer davantage l'efficacité opérationnelle de l'Agence;

(b) rationaliser la gestion des programmes de l'Agence en s'alignant sur les meilleurs pratiques en Europe;

(c) mettre en place des mesures visant à maintenir le coût à achèvement de chaque programme dans les limites de 100% de son enveloppe financière; et

APPUIE les efforts du Directeur général visant :

(a) à améliorer les processus décisionnels;

(b) à améliorer les procédures budgétaires afin de mieux adapter les demandes budgétaires de l'Agence aux besoins de ses programmes; et

(c) à mettre en place un système de gestion basé sur les performances.

identifying measures for adapting the Agency's rules and procedures to facilitate national, European Union and private initiatives and for adapting its legal framework, with the objective to take into account in particular flexibility in the funding of all ESA programmes and activities, optional and mandatory, the involvement of the Agency in new fields of applications and the participation of contributors other than Member States, Associated Member States and Cooperating States in the programmes of the Agency.

2. APPRECIATES the steps already taken by the Director General to

(a) further improve the Agency's operational efficiency;

(b) streamline management of ESA programmes according to best European practices;

(c) implement measures to keep the cost at completion of each programme within 100% of its financial envelope; and

SUPPORTS the Director General's further efforts to

(a) improve decision-making processes;

(b) improve budgetary procedures in order to better match the Agency's budget requests to the needs of its programmes; and

(c) introduce a performance-based management system.

3. INVITES the Director General to review the present system of adjustments for price-level variations and propose revisions to it, with a view to modifying the automatic adjustment mechanism, while preserving consistency between income and expenditure.

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3. INVITE le Directeur général à passer en revue le système actuel d'ajustement en fonction des variations du niveau des prix et à proposer des révisions de ce système visant à modifier le mécanisme d'ajustement automatique, tout en préservant la cohérence entre recettes et dépenses.

4. ENTERINE la proposition du Directeur général d'établir des indicateurs afin de mesurer et de suivre les performances et l'efficacité interne de l'ESA et les objectifs associés, INVITE le Directeur général à soumettre au Conseil une proposition complète avant fin 1999 et INVITE les chefs des agences spatiales nationales à utiliser des indicateurs similaires afin de constituer une base permettant d'évaluer globalement les activités de l'Europe dans le domaine spatial.

5. INVITE le Directeur général à établir, conformément à la Résolution ESA/C-M/CXLI/Rés.1 (final) et en étroite coopération avec les centres nationaux concernés, un plan d'action visant la constitution en Europe d'un réseau de centres techniques spécialisés appelés à travailler ensemble dans un esprit de transparence, de complémentarité et de réciprocité et faisant notamment ressortir les économies potentielles pour tous les États membres, l'harmonisation des règles et procédures de mise en œuvre des programmes de l'ESA et des programmes nationaux, ainsi que les bases qui conditionnent la mobilité des experts entre les centres techniques, et à soumettre ce plan au Conseil avant fin 1999. Les centres techniques constituant ce réseau mettront leurs services à la disposition de tous les États membres sur un pied d'égalité, à la charge de l'État demandeur, sans discrimination entre les demandes.

6. PREND NOTE des progrès accomplis par l'Agence dans la mise en œuvre de sa nouvelle politique industrielle.

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4. ENDORSES the Director General's proposal to set up indicators to measure and monitor the performance and the internal efficiency of ESA and their associated targets, INVITES him to submit to Council a comprehensive proposal before the end of 1999 and INVITES the heads of national space agencies to use similar indicators in order to constitute a basis for an overall assessment of the European space effort.

5. INVITES the Director General to establish, in accordance with the Resolution ESA/C-M/CXLI/Res. 1 (Final) and in close cooperation with the relevant national centres, a plan of action for moving towards a network of specialised technical centres in Europe, working together in a spirit of transparency, complementarity and reciprocity, showing in particular the potential savings for all Member States, the standardisation of rules and procedures for implementing ESA and national programmes, and the grounds for the mobility of experts between technical centres and to submit this plan to Council before the end of 1999. The technical centres making up this network shall make their services available to all Member States on an equal basis, at the cost of the requesting State, without discrimination among requests.

6. TAKES NOTE of the progress made by the Agency in implementing its adapted industrial policy.

7. INVITES the Director General to take into account the experience gained from the application of industrial-policy provisions to the new development and preparatory programmes decided upon at this meeting for the potential adaptation of the industrial policy for future programmes, and therefore DECIDES to extend the transition period from end-1999 to mid-2001 except for the measures to be taken to discontinue the current return statistics.

7. INVITE le Directeur général à tenir compte de l'expérience qui sera acquise dans le cadre de l'application des règles de politique industrielle aux nouveaux programmes de développement et préparatoires décidés à la présente session en vue de l'adaptation éventuelle de la politique industrielle pour les futurs programmes et DECIDE en conséquence de prolonger la période de transition de fin 1999 à mi-2001 sauf en ce qui concerne les mesures à prendre pour arrêter les statistiques actuelles de retour géographique.

INVITE le Directeur général à mener une analyse approfondie des résultats de la mise en œuvre des principes de politique industrielle au cours de la période de transition prolongée, en temps utile pour pouvoir soumettre des propositions au Conseil pour décision en 2001.

8. SOULIGNE qu'il est important de fixer la limite inférieure du coefficient de retour global cumulé de chaque Etat membre visée à l'article IV-6 de l'Annexe V de la Convention en deçà de laquelle des mesures spéciales doivent être prises conformément à l'article V de ladite Annexe et qu'il convient de revoir, pour les adapter, les mécanismes de financement des programmes et activités obligatoires de l'Agence et CHARGE le Directeur général de soumettre en 2001 à la décision du Conseil au niveau ministériel l'adoption de ladite limite inférieure pour la période 2000-2002 et de nouveaux mécanismes de financement des programmes et activités obligatoires de l'Agence.

9. ACCORDE de l'importance au suivi de l'évolution de l'industrie afin de contribuer à l'amélioration de la compétitivité de l'industrie européenne sur le marché mondial, notamment en parvenant à un équilibre entre les intérêts des maîtres d'œuvre et ceux des autres fournisseurs européens.

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INVITES the Director General to conduct a comprehensive review of the results of the implementation of the principles of industrial policy during the course of the extended transition period, in good time to put proposals to Council for decision in 2001.

8. UNDERLINES the importance of fixing the lower limit for the cumulative overall return coefficient of each Member State referred to in Article IV.6 of Annex V to the Convention, below which special measures are to be taken in accordance with Article V of that Annex, and the need to review for adaptation the funding mechanisms for the Agency's mandatory programmes and activities and INSTRUCTS the Director General to propose in 2001 for decision to Council at Ministerial Level the adoption of the said lower limit for the period 2000-2002 and of new mechanisms for the funding of the Agency's mandatory programmes and activities.

9. ATTACHES importance to the monitoring of trends in industry with the aim of contributing to the improvement of European industry's worldwide competitiveness, in particular by balancing the interests of prime contractors and those of other European suppliers.

10. INVITES the Director General to propose, on the basis of close dialogue with industry, further measures to ensure a fair allocation of activities among industrial firms, in particular among prime contractors and equipment suppliers, and DECIDES to put the ongoing Small and Medium-Sized Enterprises (SMEs) initiative on a permanent footing, and to further develop it taking into account the experience gained during the extended transition period.

11. WELCOMES the progress made on developing a partnership framework, ENDORSES the concept of setting-up public-private partnership projects and INVITES the Director General to make proposals to the Agency's delegate bodies concerned for adoption of specific rules and procedures,

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10. INVITE le Directeur général à proposer, sur la base d'un dialogue approfondi avec l'industrie, des mesures supplémentaires propres à assurer une répartition équitable des activités entre les sociétés industrielles, notamment entre les maîtres d'œuvre et les équipementiers, et DECIDE d'établir l'initiative actuelle en faveur des PME sur une base permanente et de l'étendre en tenant compte de l'expérience acquise au cours de la période de transition prolongée.

11. SE FELICITE des progrès accomplis dans la mise en place d'une structure de partenariat, ENTERINE le principe de la mise sur pied de projets de partenariat public/privé et INVITE le Directeur général à faire des propositions aux organes délibérants appropriés de l'Agence en vue de l'adoption de règles et de procédures spécifiques, y compris de nouveaux mécanismes de financement applicables à ces projets, en accord avec les dispositions de Convention et de ses Annexes.

CHAPITRE III
PROGRAMMES

A. NIVEAU DE RESSOURCES 1999-2003 POUR LES ACTIVITES OBLIGATOIRES

VU les Articles V.1(a) et XI.5(a)(ii) et (iii) de la Convention,

RAPPELANT la Résolution relative aux budgets 1999 des activités obligatoires et aux budgets associés au Budget général, adoptée le 16 décembre 1998 (ESA/C/CXXXVIII/Rés.2 (final)),

SOULIGNANT l'excellente qualité du programme scientifique et RAPPELANT la nécessité de mettre en œuvre en temps voulu toutes les missions approuvées, y compris Mars Express, including innovative funding mechanisms governing such projects, within the provisions of the Convention and its Annexes.

CHAPTER III
PROGRAMMES

A. LEVEL OF RESOURCES FOR MANDATORY ACTIVITIES 1999-2003

HAVING REGARD to Articles V.1(a) and XI.5(a)(ii) and (iii) of the Convention,

RECALLING the Resolution on the 1999 budgets for mandatory activities and budgets associated with the General Budget, adopted on 16 December 1998 (ESA/C/CXXXVIII/Res.2 (Final)),

UNDERLINING the scientific excellence of the Science Programme, and STRESSING the need for timely implementation of all the approved missions, including Mars Express,

HAVING REGARD to the Resolution on the review of the Agency's system for calculating the scale of contributions for the mandatory activities (ESA/C-M/CXXIX/Res.2 (Final)) of 4 March 1997,

HAVING REGARD to the Director General's proposal for the level of resources for mandatory activities covering the period 1999-2003 contained in ESA/C(98)100,

DECIDES by a unanimous vote to put at the disposal of the Agency for the period 1999-2002

- for the General Budget an amount of 649.3 MEuros at 1998 economic conditions,
- for the Science programme an amount of 1460.8 MEuros at current economic conditions (no updating of economic conditions will be made during the

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VU la Résolution relative à la révision du système de calcul du barème des contributions utilisé par l'Agence pour financer les activités obligatoires (ESA/C-M/CXXIX/Rés.2 (final)) du 4 mars 1997,

VU la proposition du Directeur général relative au niveau de ressources couvrant la période 1999-2003 pour les activités obligatoires, qui figure dans le document ESA/C(98)100,

DECIDE, par un vote à l'unanimité, de mettre à la disposition de l'Agence pour la période 1999-2002 :

- un montant de 649,3 MEuros aux conditions économiques de 1998 pour le budget général;
- un montant de 1460,8 MEuros aux conditions économiques actuelles (aucune actualisation des conditions économiques ne sera effectuée au cours de cette période) pour le programme scientifique. Ce financement est assuré sous réserve que la place des missions Mars Express et Plank/First soit préservée au sein du programme;
- un montant de 2,1 MEuros aux conditions économiques de 1998 pour le programme de transformation. Une ventilation indicative par exercice est donnée ci-après à titre d'information:

Année	1999	2000	2001	2002	**Total**	2003
Programme scientifique MEuros	355,2	352,2	352,2	352,2	**1411,8**	[ ]
Financement complémentaire des activités scientifiques (1)	10	5,6	9,7	14,7	**40,0**	[ ]
Réductions internes ESA affectées aux activités scientifiques (2)		3,0	3,0	3,0	**9,0**	[ ]
Total Programme scientifique	**365,2**	**360,8**	**364,9**	**369,9**	**1460,8**	
Budget général MEuros (c.e.1998)	167,6	163,7	160,5	157,5	**649,3**	[ ]
Programme de transformation MEuros (c.e.1998)	2,1	-	-	-	**2,1**	[ ]

(1) Le financement complémentaire de 40 MEuros sera réalisé sur la période 1999/2002, un Etat membre (l'Allemagne) ayant fait savoir à la session du Conseil ministériel qu'il verserait sa part (10 MEuros) en 1999 comme indiqué sur le tableau.

(2) Le Directeur général est autorisé à dégager les ressources supplémentaires nécessaires (9 MEuros) sur les activités de l'Agence.

period). This funding is provided on the understanding that the position of Mars Express and Planck/First in the Programme is preserved.

- and for the Transformation programme an amount of 2.1 MEuros at 1998 economic conditions. An indicative annual breakdown is given below for information:

Year (MEuros)	1999	2000	2001	2002	Total	2003
Science Programme MEuros	355.2	352.2	352.2	352.2	1411.8	[ ]
Complementary Science funding (1)	10	5.6	9.7	14.7	40.0	[ ]
ESA Internal reductions for Science (2)		3.0	3.0	3.0	9.0	[ ]
Total Science	**365.2**	**360.8**	**364.9**	**369.9**	**1460.8**	
General Budget MEuros (98 ec)	167.6	163.7	160.5	157.5	649.3	[ ]
Transformation Programme MEuros (98 ec)	2.1	-	-	-	2.1	[ ]

(1) The complementary funding of 40 MEuros will be paid over the 1999-2002 period, one Member State (Germany) having indicated at the Ministerial Council to contribute its share (10 MEuros) in 1999 as shown in the table.

(2) The Director General is authorised to find the additional resources necessary (9 MEuros) from the Agency's activities.

DECIDES that a new Level of Resources will be decided at the latest in December 2001.

B. TECHNOLOGY

1. RECOGNISES that space technology demands a European approach on a scale commensurate with the needs to be met and with the size and challenges of the markets and of the competitors, SUPPORTS the Director General's views on the need for a coordinated European policy and strategy for space technology, and AGREES on the central role to be exercised by ESA in its co-ordination.

DECIDE qu'un nouveau niveau de ressources sera arrêté au plus tard en décembre 2001.

B. TECHNOLOGIE

1. RECONNAIT que la technologie spatiale nécessite une démarche européenne menée sur une échelle proportionnée aux besoins à satisfaire ainsi qu'à la taille et aux spécificités des marchés et des concurrents, APPUIE le point de vue du Directeur général sur la nécessité d'une politique et d'une stratégie européennes coordonnées en matière de technologie spatiale et CONVIENT du rôle central que l'ESA doit jouer dans cette coordination.

2. SOULIGNE que les partenaires engagés dans les activités et programmes spatiaux de l'Europe doivent continuer à tout mettre en œuvre pour maintenir un financement adéquat et des compétences appropriées pour la recherche-développement technologique et le transfert de technologie afin de promouvoir les retombées externes ainsi que les retombées internes..

3. SE FELICITE des résultats obtenus dans le cadre des initiatives technologiques spécifiques (exposées dans la Résolution 1 du 4 mars 1997) pour améliorer la compétitivité de l'industrie européenne et INVITE le Directeur général à poursuivre et à développer ces initiatives au titre des programmes technologiques facultatifs de l'Agence.

4. SE FELICITE des progrès accomplis à ce jour pour coordonner les activités technologiques et de recherche de l'ESA grâce à la définition d'un schéma directeur de technologie applicable à l'ensemble de l'Agence.

5. INVITE le Directeur général à lancer une revue et un plan (schéma directeur de technologie spatiale européenne) sur les technologies spatiales que les États membres doivent maîtriser pour assurer l'indépendance stratégique de

2. STRESSES that the partners in European space activities and programmes must remain committed to maintaining adequate funds and competencies for technology research and development and technology transfer promoting spin-off as well as spin-in effects.

3. WELCOMES the results achieved in the special technology actions (outlined in Resolution No.1 of 4 March 1997) to improve European industry's competitiveness and INVITES the Director General to continue and extend these actions in optional technology programmes of the Agency.

4. WELCOMES the progress made to date in coordinating ESA's technology and research activities through the definition of an overall ESA Technology Master Plan.

5. INVITES the Director General to initiate a review and plan (European Space Technology Master Plan) for space technologies required in Member States for the strategic independence of the European space industry and in support of its competitiveness in the short, medium and long term.

6. INVITES the Member States to actively participate in the establishing of the above-mentioned European Space Technology Master Plan, which provides the platform for increased harmonisation of the European space technology efforts.

C. OPTIONAL PROGRAMMES

1. In addition to the mandatory activities, and in particular the Science Programme, covered by Chapter IIIA of this Resolution, WELCOMES the entry into force on this day of the Declarations, amended Declarations and amended Additional Declarations on the programmes

l'industrie spatiale européenne et pour soutenir sa compétitivité à court, moyen et long terme.

6. INVITE les États membres à participer activement à la mise en place du schéma directeur de technologie spatiale européenne susmentionné, qui fournit un cadre pour une meilleure harmonisation des activités européennes en matière de technologie spatiale.

C. PROGRAMMES FACULTATIFS

1. Outre les activités obligatoires, notamment le Programme scientifique, visées au Chapitre III.A de la présente Résolution, SE FELICITE de l'entrée en vigueur ce jour même des Déclarations, y compris des Déclarations amendées et des Déclarations additionnelles amendées, relatives aux programmes dont la liste figure ci-après et de leur souscription par les États participants intéressés, les enveloppes financières correspondantes étant exprimées aux conditions économiques de 1998:

(a) Navigation

Programme GalileoSat, qui représente la contribution de l'ESA à Galileo et comprend les activités européennes de définition, de développement et de validation du secteur spatial du système Galileo et du secteur sol associé (ESA/JCB/CXXXII/Déc.1 (final)), auquel une enveloppe financière provisoire de 500 MEuros est affectée, composée d'une première sous-enveloppe d'un montant ferme de 40 MEuros couvrant les activités de définition du programme à mener à terme d'ici fin 2000 et d'une deuxième sous-enveloppe d'un montant provisoire de 460 MEuros couvrant les activités de développement et de validation à mener à terme d'ici fin 2005.

listed below and their subscription by the Participating States concerned, the corresponding financial envelopes being expressed at 1998 economic conditions:

(a) Navigation

the GalileoSat programme as the ESA contribution to Galileo comprising the European activities for the definition, development and validation of the space and related ground segment of the Galileo system, (ESA/JCB/CXXXII/Dec.1 (Final)), for which a provisional financial envelope of 500 MEuros is allocated, composed of a first sub-envelope of a firm amount of 40 MEuros covering the programme definition activities to be completed by end-2000 and a second sub-envelope of a provisional amount of 460 MEuros covering the development and validation activities to be completed by end-2005;

(b) Telecommunications

the Advanced Research in Telecommunications Systems - ARTES programme (ESA/JCB/C/Dec. 1 (Final) rev. 9), and in particular:

(i) Preliminary studies and investigations in the field of telecommunication - ARTES element 1, for which a financial envelope of 50 MEuros is allocated for the period 2000-2005; and
(ii) Multimedia and information systems - ARTES element 3, for which a financial envelope of 309 MEuros is allocated, covering phase-2 activities during the period 1999-2002; and
(iii) Increase of the amount of subscription to the overall ARTES programme;

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(b) Télécommunications

Programme de recherche de pointe sur les systèmes de télécommunications – programme ARTES (ESA/JCB/C/Déc.1 (final) rév.9) et notamment :

(i) études et investigations préliminaires dans le domaine des télécommunications - Élément 1 d'ARTES, auquel une enveloppe financière de 50 MEuros est allouée pour la période 2000-2005 ;
(ii) systèmes multimédias/infrastructures mondiales de l'information - Élément 3 d'ARTES, auquel une enveloppe financière de 309 MEuros est allouée pour couvrir les activités de la phase 2 sur la période 1999-2002 ;
(iii) augmentation du montant des souscriptions à l'ensemble du programme ARTES.

(c) Observation de la Terre

Programme Planète vivante - programme-enveloppe d'observation de la Terre (ESA/PB-EO/LXXIV/Déc.1 (final)), auquel une enveloppe financière de 683 MEuros est allouée pour la première période du programme couvrant les années 1999-2002.

INVITE le Directeur général :

(i) à prendre des mesures appropriées pour réduire le coût de la première période du programme-enveloppe à 683 MEuros, tout en préservant l'intégrité de ses objectifs scientifiques;

(ii) à mettre au point, en concertation avec la communauté scientifique, et à proposer aux organes délibérants un plan de travail conforme au montant des souscriptions obtenues pour la première période. La

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(c) Earth Observation

the Living Planet Programme - Earth Observation Envelope Programme (ESA/PB-EO/LXXIV/ Dec.1 (Final)), for which a financial envelope of 683 MEuros is allocated for the first part of the programme covering the period 1999-2002.

INVITES the Director General to

(i) take appropriate actions to reduce the cost of the first period of the Envelope programme to 683 MEuros, while preserving the integrity of its scientific objectives.

(ii) in consultation with the scientific community, identify and propose to delegate bodies, a work plan consistent with the amount of subscription obtained for the first period. The second period will include relevant parts of the Earthnet programme from 2002 onwards;

(d) The International Space Station

the European participation in the International Space Station exploitation programme (ESA/PB-MS/XXIX/Dec.1 (Final)), for which a firm financial sub-envelope of 346.1 MEuros is allocated for the first step of early activities to be committed in 2000 and 2001, and for which the remaining amount of 333.9 MEuros, being part of the decision made at the Council meeting held in Toulouse in October 1995 for the initial phase, is allocated for activities to be committed in 2002-2004; proposals for a scheme for the financing of the variable costs of the ISS exploitation will be examined by the Participating States by mid-2001;

deuxième période inclura des éléments appropriés du programme Earthnet à partir de 2002.

(d) Station spatiale internationale

Programme d'exploitation de la Station spatiale internationale – Participation de l'Europe (ESA/PB-MS/XXIX/Déc.1 (final)), auquel une sous-enveloppe financière ferme de 346,1 MEuros est allouée pour la première étape d'activités préliminaires à engager en 2000 et 2001, tandis que le montant restant de 333,9 MEuros, qui est couvert par la décision relative à la phase initiale prise par le Conseil à sa session tenue à Toulouse en octobre 1995, est alloué aux activités à engager en 2002-2004 ; les propositions de plan de financement des coûts variables d'exploitation de l'ISS seront examinées par les États participants d'ici mi-2001.

En ce qui concerne les coûts variables, les États participants ont décidé : (a) de bloquer le montant non couvert de 32,7 MEuros, (b) que ce blocage ne doit entraîner aucune augmentation de l'enveloppe financière de la phase initiale du programme, ni de ses sous-enveloppes, (c) d'exécuter une tranche additionnelle du programme à souscrire par les États membres intéressés avant fin juillet 1999, englobant les activités liées aux technologies de la rentrée atmosphérique, dans le cadre d'une coopération avec la NASA portant sur le véhicule de retour de l'équipage (CRV) de l'ISS et (d) que, après conclusion d'un arrangement de compensation des activités CRV de l'ESA en échange des services NASA remboursables décrits dans la Déclaration, les contributions versées au titre de la tranche susvisée seront considérées comme des contributions en nature entièrement déductibles des contributions aux coûts variables dont les États participants sont redevables au titre du programme d'exploitation de l'ISS.

With regard to variable costs, the Participating States have decided: (a) to block the uncovered amount of 32.7 MEuros, (b) that this blocking shall not lead to any increase of the financial envelope, or its sub-envelopes, for the initial phase of the programme, (c) to carry out an additional slice of this programme, to be subscribed by interested Member States before end-July 1999, containing the activities related to atmospheric reentry technologies through cooperation with NASA in the ISS Crew Return Vehicle (CRV), and (d) that, following the conclusion of a barter between the ESA CRV activities and NASA reimbursable services described in the Declaration, contributions paid under the above-mentioned slice shall be considered as in-kind contributions and entirely deductible from contributions to variable costs under the ISS exploitation programme payable by the Participating States concerned;

INVITES the Director General to ensure that the programme's actual financial schedule is kept in line with the applicable Station assembly sequence.

(e) Microgravity

research programme on life and physical sciences as an extension of the EMIR-2 Programme (ESA/PB-MG/XLIV/Dec. 1, rev. 8 (Final)), for which a financial envelope of 98.4 MEuros is allocated for activities to be undertaken in the period 2000-2003;

(f) Launchers

(i) the Ariane-5 Plus programme (ESA/PB-ARIANE/CLXXI/Dec. 1 (Final), rev. 2), the corresponding financial envelope being increased by 462.5 MEuros, to 600 MEuros (589 MEuros at 1997 e.c.), for the second step of the programme to cover all activities to be committed until end-2001, it being understood that the Agency

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INVITE le Directeur général à s'assurer que l'échéancier financier réel du programme reste compatible avec la séquence d'assemblage de la station en vigueur.

(e) Recherche en microgravité

Programme de recherche en sciences de la vie et sciences physiques en tant qu'extension du programme EMIR-2 (ESA/PB-MG/XLIV/Déc. 1, rév. 8 (final)), auquel une enveloppe financière de 98,4 MEuros est allouée pour les activités à entreprendre sur la période 2000-2003.

(f) Lanceurs

(i) Programme Ariane-5 Plus (ESA/PB-ARIANE/CLXXI/Déc.1 (final), rév.2), l'enveloppe financière correspondante étant augmentée de 462,5 MEuros, ce qui la porte à 600 MEuros (589 MEuros aux c.e. 1997) pour la deuxième étape du programme afin de couvrir toutes les activités à engager jusqu'à fin 2001, étant entendu que l'Agence veille à ce que le plan financier réel du programme reste conforme au niveau des coûts réduit fixé dans la Déclaration.

(ii) Programme de développement d'un petit lanceur (ESA/PB-ARIANE/CLXXI/Déc.2 (final), rév.1), l'enveloppe financière correspondante étant augmentée de 316,9 MEuros, ce qui la porte à 378,3 MEuros (370 MEuros aux c.e. 1997), couvrant toutes les activités à engager jusqu'à fin 2002, sous réserve d'une revue prévue pour octobre 1999.

(iii) Programme ARTA Ariane-5 (ESA/PB-ARIANE/CLIV/Déc.3 (final), rév.3), l'enveloppe financière correspondante étant augmentée de 161,2 MEuros, ce qui la porte à 536,0 MEuros

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ensures that the programme's actual financial schedule is kept in line with the reduced cost level set in the Declaration;

(ii) the Small Launcher Development Programme (ESA/PB-ARIANE/CLXXI/Dec. 2 (Final), rev. 1), the corresponding financial envelope being increased by 316.9 MEuros, to 378.3 MEuros (370 MEuros at 1997 e.c.), covering all activities to be committed until end-2002 subject to a review planned in October 1999;

(iii) the Ariane-5 ARTA programme (ESA/PB-ARIANE/CLIV/Dec.3 (Final), rev. 3), the corresponding financial envelope being increased by 161.2 MEuros, to 536.0 MEuros (502.7 MEuros at 1995 e.c.), covering all activities to be committed until end-2002;

(iv) the Ariane-5 Infrastructure programme (ESA/PB-ARIANE/CLIV/Dec.2 (Final), rev. 2), the corresponding financial envelope being increased by 26.1 MEuros, to 376.6 MEuros (360.7 MEuros at mid-1995 e.c.), covering all activities to be committed until end-2001;

(v) the Future Launchers Technologies Programme (FLTP) (ESA/PB-ARIANE/CLXXVI/Dec. 1 (Final)), for which a financial envelope of 70 MEuros is allocated, covering all activities until end-2001;

REAFFIRMS that the Guiana Space Centre (CSG) is a strategic element in Europe's autonomous access to space, RECALLS that the Declaration by certain European Governments on the Ariane launcher production phase (Production Declaration) constitutes the basis for the manufacturing, marketing and launching of the Ariane launchers by Arianespace and INVITES the Director General to propose appropriate arrangements for the continuation of the CSG beyond 2000, for a

(502,7 MEuros aux c.e. 1995), couvrant toutes les activités à engager jusqu'à fin 2002.

(iv) Programme Infrastructure Ariane-5 (ESA/PB-ARIANE/CLIV/Déc.2 (final), rév.2), l'enveloppe financière correspondante étant augmentée de 26,1 MEuros, ce qui la porte à 376,6 MEuros (360,7 MEuros aux c.e. de la mi-1995), couvrant toutes les activités à engager jusqu'à fin 2001.

(v) Programme de technologie pour les futurs lanceurs (FLTP) (ESA/PB-ARIANE/CLXXVI/Déc.1 (final)), auquel une enveloppe financière de 70 MEuros est allouée, couvrant toutes les activités jusqu'à fin 2001.

REAFFIRME que le Centre spatial guyanais (CSG) est un élément stratégique pour l'accès indépendant de l'Europe à l'espace, RAPPELLE que la Déclaration de certains Gouvernements européens relative à la phase de production des lanceurs Ariane (Déclaration relative à la production) régit la fabrication, la commercialisation et le lancement des lanceurs Ariane par Arianespace, INVITE le Directeur général à proposer des arrangements adéquats concernant la poursuite des activités du CSG au delà de 2000 afin qu'une décision puisse être prise par le Conseil avant fin 1999, sous réserve de l'adoption, pour les années après 2001, d'une Déclaration relative à la production par les gouvernements concernés et NOTE avec satisfaction l'adoption le 10 mai 1999 de la Résolution relative aux prix des lancements Ariane (ESA/C/CXL/Rés.1(final)) et de la Résolution révisée relative à la redevance CSG (ESA/C/CXXI/Rés.2, rév.3 (final)) ainsi que la prolongation d'un an de la Déclaration relative à la production.

2. SOULIGNE que le programme GalileoSat offre à l'Agence et à l'Union européenne une occasion concrète de coopérer afin de promouvoir les intérêts de l'Europe dans le domaine des applications des technologies et des systèmes spatiaux ; INVITE le Directeur général à définir avec l'Union

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decision by Council before end-1999, subject to, for the years beyond 2001, the adoption by Governments concerned of a production Declaration, and NOTES with satisfaction the adoption on 10 May 1999 of the Resolution on Ariane launch prices (ESA/C/CXL/Res.1 (final)) and the revised Resolution on the CSG fees (ESA/C/CXXI/Res. 2, rev. 3 (Final)), and the extension of the Production Declaration by one year;

2. STRESSES that the GalileoSat programme offers a concrete opportunity for the Agency and the European Union to cooperate on furthering European interests in applications of space systems and technologies; INVITES the Director General to define with the European Union the necessary arrangements for the common programmatic set-up and to support efforts by the European Union to secure private funding and to designate a system operator.

3. ENDORSES the general objectives of the Earth Watch missions and INVITES the Director General to make the earliest possible proposal establishing, together with delegate bodies and Council, the appropriate framework for carrying out Earth Watch missions in partnership with industry.

4. INVITES the Director General to identify and propose the best conditions and structures for promoting efficient and effective operation and utilisation of the various infrastructure elements such as the International Space Station and launchers developed by Agency programmes and in particular to examine the scope for industrialising exploitation of the International Space Station and submit a corresponding proposal to Council by March 2000 and STRESSES the need to execute operations and utilisation activities in partnership with other European entities, such as the European Commission, or with industry, commercial users and commercial operators and to involve the various user programmes of the Agency in those activities.

européenne les arrangements nécessaires à la mise sur pied d'une structure de programme commune et à soutenir les efforts de l'Union européenne en vue d'obtenir un financement privé et de désigner un opérateur du système.

3. ENTERINE les objectifs généraux des missions de surveillance de la Terre et INVITE le Directeur général à faire le plus rapidement possible une proposition en vue d'établir, avec les organes délibérants et le Conseil, le cadre approprié à la conduite des missions de surveillance de la Terre en partenariat avec l'industrie.

4. INVITE le Directeur général à définir et à proposer les conditions et les structures optimales pour promouvoir l'exploitation et l'utilisation efficace et efficiente des divers éléments d'infrastructure tels que la Station spatiale internationale et les lanceurs développés dans le cadre des programmes de l'Agence et notamment à examiner les perspectives d'industrialisation de l'exploitation de la Station spatiale internationale et à soumettre au Conseil d'ici mars 2000 une proposition dans ce sens et SOULIGNE que ces activités d'exploitation et d'utilisation doivent être exécutées en partenariat avec d'autres entités européennes, comme la Commission européenne, ou avec l'industrie, les utilisateurs commerciaux et les opérateurs commerciaux et doivent associer les divers programmes utilisateurs de l'Agence.

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RESOLUTION ON THE LONG-TERM SPACE POLICY COMMITTEE

(adopted on 12 May 1999)

Council, meeting at Ministerial Level,

HAVING REGARD to the Long-term Space Policy Committee's Report (ESA/C-M(99)3),

1. WELCOMES the above Report.

2. COMMENDS the Committee on the results of its work and NOTES that its mandate has now been completed.

3. INVITES the Director General and the Council at Delegate Level to further investigate possibilities to implement the actions listed in the Report.

ESA/C-M/CXLI/Rés.3 (final)

PROJET DE RÉSOLUTION RELATIVE AU COMITÉ DE LA POLITIQUE SPATIALE A LONG TERME

(adoptée le 12 mai 1999)

Le Conseil, siégeant au niveau ministériel,

VU le Rapport du Comité de la politique spatiale à long terme (ESA/C-M(99)3),

1. ACCUEILLE FAVORABLEMENT ledit rapport;

2. FÉLICITE le Comité des résultats de ses travaux et PREND NOTE de ce que son mandat est maintenant achevé;

3. INVITE le Directeur général et le Conseil siégeant au niveau des délégués à poursuivre l'examen des possibilités de mise en œuvre des actions énumérées dans ce rapport.

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ESA's Mars Express Mission – Europe on Its Way to Mars

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ESA's exciting and fast-track Mars Express mission is the first of the new flexible (F) missions, which are based on a new implementation scenario to maintain overall mission cost below a very stringent cost cap. The key features of an F-mission are streamlined management, up-front definition of the payload, and the transfer of more responsibility to industry. The cost ceiling is 175 M€ for future F-missions, but only 150 M€ for Mars Express. The scientific objectives of the mission include the remote and in-situ study of the surface, subsurface, atmosphere and environment of the planet Mars. ESA's Science Programme Committee preliminarily approved Mars Express in November 1998, provided sufficient funding would be available, and gave its full approval on 19 May 1999.

The selection of the scientific payload for Mars Express was completed in early May 1998 whilst the spacecraft design was still undergoing competitive feasibility studies. Towards the end of 1998, Matra Marconi Space (MMS) was chosen as Prime Contractor for the entire spacecraft procurement programme. The payload is composed of seven instruments and a lander, Beagle 2, to search for traces of life on Mars. Beagle 2 is currently only confirmed until the end of this year and its continuation is subject to the agreement of a financial and technical plan by the end of 1999.

ESA's aim is the implementation of a top-class mission at a much lower cost than hitherto achieved. Significant savings will be made by purchasing recurrent systems from ESA's Rosetta mission. A compressed implementation schedule, a new relationship between ESA, industry and the scientific community, and the exploitation of synergies between the ground operation systems of Rosetta and Mars Express will help the latter to stay within the allocated budget.

The launch by a Soyuz/Fregat must take place within an eleven-day launch window opening on 1 June 2003.

Introduction

In the broad context of planetary science, Mars represents an important transition between the outer volatile-rich, more oxidised regions of the accretion zone of the terrestrial bodies (asteroid belt) and the inner, more refractory and less oxidised regions from which Earth, Venus and Mercury accreted. Its size, the degree of internal activity, the age of its surface features, and the density of its atmosphere are manifestations of Mars' special position and its transitional character. Its parameters are intermediate between those of the large terrestrial planets (Earth, Venus) and the smaller planetary bodies (Mercury, Moon, and asteroids). Although geologically less evolved, the Martian surface is more Earth-like than that of any other terrestrial planet. Consequently, the exploration of Mars is crucial for a better understanding of the Earth from the comparative-planetology perspective.

Spacecraft exploration of Mars started in the 1960s. The first global survey was conducted by Mariner-9 in 1971, but the most significant and scientifically rewarding mission was Viking in 1976, consisting of two orbiters and two landers. Most of the existing environmental models of Mars have been derived from Viking data. More recently, the United States, Russia and Japan have launched new missions to Mars, including Mars Pathfinder, Mars Global Surveyor and the failed Mars-96 mission in 1996, Planet-B and other Mars Surveyor missions in 1998.

A new series of extremely challenging missions will be launched in 2003 and thereafter. They include ESA's Mars Express, NASA's telecommunications orbiters for high-speed Internet access to assets on and near Mars, and an aeroplane flying in the atmosphere of Mars on 17 December 2003, exactly a century after the Wright Brothers' first human flight on Earth. Starting in 2003, NASA also intends to send sample-return missions to Mars. Tiny return capsules, about 14 cm in diameter and holding a treasure of Martian soil and rocks, would lift off from Mars in March 2004 and in the autumn of 2006. Mars Express would aid in tracking the capsules as they orbit around Mars, in order to help another spacecraft to grab them for return to Earth.

The spacecraft parameters, launcher capability and the celestial constellation of Mars and Earth lead to a launch window for Mars Express opening on 1 June 2003 and closing eleven days later. The launch will be provided by a Soyuz/Fregat launcher from Baikonur in Kazakhstan. ESOC will conduct the operations using their new 35m-ground station near Perth, in Australia. The mission is optimised for observations of the Martian surface from a near-polar orbit with pericentre and apocentre altitudes of 250 and 11 490 km, respectively (Fig. 1). 440 days into the mission, the apocentre will be lowered to 10 050 km.

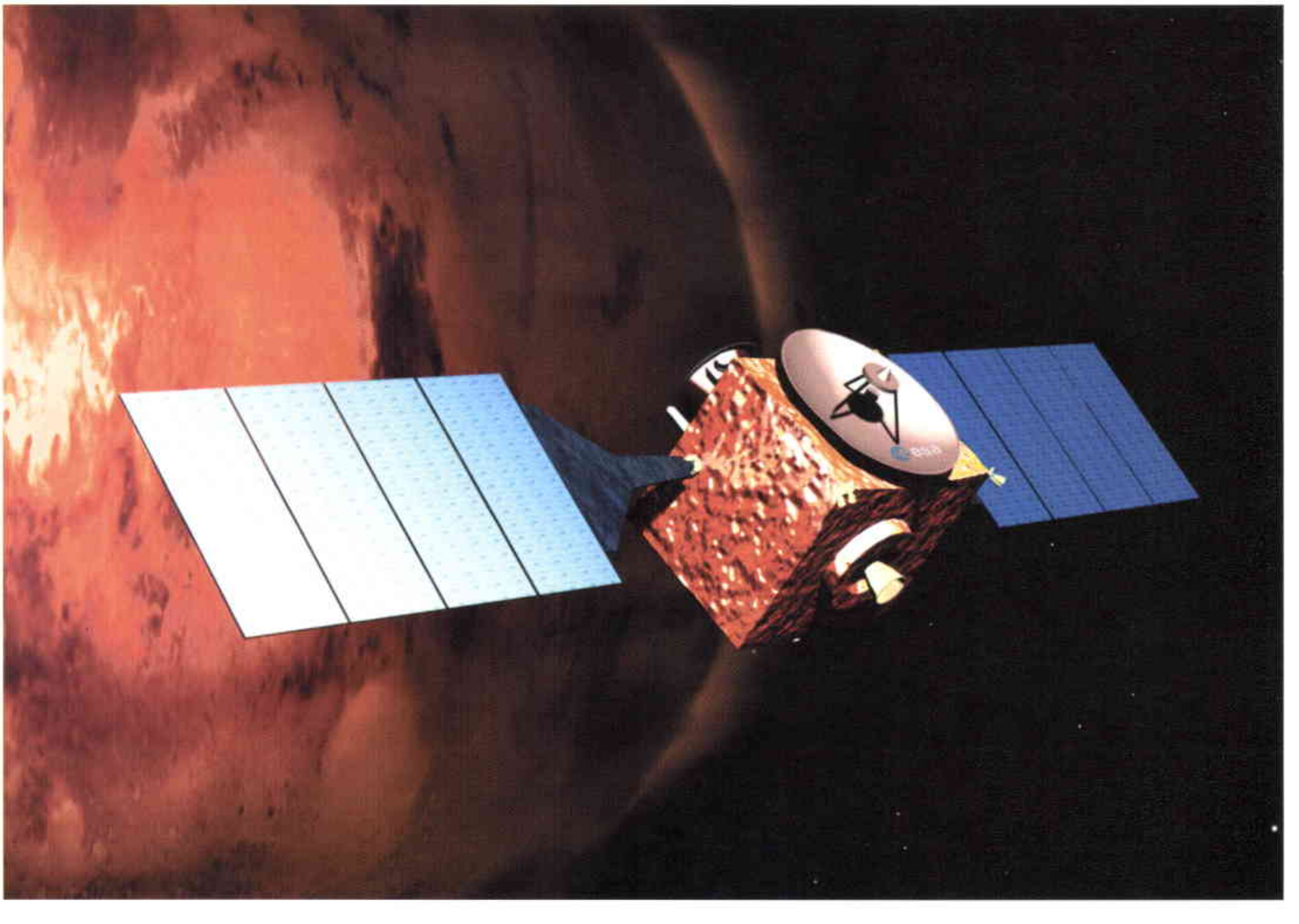
Beagle 2, a 60 kg-class Lander, will be delivered to a yet to be selected location on the surface of the planet. This Lander will focus on the geochemistry and exobiology of the Martian surface. In particular, it will study the morphology and geology of the landing site, the chemical and mineralogical composition of Martian surface rocks and soils, and the potential signatures of life, using a robotic mobile device.

ESA's Science Programme Committee (SPC) reconfirmed its support for Mars Express in November 1998, provided that the mission's implementation does not impact on other already selected missions. Following this positive recommendation and an intense and highly competitive industrial study phase, Matra Marconi Space (MMS) was chosen as Prime Contractor on the basis of a firm fixed price of 60 M€ for the entire procurement programme. Finally, ESA's Council endorsed the initiation of the definition phase, but stated that the Council at Ministerial Level in May 1999 must decide on the level of resources for the Scientific Programme. The consequent effect on the overall Science Programme will be assessed prior to transfer of the Mars Express project to the development and production phase.

New management approach

One of the major constraints imposed by ESA's science management on the mission's implementation is that the cost at completion must not exceed 150 M€. A breakdown into its major elements leads to the conclusion that the industrial procurement of the spacecraft cannot exceed 60 M€. Launch-service costs and

Figure 1. Artist's impression of the Mars Express spacecraft



ESA's internal and mission operations costs must be minimised to stay within the cost ceiling. ESA's management approach has therefore had to be changed significantly from the traditional methods employed in the past.

Many changes with respect to previous scientific missions have indeed been introduced, including industrial management of the scientific payload, establishment of direct interfaces between industry and the environmental test facilities, and simplified management and reporting requirements by ESA. Responsibility for the technical interface with the Soyuz/Fregat launch services provider, Starsem, is also delegated to industry.

Based on experience gained from the initial Horizon 2000 projects, both industry and the scientific community have acquired sufficient experience to establish and maintain a direct dialogue covering payload/spacecraft interfaces. Consequently, ESA decided to relinquish its traditional role as the interlocutor between the two parties. As part of the drive for increased efficiency, the Agency will only 'observe' the progress of the scientific payload, but will retain full control over science and instrument-performance issues. Responsibility for the timely delivery of all payload elements will rest with industry, which also has to ensure the availability of agreed payload resources.

This approach is new and a rapid learning process will have to take place. Interface changes, which may also have a cost impact for industry and/or the instrument teams, will have to be negotiated between these two parties. The advantage for ESA is that it can reduce its own costs by managing the project with a smaller team of about 10 persons. A team of this size can neither deal with detailed design issues, nor can it follow all industrial activities. Specialist support will be sought from experts within ESA's Directorate for Technical and Operational Support as and when required. A conventional review cycle will be executed, but the organisation of the reviews will differ from those conducted in the past. A key feature of the Mars Express reviews will be the co-location of ESA's review team with the industrial project team. The findings and conclusions will be reported to ESA's senior management.

ESOC has been able to offer an economically attractive quotation for Mars Express mission operations, based on the maximum reuse of operational systems being developed for the Rosetta mission. This will also include the sharing of key personnel to ensure coherence between the two Mission Operations Centres. A high degree of commonality will be achieved not only because of the common on-board system, but also due the similar mission scenarios. Rosetta will be launched six months ahead of Mars Express and will be entering a period of extended of hibernation at the time of the Mars Express launch. The timing also matches very well with the interplanetary cruise and nominal science mission phase for Mars Express. The planning and execution of the instrument flight operations also rests with ESA and will be performed in collaboration with the scientific community.

International co-operation

Mars Express will play an exciting and pivotal role in the international exploration of Mars. To carry out all the data-relay services requested, the mission would have to be extended from its nominal end in autumn 2005 to about summer 2008. The associated cost will have to be covered by contributions from the organisations benefiting from the mission extensions.

ASI, the Italian Space Agency, intends to provide significant contributions by developing an orbiter-to-lander telecommunications package, offering access to a new ground station in Sardinia, and supporting both spacecraft and science operations. ESA and ASI have already signed a working agreement.

Scientists in several ESA Member States are studying the implementation of a network of three to four stations, so-called 'Netlanders', on the surface of Mars. These landers are intended to establish the first network of scientific stations on the planet's surface in order to study its internal structure and activity and to provide insight into its weather patterns. Simultaneous measurements at all lander sites are required, which will also address geology and geochemistry. Mars Express, which would already be in its extended-mission phase, could provide data-relay services.

NASA wishes to implement alternative communication links via Mars Express between Earth and its own landers and rovers, to be launched in 2003 and 2005. Mars Express will also play an essential part in the determination of the precise orbits of the sample-return canisters, after their launch from the planet in 2004 and 2006, respectively. An Earth-return spacecraft will then capture and return these canisters to Earth.

The Japanese Institute of Space and Astronautical Sciences (ISAS) recently announced a delay in the arrival of the Japanese Nozomi mission at Mars. Owing to technical problems, an alternative interplanetary trajectory has had to be chosen and Nozomi will not now arrive until 2004 (originally late-1999). New and very exciting co-ordinated measurements could be performed between Mars Express in its polar orbit and Nozomi in a highly elliptic, near-equatorial orbit. The first steps towards a close scientific collaboration have been initiated.

Table 1. Scientfic objectives of Mars Express and Beagle 2

Mars Express Orbiter
- Global high-resolution photo-geology (incl. topography, morphology, paleo-climatology, etc.) with 10 m resolution
- Global spatial high-resolution mineralogical mapping of the surface with 100 m resolution
- Global atmospheric circulation and high-resolution mapping of atmospheric composition
- Subsurface structure at kilometre scale down to the permafrost
- Subsurface/atmosphere interactions
- Interaction of the atmosphere with the interplanetary medium.

Beagle 2 Lander
- Meteorology and climatology
- Landing-site geology, mineralogy and geochemistry
- Physical properties of the atmosphere and surface layers
- Exobiology (i.e. search for signatures of life)

Payloads of Mars Express and Beagle 2

The Mars Express Orbiter's payload represents the core of the mission. Its key scientific objectives include high-resolution imaging and mineralogical mapping of the Martian surface, radar sounding of the subsurface structure down to the permafrost, precise determination of the atmospheric circulation and composition, and study of the interaction of the atmosphere with the interplanetary medium (Table 1).

Beagle 2 addresses the geology, geochemistry, meteorology and exobiology (i.e. the search for the signatures of life) of the landing site and includes a number of robotic devices. It will deploy a sophisticated robotic sampling arm, which could manipulate different types of tools and retrieve samples to be analysed by the geochemical instruments mounted on the lander platform. One of the tools to be deployed by the arm is a 'mole' capable of subsurface sampling in order to reach soil unaffected by solar UV radiation.

Table 2 summarises the payload of the Mars Express Orbiter, which includes the following instruments:

High-Resolution Stereoscopic Camera (HRSC)

HRSC will provide high-resolution, stereo, colour, multiple-phase-angle and global coverage imaging of the planet Mars. It will allow characterisation of the surface morphology and topography, determination of the geological evolution as well as the identification of geological units, refinement of the geodetic control network, analysis of atmospheric phenomena including climatology, the role of water and surface/atmosphere interactions.

Table 2. Scientific payload complement of the Mars Express Orbiter

Acronym	Instrument	Principal Investigator	Other Countries Involved	Technique
HRSC	High-Resolution Stereoscopic Camera	G. Neukum, Berlin, Germany	D, F, RU, US FI, I, UK	Push-broom scanning camera with 9 CCD's
OMEGA	Observatoire pour la Minéralogie, l'Eau, les Glaces et l'Activité,	J.P. Bibring, Orsay, France	F, I, RU	Visible- and near-infrared spectrometer
PFS	Planetary Fourier Spectrometer	V. Formisano, Frascati, Italy	I, RU, PL, D, F, E, US	Infrared spectrometer
MARSIS	Mars Advanced Radar for Subsurface and Ionospheric Sounding	G. Picardi, Rome, Italy	I, US, D, CH, UK, DK	Subsurface radar and altimeter
ASPERA	Analyser of Space Plasmas and Energetic Atoms	R. Lundin, Kiruna, Sweden	S, D, UK, F, FI, I, US, RU	Neutral- and charged-particle sensors
SPICAM	Spectroscopic Investigation of the Characteristics of the Atmosphere of Mars	J.L. Bertaux, Verrières, France	F, B, RU, US	Ultraviolet spectrometer
MaRS	Mars Radio Science Experiment	M. Pätzold, Cologne, Germany	D, F, US, A	Radio-wave propagation

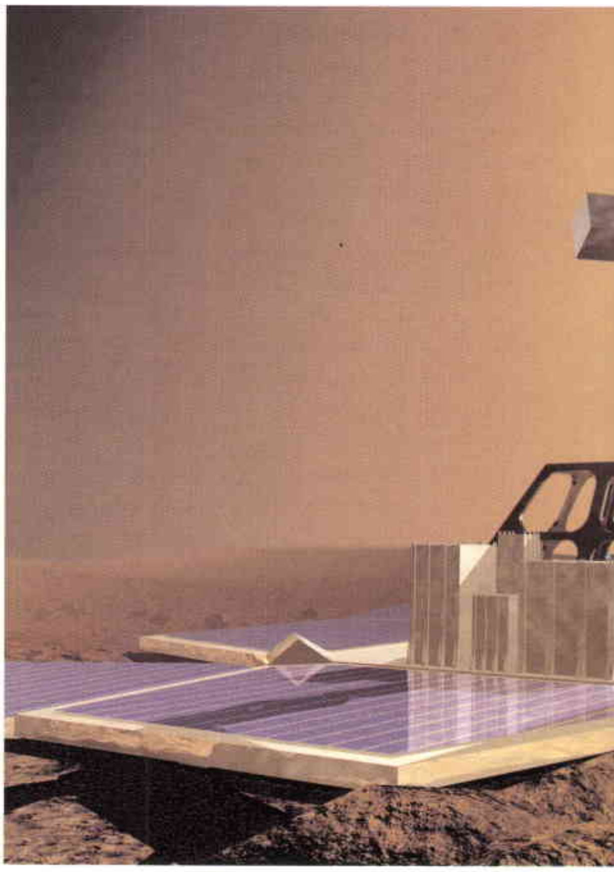


Figure 2. Artist's impression of Beagle 2 in operational configuration on the Martian surface

Observatoire pour la Minéralogie, l'Eau, les Glaces et l'Activit (OMEGA)
OMEGA is a visual and near-infrared mapping spectrometer, which will provide the mineralogical and molecular composition of the Martian surface at medium resolution and with global coverage, through the spectral analysis of the re-diffused solar light and surface thermal emission. This will allow the characterisation of the composition of surface materials (i.e. silicates, oxides, hydrates, carbonates, frost and ices), and monitoring of the atmospheric dust.

Planetary Fourier Spectrometer (PFS)
PFS is a Fourier infrared spectrometer optimised for atmospheric studies, with two channels with 10 and 20 km footprints, respectively. It will provide three-dimensional temperature-field measurements of the lower atmosphere up to 50 km altitude, minor-constituent variations (H_2O and CO_2) and the optical properties of atmospheric aerosols, which will allow the study of global atmospheric circulation. The instrument will also provide data on the thermal inertia of Mars' surface.

Spectroscopic Investigation of the Characteristics of the Atmosphere of Mars (SPICAM-UV)
This ultraviolet spectrometer is devoted to the study of the atmosphere with both nadir and limb viewing modes. It will measure the ozone content of the atmosphere as well as of the coupling of O_3 and H_2. In addition, stellar occultation techniques will provide vertical profiles of CO_2, O_3 and dust. All of these measurements are important fundamental inputs to meteorological and dynamic models of the atmosphere.

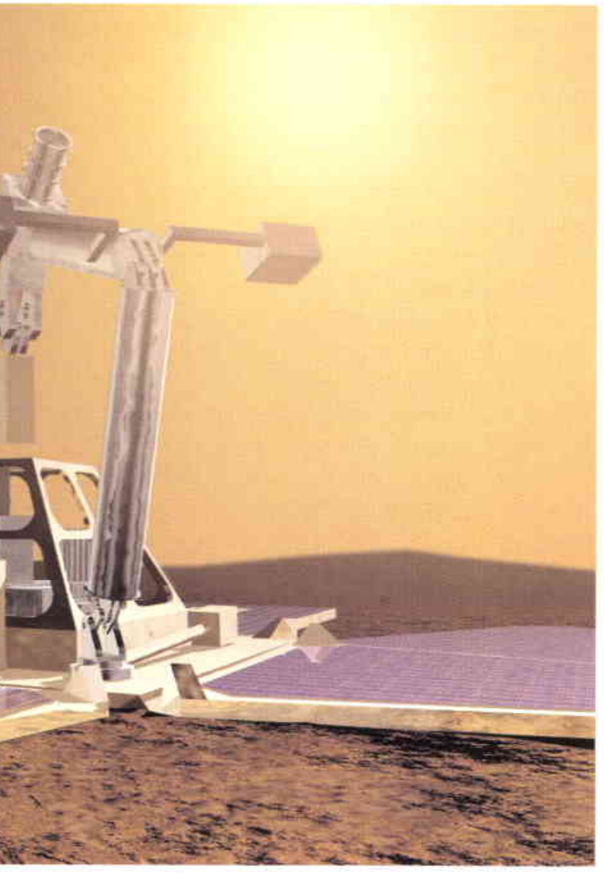
Mars Advanced Radar for Subsurface and Ionospheric Sounding (MARSIS)
MARSIS will investigate the subsurface structure of Mars to a depth of a few kilometres, in particular to map the distribution of liquid and ice water, allowing key issues associated with the planet's geologic, climatic and possibly organic evolution to be addressed. In addition, this multi-frequency nadir-looking instrument will provide altimetry and surface-roughness data during nighttime using its two 20 m antennas, as well as ionospheric measurements during daytime.

Analyser of Space Plasmas and EneRgetic Atoms (ASPERA)
ASPERA is an imager of energetic neutral atoms and an analyser of space plasmas. It will allow the plasma-induced atmospheric escape, as well as interaction of the solar wind with the ionosphere of Mars, to be determined. Plasma and magnetic-field interaction with the atmosphere addresses fundamental questions on the climatic and water-related evolution of Mars, with potential biochemical importance. The neutral particle imager and electron and ion spectrometer are mounted on a scanning platform.

Mars Radio Science Experiment (MaRS)
MaRS will use the Mars Express Orbiter radio subsystem to sound the neutral and ionised atmosphere at occultation, determine the dielectric properties of the surface, and observe gravity anomalies.

Beagle 2
Beagle 2 (Fig. 2) is a 60 kg-class Lander that will address the scientific objectives listed in Table 1. The consortium leader is Prof. C. Pillinger (Open University, UK). The Lander carries the following set of instruments and mechanisms for in-situ analyses:
- gas chromatography and mass spectroscopy
- sample handling system, robotic arm and a mole
- microscope, panoramic and wide-angle cameras
- Mössbauer and X-ray spectrometers
- environmental sensors.

Spacecraft design
The spacecraft is conventional in terms of the design of its body, but includes special features that will provide aerobraking in the Martian



atmosphere should this become necessary. The design is optimised for a Soyuz/Fregat launch, but is also fully compatible with a Delta-II vehicle. A body-mounted High-Gain Antenna and a pair of rotating solar arrays are the spacecraft's most obvious features. The solar array has two symmetrical wings in order to minimise the torques and forces applied during the spacecraft's insertion into orbit around Mars.

Within the overall integrated design of the spacecraft, just four main assemblies are foreseen, to simplify the development and integration process (Fig. 3):
- the Propulsion Module with the core structure
- lateral walls supporting the spacecraft avionics and the solar arrays
- shear walls and the top- and bottom-face supporting the payload units; the top face is nadir-pointing during science observation and Lander communication around Mars. It also carries Beagle 2, the associated relay antenna and ASPERA-3, and
- lateral walls to support the High Gain Antenna and the instrument radiators, respectively.

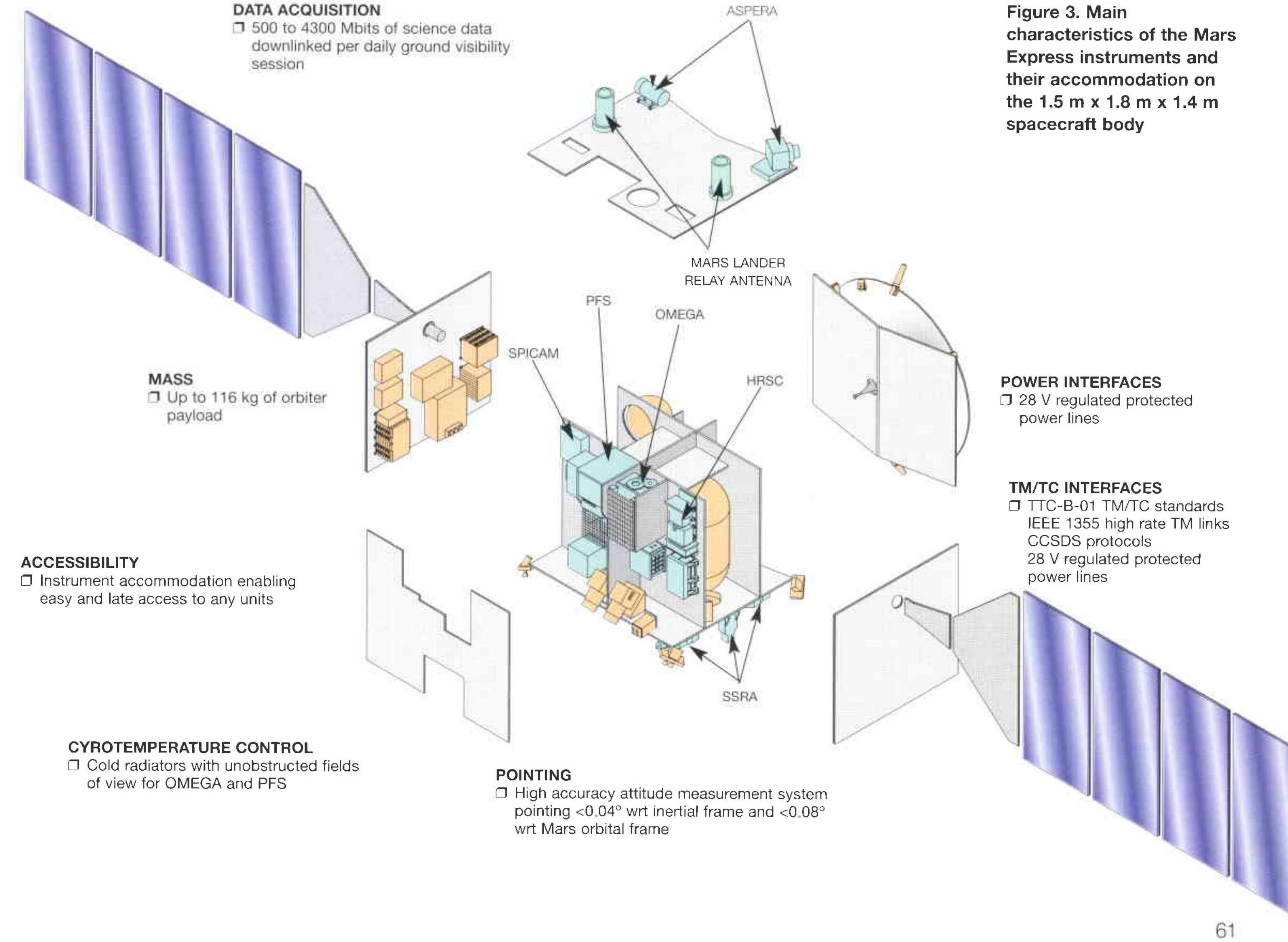


Figure 3. Main characteristics of the Mars Express instruments and their accommodation on the 1.5 m x 1.8 m x 1.4 m spacecraft body

The cost and schedule targets are to be met through the extensive use of existing and proven technologies. The procurement of recurring hardware and software, together with the standardisation of most interfaces, including those to the scientific payload, enables a simplified, low-risk development programme. Synergies with ESA's Rosetta programme are fully exploited to benefit from a contemporary, high-performance, low-risk deep-space programme by ESA. Beyond the reuse of existing items, commonality of operations between Rosetta and Mars Express allows ESOC to optimise mission-operation activities. Mars Express also takes advantage of equipment being developed for commercial telecommunications spacecraft or other small satellites. This contributes to a cost-effective solution meeting the stringent conditions of the firm fixed-price contract.

The spacecraft has to accommodate various classes of scientific experiments: nadir-pointing optical instruments, a radar/altimeter instrument with two 20 m and one 4 m tubular antennas, two particle detectors, a Lander relay terminal and, finally, Beagle 2 itself.

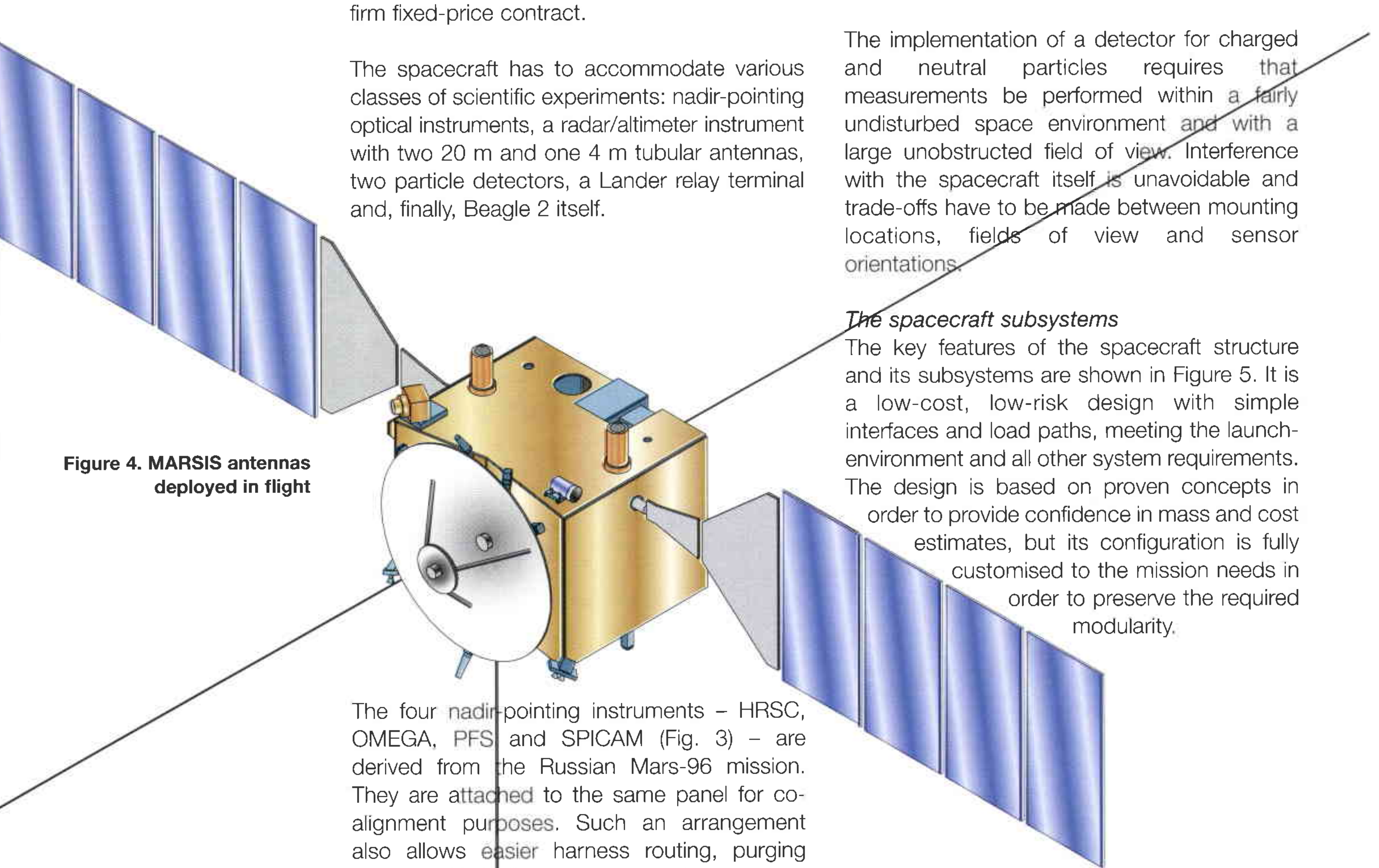


Figure 4. MARSIS antennas deployed in flight

The four nadir-pointing instruments – HRSC, OMEGA, PFS and SPICAM (Fig. 3) – are derived from the Russian Mars-96 mission. They are attached to the same panel for co-alignment purposes. Such an arrangement also allows easier harness routing, purging equipment mounting and, as was demonstrated on Mars-96, it can cope with the thermal constraints related to the orientation of their heat pipes and with the proximity of the spacecraft thermal radiators. This minimises the impacts on testing, especially in thermal vacuum, and on the overall mass budget.

The alignment of the instrument axes with the launch direction is optimal in terms of compatibility with thruster plume impingement and any eventual aerobraking. Viewing is in the anti-ram direction during low-altitude passes through the Martian atmosphere. Compatibility with aerobraking is a design requirement, but it would only be used to recover from an anomaly.

SPICAM UV, in addition to nadir-viewing, also requires special orientations of the spacecraft which allow 'Sun-occultation observations'. The incorporation of the solar occultation channel is based on a small pointing mirror in front of the opto-mechanical assembly.

After acquisition of the nominal orbit near Mars, the dipole antenna (40 m tip-to-tip; Fig. 4) and a 4 m-monopole antenna will be deployed in such a way that the dipole is oriented perpendicular to the flight and nadir directions, whilst the monopole points in the vertical direction.

The implementation of a detector for charged and neutral particles requires that measurements be performed within a fairly undisturbed space environment and with a large unobstructed field of view. Interference with the spacecraft itself is unavoidable and trade-offs have to be made between mounting locations, fields of view and sensor orientations.

The spacecraft subsystems

The key features of the spacecraft structure and its subsystems are shown in Figure 5. It is a low-cost, low-risk design with simple interfaces and load paths, meeting the launch-environment and all other system requirements. The design is based on proven concepts in order to provide confidence in mass and cost estimates, but its configuration is fully customised to the mission needs in order to preserve the required modularity.

The structure has several main functions. Firstly, it provides the mechanical interfaces to the spacecraft equipment; secondly, it secures the mating to the launcher interface for both the on-ground and launch phases; thirdly, it fulfils the launcher stiffness requirements; and fourthly it maintains the alignment of the payload elements within the demanding limits. The structure is derived from small-satellite applications, limiting the number of complex elements to a minimum. The only large

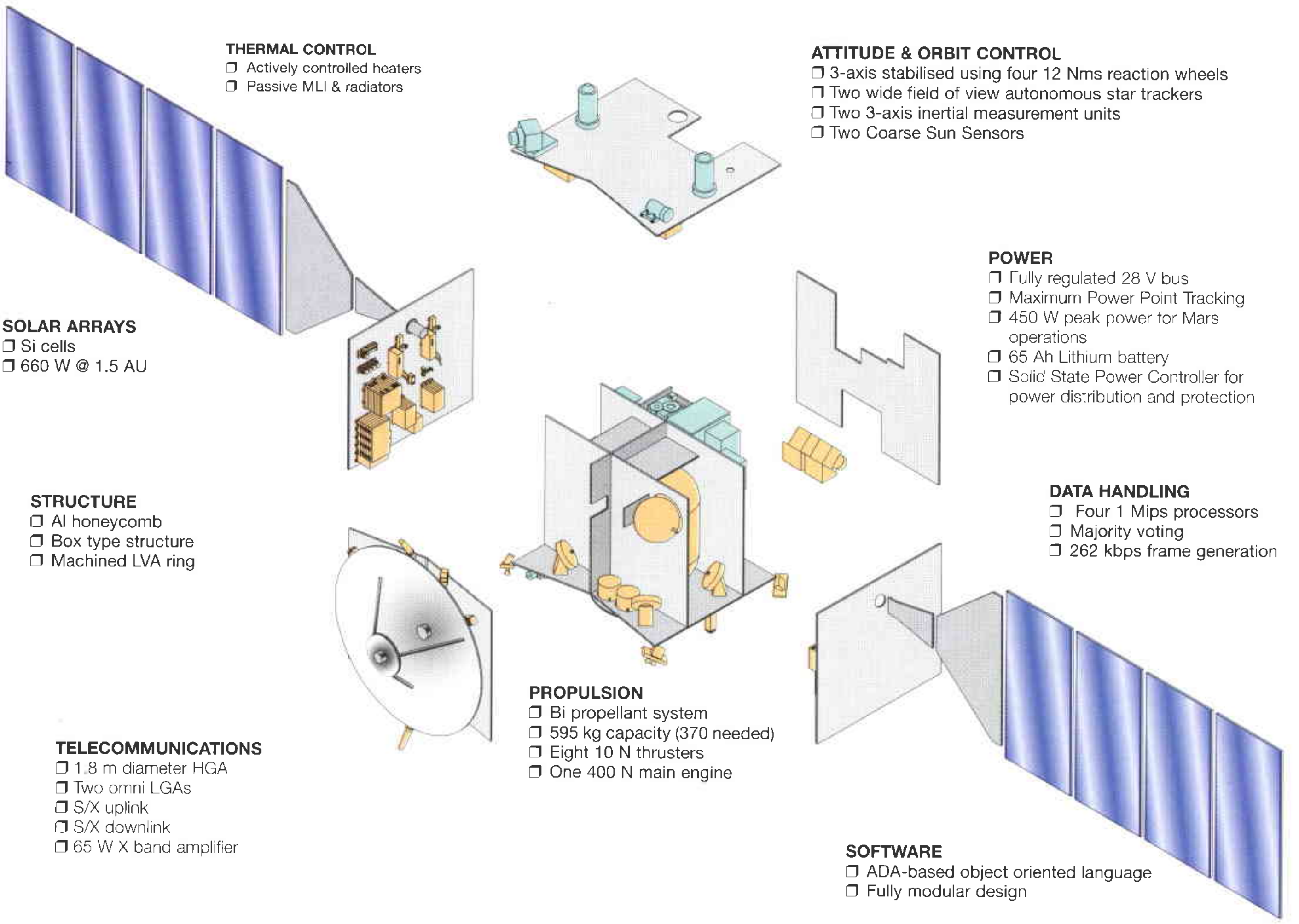


Figure 5. Spacecraft structural elements and key subsystem features

cylindrical element is the Launch Vehicle Adapter. The remaining structural items are principally flat, standard panels with aluminium skins and aluminium honeycomb.

Thermal control

The thermal-control subsystem is designed to maintain all equipment within allowed temperature ranges during all mission phases. Most of the spacecraft units are collectively controlled within a thermal enclosure. For more demanding units like payload sensors (HRSC and OMEGA optics, PFS and SPICAM sensors) featuring their own thermal control, special precautions are taken by individually insulating them and by providing them with dedicated radiators to ensure the correct temperature levels. External units (MARSIS antennas, ASPERA units) are insulated from the spacecraft, as they have to withstand greater temperature ranges than the others. Beagle 2 is thermally decoupled from the spacecraft to avoid heat leaks after Lander ejection.

Attitude and Orbit Control System (AOCS)

The AOCS architecture selected for Mars Express is inherited from Rosetta. Attitude and orbit control is achieved using a set of star sensors, gyroscopes, accelerometers and reaction wheels. A bi-propellant reaction-control system is used for orbit and attitude manoeuvres by either the 400 N main engine or banks of 10 N thrusters.

Six main modes cover the mission's operational phase. The Mars Pointing Mode and the Inertial Pointing Mode enable the spacecraft to follow variable attitude profiles along the orbit. The Main Engine Boost Mode controls the major trajectory corrections during the interplanetary cruise, the Mars-orbit insertion and acquisition of the final orbit. The Fine Trajectory Correction Mode performs small corrections of the trajectory using the 10 N thrusters. The Aerobraking Mode will be used for recovery should an anomaly leave too little fuel for nominal orbit acquisition. The Slew Manoeuvre Mode uses the reaction wheels for the transitions between all of these modes. Backup modes, to be used in the case of a serious anomaly, are covered by the Sun/Earth reacquisition modes.

Propulsion

A bi-propellant system, based on the heritage of earlier telecommunications spacecraft, has been adopted to meet the requirement for a high-performance, low-cost propulsion system with minimum mass. Throughout the interplanetary cruise, the system will operate in a pressure-regulated mode using only the 10 N thrusters. A few days before Mars orbit insertion, the main engine will be primed and its thrust calibrated by making specific manoeuvres. This will ensure that the main engine can be used safely for the Mars orbit insertion and acquisition of the operational orbit. Should a main-engine failure be detected at this stage, a set of the 10 N thrusters would be used to carry out the capture manoeuvre. In this case, only a degraded orbit around Mars could be established, but aerobraking could help to achieve the nominal orbit. The pressurant and main-engine assemblies will be isolated once the spacecraft has reached its final orbit; the rest of the mission will be performed in blow-down mode with the 10 N thrusters only.

Electrical architecture

The long propagation times for signals from Earth and Mars (up to 20 minutes) and the limitations due to the fact that only one ground station near Perth, in Australia, is foreseen in the nominal mission design, require a high level of autonomy within the spacecraft systems. In addition, the large volume of data generated by the instruments requires a very high data transmission rate to the ground station. Finally, the spacecraft must also be able to cope with a highly variable environment due, for instance, to the changing distances between the Sun, Mars and Earth, which result in large variations in the solar flux and data-transmission rates.

The data-handling architecture is organised around the two Control and Data Management Units (CDMU). Their tasks are to decode and execute the commands from the ground, format housekeeping and science telemetry, manage the on-board data distribution, and do all of the real-time computation onboard. The CDMU features two MA3-1750 Processor Modules, and a 10 Gigabit solid-state mass memory is used to store housekeeping and science data telemetry until its transmission to the ground. It also collects science data from some high-rate instrument interfaces. The communications link with the Earth can switch between S-band or X-band frequencies. Low-gain antennas allow omni-directional transmission and reception at S-band, while a parabolic high-gain antenna allows high-rate data transmission and telecommand reception at S- and X-band.

Electrical power is generated by a two-winged solar array with 11 m^2 of silicon cells and a tip-to-tip wing span of about 12 m. The array is oriented towards the Sun by a rotating drive mechanism. A 64.8 Ah lithium-ion battery supplies the power needed during eclipses. A 'maximum power point tracker' always keeps the solar-array power generation at its most efficient. The +28 V regulated power bus distributes power to all users via a Power Distribution Unit with solid-state switches.

Spacecraft development plan

The overall development and verification approach is designed to ensure the meeting of all requirements, and delivery on time and within the allocated budget. This is secured by early procurement and validation, whilst thorough testing and verification minimises the risk. The major guidelines for the development and verification approach for Mars Express are:
- use of recurrent equipment wherever feasible and the restriction of development activities to a small number of items
- risk-reduction actions as early as possible in the programme
- development of spacecraft subsystems or modules as independently as possible
- spacecraft qualification and acceptance verification programme.

In a totally new approach for ESA (Fig.6), the industrial team will be responsible for the management of all scientific-payload interfaces, with the Agency remaining responsible for scientific performance and operational aspects. The development programme for each instrument will be defined by the Principal Investigator and approved by MMS for the interface aspects, with the objective of achieving timely delivery of a fully qualified flight instrument. The test sequences, validated at instrument level, will be reused at system level. For this purpose, spacecraft interface simulators will be proposed to the scientific teams to support the development of their instrument. The validation and model philosophy at system level requires that the instrument-model philosophy includes a structural model, an engineering model, or at least an electrical simulator for advanced system electrical and functional validation, and a flight model.

Payload management

A novel scheme is being implemented for instrument interfaces on Mars Express. The spacecraft contractor has responsibility for the instrument interface management, the allocation of resources, the provision of an acceptable environment for the instruments, timely delivery of the instrument models, progress monitoring and the administration of changes and non-conformances. The Principal Investigators, together with ESA, remain responsible for the scientific performances of the instruments and related in-flight operations.

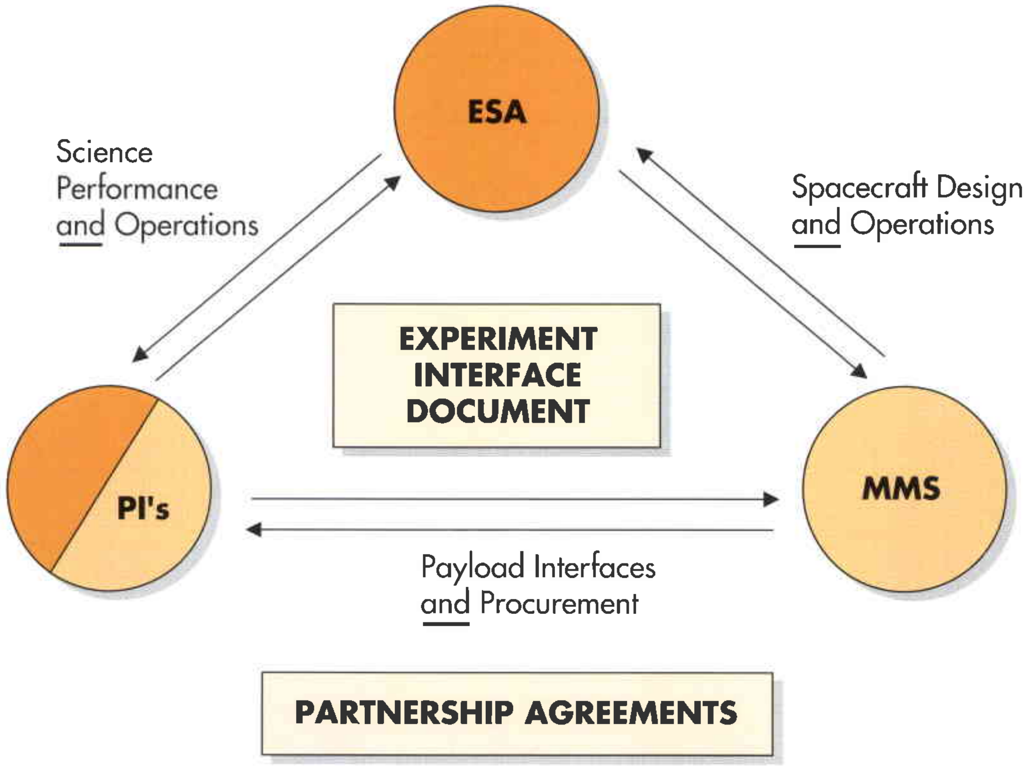


Figure 6. A new relationship between Principal Investigators, ESA and industry

MMS bases the management of the instrument interface on the requirements contained in the Experiment Interface Document (EID-A), as a document applicable to both Principal Investigators and Industry, covering all technical and programmatic aspects. A partnership agreement between MMS and the Principal Investigators has already been established and forms the basis for the EID-A. As part of that agreement, the Principal Investigators will support the industrial team in the timely establishment of the detailed interface control document for the instruments. Progress monitoring, instrument reviews and active participation by the scientists in the instrument verification on the spacecraft will ensure timely delivery of and satisfactory in-orbit performances by the payload.

Planning

The ultimate objective is to execute the launch within the window opening on 1 June 2003 and closing eleven days later. To this end, MMS aims to deliver a fully qualified spacecraft as early as November 2002. The current planning features a three-month margin at spacecraft level with respect to the specified delivery date.

The spacecraft definition phase (Phase-B) will be completed by the end of 1999 (Fig. 7). A detailed plan has been established for this phase and procedures will be implemented to monitor the technical progress against the plan. Commencing in summer 1999, Equipment Suitability Reviews will be held to assess the compatibility of the recurring units with the system requirements. Early activities – for instance the procurement of long-lead items, test-equipment manufacturing and breadboard manufacturing – will be initiated halfway through the design phase in order to protect the schedule. A Preliminary Design Review in November 1999 will conclude the design phase and, upon its successful completion, the go-ahead will be given for the development and production phases (Phases-C and D), nominally starting in January 2000.

Challenges for the industrial team

Mars Express is a formidable challenge for European industry in that it involves executing a very ambitious scientific mission within a stringent cost cap, but without breaching the Agency's standard procurement rules. The mission requirements are very specific and so far unprecedented in Europe. The design and verification effort at system level is therefore completely tailored to this mission and requires strong up-front engineering and rigorous management at spacecraft level.

The intensive reuse strategy necessary to achieve attractive equipment costs coupled with low risk left little flexibility for achieving the required geographical-return targets. New elements or modifications introduced to customise the design to specific mission needs have provided more latitude in this respect. The recurrent units are drawn mainly from ESA's Rosetta programme.

The costs associated with the tasks undertaken by the Prime Contractor remain

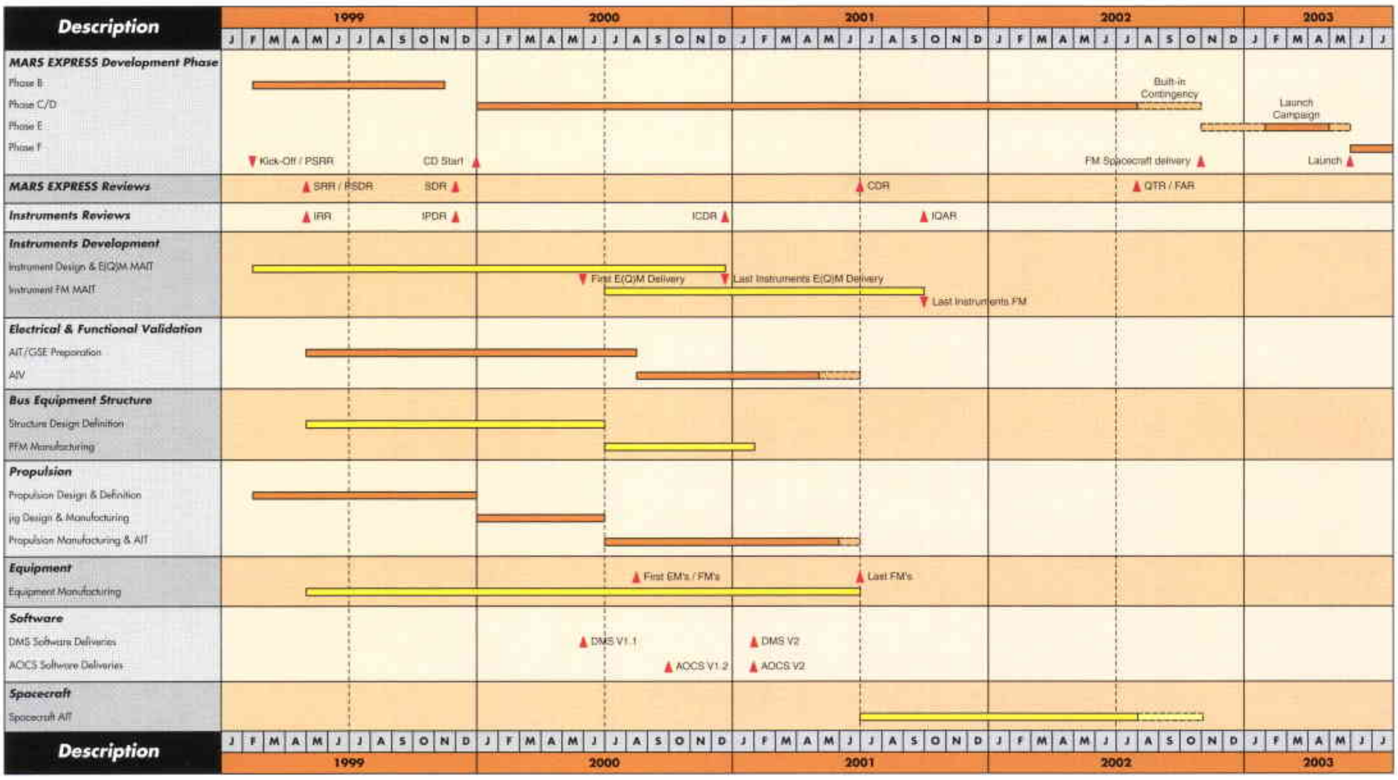


Figure 7. Activities and key events in the procurement of the Mars Express spacecraft

well below those of other programmes in absolute terms, but represent a higher percentage of total programme cost. This stems from the fact the total and unit costs are much lower than for earlier science missions, whereas the prime engineering and management tasks are those associated with a low-risk, high-performance, deep-space scientific spacecraft. These tasks will be shared very efficiently between several companies. New approaches have been introduced to handle the resulting challenges.

In this context, the selection of a skilled and motivated industrial project team with clear objectives is critical to success. All team members must be focused on:
- cost as a paramount parameter
- reuse of existing designs, especially during the detailed definition phase
- in-depth understanding of requirements, particularly scientific requirements, as the best way to avoid over-design
- mission customisation of the spacecraft must be maintained for a limited number of elements and interfaces.

Secondly, there has to be a clear division of responsibilities and clean interfaces between the industrial team, ESA and the scientific teams. The breakdown of activities that has been chosen is the most efficient possible based on company skills and cost efficiency. The spacecraft interfaces with the payload are under direct industrial management, enabling straightforward problem-solving.

The management methods and tools used in the procurement phase must allow cost and scheduling targets to be achieved with minimum risk. Risk minimisation for new developments and elements requires the selection of reliable subcontractors. The numerous interfaces between spacecraft, ground segment, test centre and launcher call for efficient management by an experienced industrial team.

Last but not least, good people management has a role to play in the overall effort towards successful implementation of Mars Express. A small but fully empowered industrial project team will facilitate communications with the scientific teams and with ESA. Hands-on management is emphasised, with the direct involvement of the project manager in technical decisions and the delegation of cost and schedule responsibility to project team members.

S-Cam: A Technology Demonstrator for the Astronomy of the Future

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S-Cam is a cryogenic camera developed within the Astrophysics Division of ESA Space Science Department. The camera has been designed as a technology demonstrator, aiming to prove the potential of a new generation of single-photon counting detectors based on Superconducting Tunnel Junctions (STJs). This article provides an overview of the cryogenic detector development, a description of the S-Cam system and a summary of the results obtained both during testing at ESTEC and during actual observations at the William Herschel Telescope in La Palma (Canary Islands, Spain). Initial observations were performed on the Crab pulsar, a neutron star about 10 km in diameter and about 6000 light years from Earth, with a weight equal to that of our Sun and spinning with a period of 33 msec.

Introduction

Modern astrophysics is concentrating on phenomena that only a few years ago were inaccessible. The confirmation of various astrophysical models implies higher and higher precision, thereby requiring more sensitive and accurate instrumentation. Examples of this trend in space are represented by the mapping of the star population of our galaxy with extremely high positional accuracy (Hipparcos and GAIA) or by ever more detailed analysis of the isotropy of the Cosmic Background Radiation (COBE and Planck). Such efforts are being made in all portions of the electromagnetic spectrum, from submillimetre waves to X-rays, covering a photon energy range which varies from meV (at wavelengths of order 1 mm) to several tens of keV (at wavelengths of order 1 angstrom), c.f. XMM.

At all wavelengths covered by astronomical observations, the overall scientific performance is determined by two main factors: the telescope collecting area, which determines the signal that can be detected in a given time, and the detailed properties of the associated detectors placed at the telescope's focus. Photon detectors play a central role, representing the main diagnostic possibility available to astrophysics, and in the end determining the ability to achieve ever more ambitious scientific goals.

The possibility of detecting individual optical photons has been available for a number of years (exploited, for example, by ESA's Faint Object Camera on the HST), but only with low detection efficiency and no wavelength information. Within the Astrophysics Division at ESTEC, we have exploited the physical phenomenon of superconductivity to propose and develop the most advanced optical detection system, allowing individual optical photon counting at high event rates, with very high efficiency across the ultraviolet (UV) to infrared (IR) range, and very low noise. Most importantly, this work has led to the first optical detector that can determine, intrinsically and without the use of dispersive elements or filters, the energy of each individual photon.

While several detector technologies allow single-photon counting at higher energy (UV and X-ray), in the recent past only detectors such as photomultiplier tubes could do the same at lower energies, in the extreme ultraviolet (EUV), visible and near-IR (NIR) range. More recently, cryogenic detectors, such as superconducting tunnel junctions and bolometers operating at temperatures below 1 K, have allowed a drastic performance improvement, with very high responsivities, excellent energy linearity and large count-rate capabilities. As a result of the strong responsivity (as high as 10^4 e^-/eV for Superconducting Tunnel Junctions, or STJs), it is possible to count single photons at wavelengths up to a few microns (NIR). By operating the sensors in photoconductive mode (i.e. collecting the electric charge induced in the detector electrodes by the photo-absorption event), it is possible to measure the energy (i.e. the wavelength) of the detected photons. The resolving power ($E/\Delta E = \lambda/\Delta\lambda$) is of order 10 –100, depending on the intrinsic detector characteristics. The fast response time allows for high count rates and for the capability to associate a well-defined time of arrival to each detected event.

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Once the fabrication technology is mature enough, it will be possible to produce larger arrays based on such individual elements (pixels), providing the possibility to record an image at the focal plane of dedicated optics. In such a configuration, we have an instrument defined as an 'imaging spectrometer', i.e. a camera that can provide two-dimensional images in addition to spectroscopic information on the detected photons. An important aspect that needs to be highlighted is the fact that these detectors provide spectroscopic information without the need for any additional device in the optical path, operating in a non-dispersive mode, i.e. with the highest possible photon detection efficiency.

Space-based observatories operating over a wide wavelength band provide an ideal platform to fully exploit the capabilities of this new generation of photon detectors. This is due to the absence of any filtering induced by the Earth's atmosphere and by the reduced thermal background radiation present in space when looking at faint objects such as stars and distant galaxies.

The recent advances made by cryogenics have drastically simplified the installation of cryogenic equipment on board spacecraft, as clearly demonstrated by the success of ISO (the Infrared Space Observatory) and by several other missions presently being developed (such as FIRST and Planck) or under study (such as XEUS). In order to simplify the future integration of cryogenic instrumentation on board spacecraft, a number of research and development activities have been undertaken by the Astrophysics Division in collaboration with the Directorate of Technical and Operational Support. These include a series of technical developments in the area of mechanical coolers, ^{3}He sorption coolers, Adiabatic Demagnetisation Refrigerators and related cryogenic wiring. In parallel, another series of activities are dedicated to the development of suitable IR filters, allowing high throughput in the visible and EUV and high suppression of any residual thermal radiation.

The development of this first ground-based camera has proved extremely important in identifying the critical aspects of a future space-based cryogenic instrument and in highlighting the operational constraints deriving from its use for astronomical observations. With this goal in mind, S-Cam has been designed as a technological demonstrator for operations at the William Herschel Telescope, in La Palma, Canary Islands (Spain).

The Astrophysics Division has been involved in the development of STJ-based detectors for about a decade, within an R&D programme that has produced world-class devices with excellent spectroscopic performance, from the X-ray to the NIR. The detectors have been manufactured under ESA contract by Oxford Instruments (UK) and operate at a temperature of about 300 mK. The detectors are fabricated according to ESA requirements and are tested in the laboratories of the Astrophysics Division. The latter's interest in this activity is mainly related to the potential scientific exploitation of these devices and to their utilisation on board future astrophysics missions.

STJ detector development

The development of STJs as photon detectors within the Astrophysics Division started with niobium-based devices, operated as X-ray detectors at a temperature of about 1.2 K. More recently Nb-Al and tantalum-based devices have been optimised for the detection of visible photons, with an operating temperature of about 0.3 K. Such devices have a square geometry, with typical dimensions of order 20-50 μm; they are based on multilayer structures (e.g. Nb-Al-AlOx-Al-Nb), with two superconducting electrodes separated by a very thin oxide layer. The thickness of the electrodes is typically some 100 nm, while the barrier is only 1 nm thick. To achieve the best detector performance, it is necessary to fabricate high-quality devices characterised by a highly uniform isolating barrier and by crystalline thin-film electrodes. Such devices have achieved resolving powers ($E/\Delta E$) exceeding 100 at soft X-ray energies and of order 10 at visible wavelengths.

The 6 x 6 element array detector fabricated for the focal plane of S-Cam is based on Ta-Al devices, having a size of 25 μm. This detector represents the first STJ array capable of providing imaging and spectroscopic information at visible wavelengths; it has been manufactured to ESA requirements, and it is the result of several years of development and testing. The array's development has required particular effort in ensuring the reproducibility of the current/voltage characteristics of all of its elements and an adequate fabrication yield.

The geometry of the detector is presented in Figure 1; the characteristic 45° rotation of the pixel squares is due to specific operating requirements. Each single element is connected to its own readout electronics by means of Nb wiring 2 μm thick, deposited on top of a passivating SiOx layer. The pixels are separated by gaps 4 μm wide, so that the total filling factor of this Focal Plane Array is 0.74. To maximise the photon collection efficiency, the detector is illuminated from the rear, through the sapphire substrate, which is highly transparent in the visible range. The single-detector quantum efficiency has been modelled theoretically and subsequently measured experimentally at EUV wavelengths, showing a value of in excess of 70% from 200 to 800 nm.

Figure 2 shows, in the form of a 3D histogram, the responsivity of each of the array elements, as measured from soft X-ray tests. The responsivity of the detector is a key parameter, indicating the amount of signal that can be extracted per unit of energy absorbed (in this case, electron/eV, where a visible light photon has an energy ranging from 2.6 eV in the blue to 1.8 eV in the red). The plot indicates a rather high degree of uniformity, with all pixels varying by no more than 5%. Moreover, all of the devices have similar current/voltage characteristics, with very low 'dark-currents' (well below 1 nA at a bias voltage of about 100 μV), thus allowing the signal-to-noise ratio to be optimised.

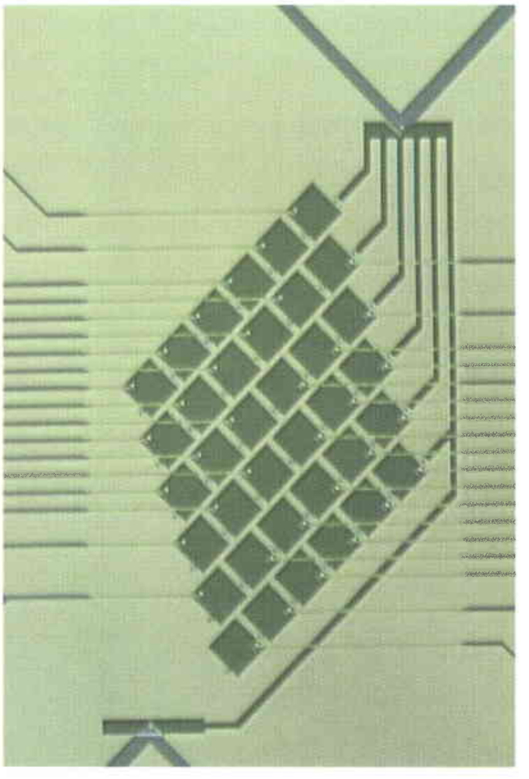


Figure 1. Optical microscope photograph of the 6 x 6 array

Several activities aimed at further improving the array performance are presently underway. There are two main goals to be achieved: (a) a significant increase in the detector active area to allow for a corresponding increase in field of view; and (b) an improvement in the spectroscopic performance by moving to superconducting materials with a lower energy band-gap. Both goals must be achieved while preserving (and possibly improving) the fabrication yield.

Enlargement of the field coverage requires a drastic increase in the number of pixels (from the current 36 to well in excess of 1000) in order to enhance the active area without under-sampling the Point Spread Function of the optical system. Such an increase in number of pixels may imply a corresponding increase in the number of readout channels, thus posing significant challenges in terms of wiring access and cryogenic performance. The adoption of lower band-gap superconductors implies lower operating temperatures (from 400 mK down to below 100 mK) and the need to address materials-science and technological issues related to the controlled deposition and patterning of high-quality thin films.

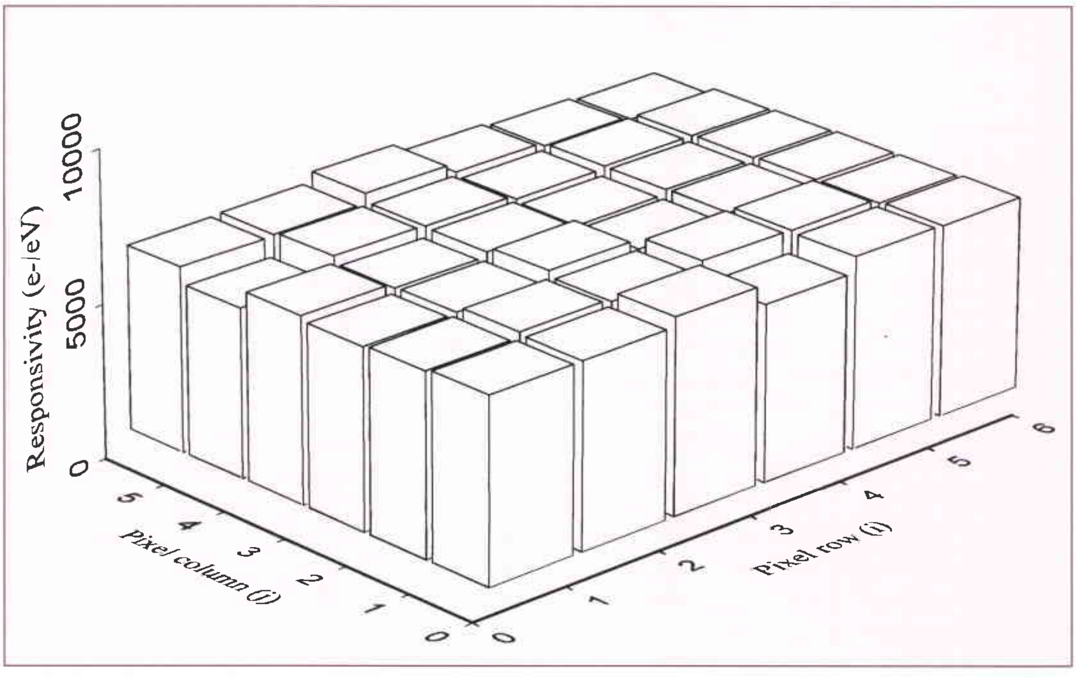


Figure 2. Mapping of the array's responsivity (36 elements)

The array development programme is explicitly oriented towards applications, including future ground and space-based instrumentation for astrophysics. In the ground-based applications category, we can mention the improved versions of S-Cam, which will significantly enhance the performance of the Mark I camera, being designed for operations at a large-diameter telescope. As far as space-based applications are concerned, two different possibilities merit mention: (a) the development of non-dispersive, low-to-medium resolution imaging spectrometers operating in the NIR-Visible range; (b) the development of high-resolution imaging spectrometers for the soft X-ray range (up to 10 keV).

Table 1. S-Cam requirements

Camera band pass	300 – 600 nm
Provided data/event	Wavelength, event arrival time, pixel identification
Typical resolving power	Order 10 (at 300 nm)
Event time accuracy	5 μs (absolute accuracy UTC)
Max. count rate per pixel	1 kHz
Camera field of view	3.6 x 3.6 $arcsec^2$ (0.6 arcsec/pixel)
Effective observation time	>12 hours (cooler hold time)
Camera focus adjustment	WHT secondary mirror and S-Cam optical unit
Camera guiding	WHT telescope facility (autoguider)
Filter wheel	Two sets of 8 filters on 2 independent wheels
Camera operations	Remotely controlled from the WHT control room
On-line data analysis	'Quick-view' facility running on control computer
Data storage	On control computer (FITS), total capacity >8 GB

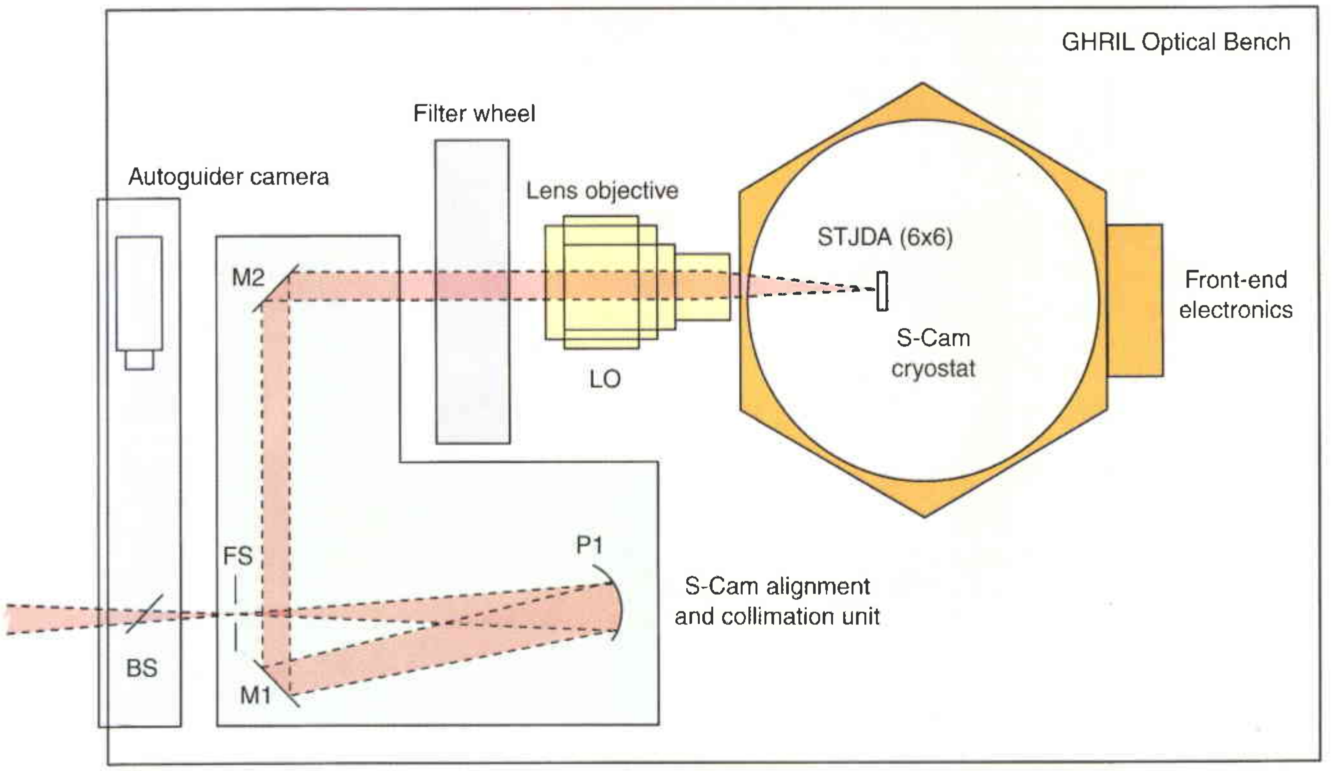
S-Cam development

The S-Cam design is based on the instrument requirements listed in Table 1, which reflect both the operational needs of astronomers using the camera and the observation-site characteristics. Among the most significant issues are the resolving power, the time-tagging, the count-rate and the plate-scale requirements.

The required resolving power matches the intrinsic capabilities of tantalum-based detectors, and requires strict control over the electronics noise and any stray IR radiation impinging on the Focal Plane Array. The latter component is particularly important for a cryogenic camera designed to operate the detector at a base temperature as low as 300 mK. The 5 μs absolute accuracy time-tagging requirement is crucial from an astronomical point of view, since it allows accurate timing analysis for variable sources and the validation of specific astrophysical models. The count-rate performance is also important, since it determines (in conjunction with the plate scale and the image optical quality) the maximum object brightness that the instrument can tolerate without the help of any means of attenuation (i.e. without filters). In addition, the capability to count single photons implies the potential for a large number of events, i.e. the need for adequate data processing and storage performance. Finally, the plate-scale requirement is critical in defining the camera Field Of View. Adequate sampling of the optical system Point Spread Function is necessary, however, in defining the characteristics of the unit interfacing the camera to the Nasmyth focus of the William Herschel Telescope. The cryostat base temperature is linked to the detector choice, while the hold time is determined by operational and logistic requirements.

On the basis of the requirements listed in Table 1, it was then possible to define the detailed engineering of the complete system. The overall architecture is described by the block diagrams of Figures 3 and 4. The complete system is composed of an optical unit, a cryogenic system based on a ^4He cryostat and hosting a ^3He cryo-sorption cooler, analogue front-end electronics based on 36 charge-sensitive preamplifiers and digital data acquisition and storage equipment.

Figure 3 shows the units located on an optical bench inside the Ground-based High Resolution Imaging Laboratory (GHRIL) room (Fig. 5), a dark cabin which is at one of the two Nasmyth foci of the alt-azimuth telescope. The optical unit of S-Cam includes reflective and refractive units, used to provide a plate scale of 0.6 arcsec per pixel on the Focal Plane Array. There is a filter-wheel unit in the parallel beam portion of the optical path to provide the optional attenuation via different neutral-density and pass-band filters. The main cryostat is also located on the GHRIL optical bench. The analogue, 36-channel Front-End Electronics is mounted directly on the cryostat to minimise noise pick-up and grounding problems (Fig. 4). The output of the charge-sensitive pre-amplifiers is then processed via shaping filters and processed via a dedicated data-acquisition unit, in order to provide the required spectroscopic and time-tagging information (Fig. 6). The latter is provided by a time-reference receiver exploiting the Global Positioning System; such a time reference is within 1 μs of UTC (Universal Time Coordinated, maintained by the Bureau Internationale des Poids et Mesures, in Paris). The data-acquisition system is controlled by a PC-based unit, also located in the GHRIL room. The actual control of the instrument is more than 50 m away from the telescope control room; the Graphical User Interface of the camera and the related quick-look software are running on a second PC, also responsible for the data storage. The data are stored in the



BS: Beam splitter for autoguider camera
FS: Field stop (adjustable)
P1: Parabolic mirror (1x translation, 2x rotation)
M1: Beam folding mirror (2x rotation)
M2: Beam folding mirror (2x rotation)
LO: Lens objective (3x translation)

Figure 3. S-Cam block diagram: optical unit and cryostat

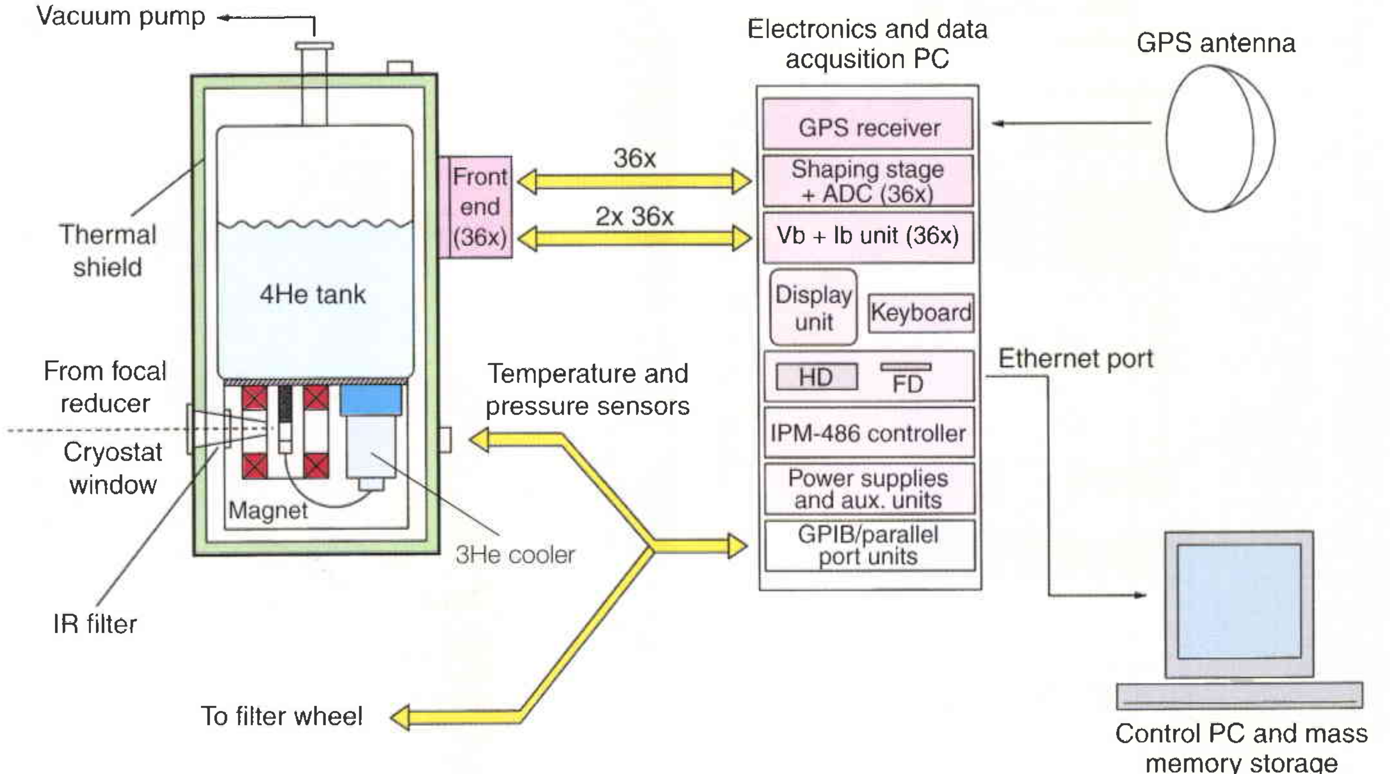


Figure 4. S-Cam block diagram: cryostat, front-end and data-acquisition electronics

Figure 5. The William Herschel Telescope in La Palma

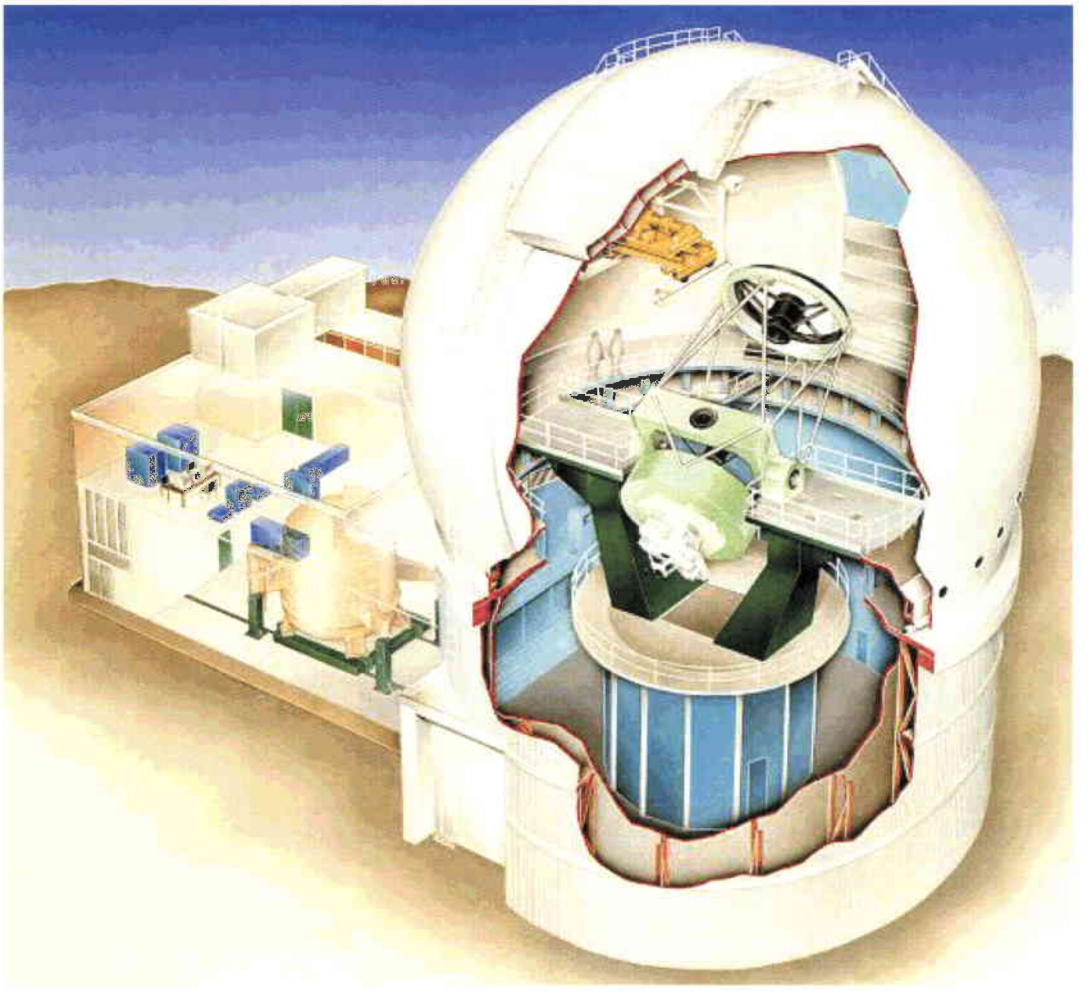
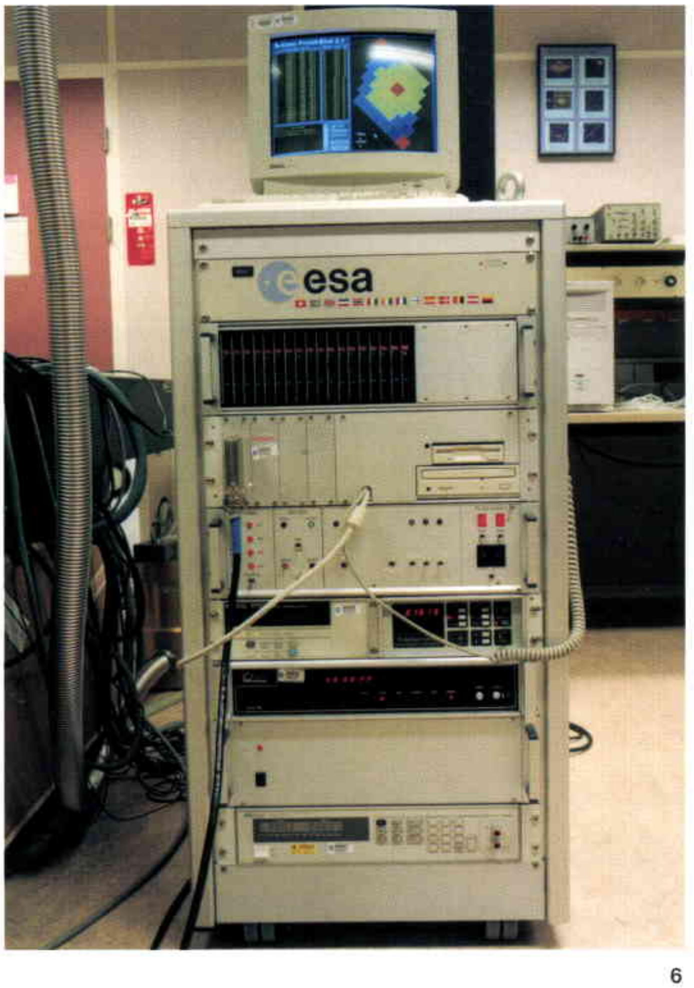


Figure 6. The S-Cam electronics rack

Figure 7. The S-Cam system undergoing testing at ESTEC (NL)



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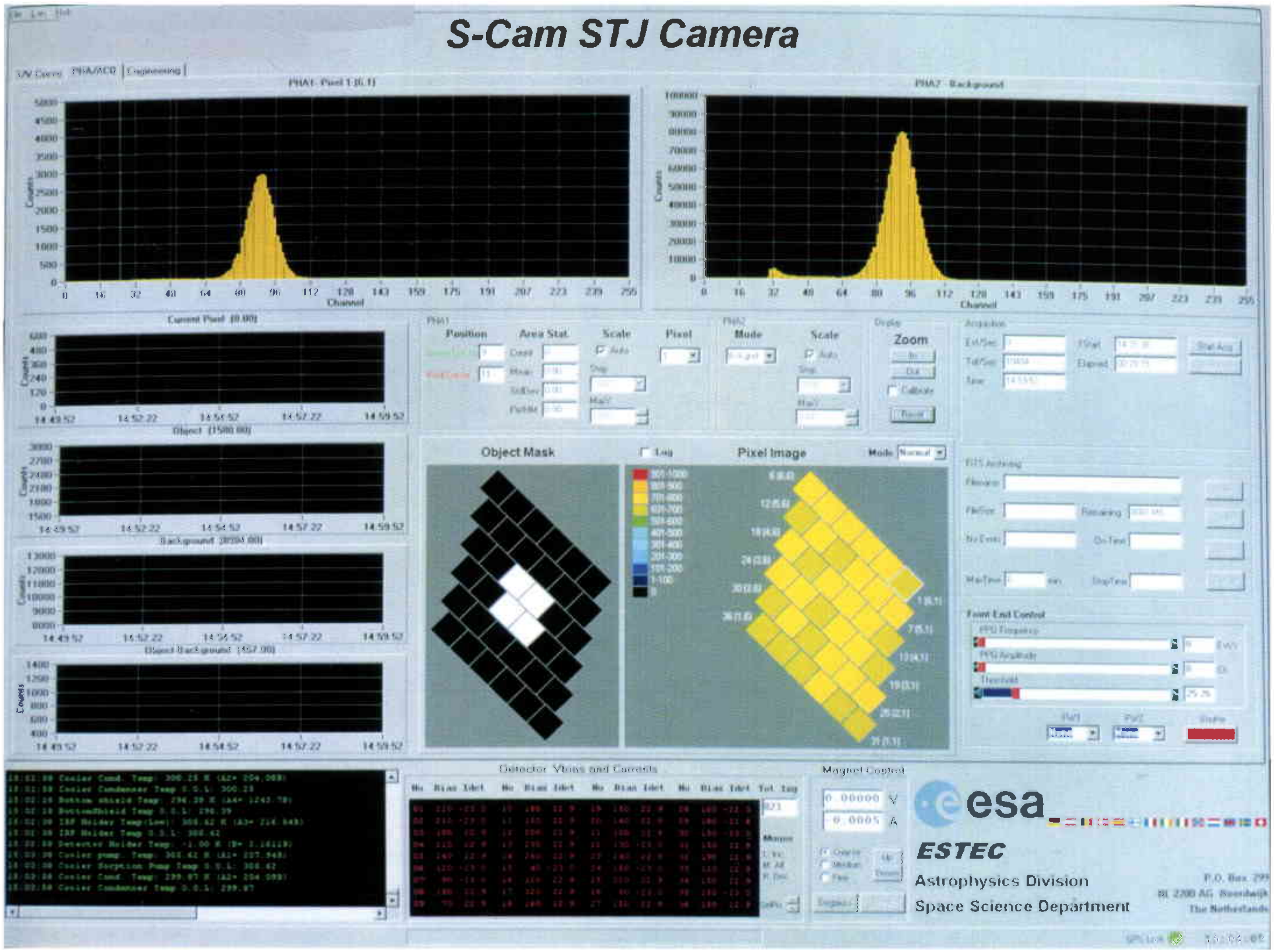

Figure 8. The main panel of the S-Cam Graphical User Interface software

FITS (Flexible Image Transport System) format in order to allow immediate access by means of standard astronomical data-analysis software.

Figure 7 is a photograph of the system while undergoing integrated system testing in the laboratory; the main system components are clearly visible. Figure 8 shows the main panel of the Graphical User Interface software.

The system tests took place at different levels of integration, between January and May 1998 at ESTEC. The integrated system tests were conducted in the period July to December of the same year. Such tests allowed us to verify the main system performances, including the instrument's resolving power, prior to the first observation campaign at the telescope site. Figure 9 shows the resolving power (expressed in the form of the ratio $\lambda/\Delta\lambda$) in the wavelength range of interest. This result, as a consequence of several degrading mechanisms, corresponds to a moderate spectroscopic resolution; nevertheless, it allows one to perform astronomical measurements never attempted before. Specific tests have addressed other aspects, such as the uniform array response to a flat field illumination, the capability to properly image, the maximum sustainable count-rate, the accuracy of the event timing, the linearity of the energy response and the related calibrations. The cryogenic system has shown excellent performance, with a base temperature of 320 mK and a hold time in excess of 8 hours.

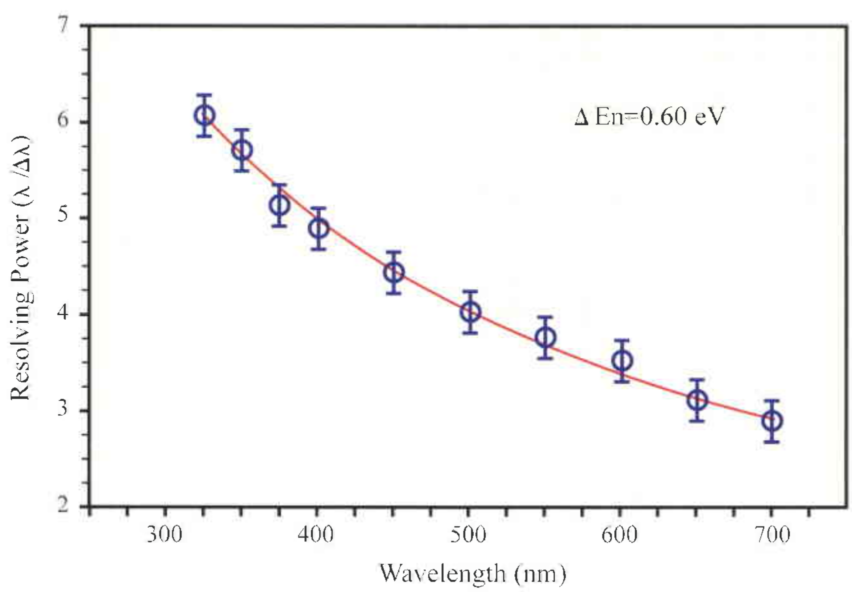

Figure 9. Resolving power as a function of photon wavelength for a typical array pixel

S-Cam was shipped at the beginning of January 1999 to the William Herschel Telescope in La Palma. The system was installed in the last week of January and the instrument saw first astronomical light in the first week of February. The very first astronomical observations took place immediately thereafter. This first campaign was conducted successfully: no major interface problems were encountered, but numerous opportunities for possible improvements and refinements were highlighted.

The William Herschel Telescope is managed by the Isaac Newton Group (ING), which also operates smaller telescopes on the same site. It is the largest telescope in Europe, with a classical Cassegrain configuration and a paraboloidal, 4.2 m-diameter primary mirror. The telescope has an alt-azimuth mount, requiring accurate computer control to track an object on the sky.

During the S-Cam campaign, astronomical observations concentrated on time-varying objects in order to take maximum advantage from the time-tagging performance of the camera. Several celestial objects have been observed, including pulsars, white dwarfs and binary systems. The most interesting results have been obtained by observing the Crab pulsar, a neutron star spinning at about 30 rev/sec and initially discovered in 1968 by radio astronomers. This neutron star, together with its surrounding nebula, is the remnant of a supernova explosion recorded in 1054 AD. The explosion took place in the Taurus constellation, approximately 6000 light years from the Earth. Figure 10 shows the light curve produced by the pulsar over an integration period of 10 min: the two peaks correspond to the emissions from the two different magnetic poles of the spinning neutron star.

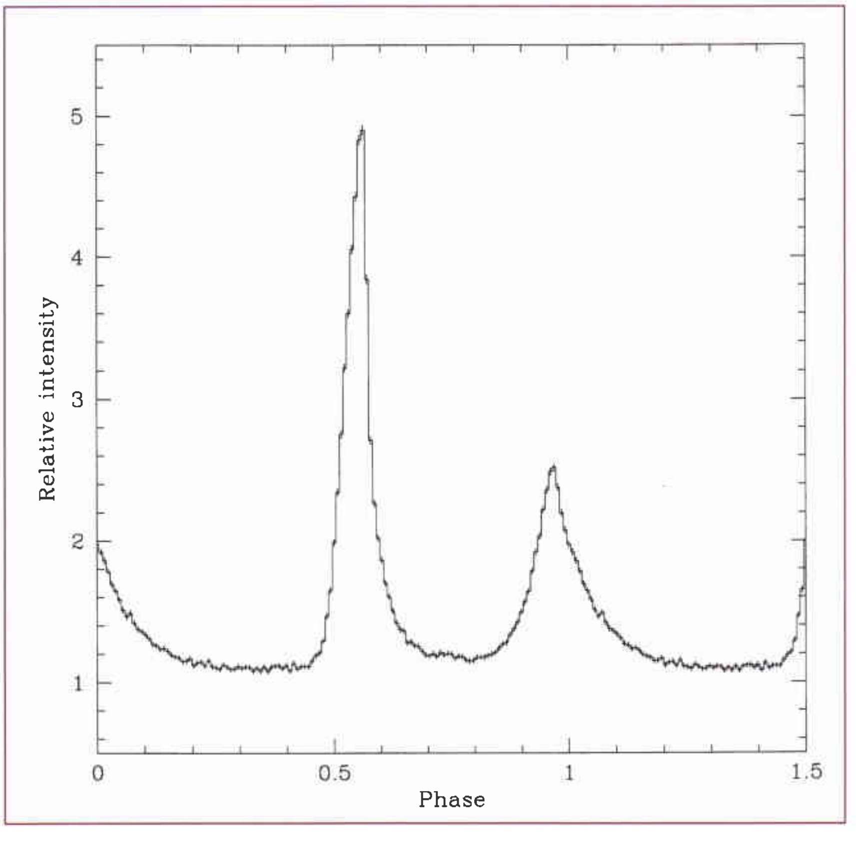

Figure 10. Light curve of the Crab pulsar

Conclusions

The development of S-Cam and its commissioning at the William Hershel Telescope represent a significant milestone in the R&D activity programme of the Astrophysics Division. Such a milestone is particularly important in view of the effort being made by ESA to manufacture cryogenic detectors based on STJs with highly innovative performance. In this respect, S-Cam represents a world first in terms of the technologies involved and the performance offered to astronomers. Possible applications of these technologies outside astrophysics include materials-science diagnostics, biomedical instrumentation and remote sensing, with particular relevance to high-speed spectro-photometry, low-light imaging spectroscopy and the study of luminescence phenomena.

Acknowledgements

The S-Cam project has required the combined efforts of several people. We would like to acknowledge the key role played by P. Verhoeve (ESA) in the characterisation of the array detector and by B. Christensen (Unigate Technologies) in the development of the complete camera software. We also wish to mention the support received from D. Doyle (ESA) for the characterisation of the optical unit's performance, and from the ESTEC Transport Office, which took care of equipment delivery.

While the overall S-Cam system was designed, assembled and tested at ESTEC, several contractors were involved in the manufacturing phase. The optical unit was manufactured by SESO (F), the ^{4}He cryostat by Bradford Engineering (NL), and the ^{3}He cooler by CEA/TBT (F). The detector array was manufactured by Oxford Instruments (UK). We also wish to thank Mr. F. van Schaik (Messer Nederland) for the delivery of liquid helium to La Palma.

Last but not least, we would like to acknowledge the excellent support received from the WHT staff, and in particular P. Moore and C. Benn of the Isaac Newton Group.

European External Payloads Selected for Early Utilisation on the International Space Station

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Introduction

With the launch and subsequent coupling of the first two elements, 'Zarya' and 'Unity', at the end of 1998, the build-up of the International Space Station has begun in earnest. In all, more than 100 elements and 460 tonnes of structures, modules, equipment and supplies will be placed in orbit by the year 2004. Utilisation of ISS for different fields of research will already start in 1999, increasing year by year during the Station's assembly phase and keeping pace with the launch and assembly of the various modules and external structures designed for supporting and operating payloads.

The external sites of the International Space Station (ISS) have huge utilisation potential for many different space disciplines. As a platform in a high-inclination, low Earth orbit and with a lifetime of 15 years or more, the ISS will provide payload mass, volume, power and communications capabilities far exceeding those of free-flying satellites. Every three months, the Space Shuttle and other servicing vehicles (ESA's Automated Transfer Vehicle, Progress, etc.) will take astronauts, new equipment and stocks of consumables up to the ISS.

The external payloads selected for the ISS assembly phase represent first-class science, as is demonstrated for example by the fact that two Nobel Prize winners are involved in two of the experiment teams (for ACES and AMS). Another payload (GTS) offers commercial services in the fields of protection against car theft, and wristwatch accuracy control.

The first externally mounted European payload will be launched this year as part of the Russian Service Module. Further European payloads have already been selected and are under development. The following paragraphs briefly describe the opportunities offered by the Station for mounting and operating payloads exposed to the external space environment, as well as those European payloads that have already been selected.

Opportunities being offered (Fig. 1)

The International Space Station is the largest international cooperative civil space programme ever undertaken. It is based on an Inter-Governmental Agreement (IGA) concluded in January 1998 between the Governments of five 'International Partners': the United States of America, Russia, Japan, Canada and Europe (11 States).

The European contributions to ISS include the 'Columbus' laboratory, the Automated Transfer Vehicle (ATV) to supply the Station and periodically raise its orbit, and several ground infrastructure elements. Through its contribution, Europe has acquired certain rights for Station utilisation, as well as participation in its management and operation. Based upon this formal right of access, it is possible to build up a strong, long-lasting ISS utilisation programme for the European user communities.

The International Space Station will provide broad opportunities for researchers in the life and physical sciences, remote sensing, technology and commercial applications sectors to exploit the unique attributes of space. These include prolonged exposure to microgravity, near-vacuum, and the space-radiation environment, but also those opportunities provided by exploiting the Station as an observation platform for celestial- or Earth-viewing payloads.

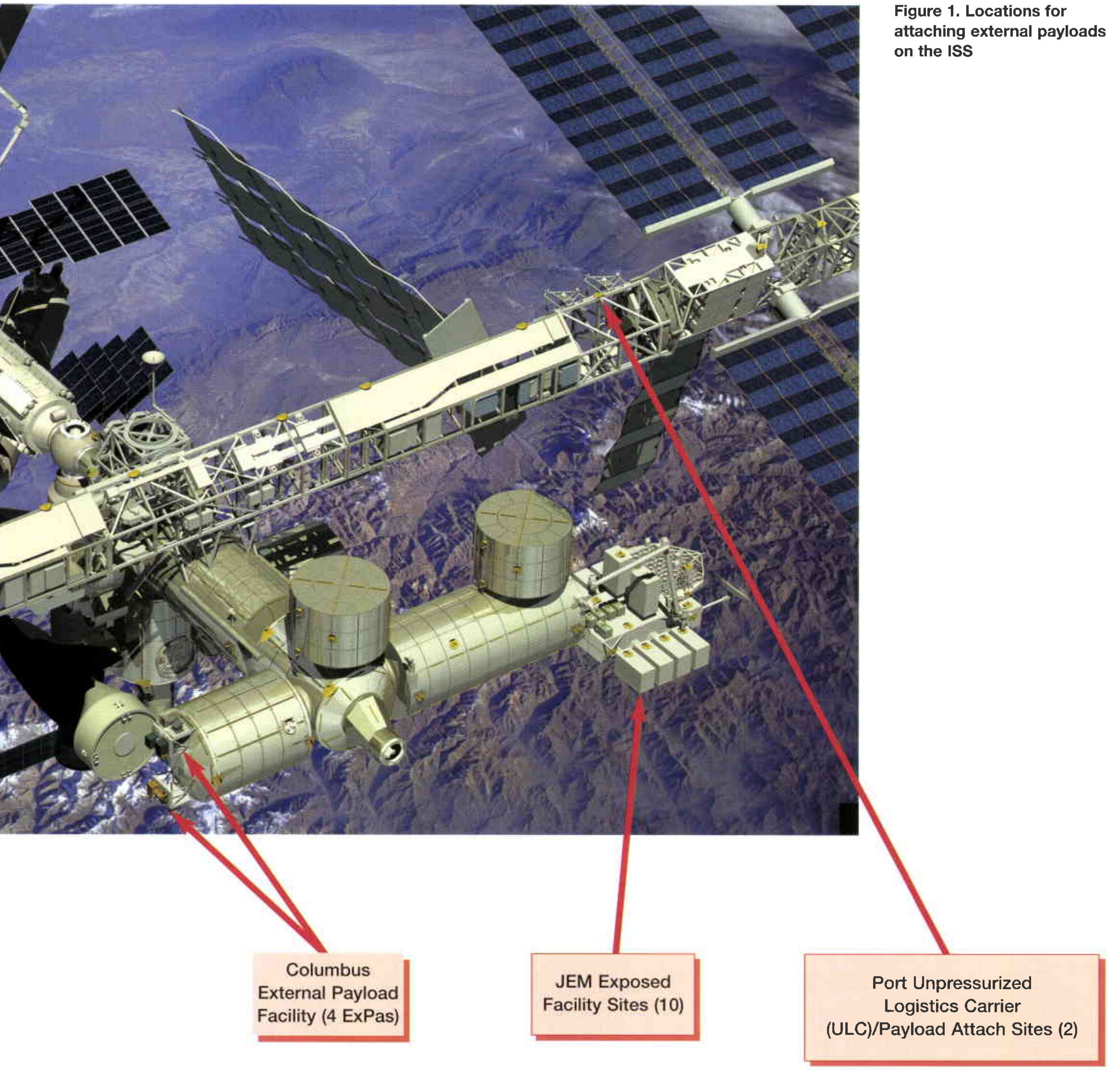


Figure 1. Locations for attaching external payloads on the ISS

The ISS offers a choice of several external sites for mounting payloads to be exposed to the surrounding space environment:

- 4 locations on the S3 segment of the US-provided 107 m-long Station Truss
- 10 locations on the Japanese-provided JEM
- 4 locations for Express Pallet Adapters on the Columbus laboratory's External Payload Facility
- mounting locations on the Russian segment.

A number of experiments can already be performed during the Assembly Phase when the Space Shuttle and Russian launchers visit the Station, and between flights when the on-board crew is available as experiment operators or as research subjects.

Sets of research hardware will be transported to the Station primarily on dedicated Shuttle Utilisation Flights (Fig. 2). These flights will start with UF1 in 2000 and end, according to the present build-up schedule, with UF7 in 2003, by which time the laboratories and external-payload sites will have been outfitted with the first generation of research equipment. From then onwards, five Shuttle flights and additional logistics flights by the Partners' mixed fleet of vehicles are planned each year for taking the astronauts to and from the Station and re-supplying ISS logistics and payload items.

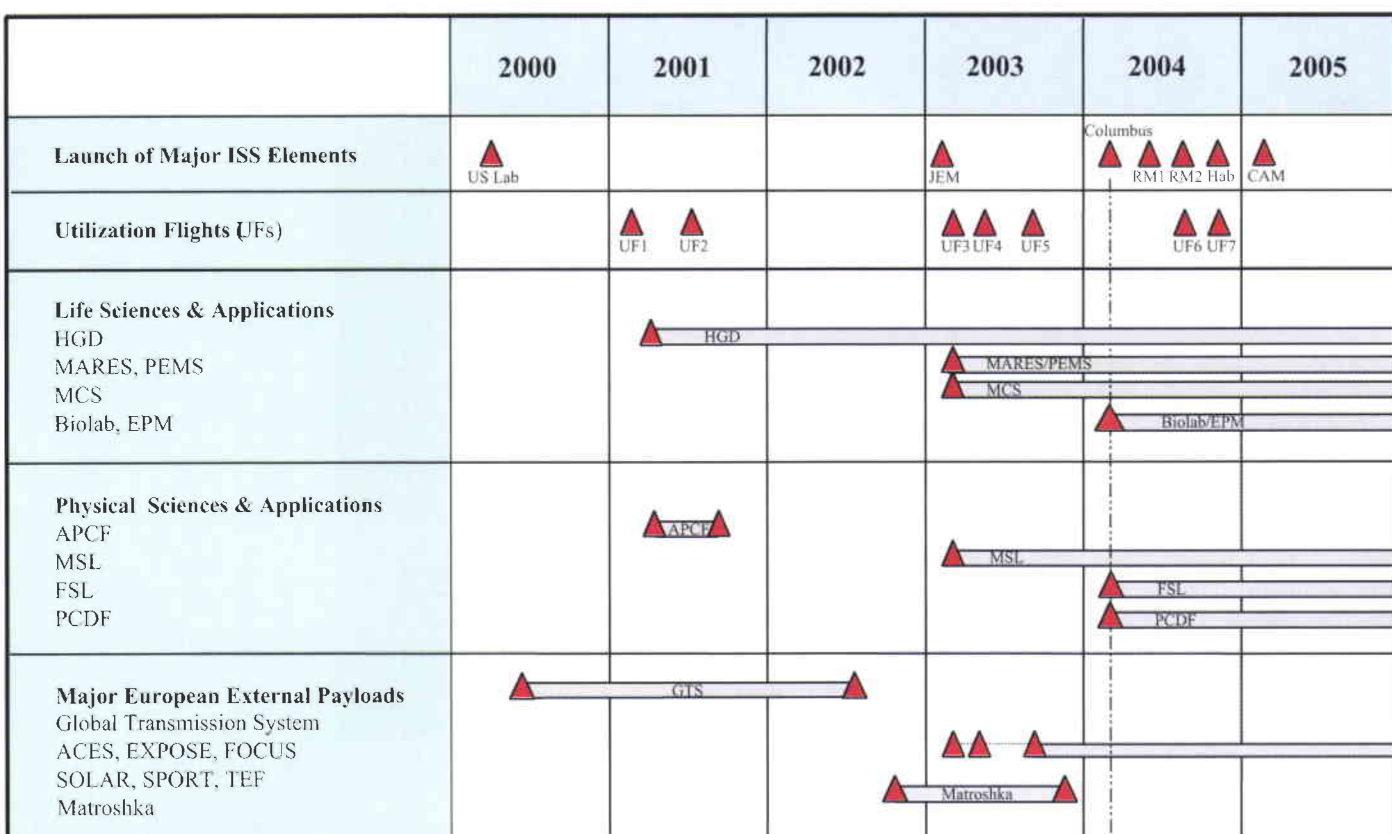
The ESA AO

In December 1996, ESA issued an Announcement of Opportunity (AO) for Externally Mounted Payloads during the Early Space Station Utilisation Period (ESA SP-1201). This AO was based on an ESA/NASA Agreement that affords European payloads access to the US-provided external Truss attach sites during the period 2002-2005. The AO was mailed using user-programme distribution lists and was also posted on the ESA Web Site. 102 proposals had been received by the April 1997 closing date, with the following distribution by discipline:

- Space Technology 48
- Space Science 23
- Life Sciences 14
- Physical Sciences 11
- Earth Observation 6

Some 350 investigators from 23 countries were involved in these proposals.

Figure 2. The milestones for major utilisation-related launches



ACES = Atomic Clock Ensemble in Space	Expose = Exposure Unit for Exobiology Samples	JEM = Japanese Experiment Module	PCDF = Protein Crystallisation Diagnostics Facility	UF = Utilization Flight
APCF = Advanced Protein Crystallisation Facility	Focus = Fire Detection Infrared Sensor Payload	MARES = Muscle Atrophy Research & Exercise System	PEMS = Percutaneous Electrical Muscle Stimulator	
CAM = Centrifuge Accommodation Module	HAB = US Habitation Module	MCS = Modular Cultivation System	RM = Russian Research Module	
EPM = European Physiology Modules	HGD = Hand Grip Dynamometer	MSL = Material Science Laboratory	TEF = Technology Exposure Facility	

The evaluation of the science and technology proposals was organised by each ESA user programme, using external peer review groups, and applying the evaluation criteria defined in the AO. The results of the peer review were presented to the existing ESA User Advisory Bodies for each discipline, and ultimately to the relevant User Programme Boards. In parallel, a technical team, including industrial contractors, began to assess the technical aspects of the proposals.

Based on the list of peer-recommended and technically feasible experiments, the Executive presented the European Utilisation Board (EUB) with a list of 10 discipline-oriented groupings, each of which comprised a complement of instruments per Express Pallet Adapter. From these 10 groupings, a final selection of 5 had to be made. This was achieved through several iterations, taking the following aspects into consideration:
- funding support by Member States for the experiments proposed
- compatibility with accommodation and/or operational constraints imposed by the Space Station
- expected readiness of payloads to meet the delivery dates for flight
- interdisciplinary aspects, the ESA Space Station User Panel (SSUP) having recommended a fair balance between the different disciplines.

The final payload complement was selected by the Manned Space Programme Board in December 1997 and consists of the following five Express Pallet payloads: ACES, EUTEF, EXPORT, FOCUS and SOLAR.

The Express Pallet System

The Express Pallet System (Figs. 3a,b) allows payloads to be mounted at external sites on the ISS Truss structure. This US-provided Pallet System will be launched and retrieved by the Space Shuttle.

The Pallets, which will be attached at specific locations on the Truss, can be zenith- or nadir-facing, allowing them to carry instruments requiring solar or celestial viewing (zenith) or Earth viewing (nadir). The Express Pallet will house six Adapters, each capable of carrying up to 225 kg of payload on a 1 m^2 mounting surface. ESA's instruments will be grouped to fully occupy Adapters: the SOLAR, EXPOSE/

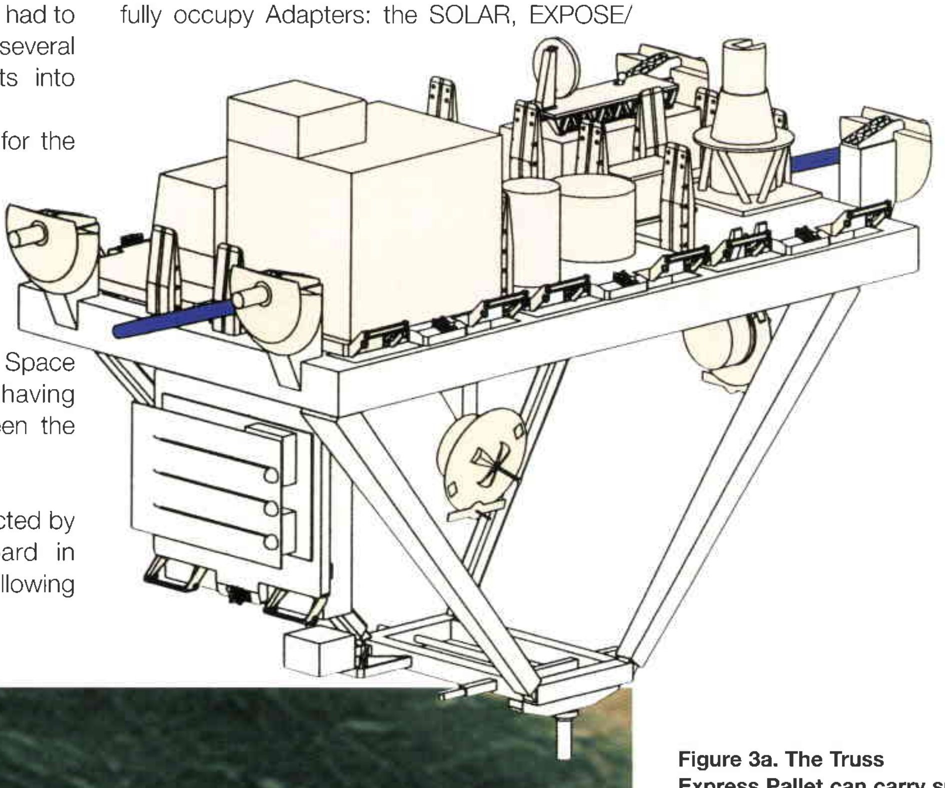


Figure 3a. The Truss Express Pallet can carry six ExPAs

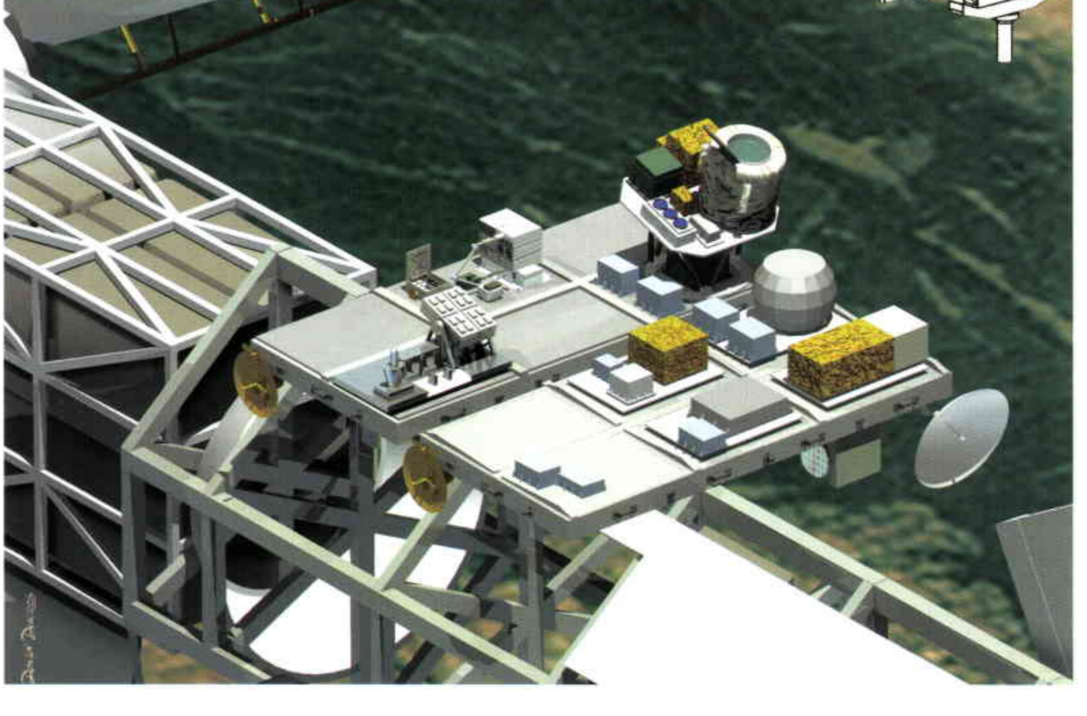


Figure 3b. The Express Pallet, carrying six ExPAs, mounted on the ISS Truss (ESA/D. Ducros)

SPORT (EXPORT) and EUTEF packages are zenith-oriented, while ACES and FOCUS are nadir-oriented. It is planned that two of the three Adapters will be exchanged during the three-year mission.

The first five European payloads

1. ACES – An Atomic Clock Ensemble in Space (Fig. 4)

The core of this project is a laser-cooled caesium atomic clock ('Pharao'), which exploits the microgravity conditions onboard the Space Station. The investigator team includes researchers belonging to the group that received the Nobel Prize for Physics in 1997.

Pharao will improve clock frequency stability and accuracy by a factor of 100 compared with the best measurements currently achievable on Earth, opening up new opportunities in various fields of fundamental research and applications. This ultra-precise measurement of time will allow relativistic measurements and tests, applications in atmospheric physics and geodesy, navigation and advanced telecommunications.

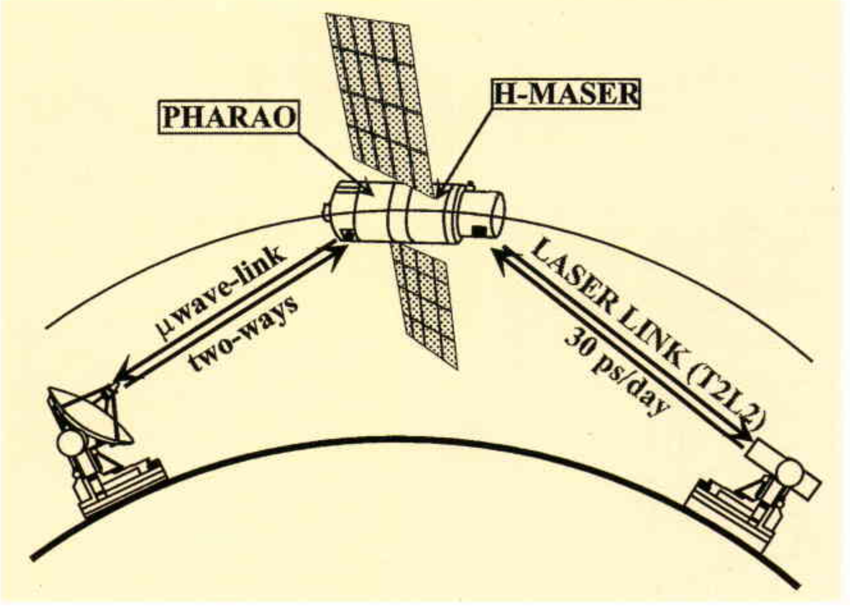


Figure 4. The ACES concept; Pharao is the laser-controlled atomic clock and the hydrogen maser serves as the reference clock

The ACES Principal Investigators (PIs) are Prof. C. Salomon from the Ecole Normale Supérieure, Paris and Prof. A. Clairon of the Laboratoire du Temps et des Fréquences, Paris. A Swiss hydrogen-maser clock provided by Dr. L.G. Bernier, also a PI, from the Observatoire Cantonal de Neuchatel, Switzerland, will serve as a reference clock. The important time transfer by laser link will be realised from the Observatoire de la Côte d'Azur in Grasse, France, with PIs Dr. E. Samain and Dr. P. Fridelance.

2. EUTEF – The European Technology Exposure Facility (Fig. 5)

EUTEF is a multi-user support facility that will be developed under the auspices of ESA's Manned Spaceflight and Microgravity Directorate, located at ESTEC in Noordwijk. It will provide modular accommodation for a variety of technology payloads requiring space exposure. It incorporates a material-properties laboratory allowing periodic onboard measurements of surface degradation, and a comprehensive environment-monitoring package to characterise the ISS space environment, including high-energy cosmic radiation, the natural and ISS-induced plasma environment, atomic-oxygen concentration, etc. An ASI-provided robot arm, to be incorporated with a tele-operated intelligent gripper for payloads, will allow the servicing of payloads, the exchange of exposed material within EUTEF modules, or the pointing of samples to a specific environment.

Several proposed EUTEF experiments — from France, Germany, the United Kingdom, the Netherlands, Italy and Spain — have already been selected. Industrial initiatives to qualify advanced and innovative sensors, components or subsystems have been selected with the highest priority. One example in this respect is the testing of a high-temperature super-conductor for advanced satellite communications.

3. EXPORT – consisting of EXPOSE and SPORT (Fig. 6a,b)

Eight exobiology experiments have been selected for accommodation on an exposure

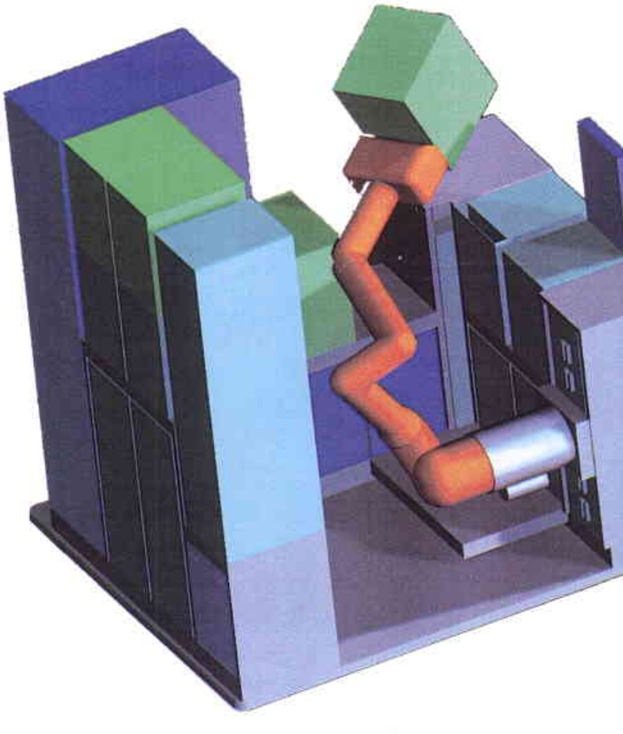


Figure 5. The Technology Exposure Facility (TEF) supports space technology research and development

Table 1. Instruments and experiments selected for EUTEF

Acronym/ Name	Ref. No.	Ctry	Principal Investigator	Description
PLEGPAY	16	I	A. Matucci	Plasma contactor electron gun
FIPEX	47	D	S. Fasoulas	Gas sensor for atomic-oxygen flux
	51	ESA	M. v. Eesbeck	Effect of space exposure of materials on thermo-optical and mechanical properties
	54	F	J.C. Mandeville	Monitoring and detection of micrometeoroids and space debris
	55	F	A. Paillous	Calorimetric/dynamic measurement of thermo-optical property degradation
	56	ESA	M. v. Eesbeck	Effects of contamination/radiation on optical surfaces
	57	UK	A.R. Chambers	Atomic-oxygen experiment
	58	D	B. Schaefer	Manipulator system identification and dynamic model validation
	59	I	P.G. Magnani	Intelligent axis for A & R
	60	I	E. Re	Tactile sensor-based robot control
DEBIE	62	ESA	G. Drolshagen	Active meteoroid/debris impact detector
	64	NL	C. Heemskerk	Robot inspection and measurement of LEO environment on solar cells
	66	NL	W. Jongkind	Teleoperated intelligent gripper for handling tasks
	68	UK	R.A. Rowntree	Tribology laboratory for bearing cage stability/wear and loss of fluid lubricants testing
CREEP	81		E. Daly & A. Zehnder	Columbus Radiation Environment and Effects Package
HTSC	18	D	M. Klanda	High-Temperature-Superconductor Demonstrator
HEPTES	88	D	S. Krause	Heat-Pipe/Thermal-Energy-Storage Receiver Element

unit oriented towards the Sun (Table 2). A range of organic molecules and micro-organisms will be exposed unshielded to solar ultraviolet radiation and the space environment (vacuum, cosmic radiation). This study of photochemical processes will support conclusions as to the origin and evolution of life, and on the survival capability of micro-organisms in space.

SPORT, with Principal Investigator Prof. S. Cortiglioni from the Istituto di Technologie e Studie Della Radiazioni Extraterrestri, CNR, Bologna, Italy, and further Co-Investigators from Italy and Russia, will measure the polarisation of the sky diffuse background radiation in the unexplored wavelength range between 20 and 70 GHz. In this spectral range, the galactic synchrotron radiation is the strongest source of polarised emission; however, the detection of small contributions from the linear polarisation of the cosmic

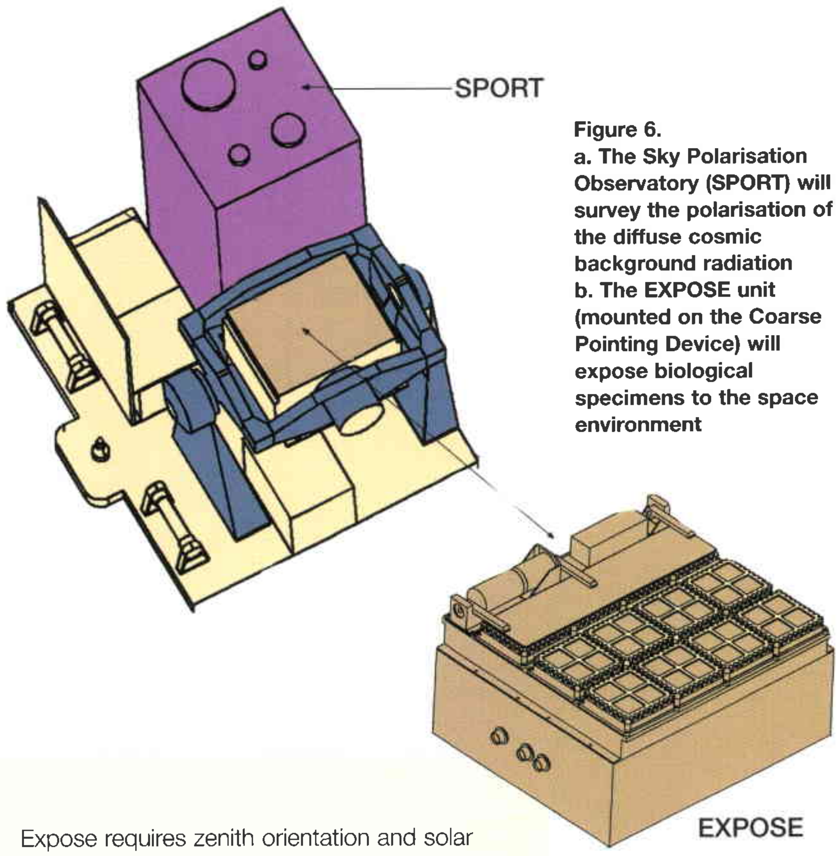


Figure 6.
a. The Sky Polarisation Observatory (SPORT) will survey the polarisation of the diffuse cosmic background radiation
b. The EXPOSE unit (mounted on the Coarse Pointing Device) will expose biological specimens to the space environment

Table 2. EXPOSE characteristics

Pointing requirements	Expose requires zenith orientation and solar pointing
Pointing	Coarse Pointing Device
Sample exposure variable control	Motorised lids/shutters
EXPOSE features:	
Sample containers	12
Selectable open/close lids	8
Permanently open	4
Atmosphere	Vacuum or inert gas
Temperature control	Heating (only)
Sensors	UV, radiation, temperature and pressure
Active signals	Real-time telemetry

microwave background radiation would be of great interest for modern cosmology.

4. FOCUS – Intelligent Fire Detection Infrared Sensor System (Fig. 7)
FOCUS will detect, from the ISS orbit, and analyse high-temperature events such as vegetation fires and volcanic eruptions. Large forest and savannah fires, as well as volcanic activities, have global atmospheric consequences (e.g. greenhouse effect, cloud generation, climate change) and the measurements onboard the Station will contribute to the classification, atmospheric composition determination and geocoding of the data, which will be transmitted to a worldwide scientific, application-oriented and pre-operational user community.

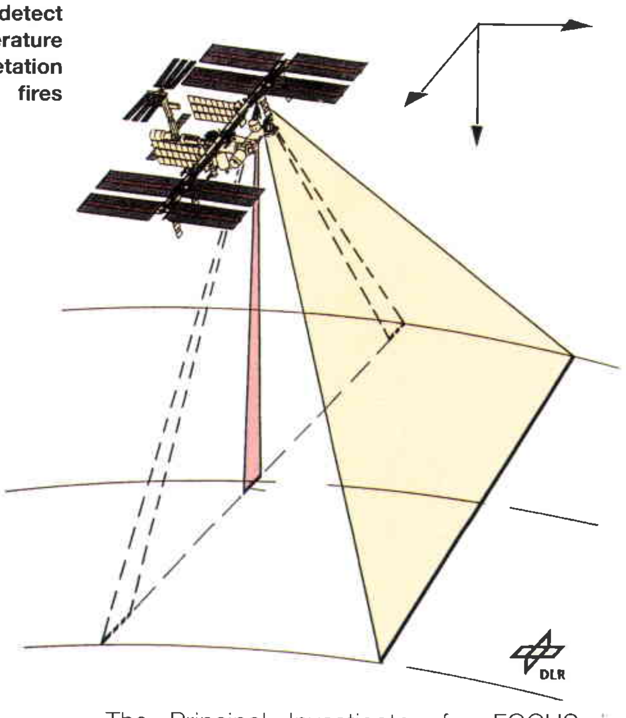


Figure 7. FOCUS will detect terrestrial high-temperature events such as vegetation fires

The Principal Investigator for FOCUS is Prof. H.P. Röser from the DLR Institute für Weltraumsensorik, in Berlin (D). Further important contributions are being made by various institutes in Spain, Italy, Germany, France, Greece and Russia.

5. SOLAR – A Solar Monitoring Observatory (Fig. 8)
The main objective of this experiment is to measure the solar spectral irradiance with unprecedented accuracy. Apart from the scientific contributions for solar and stellar physics, knowledge of the 'solar constant' and its variations is of great importance for atmospheric modelling, atmospheric chemistry and climatology.

The SOLAR observatory consists of three instruments, which complement each other and together cover the wavelength range 17 - 3000 nm in which 99% of solar energy is radiated. They are:

- *SOVIM (Solar Variable & Irradiance Monitor):* The Principal Investigator is Prof. C. Fröhlich from the World Radiation Centre in Davos (CH), who has teamed up with several co-investigators from Belgium, France, ESTEC, Switzerland and the USA. A similar instrument (SOVA) has already been flown on ESA's Eureca retrievable carrier.
- *SOLSPEC (Solar Spectral Irradiance Measurements):* The Principal Investigator is Dr. G. Thuilllier from the Service d'Aeronomie/CNRS, Verrières le Buisson (F). The co-investigators come from Belgium, France, Germany, Switzerland, the United Kingdom, the USA and Switzerland. SOLSPEC has already been flown on various Spacelab missions and on Eureca.
- *SOL-ACES (Solar Auto-Calibrating EUV/UV Spectrophotometers):* The Principal Investigator is Dr. G. Schmidtke from the Fraunhofer Institut für Physikalische Messtechnik in Freiburg (D), with co-investigators from Germany and the USA. SOL-ACES is a new instrument that is still to be developed and covers the solar spectral irradiance range from 17 to 220 nm.

The three instruments are mounted on a Coarse Pointing Device, which provides Sun-pointing for about 13 minutes per orbit.

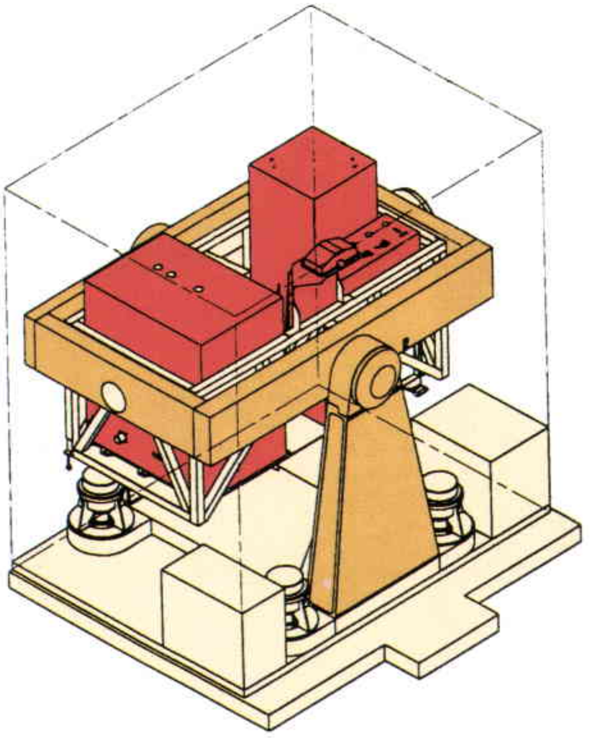


Figure 8. The Solar Monitoring Observatory (SOLAR) will measure the Sun's total and spectral radiance

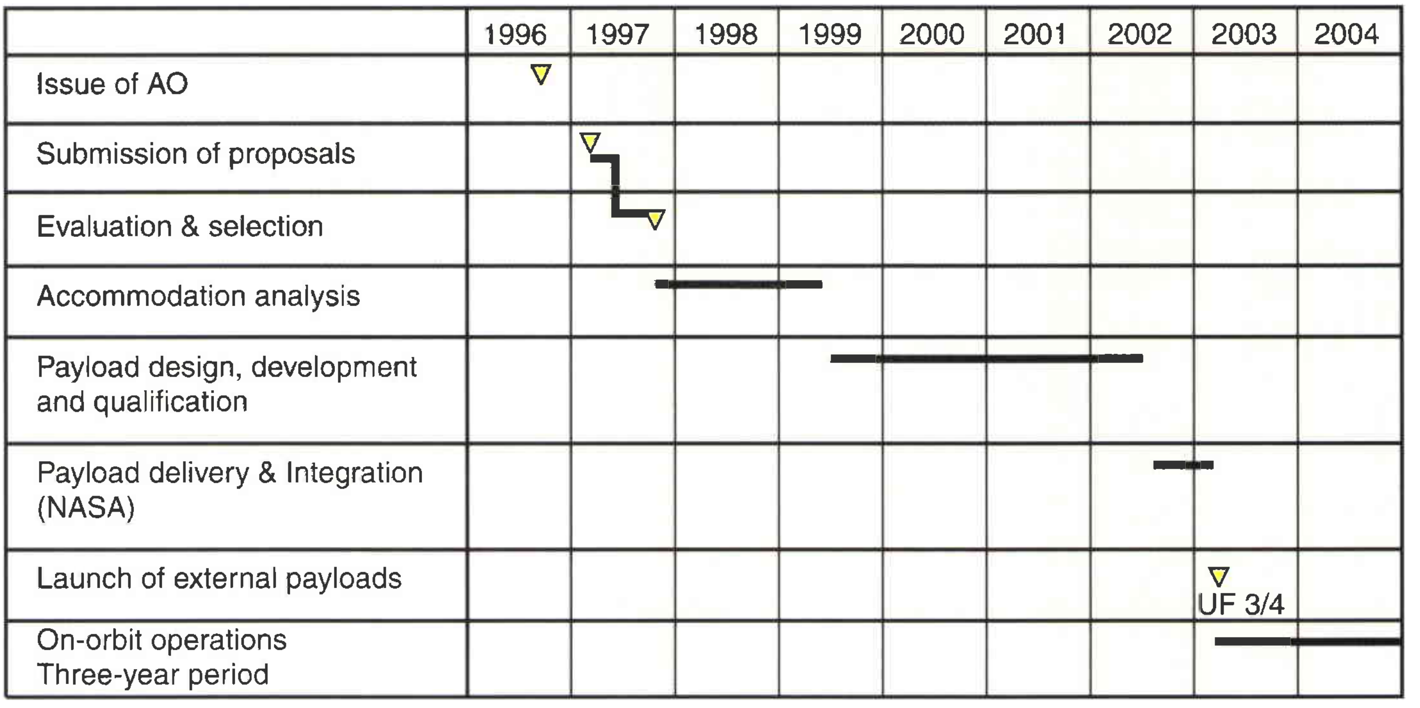


Figure 9. The overall schedule for ESA's Express Pallet Project

Overall schedule for ESA's Express Pallet project
As can be seen in Figure 9, approximately one year elapsed between the issuing of the Announcement of Opportunity and the selection of a feasible payload complement. Last year (1998) was used mainly for accommodation analyses for the five different adapters. The main development effort (Phase-C/D) is due to start in May 1999, in order to meet the projected Shuttle launch dates for UF3/4 at the end of 2002.

ESA's use of the Russian Segment
The Russian Segment of ISS is an attractive place to fly external payloads, and two European payloads are already selected, the 'Global Transmission Services System' (Fig. 10) and 'Matroshka' (Fig. 11a, b).

The Global Transmission Services (GTS) System
As a continuation of the recent successful cooperation between ESA and Russia on the Mir station, both sides have agreed to

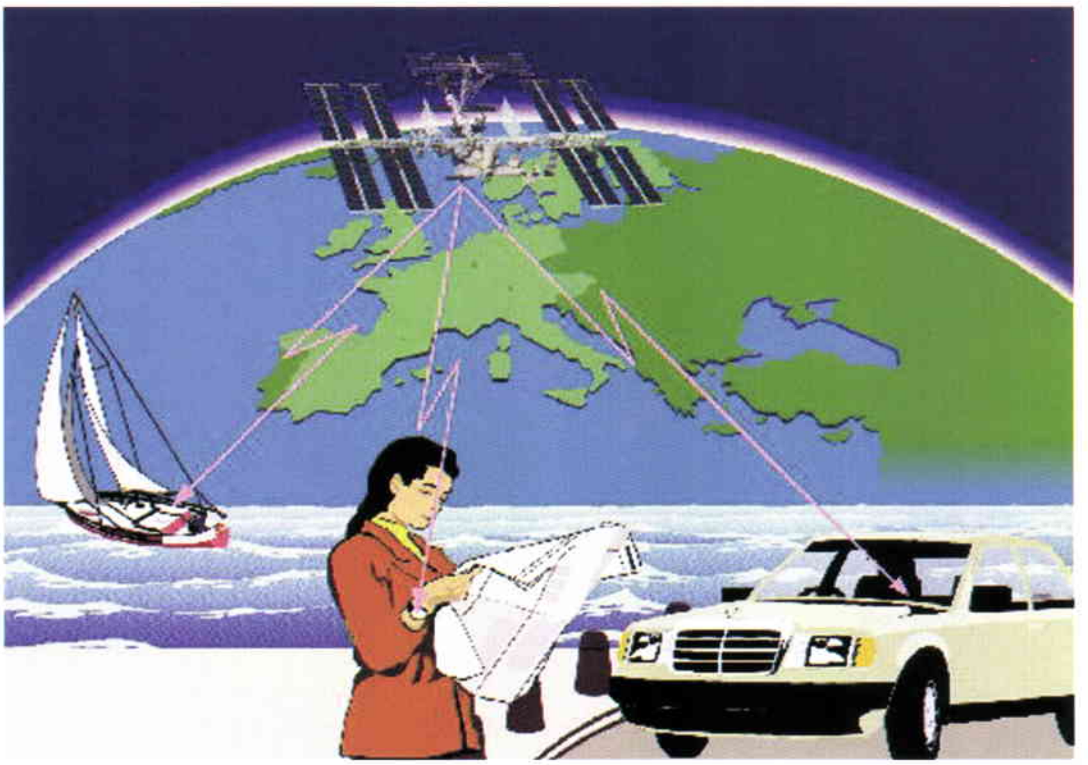


Figure 10. The Global Transmission Services (GTS) system, which will broadcast data and high-accuracy time signals

implement GTS as a Euromir-E replacement activity. GTS is a relatively small payload that will transmit highly accurate time and coded data signals for dedicated receivers on the ground.

The GTS experiment uses a transmitter accommodated onboard the ISS for signal distribution via an externally mounted antenna (with a transmission cone half-angle of approx. 70 deg) on the Russian Service Module. The signals transmitted – at two dedicated frequencies in the 400 MHz and 1.4GHz ranges – can be received for 5 -12 min several times per day by ground receivers with sufficient sensitivity.

The same services – specifically the highly accurate time signal – will be available through dedicated connections to users accommodated on-board the Russian Segment. Applications foreseen include:
- accurate time receipt and automated local time conversion for mobile users on the ground (e.g. wrist watches)
- car theft-protection (electronic car keys)
- coding and re-coding of electronic cards (chip cards, smart cards, credit cards).

Figure 11a. Matroshka will be mounted on the outside of the Russian Service Module

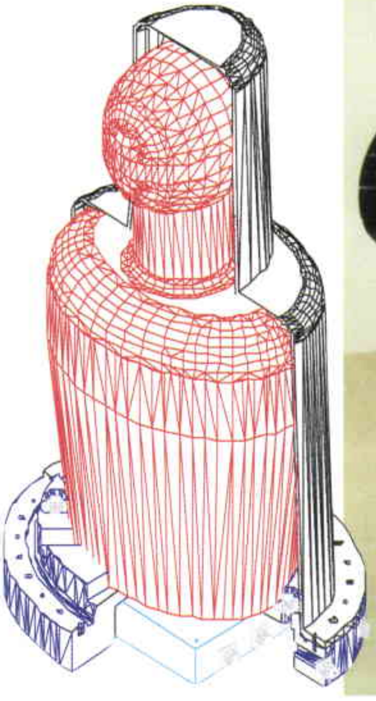


Figure 11b. Mathematical model of the Matroshka human torso/head dummy

The GTS experiment, which will begin operating approximately six months after launch of the Russian Service Module, will last at least two years.

The Matroshka payload

The Matroshka experiment (Fig. 11) aims to measure the radiation that an astronaut faces during Extra Vehicular Activity (EVA). Knowledge of the radiation doses to which sensitive body organs are exposed during long EVAs is an important prerequisite for radiation risk assessment.

The Matroshka payload consists of a human torso/head dummy, composed of various tissue substitutes simulating the human body in terms of size, shape, orientation, mass density and nuclear interactions. At the sites of the body organs of interest, spaces are provided at the surface and at different depths within the phantom to accommodate dosimeter packages to measure any ionising radiation received.

The key milestones for the Matroshka project are currently:
- launch with Progress 268 in mid-2002
- external operation on the Russian Service Module from mid-2002 (installation during EVA No. 37) to mid-2003 (retrieval during EVA No. 47)
- sample return with the eighth Soyuz flight to the ISS.

The data gathered will be used to reduce uncertainties in risk estimates for radiation-induced cancer, and for the refinement of the shielding needs for transport facilities for future long-duration missions. They also have important implications for ISS crew health and for mission planning, and thereby contribute to the ISS environmental monitoring effort.

The AMS Experiment

A further important external payload, selected by NASA, but with an important European scientific contribution, is the Alpha Magnetic Spectrometer (AMS) experiment (Fig. 12). This payload is designed for the study of antimatter and missing matter. To be located on an ISS Express Pallet in a zenith-pointing position, the AMS is an international collaboration between China, Finland, Germany, Italy, Russia, Switzerland, Taiwan and the United States. The team is led by Nobel Prize winner Prof. S.C. Ting.

The key scientific objective is to search for antimatter, basically anti-helium and anti-carbon, with a detector sensitivity 10^4 to 10^5 times better than current limits. The Big Bang

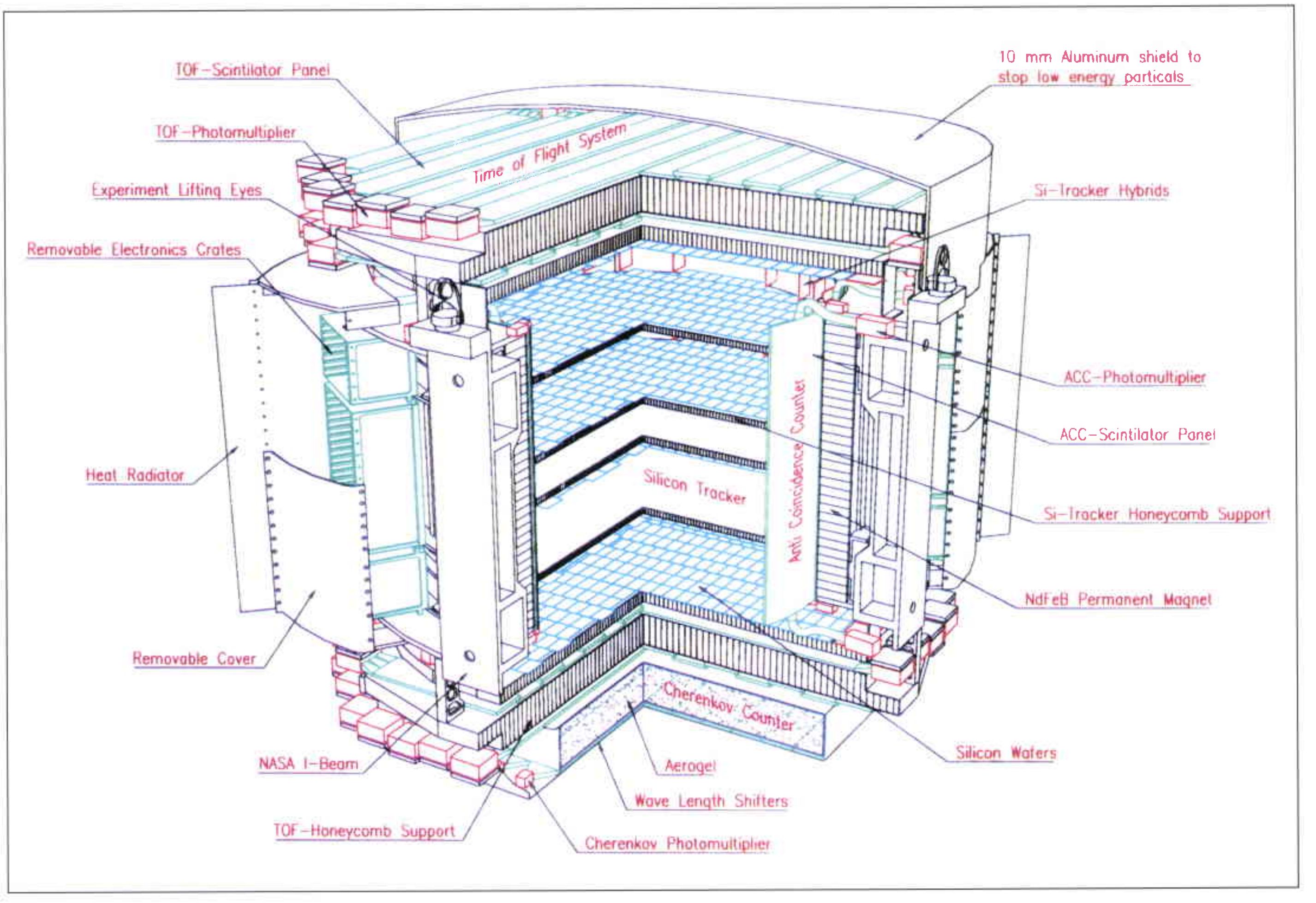
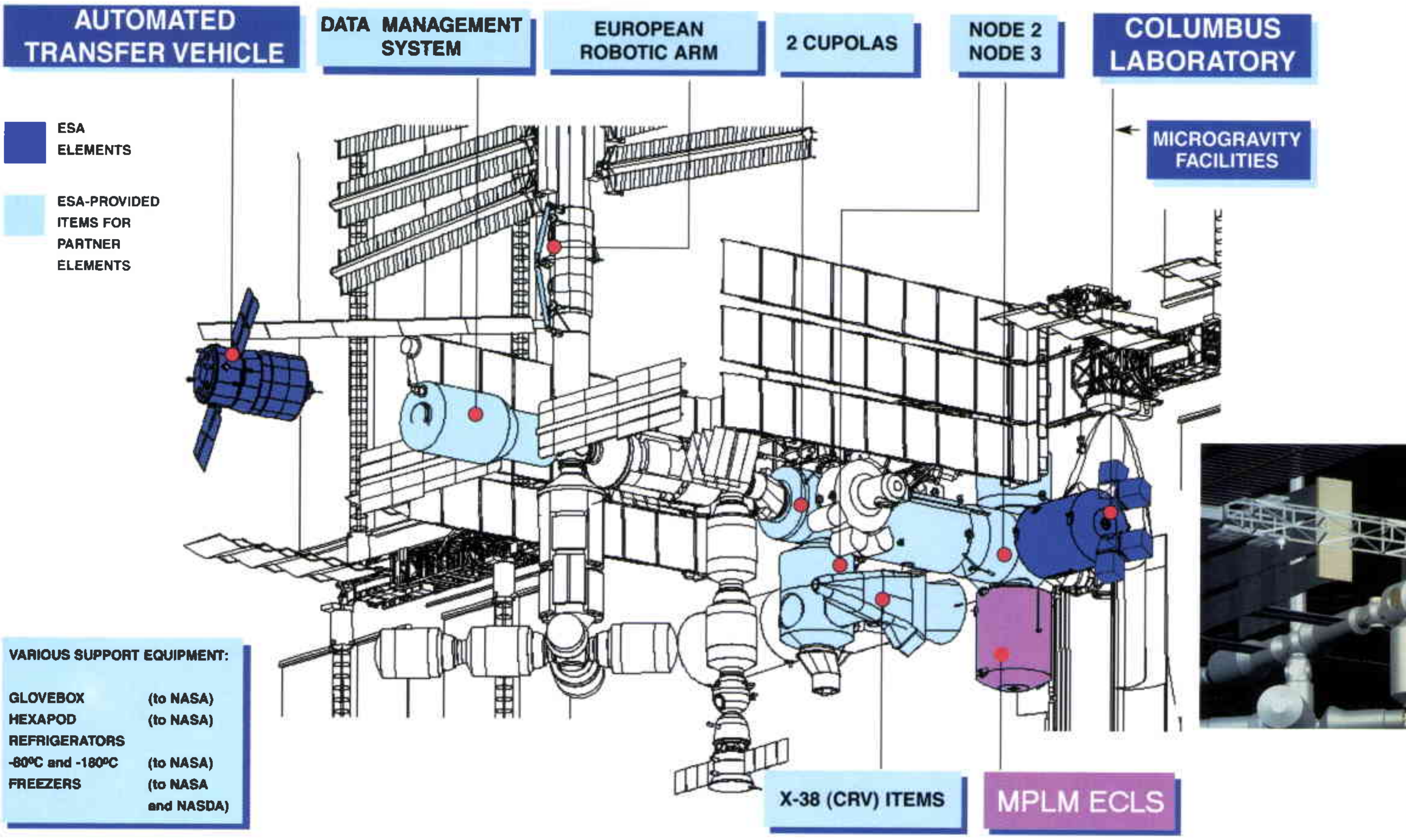


Figure 12. The detector arrangement for the Alpha Magnetic Spectometer (AMS), designed to measure anti-matter particles

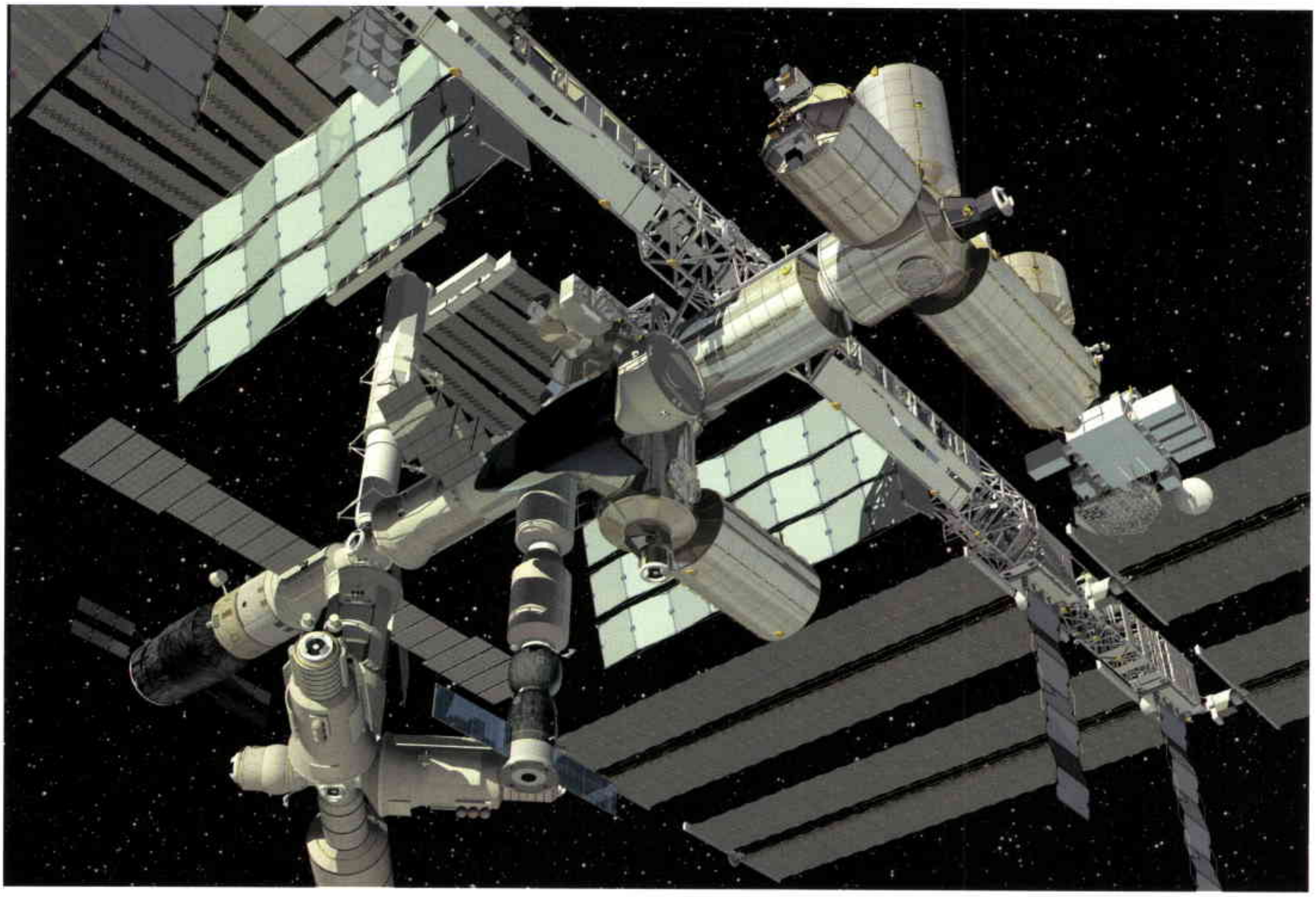
theory of the origin of the Universe requires matter and antimatter to be equally abundant at the very hot beginning. The AMS payload is expected to detect a few anti-carbon nuclei per week if the present theory of the Big Bang is correct.

Conclusion

ESA is committed to fly the payloads that have been selected on the external sites of the ISS to which it has negotiated access. Detailed accommodation analyses have been carried out and the implementation phase will start this year. A wide range of first-class science and earth-observation studies, industrial space-technology tests and the provision of new services can be achieved using the ISS external sites. As the quality of the more than one hundred responses received to the Announcement of Opportunity has amply demonstrated, the European research community and European aerospace industries are more than ready to exploit these new opportunities that the International Space Station will provide.



ESA's contributions to the ISS. MPLM is highlighted in pink; the other ESA-provided items for Partner elements are in light blue.
Right: MPLM remains berthed only while the Space Shuttle is docked to the Space Station – the spaceplane is omitted here for clarity.
(ESA/Alenia Aerospazio)



Environmental Control & Life Support for the Multi-Purpose Logistics Module

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ESA has provided the Environmental Control and Life Support (ECLS) Subsystem for Italy's Multi-Purpose Logistics Module (MPLM) contribution to the International Space Station (ISS). In exchange, the Italian Space Agency (ASI) is providing a derivative of the MPLM primary structure for ESA's Columbus ISS laboratory module. Considerable savings have been achieved by the development and qualification of common hardware – more than 25 million Euros for each project. MPLM's ECLS Subsystem is described here, with emphasis on its similarity to the version used by Columbus.

Introduction

Assembly of the 470-tonne ISS began at the end of 1998 with the mating of the first two modules in orbit. Although assembly will not be completed until 2004, productive work aboard this outpost will begin in early 2000. This will require a regular flow of equipment, materials and consumables delivered by a range of vehicles. Other items, such as the results of experiments, will need to be returned to Earth.

Europe is providing two crucial elements of this ferry network. ESA's Automated Transfer Vehicle (ATV) and its mixed cargo will be launched on Europe's large Ariane-5 rocket. Italy is separately contributing the Multi-Purpose Logistics Module (MPLM) to be carried in the Space Shuttle's payload bay.

In late 1995, ESA's Council authorised the 'Arrangement Between the European Space Agency and the Italian Space Agency on the Exploitation of Common Features of the Pressurised Modules Developed by the Parties'. The goal was to avoid the duplication of development efforts by sharing common features on ESA's Columbus laboratory and ASI's MPLM. This led to ASI providing ESA and the Columbus prime contractor, DASA, with a derivative of the MPLM primary structure for Columbus. In exchange, ESA provided ASI and the MPLM prime contractor, Alenia Aerospazio, with the ECLS Subsystem for the three MPLM Flight Models. The estimated saving to each programme is more than 25 million Euros.

The ECLS Subsystem was designed to satisfy both MPLM and Columbus. The contract was awarded by ESA in early 1996 to Dornier Satellitensysteme of DASA, and the deliveries of all MPLM ECLS engineering models, associated Ground Support Equipment and the three Flight Model sets, with minor exceptions, were completed in 1998. The Columbus ECLS deliveries are planned for 1999.

MPLM ECLS Subsystem

MPLM is a unique part of the overall ISS logistics scenario: it is the only logistics module capable of transferring complete International Standard Payload Racks (ISPRs) to and from the ISS. The module will be berthed at Node-2 (Node-1 on its debut mission in mid-2000) using the Station or Shuttle robot arm.

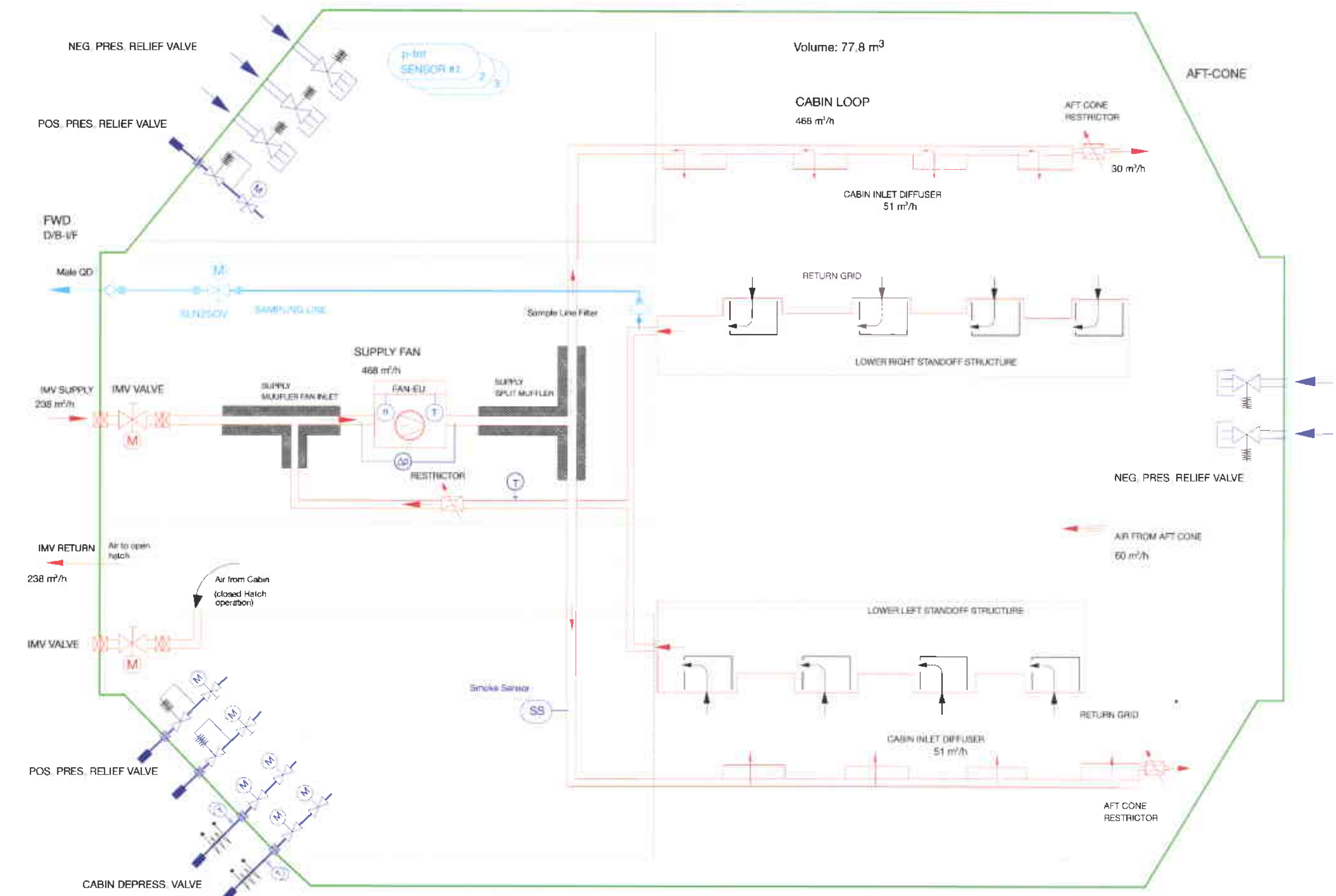
Equipment will be transferred by Station and/or Shuttle crew members, and this is where ESA's contribution to MPLM is critically important. The Agency-supplied ECLS Subsystem will maintain comfortable conditions for three astronauts to work in the module simultaneously for the projected MPLM mission length of two weeks. Drawing on Station resources, the ECLS controls the module's internal environment to provide a safe, sea-level 'shirtsleeve' environment.

In particular, it must provide: temperature and humidity control; atmosphere pressure control; fire detection and suppression; contamination monitoring and control.

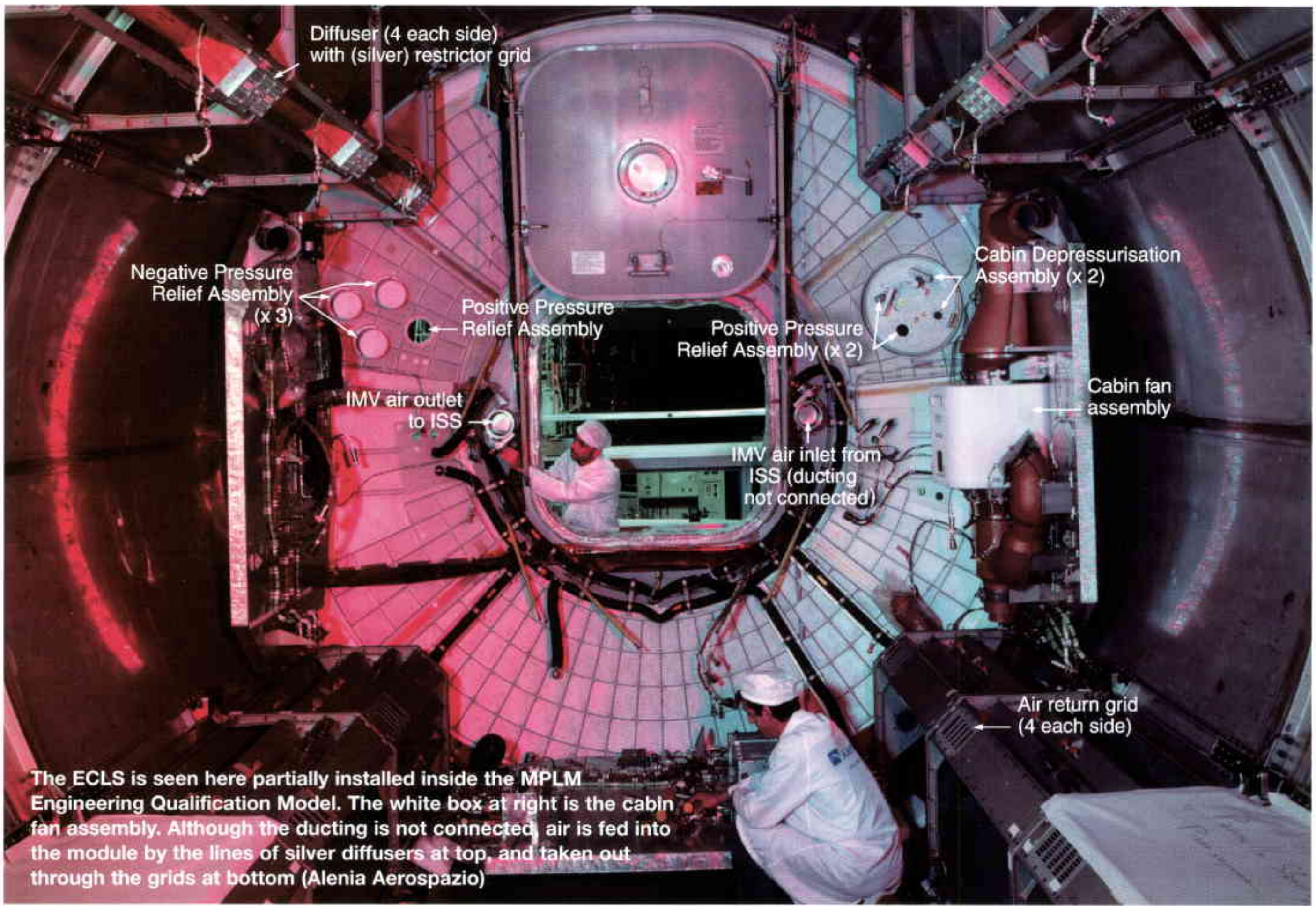
Temperature and Humidity Control

The ECLS Subsystem collects fresh air from

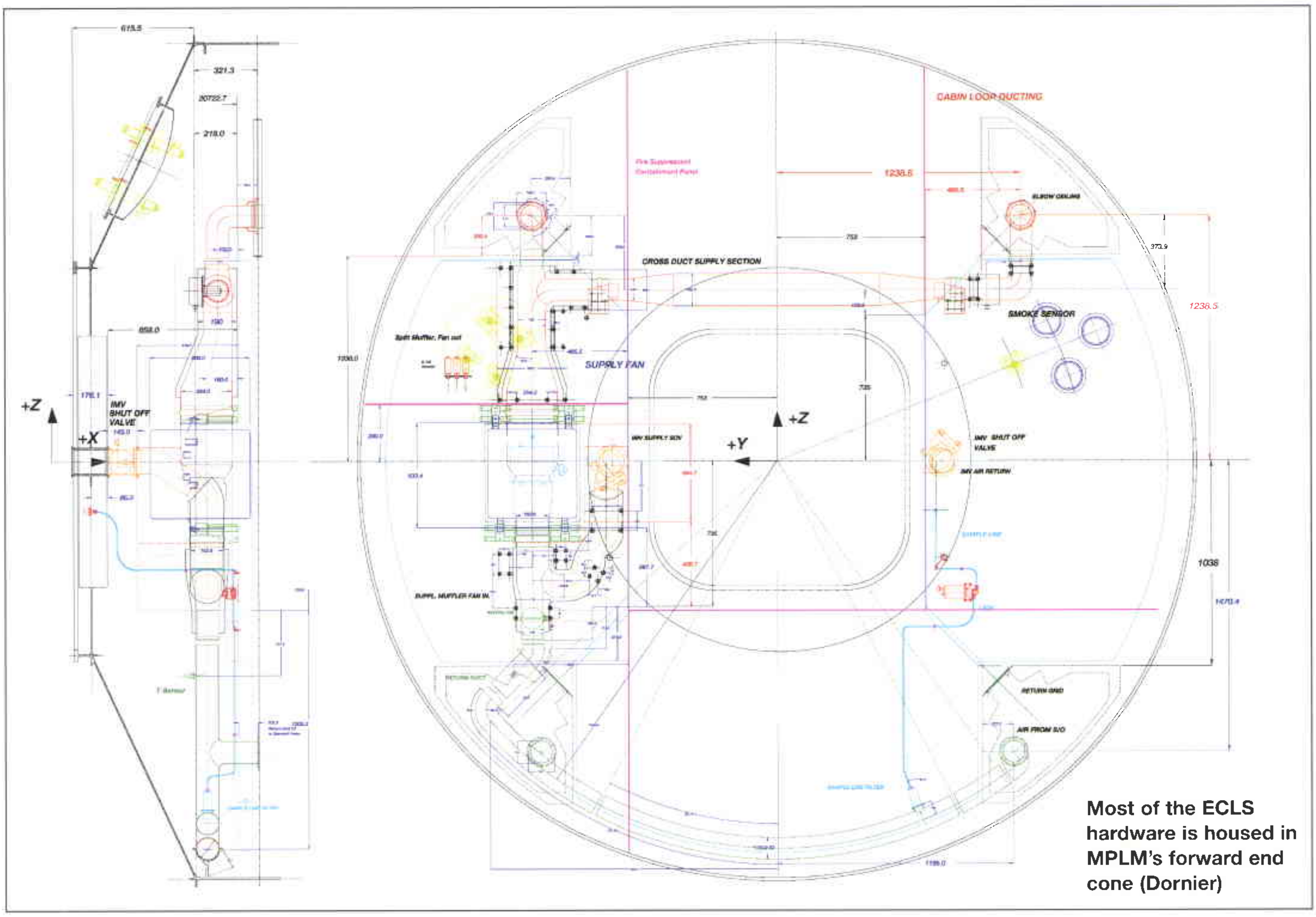
This article is abbreviated from the ESA brochure BR-143 'Supporting Life: Environmental Control and Life Support for the Multi-Purpose Logistics Module of the International Space Station'. An electronic version will be posted at http://esapub.esrin.esa.it/



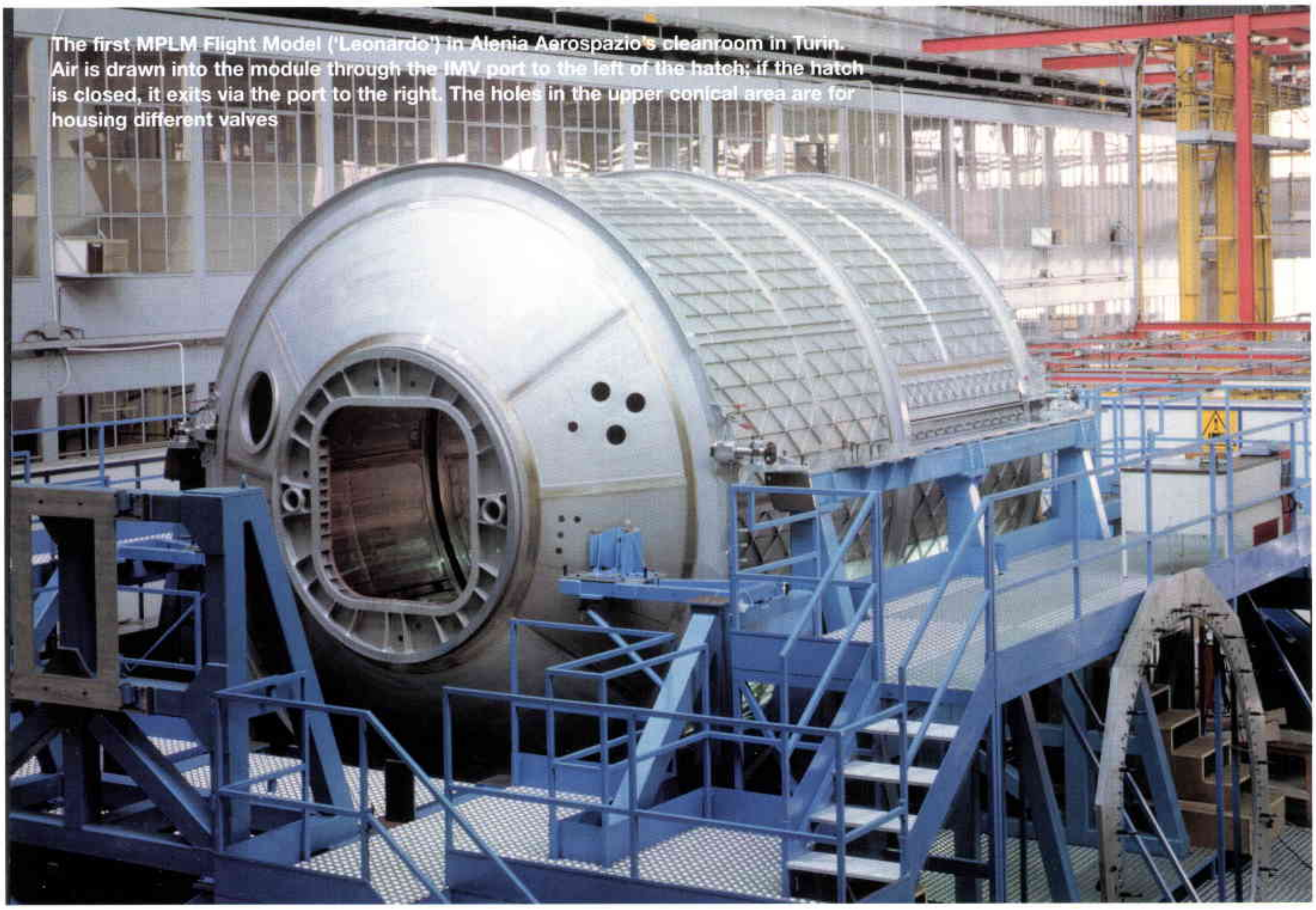
The layout of MPLM's environmental control and life support subsystem (Dornier)



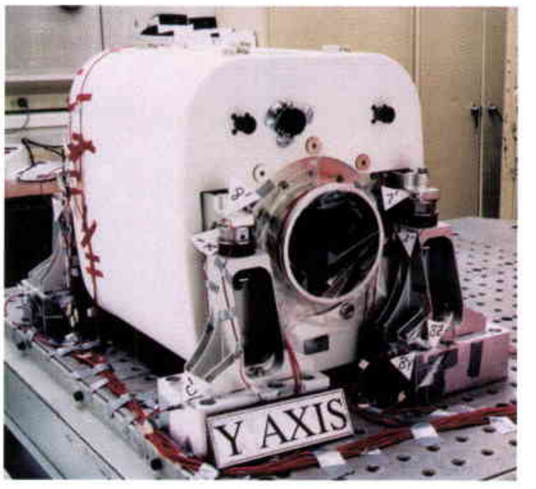
The ECLS is seen here partially installed inside the MPLM Engineering Qualification Model. The white box at right is the cabin fan assembly. Although the ducting is not connected, air is fed into the module by the lines of silver diffusers at top, and taken out through the grids at bottom (Alenia Aerospazio)



Most of the ECLS hardware is housed in MPLM's forward end cone (Dornier)



The first MPLM Flight Model ('Leonardo') in Alenia Aerospazio's cleanroom in Turin. Air is drawn into the module through the IMV port to the left of the hatch; if the hatch is closed, it exits via the port to the right. The holes in the upper conical area are for housing different valves



The cabin fan assembly undergoing a random vibration test during its qualification phase

the Station/MPLM Inter Module Ventilation (IMV) Interface, distributes it throughout the cabin and then returns it to the ISS for revitalisation. The air enters through a port to the right of the hatch in the forward end cone, and normally exits via the open hatch.

Ventilation is provided throughout the habitable volume to prevent dangerous pockets of stale air, and the temperature is monitored. The humidity and temperature are controlled from the Station Node.

The required airflow of 468 m^3/h is provided by a single fan assembly in the forward end cone. The air is distributed by ducting and diffusers in two branches along the upper cabin – four diffusers on each side. Each diffuser emits about 51 m^3/h to produce the required cabin air movement. A further 30 m^3/h is routed from each branch along the roof into the aft cone. Restrictor grids in the diffusers and restrictors in the outlets to the aft cone adjust the flows.

The air is sucked from the module via return grids in the lower stand-offs. The two branches are mixed in a junction duct and led back to the fan inlet, where the Station supply is added. A restrictor in the return duct ensures the pressure is lower than at the IMV supply interface, so air continues to be sucked from the Station.

Normally, air flows back to the Station through the open hatch. If the hatch is closed, the air travels through the separate dedicated IMV return duct. To isolate the module from the Station, a motorised valve in each of the IMV supply and return ducts closes off the airflow.

MPLM's cabin air is also monitored by a temperature sensor.

Cabin Ventilation Test

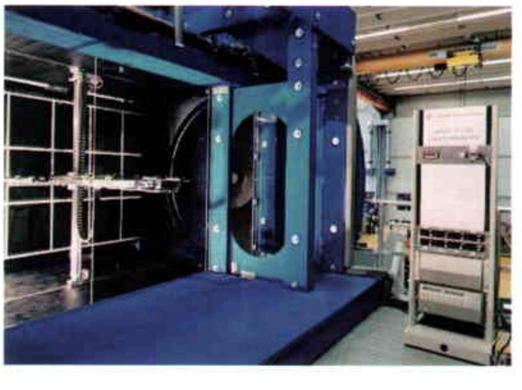
A cabin ventilation qualification test was performed using a full-scale cabin simulator/ mock-up. The two photographs show the test article with equipment installed for air speed and temperature measurements. The test verified that the cabin comfort requirements have been achieved: air speed is 0.076-0.203 m/s within at least 67% of the habitable volume, except near the diffuser outlets. The optimum airflow for injection through each of the eight cabin air inlet diffusers was found to be 51 m^3/h.

Atmosphere Pressure Control

The total atmospheric pressure is monitored, and MPLM's data management system transmits an emergency signal to the ISS if MPLM's air pressure strays beyond pre-set limits. Pressure valves protect the module's structural integrity and support fire suppression.

Positive Pressure Relief Assembly (PPRA)

MPLM's structure is designed to handle a pressure differential of 1.034 Earth-atmospheres (1048 hPa). To prevent it from reaching this level, the valve in the PPRA opens and vents air from the cabin when the pressure differential rises to 1.014 atm (1027 hPa). This 'crack pressure' can be reached when the MPLM is isolated, for example, inside the Shuttle during launch, when the internal temperature might increase because equipment is powered up without active cooling.



A cabin ventilation qualification test on a full-scale cabin mockup at Dornier showed that the required air speed of 0.076-0.203 m/s in at least 67% of the habitable volume had been achieved

The assembly provides 'two-failure tolerance' by using three valves in parallel, any one of which can do the job. Two are housed in a feed-through plate in the upper area of the forward cone; the third is mounted directly in the cone's lower area.

Each assembly comprises a power-independent pneumatic pressure relief valve and a butterfly shut-off valve, installed in series. The shut-off valve can be closed electrically by a brush-type 28 V DC motor or by manual override; this isolates the assembly in case the pneumatic relief valve or motor fail.

Ground controllers or Space Station crews can use the electric motors to deactivate the system when it is not required. For example, when MPLM is docked with its hatch open and the Station is providing overall pressure control.

Negative Pressure Relief Assembly (NPRA)
MPLM's internal pressure might fall below external pressure during ground operations, launch abort or nominal reentry. This negative differential is prevented from reaching the structure's design level of 0.0336 atm (34 hPa) by the NPRA.

This NPRA consists of a set of pneumatic, power-independent valves. As this capability is needed mainly during launch and reentry – when MPLM is unmanned – manual override is unnecessary. Three of these valves are mounted directly in the forward cone's lower area; two are positioned in the aft cone bulkhead.

The redundant cover on each is one-failure tolerant against leakage to space during nominal on-orbit mission phases, when the pneumatic portion of the valve is not needed. This phase can last up to 15 years for the Columbus module.

Cabin Depressurisation Assembly (CDA)
The CDA can vent the cabin air to space in less than 10 minutes as an integral element of the MPLM/ISS/Columbus fire suppression scheme. It consists of two separate units on the same feed-through plate as the two PPRAs in MPLM's forward cone upper area. Each is equipped with two butterfly shut-off valves, arranged in series so that the failure of one valve does not cause unexpected depressurisation or prevent closure after intentional venting. A 28 V DC brush motor operates each valve on command from the ISS data management system via MPLM's data management system. Manual override is unnecessary because they would be activated only when the module is unmanned.

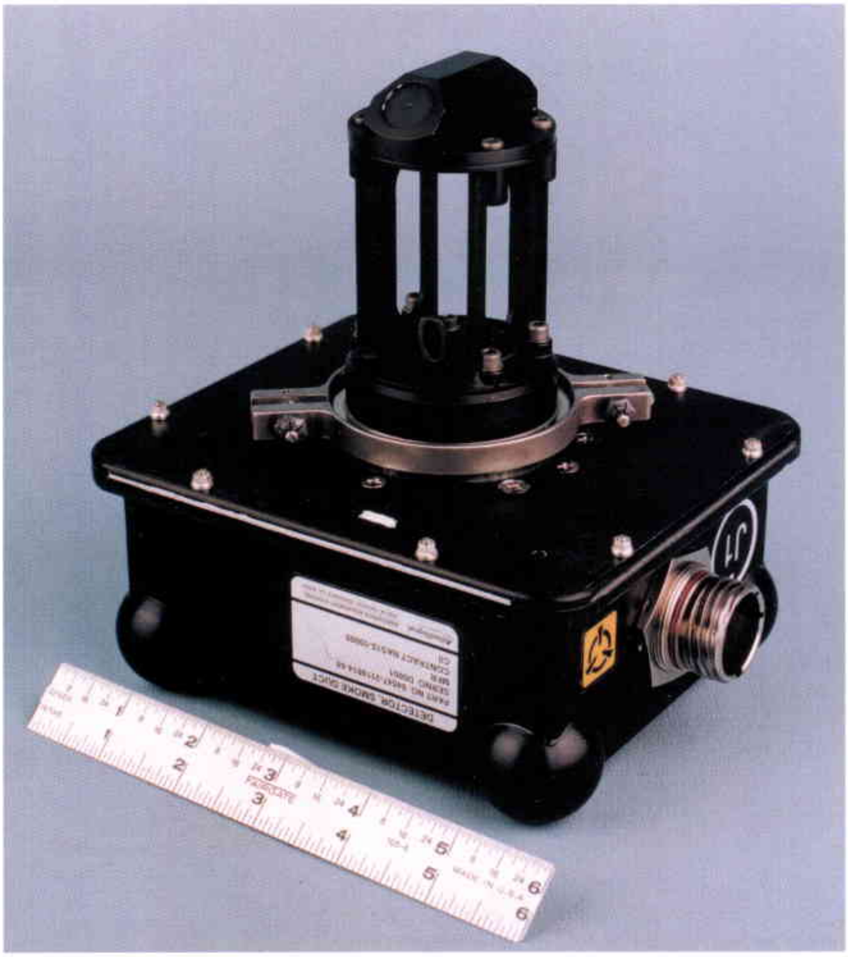
The Positive Pressure Relief Assembly bleeds off air if the pressure climbs too high. The unit mounted inside MPLM is at left. The valve can be closed manually by the handle at left or by the remotely-controlled electric motor at right. The unit mounted outside MPLM is at right

Total Pressure Monitor
MPLM is equipped with three redundant pressure sensors for monitoring the module's internal air pressure. They are designed for an absolute pressure measurement range of 0.0010–1.0856 atm (1–1100 hPa) with an accuracy of about 0.0158 atm (16 hPa).

The sensor uses a diaphragm that deflects in proportion to the applied pressure. This deflection is coupled to a resistive strain gauge bridge circuit, which sends a signal to the MPLM data management system for translation into a pressure reading.

Fire Detection and Suppression
The prospect of fire breaking out in the module is reduced by careful selection of non-flammable materials and by controlling potential ignition sources. The next level of protection and fire localisation is achieved by normal housekeeping monitoring of powered equipment to detect anomalies in temperatures, voltages and currents, for example, that could trigger a fire. If an anomaly is found, the affected equipment is switched off and redundant equipment is activated. Also, airflow in areas housing powered equipment would be halted by turning off the fan, specifically to avoid feeding any fire with oxygen. The fan can be switched on/off by the crew from any other ISS module or by ground controllers.

There is a portable extinguisher for the crew to fight fires in the forward end cone where most of MPLM's powered equipment is located. That area is divided into three compartments, so that



A single Duct Smoke Detector (DSD) on a cabin air duct alerts the MPLM data management system if it detects smoke

the carbon dioxide from a single extinguisher would reduce the oxygen concentration in any one below the minimum (10.5% by volume) necessary for sustaining a fire.

As a last resort, the hatch would be closed to isolate the module before the cabin air is dumped via the CDA.

Fire Suppression Tests

Full-scale mock-ups of the three forward cone compartments, where most MPLM powered equipment is located, were built to verify that a fire can be suppressed with a Station portable fire extinguisher. During early fire suppression development tests, the importance of leakage between the module shell and compartment close-out panels was identified. Great care was therefore taken in simulating those leakage areas.

The qualification tests were performed with the mock-ups in two orientations in order to eliminate the influence of gravity. It was shown that the fire could be suppressed in two side compartments, but leakage was too high in the third compartment, in the lower part of the forward cone, to achieve the low oxygen level. The sealing was improved and the qualification test for that compartment was successfully repeated.

Cabin Air Contamination Monitoring and Control

The cabin air's major constituents and trace gas contamination are measured by the Station's ECLS equipment. Samples of the cabin return air are periodically drawn into the Station via a dedicated tube.

The sampling line consists of a 1/4-inch (0.635 mm) diameter tube connected at one end to the cabin air return duct upstream of the cabin fan, and at the other end to the forward cone bulkhead. At the cabin end, a particle filter (mesh size 2 μm) screens out debris. A Line Shut-Off Valve (LSOV) isolates the line from the Station. It is normally operated electrically by a 28 V brush-type motor, but it is equipped with a manual override in case of motor failure.

Sharing with Columbus

ESA developed the common ECLS under its MPLM activities and procured the equipment needed for Columbus at recurring cost. The design drivers of both projects were combined: each MPLM is designed for 25 flights, and replaceable items on Columbus are designed for 10 years on-orbit.

Existing Space Station hardware – such as the Duct Smoke Detector – was incorporated where feasible. In other cases (CDA, NPRA, PPRA), designs used in NASA's Space Shuttle Orbiter and ESA's Spacelab were substantially improved to meet the more stringent requirements of the MPLM and Columbus programmes.

The Table summarises the hardware used in MPLM's ECLS Subsystem and its commonality with Columbus and the ISS. It is clear that common hardware has been used in most items.

Identical components used in both programmes are the cabin air diffuser, cabin air temperature sensor, IMV Shut-Off Valve, Line Shut-Off Valve, NPRA, CDA and PPRA.

The Duct Smoke Detector was developed for the ISS and is adopted by MPLM and Columbus not only to re-use existing hardware, but also to create similar alarm threshold conditions over the whole station complex. For MPLM, the detector was subjected to further qualification to cover the additional demands imposed by repeated launches on the 25 missions. All the others on the Station, including Columbus, are launched only once and checked periodically on-orbit using their inbuilt sensors. They can be replaced by the crew if necessary.

MPLM ECLS Hardware Commonality with Columbus and International Space Station					
Hardware Item	**MPLM/ Columbus Common**	**MPLM/ ISS Common**	**MPLM/ Columbus Similar**	**MPLM Dedicated**	**Remarks**
Cabin Fan Assembly/ Fan Damping System		X		X	FDS not needed on Columbus
Cabin Loop Ducting			X		
Cabin Air Diffuser	X				
Cabin Temperature Sensor	X				
IMV Shut-off Valve	X				
Negative Pressure Relief Valve	X				
Positive Pressure Relief Valve	X				
Cabin Depressurisation Assembly	X				
Total Pressure Sensor				X	Different Columbus and MPLM electrical interfaces
Sampling line			X		Line routing adapted to module; common sample filter
Line Shut-off Valve	X				
Duct Smoke Detector	X	X			ISS common item used on MPLM and Columbus

Identical cabin loop ducting is not feasible because the modules have different internal layouts. However, the material and construction of the single ducts and their incorporated features (such as mufflers) are similar and the experience from the MPLM development efforts is directly applicable to Columbus. Common parts such as the flexible bellows for duct connection are also incorporated.

A common fan was not adopted because of different schedule, mass, volume, noise and operational requirements. An existing ISS fan was used for MPLM, already qualified within the Station programme, but subjected to further testing to cover the 25 MPLM missions. In addition, since the MPLM fan launch vibration loads are higher than for the ISS, a fan damping system was developed. For Columbus, a new European fan is being developed.

Conclusion

The ECLS Subsystem for MPLM has been successfully developed, and the hardware for three module flight units delivered to ASI. This effort forms part of the cooperation between ESA and ASI aimed at improving the overall efficiency of industrial development for Europe's contribution to the International Space Station.

In exchange for the development of MPLM's ECLS Subsystem, the Columbus flight unit primary structure – directly derived from MPLM's design – is currently being manufactured under ASI's responsibility. As the requirements for the two modules are so similar, the Columbus structure needs no dedicated qualification testing.

Considerable savings for both projects have been achieved by single development and qualification of common hardware – a significant contribution to improving the affordability of manned space programmes. esa

The Envisat Radar Altimeter System (RA-2)

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Following on from the great success of its ERS-1 and -2 satellites, which have contributed to a much better understanding of the role that oceans and ice play in determining global climate, ESA is currently preparing Envisat, Europe's largest remote-sensing satellite to date, for launch. Its payload includes an advanced instrument complement designed to guarantee the continuity of observations started by its predecessors and to meet the global Earth-monitoring requirement on a longer time scale. In particular, the altimetry from Envisat will benefit from the improved performance of a dual-frequency Radar Altimeter (RA-2) working in synergy with the Microwave Radiometer (MWR) and Doppler Orbitography and Radio-positioning Integrated by Satellite (DORIS) instruments. The ground processing products that will be available in near-real-time will be as comprehensive as the off-line products, differing only in terms of the availability and quality of the auxiliary data.

The mission

RA-2 has an essential role to play in the Envisat mission, as indicated in Table 1. Operating over oceans, its data can be used to monitor sea-surface topography, thereby supporting research into ocean circulation and sea-level change, as well as providing observations of the sea floor structure or shape, and marine geoid characteristics. It will also be possible to determine near-sea-surface wind speeds and significant wave heights, data that are important for both weather and sea-state forecasting. RA-2 will also be able to map and monitor sea ice and polar ice sheets, allowing the energy/mass balances of the world's major ice sheets, including the Antarctic, to be better determined.

In addition to operating over oceans and ice, RA-2 can also be used over land surfaces. From its observations of range and reflectivity, it will be possible to determine land surface elevations, and surface characteristics.

Because Envisat will follow the same ground track as ERS-1 and ERS-2, a continuous time series of local sea-height variations can be constructed, which will eventually span more than 15 years. This will allow the examination on inter-annual to decadal time scales of changes in: global and regional sea level; dynamic ocean circulation patterns; significant wave height climatology; and ice-sheet elevation.

We will focus here on a few of the main RA-2 mission objectives in the context of oceans, ice sheets and sea ice. A more comprehensive discussion of the Envisat RA-2/MWR instrument concept in the context of science and applications is provided in ESA SP-1224 (available from ESA Publications Division).

Table 1. Contributions of RA-2 and MWR-2 to the Envisat mission objectives

DISCIPLINES	GEOPHYS. QUANTITY	CONTRIBUTION FROM RA-2/MWR
Atmosphere	Water vapour content	MWR
	Precipitation	RA-2/MWR (research)
	Ionosphere	RA-2
Land	Surface Elevation	RA-2
Ocean	Sea Level Topography	RA-2
	Mean Sea Level	RA-2
	Waves	RA-2
	Wind Speed	RA-2
Sea Ice/Ice Sheet	Topography/Elevation	RA-2/MWR (research)
Gravity	Marine Gravity Anomalies	RA-2

Oceans

The Envisat ground segment has been designed to accommodate real-time operational ocean monitoring. There are a variety of operational applications that can utilise measurements from the RA-2 system. Significant wave height and wind speed, for example, are routinely used by Numerical Weather Prediction centres. These data are made available within a few hours of satellite acquisition and are mostly independent of the quality of the satellite orbit determination.

In the coming years, mesoscale and large-scale monitoring and prediction will assimilate near-real-time altimetry into high-resolution ocean models. For instance, the goal of the Mercator project is to implement (within about 3 years) a system that simulates the North

Atlantic Ocean circulation with a primitive-equation high-resolution (~10 km) model that takes in altimeter, sea-surface temperature (SST) and in-situ data. The system will be used both for scientific research and operational oceanography. It will also contribute to the development of a climatic prediction system.

Mercator is a contribution to the Global Ocean Data Assimilation Experiment (GODAE), for which a pilot demonstration phase is planned in 2003 - 2005. GODAE is intended to demonstrate the practicality and feasibility of routine real-time global ocean-data assimilation and prediction. It will emphasise integration of the remote sensing (in particular altimetry) and in-situ data streams, and the use of models and data assimilation to extract maximum benefit from the observations.

It is clear that a more detailed understanding of ocean circulation is required in order to refine the climate-model predictions of a 13 – 111 cm increase in the average global sea level in the next century. This range implies virtually no general impact at its low end, but could have a devastating impact on low-lying countries at the high end. Most of this range of uncertainty can be assigned to lack of knowledge of ocean circulation, and especially its heat and fresh-water transport.

To advance our knowledge and prediction capabilities for the world's climate on seasonal, inter-annual, and longer time scales, it is essential that ocean-circulation processes be well observed, understood and modelled. Global and repetitive observations of ocean topography are therefore a critical element of research into climate dynamics and perturbations to the coupled atmosphere – ocean system. This is illustrated in Figure 1, which shows the altimeter observations of the 1997/98 El Niño.

Ice sheets
Recently, ERS Radar Altimeter measurements (4 million ice-mode cross-over points) have been applied to show that the average elevation of the Antarctic Ice Sheet interior (63% of the grounded ice sheet) fell by 0.9 ± 0.5 cm/year from 1992 to 1996. Moreover, when the variability of snowfall observed in Antarctic ice cores is accounted for, it can be concluded that the mass imbalance of the interior of the Antarctic Ice Sheet this century is only –0.06 ± 0.08 of the mean accumulation rate. Hence, it has been at most only a modest source or sink of sea-level mass this century. The continued availability and in particular the improved accuracy of such elevation-change data to be expected from RA-2/MWR will further enhance the value and importance of monitoring ice-sheet elevation changes. This is illustrated in Figure 2, which shows a Radar Altimeter topography map of Greenland.

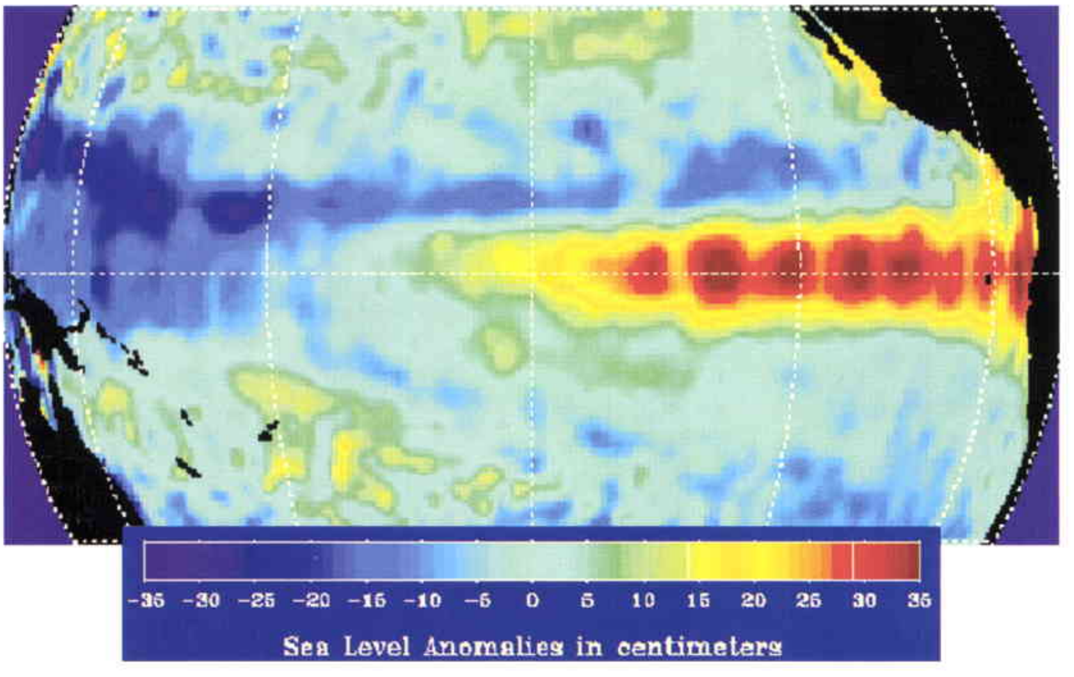


Figure 1. Sea-surface topography anomaly (red-to-yellow colours) during the 1997 El Niño event, derived from the ERS Radar Altimeter (RA) (courtesy of Delft Univ. of Technology/ESA-ESRIN)

Sea ice
A recently developed technique using data from the ERS satellites has demonstrated the potential of spaceborne radar altimetry for measuring sea-ice freeboard height (or elevation), and thereby deriving sea-ice thickness estimates (S. Laxon, pers. com.). The accuracy of these altimeter estimates is in the region of ~0.5 m compared with sonar measurements and models. RA-2 is expected to provide a significant improvement in sea-ice

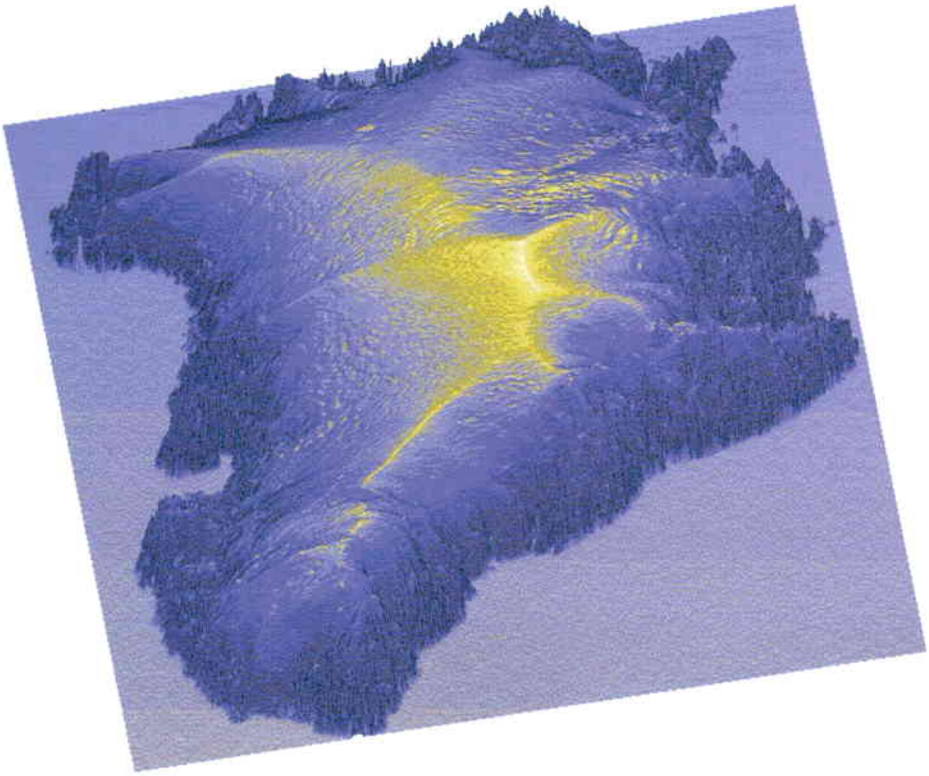


Figure 2. Radar Altimeter map of Greenland (courtesy of the University of Bristol Centre for Remote Sensing)

freeboard height determination over that provided by the ERS altimeters; the onboard tracking system will provide a much more stable record of the peaked echoes that dominate in ice-covered seas. Bearing in mind the sparse in-situ observation of temporal and spatial sea-ice thickness changes, these altimetric measurements may (although coarse in resolution and unable to cover the entire central Arctic polar region) provide valuable data for sea-ice mass fluctuation studies.

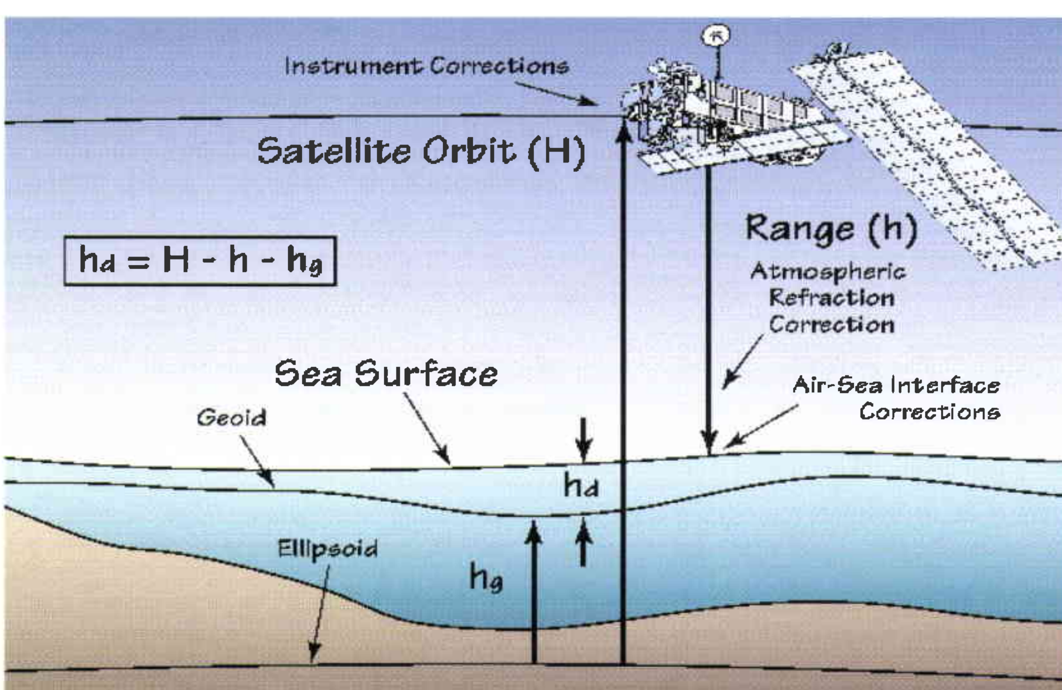
As seen from Table 1, practically all disciplinary areas of interest within the Earth system, including the ocean, the cryosphere, the land, and the planet's gravity field, are addressed by the Envisat altimeter mission in the context of scientific research, climate monitoring and near-real-time sea-state and ocean circulation forecasting. In addition, the 35-day repeat orbit at 98.5° inclination offers optimum synergistic combinations with the simultaneously operating Jason/GFO altimetric missions. The advantages of exploiting simultaneous altimeter missions with such widely different spatial and temporal samplings and inclinations have already been clearly demonstrated by the combined use of the ERS and Topex/Poseidon altimeters.

Instrument operation

The principle of radar altimetry is depicted in Figure 3. The actual altitude of the Earth's surface with respect to the reference ellipsoid can be calculated by subtracting from the satellite-to-Earth's-surface range (h) measured by the altimeter, the independently known satellite orbit height (H).

Over the oceans, the altimeter is able to measure the distance (h) between the spacecraft and the mean sea surface to an accuracy of a few centimetres (the radar actually measures the time delay of the echo reflected by the ocean surface to an accuracy of the order of 100 psec, which is then converted into a distance measurement). The reason why such a high accuracy can be achieved lies in the well-known modelling of the radar echo reflected by the ocean surface and the relationship that can be established between the waveform characteristics and the sea-state conditions (Fig. 4). The radar-echo

Figure 3. The principle of altimetry measurements



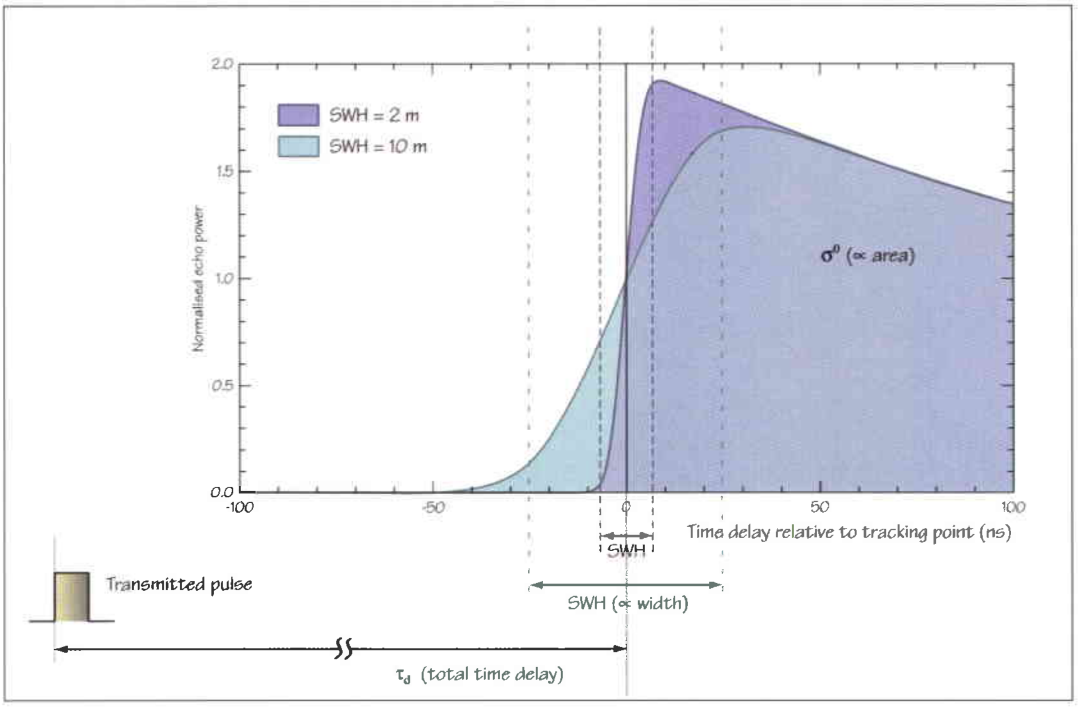


Figure 4. The transmitted pulse, the shape of the echo from the ocean, and the parameters derived from it

waveform can be analytically described by the so-called 'modified Hayne model', which has been well-validated by earlier altimetric missions. The satellite-to-Mean Sea Surface (MSS) distance h (in metres) can be calculated from the time delay τ_d between the transmitted pulse and the reception of the mid-point of the waveform's leading edge. The measured delay is translated to a distance via the relationship h (cm) = $15\tau_d$ (ns). The Significant Wave Height (SWH) is related to the spreading of the waveform leading edge (the smoother and longer the leading edge, the higher the waves are) and can be retrieved via the relation SWH (m) = $4\sigma_S$ (m) (σ_S inversely proportional to echo leading-edge slope). The backscatter coefficient (σ_0) is related to the received echo power (waveform amplitude). The wind speed at the sea surface can be related to σ_0 via established models.

The RA-2 mission objectives are not limited to ocean surfaces. The instrument has been conceived such as to maximise the coverage and the tracking of non-ocean surfaces also (within the capabilities of the pulse-limited technique). To achieve this, a clear separation has been made between two main functions, namely: the collection of meaningful radar echoes without any extraction of geophysical parameters is accomplished on-board; and the estimation of the relevant geophysical quantities is only implemented on the ground. Previous altimeters had these two functions merged on board, thereby increasing the constraints on their optimisation. Their clear separation for RA-2 has made it possible to dedicate onboard processing resources to achieving more robust and autonomous instrument operation over different types of surfaces.

RA-2 is a fully redundant, nadir-pointing, pulse-limited radar operating via a single antenna dish at frequencies of 13.575 GHz and at 3.2 GHz, enabling the correction of height-measurement errors introduced by the ionosphere. It is designed to operate autonomously and continuously along the orbit to collect, on a global scale, calibrated samples of the earliest part of radar echoes from ocean, ice, and land and from their boundaries, without interruption.

The radar's functioning is illustrated in Figure 5, where only the 13.575 GHz chain is shown. RA-2 exploits linearly frequency-modulated pulses called chirps to achieve high range resolution and low peak-power demands.

During transmission, the pulses produced by the chirp generator are amplified by either Ku-band (13.575 GHz) or S-band (3.2 GHz) chains. For every four pulses transmitted at Ku-band, only one pulse is radiated at S-band. The amplifiers exploit travelling-wave-tube technology at Ku-band, and bipolar transistors at S-band. The front-end electronics route the signals to the dual-frequency, centre-fed parabolic antenna, and prevent the transmitted power from damaging the sensitive receiver designed to process very weak signals.

In reception, the front-end electronics route the echoes to the receiver. Each echo is the superposition of transmitted chirp replicas, backscattered by the many reflectors on the surface below, delayed by the time (about one five thousandth of a second) that the chirp

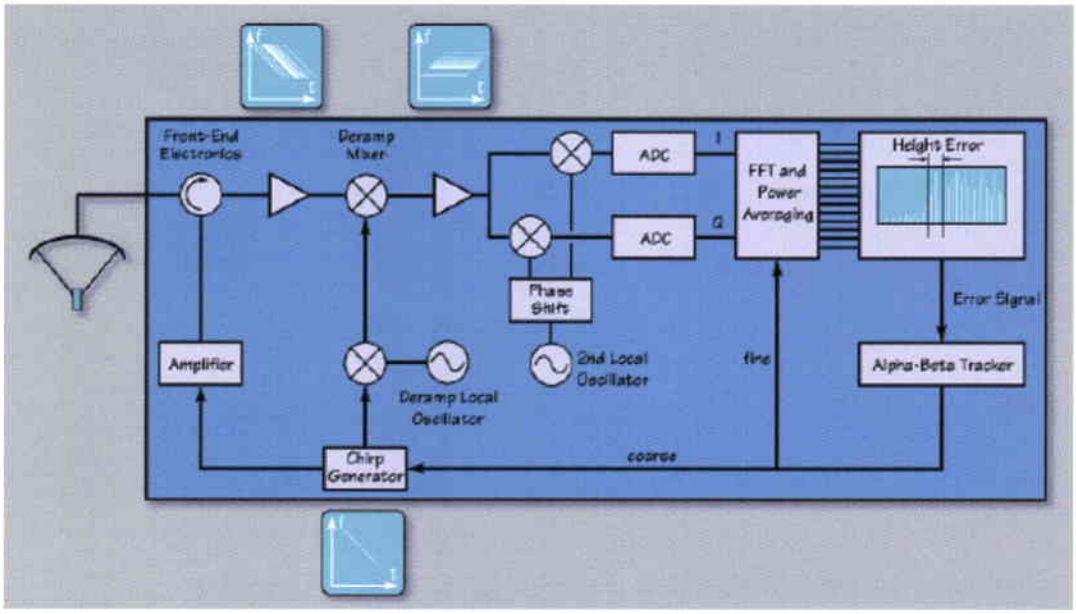


Figure 5. Block diagram of the Radar Altimeter

pulse has taken to travel back and forth across the radar-to-reflector distance. At this point in time, the onboard processor triggers the generation of a new chirp signal to down-convert the incoming echo. This operation, called 'de-ramping', transforms the various received replicas into different tones of constant frequency and converts the height differences between the various surface reflectors into frequency differences, which can be more accurately resolved by spectral filtering. After further amplification, the signal is converted into its in-phase (I) and quadrature (Q) components and is sampled. A 128-point complex Fast Fourier Transform is implemented to resolve echo details with a resolution that is inversely proportional to the transmitted chirp bandwidth. Square-modulus extraction and averaging are applied to the samples to reduce fluctuations and data rate.

The onboard processor is programmed to run all RA-2 operations autonomously, although it can be bypassed by ground commanding if necessary. Operations start with the automatic detection and acquisition of the surface echoes by the main channel (13.575 GHz). As soon as the acquisition is successfully accomplished, RA-2 automatically starts the tracking phase. During this phase, a tracking window is locked on the earliest part of the echoes and its position, gain and resolution are updated by the new on-board processor. The Model-Free Tracker (MFT) software allows interruption-free collection of the echo samples around the complete orbit, irrespective of surface type. Three range resolutions are available, corresponding to the three transmit bandwidths of 320, 80 and 20 MHz. Over open ocean surfaces, where the echo shape can only have smooth variations for periods of seconds, RA-2 always uses its highest resolution. Over coastal zones, ice and land where the tracking could be lost due to the unpredictable and fast-changing echo shape, RA-2 can autonomously switch to a coarser resolution. If tracking is indeed lost accidentally, an automatic procedure re-starts operation from detection and acquisition. Internal calibration data are routinely collected every second without interrupting echo sample collection. Those data are processed on the ground to compensate instrument time-delay and gain variations with respect to pre-launch calibration, due for instance to ageing or in-flight temperature conditions.

The Pulse Repetition Frequency (PRF) of the main channel has been increased to about 1800 Hz, in order to collect a higher number of independent observations per second and thereby improve the measurement accuracy.

The data from the S-band channel, highly sensitive to ionospheric effects, allow the accurate correction of these effects on the main-channel height measurements. Corrections are applied to both the near-real-time and the offline products. Single-frequency altimeters have to rely instead on ionospheric models that are less accurate and do not account for small-scale spatial variations. The echoes received by the secondary channel are always sampled at a fixed resolution, corresponding to the 160 MHz band, in a window whose position and gain are related to those of the main channel.

The averaged echo samples are sent to ground via time-tagged source packets. Internal calibration and ancillary data are also added. Furthermore, a new RA-2 feature allows the storage, by ground command, of up to 2000 unaveraged individual echo samples and their transmission to ground in several source packets. Individual echo collection is made available as a dedicated data product for research purposes.

A summary of RA-2 design parameters is provided in Table 2.

The RA-2 development programme has been successfully completed and the instrument is now being integrated onto the satellite. Figure 6 shows the RA-2 flight-model panel after the completion of its acceptance-test programme.

RA-2 operation and performance verification has been carried out extensively on the ground by using an RA-2 Return Signal Simulator connected to the antenna port, to produce echoes representative of complex combinations of ocean, land and ice, and their boundaries. The rms accuracies measured during the ground testing over open ocean for the three engineering parameters – time delay τ_d (ns), radar cross-section σ_0 (dB), and echo leading-edge slope σ_s (cm) – are summarised in Table 3 as a function of σ_s.

The accuracy contributions achievable by the altimetry system are summarised in Table 4.

The data products

Based on the experience gained from the ERS missions, significant improvements have been built into this new generation of altimetric products, particularly in terms of the enhanced quality of the near-real-time observations, which are now nearly as good as the final precise product. The product specification process has included wide consultation with users of ERS and Topex/Poseidon altimetric data. Further product refinement and state-of-the-art algorithm specification have been elaborated by three European Expert Support Laboratories. Moreover, the RA-2 and MWR products and algorithms are being peer-reviewed by independent experts.

The Envisat RA-2 and MWR data products will be globally processed in both near-real-time

Table 2. Summary of RA-2 design parameters

Orbit range (km)	764, 825
Operative frequencies (GHz)	13.575, 3.2
Pulse length (microsec)	20
Ku chirp bandwidths (MHz)	320, 80, 20
S chirp bandwidth (MHz)	160
Ku transmitter peak power (W)	60
S transmitter peak power (W)	60
Ku-PRF (Hz)	1795.33
S-PRF (HZ)	448.83
I/Q A/D conversion bit number	8 + 8
Number of FFT points	128
Max. data rate (kbit/sec)	91
Antenna diameter (m)	1.2
Measured power consumption (W)	126
Mass (kg)	112

Table 3. RA-2 rms retrieval accuracies for the three engineering parameters

rms	σ_s =0.5 m	σ_s =1 m	σ_s =2 m	σ_s =3 m
τ_d (ns)	0.15	0.16	0.24	0.39
σ_o (dB)	0.49	0.52	0.52	0.52
σ_s (cm)	3.1	4.1	5.4	6.7

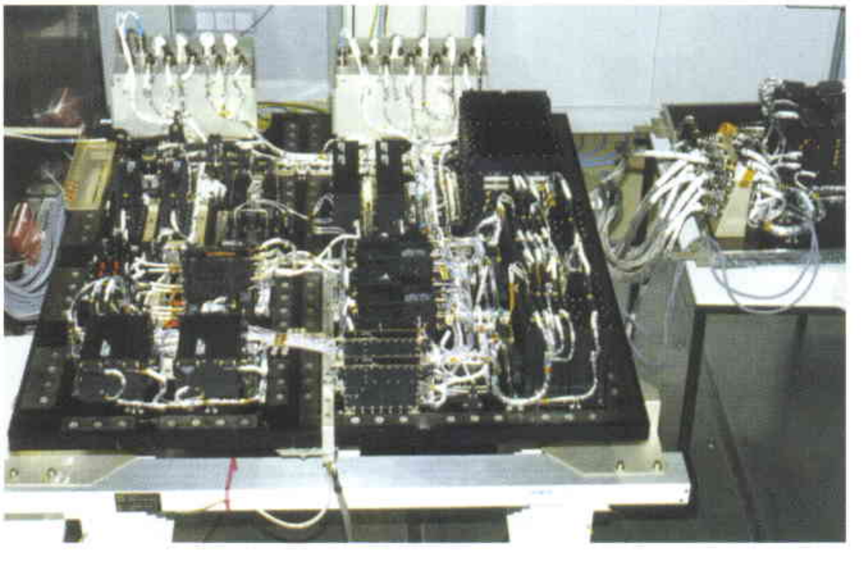


Figure 6. RA-2 flight-model panel after the completion of its acceptance test programme

Table 4. Altimetry error contribution budget

CONTRIBUTION	NON-CORRECTED EFFECT (CM)	RESIDUAL ERROR AFTER CORRECTION (CM)	COMMENTS
Instrument Error		2.4	Measured . (Table 3 for σ_s =1 m (SWH=4m)). h(cm) = 15τ_d(ns)
Orbit		~ 3	DORIS precise orbit
Sea-State Bias	0-20	~ 2	
Dry Troposphere	~230	0.2-2	
Wet Troposphere	0-30	1-2	Real-time use of MWR data

and offline with an identical processing algorithm, including the wet tropospheric correction from the microwave radiometer and the ionospheric correction from the two frequencies, as well as many other improvements originating from the novel design of this second-generation Radar Altimeter. The near-real-time processing is therefore comprehensive and the same as for offline products; only the availability and quality of the auxiliary data differ.

The suite of RA-2 products is based on the principle of one main Geophysical Data Record (GDR). The Envisat product's general format is exploited to add substructure inside the product to hold such additional data as the averaged waveforms (at 18 Hz), the individual waveforms (at 1800 Hz), and the Microwave Radiometer data set. Thus, the same product covers the standard once per second data (GDR) and the waveform data (SGDR). Moreover, this product is global and independent of the subsatellite terrain and of the Radar Altimeter measurement resolution mode, thereby avoiding artificial boundaries between geographical features like land/sea or land/lake transitions and ensuring that lake or wetland data always end up in the same data product.

The Fast Delivery GDR (FDGDR) product is delivered in less than three hours, for weather-forecasting, sea-state and real-time ocean-circulation applications. A subset of the FDGDR, called FDMAR (Marine Abridged Record) is extracted to reduce the volume of online data transfers. This product is then delivered again in less than 3 days for ocean-circulation monitoring and forecasting applications, substituting the meteo predictions for the more precise analyses and the preliminary orbit for an improved orbit solution. The final products containing the most precise instrument calibrations and orbit solutions are delivered within 3-4 weeks. The schematic in Figure 7 summarises the organisation and latency of the product generation. One of the major differences is constituted by the quality level of the orbit, thanks to the DORIS system. The expected orbit accuracy is:

- better than 50 cm for the Orbit Navigator, used for FDGDR production
- around 10 cm for the DORIS preliminary orbit, used for IGDR (Interim Geophysical Data Record) production
- around 3 cm for the DORIS precise orbit used for GDR production.

The Envisat products are categorised into three distinct levels:

- Level 0 (raw): unprocessed data as it comes from the instrument.
- Level 1b (engineering): data converted to engineering units, with instrumental calibration applied (IF filter – corrects power distortions of echo waveforms – internal range calibrations, corrections for possible drift of reference timing source, no retracking); the product segmented in half-orbit (pole-to-pole) mainly contains datation (conversion of satellite time to UTC) geolocation, time delay, orbit (<50 cm NRT to ~3 cm offline with DORIS precise orbit), sigma-zero, averaged waveform samples at 18 Hz data rate, individual waveform at full pulse-repetition frequency and MWR brightness temperatures.
- Level 2 (geophysical): data converted to geophysical units (with retracking); the product mainly contains datation, geo-location, output from retrackers (range, wind speed, significant wave height, etc.), at 1 Hz plus some 18 Hz parameters (range, orbit). All geophysical products, including the near-real-time products, are retracked (waveform data are fully processed in the ground processor to extract the geophysical parameters).

In order to retrieve the geophysical parameters over all types of surface (ocean, ice or land, sea-ice, etc.), four specialised retrackers are run continuously in parallel over all surfaces:

- Ocean retracker: optimised for ocean surfaces, it is based on a modification of the Hayne model
- Ice-1 retracker: optimised for general continental ice sheets, it is a model-free retracker called the Offset Centre of Gravity echo model; it is used for ERS and will ensure continuity of the measurements
- Ice-2 retracker: optimised for ocean-like echoes from continental ice sheet interior, it is a Brown-based model retracking algorithm
- Sea Ice retracker: optimised for specular returns from sea-ice, it is a threshold retracking scheme for peaky waveforms.

The usual necessary geophysical corrections are available in the product. The ionospheric correction will come from the dual-frequency altimeter, backed up by the measurements from DORIS and the Bent model. The wet tropospheric correction will come from the on-board microwave radiometer, backed up by a value computed from ECMWF fields.

The FDGDR will be processed in the receiving stations and delivered in less than 3 hours. The IGDR and the final precision GDR products will be processed off-line at the Processing and

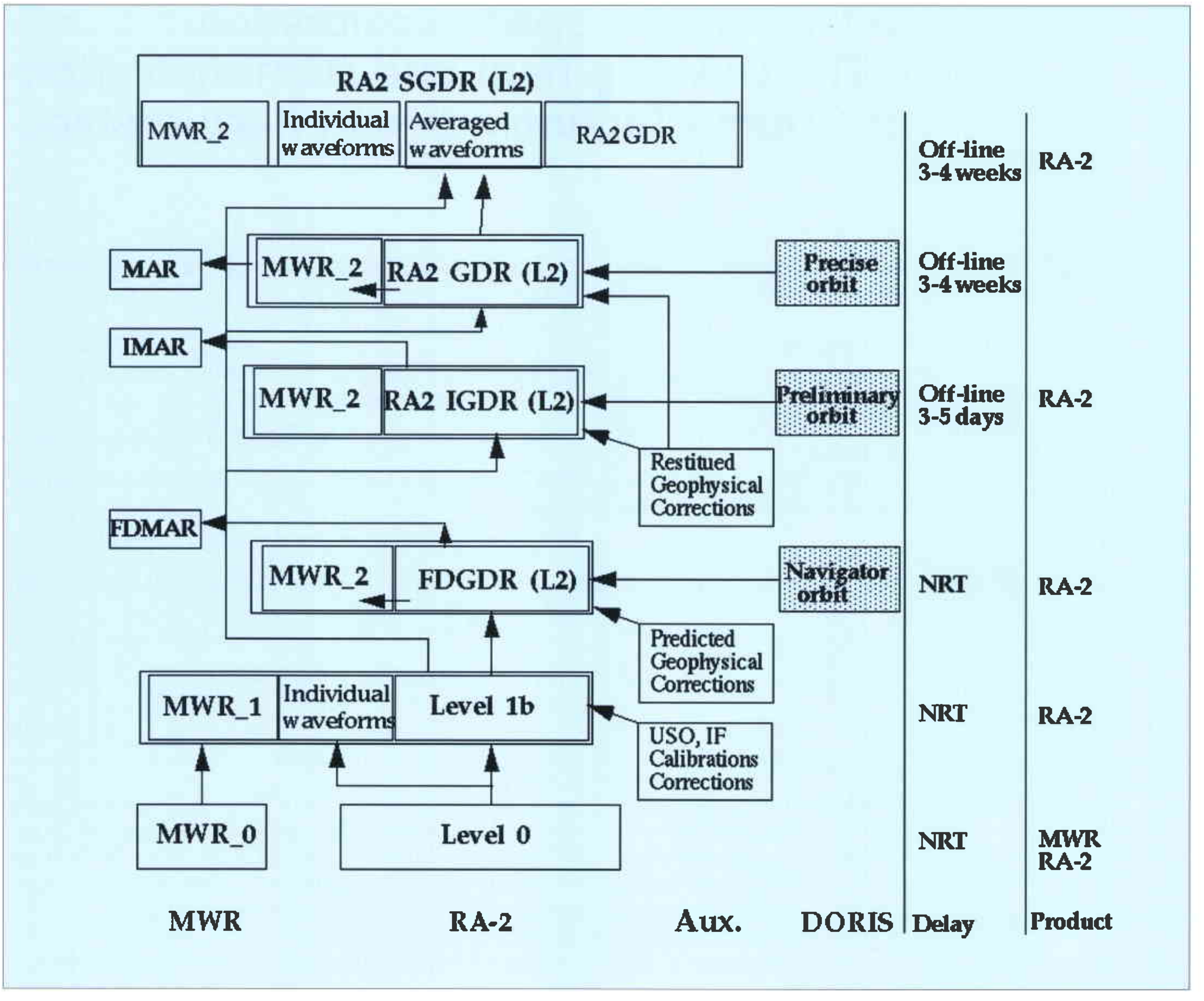


Figure 7. Envisat Radar Altimeter and Microwave Radiometer product tree

Archiving Centre in Toulouse, France, using the same algorithms as the Fast Delivery processor.

In summary, the GDR products will be built from four specialised retrackers running in parallel over all surfaces. The data coverage will be up to 81.5° N and S in a dense ground-track layout (35-day repeat cycle). The Envisat ground system will deliver global NRT data in less than 3 hours. These will already be of near-GDR quality as they will be built with the same algorithms and will contain the good-quality orbit produced in real time by the DORIS navigator. The full exploitation of the data from RA-2 demands high-quality absolute calibration at Ku- and S-bands for the three instrument parameters, as well as a very accurate cross-calibration with other altimeter data during overlapping flights, to provide the user community with a continuous and consistent altimetric time series.

The Envisat User Service is the unique interface to the user community. It will register data requests, both fast-delivery and offline, and organise the acquisition, processing and product delivery. It is accessible using a WWW browser via a Unified User Services Interface. This means that users will be able to access Envisat data services at any station or centre via an identical user interface.

Solar Sails for Space Exploration – The Development and Demonstration of Critical Technologies in Partnership

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Introduction

Solar-sail technology holds the promise of significantly enhancing the interplanetary transportation infrastructure for space-exploration missions in the new millennium, by exploiting the freely available space resource of solar radiation pressure for primary propulsion.

This article presents results of a joint ESA/DLR effort to pre-develop the technologies required to validate the concept of space exploration by solar sailing. This co-operative effort is considered a prototype for a new form of partnership with other space agencies and industrial partners involved in technology R&D aimed at exploiting new application opportunities.

A solar sail consists of a large, lightweight and highly reflective surface that relies on the momentum transferred from solar photons for passive propulsion. By making use of this innovative means of low-thrust propulsion, extended missions in our Solar System which require a ΔV of several tens of kilometres per second would become possible. For missions needing such high propulsion energies, solar sails could either complement other more traditional means of space propulsion, or provide all of the propulsion needed. Typical examples might be a Mercury Orbiter, a (multiple) main-belt asteroid rendezvous, a small-body sample return, or a solar polar orbiter in a 90° inclined orbit (to the ecliptic) at about 0.5 AU solar distance.

Based on promising results obtained during system studies by DLR (in cooperation with NASA/JPL) and by ESA, a joint effort for the development of solar-sail technology on a co-funding basis was initiated in 1998.

Potential solar-sail mission applications

Solar sailing has been investigated as an alternative means of propulsion in several studies for planetary missions such as a Mercury Orbiter. Mission analysis has shown that solar sails can be utilised for a low-thrust spiral transfer to Mercury with essentially zero Earth-departure relative velocity, and allowing suitable rendezvous conditions at Mercury arrival. For the Earth-Mercury trajectory shown in Figure 1, the maximum acceleration delivered by the sail at 1 AU solar distance (referred to as the characteristic acceleration a_c) is large enough to provide a transfer flight time of 1.8 years. Departing from Earth in January 2003, therefore, would result in arrival at Mercury in November 2004.

An example for the associated sail size and mass would be a 125 m x 125 m sail carrying a spacecraft with a net mass of 110 kg, including the scientific payload. Assuming 8 g/m^2 for the sail itself, the launch mass of the complete spacecraft would be about 235 kg. This would mean that it could potentially be launched at relatively low cost as an Ariane-5 mini auxiliary payload.

Once at Mercury, solar sails would also allow a Sun-synchronous orbit about the planet to be established. The highly effective and basically endless propulsion capability of a solar sail could be used to produce a rotation of the orbital plane around Mercury, allowing the spacecraft to operate continuously near the planet's terminator.

Another promising solar-sail application is a mission to a close circular polar orbit at 0.3 AU to 0.5 AU solar distance, which would provide an interesting opportunity for solar observations and space-physics investigations. This would allow close-up observation of the solar poles, with a relatively short transfer time and a high repetition rate. The only observations to date of the Sun's polar regions have been made by ESA's Ulysses spacecraft, which passes above the poles at a distance of approximately 2 AU, as a result of the Jupiter Gravity Assist (JGA) trajectory used to position the spacecraft in its elliptic, polar orbit around the Sun.

The solar-sail transfer would be carried out in two flight phases:

- a spiral to a semi-major axis of 0.3 — 0.5 AU
- a spiral to increase the orbit's inclination to 90° (so-called 'orbit cranking').

The analysis shows that the trip time needed to reach a semi-major axis of 0.3 AU would be about 1.5 years, and the subsequent 'cranking orbit' to achieve a heliocentric inclination of 90° would take 2 years (Fig. 2).

New mission opportunities applying solar-sail technologies are currently being addressed by NASA also. The Jet Propulsion Laboratory (JPL), for instance, has recently completed a study of a proposed Solar Polar Sail Mission that would use solar-sail propulsion to place a spacecraft in a circular 4-month orbit at a distance of 0.48 AU from the Sun with an inclination of 90°. The mission would provide data on the solar corona to complement observations of the Sun's disk and the solar-wind data obtained near Earth. Another potential solar-sail mission, proposed by NOAA in cooperation with NASA as well as by European scientists, is a sailcraft to be stationed sunward of the Sun-Earth Lagrangian point L1. Solar photon pressure on the sail would be required for the sailcraft to fly inside the L1 point whilst remaining on the Earth-Sun line (the outward radial force on the sail must compensate for the lower centrifugal force on the sailcraft). From this vantage point, the sailcraft would deliver a factor 2 improvement in solar-storm warning time (60 min compared to 30 min) over a conventional satellite stationed at L1. A similar mission concept called 'Vigiwind' was proposed in Europe by U3P and CNES in 1996.

Transfers to Pluto and beyond would also be possible with solar-sail propulsion. So-called 'indirect' or 'solar photonic assist' trajectories, investigated recently by DLR, allow short trip times to Pluto with solar sails. Figure 3 shows the ecliptic projection of a transfer to Pluto using a sailcraft with a characteristic acceleration of 0.7 mm/s^2 and a double swing-by at the Sun. The transfer time from Earth to Pluto flyby in this case is about 10.5 years, which compares favourably with conventional

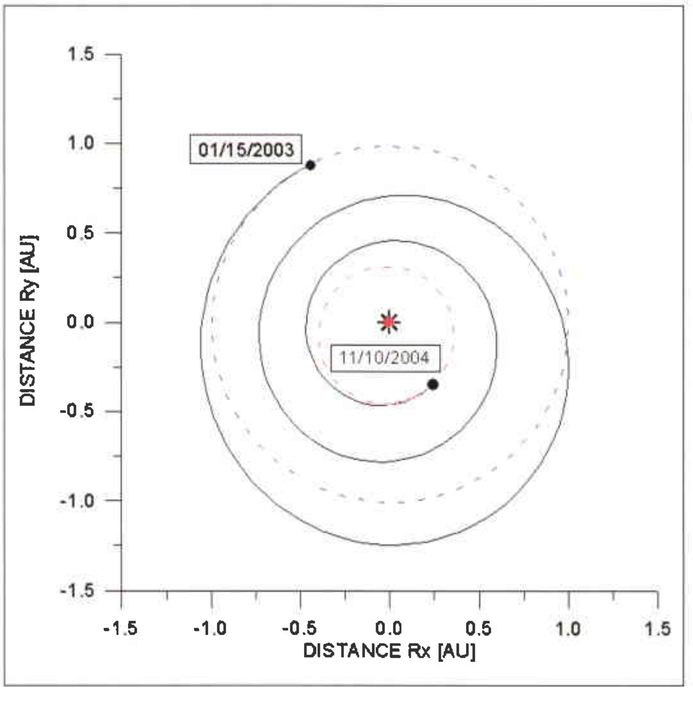

Figure 1. Interplanetary transfer from Earth to Mercury, with a characteristic acceleration a_C of 0.55 mm/s^2

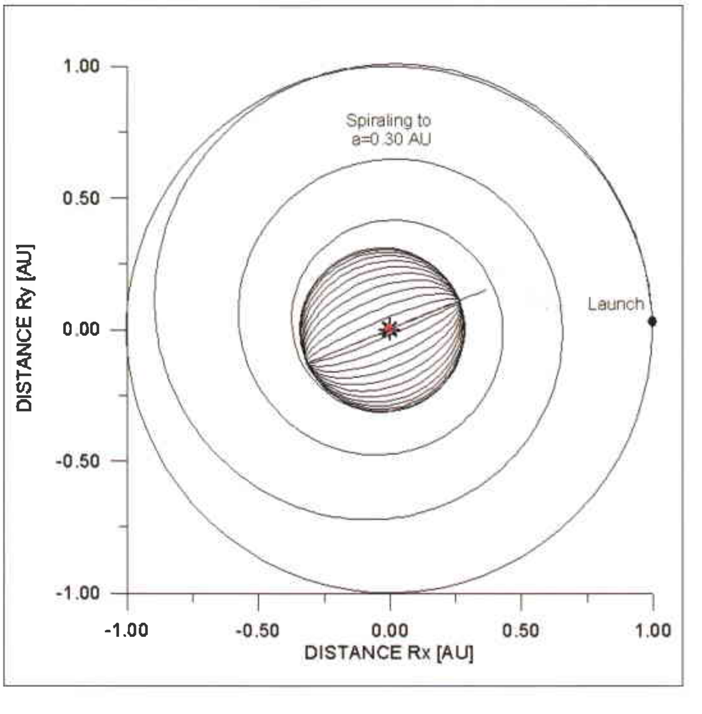

Figure 2. Spiral trajectory to a close solar-polar orbit (ecliptic projection) a_C = 0.50 mm/s^2

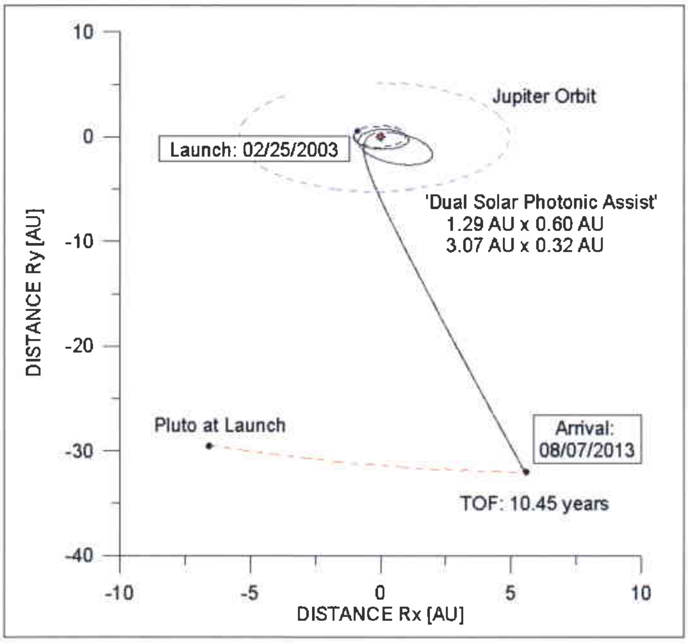

Figure 3. A solar-sail 'dual solar photonic assist' transfer to Pluto

transfers of 11 to 13 years using multiple-gravity-assist trajectories at Venus and Jupiter.

By extending the principle of single or multiple 'solar photonic assist' trajectories, advanced solar sails might be capable of achieving high enough speeds to propel spacecraft out of our Solar System. Assuming that 'second-generation' solar sails might have characteristic accelerations (a_C) in the order of 1 to 3 mm/s^2 and ultra-light sail structures of 1 to 5 g/m^2, very high speeds could indeed be achieved. By using close solar approaches to within 0.3 AU or even less, using special sail coatings and high-performance materials capable of handling the very high temperatures, escape velocities of 50 to 100 km/s or more might be achievable.

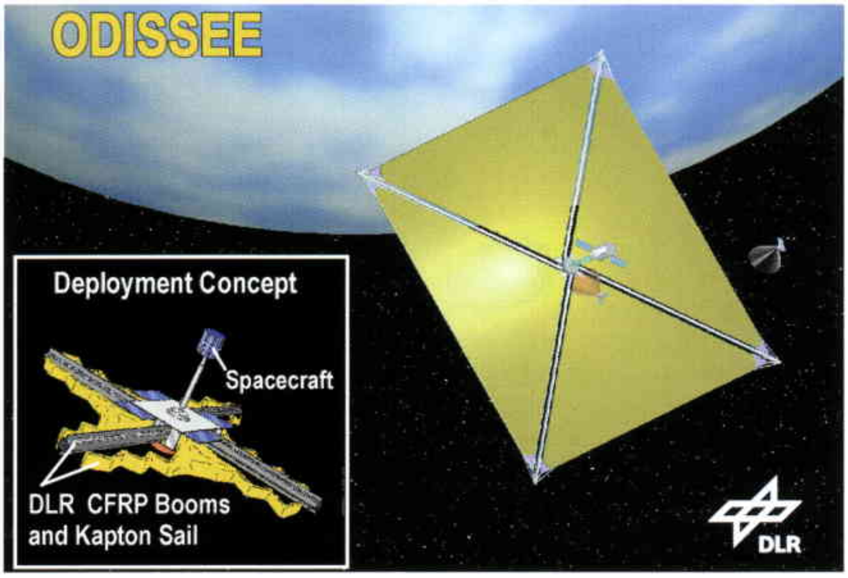

Figure 4. Conceptual design for the deployed square sail

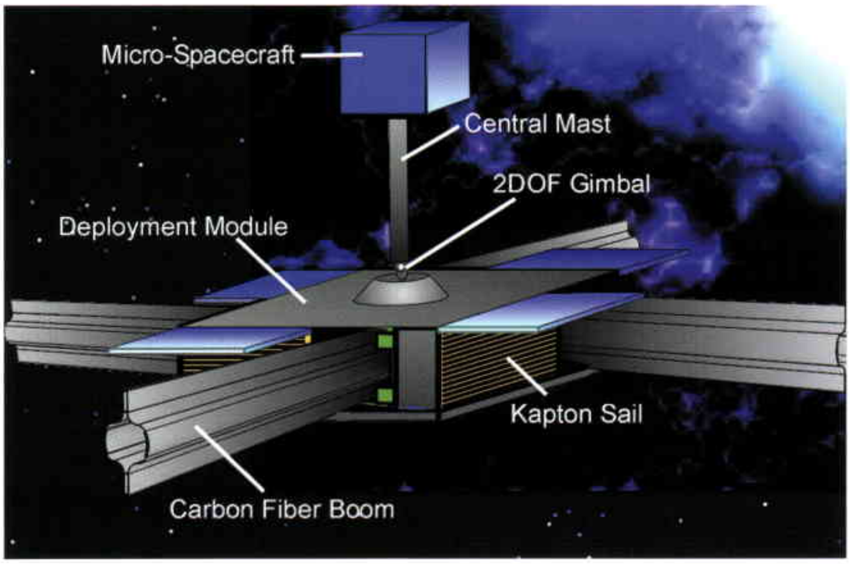

Figure 5. Sailcraft baseline concept, partially deployed

The mission concept envisages a sailcraft that is injected into a heliocentric orbit at 1 AU, in which the solar sail is then deployed. In a corresponding NASA study, the mission trajectory would carry the sailcraft to 2 AU approximately one year after launch and then sunward to a perihelion distance of 0.25 AU to exit the Solar System with a velocity of 10.9 AU/year. At this velocity, a Jupiter orbital distance would be achieved within 2.1 years after launch, and 200 AU within 20 years.

The sailcraft concept

Various solar-sail design concepts have been proposed in the past. For the joint ESA-DLR technology development effort, a square sail with diagonal booms supporting four triangular segments was chosen as the baseline configuration. The sail structure is composed of three major elements: the booms, the sail film segments, and a central deployment module. The four supporting CFRP (Carbon Fibre Reinforced Plastic) booms are unrolled from the central deployment module and the folded sail film segments are released from storage containers. Figure 4 shows a conceptual design for the square sail in Earth orbit, together with a partially deployed sail (lower left). The concept is based on the ODISSEE proposal (Orbital Demonstration of an Innovative, Solar Sail driven Expandable structure Experiment).

Figure 5 shows the partially deployed CFRP booms, with the storage containers for the sail film segments. The film segments are folded in two directions ('accordion fashion', also referred to as 'frog-leg folding' due to the unfolding behaviour), thereby minimising storage volume and allowing controlled sail release. Once in orbit, the micro-spacecraft and sail module are separated from each other by a collapsible 10 m mast, which is housed inside the spacecraft in its stowed configuration. This structure is referred to here as the 'central mast', or 'sailcraft control mast', connecting the spacecraft and the sail structure. The central mast is attached to the sail deployment module via a two-degree-of-freedom (2 DOF) actuator gimbal, which allows the control mast and attached spacecraft to be rotated with respect to the sail. In this way, the center-of-pressure (CP) can be offset from the centre-of-mass (CM), and using solar radiation pressure as an external force a torque can be generated to control the sail's attitude.

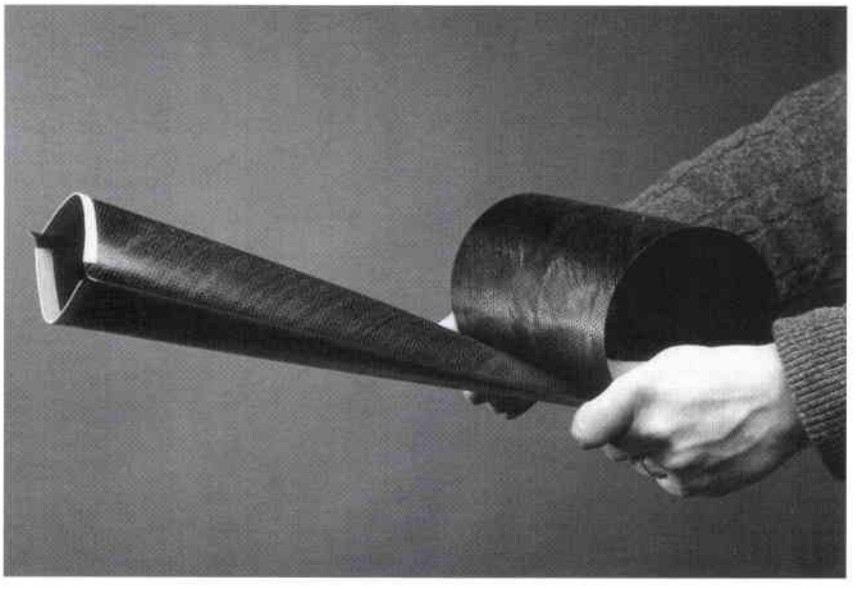

Figure 6. A CFRP deployable boom

The carbon-fibre booms, developed by DLR, combine high strength and stiffness with low density, and can be stored in a small volume. They consist of two laminated sheets, which are bonded at the edges to form a tubular shape (Fig. 6). They can be pressed flat around a central hub for storage, and uncoil from the hub during deployment. Once deployed, they resume their original tubular shape and exhibit high bending stiffness.

The design for the deployment module housing the rolled-up booms and folded sail film is driven mainly by the severe volume constraints of the Ariane-5 ASAP (Ariane Structure for Auxiliary Payloads) launch option.

To analyse the baseline configuration further and to test the deployment behaviour of folded sail segments, an 8 m x 8 m solar-sail mock-up (Fig. 7) was built at DLR. The four diagonal booms are made of aluminium and are not deployable. The sail itself was manufactured from 12-micron Mylar film, aluminised on one side. The upper triangular sail segment was 'frog-leg-folded' and stored in a sail container sized to match the storage volume available for the proposed ODISSEE orbital test flight. The sail segment was deployed successfully in several ground tests involving motors and deployment ropes to unfurl and tighten the sail.

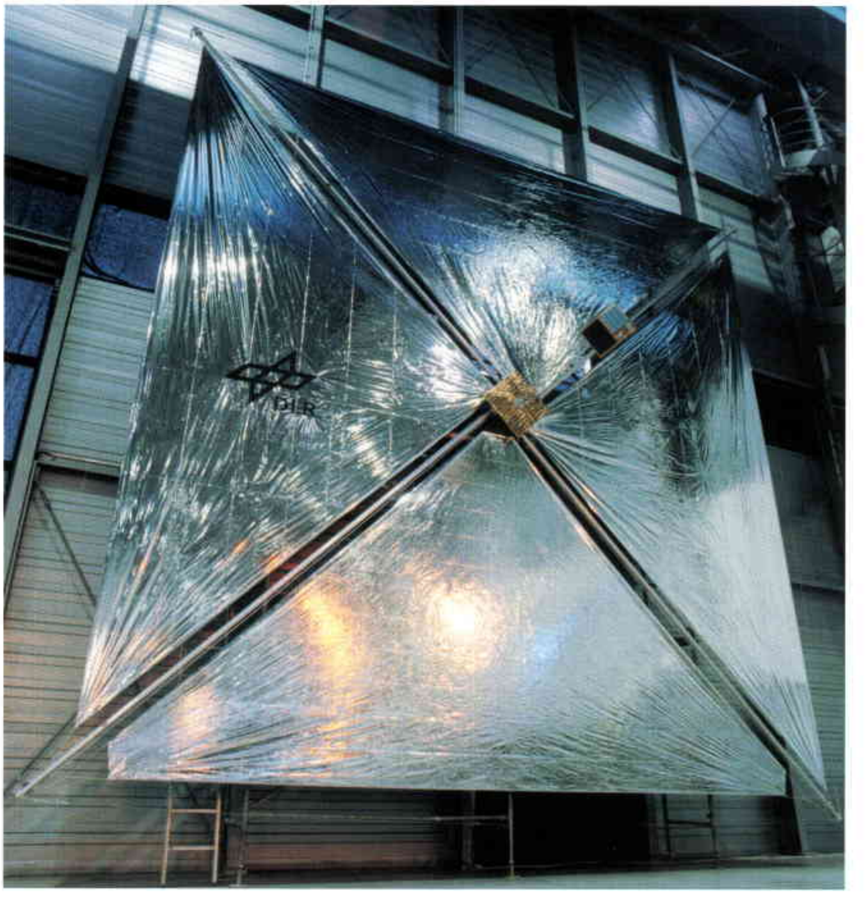

Figure 7. The DLR solar-sail mock-up

Technological challenges of solar-sail deployment

Although the basic idea behind solar sailing appears simple, challenging engineering problems have to be solved to exploit photonic propulsion for orbit transfer. Since the spiral orbit-raising efficiency depends basically on the overall spacecraft mass to solar sail area ratio, lightweight technological solutions for large in-orbit deployed sail surfaces are required. The technical challenges are:

- to fabricate the sails using ultra-thin films and lightweight deployable booms able to carry the in-orbit loads
- to package the sails and booms into a small volume
- to deploy these lightweight structures successfully in space, and
- to control the large but low-mass structure.

The solutions to these challenges must first be demonstrated to the greatest possible extent on the ground in 1 g, and subsequently via an in-orbit demonstration mission, before solar-sail propulsion can be considered viable for any mission.

The deployment module uses a square sail design with diagonal booms to support four triangular sail film segments, which are stowed in small containers next to the coilable-boom compartment. The volume constraint of an anticipated Ariane-5 piggy-back launch places extreme demands on the engineering ingenuity of the four-boom deployment solution, while the in-orbit loads due to solar pressure and the effects of manufacturing tolerances call for boom-stiffness performances in excess of the solutions known today. As a consequence of the high stiffness requirements for the booms, their release from a central deployment mechanism has to have proper position guidance components at the exit of the module, whilst still aiming for limited contact to achieve low friction in order to limit the power requirement for the actuation unit.

There are other technical reasons for supporting this field of technology development and demonstration. Engineers would learn through synergy how to deploy and control very large, but extremely lightweight structures for, for example, antennas and solar generators. Micro/nano-technologies, like the micro-machined propulsion thrusters being developed by ESA, could play a complementary but essential role in attitude control.

Planned demonstrations

Two major milestones are foreseen in terms of demonstrations:

- Currently a 20 m x 20 m breadboard model of a fully deployable sail structure is being developed on a co-funding basis by DLR and ESA.

- Recent cooperative pre-Phase-A studies by DLR together with NASA/JPL, as well as an ESA feasibility study, have concluded that a low-cost technology-demonstration mission in Earth orbit is the best approach to demonstrate and flight-validate the basic principles of sail fabrication, packaging, storage, deployment, and control.

The breadboard model is intended to demonstrate the feasibility of a fully deployable lightweight structure via a ground demonstration in a 1g environment under ambient environmental conditions. This breadboard model will provide experience with the deployment of lightweight booms and sail segments, as well as the manufacture, folding and storage of large areas of reflective film.

Following successful completion of the ground demonstration, a low-cost technology-demonstration flight to validate solar-sail technology in Earth orbit is proposed. A 'piggy-back' launch on an Ariane-5 would minimise launch costs. This launch vehicle offers the ASAP-5 (Ariane Structure for Auxiliary Payloads) ring structure, which can accommodate up to 8 micro-spacecraft, each with a maximum mass of 100 kg. The volume for each ASAP payload is restricted to 60 cm x 60 cm x 80 cm. Once Ariane-5 had reached its standard Geostationary Transfer Orbit (GTO), with a perigee of 620 km and an apogee of 35 883 km, the sailcraft would be ejected, the sail fully deployed, and performance and manoeuvrability tests performed as part of the primary mission objectives. Sail deployment would be observed with several wide- and narrow-field micro-cameras mounted on the spacecraft.

Two alternative mission routes are being studied:
Route 1 (DAEDALUS): The sailcraft performs a number of orbit changes in Earth orbit to explore its potential for Earth-directed applications. The mission would end with a controlled re-entry of the sailcraft after several months in orbit.
Route 2 (ODISSEE): The sailcraft performs an orbit transfer to the Moon. A high-resolution camera on the sailcraft could explore lunar areas during a polar flyby or from lunar orbit.

The performance for spiral orbit-raising using low-thrust solar-sail propulsion depends on the overall mass-to-area ratio, which for ODISSEE would be about 48 g/m^2. Reaching lunar distance from GTO would take approximately 550 days. Depending on the navigation strategy chosen, the sailcraft could perform a lunar polar flyby to continue its journey to Earth escape and possibly a near-Earth asteroid rendezvous, or the sail might be used for a weak orbit capture into a highly elliptical lunar orbit. Figure 8 shows a typical steering profile for the sail attitude for one orbit. An acceleration and drift phase can be identified. During the acceleration phase, the solar sail raises the orbit, whereas during the drift phase almost 'edge-on' sailing is required in order to avoid deceleration. In the baseline scenario only one side of the sail is used for 'primary propulsion', reflecting the incident light. Therefore, the front side of the sail, facing the spacecraft, has to be reoriented towards the Sun.

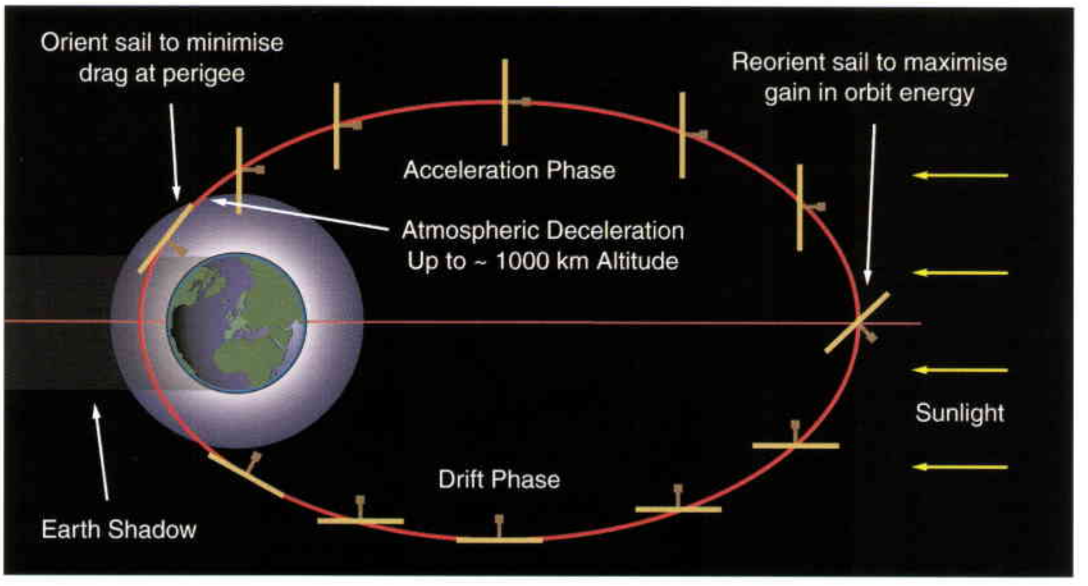

Figure 8. Sail steering profile in GTO

The breadboard-model development is foreseen to bridge the gap between the largely theoretical feasibility study and flight-hardware development. This philosophy fosters early hardware development and extensive testing where possible in order to reduce the inherent project risks. The envisaged low-cost flight validation of a solar sail in Earth orbit by the beginning of the new millennium is seen as an example of rapid prototyping for emerging advanced, breakthrough technologies. Such a validation flight is being proposed as a means of ensuring technology readiness for post-2000 space-science missions utilising solar sails.

A trial case for technology development and demonstration in partnership

Co-funding of concerted activities in this field of technology development and demonstration is the agreed option for ESA and DLR because of:

- the interest in solar-sail propulsion for future interplanetary missions and the applicability of associated large-structure technology for future Earth-directed space services
- the fact that such technology has not been flown before on any space mission, nor has it been demonstrated in space
- the promising results obtained in system studies by both DLR and ESTEC
- the high technological interest on the part of ESA and DLR in the advanced technologies required by the solar-sail concept, which has led ESA to include relevant activities in its technology programme.

ESA has been involved in co-funding initiatives with its industrial partners for ten years or more, particularly in the technology research and development area. Since 1993, a few ESA programmes have formally introduced the idea that the Agency and industry (or another partner organisation like DLR willing to work with ESA) could co-fund all or some of their activities, two early examples being Artes-4 and GSTP.

At an ESA Council Meeting at Ministerial Level in March 1997, a Resolution was finalised and approved which promoted the idea of further improving European industry's world-wide competitiveness as well as the concept of 'partnership' (in this context, partnership is seen as a concept, and co-funding as a mechanism). The partnership scheme applied to the solar-sail activity brings together the Agency, the German Aerospace Centre DLR as an interested institutional partner, and Invent GmbH, a small German SME which is developing the deployment module.

Conclusion

The emerging economic and political environment for space activities initiated by ESA and other space agencies in Europe calls for more and better co-operation and partnership between them and with industry. ESA has developed a set of guidelines for co-funding arrangements, which should help the industrial partners to improve their international competitiveness in the area of technology R&D.

The proposal of a co-operation agreement in the field of solar-sail development and demonstration has been welcomed by both ESA and DLR. The current activity is considered a prototype for a partnership in the development of strategic technology. Solar-sail technology holds the promise of significantly enhancing, or even enabling, space-exploration missions in the new millennium, by exploiting the space-pervading resource of solar radiation pressure.

Academic and Industrial Cooperation in Innovative Space Research

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The European Space Agency's interest in the broad area of academic research stems from the objective of building up capacity in universities in order to stimulate technological innovation, synergy and harmonisation throughout the ESA Member States. This article gives an overview of several initiatives and activities within the Directorate of Industrial Matters and Technology Programmes pertaining to academic research and cooperation, namely the Academic Research Programme (TRP), the Academic Research Pilot Initiative for the Mapping and Harmonisation of Space R & D Activities in European Universities, studies on University-Industry Relations in the Space Domain, and the Conference on Academic and Industrial Research Cooperation in Space (Vienna, 4-6 Nov 1998). Conclusions and recommendations resulting from the studies and the conference are also provided.

Introduction

ESA recognises that the interaction with the university and research centre community is of a different nature to that of industry in that it emphasises both scientific and technological cross- and multi-disciplinary innovative research, as well as the advancement of knowledge and education. The challenges of the 21st century demand creative and breakthrough solutions to space science and engineering problems. The funding of activities in institutes of higher education to encourage new ideas and stimulate subsequent innovative research and development is a necessary step in this direction.

Basic research in the space field is to a great extent carried out in universities; such efforts, however, may not always be taken full advantage of by the space industry or by agencies responsible for space activities. Although networks facilitating cooperation and exchanges between universities and industry do exist at European level, these are not necessarily in the space domain.

Since a university has two other interrelated missions besides research, namely education and a role in society, the research it undertakes could also be used as a basis for curriculum development (particularly in science, technology and engineering), enhancement of student research potential and contribution to the space workers pool, and for student and regional community outreach programmes in space topics.

A framework thus needs to be developed which would improve and reinforce the contacts and relations between academic research institutions and industry, particularly SMEs, in the space field and which would also encourage university groups not usually involved in space activities to create partnerships with industry (and vice-versa), and to enhance innovation and competitiveness in the space domain. Such a framework should be designed to assist regions within Member States to develop an academic research enterprise in conjunction with local industry which is directed towards longer-term, self-sustaining competitive capabilities, contributing not only to the improvement of the European space industry in general, but also to the region's overall economic viability in the future.

It is against this background that ESA's Directorate of Industrial Matters and Technology Programmes has initiated a number of activities with the ultimate aim of supporting the academic community in break-through research leading to innovative applications in the marketplace (Panel 1). The purpose, then, is to contribute to a more coordinated and innovative European technology research and knowledge base by harmonising the type and extent of space technological work carried out at universities, and showing how universities and industry could be mutually beneficial to each other in encouraging entrepreneurship and in sharing long-term objectives.

Academic Research Programme

Universities and research centres have always been involved in ESA's Technology Research Programme (TRP) either by providing ideas or input, by obtaining direct contracts or by acting

Objectives of D/IMT Academic-Industry Cooperation Activities ***Panel 1***

The main objectives of the various academic-industry cooperation activities can be summarised as follows:

- exploring and improving conditions for synergy and exploitation of research results between universities and industry in order to stimulate innovation and excellence in basic research, thus ensuring European competitiveness in the longer term and enabling new space programmes
- enhancing regional cooperative programmes among universities and local entities by encouraging scientific and technical R&D groups in both academia and SMEs, not usually involved in space activities, to create partnerships and exchange knowledge to the benefit of the space effort and the local community.
- provide the basis for any necessary technical and institutional framework for an expanded role for ESA in fostering links between academia and industrial sectors.

as sub-contractors. Whilst the research resulting from this method of working has been worthwhile, it was felt that an additional impetus was required. Hence the establishment of Academic Research as one of the Technology Domains under the Technology Axes of the current Basic Technology Research R&D Programme (1997-1999), in order to complement and enhance earlier arrangements by emphasising industry(SME)-backed research in universities which would eventually become a capability-building effort.

The Academic Research Programme (ARP) should ideally concentrate on institutes of higher education which have a demonstrated competence and are able to offer a high rate of return – though this is not to say that universities which currently have little or no involvement in European space programmes would be precluded. Universities would be expected to conduct frontier research into space-related developments, which could be transferred into applications and exploited by local industry (SMEs) to the benefit of the European space programme, thus contributing to a stronger science and technology research and knowledge base. Such developments have the effect of raising the profile of research, transferring knowledge from the academic to the public or market domain, and fostering regional development.

Funding options

Various options under which the funds available from the Academic Research Programme could be allocated for unsolicited proposals from academic institutions in order to complement the existing participation of universities in the TRP have been explored. These included the following methods:

- Joint Academic/Industry Research Programme:
  Part of the funds could be used to establish a Joint Academic/Industry Research Programme whereby awards of e.g. 10 000 € would be given to a university researcher to collaborate with a local industrial partner. This seed funding would be matched by the university and/or industry. The aim would be to bring university researchers together with industrial researchers and technologists in highly innovative space R&D projects with significant economic (return on investment) development potential. It would have the effect of introducing top university scientists and engineers to real industry problems, and would give the region's smaller industries access to the high-tech, high-cost facilities at universities.

- Direct funding:
  Another way could be to provide funds directly to institutes of higher education in order to stimulate R&D in non-defined areas (i.e. in topics not initially suggested or defined by ESA). There could be two approaches – proposals from universities can be either unsolicited or solicited. In both cases, there would be some form of Announcement of Opportunity. This could be made in a number of ways:
  - via an Academic Research Activities home page on the Internet (linked via ESA pages such as the Industry home page or EMITS); this is likely to generate many responses (replies from non-European countries could be controlled) some of which, however, may be frivolous
  - via an announcement in the ESA Bulletin; this would go to a much smaller space oriented community and thus be more manageable. On the other hand, such an approach is likely to miss non-space oriented universities which are considered vital to the success of the activity
  - via TRP Technology Gatekeepers who could be asked to recommend

universities able to do research in given areas based on their experience; the university could then be approached to do solicited research or could be requested to make unsolicited proposals
- via university vice-chancellors; any general announcement is likely to generate several requests from different departments within a university. Since funds are limited, it might be useful to put the onus on the university itself to select proposals initially. The university vice chancellor (or equivalent) could be asked to solicit proposals on ESA's behalf, evaluate them and forward a maximum number to ESA.

Allocation of funds
Following discussion on the preceding options, the following approach was adopted as the initial scheme. Funds available under the Academic Research Programme are allocated in collaboration with the TRP Technology Gatekeepers. A selected number of these twenty or so staff members are issued with an Announcement of Opportunity (for contracts up to 50 k€) under which they are asked to find and recommend universities able to do innovative and breakthrough research in given areas based on their experience. The universities then make an unsolicited proposal involving, or endorsed by, a local SME. Such involvement can take the form of matching funds, provision of staff, making available research or marketing facilities, and so on. Funding is given for only one year's activity and the Technology Gatekeeper monitors the work.

Grants are given to universities (or research centres) as seed money for upstream research that ESA should not or cannot do itself, and a local industrial company (as user or applicator) is ideally identified and involved from the start. Equally, it should be research that the SME also cannot do by itself. Further, under the ARP, the proposals cannot be submitted by an SME even though it may want to work with a given university.

Although the SMEs do not receive direct funding from ESA at this stage, they can benefit by being able to avail themselves of the university's facilities, obtain visibility during the research phase by contributing to joint published papers, and being able to exploit and apply the research into marketable products and thus reap later rewards.

Based on their experience and contacts, the Technological Gatekeepers require prospective universities to submit a short proposal which principally includes: the background and introduction to the proposal; a statement of why the research is innovative and interesting or necessary for broad space use, and how it might be later applied and in what time scale; a concise description of the actual research to be undertaken, its estimated duration and cost, and details on the precise output to be achieved; and an indication of the interest, type and extent of involvement of the SME.

The Technological Gatekeepers make an initial assessment of the proposals and pass them, together with a recommendation on whether to accept or not, to the Academic Research Programme Coordinator who arranges for them to be further evaluated. Criteria for the acceptance of proposals include: novelty (breakthrough potential) and general usefulness of the research; the planned exploitation or application of the research at a later stage, the interest, suitability and relevance of the research for space; the priorities and balance indicated by ESA's Dossier 0; and the relationship proposed between the university and its SME partner. The development of a simplified small contract procedure means that, following acceptance, work can start almost immediately.

Within the constraints of the TRP budget, some 30 proposals for funding under the envelope for Academic Research have so far been received of which about 20 have been accepted. The funds requested varied from as little as 5 k€ in one case to 70 k€ in another, although the average amount given was 38 k€. Nearly all Member States have one or more universities receiving funds under the Academic Research Programme.

Other initiatives under the TRP

Academic Research Cooperation Programme
The Academic Research Cooperation Programme (ARCoP) is a follow-on initiative to the ARP. However, unlike the present ARP, where SMEs are not expected to receive direct funding from ESA, in the ARCoP programme only SMEs would be given the possibility to submit proposals, though preferably in cooperation with a university or research centre. An Announcement of Opportunity is expected to be issued in the first half of 1999 and it is anticipated that the proposals selected will be funded to a maximum of 30 k€ per proposal. Funding is not given to both a university or research centre and an SME for the same research project, and the same simplified procurement procedures developed for the ARP would be implemented.

Announcement of Opportunities for Technology
The Announcement of Opportunities for

Technology (AOT) within the current TRP has the objective of soliciting proposals from non-primes (including SMEs as well as universities and research centres) for the development of near-to-market products in the space domain in order to gain better positioning of new technologies in the commercial market. The AOT is essentially a partnership scheme involving ESA, industry and other European partners dedicated to improving the worldwide competitiveness of European industry, and leading to a significant and demonstrable improvement of space products close to market. The Announcement of Opportunity for Technology Innovation for 1998 resulted in some 21 proposals being selected for co-funding. It is expected that a new AOT will be available in the first half of this year. Although not aimed specifically at universities and research centres, such institutions are not discouraged from replying to the AOT.

Academic Research Pilot Initiative

Through its Directorate of Industrial Matters and Technology Programmes, ESA is undertaking a technology mapping exercise to be used as input to the European Space Technology Master Plan (ESTMP), which is being established in cooperation with the major players of the European space sector, namely space industry companies and national space agencies. One area that has to be addressed in this cooperation is that of universities and research establishments, as regards their research and development activities relevant to medium- and long-term space needs.

Through its Technology Research Programme, as well as other programmes such as the ARP, ESA does provide some funding for universities working in areas deemed to be of interest. However, the Agency would like to obtain a more complete picture of the space-related research and development actually being carried out in universities. An exercise is thus underway to map the European known technological priority requirements and future needs (as given in Dossier 0) with the current research in universities and research centres. The major objective of this ongoing Academic Pilot Research Initiative is to push for innovative R&D in order to prepare for the long-term competitiveness and capability of the European space industry. The results should prove useful to space agencies, industry and research sectors, serving to harmonise the type and extent of space technological research carried out in universities. Furthermore, they would clarify current academic research priorities, where redirection of effort or additional funding might be desirable, and reveal areas of technological research and development that could lead to innovations applicable to the space sector (Panel 2).

Given the enormity of what is essentially an in-house effort, rather than targeting all institutes of higher education and research establishments in the Member States, during December 1998 some 640 questionnaires were initially sent out to all the university departments given in the ESA Bidders List. To date 179 (28%) completed questionnaires have been returned from a total of 96 different university departments/institutes. Replies were received from all Member States except Denmark, though the number of returns was rather low from some other countries (particularly France and Sweden). Both Italy and the UK provided almost 50% response.

The results from an analysis of the questionnaires show the extent of cooperation between universities and other bodies: some 80% of respondents carry out their research activities with other partners – usually either another university, a research institute, or large industry. Most respondents had multiple partners and many of these partners were in different countries. Regarding funding of space technological R&D, many activities were co-funded or funded by the universities themselves. Roughly half of all the research activities were being undertaken without ESA funding. In fact, although ESA was a co-funder for 40% of the activities, only 14% were fully funded by ESA. The biggest source of funding was government departments or programmes – mainly in Italy, the UK and Germany. Other important sources of funding were large industrial companies and the EC. Although many of the topics where European requirements for prioritised technology R&D, as exemplified by Dossier 0, were being well-covered by academic research, others were not. Furthermore, research was ongoing in several areas where there were no apparent Dossier 0 requirements.

University-industry relations in the space domain

Background

In line with the overall activities for academic-industry cooperation, two parallel General Study contracts (50 k€ each) were run during 1998: one with the Technical University of Dresden (TUD) (D) working in conjunction with HTS GmbH (D) and JRA Aerospace and Technology Ltd. (UK), and the other with the Turku School of Economics and Business Administration (SF) also working in conjunction with JRA for coordination, monitoring and support. The overall goal of the studies was to eventually be able to contribute to a stronger

Mapping Technological Priority Requirements ***Panel 2***

The following tasks are to be undertaken within the framework of the three-step approach currently foreseen for the European Space Technology Master Plan (ESTMP):

Task 1 - Inventory
- map ESA's known technological priority requirements and future needs with current and planned research in European universities and research centres in the space technology field
- map existing cooperative relations and links between and among European universities and research centres, and the European space industry and SMEs
- identify the most effective methods and mechanisms for transferring the results of university space-related R&D and knowledge to the market place.

Task 2 - Prioritisation
- establish a priority list (with justifications) of technologies relevant to the European space effort and that are currently being, or could in future be, researched and developed in universities or research centres either alone or in conjunction with an SME or larger industry
- access these space-related technologies, as well as the university research and education process, against the four axes of European strategy as defined by ESA's Director General with the aim of building up university research activities in the space technologies
- compare space technology R&D, collaboration with industry and transfer to the market place at European universities with those of universities in the USA, Japan and elsewhere.

Task 3 - Synthesis
- determine whether current funding and cooperative mechanisms for academic research are adequate and what new approaches might be required (e.g. from ESA, industry, the EU, governments)
- review whether university curricula meet the needs of tomorrow's space technologists
- establish coordinated and harmonised planning of space-related technology R&D within European universities and research centres in line with the ESTMP.

University-Industry Relations Study Tasks ***Panel 3***

The following tasks constituted the major activities of the studies:
- conduct a review of the existing cooperative relations between universities on the one hand and industry (particularly SMEs) and research centres on the other, in space-related areas in ESA Member States
- examine and compare the methods and mechanisms (and their effectiveness) currently employed in Member States for transferring the results of university R&D in both scientific and technology domains to the marketplace - particular attention being paid to the transfer of space-related know-how, research and technologies
- identify current and on-going space-related research and developments in universities and ascertain whether such research is likely to be of benefit to ESA and European space industry in the short-, medium- and long-term
- identify and propose activities and promising areas of long-term research into topics from which future space missions could benefit, and which could then be conducted at universities, later proving beneficial to promote cooperation and information exchange between the universities and SMEs
- formulate requirements aimed at improving and facilitating the relations and interfaces between academic institutions on the one hand and industry (particularly SMEs) and research centres in space-related areas, as well as space agencies (including ESA) on the other
- ascertain what funding (e.g. grants, matching funds, seed money) might be required for university scientific and technical research activities needed by the European space industry; determine which universities could undertake the research, with whom and what (additional or proved) mechanisms are required to bring university space R&D efforts to the market place via local SMEs as rapidly as possible
- identify a number of initiatives, either on-going, planned, or newly proposed, being carried out either in universities that could be made into cooperative ventures (i.e. by teams from both a university and an SME in the same region) and that would be suitable to act as pilot projects in this context.

science and technology research and knowledge base by encouraging greater cooperation between universities and industry in the same region. The actual activities undertaken by the contractors are given in Panel 3.

The two study teams took different approaches to the tasks and concentrated on a different set of countries in order to avoid duplication and overlap. The TUD study, which covered the German-speaking ESA Member States (Germany, Switzerland and Austria), Russia and Eastern Europe, tended to be more 'horizontal' and quantitative, looking at relations between research groups according to the technology classification of Dossier 0. The research found that academic-industry relations were broadly aligned with requirements of the space industry and also identified university groups without much contact with SMEs.

To complement the Technical University of Dresden study, the geographical focus of the parallel Turku study was on the Western European countries and Scandinavia. The European Union and nine European countries (Belgium, Denmark, Finland, France, The Netherlands, Norway, Spain, Sweden, United Kingdom) and the technical universities within them were reviewed to identify the types of collaborative practices employed and encouraged. In addition, seven Asian countries (Hong Kong, India, Japan, Korea, Malaysia, Singapore, Taiwan) and the US were reviewed to determine what sort of support and mechanisms are being utilised in university-industry collaboration outside of Europe. The Turku study was a logical extension of the TUD study and was more 'vertical' and qualitative, addressing more practical issues associated with the establishment of university-SME partnerships.

Summary of study conclusions

The transfer and commercialisation of space technology presents opportunities to European industry to enhance its competitive standing in the global applications marketplace. The role of universities and SMEs in this process is becoming increasingly important, particularly with the widespread recognition of the abilities of SMEs to mobilise the outputs of university research and to provide the impetus for innovation. It was found that there was a disparity across Europe among both universities and SMEs in the activities currently practised which promote collaboration, and that the space-specific collaborative activities are limited in focus. Furthermore, SME-specific support is limited in both the university and space industry settings. What is required is new mechanisms to create opportunities to bring more space R&D innovative efforts in both science and technology at universities to the marketplace via industry as rapidly as possible.

A literature review of some 40 print sources and interviews with two dozen SMEs in Finland and the UK highlighted a number of key issues for these companies in participating in technology transfer and collaborative research activities. In particular, it was found that SMEs often lack the resources for space technology transfer, including financing, managerial and other human resource support. Possibly as a result of this, they typically tend to seek short-term (i.e. less than one year) business solutions. In addition, SMEs have different communication needs than larger enterprises, and rely more on personal contacts and print materials than their larger counterparts. They also prefer informal contracts, and mechanisms that are simple and familiar to them.

There is a clear need in Europe for a single information disseminator, especially for technology requirements, and an objective assessment of the support that can be provided to space and non-space companies by university-based space research groups. This clearly points to a requirement for mechanisms to promote long-term collaborative activities.

In the Turku study, nine such primary mechanisms were identified. An assessment of each mechanism was made to determine the long-term effectiveness in promoting continued university-industry collaborative relationships (based on criteria such as frequency, duration and scope of contact) and the level of contribution/inputs of the participants. Among the most effective mechanisms were collaborative research and exchange of personnel.

Whilst European countries and universities offered a similar breadth of programmes and support mechanisms as their counterparts in the US and Asia, there were some notable differences, for instance: the concept of an Industrial Liaison Office and the use of intermediaries is not standard practice in much of Europe. Furthermore, collaborative mechanisms that support long-term relationships and support services, which focus on business planning and strategy as well as technology development, are lacking in many European countries. Indeed, many support services in the US are provided on a fee-for-service basis, which could be adopted in Europe and work to minimise the need for government funds. Some areas of technology development in Asia are specifically reserved for SMEs, whereas support for SMEs in general is inconsistent across Europe. Industrial PhD programmes are gaining popularity in Europe, however, they have yet to prove their achievements and success in promoting collaboration.

A review of space agency support for university-industry collaboration was also completed utilising print and WWW information, as well as personal contacts. This review included agencies in the US, Japan, European Union, Belgium, Denmark, France, Spain, and the UK. Key findings for Europe were that gaps exist in SME support programmes and that there is a lack of focus on long-term programmatic support, such as access to facilities and technical/business expertise. In addition, awareness of space support programmes is irregular and nationalistic, and assessment of university space research capabilities is virtually non-existent. A strong 'big picture' provider and a road map for long-term research are also lacking.

Because it was determined that the existing mechanisms were insufficient for promoting the development of long-term university-industry collaborations in the space sector, two alternative collaboration mechanisms were developed and analysed. The first was a cluster model in which SMEs could be matched to individual university research groups to form a series of clusters, potentially fulfilling some future space technology requirement. Clustering among university research groups and businesses can provide not only informal links and collaborations that promote information sharing and long-term relationships across borders and sectors, but also a low initial investment collaboration option which is SME-friendly. A rationale and methodology for forming the clusters was developed, and a proposal was made for the formation of nine distinct clusters in seven different European countries. An association model was also developed which proposes that universities or intermediary organisations seek to establish a forum with businesses, in particular with SMEs, with the express purpose of investigating technology development and commercialisation opportunities within the space sector.

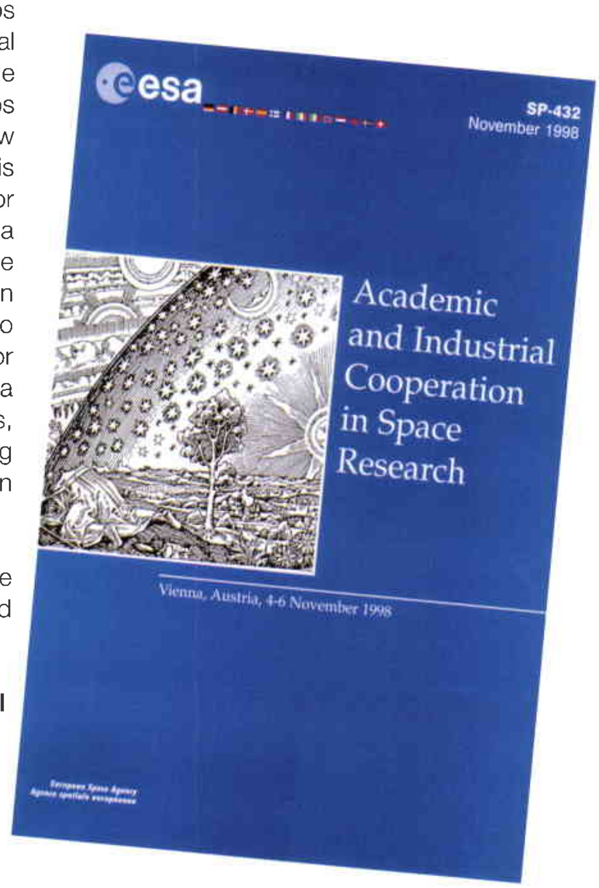
Resulting recommendations to ESA are discussed in the section 'Summary and Recommendations'.

Conference on Academic and Industrial Cooperation in Space Research

Background

The forgoing ESA assessment studies on university-industry relations provided useful input on issues requiring assimilation and discussion, and it was to this end that ESA organised a conference in Vienna, Austria from 4-6 November 1998. The main objectives of the conference were, firstly, to provide a stimulating forum for bringing together staff from universities, research centres and industry, particularly SMEs, with a view to presenting their collaborative leading-edge research activities, exchanging ideas, and discussing ways of enhancing medium- and long-term research cooperation, synergy and transfer in specific fields of interest to the space sector. Secondly, to explore what expanded role ESA should play in providing a framework for stimulating and fostering more collaboration leading to innovative and commercially-viable space applications. It was anticipated that the conference would provide recommendations for the formulation of policies and procedures for the transfer and use of research, knowledge and personnel in the space domain between universities, industry and ESA.

The conference was attended by some 100 delegates from virtually all ESA Member States as well as the US. Papers presented (contained in ESA SP-432) covered cooperative ventures between universities and industry, particularly SMEs, in a wide variety of initiatives including: joint development of, and flight opportunities for, scientific payloads; joint development of advanced technologies; transfer of technology and knowledge to industry; and building up of industrial capabilities.



Two hypotheses were advanced and addressed during the ensuing discussions. The first noted that the degree of interaction and cooperation between academia and industry has a profound influence on the competitive ability of the space community in all fields, i.e. from basic science to commercial applications. The second stated that we are far from the optimum in this respect in European space activities. The question then becomes: What can ESA, academia and industry do to improve the situation? A good deal of discussion took place on the topic of industrial and academic cooperation in space research (summarised below), and a number of recommendations were made (see section 'Summary and Recommendations').

The changing space industry

The space environment is changing, strongly affecting all players, i.e. the space industry, space agencies, SMEs, research establishments and universities. Space activities are also forcing transformation in the roles and interaction amongst the partners.

With the growing importance of space applications as essential contributors to the knowledge-based information society of the next century, the economic dimension of space is changing dramatically. Already today, the commercially-oriented space applications business counts on private investments, which exceed public space budgets – in fact, 1998 saw the production of more private than government-financed satellites. Space applications businesses are growing and have all the ingredients of becoming even bigger in the years to come. This can be attributed to industrial competitivity on a global scale, which has become the key driver for survival.

As a consequence, the roles played by space agencies will make the transition from exclusive leadership to genuine partnerships, and in the applications fields to one of supporting industry. Public-private partnerships will become the rule for many new ventures and will not remain mere exotic exceptions. Industry, in turn, will have to develop a more long-term strategic orientation, take more independent user and market-oriented initiatives, and invest while assuming the principle risks of business success or failure.

This era also opens new opportunities to SMEs with entrepreneurial spirit. Their flexibility, short response times, and cost effectiveness can put them in a strong position to corner a myriad of newly emerging market niches. Small satellite systems or ground equipment, for example, are becoming more powerful and less expensive, and today they can be afforded by many new customers and/or replace more complex solutions of the past.

Universities must respond to this new future and become proactive by adjusting their space curricula and research agendas. Research establishments must seek to open up to industry more than in the past and work in joint ventures with multiple partners. As knowledge update cycles continue to accelerate, more efficient interaction mechanisms between industry and academia could become survival issues for a number of players also in the space field.

Two paradigm shifts of fundamental importance to the conference were noted. One was that the fundamental changes in space activities and the space business are enormous – this has an effect on industry, society, the role of space agencies, public/private bodies, partnerships with industry and so on. The second was the shift from an industrial to a knowledge-based society with the need for closer cooperation in the development of new knowledge, coupled with a need for more rapid knowledge transfer and likely shorter knowledge update cycles. For example, telecommunications, navigation, remote sensing are all upgrading the knowledge base and enhancing society life, e.g. in agriculture, cartography, communications, etc. The challenge is to recognise, accept and respond adequately to these two paradigm shifts.

The university environment

Although the modern university is fundamentally an institution which conducts research and trains researchers, it does have other roles such as educating the population, providing education and training for industry and government, providing specialist consulting services, and acting as a think-tank. It has been noted, however, that the role of universities in research and high technology is decreasing in general and is often poor. There is a clearly a need to do something about this – mainly by universities becoming more involved with industry possessing fast market response times.

While most universities are undoubtedly excellent in specialist technical domains, they are also perceived to be unfamiliar with business cultures, shying away from real-world problems, good in information gathering but weak in knowledge transfer, and emphasising newness rather than efficiency. Universities are also often believed to exhibit poor evidence of cooperation on innovative, long-term frontier research partly because they advocate taking a step-by-step approach leading to incremental improvement rather than breakthroughs. In particular, and in so far as space research is concerned, more industrial integration is needed with university faculties.

In Europe, there has traditionally been a strong demarcation between the academic and industry worlds because of different cultures, motivations, mechanisms for getting things done, knowledge domains, etc. In the university community there are highly qualified professors, motivated graduates, flexible working arrangements and a concentration on mid- to long-term fundamental (and increasingly applied) research. In industry, the emphasis is more often on near-term research, strong financial and time constraints and rigid working rules. Often, industry lacks the ability to independently carry out highly specialised applied research.

Happily, the situation is gradually changing with collaboration in all areas of the space field and a new trend in small spin-off companies. There are three main areas of cross-fertilisation between industry and universities in so far as space programmes are concerned: space research, teaching and training. University staff could provide seminars and specialised courses in industry, e.g. continuous teaching in basic knowledge and specific, project-oriented training in state-of-the-art knowledge. Conversely, industry could bring its expertise and operations to universities by providing engineers to lecture to students and by having industry representation on the university board of advisors. Longer-term student immersion in industry (with e.g. a thesis as output) would be more beneficial than shorter-term (few weeks) to both students and industry.

These ideas imply new methods of education, which, in some institutions, are already taking place. For example, The University of Surrey is practising 'learning by doing'. TU Dresden is giving entrepreneurship courses to train undergraduates with, among others, skills in creating business plans. The International Space University takes post-graduate students and young professionals who are already well-educated in their own particular discipline and gives them a good foundation in all the other disciplines encountered during a space programme.

British Aerospace has invested in its own Virtual University under a Managing Director/Vice-Chancellor to meet the industrial challenges in an ever-changing environment. It is part of BAe's commitment to expand the knowledge base and build in a self-sustaining culture of learning and continuous improvement right across the company through education, training and research. In conjunction with partner universities, BAe is offering to staff an array of education and training programmes (many degree courses) containing a balance between academic content and the unique requirements of the company.

A rather more ambitious initiative is being undertaken by the Michigan Virtual Automotive College, which is a consortium linking the State of Michigan, Michigan's universities and the automobile industry. The idea is that MVAC will integrate the automotive education and training offerings of Michigan's higher education providers with the support services needed by local car manufacturers and suppliers to provide convenient, cost-effective, and high-quality automotive education and training. MVAC provides surveys and assessments of the automotive industry needs, and creates education and training programmes to ensure that the car industry is kept supplied with the correctly trained personnel.

Another instance is found in Sweden where a strategic research education programme on advanced instrumentation and measurements based at Uppsala University has been proposed to ensure that Swedish industry has access to highly qualified PhDs. There is also the European Consortium for Advanced Training in Aerospace, comprised of universities and major industrial companies, with the aim of educating and training aerospace engineers and scientists in areas of multi-cultural and international cooperation in an effort to improve European competitiveness in this field.

As part of the objectives to strengthen Europe's competitiveness and to have a more active role in the future of Europe, ESA is faced with challenges of reinforcing, in a pan-European manner, its contribution to promoting excellence in education in the space field and, in particular, in favouring the creation of a talented workforce needed for the 21st century. Additionally, it is charged with setting up strong and lasting partnerships amongst ESA, industrial and educational communities, and enhancing scientific and technological literacy in Europe. Meeting these objectives required the creation of a dedicated Office for Educational Project Outreach Activities. The Office will endeavour to promote the inclusion of space-related topics in the curricula of students at all levels, and to foster the creation of possibilities for students to actively work on space projects before graduating, thereby promoting space activities and preparing them for a career in the space field. In addition, students will be offered the opportunity to work on real projects together with professionals from ESA, national space agencies and European industry and will be made aware of technology available on the market or in its development stage, as well as how to evaluate it.

The industry environment
Several barriers and perceptions were identified that hinder the university-collaborative process in the space industry. Specifically, there is a common belief that space technology is too high-tech, over-engineered and complicated for 'real-life' application. Furthermore, the space sector is widely perceived by SMEs as a club which is difficult for them to penetrate, particularly with its reliance on consortia and prime contractor networks. The European space industry has, however, demonstrated a capability to reach businesses including SMEs through a variety of mechanisms including personal networks within the SPACELINK group, the distribution of the TEST catalogue of transferable technologies and the ESA web site. Although technology licensing tends to be the preferred method of transfer in the space community, it does not tend to promote long-term relationships. Additionally, communication gaps still exist between universities and SMEs – indeed, it is said that most SMEs are unaware of European university space research capabilities.

SMEs are considered as being excellent in their technical domain, though unfamiliar with academic research culture, unscientific in their approach and often as having only a vague perception of real-world problems. They are highly dependent on the acquisitional and administrative infrastructures of larger industrial partners. Their activities are often single-task based rather than having a strategic intent. SMEs could be an interface or catalyst between academia, large industry and space agencies in so far as R&D is concerned because they have simple organisational structures; offer motivated personal undertaking, inventiveness and intellectual capital; have a fast adaptive response to new market requirements and new technological concepts; and are flexible.

SME expectations from cooperation with universities could be seen as leading to new applications, providing a synergy effect in non-space related industry, as a prelude to establishing innovative teams (possibly at student level), as a way of attracting knowledge, and keeping qualified people. Currently there are too few PhDs attracted to industry and, thus, there is a need to guide academic research towards industry. Since industry felt it was not sufficiently represented on academic boards, then this is possibly one aspect to consider.

The relationship between industry and academia is changing. For instance, US industry is now attracted to NASA's Space Grant consortia not only because of the collaborative nature of the consortium and the positive political influence, but also because of the possibility to carry out high risk R&D for minimal cost. It also affords a single source of resident expertise, as well as employees with problem-solving experience. On the other hand, university attraction for US industry is the ability to tap industry for political, economic, human and infrastructure resources, and gain real-world expertise for faculty and students by enabling them to attend summer or academic internships in industry. In addition, universities are able to tap industry for mentors and use industry as a vehicle for technology transfer to reap the benefits of subsequent royalties.

Universities benefit from international partnerships and exchange opportunities because they are exposed to different ways of working. Besides benefiting from (space) industry's experience, students are provided with an opportunity to learn on the job and gain working experience before actually entering the workforce. In fact, industry wants more multi-disciplinary people to work in its ranks to provide a cross-fertilisation of research. Many industry applications benefit from leading-edge research, which in turn stimulates new applications.

Improving academic-industrial cooperation
Academic-industry relations are essential, not necessarily for the business case of today, but for that of tomorrow. A number of mutual benefits of academic-industry cooperation have been advanced:
- by expanding knowledge, industry can become more competitive
- industry fosters research by funding universities and research centres
- industry may be regarded as a link between the market and the scientific community and, thus, is able to transfer research results to operational products and universities get real-world testing of scientific models
- university labs can orient research as a function of the market
- industry encounters reduced R&D costs for innovation and new technology that can be translated into a significant competitive advantage in terms of quality and efficiency
- a richer industrial fabric would result from new spin-off SMEs.

Thus, there are advantages to both universities and industry to be gained with closer cooperation.

Of course, there are a number of potential pitfalls that need to be overcome. These include communication and cultural barriers, and the very different reasons for being in existence. Attention must be paid to ensuring respect for intellectual property rights and that industry secrets are not leaked to competitors. Equally, industry must not think that students and faculty can be used as a source of cheap labour. Instead, industry should contribute to motivate advanced research with, for example, appropriate award schemes.

Cooperation in some areas between universities and industry is happening naturally and no special measures are needed in these cases to facilitate or improve cooperation. In the biotechnology field, for instance, nothing happens without good cooperation between universities and industry – it is a natural process and more formal cooperation is probably unnecessary. On the other hand, in the space field, it would be very desirable to have a greater degree of cooperation particularly where SMEs are concerned.

Suggestions for successful cooperation between academia and industry include: establishing effective communication, finding areas of common interests and defining common problems, initiating solutions that benefit both partners – particularly public/private partnerships, more ESA funding for academia (e.g. for funding PhDs in innovative research fields) to induce other kinds of cooperation. Closer physical locations are also seen as an advantage – science parks have not generated close symbiotic relations. Integrated university/industry sites may also foster further exchange in staffing, e.g. academics working in industry. This could sharpen academic research with real applications, provide independent funding, enthuse and train a young generation of engineers in technology, as well as management and finance.

The European Universities Space Research Association: a proposal

ESA clearly has a role to play in fostering such cooperation. In light of its desire to reposition itself and enhance its role within the space community, it might be advantageous for ESA to initiate the creation of a European Universities Space Research Association (EUSRA). The proposed association would provide a mechanism through which universities and other institutes of higher education could cooperate more effectively, not only with one another, but also with ESA, national space agencies and the space industry at large.

A similar body, the Universities Space Research Association (USRA), set up as an independent consortium of universities and specifically oriented toward the problems of NASA, has been successfully functioning in the US for almost thirty years. Standing panels of scientific experts provide programme guidance in specific areas of research. Most of USRA's activities are funded by grants and contracts from NASA.

The Association of Aerospace Universities is a network of UK universities involved in aerospace teaching and research. It was formed in 1997 to enable universities to collaborate and promote courses, consultancy and research expertise, to strengthen links with the aerospace industry and commerce, and to develop relevant higher education provision.

Obviously, it will be necessary to gauge the interest of universities in the ESA Member States, but an initial survey has shown that no such European-level academic body specifically oriented to space activities exists at present, and that universities would welcome some form of organised cooperation.

The precise composition, management, activities and funding of the EUSRA would have to be discussed and formulated. There should be some form of a Board of Directors responsible for setting corporate policy, with one Board member being selected from each Member State and possibly including a representative from ESA, the EU and national space agencies. Each university or institute of higher education in the Member States wishing to join EUSRA would appoint a representative to serve on the EUSRA Council of Institutions which would oversee and sponsor collaborative programmes of research activities, conducted jointly by universities (possibly with local SMEs) and relating to the needs of the various space projects at European and national level, as well as the space industry itself.

ESA already funds research conducted at universities through a variety of programmes and means. This funding could be possibly be consolidated and channelled to/through the EUSRA. Additional funding could come from the EU, national space agencies, industry and, possibly, the universities themselves.

Summary and recommendations

General conclusions

There are many institutes of higher education and research with currently little or no involvement in European space programmes and which could develop useful synergy with them. Thus, a mechanism or framework which would bring such institutions into the space fold with the assistance of local small- and medium-sized enterprises (SMEs), while at the same time improving and reinforcing the overall contacts and relations between academic institutions and industry, would be a useful development. Furthermore, the support of industry in strengthening, expanding and enriching science/engineering curricula and improving educational capabilities, training opportunities and skills in space and related fields, is also a vital aspect. This would constitute a capability-building effort in line with the decision of the ESA Council at Ministerial Level to stimulate innovative capacity of European industry, paying special attention to SMEs. Universities could conduct research into space-related developments – particularly those at the cutting edge of technology (e.g. micro/nano technologies, superconductivity, interferometry, materials, energy sources, biogenetic applications, etc.) – which could be exploited by local space industry.

The motivation for the Vienna conference was to identify and discuss which mechanisms could be used for improving and harmonising innovation in space research especially between universities and industry. Universities have changed dramatically over the past twenty years – they support the industrial base more and still have a leading role to play in creating ideas and knowledge. While there are various degrees of cooperation between academia and industry with many examples of success stories, there are still too many scattered initiatives that could benefit from a wider harmonisation at European level.

ESA should foster new ways of thinking and collaboration. There needs to be a change in universities to some extent – a new kind of reward system, for example – and this requires also a cultural change to break through existing barriers. Communication, strategic and marketing channels are all needed as facilitators and graduates coming out of universities should not just have scientific/ technical knowledge, but also business, marketing, and entrepreneurial skills and understanding.

SMEs and universities do not have the resources to keep up with space programme needs and, therefore, ESA should promote these more and make its knowledge more readily available. Good communications are required, especially since universities have to promote themselves (through publications, research, etc.) and also need industry support. Successful cooperation should result in new applications and space developments with synergy effects in the non-space sector.

Recommendations

The two studies on university-industry relations in the space domain referred to earlier made a number of recommendations to ESA for improving the state of academic and industry cooperation (Panel 4). In addition, at the Vienna conference several other well-received general and specific recommendations were also made. Some of the more pertinent ones are detailed below.

It is abundantly clear that a role for the

Recommendations for General University-Industry Cooperation ***Panel 4***

- make the specific research capabilities and competencies of university departments better known
- encourage dual university-industry teams through specific budget lines (national/European levels)
- increase the number of national and European thesis grants earmarked for joint university-industry research
- industry should reserve a share of its R&D budget for joint university-industry research
- have internships in industry for PhDs/Masters with a focus on projects with universities
- reduce the intellectual barriers between universities and SMEs – this could be facilitated by entrepreneurship programmes at student (undergraduate) level between universities and SMEs
- improve communication links and generate resource support (human, financial, business)
- facilitate the matching process by having audits of university research departments with results available to SMEs and cluster complementary SMEs that could be partnered with university developments
- make more funding available for encouraging innovative university-industry commercialisation projects.

European Space Agency exists not only to raise the awareness of future space technology requirements amongst universities and SMEs, but also to provide market knowledge and reduce barriers to space industry entry, as well as to build an infrastructure in support of university-SME collaboration. Provision of such collaboration support would allow universities and businesses to focus on their core competencies and maximise resource utilisation.

In this context, one of the most immediate recommendations was that ESA should create some kind of Office for Academic Research Activities, within the Directorate of Industrial Matters and Technology Programmes, whose tasks are to promote and coordinate the Agency's academic-industry collaboration on R&D activities (such as the establishment of the EUSRA outlined above), map and monitor the innovative technological research conducted in universities, and ensure that such technological research is harmonised throughout the Member States in accordance with the ESTMP. Such an office would obviously work in close cooperation with those responsible for ESA's SME Initiative, as well as the Office for Educational Project Outreach Activities and PRODEX.

Other recommendations to ESA were that:

- mechanisms between ESA and the EU should be revisited and reinforced. Since the EU already has action plans involving universities-industry links in non-space areas (e.g. COMETT), then possibly ESA could use these mechanisms for training, research, teaching, etc., in the space field, and integrated into a unified policy and action plan. In addition, further harmonisation with other EU programmes (e.g. CRAFT) might reduce ESA budget needs, may reveal new SMEs not yet involved in space, and may improve access/relations to commercial markets. In this respect, ESA could run a funding scheme similar to, or perhaps even in concerted action with, the EU CRAFT programme, whereby groups of space oriented SMEs could be awarded funding to develop near-market technologies and products.

- ESA should make more information available and make it easier for universities to find out what industry does and needs. Examples could be the setting up of EUSRA, funding PhDs, workshops where universities can present their research and industry can say what their requirements are, technology fairs where short 'product/service presentations' could be given, and having a dedicated Academic Research Web page.

- ESA could establish a kind of supply chain review (i.e. identify all SMEs and university institutes that provide technologies or services to ESA contractors) to 'capture' the companies and institutes currently involved in space activities. ESA could provide funding on a competitive basis to supply the 'chain members' (SMEs and institutes) looking for development and expansion of their range of products and services, particularly through university-based contract research.

- ESA could co-fund regular technology audits within space SMEs in order to establish and consolidate its long-term technology needs. Using the outputs of these activities, ESA could then direct the SMEs to university research groups in their country that could help to promote, and permanently upgrade, their technological base, either through technology transfers or contracted research.

The ESA Department of Industrial Matters and Technology Programmes is giving active consideration to these recommendations and will shortly ascertain whether the European space sector should elaborate priorities and strategies on long-term innovative and harmonised technological research in universities and research centres. If so, it will determine the criteria to be adopted in distributing the work plans of a coordinated/cooperative European space research programme.

Ten Years of Fundamental Physics in ESA's Space Science Programme

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On 15 June 1989, ESA's Science Directorate issued a Call for Mission Proposals which specifically also asked for proposals in fundamental physics. In response to this Call the scientific community submitted five proposals aimed at detecting gravitational waves, testing the Equivalence Principle, measuring the gravitational constant with high precision, and searching for the elusive Fifth Force and for Dark Matter in the Universe. Today, 10 years later, the new field of fundamental physics in space has matured with one mission (GP-B) about to be launched by NASA, two industrial studies (LISA, STEP) in progress this year in ESA at Phase-A level, and several other experiments either flying or being readied for flight, including experiments on the International Space Station. There is clearly now a community of fundamental physicists in Europe in need of space flight opportunities, just as there are communities of astronomers and Solar System scientists. The only difference is that the technologies enabling meaningful fundamental-physics missions have only became available 30 years later.

Early days

In the beginning, ESA's Space Science Programme (actually ESRO's in those days) consisted only of small magnetospheric satellites. ESRO-II, ESRO-IA, HEOS-1, ESRO-IB, HEOS-2 and ESRO-IV were launched between 1968 and 1972, addressing primarily problems in plasma physics. Throughout the 1970s, Solar System exploration continued to be limited to magnetospheric research, with the launches of GEOS-1 and -2 and ISEE-2. The first astronomy satellites (TD-1, COS-B and IUE) were launched between 1972 and 1978, making observations at UV, X- and γ-ray wavelengths.

There was also interest in fundamental-physics missions in those early days. COPERS (the Commission Préparatoire Européenne de Recherche Spatiale, which existed from December 1960 until March 1964) planned eight ad-hoc groups, representing the main fields in space science at that time, among them a group on Geodesy, Relativity and Gravitation; this group was, however, not realised when ESRO came into existence in 1964. A far-sighted Italian proposal in 1964 suggested that ESLAR (the predecessor of ESRIN) should study drag-free satellites, a key technology required for fundamental-physics missions. This early phase culminated in the Phase-A study of the SOREL (Solar Relativity) mission in 1970-71. The goal of the SOREL mission was to measure:

- the gravitational redshift to 3 parts in 10^6
- the time delay and deflection of laser light passing close to the Sun
- the solar quadrupole moment J_2.

This required a spacecraft that would be drag-free to the level of 10^{-12} m/s^2, and in the one-way laser option a high-precision on-board clock (caesium or hydrogen-maser clock) and in the two-way laser option an on-board laser. None of these technologies existed at that time and would have had to be developed and space-qualified at considerable cost. It was mostly for that reason that the plans for the SOREL mission were not further pursued.

The existence of three distinctly different fields in space science in the 1970s was also reflected in ESA's scientific advisory structure at that time. It consisted of the Launching Programmes Advisory Committee (LPAC, the predecessor of today's SSAC) and the

- Solar System Working Group (SSWG)
- Astrophysics Working Group (AWG)
- Fundamental Physics Panel (FPP).

The FPP had ten members, among them a former Director General of ESRO (H. Bondi) and a later Director General of ESA (R. Lüst). However, the founding fathers of 'Fundamental Physics in Space' soon realised that the technology needed to carry out high-precision experiments in space did not yet exist and the Panel became inactive after 1979. The SSWG and the AWG still exist today.

Composition of ESA's Fundamental Physics Panel (1971-1979)

H. Bondi (Chairman)	R. Lüst
J. Blamont	G. Occhialini
G. Cocconi	I.W. Roxburgh
G. Colombo	E. Schatzman
B. Laurent	D. Sciama

In 1972, the Italian Physical Society organised a summer school in Varenna devoted to Experimental Gravitation. The Proceedings, published in 1974, give an excellent account of the state of the art at that time and include papers not only on the SOREL mission, but also on redshift experiments using high-precision clocks such as Gravity Probe A, the gyroscope experiment (later named Gravity Probe B), the STEP mission, several methods to detect gravitational radiation and the technique of drag-free satellites.

With the launch of Giotto in 1985, ESA's Solar System exploration began to include the exploration of the solid bodies — first comet Halley, and later, with the launch of the Huygens probe in 1997, the Saturnian moon Titan. Missions to the Moon, Mars and Mercury are now under study. Solar physics was added with the launch of Soho in 1995.

Astronomy saw the addition of the new field of astrometry with the launch of Hipparcos in 1989, and ISO, launched in 1993, opened up the possibility of observations in the infrared.

Fundamental physics as a science discipline in its own right was also included in ESA's Long-Term Space Science Programme 'Horizon 2000' (ESA SP-1070) with a chapter on Space Experiments in Relativity and Gravitation by I.W. Roxburgh. The paper does not describe a specific mission in fundamental physics, but lists several possibilities for including fundamental physics experiments on suitable Solar System missions, such as Mercury Orbiter, Solar Probe or a mission to the outer planets. Concerning gravitational waves Roxburgh wrote (in 1984):

'At present we are unable to predict with any confidence the strengths of any such waves passing through the Solar System, but the successful discovery of such waves could be of immense significance for gravitational physics and for astrophysics'.

In 1987, the Austrian Space Agency together with ESA organised a summer school in Alpbach devoted to 'Space Science and Fundamental Physics'. The Proceedings of that summer school (ESA SP-283) include several papers describing future missions in fundamental physics, such as a test of the Equivalence Principle and the detection of gravitational waves with long-baseline interferometers in space.

Restarting fundamental physics in space

With the discontinuation of the FPP in ESA's science advisory structure in 1979, the possibilities of realising a fundamental-physics mission in ESA essentially disappeared and interest within the Agency in fundamental physics almost completely vanished. This changed in the late 1980s with the enunciation of the 'fifth force' hypothesis by E. Fischbach and co-workers, triggering a suite of highly publicised experiments worldwide and calling attention to the fact that gravity, itself the 'oldest' of the known forces, was in some ways also the least understood. A 'fifth force', coexisting with conventional gravity, would lead to a net interaction between macroscopic bodies, which would show small deviations from the behaviour expected from the classical Newtonian inverse-square law of gravity. If such a force were to exist, it would be very small and possibly easier to detect in a gravitationally less disturbed experiment in space.

Fundamental Physics in Space

The field of 'Fundamental Physics in Space' includes those research activities in gravitational and particle physics aimed at finding new, more comprehensive concepts and laws, the testing of existing ones, and the resolution of some very basic inconsistencies. This includes:

- the direct detection and detailed analysis of gravitational waves
- the investigation of possible violations of the Equivalence Principle
- the search for new hypothetical long-range forces
- the testing of General Relativity and its alternative theories
- the unification of the fundamental interactions of nature
- particle physics, in particular the search for antimatter in space
- the development and fundamental application of space-based ultrahigh-precision atomic and other clocks.

The technologies used in fundamental-physics experiments (e.g. high-precision accelerometers), the requirements on spacecraft, and the high degree of spacecraft/experiment interrelationship are distinctly different from missions in Solar System exploration and astronomy. For example, fundamental-physics spacecraft typically have to be in purely gravitational orbits, i.e. they have to be drag-free.

ESA's Call for Mission Proposals for the second medium-size project (M2) within the framework of ESA's Long-Term Space Science Programme 'Horizon 2000' was issued on 15 June 1989. It specifically also asked for proposals in fundamental physics. In response to this Call, five proposals were submitted in the field of fundamental physics (out of a total of 22):

- a mission to detect and observe gravitational waves
- a Satellite Test of the Equivalence Principle (STEP)
- Newton, a man-made 'planetary system' in space to measure the Constant of Gravity G
- GRAVCON, an experiment to measure the Constant of Gravity G
- APPLE, a proposal for the determination of the Fifth Force and the detection of Dark Matter in the Universe.

Of these five proposals, STEP and Newton were given the highest priority by the 'Ad-hoc Working Group on Fundamental Physics'. However, only STEP was selected by the SSAC on 9 February 1990 for study at Assessment Level. Later, in mid-1990, the STEP payload was enlarged by incorporating the scientific objectives of Newton and GRAVCON.

The renewed interest in fundamental physics may have been triggered in ESA by the curiosity about the 'fifth force', but what was not perhaps fully realised at that time was that, unlike in the 1970s, in the early 1990s the technologies for carrying out meaningful fundamental-physics missions had in the meantime become available. Key technologies, such as high-precision accelerometers, drag-free control using He-proportional thrusters or small ion thrusters, ultra-stable lasers in space, He-dewars, high-precision displacement sensors (SQUIDs), magnetic spectrometers, small lightweight H-maser clocks and atomic clocks using laser-cooled caesium atoms had been developed and were either already space-qualified or about to be space-qualified. Already in 1976, NASA sent an H-maser clock to an altitude of 18 000 km on a suborbital rocket flight (Gravity Probe A) to test Einstein's 'clock gravitational frequency shift' formula (the clock on the rocket appears to run faster than the one on the ground). NASA's Gravity Probe B (GP-B), to be launched in October 2000 into a polar orbit at 650 km altitude, will test two predictions of Einstein's theory of General Relativity — geodetic precession and frame-dragging precession — to 1 part in 10^5 and 400, respectively. For GP-B several key technologies had to be developed which are now available for other fundamental-physics missions.

The STEP mission

STEP was proposed to ESA in November 1989 by a team of scientists from Europe and Stanford University. Work at Stanford on the design of the STEP experiment had already begun much earlier, in 1971. The original proposal comprised three accelerometer systems accommodated in a cryogenic dewar to test the Equivalence Principle to a precision of 1 part in 10^{17}, along with a limited geodesy co-experiment and an aeronomy co-experiment. The boil-off helium from the dewar would be used to feed small proportional thrusters to compensate for the drag of the residual atmosphere at orbital (~ 500 km) altitude.

This proposal was studied as an ESA/NASA collaborative project in 1991 at Assessment level and in 1992 at Phase-A level. In the end it was not selected as the M2 project and was subsequently re-proposed in May 1993 as a candidate for the third medium-size project (M3). During the M3 cycle, STEP was studied again at Assessment and Phase-A levels, this time as a European-only project. Again, it was not selected as a flight project because at the time of the selection (April 1996) there were other proposals in the scientific community aimed at achieving STEP's main scientific objective, a test of the Equivalence Principle, at much lower cost and even higher precision. A 20 M€ contribution by ESA to a NASA-led STEP project with a launch in 2004 is now included in ESA's Space Science Programme. ESA's contribution to the project is envisaged to be the Service Module and possibly a few other elements. The Service Module design is presently the subject of a four-month industrial study.

The Equivalence Principle postulates the equivalence between inertial and gravitational mass or, stated differently, that bodies of different mass and/or composition fall with the same acceleration in a gravitational field. This contention cannot be proven, it can only be tested to higher and higher precision. The most precise ground-based tests today have achieved a precision of 1 part in 10^{12}. Experiments on the ground are limited at this level because of unshieldable seismic noise and the weak driving acceleration. In space, this test could be done a factor 10^6 more precisely.

Einstein generalised the Equivalence Principle and made it the foundation of his theory of General Relativity. A violation of the Equivalence Principle at some level would either require a modification of Einstein's theory or constitute the discovery of a new force. There are, in fact, good reasons to believe that General Relativity is not the ultimate theory of gravity. Gravitation, electromagnetism and the weak and strong interactions are the four known fundamental forces of Nature. Einstein's theory of gravity, General Relativity, provides the basis for our description of the Big Bang, the cosmological expansion, gravitational collapse, neutron stars, black holes and gravitational waves. It is a 'classical', non-quantum field theory of curved space-time, constituting an as yet unchallenged description of gravitational interactions at macroscopic scales. The other three interactions are dealt with by a quantum field theory called the 'Standard Model' of particle physics, which accurately describes physics at short distances where quantum effects play a crucial role. But, at present, no realistic theory of quantum gravity exists. This fact is the most fundamental motivation for pursuing our quest into the nature of gravity.

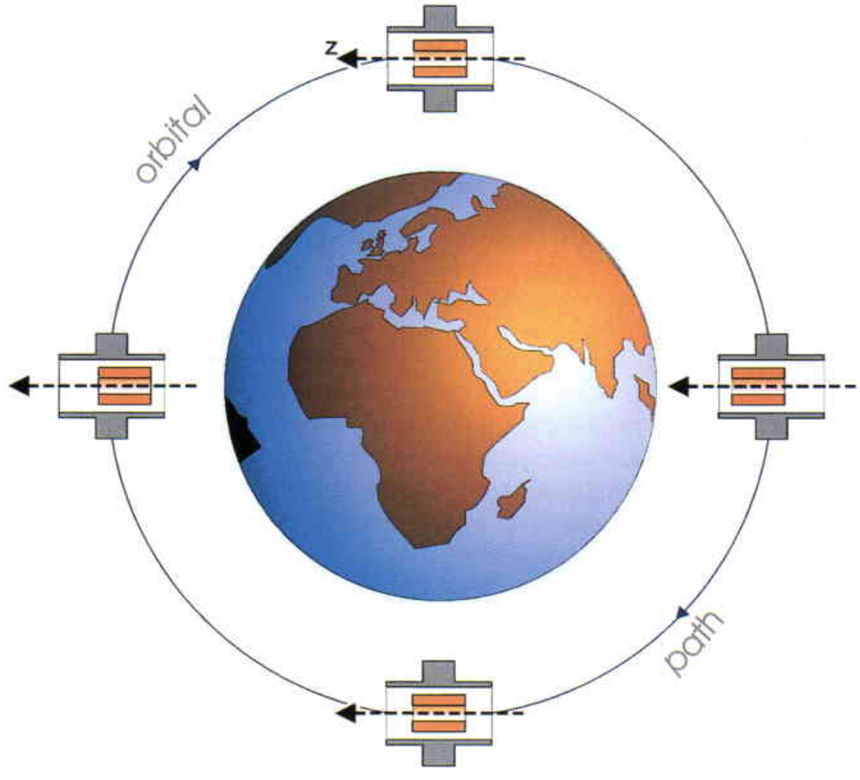


Figure 1. Relative motion of two concentric cylindrical test masses in the case of an Equivalence Principle (EP) violation. The masses are constrained to one-dimensional motion. In this example the inner test mass falls faster towards the Earth. The EP violation signal is periodic at orbital frequency

The Standard Model successfully accounts for all existing non-gravitational particle data. However, just as in the case of General Relativity, it is not a fully satisfactory theory. Its complicated structure lacks an underlying rationale. Even worse, it suffers from unresolved problems concerning the violation of the charge conjugation parity symmetry between matter and antimatter and the various unexplained mass scales. Purported solutions of these shortcomings typically involve new interactions that could manifest themselves as apparent violations of the Equivalence Principle.

The truly outstanding problem remains the construction of a consistent quantum theory of gravity, a necessary ingredient for a complete and unified description of all particle interactions. Super-string theories — in which elementary particles would no longer be point-like — are the only known candidates for such a grand construction. They systematically require the existence of spinless partners of the graviton: dilatons and axion-like particles. The dilaton, in particular, could remain almost massless and induce violations of the Equivalence Principle at a level that — albeit tiny — may well be within STEP's reach.

The simplest way of testing the Equivalence Principle would be to throw two masses (e.g. spheres) of different composition from a high tower and measure any difference in the arrival time on the ground (taking into account the effect of air resistance). Galileo was, for a long time, reputed to have performed such an experiment from the Leaning Tower of Pisa although, as we know today, he never actually did so himself.

The STEP Project is the modern version of this experiment. The test masses are placed inside a satellite in low-Earth orbit, where they 'fall around the Earth' (Fig. 1). In this way, the test masses never strike the ground, and any difference in the rate of fall can build up over a long time period. In Earth orbit the signal is periodic and the experiment can be repeated several thousand times during the mission lifetime. However, even at 500 km altitude, the density of the Earth's atmosphere is sufficient to brake the satellite and to disturb the experiment. The satellite must therefore compensate for the braking by firing a combination of proportional thrusters so that the satellite is 'drag-free' and the test masses inside are free-floating and follow a purely gravitational orbit.

The test masses are in the form of hollow cylinders whose axes are centred on each other to eliminate any disturbances from the Earth's gravity gradient. Any differential motion of these two test masses is sensed by coils coupled to SQUID (Superconducting Quantum Interference Device) magnetometers, forming a super-conducting differential accelerometer. The SQUIDs can detect any differential motion of the two typically 500 g test masses with a sensitivity of 10^{-15} m, the diameter of the nucleus of an atom. To sample a variety of test-mass materials, STEP carries four such differential accelerometers.

The payload chamber is accommodated inside a superfluid helium dewar, which cools the payload to 1.8 K. The cryogenic dewar is mounted below a three-axis-stabilised, drag-free spacecraft (Fig. 2) which uses the helium boil-off from the dewar to feed a number of proportional thrusters to compensate for the residual air drag at orbital altitude. STEP's orbit is circular and at low altitude (~500 km). A Sun-synchronous (i.e. almost polar) orbit was chosen to avoid eclipses, thus providing a highly stable thermal environment throughout the mission lifetime of 6-8 months. During flight, the spacecraft rotates about its long axis at a small multiple of the orbital frequency, in order to spectrally shift the science signal from orbit-fixed systematic error sources.

The LISA mission

The primary objective of the LISA (Laser Interferometer Space Antenna) mission is the detection and observation of gravitational waves from massive black holes and galactic binaries in the frequency range $10^{-4} - 10^{-1}$ Hz. This low-frequency range is inaccessible to ground-based interferometers because of the unshieldable background of local gravitational noise and because ground-based interferometers are limited in length to a few kilometres.

The ground-based interferometers LIGO, VIRGO, TAMA 300 and GEO 600, with baselines from 0.3 to 4 km and the LISA interferometer in space, with a baseline of 5 million km, complement each other in an essential way. Just as it is important to complement the optical and radio observations from the ground with observations from space at submillimetre, infrared, ultraviolet, X-ray and gamma-ray wavelengths, so too is it important to complement the gravitational-wave observations made by the ground-based interferometers in the high-frequency regime (10 to 10^3 Hz) with observations in space in the low-frequency regime.

Ground-based interferometers can observe the bursts of gravitational radiation emitted by galactic binaries during the final stages (minutes and seconds) of coalescence, when the frequencies are high and both the amplitudes and frequencies increase quickly with time. At low frequencies, which are only observable in space, the orbital radii of the binary systems are larger and the frequencies are stable over millions of years. Coalescences of massive black holes are only observable from space. Both ground- and space-based detectors will also search for a cosmological background of gravitational waves. Since both kinds of detectors have similar energy sensitivities, their different observing frequencies are ideally complementary: observations can provide crucial spectral information.

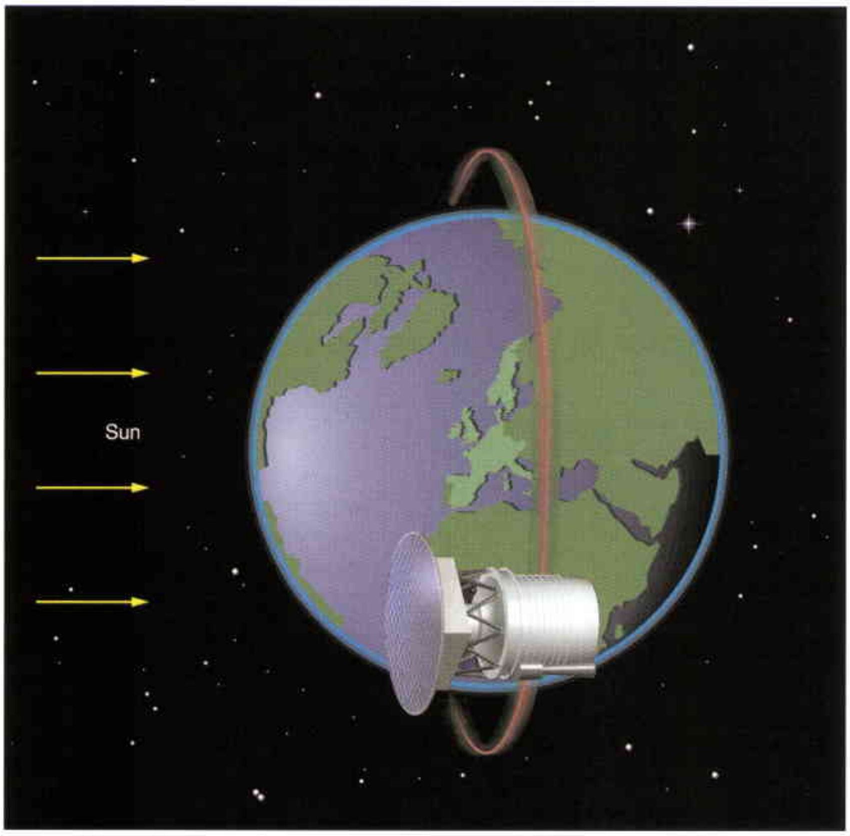


Figure 2. The STEP spacecraft in low-Earth, Sun-synchronous orbit at 500 km altitude

In Newton's theory, the gravitational interaction between two bodies is instantaneous, but according to Einstein's theory of gravity this should be impossible because the speed of light represents the limiting speed for all interactions. If a body changes its shape, the resulting change in the force field will make its way outward at the speed of light. In Einstein's theory of gravity massive bodies produce 'indentations' in the 'fabric' of space-time and other bodies move in this curved space-time taking the shortest path. If a mass distribution moves in a spherically asymmetric way, then the indentations travel outwards as ripples in space-time called 'gravitational waves'.

Gravitational waves are fundamentally different from the familiar electromagnetic waves. While the latter, created by the acceleration of electric charges, propagate in the framework of space and time, gravitational waves, created by the acceleration of masses, are waves of the space-time fabric itself. Unlike charge, which exists in two polarities, mass always comes with the same sign. This is why the lowest-order asymmetry producing electromagnetic radiation is the dipole moment of the charge distribution, whereas for gravitational waves it is a change in the quadrupole moment of the mass distribution. Hence those gravitational effects that are spherically symmetric will not give rise to gravitational radiation. A perfectly symmetric collapse of a supernova will produce no waves, whilst a non-spherical one will emit gravitational radiation. A binary system will always radiate.

Gravitational waves are a direct consequence of Einstein's theory of General Relativity. If that theory is correct, gravitational waves must exist, but up to now they have not been detected. There is, however, strong indirect evidence for the existence of gravitational waves: the binary pulsar PSR 1913+16 loses energy exactly at the rate predicted by General Relativity through the emission of gravitational radiation.

Gravitational waves distort space-time: in other words, they change the distances between free macroscopic bodies. A gravitational wave passing through the Solar System creates a time-varying strain in space that periodically changes the distances between all bodies in the Solar System in a direction perpendicular to that of wave propagation. These could be the distances between spacecraft and the Earth, as in the case of Ulysses or Cassini (attempts have been and will be made to measure these distance fluctuations) or the distances between shielded proof masses inside widely separated spacecraft, as in the case of LISA. The main problem is that the relative length change due to the passage of a gravitational wave is exceedingly small. For example, the periodic change in distance between two proof masses, separated by a sufficiently large distance, due to a typical white-dwarf binary at a distance of 50 pc, is only 10^{-10} m. This does not mean that gravitational waves are weak in the sense that they carry little energy. On the contrary, a supernova in a not too distant galaxy will drench every square metre here on Earth with kilowatts of gravitational radiation intensity. The resulting length changes, though, are very small because space-time is an extremely stiff elastic medium, so that extremely large energies are needed to produce even minute distortions.

It is because of the extremely small distance changes that gravitational waves have not yet been detected. However, with the LISA space interferometer, orbiting the Sun at 1 AU, millions of sources will be detected in one year of observation with a signal-to-noise ratio of 5 or better. The LISA mission comprises three identical spacecraft located 5×10^6 km apart forming an equilateral triangle (Fig. 3). The distance between the spacecraft — the interferometer arm length — determines the frequency range in which LISA can make observations; it was carefully chosen to allow for the observation of most of the interesting sources of gravitational radiation. The centre of the triangular formation is in the ecliptic plane, 1 AU from the Sun and 20° behind the Earth. The plane of the triangle is inclined at 60° with respect to the ecliptic. These particular heliocentric orbits for the three spacecraft were chosen such that the triangular formation is maintained throughout the year, with the triangle appearing to rotate about the centre of the formation once per year.

While LISA is basically a giant Michelson interferometer in space, the actual implementation in space is very different from a laser interferometer on the ground and is much more reminiscent of a 'spacecraft tracking' technique, but then realised with infrared laser light instead of radio waves. The laser light going out from the centre spacecraft to the other corners is not directly reflected back because very little light intensity would be left over that way. Instead, analogous to an RF

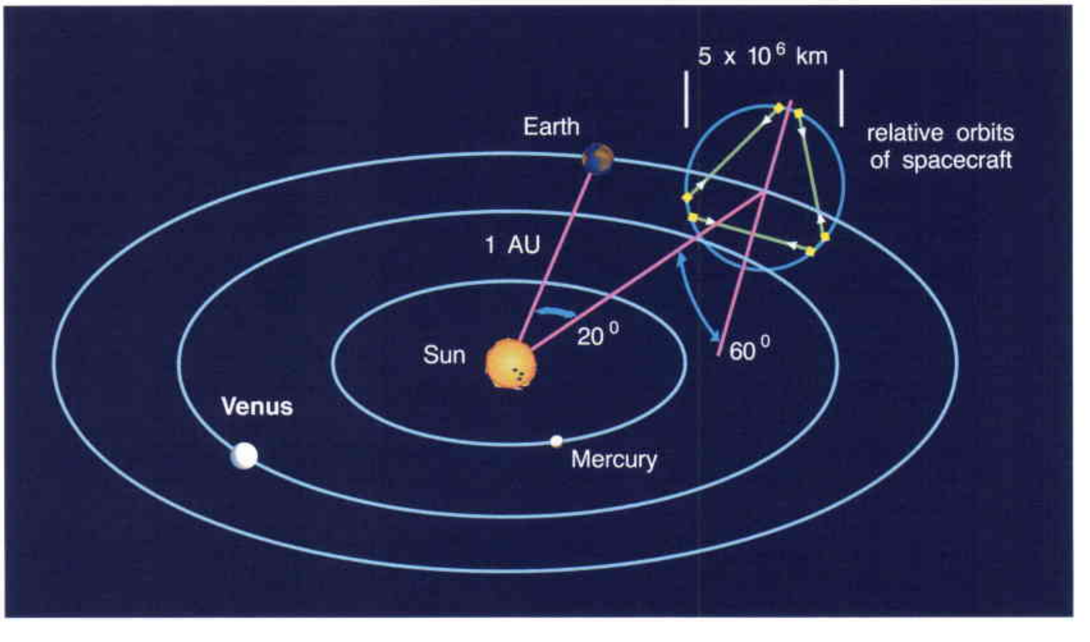


Figure 3. Schematic of the LISA configuration (not to scale). Three distant satellites linked by infrared laser beams form a giant 5 million km triangular interferometer, which is sensitive to fluctuations in the separations between the satellites caused by gravitational waves. The plane of the triangle is tilted by 60° out of the ecliptic

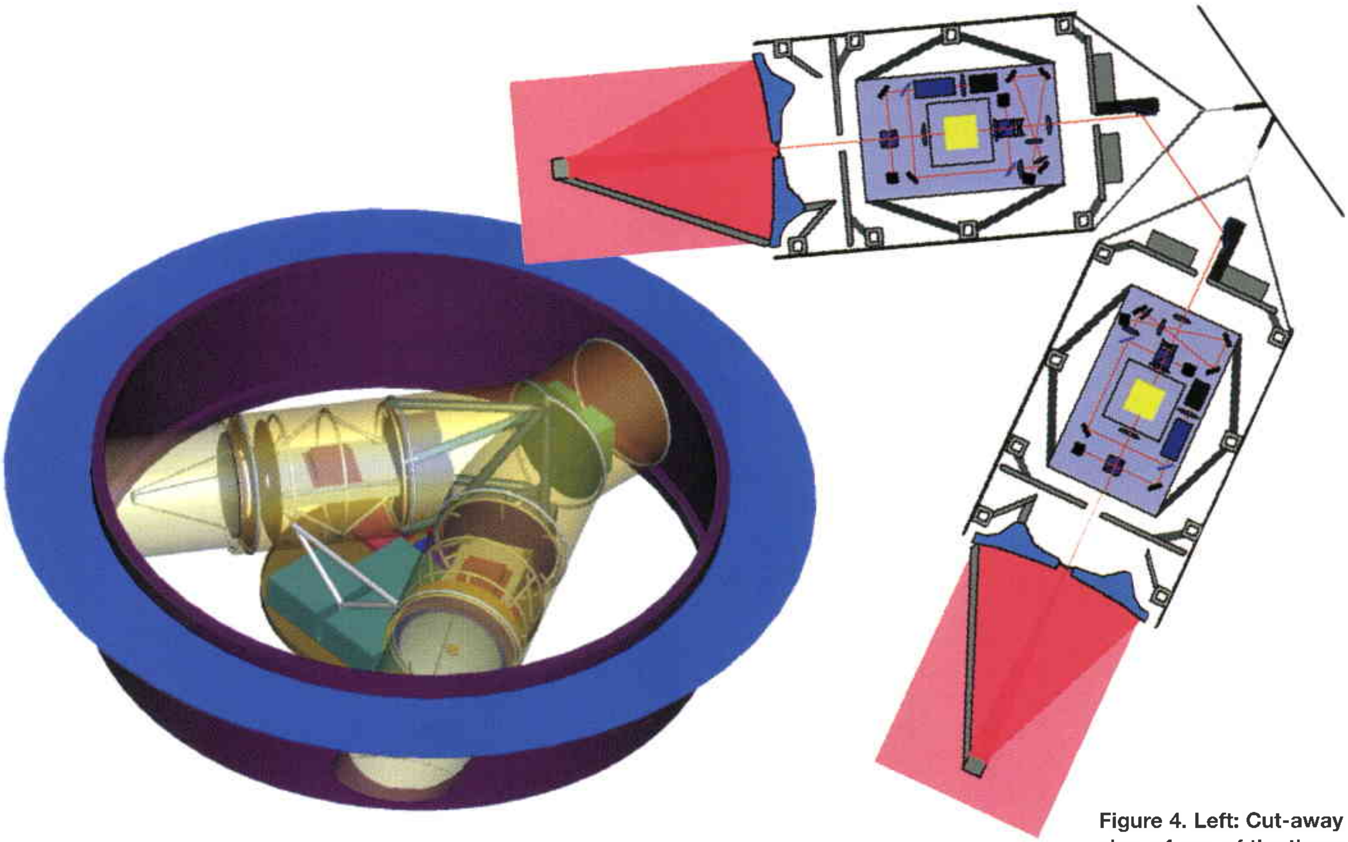


Figure 4. Left: Cut-away view of one of the three identical LISA spacecraft. The main structure is a ring with a diameter of 1.8 m and a height of 0.48 m, made from graphite-epoxy for low thermal expansion. A lid on top of the spacecraft is removed to allow a view of the Y-shaped payload.
Right: Detail of the payload on each Y-shaped LISA spacecraft, consisting of two identical telescopes and two optical benches each housing a drag-free test mass (the yellow cubes in the centres)

transponder scheme, the laser on the distant spacecraft is phase-locked to the incoming light providing a return beam with full intensity again. After being transponded back from the far spacecraft to the centre spacecraft, the light is superposed with the on-board laser light serving as a local oscillator in a heterodyne detection.

Each spacecraft contains two optical assemblies (Fig. 4). The two assemblies on one spacecraft each point towards an identical assembly on each of the other two spacecraft. A 1 W infrared laser beam is transmitted to the corresponding remote spacecraft via a 30-cm aperture f/1 Cassegrain telescope. The same telescope is used to focus the very weak beam (a few pW) coming from the distant spacecraft and to direct the light to a sensitive photodetector, where it is superimposed with a fraction of the original local light. At the heart of each assembly is a vacuum enclosure containing a free-flying polished platinum-gold cube, 4 cm in size, referred to as the 'proof mass', which serves as an optical reference ('mirror') for the light beams. A passing gravitational wave will change the length of the optical path between the proof masses of one arm of the interferometer relative to the other arm. The distance fluctuations are measured to sub-Angstrom precision which, when combined with the large separation between the spacecraft, allows LISA to detect gravitational-wave strains down to a level of order $\Delta l / l = 10^{-23}$ in one year of observation.

The spacecraft mainly serve to shield the proof masses from the adverse effects due to the solar radiation pressure, and the spacecraft position does not directly enter into the measurement. It is nevertheless necessary to keep all spacecraft moderately accurately ($10^{-8}\,\mathrm{mHz}^{-1/2}$ in the measurement band) centred on their respective proof masses to reduce spurious local noise forces. This is achieved by a 'drag-free' control system, consisting of an accelerometer (or inertial sensor) and a system of ion thrusters. Capacitive sensing is used to monitor the relative motion between each spacecraft and its test masses. These position signals are used in a feedback loop to command micro-Newton ion-emitting proportional thrusters, to enable the spacecraft to follow its test masses precisely and without introducing disturbances in the bandwidth of interest. The same thrusters are used for precision attitude control relative to the incoming optical wave fronts.

Each of the three LISA spacecraft has a launch mass of about 460 kg (incl. margin). Ion drives are used for the transfer from the Earth orbit to the final position in interplanetary orbit. All three spacecraft can be launched by a single Delta II 7925H.

LISA was proposed to ESA in May 1993 in response to ESA's Call for Mission Proposals for the third Medium-Size Project (M3). The proposal was submitted by a team of American and European scientists who envisaged LISA as an ESA/NASA collaborative project. The mission was conceived as comprising four spacecraft in a heliocentric orbit forming an interferometer with a baseline of $5x10^6$ km.

LISA was selected for study as an ESA-only project, but it became clear quite early in the Assessment Phase that it was not likely to be a successful candidate for M3 because the cost for an ESA-only LISA considerably exceeded the M3 limit of 350 M€. In December 1993, LISA was therefore re-proposed to ESA, this time as a Cornerstone project for 'Horizon 2000 Plus', involving six spacecraft in a heliocentric orbit with a pair of spacecraft at each vertex of an equilateral triangle. Both the Fundamental Physics Topical Team and the Survey Committee realised the enormous discovery potential and timeliness of the LISA Project and recommended it as the Third Cornerstone for 'Horizon 2000 Plus'. However, the Survey Committee also noted that the inclusion of LISA as a Cornerstone *'will require a modest increase in the funding of the ESA Scientific Programme beginning in 2001'*.

Being a Cornerstone in ESA's Space Science Programme implies that, in principle, the mission is approved and that funding for industrial studies and for technology development is provided right away. The launch year, however, is dictated by scientific priorities and the availability of funding. Considering realistic funding scenarios for ESA's Space Science Programme, LISA could probably only be launched after the other two Cornerstones of Horizon 2000 Plus, namely Mercury Orbiter and Interferometry (either GAIA or IRSI), i.e. after 2017. Because of the large inequality between the ESA and NASA science budgets, it must then be expected that even the most optimistic opportunity for ESA to launch the LISA Cornerstone will be pre-empted by an earlier NASA mission. For this and several other reasons, it was decided in January 1997 to put LISA on an equal footing with the other two Cornerstones in Horizon 2000 Plus, with a possible launch as early as 2009. A launch around 2009 would be ideal as it is around that time that the first detection of gravitational waves by the ground-based interferometers in the high-frequency regime can be expected. There still remained, however, the problem of LISA's cost exceeding the Cornerstone limit, with the cost of the six-spacecraft project initially estimated to be about 800 M€.

In 1996 and 1997, the LISA team made several proposals as to how the cost might be drastically reduced without compromising the science, the most important being the reduction in the number of spacecraft from six to three. This was achieved by replacing each pair of spacecraft at the vertices of the triangular configuration by a single spacecraft carrying essentially two identical instruments in a Y-shaped configuration. With these and a few other measures, the total launch mass could be reduced from 6.8 to 1.4 t and the total cost could be reduced accordingly (to $330 M, excluding the payload, according to a recent JPL Team-X cost estimate, a figure not yet confirmed by ESA).

Perhaps most importantly, the LISA Study Team and ESA's Fundamental Physics Advisory Group (FPAG) proposed in February 1997 that the LISA mission be carried out in collaboration with NASA. This makes sense not only from a cost-saving point of view, but also because the LISA team is an international one and the LISA mission-definition work was carried out jointly between Europe and the USA. The FPAG recommended limiting the cost to ESA to 150 M€ in this collaboration, as was done on a smaller scale with a cost cap of 20 M€ for STEP.

Presently, ESA is carrying out a six-month industrial system-level study, with support from the LISA Science Team of about 30 scientists. On the US side, a LISA Mission Definition Team consisting also of about 30 scientists has been formed. Both teams have partial team membership overlap to ensure that both teams work towards defining the same mission. As a first activity, in February 1999 the US team agreed on a Technology Plan with a total budget of $33 M to be implemented by the LISA Pre-Project Office at JPL in the next couple of years.

The need to demonstrate key LISA technologies in space

When LISA was presented together with the other three Cornerstone missions in 'Horizon 2000 Plus' to the scientific communities in the ESA Member States in 1995, prior to the Ministerial Conference in Toulouse, several Delegations expressed concern about the testability of key LISA technologies on the ground, remarking: *'It is very risky to launch a mission costing nearly 800 M€ without having a high degree of confidence that the key technologies will work; however, testing these technologies on the ground under 1 g conditions is not possible'*.

Similar concern was also raised by ESA's Science Programme Committee (SPC) in May 1996: *'The technology required for a successful LISA mission is extremely demanding and, furthermore, some key subsystem elements (e.g. drag-free control,* *zero-g accelerometry) can only be tested in space. The overall technical feasibility of LISA still needs to be demonstrated.'*

In February 1997, during a meeting at JPL, the LISA team came to the conclusion that a technology-demonstration mission is a necessary precursor to the LISA project. By that time it had become clear that the cost for such a mission could be kept relatively low. The LISA team, together with their US colleagues, therefore submitted a detailed proposal to ESA in May 1998 for a technology-demonstration mission (Fig. 5) that would test:

- the inertial sensor performance to within an order of magnitude of the LISA requirements
- the low-frequency laser interferometry between two inertial sensors
- drag-free satellite operations using field emission ion thrusters.

In December 1998, an updated proposal was submitted which was broader in scope, also addressing key IRSI and XEUS technology-demonstration needs. This revised proposal suggested a collaboration with NASA on ST-5 (previously called DS-5), with a launch in 2003. For the ST-5 slot of $28 M, there are currently three candidates: solar-sail technology, a cluster of nano-satellites, and a Disturbance Reduction System. The latter would include the testing of key technologies for LISA and would also involve some aspects of space interferometry for imaging interferometry projects. One of these three candidate projects will be selected by NASA in late July 1999, following parallel six-month studies at Phase-A level. ESA was recently invited by NASA to consider a possible collaboration on the Disturbance Reduction System. In the most likely collaborative scenario, ESA would contribute all or part of a small drag-free satellite (with a cost cap of 10 M€) which would carry the relevant technology items from both ESA and NASA, with NASA providing the launch and mission operations.

Ideally, such a technology-demonstration mission should be launched about five years before LISA. A launch much earlier would not allow full utilisation of the latest technologies to be tested, while a launch much later would not allow full advantage to be taken of the knowhow obtained during the technology-demonstrator flight in the design phase of the LISA mission. To preserve the possibility of a aunch of the NASA/ESA collaborative LISA mission in 2009, the technology-demonstration mission should therefore ideally be launched in the 2003-2005 time frame.

On the European side, a technology-demonstration mission addressing the technology for both the LISA and a multi-satellite infrared interferometry mission is foreseen for launch in 2005 as the second in a series of Small Missions for Advanced Research in Technology (SMART-2). ESA would nevertheless be interested in exploring the possibility of carrying out this mission, at least in part, in cooperation with NASA at an earlier time if ESA's technology needs could be realised in a more cost-effective manner.

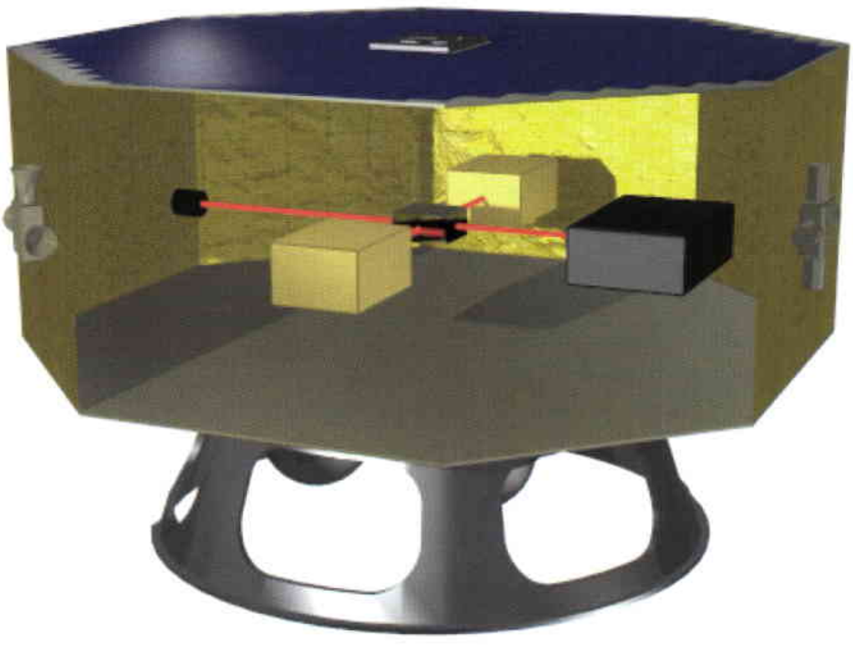


Figure 5. Cut-away view of the proposed LISA technology-demonstration spacecraft, showing two test masses (4 cm Pt-Au cubes, highlighted in yellow) with laser metrology

Next-generation fundamental-physics missions

In response to the Call for Mission Ideas for Horizon 2000 Plus in 1993, ESA received 28 proposals for fundamental-physics missions, which were subsequently evaluated by Topical Team 5 (TT-5). This constitutes the most complete survey of the possibilities of space for fundamental physics so far. Based on their scientific objectives, the proposals were categorised into six groups. One group was aimed at testing General Relativity and its alternative theories of gravity by measuring the so-called 'PPN parameters' (explained below), while another group of proposals searched for new particles in space. One in each group was selected and briefly described below; apart from STEP and LISA, these two proposals consistently received the highest rankings in two evaluations (by the FPAG for M3 and by TT-5 for Horizon 2000 Plus).

Testing theories of gravity (and General Relativity in particular) has received renewed attention especially for the cosmological consequences of possible violations. A large class of alternative scalar-tensor theories contain a cosmological attractor mechanism toward General Relativity. Approximate estimates based upon inflationary cosmologies indicate that in the present epoch General Relativity provides indeed an excellent description of gravitation, accurate to a level of 10^{-7} — 10^{-5}. However, due to the uncertainties of the theoretical estimates, every experiment able to improve the present accuracies is significant. If a discrepancy is confirmed, it would indicate that mass does not curve space as predicted by Einstein's theory. Such a result would be a milestone in our knowledge of the fundamental laws of the Universe. A measurable violation could indicate the type of scalar-tensor theory evolution of the Universe. In the weak-field, small-velocity approximation, theories of gravity are classified using the Parametrised-Post Newtonian formalism (PPN). In the simplest case, this classification is based upon just two parameters, called β and γ. The former measures the amount of nonlinearity in the superposition law for gravity, and the latter the space curvature produced by a unit mass.

The proposed SORT (Solar Orbit Relativity Test) mission is aimed at improving, by four orders of magnitude, the measurement of the PPN parameter γ by measuring the deflection and the time delay of laser light passing close to the Sun. γ is a measure of the strength of the coupling of mass to the curvature of space; in General Relativity γ =1. Present experimental limits on $|\gamma-1|$ are about 10^{-3}. Measurements of γ at the 10^{-7} level have considerable theoretical significance because generic tensor-scalar theories of gravity predict a natural weakening during the cosmological expansion of the observable deviations from General Relativity down to the level of 10^{-7}. SORT proposes to combine a time-delay experiment (via laser signals sent from the Earth and recorded by precise clocks on board two satellites orbiting the Sun) with a light-deflection experiment (interferometric measurement on Earth of the angle between the two light flashes emitted from the same satellites). SORT is the modern version of the SOREL mission studied by ESA in 1970/71. For comparison, SOREL aimed at determining γ to a precision of 5×10^{-4} and β to 5×10^{-3}.

The proposed SSPIN (Satellite Search for Pseudoscalar Interactions) mission is designed to search for a weak spin-dependent force at the level of $g_p \bullet g_s = 6\times10^{-37}$ (where g_p and g_s are spin-coupling constants) at the range of 1 mm, 10 orders of magnitude better than is currently achievable on the ground. This is possible by placing a highly sensitive payload at cryogenic temperature in a drag-free satellite in a geosynchronous orbit. This experiment was previously included in the M2- and M3-STEP payloads and studied for several years. SSPIN would be three orders of magnitude more sensitive than the MSC experiment on M3-STEP, which would put us in the realm of actually detecting the axion, a hypothetical, weakly interacting, massive particle which has been postulated to reconcile the theoretically allowed level of charge conjugation parity (CP) violation in the strong interactions, with the current upper limit to the electric dipole moment of the neutron. It has also been invoked as a possible candidate for the elusive 'Dark Matter' in the Universe.

Both missions rely on drag-free control and high-precision accelerometers. In addition, SSPIN needs cryogenics and SQUID sensing. These techniques will already have been developed for STEP, which is therefore an ideal testbed not only for LISA, but also for fundamental-physics missions in the more distant future. As these missions will probably only fly after 2010, further improvements in technology can be expected which will make them even more exciting for the physics community. As fundamental physics is a very young field, many more competitive ideas for missions can be expected to emerge by the time the next fundamental-physics mission will be selected after STEP and LISA.

Fundamental physics on non-dedicated ESA missions

Existing and future ESA Solar System exploration and astronomy missions also offer attractive possibilities for fundamental physics. Precise, two- or three-way tracking of interplanetary probes, such as the Ulysses and Cassini spacecraft, can set upper limits on low-frequency gravitational waves. These appear as irregularities in the time-of-communication residuals after the orbit of the spacecraft has been fitted. The irregularities have a particular signature. Searches for gravitational waves have produced only upper limits so far, but this is not surprising: their sensitivity is far short of predicted wave amplitudes. This technique is inexpensive and well worth pursuing, but will be limited for the foreseeable future by some combination of measurement noise, the stability of the frequency standards, and the uncorrected parts of the fluctuations in propagation delays due to the interplanetary plasma and the Earth's atmosphere. Consequently, it is unlikely that this method will realise an r.m.s strain sensitivity much better than 10^{-17}, which is six orders of magnitude worse than that of the space-based LISA interferometer.

During conjunctions, the radio signal passing close to the Sun experiences a measurable time delay and frequency shift, which allows one to determine the space curvature parameter γ. The radio-science investigation on Cassini will allow us to test this prediction to a precision of $\sim 10^{-4}$. The best experiment to date was performed by the Viking Mars Lander mission in 1971, which achieved a precision of 2×10^{-3}.

A Mercury Orbiter would allow γ to be measured to a precision of $\sim 2\times10^{-5}$ and β to a precision of 7×10^{-4}. On the astronomy side, Hipparcos has already achieved a precision of 10^{-3} for γ and GAIA is expected to achieve a two orders of magnitude improvement over that.

Fundamental-physics experiments on the ISS

Already under development is the AMS (Alpha Magnetic Spectrometer) to be flown on the International Space Station (ISS) in 2004/5. There are also two precursor flights on the Space Shuttle; one has already taken place successfully in 1998, the other will take place in a few years' time. A major objective of the AMS is the search for antimatter in the Universe. According to standard theories, at the very beginning there should be as much matter as antimatter, but the antimatter has not yet been detected. The AMS is a US-led project with most contributions coming from Europe.

Also under development for flight on the ISS is the PHARAO (Project d'Horloge Atomique par Refroidissement d'Atomes en Orbite) clock, which uses laser-cooled caesium atoms to improve the accuracy of the time frequency standard by two orders of magnitude. The French PHARAO atomic clock is complemented on the ISS by a Swiss hydrogen maser clock to provide a longer-term frequency standard; together they form the Atomic Clock Ensemble in Space (ACES). The ultra-high precision of PHARAO will allow 'new records' to be set for two fundamental-physics constants:

- determination of the space-curvature parameter γ to 1 part in 10^5 (two orders of magnitude improvement)
- determination of the gravitational redshift to 3 parts in 10^6 (almost two orders of magnitude improvement over the Gravity Probe A suborbital flight in 1976).

Proposed for flight on the ISS, but not yet accepted, is a test of the Equivalence Principle using protons and antiprotons — the Weak Equivalence Antiproton Experiment (WEAX). In space this test can be done three orders of magnitude more precisely than on the ground.

Fundamental Physics as an emerging space-science discipline

It is now widely understood that the scientific objectives of fundamental-physics missions are distinctly different — *questioning* the laws of Nature — from the scientific objectives of astronomy and Solar System missions — *accepting and applying* the laws of Nature. Also, the technologies used in fundamental-physics missions (the spacecraft typically carry proportional thrusters and high-precision accelerometers to allow drag-free operation), the requirements on spacecraft design (e.g. no moving parts, no deployable solar arrays, extremely high thermal stability) and the high degree of spacecraft/experiment inter-relationship (e.g. the signals from the payload are used to control the spacecraft) are distinctly different from Solar System exploration and astronomy missions.

Fundamental-physics experiments on the ground are limited in achievable precision. Many tests can be carried out in space with much higher precision (e.g. STEP: 10^6 better), whilst some observations can only be made in space (e.g. gravitational waves at low frequencies). It is therefore no surprise that the number of proposals received in response to ESA's Calls for Mission Proposals has been steadily growing: 5 (out of 22) proposals for M2, 16 (out of 48) proposals for M3 and 28 (out of ~100) proposals for Horizon 2000 Plus. Roughly a quarter of all mission proposals have been submitted in the past and are likely to be submitted in the future by the fundamental-physics community.

Fundamental Physics in Space is a rapidly growing new field with enormous discovery potential in physics, and a major technology driver. ESA recognised this in early 1994 by setting up the Topical Team on Fundamental Physics (TT-5) and in December 1994 by setting up the Fundamental Physics Advisory Group (FPAG). NASA followed in 1997 by setting up the Gravitational and Relativistic Physics Panel and the Fundamental Physics Discipline Working Group. In 1996, COSPAR decided to create a new Scientific Commission (SC-H) to cater for the needs of the fundamental-physics community. ESA's Long-Term Space Science Programme was fully described in 1984 in 'Space Science: Horizon 2000' and in 1995 in 'Horizon 2000 Plus'; both publications include chapters on fundamental physics, the latter describing a Cornerstone mission and a number of medium-size and small missions. However, it is also stated in the latter publication that the inclusion of the fundamental-physics discipline will require a modest increase in the funding of ESA's Space Science Programme.

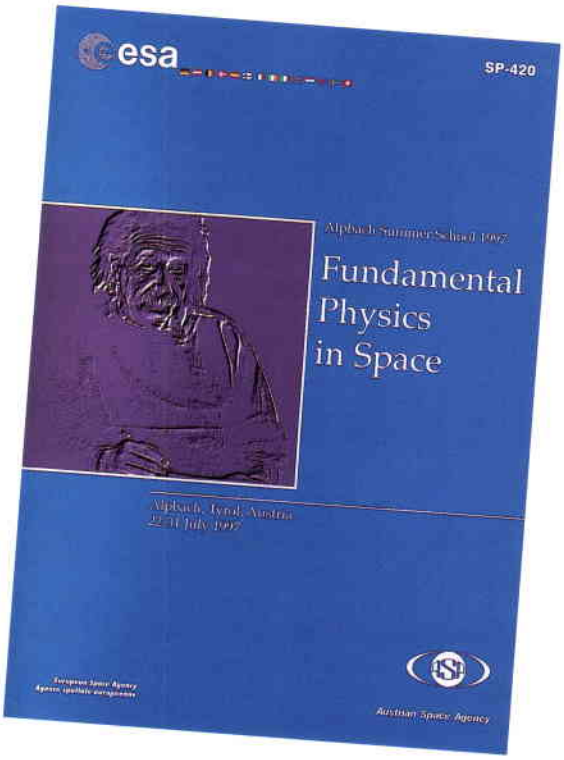
NASA has recently published a 'Roadmap for Fundamental Physics in Space', which represents a long-term framework within which to establish and advocate NASA's future research and technology development programme in fundamental physics. It identifies three sets of focussed scientific investigations (called 'campaigns'), which comprise a scientifically rewarding, technologically challenging, flexible and exciting programme of fundamental-physics research in space. These campaigns are:

- Gravitational and Relativistic Physics
- Laser Cooling and Atomic Physics
- Low-Temperature and Condensed-Matter Physics.

The Roadmap describes a number of missions or experiments in each of these campaigns. The Gravitational and Relativistic Physics Campaign describes six missions, among them the NASA/ESA collaborative STEP and LISA missions.

Fundamental physics as a discipline in its own right is also now recognised by many European space agencies. CNES defined in 1993 a new scientific theme 'Fundamental Physics' and set up a Fundamental Physics Working Group. ASI has recognised the emergence of this new discipline through the appointment of a representative specifically for fundamental physics in its Scientific Council. PPARC has recently set up a science committee and is already demonstrating its interest in fundamental physics by encouraging submissions on gravitational-wave detectors in space. DLR has identified fundamental physics as a scientific discipline with a 'high priority in the future' and has explicitly expressed a wish to participate in LISA and STEP. The Austrian Space Agency (ASA) organised (together with ESA) the 1997 Alpbach Summer School 'Fundamental Physics in Space' (Proceedings available as ESA SP-420).

Following a recommendation by the ESA Space Science Department (SSD) Advisory Committee in 1997 (a group of outside senior scientists who review SSD's activities every two years), a Fundamental Physics Office was set up in SSD in mid-1998, initially with two staff scientists, in addition to the already existing Solar System, Astrophysics and Earth Sciences Divisions.



Conclusion

Considering that the required technologies are now mature, that there is a sizeable community in Europe in need of space flights (a quarter to a third of all proposals come from that community), and that fundamental physics in space is now recognised by many space agencies, it is only a question of time and money until Europe realises its first fundamental-physics mission.

The ISO Data Archive

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The Infrared Space Observatory (ISO) Data Archive, developed by the ISO Data Centre in Villafranca, Spain, offers the astronomical community fast and easy access to all ISO products and related information through a pioneering World Wide Web (WWW) interface. The first release – issued on 9 December 1998 at http://www.iso.vilspa.esa.es/ – has already been accessed by many astronomers and visitors wishing to query the ISO database and to retrieve important scientific data.

Introduction
ISO was the world's first true orbiting astronomical infrared observatory. During its in-orbit lifetime from November 1995 to May 1998, it made about 30 000 individual observations of many types of astronomical objects, from within our own Solar System out to the most distant galaxies. These observations were made with a wide variety of spectral and spatial resolving powers and at wavelengths from 2 — 240 microns. The resulting database provides a treasure trove of information for further astronomical research.

During the in-orbit operations, the data from the satellite were processed on a daily basis. In addition to being distributed to the astronomer who had requested it, each observation was loaded into an ISO product archive – essentially for operational use by experts located at the ISO Science Operations Centre in Villafranca, Spain.

ISO is now in a 3.5-year long 'post-operations' phase, designed to maximise its scientific exploitation. All data, along with the associated calibration information, had to be made readily accessible to the worldwide scientific community. This involved building a new and more modern archive structure and user interface, as well as reprocessing all the observations with the latest version of the 'pipeline' data processing software.

The resulting ISO Data Archive was opened to the public on 9 December 1998, only six months after the end of the operations. Through a pioneering user interface based on Java, complex queries can be issued to the ISO database. Textual and visual presentations of the data aid in selecting observations for retrieval via FTP (File Transfer Protocol).

The ISO Data Archive was designed and developed at the ISO Data Centre in Villafranca. Due to continuous and fruitful cooperation between users and developers, it provides a unique, state-of-the art astronomical data archive.

Requirements for a new archive
Approximately one year before the end of ISO operations, it was decided to re-evaluate the existing ISO product archive concept. The new archive had to be more general-user oriented, open to the external world through modern and powerful technologies (e.g. WWW), and require less human intervention for its establishment and maintenance.

The approach adopted was to build something new out of the internal archive that would not only reuse, where possible, the existing technical and human expertise, but would also meet the following primary new requirements:
- open the archive to the external world via a fast connection to the Internet
- a WWW interface to the archive
- more powerful means for queries and retrieval requests
- proprietary data: access to each observing programme restricted to specified astronomer(s) for the first year after its completion
- provision of so-called 'browse products' to provide a fast and accurate impression of the data for each observation
- automatic processing of the ISO products from the telemetry
- uplink and downlink data held in a single database
- modular and flexible design that can evolve with additional user requirements.

A workshop was held in March 1997 involving ISO experts from the instrument institutes and the Science Operations Centre, as well as experts from other astronomical archives. This led to a concept document, which defined the foundations of the new ISO Data Archive. Figure 1 gives a schematic view of the system as seen by the user.

A second workshop, involving astronomers with ISO experience ranging from novice to expert, defined the detailed user requirements and produced the first version of the ISO Data Archive User Requirements Document.

In parallel, an engineering team was established to follow-up the various software concept, design and development phases according to the ESA PSS-05 software engineering standards.

Design and development

The overall approach included regular interaction between the users and the development team in keeping with the 'formality' frame as defined in PSS-05 in order to avoid modifications without control. Therefore, many reviews were held during the software requirements and design phases. During the development phase, several beta releases of the ISO Data Archive were issued for testing. This interaction was an important factor for success as most of the look-and-feel issues and bugs were discovered and corrected before version 1.0 was released to the public. The overall project schedule from start to release of the ISO Data Archive version 1.0 is shown in Figure 2.

Database design

Early on, with the use of a CASE (Computer-Aided System Engineering) tool, a Logical Data Flow Model was set up to define the overall system followed by a Physical Data Flow Model for the architectural design. This was then developed into specific system components that could then be transformed into pieces of future software code.

On the database side, a Conceptual Data Model was defined and extensively reviewed with the users. It was then transformed into a Physical Data Model to define a detailed database structure using a CASE tool that generated database tables and indexes from the model.

User interface

To design the user interface – once Java was adopted (see accompanying panel) – a 'class tree' was defined using the Rumbaugh Style Object Model.

One of the important new features of the ISO Data Archive is the provision of 'browse products' or 'quick-look' data associated with each observation. These products enable users to make informed decisions as to which

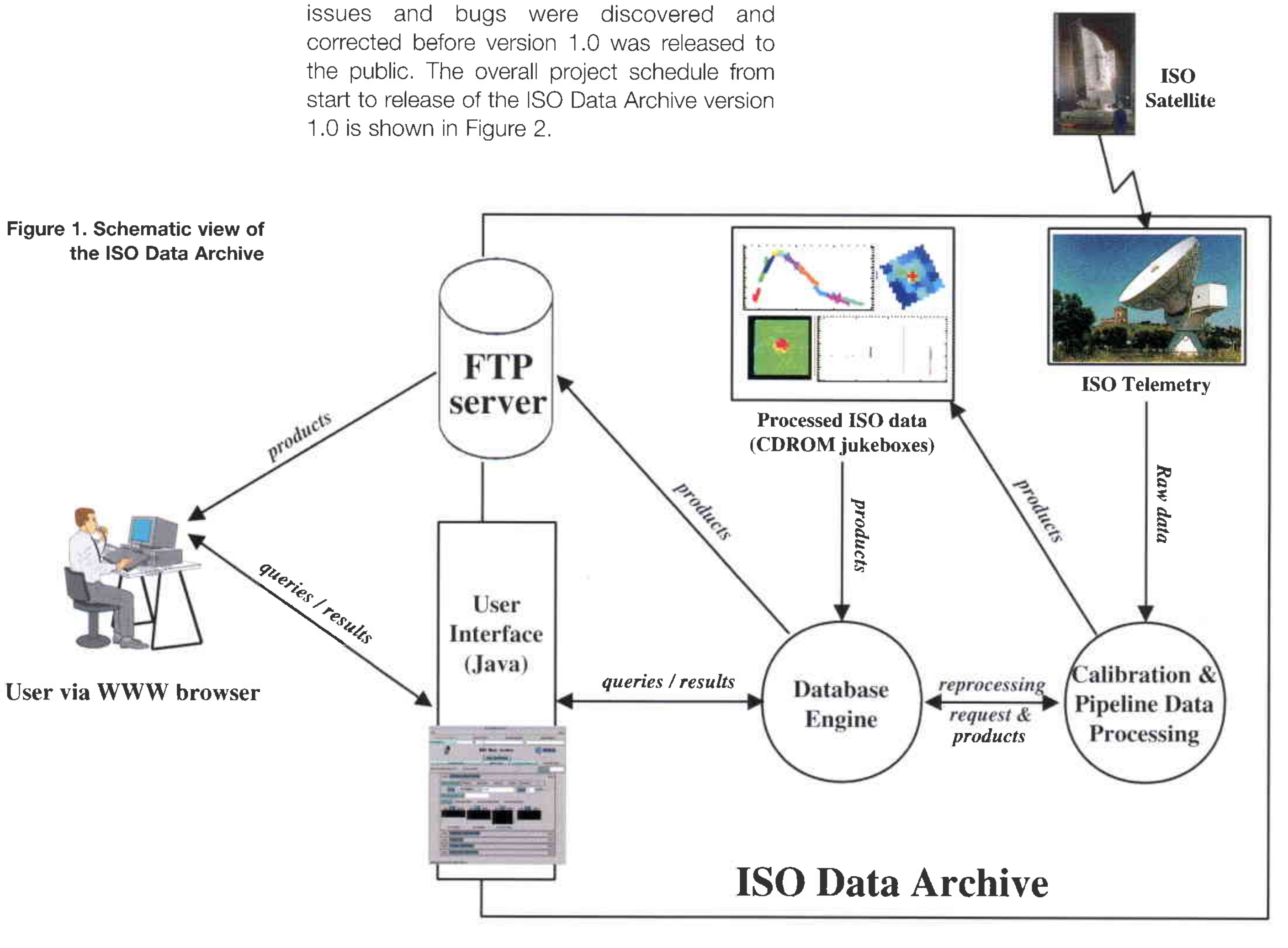


Figure 1. Schematic view of the ISO Data Archive

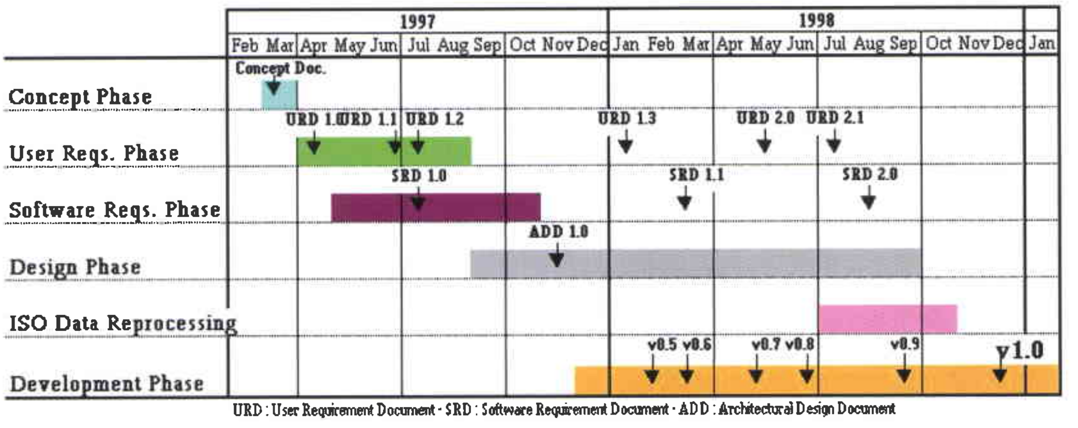


Figure 2. Overall ISO Data Archive project schedule

observations they want to download for detailed astronomical analysis. The quick-look products were developed as a joint effort between the ISO Data Centre, the Infrared Processing and Analysis Center (Pasadena, USA) and the French ISO Centre (Orsay, France). These products consist of:

- an icon (GIF file): a 56 x 56-112 pixel visual representation of the data content of the observation
- a postcard (GIF file): a screen-sized enlargement of the icon containing extra information about the observation (Figure 3 shows an example for each instrument)
- a survey product (FITS file): a fully processed product, which can be quickly downloaded by the user and manipulated using standard astronomical tools.

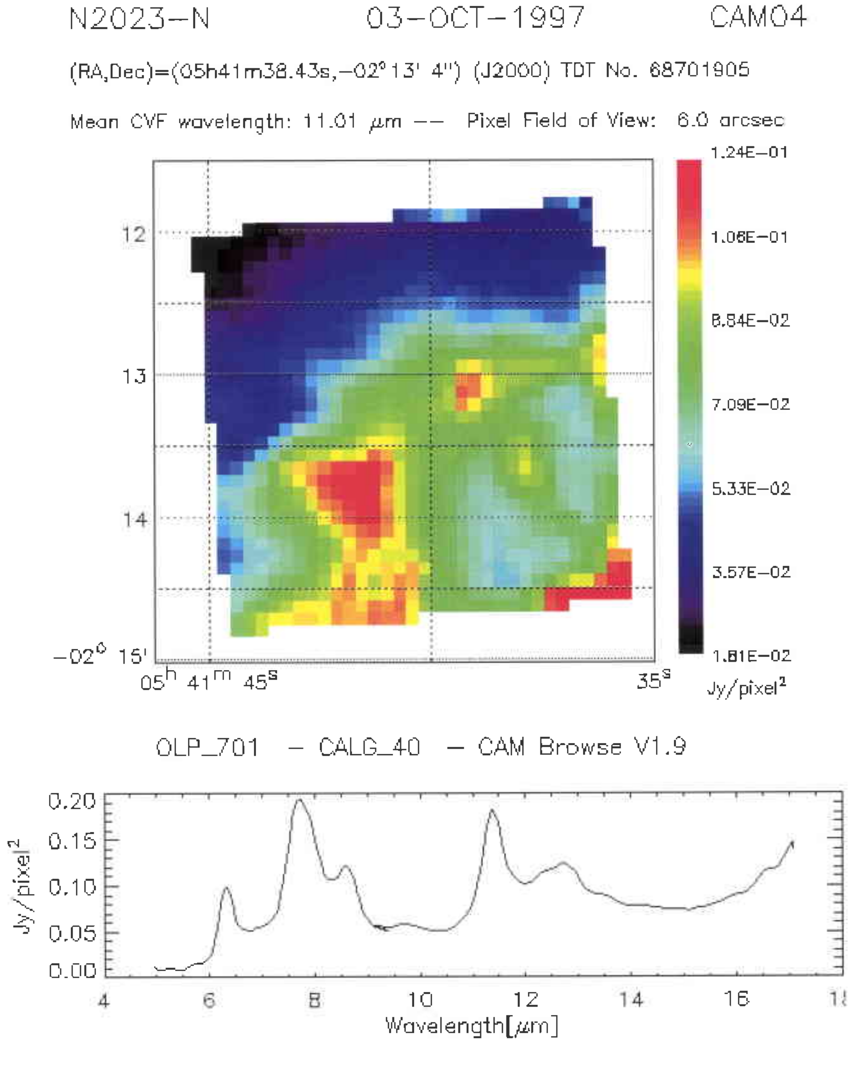
Data processing

An important design requirement was to automate data processing. During normal operations, an operator processed each day's data on two VAX/VMS machines, typically requiring about 24 hours. Up to three days' data could be processed simultaneously by three operators.

To solve this, all the telemetry (TDF) was put online on hard disk (about 350 GBytes) and parallel processing was performed over a cluster of six ALPHA/OpenVMS machines. These developments improved the processing rate to 20 days of data per day, more than six times the speed obtained during normal operations. Moreover, a single operator can now monitor it all.

The data processing and calibration software has been, and will continue to be, constantly updated and improved, as the behaviour of instruments is better understood. Thus, at the end of operations, in May 1998, all ISO observations (around 900 days of data) were bulk-reprocessed (BKRP) with the latest version of the pipeline software to produce the first uniform 'ISO interim archive'. A second, full reprocessing of all data with the latest software version is foreseen towards the end of the archive phase, i.e. mid-late 2001. This reprocessing will create the final 'ISO legacy archive'. In the meantime, it is planned to have one major update per instrument per year of the calibration and processing software. To enable the astronomical community to take advantage of these improvements, an on-the-fly reprocessing facility for all data products will be provided through the interface to the ISO Archive.

Figure 3a. Postcard example of CAM observation



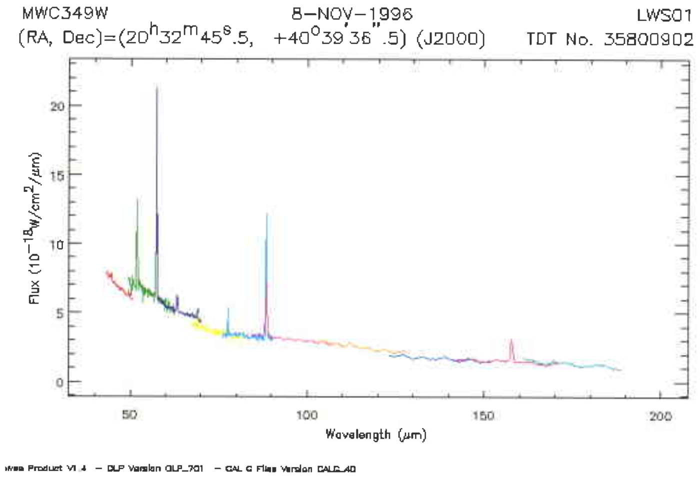


Figure 3b. Postcard example of LWS observation

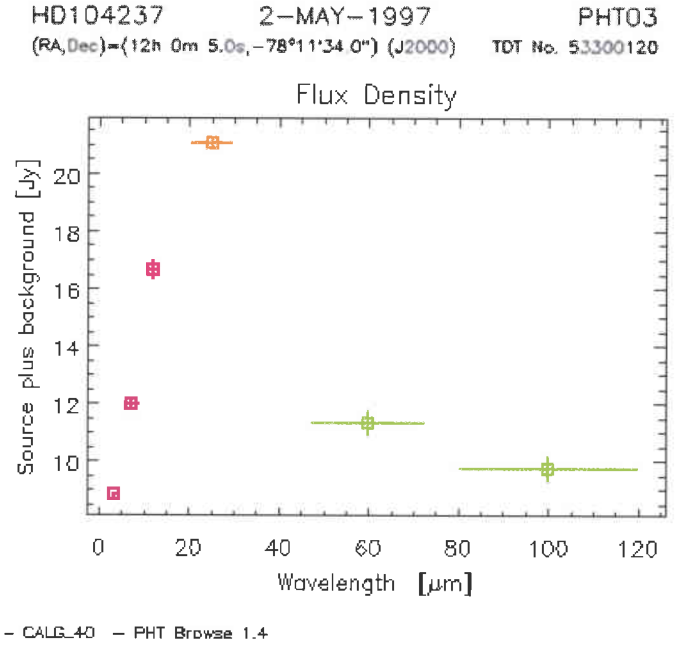
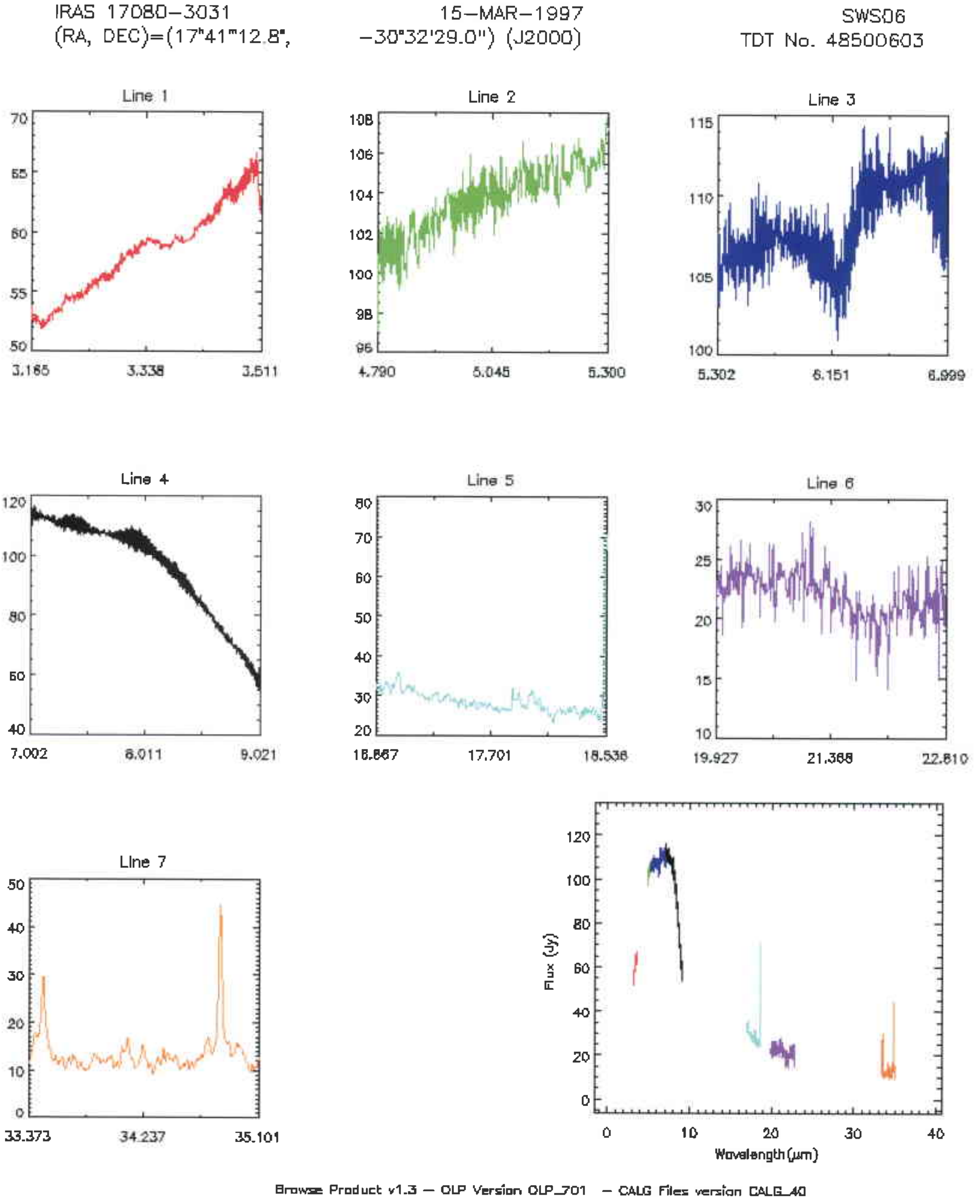


Figure 3c. Postcard example of PHT observation

Figure 3d. Postcard example of SWS observation



System design
The top-level system design is presented in a simplified form in Figure 4. This design integrated totally new parts (user interface, archive engine) with already existing systems (pipeline, update archive and CD creation) most of which needed some upgrade to fit into the new scheme.

The pipeline processing takes the telemetry from the TDF store and generates bulk-reprocessed products, which are ingested in the archive engine and copied onto CD-ROM jukeboxes. Via the WWW user interface, users can query the archive engine for products and can request those selected either from the prepared ISO data (stored product) or by triggering a processing request to obtain the latest version (processed product). In the case of the latter, the pipeline processing will generate the products on-the-fly and will return them to the archive engine. In both cases, the stored or processed products are put in the product distribution store and an e-mail is sent to inform the user that the requested products can be retrieved via FTP. If the products were requested on CD-ROM rather than via FTP, an operator will generate the CD-ROM, which is then mailed to the user.

This overall design has been very stable from the beginning and has managed to integrate all new user requirements to date.

The ISO Data Archive is connected to the Internet via a dedicated 2Mbits/second link to the European Academic Network called TEN-155, which ensures very high capacity connectivity between all European countries.

Currently, the ISO Data Archive consists of about 400 GBytes of data stored on around 600 CD-ROMs spread over two CD-ROM jukeboxes. The database (tables and indexes) volume is about 6 GBytes and resides on hard disk. The archive is connected to the Internet via a dedicated 2Mbits/second link.

ISO Data Archive usage
Prior to releasing the archive, all newly reprocessed data was distributed directly to its 'owners', i.e. the ISO observers who requested those observations. Additionally, all basic science products were exported to the instrument institutes (about 220 GBytes). These distributions were made so as to avoid an initial overload on the archive.

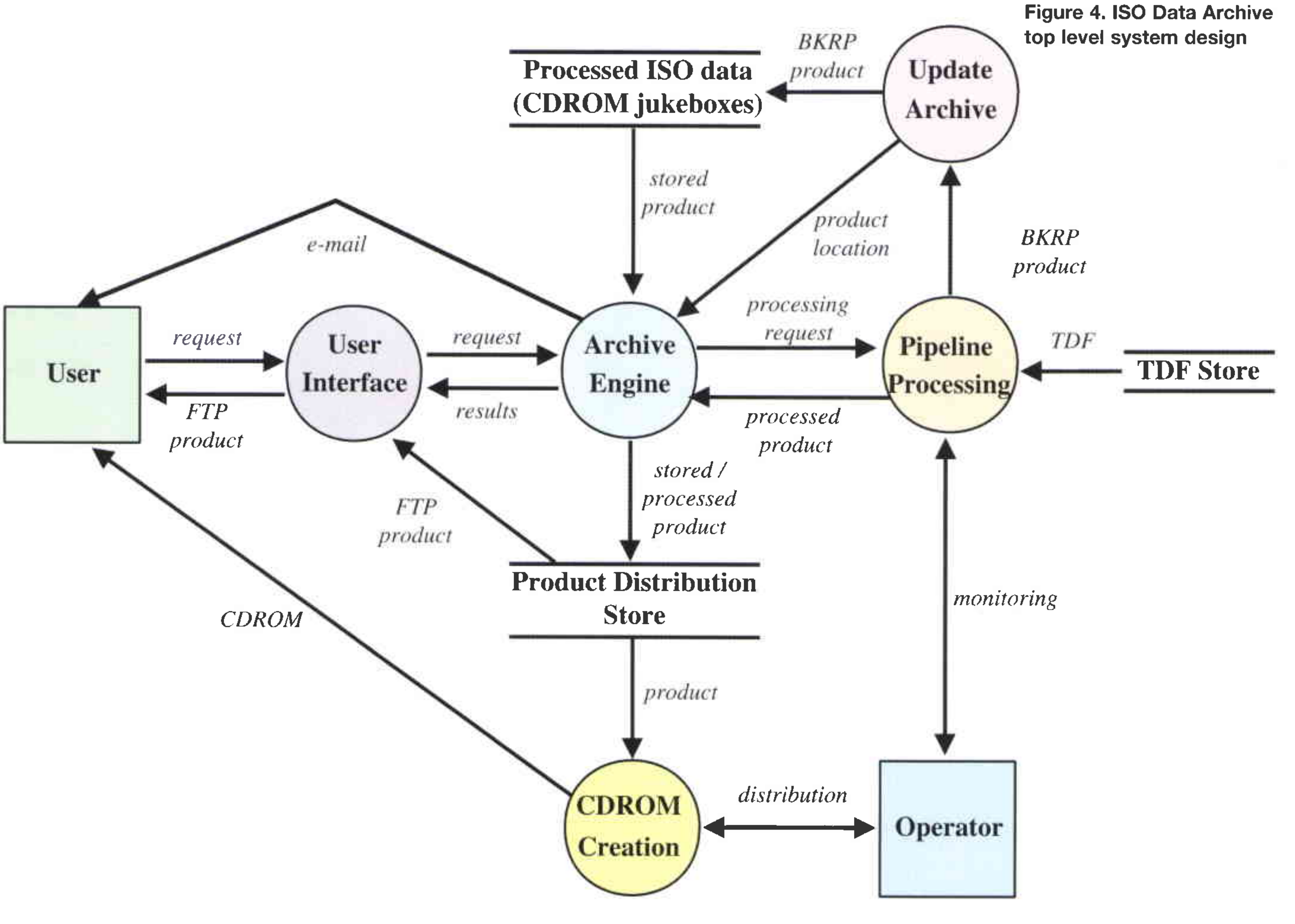


Figure 4. ISO Data Archive top level system design

The Choice of Java

At the start of the ISO Data Archive development phase, it was decided to adopt Java as the programming language for the user interface. At that time (1997), the choice was somewhat risky since Java was not always stable within the major WWW browsers. Nonetheless, its many other advantages made it the best choice.

Instead of using many standard WWW forms associated with cgi-bin scripts written in perl or C, Java allows integration of diverse facilities into a single application. Using the Java object-oriented approach, the interface is made of modular and 'living' components such as on-line help, subpanels and input fields according to other parameters. Control of displayed components on the screen is made easier and handling of quick-look data (e.g. icons, postcards) is more efficient. Moreover, this approach allows some level of user configurability.

Java also offers the possibility of doing various tasks in parallel, like consulting the help facility while querying the database.

Once the ISO Data Archive Java applet (current size is around 500 kbytes) is downloaded to a user's computer, many operations are performed using the client computer's own resources (e.g. CPU, memory). This avoids unnecessary interactions with the ISO Data Archive server for faster access. Additonally, using a specific Java driver for the SYBASE database enhances access to the user interface.

Using the Java object-oriented approach and the Model View Controller (MVC) paradigm, the ISO Data Archive is modular and flexible, easier to maintain, and source code documentation is automatically generated. This approach is particularly appropriate for developing complex and portable graphical user interfaces viewable through WWW browsers. The effort required for developing and maintaining such an archive using WWW forms and cgi-bin scripts would probably have been much higher.

However, using a new technology was not problem-free. The first beta releases suffered from the then-poor implementation of Java in the most popular WWW browsers. To circumvent this, without extra effort, a standalone Java application of the ISO Data Archive was made available. This could be installed by the user and ran without a browser, thereby avoiding Java instability.

But with the ensuing beta releases of the ISO Data Archive and the improvement of the WWW browsers, the ISO Data Archive v1.0 issued in December 1998 was very stable and reliable, in both stand-alone and browser environments, and the choice of Java definitely paid off.

How to Use the ISO Data Archive

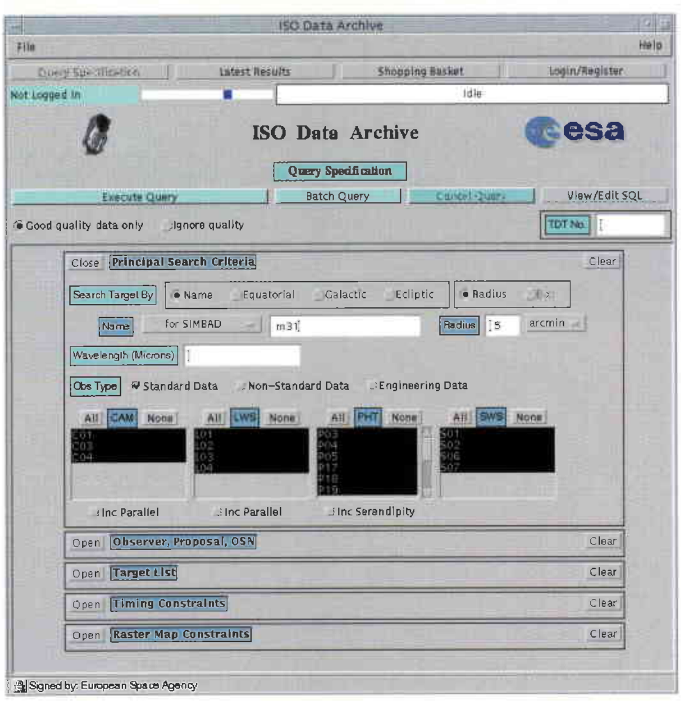


Figure 5. Making a query within the ISO Data Archive

User registration and login

Though anyone can query the archive, a user name and password must first be requested and issued. The login mechanism is necessary to protect proprietary data, helps in monitoring archive usage and avoids possible disturbances from hackers. Additionally, an e-mail address is required for notification from the archive.

Making a query

Having reached the ISO Data Archive on the WWW <http://www.iso.vilspa.esa.es/> (Data Archive section, General user), and having started the Java applet, users can define a query as shown in Figure 5.

The *Query Panel* consists of various sub-panels, which can be opened or closed to specify query parameters.

The *Principal Search Criteria* panel, opened by default, allows the astronomer to query against general parameters such as:

- target name as given by the proposer or as known in the various astronomical archives (e.g. NED and SIMBAD)
- coordinates
- wavelength ranges
- type of observing mode (AOT) used by the satellite
- instrument

Aimed more at expert users, the interface supports querying of non-standard modes, including engineering data and additional observations obtained in parallel with other instruments, or while slewing between targets. Queries can also be made against the 'quality' flag associated with each observation.

Other sub-panels are more specific and support searches against parameters like:
- observer or proposal name, proposal text, observation number
- date, time, uplink software version, revolution or phase in orbit
- target name list
- observation list
- raster map parameters.

For each of the parameters, help can be obtained by clicking the mouse button on the field.

Once the user has completed the search criteria, the query can be executed. If the query is too complex to complete quickly, the system will trap it, stop it, suggest that the user runs it in batch mode, and send an e-mail when the results are available.

Getting the results

Once a query has been executed, the ISO Data Archive returns the list of ISO observations matching the constraints in the *Latest Result* panel. A subset – sized to fit the screen – of the returned list of observations will be displayed. The user can scroll through this list using navigational buttons.

Figure 6 shows an example of the information displayed for each observation. An icon (one of the browse products) on the right-hand side of the screen gives an immediate visual impression of the data content of the observation. The postcard can be viewed by clicking on the icon. The amount of information and observations displayed can be customised; the main parameters are:
- target name
- observing mode
- coordinates
- observation type and number
- field-of-view
- wavelength range
- observer and proposal identification
- date, time and observation lengths
- quality of the data.

More detailed information, linked and associated files are offered for each observation.

Requesting the data

Another innovative and friendly feature of the ISO Data Archive is the wide selection of possibilities offered for the retrieval of data. Observations can be selected for retrieval by moving them to the 'shopping basket'. From this subpanel, the user can select the level of products to be retrieved for each observation individually, collectively, or a combination thereof, i.e.:
- Raw Data
- Basic Science (default)
- Fully Processed
- Quick-Look
- Custom
- All.

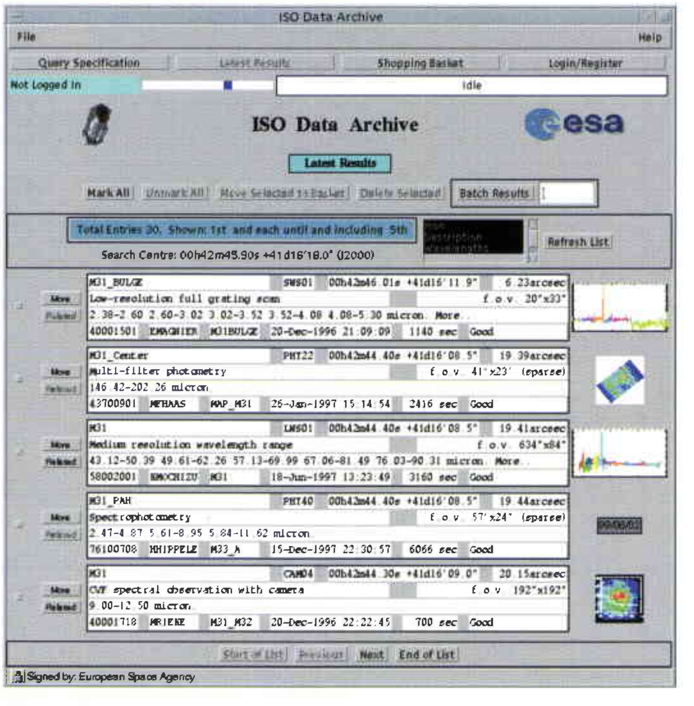


Figure 6. Viewing the results from a query

Once completed, the user presses the 'Submit Request' button. The user interface then determines the volume of data, checks whether the daily quota for the user has been exceeded and asks the user for a compression format. The download time by FTP (default means of data retrieval) can be estimated if required. The archive processes the data retrieval task and copies the data into an FTP (public or secure) area and stored for a period of seven days. The user is informed via e-mail.

Alternatively, the user can request the data on CD-ROM. In this case, an operator at the ISO Data Centre creates the CD-ROM and sends it by normal mail to the user. However, due to the excellent Internet connectivity of the ISO Data Archive, all data requests to date have been handled by FTP rather than the more expensive and slower CD-ROM route.

When the archive was released, only some 6% of the standard observations were available. Nevertheless, the archive has been extensively and smoothly used by a significant number of users (see Table 1). Access will continue to increase in the future with the availability of all the data by August 1999, and as new versions of calibration and processing software with further improvements are released.

Table 1. Archive usage

Accesses	around 8000
Hosts	around 1000
Users	156
Data requests	around 2000
Data Volume	33 GB

Future developments

A phased approach is being taken for the overall development. Version 1 of the ISO Data Archive implements most of the original user requirements. Version 2 (mid-1999) is aimed at incorporating the specific needs of expert users. Version 3 (end-1999) will fully implement all user requirements. Among other features, it is planned to:

- add more data to serve the needs of instrument experts
- add extra subpanels to the user interface to access these new data
- implement the ISO products on-the-fly reprocessing
- integrate links to and from other astronomical archives
- provide a direct interface to the ISO Data Archive for other astronomical archives and programs
- add interactive browse product display tools
- implement a 'user-defined function': essentially scripts that can be run on the data products themselves; these are being developed for expert users by the ISO Spectrometer Data Centre (Garching, Germany)
- consider putting all ISO products on hard disk rather than on CD-ROM jukeboxes.

Conclusions

The ISO Data Archive, designed and developed by the ESA ISO Data Centre in Villafranca Spain, has been available to the external world since 9 December 1998. It provides fast and easy access to ISO observations data via a modern, innovative, efficient and effective user interface based on Java technology.

After a smooth design and development phase with constant collaboration with science users, several beta versions were tested by end-users in order to release a stable and high-quality archive.

By the end of 2001, all ISO products will have been reprocessed with the latest calibration software and final improvements will have been implemented to leave the legacy ISO Data Archive to the world astronomical community.

Acknowledgements

We would like to thank the software team who designed and developed the ISO Data Archive: Richard Carr, John Dowson, Antonio de la Fuente, José Hernández, Neil Jenkins, Arno Plug, Andy Pollock, Pedro Osuna, Richard Saxton, Alex Scohier and Colin Todd. We owe special thanks to Deborah Levine for all her work on the user requirements. Kieron Leech is thanked for the user test team.

We also thank all others, too numerous to mention by name here, who participated in the ISO Data Archive project and contributed to its successful first release.

The ISO Data Archive is one element of the ISO Post Operations phase, which is a collaborative effort coordinated by the ISO Data Centre in ESA, Villafranca, Spain and includes six national data centres: the French ISO Centres (Orsay-Saclay, France), the UK ISO Data Centre (Rutherford, UK), the ISO Spectrometer Data Centre (Garching, Germany), the ISOPHOT Data Centre (Heidelberg, Germany), the Dutch ISO Data Analysis Centre (Groningen, the Netherlands) and the Infrared Processing and Analysis Center (Pasadena, USA). esa

Integrated Network Management

– The Key to the Efficient Management of Complex Operational Networks

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Together with industry, ESA has conducted a study of state-of-the-art network management concepts in the context of assessing its future space operations networking requirements. The validity of the principles involved and the potential for improved efficiency have been demonstrated with the help of ESA's Interconnection Ground Subnetwork (IGS) Testbed environment.

Introduction

Management is defined as the act, manner, or practice of managing: handling, supervision, or control. Recognising the importance of appropriate management whenever organisational complexity needs optimisation for efficiency or disaster prevention in an organisation or industry, management principles, techniques and strategies have been continuously developed and adapted to changing boundary conditions. The management of complex technical projects has undergone similarly expeditious development in recent years. Multimedia networks with continuously changing profiles of users and traffic flows are good examples of the complex architectures and very demanding conditions facing today's network operators. By tailoring the network management system to the particular operational system scenarios involved and careful selection of the technologies used, the stresses associated with operating such networks under extreme time pressure can be considerably reduced.

Motivation

The operational networks required to support the communications needs of space missions are a major cost element in the operation of satellite ground segments. Cost optimisation for each individual project has tended to lead to the use of different basic communication services, highly customised to the specific needs of each mission. Typical communication bearer services today are terrestrial and satellite links, Frame-Relay-based Virtual Private Networks (VPNs), Narrowband Integrated Services Digital Network (N-ISDN) on-demand services, permanent and on-demand services via satellite with Very Small Aperture Terminals (VSATs), and Broadband Integrated Services Digital Networks (B-ISDNs) based on the Asynchronous Transfer Mode (ATM). Whilst on the one hand the cost-optimised mapping of the mission requirements to the most appropriate communications service reduces service charges, on the other increased effort is needed to operate these communication systems due to the added heterogeneity. To counterbalance this increased operational involvement, sophisticated Integrated Network Management Systems are needed that will ease the routine operations and simplify troubleshooting in the event of problems.

In addition, the complexity involved in running operational mission-support networks has increased considerably in recent years because new communication techniques supporting multimedia (voice, video, data) applications make the attendant networking support quite demanding.

ESA presently runs two operational networks: OPSNET for its unmanned missions, and the Interconnection Ground Subnetwork (IGS) Testbed as a precursor to the operational IGS for the International Space Station. OPSNET typically uses leased lines enhanced by N-ISDN and Frame Relay VPN services, while the IGS Testbed uses leased lines, N-ISDN, VSAT and ATM services.

Major cost reductions have been achieved for both networks through the introduction of on-demand connectivity, which is particularly cost-efficient in providing backup capacity or additional short-term connectivity when user needs dictate. However, the reliable and controlled establishment and provision of such on-demand connectivity in the operational network environment creates an additional workload for the operators and adds considerable complexity to the routine operations, which needs to be contained in order to ensure safe long-term operation. In addition, the new multimedia applications have added totally new equipment, e.g. for video, to the operational network, which also needs to be managed and integrated into a network management scheme to ease both its routine operation and fault recovery.

In summary, therefore, the safe and reliable operation of these very dynamic and complex networks and services, requiring even greater operator involvement, calls for optimum network management support tools if the manpower required is not to increase. The goal should rather be to reduce the number of network operators required and to allow a reduction in the skill profile for 24hour/7day-shift positions.

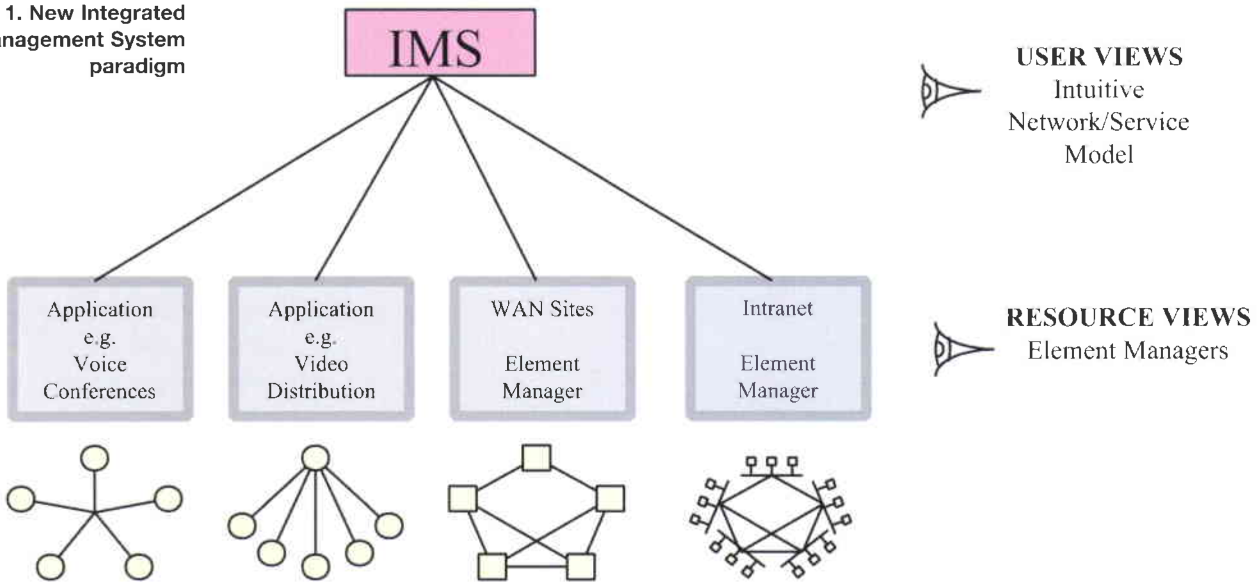
Key features for an Integrated Network Management System

Experience in operating large space-mission support networks like OPSNET and the IGS Testbed over long periods indicates that network management does not need to be fully integrated into one system, as was the paradigm for such systems in the past. The major elements of a network, such as the Wide Area Network (WAN) switches, the routers, the voice-conferencing equipment, the video distribution equipment, etc. are equipped with dedicated, often proprietary, management systems fully optimised for the configuration and operational needs of the particular equipment. Attempts at achieving an overall integrated network management system in the past have led to tremendous software maintenance problems when new releases were deployed for the individual network elements, since this also required updates in the Integrated Network Management software. In practice, the management systems were rarely ever complete and up to date and were therefore treated with suspicion by the operations personnel.

It was therefore necessary to depart from this old paradigm and apply an integrated network management approach more suited to today's operational environment. This leads to the concept depicted in Figure 1, still keeping the dedicated Element Management Systems that are most suitable for fulfilling their particular job of configuring and managing the devices that they control. In particular, they provide very detailed Resource Views of the devices they manage. The Integrated Management System realises higher level operator and user-oriented views that resemble a certain overall service model and provide an intuitive graphical display of end-to-end service. These higher level views can only be generated by a combination of information from the different Element Management Systems. The Integrated Management System becomes more of an umbrella system, not replacing the individual Element Management Systems, but rather creating an umbrella for the entire system with added functionality.

The key features of such an umbrella Integrated Management System can be summarised as follows:

Figure 1. New Integrated Management System paradigm



1. Online Unified View of the entire network resources via the horizontal integration of high-level management information from Element Management Systems. Generation of useful synoptics for the network operator, with the ability to export views to actual end users.
2. Offline Network History Summary, which complements the online view with long-term availability and performance information, allowing for the independent verification of Service Level Agreements (SLAs) with telecommunications operators. Such long-term reports provide the basis for future planning and allow easy tracking of failure correlations and performance evaluation.
3. Service Management Views, which present the end-to-end application view as perceived by the end user, thereby aggregating the management information of the various elements that provide the service.
4. Automated Connection Management, which ensures reliable and efficient activation and release of on-demand communication resources according to high-level communication service schedules coming from mission operations. This is also useful for automatic initiation of preplanned recovery procedures if, for instance, performance degradations or failures are detected.

A state-of-the-art Integrated Management System has to fulfil the following architectural and software requirements, for which the rationale is provided in the next section:

1. Simple Network Management Protocol (SNMP) for the transfer of information between the Integrated Management System and the Element Management Systems based on high-level information. In addition, access to low-level device-embedded SNMP agents and a migration possibility to also support legacy devices that do not yet support SNMP.
2. Commercial-off-the-Shelf Network Management Platform that provides all basic functionality for SNMP data exchange and easy generation of animated customised graphical views.
3. World Wide Web (WWW) based remote access for the export of user views.

Taking into account the above requirements for a new Integrated Management System, a prototype system was built and demonstrated in a reference network that combined on-demand ISDN and ATM connectivities for the provision of video and data services.

Design of the prototype Integrated Management System (IMS)

Past concepts for Integrated Network Management have often proved inadequate in many practical cases. Omnipotent monolithic systems, generic enough to cope both with detailed device management and the more general functions at network or even service level, required heavy development efforts for producing what often turned out to be rigid and never complete solutions.

A more pragmatic strategy is to seek simple individual solutions that can be loosely combined to form a prototype system and derive systematic techniques applicable to real operational environments. This implies the very careful selection of some key system and software requirements:

1. Standardised use of the Simple Network Management Protocol (SNMP)

SNMP is the standard network management protocol of the TCP/IP (Transmission Control Protocol/Internet Protocol) family. It is used for the exchange of management information between two conceptual entities: a manager (typically a managing application) and an agent (e.g. the management interface of a network device, or an element management system). It provides three basic communication interactions:

- 'Get-Requests', which allow a manager to acquire the current value of selected variables of a Management Information Base (MIB) instrumented by the target agent, i.e. monitoring.
- 'Set-Requests', which provide new values to be assigned by the agent to the given MIB variables, i.e. control.
- 'Traps', which are asynchronous notifications delivered by an agent to a manager upon detection of a particular condition (e.g. an alarm event).

Given the tremendous success of SNMP, this protocol has been selected for the exchange of management information between the IMS and, preferably, high-level interfaces provided by element managers or, by default, the lower level MIBs supplied by agents directly embedded in the equipment. A flexible solution, based on the LT-301, which is a small adapter from SNMP Research Inc., also allows one to add SNMP support to legacy devices that can only be controlled by messages and commands from their console port.

2. State-of-the-art off-the-shelf Network Management Platform

A network management platform provides a set of basic building blocks, e.g. for event handling or graphical network map animation, which can be customised for specific network management applications. After a comparative analysis, the HP OpenView Network Node Manager (HP-OV NNM) product has been selected as the core platform for the IMS. This platform offers a high stability for the custom-built applications and ensures compatibility with future trends in network-management technology. It is presently the market leader. It is also rather flexible and open, and thus minimises the development effort for those custom applications designed to take advantage of the platform's built-in features.

3. Use of Web-based technology for the export of high-level views
The IMS must provide a synthetic and intuitive model of the communications network. This high-level presentation is not only of major interest for the network operators, but can also be very useful for the end users. The easiest way to ensure wide accessibility is to make use of the World Wide Web, the HyperText Markup Language (HTML) and JAVA technology. To avoid unnecessary work, however, it is better to rely on the standard export mechanism inherent in the network management platform, which will benefit from future enhancements.

The resulting architecture of the IMS prototype is shown in Figure 2.

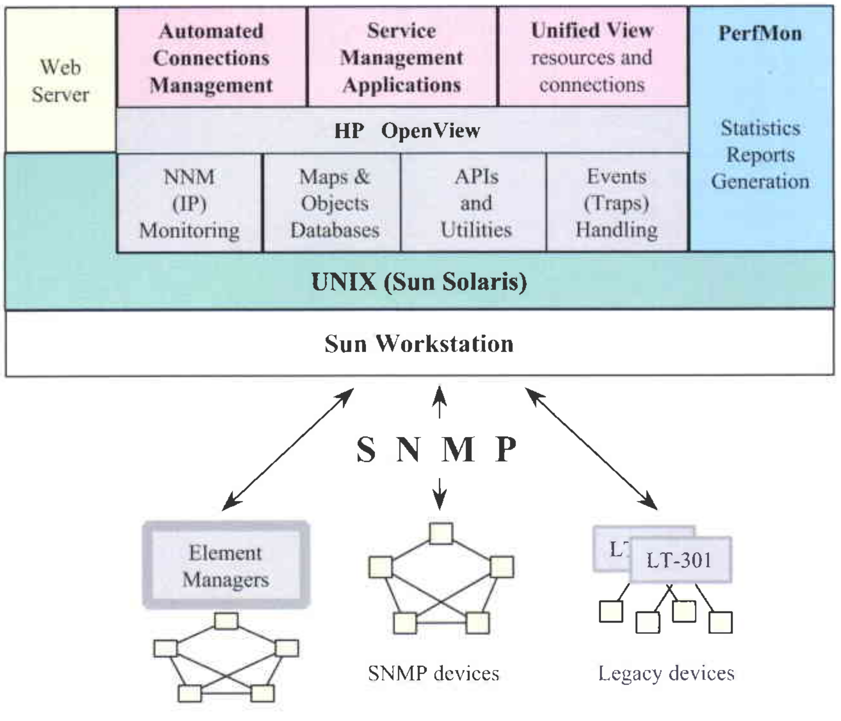


Figure 2. IMS prototype software architecture

The standard IP node management application of HP OpenView NNM ensures the detection and monitoring of the IP data network components (called the Intranet). For the majority of non-IP-related managed objects, like physical resources or logical communication services (e.g. equipment ports, protocol entities, virtual channels), a custom model is created in the OpenView objects database. Here the managed objects are represented in the graphical map as icon and connection symbols according to a layout derived from custom network operations conventions. As dynamic connections play an important role in the IMS logical views, specific techniques have been used for their graphical representation.

Status monitoring of those objects relies mainly on simple 'trap-triggered polling' mechanisms. Custom scripts are attached as automatic actions to relevant types of SNMP traps. Upon event (trap) reception, the script retrieves additional diagnostic information by querying the originating SNMP agent (polling), to identify the corresponding OpenView objects and to choose the status colour to be used for their representation in the unified view.

Some state transitions are, however, not reflected by the spontaneous generation of traps. This is typically the case for dynamic activation and release of virtual channels. For those cases, simple dedicated polling programs continuously inspect appropriate state variables from the device MIBs, thereby deriving the animation of the colour of corresponding graphical objects in the views. The OpenView Web export capability allows remote access to the views.

With the Performance Monitoring (PerfMon) tool, raw historical observations are continuously collected and stored in log files that are regularly processed to automatically update an integrated set of hyperlinked Web reports. These represent the availability and performance summaries through a mix of tabular and chart data on different time scales (day, month, 12-months).

Dedicated Service Management Applications receive service related configuration and status data by traps. They dynamically draw their own views in the OpenView graphical map. A simple menu-driven control interface permits the on-demand execution of network device configuration commands by the invocation of custom scripts of SNMP Set-Requests.

An editor (replacing the mission-planning interface) of high-level service requests generates a communications schedule that is translated into a series of UNIX at-jobs by an Automated Connections Management robot. At the specified time, those scripts are executed, and the necessary atomic commands to the managed network components are issued through SNMP Set-Requests.

Customised IGS Testbed Intranet view

The basic IP Network Node Manager

application of the HP OpenView product has been tailored to monitor the IGS Testbed Intranet. Its topology is depicted in Figure 3. As this network is still under construction, not all sites are yet represented.

It is a star-shaped network with a central node at ESOC. The Johnson Space Centre (JSC) and Marshall Space Flight Centre (MSFC) are connected through different paths (IP tunnelling over ESA/NASA IP links, Frame Relay circuits over leased lines and backup links over inverse multiplexed ISDN). An experimental connectivity with MSFC over public ATM is also foreseen.

User Support Operations Centres (USOCs) and ESA Control Centres will gradually be added, as indicated in the right part of Figure 3. At each site, a LAN segment dedicated to network management traffic (NM LAN) is separated from the local Operational LAN (OPS LAN).

Reference network for the IMS prototype

The reference network for the development of the IMS prototype involves public ISDN-based connectivity, as already used in actual mission-support scenarios, and the use of an experimental ATM infrastructure. It offers combined data and video-conferencing services. The demonstration in the context of the IGS Testbed has been conducted in two steps. First, a unified model of a representative heterogeneous network configuration has been integrated as an overall synoptic of the status of resources and connections. Then a dedicated Video Service Management facility has been built-in for the easy setting up and control of video conferences. In addition, an Automated Connection Management Application has been developed for orchestrating dynamic service provisioning according to high-level communication service requests coming from mission planning.

Figure 4 shows the reference network configuration used for the final demonstration of the combined exploitation of the different IMS custom applications in a scenario of automatic setting up of end-to-end video conferences over ISDN and ATM.

A video Multipoint Control Unit (MCU) allows one to configure two-party and multi-party conferences between video channels. Five of the eight available user ports were used in the demonstration. One remote video codec was connected through inverse multiplexed dynamic ISDN calls (6 individual ISDN B-channels of 64 kbps each need to be aggregated to obtain the 384 kbps required for the video transport). Another video codec could be connected either through ISDN calls or through dynamically enabled ATM Permanent Virtual Circuits (PVCs). A complete scenario involving the combined use of the Automated Connections Management Application, of the specific Video Service Management Application, and of the Unified

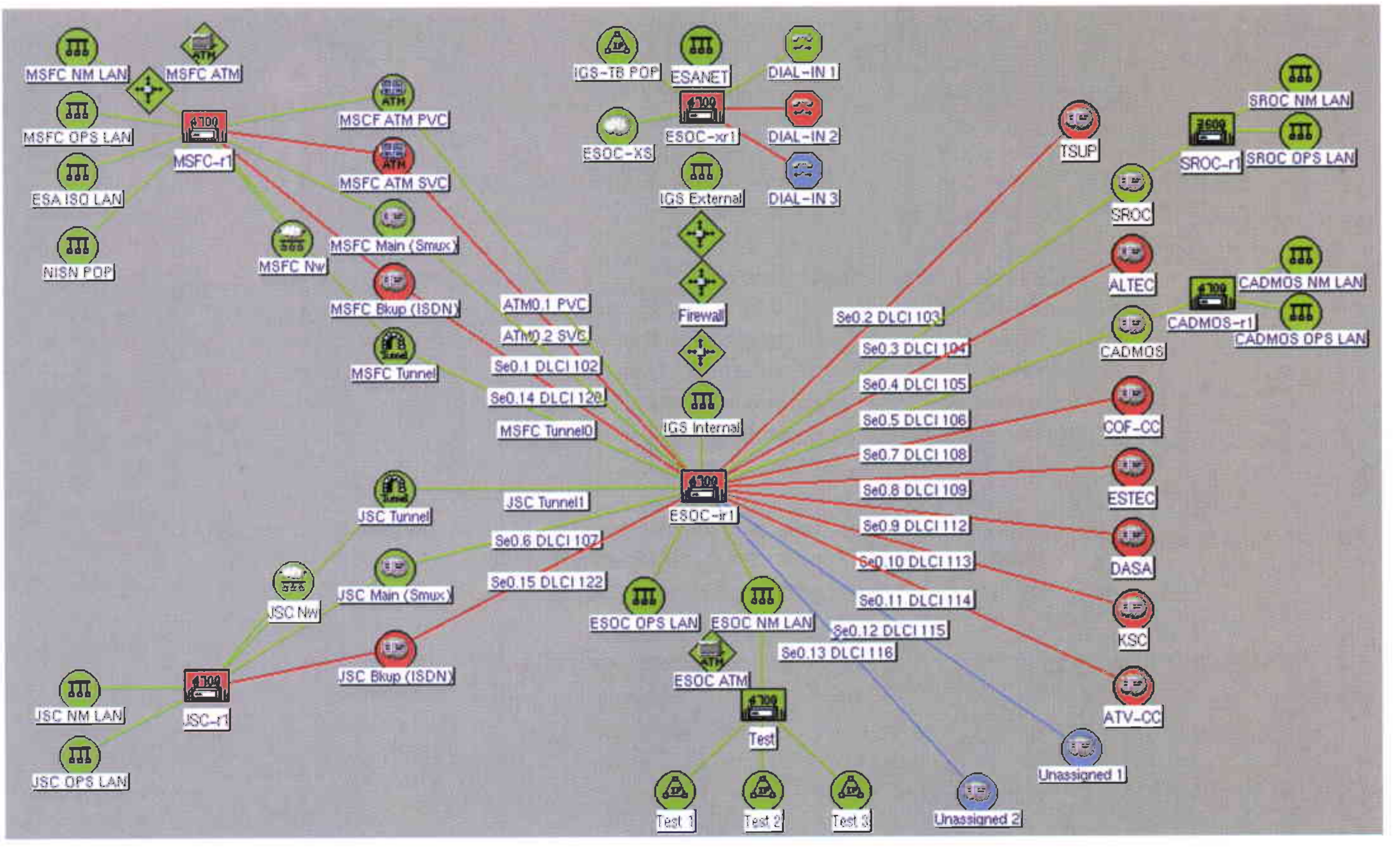


Figure 3. IGS-Testbed Intranet view

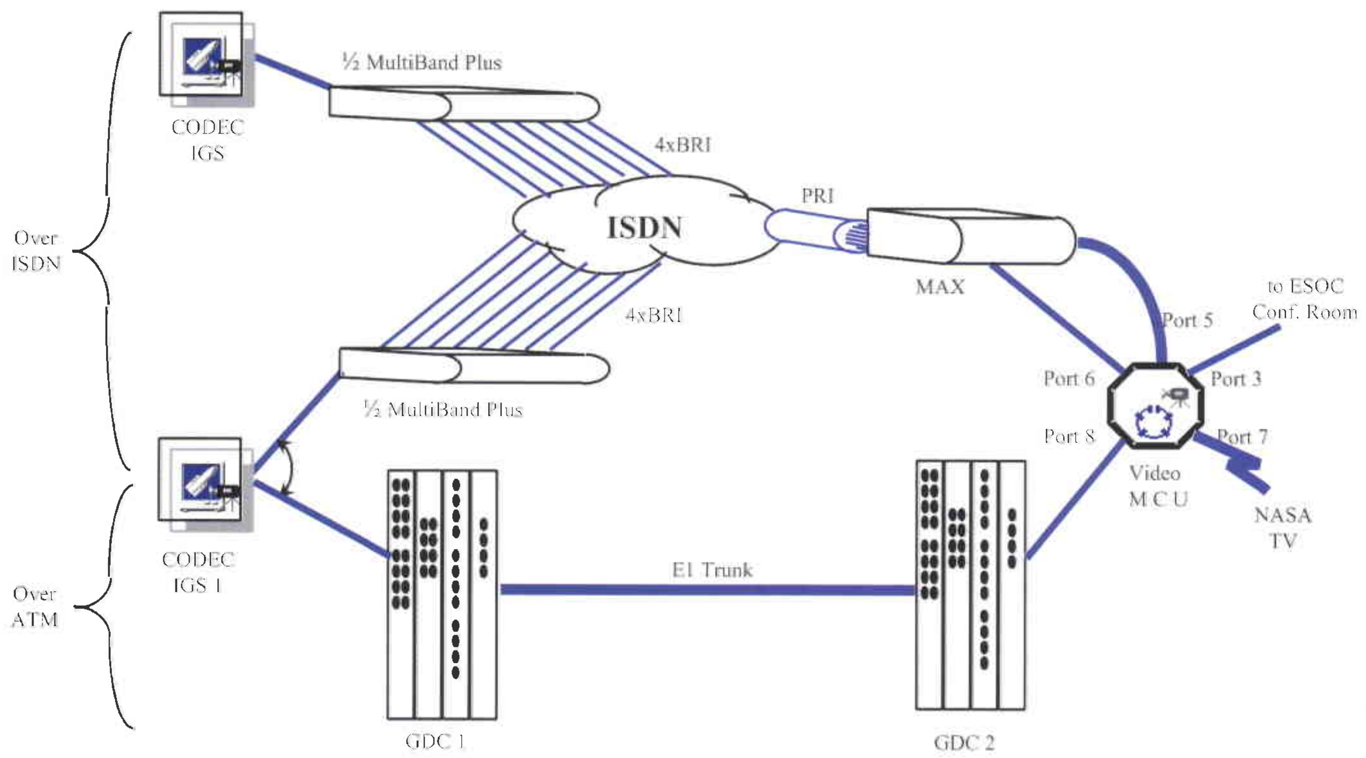


Figure 4. Reference network for the IMS prototype

View has been demonstrated with this reference network infrastructure.

The real-time unified view

Although the unified view is manually custom designed, it has been possible to model the network objects in a systematic fashion by combining the network element MIBs information and by adapting IGS Testbed-specific network operation conventions.

Particular emphasis was put on the intuitive visualisation of communication relationships. For instance, coloured graphical links synthesise the state of all active components in a path, as well as the state of the logical end-to-end service channels. Different techniques have been used for an animated display of dynamic connections, with minimal effort. The methods rely on an a priori knowledge of the conventional configuration of the communication resources.

The example in Figure 5 illustrates the technique used for inverse multiplexed trunks over the public ISDN, the left-hand OpenView window being the synoptic of the reference network shown in Figure 4.

Figure 5. Real-time unified view of the reference network

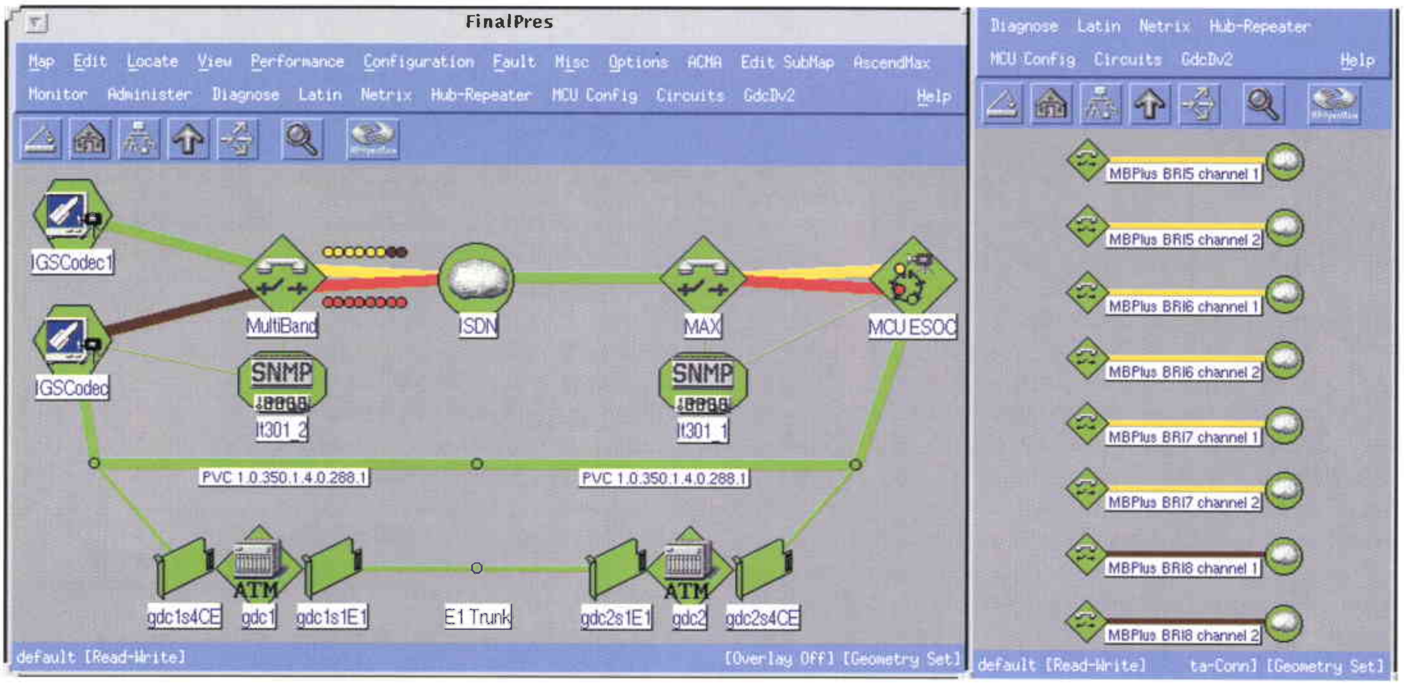


Table 1. Cost-efficient dynamic ISDN trunk bandwidth allocations for multiplexed services

Combined services	**Number of 64 kbps ISDN B-channels supporting the multiplexed trunk**
Voice + low data rate	2xB = 128 kbps
Voice + low data rate + high data rate	4xB = 256 kbps
Video	7xB = 448 kbps
Video + voice + low data rate	8xB = 512 kbps
Video + voice + low data rate + high data rate	10xB = 640 kbps

Cost-efficient multiplexing of on-demand multimedia services over long-distance ISDN trunks involves the dynamic aggregation of a minimum number of 64 kbps ISDN B-channels to achieve the bandwidth needed at a given moment. Typical assignments are presented at Table 1.

In our example, a trunk could amount to a maximum of 4 dedicated Basic Rate Interfaces (BRIs), where each BRI may support up to two B-channels. The direct (nonmultiplexed) transmission of a video signal necessitates 6 B-channels. In the upper view, the trunk is represented by a single connection symbol (e.g. the upper link between the MultiBand icon and the ISDN network icon). On the right-hand side of Figure 5, a zoom view displays the possible 8 B-channels of the 4 BRIs, of which 6 are in the process of being established.

When a call is in progress, the trap-triggered polling mechanism detects how many channels are already dialled, and assigns them a yellow colour. Once the call is in service, the actual number of channels involved is coloured in green. Upon call release, all channels will be shown in red. The status colours of the compound trunks in the upper-layer view are painted accordingly. A variant of this techniques shows every channel as a bullet near the trunk representation in the upper submap; the visual effect is that of an animated sliding bar of LEDs.

Long-term statistics

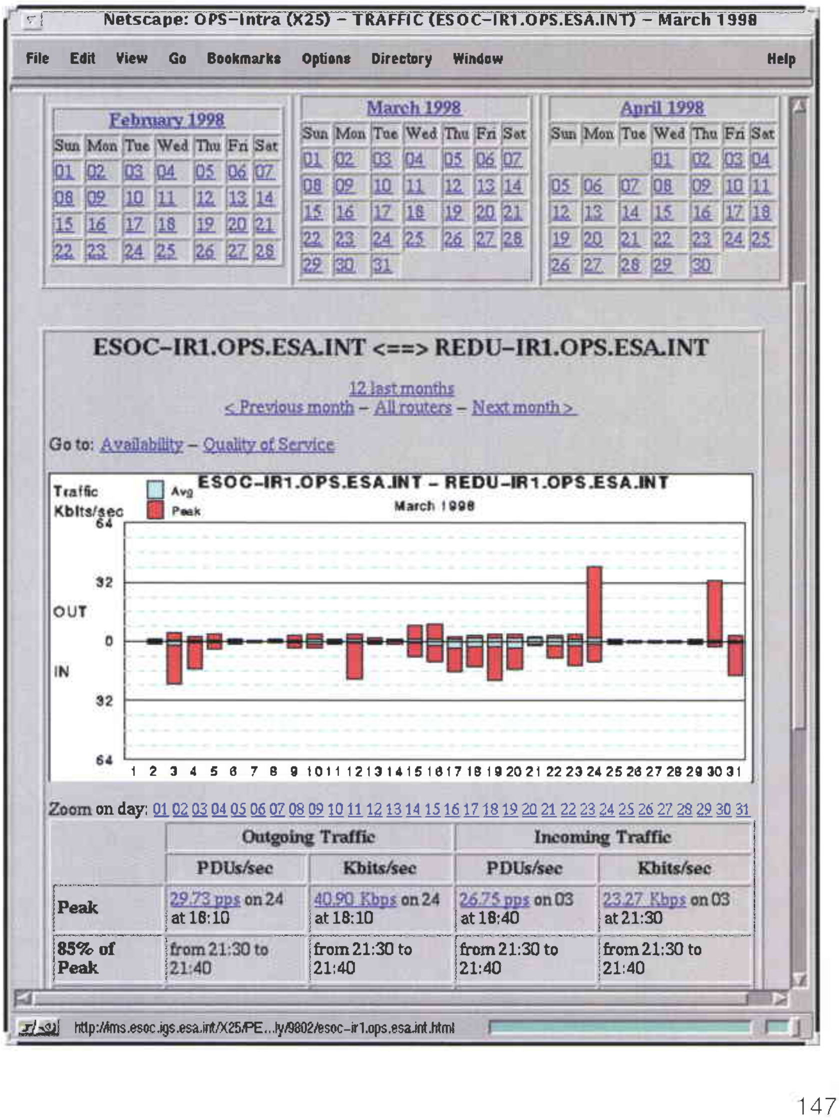
The PerfMon tool, initially developed by Aethis for ESA to monitor routers and Local Area Networks (LANs) of the administrative network in the frame of the CNMS project, has been enhanced and has been integrated with the IGS Testbed. As a spin-off, it was also installed in the recently established OPSNET Intranet.

This tool consists of a series of dedicated poller programs that efficiently collect samples of status and performance indicators via SNMP Get-Requests. These observations are regularly processed by flexible scripts, written in PERL, to update summary reports showing statistics for the short, medium and long term. The resulting reports present multiple facets of the network history: availability, traffic utilisation, Quality of Service (QoS) indicators, and delay measurements for different protocols supported by the routers.

As the set of reports generated is presented on a web site, presenting hyperlinked intuitive views at different levels of granularity, operators and users can obtain a complete picture of past network behaviour by navigating through the web site, and thereby avoiding printing large piles of paper.

The sample web report in Figure 6 shows average and peak traffic over an X.25 link between ESOC in Darmstadt (D) and Redu in Belgium (B).

Figure 6. Long-term statistics



Video service management

The video Multipoint Control Unit (MCU) is a console-controlled device, the management interface of which has been mapped to be 'SNMP-manageable' by using a LATIN (Legacy Adapter To INternet) agent. A specific Video Service Management application has been developed for the IMS to make the MCU's management more intuitive. This application generates its own OpenView submap according to layout directives in a configuration file. Typically, the icons of the 8 MCU ports are placed in a circle (Fig. 7).

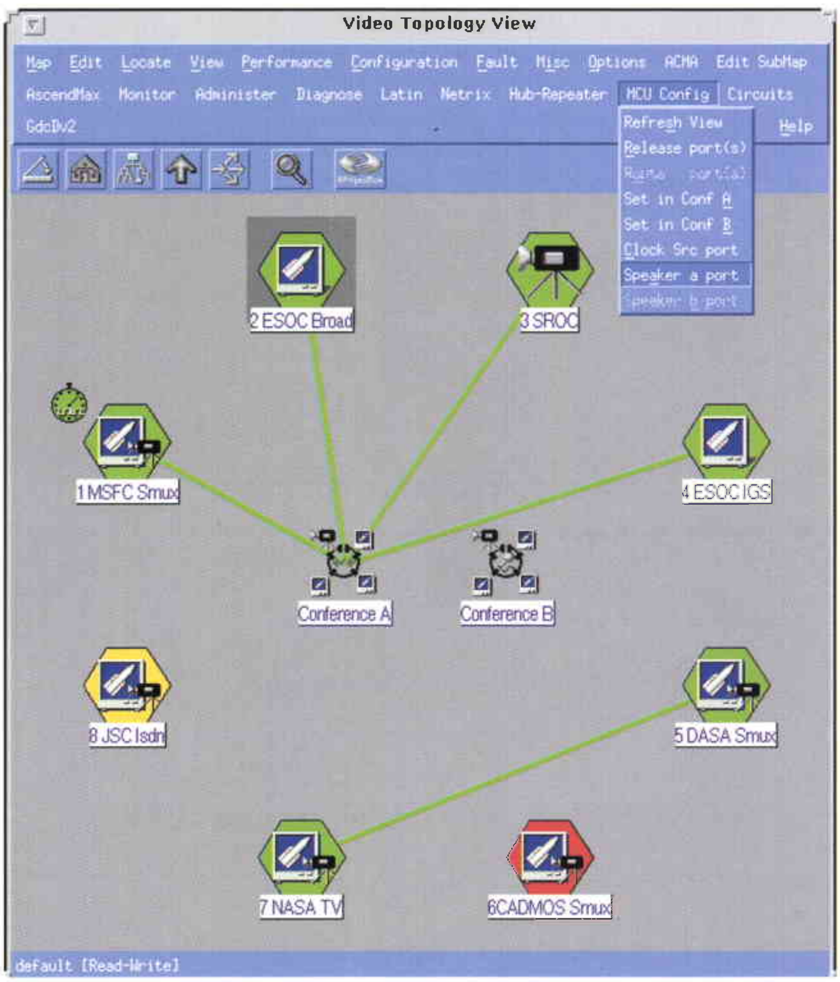


Figure 7. Video Service Management view

The device can establish two-party conferences in which both connected codec devices receive signals from each other. It also supports up to two multi-party conferences ('A' and 'B'), represented by the two central icons.

In a multi-party conference, the 'Current Speaker' signal is sent to all others, while the signal of the 'Previous Speaker' continues to be sent to the now Current Speaker. In order to distinguish the three roles, a simple 'monitor' icon is used for passive participants, while a 'camera' icon identifies the Current Speaker, and the Previous Speaker icon combines a monitor with a small camera. The icon of each conference is also dynamically selected to identify its operating mode. When it is 'Voice Switched', the louder sound source is automatically assigned as Current Speaker, while in 'Local Control' mode this selection is manually controlled.

In Figure 7, a multi-party conference 'A' has been established between the ports 1, 2, 3 and 4. Port 3 is the Current Speaker and port 1 is the Previous Speaker, whilst ports 2 and 4 are passive participants. A two-party conference is also established between ports 5 and 7. Port 6 is experiencing a bad signal, e.g. communication with the corresponding remote codec device is not established. The signal at port 8 is not synchronised. The signal at port 1 is used as the reference clock for the MCU device.

In addition, a context-sensitive menu allows simple control of the MCU behaviour. It is possible to refresh the view (to get the initial configuration before the occurrence of the first poll). Selected port(s) can be released from their two- or multi-party conference. Two selected ports can be connected in a two-party conference. Selected port(s) can be assigned to conference A or B. A single member port can be configured as Current Speaker of its conference A or B. A single selected port can be used as Clock Source.

Automated Connection Management

The scope of a prototype Automated Connection Management Application (ACMA) has been defined following an analysis of three types of information:

- a prototype database of high-level Communications Service Requests has already been built by the Mission Planning Team
- all communications services anticipated for the real IGS have been identified
- a survey of the logical communication resources of the IGS Testbed controllable by management commands has been performed.

The principal hypothesis in mission-related operational environments is that the detailed characteristics of possible connections are pre-configured in the network elements. The definition of those service instances associated with a description of their control is specified in a 'Network Resources Description' file. A formal high-level definition of the Communication Service Schedule, normally derived from mission planning, forms the second input for the Automated Connections Management Application (ACMA). In the prototype implementation this is generated with a local graphical editor.

The ACMA robot identifies all services that have to be activated or released at each transition of the communication service schedule (Fig. 8). According to the network resource definitions, the robot translates the end-to-end service definitions into sets of necessary connections, and maps their definition into elementary actions to be executed on various components of the network infrastructure. This results in a series of command scripts (typically SNMP Set-Requests) that are scheduled as UNIX at-jobs for automated execution at the requested points in time.

The feedback from the ACMA is displayed in the unified view by its status monitoring mechanisms. As only real feedback is obtained directly from the network, a command that does not succeed will not erroneously be taken into account in the display.

Lessons learned
More and more of the network devices on the market provide an SNMP management interface. However, the experience gained in integrating their monitoring and control into the IMS unified view and ACMA applications highlights the importance of the completeness of their SNMP MIBs. To allow the correct integration of a complete IMS model and a further automation of its construction, the resource MIBs have to provide access to:

- state information about the hardware interfaces
- state information about the logical connections
- complete configuration to be automatically learned by the management applications
- sufficient performance indicators for providing relevant on-line diagnostics and for feeding statistics reports with complete sets of useful observations
- full control of the activation and release of logical communications resources prepared in the network elements.

This strong requirement is an important recommendation for future procurements of network equipment to ensure smooth integration with high-level management functions. Ideally, this comprehensive SNMP management interface has to be offered by the dedicated element managers performing a first level of consolidation of the management view of individual network resources.

For better automation of the creation of the unified service model, however, the network element configuration MIBs represent just one of the two information sources needed. Knowledge about conventions of network operations and usage practices needs to be taken into account in designing a formal high-level representation of the overall communications model.

Finally, the pragmatic approach followed in the incremental set-up of the IMS prototype has proved its worth. In can be considered as a rapid prototyping of the required functionality, which allows immediate exposure of the proposed solution to operations personnel and immediate incorporation of their valuable comments. The mapping to the greatest extent possible of the individual features required to built-in mechanisms in the commercial-off-the-shelf network management platform allows

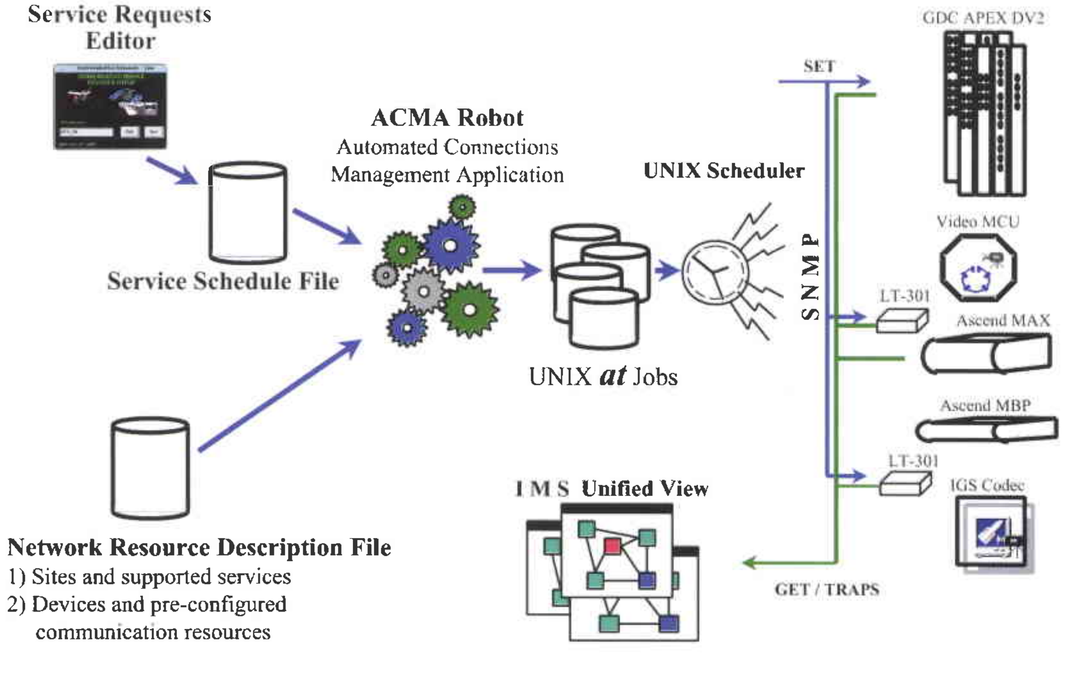


Figure 8. An Automated Connections Management Application (ACMA)

practical solutions suitable for real network operations to be achieved quickly. Those individual solutions can then be loosely combined to form a complete IMS system.

Next steps

The manual process of building up the unified view network model and the associated intuitive views will become too heavy when scaled to really large networks. A formalism has therefore to be inferred from this initial work for designing tools that can help in further automating the generation of the IMS custom configuration. Additional sophisticated Service Management Applications can be developed to tackle special management requirements of voice, video and data services. For instance, an appropriate visualisation of any degradation in quality of service, e.g. temporary loss of redundancy, would be valuable in supporting proactive troubleshooting.

The Automated Connections Management still needs to be extended to cover the complete set of communications characteristics, e.g. asymmetric/multipoint connections and specification of requested quality of service. Additional validity checks and the detection of potential conflicts in the communications service schedules are also necessary to allow the ACMA to be interfaced to the actual mission planning.

Finally, the intuitive presentation of overall communications state and its distribution to a large community of concerned users can be enhanced by the exploitation of new features provided by the recent version 6.0 of the HP OpenView platform. In particular, custom Alarm Correlation rules will help in integrating interrelated elements of information obtained from different management interfaces, and the new JAVA-based application programming interface will permit a better graphical presentation of web-based remotely accessible logical service oriented views.

Further developments of the IMS technology foresee adaptations to the operational conventions and constraints of OPSNET. Possible uses in other network environments such as the IGS are also envisaged.

Conclusion

The requirements for operational networks to support such mission scenarios as the Columbus science operations include integrated multimedia support and the integration of several different technologies (ATM, VSAT, ISDN, etc.), resulting in heterogeneous networks. The usage of the various network resources and services can be rather dynamic. The on-board experiment profile changes over time, resulting in changed geographical data flows on the ground, changed data rates or data volumes to be transported, and the involvement of different users in voice and video conferences. To minimise traffic charges, the network resources allocated have to match the actual needs and the appropriate connection technology has to be selected. Since Columbus will be operational for at least a decade, the connectivity and data-transport charges that will be accrued are major cost drivers.

The study and final prototype demonstration that have been reported here have shown that an Integrated Network Management approach can have worthwhile cost and labour-saving benefits in such situations:

- The integration of subnetworks and services into a single network management platform allows a unified umbrella view of the entire system to be maintained by a single operator.
- The automated connection and service configuration management allows complex configuration changes can be preconfigured and then executed at the scheduled time for a predefined period. Operator intervention is required only for real-time changes or trouble-shooting purposes. Configuration changes to circumvent performance degradations or equipment failures can also be automated according to preselected routines.
- Reports summarising the network performance history and trend indications are generated automatically.
- The implementation demonstrated a very effective way to match the human intuitive perception. This enables the operator to think in terms of more abstract logical network services including end-to end services.

All in all, the Integrated Network Management system approach allows one to optimise the cost of providing and operating network resources for highly complex operational systems with minimum staff requirements.

Acknowledgement

The authors would like to thank the other Aethis team members – T. Grootaers, L. Steenput and J. Maes – who helped to turn this project into a successfully demonstrated prototype. The demonstration would not have been possible without the active support of the Cap-Gemini team in charge of the IGS Testbed infrastructure at ESOC, namely G. Buscemi, A. Boccanera, F. Sintoni and A. Bernal.

Focus Earth

ERS Data Helps in Monitoring Protected Areas — An ESA-supported pilot project on the Mediterranean Coast of Turkey

(Winner of the 1998 Henry Ford European Conservation Award)

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With the uninterrupted availability of radar data from its European Remote-Sensing Satellites ERS-1 and ERS-2, ESA is providing the remote-sensing user community with a reliable and efficient means for surveying and monitoring environmentally endangered areas.

A mapping and monitoring project using ERS remote-sensing data has recently been conducted in the Köycegiz-Dalyan region, on Turkey's southwestern Mediterranean Coast (Fig. 1). This region is one of fourteen declared as Specially Protected Areas by the Turkish Government, with the aim of fostering nature conservation and protecting sites of special historical, cultural or environmental interest. The area includes the 10 km-long Dalyan Channel linking the Köycegiz Lagoon with the Mediterranean Sea, and Iztuzu Beach, one of the most important of the 17 known nesting sites for sea turtles (Caretta caretta) in the Mediterranean (Fig. 1). The oriental sweet gum tree (liquidambar orientalis) is endemic here and has been declared a protected plant due to the growing pressures on its natural environment.

Figure 1. The Köycegiz-Dalyan Protection Area and the Caretta caretta sea turtles

The primary objective of the ESA-supported pilot project was to promote the application of remote-sensing data for the conservation and sustainable management of the Mediterranean coastal zone. This required systematic surveying on a trans-national level. The main component of any effective environmental management approach is a system that supplies complete and accurate information to decision makers by exploiting up-to-date data collection and processing technology. One of the main aims of the project was therefore to develop a computer-based information system for the Turkish Mediterranean coastal zone that utilises all available and relevant data effectively – both remotely-sensed satellite data and ground-based information. Two of the main system requirements were for land-cover mapping, i.e. land-use change, vegetation productivity and biomass, and mapping of the effects of disturbances from such sources as flooding, fires, disease, and harvesting or logging. The collection of optical satellite imagery over this area is often hampered by cloud cover, but radar satellites like ERS have no such limitations, providing high-resolution images independent of cloud cover and illumination conditions (day and night).

Multi-temporal data sets of ERS-1 and ERS-2 SAR (Synthetic Aperture Radar) precision imagery covering the period between March and September 1996 were used for land-use mapping, and in particular for monitoring the distributions of different vegetation species. The work was supported by field trips, the use of topographical maps, and aerial photography. Visual interpretation of the SAR imagery was carried out after a period of familiarisation with the satellite-gathered data and the building up of a good general knowledge of the area. Automatic (supervised) classification of the data was also attempted.

The image in Figure 2 is composed of three ERS SAR data sets acquired in the same year, but during different seasons. By assigning a specific colour to each data set, seasonal variations have become visible: on land, due to changes in soil moisture content or crop growth, and at sea due to the wind and wave conditions prevailing on the day of image acquisition. Black (low) and white (high) correspond to unchanged backscatter values over time. The mono-temporal image (Fig. 2a) shows the sea-surface conditions in two SAR images taken over the lagoon on 10 and 11 November 1995, respectively.

As the Digital Elevation Model (DEM) of the area (Fig. 2b) shows, the local terrain is quite mountainous. In the SAR images, the geographical relief is very well represented visually and the topographic and geomorphologic units are well delineated. Hill or ridge slopes facing the radar are, however, subject to some foreshortening and/or layover effects.

In Figures 2c-e, the urban areas are characterised by high and constant backscatter values, due to the presence of 'corner reflectors'. The reed belt along the lakeshore is easily discernible and its border is clearly delineated. Linear objects such as roads or rivers, being smooth or flat, are easily distinguished by their dark colours in both the monochromatic and multi-temporal images.

In the upland areas, the presence of woods - mainly red pine forest - is revealed by greyish hues. In the lowland areas, the yellow and blue tones correspond, respectively, to cereal crops and late crops like corn, sunflowers, etc. (Fig. 2). A good example is provided by Figure 2f, in which seasonal development could be compared with data obtained from the Dalaman State Production Centre. In this way, phenological development in conjunction with the crop calendar has been used successfully for the verification and testing of a crop-growth monitoring experiment. The results have subsequently been applied for the classification of crop types throughout the whole project area.

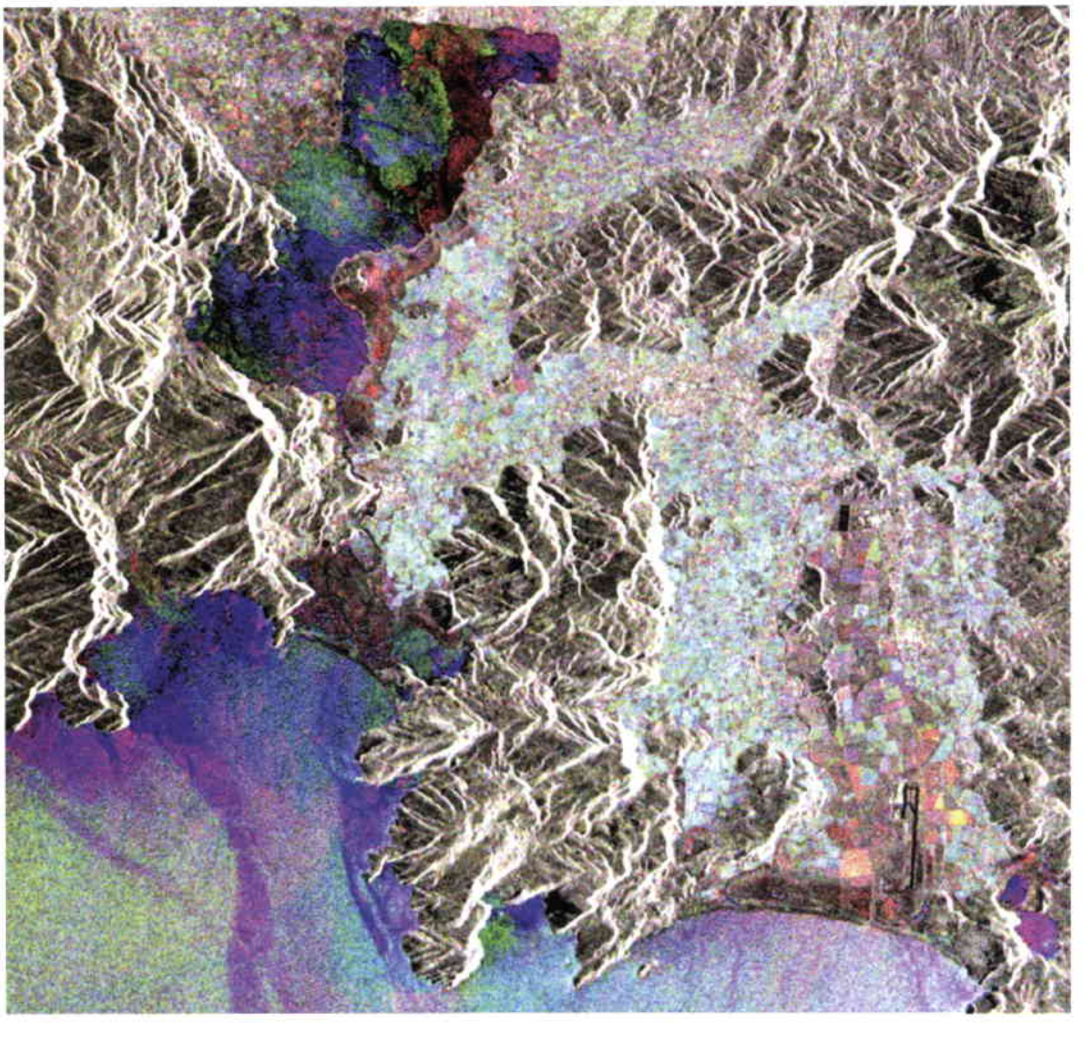


Figure 2. Multi-temporal ERS SAR image covering the period between March and September 1996, used for land-use mapping and especially the monitoring of the distribution of different vegetation species

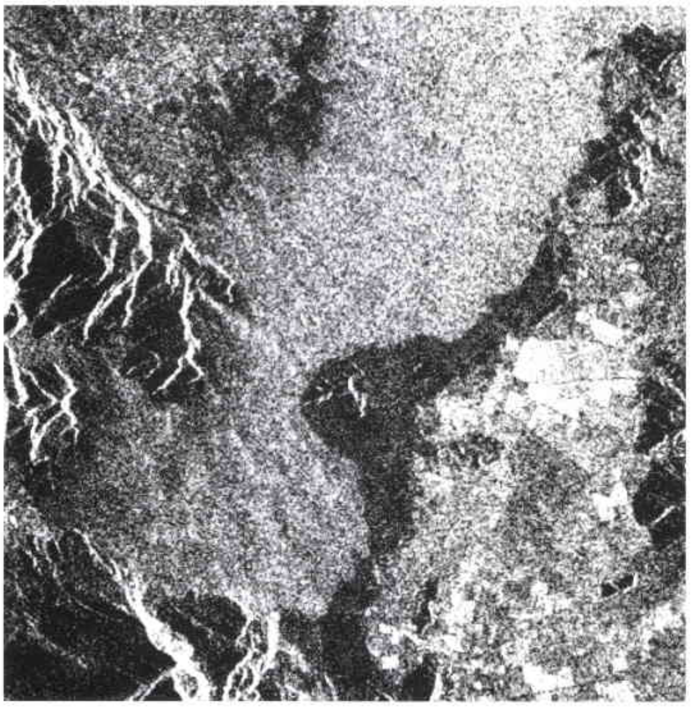


Image taken on 10 November 1995.

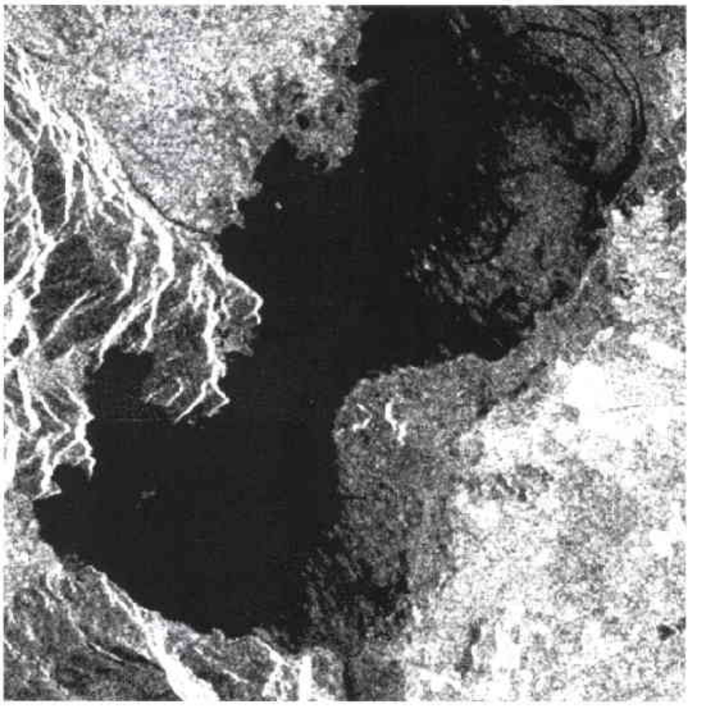


Image taken on 11 November 1995.

Figure 2a. Backscattering changes in the lake surface due to wind effects. The very frequent changes in the backscatter from a water body can be used for its clearer delineation

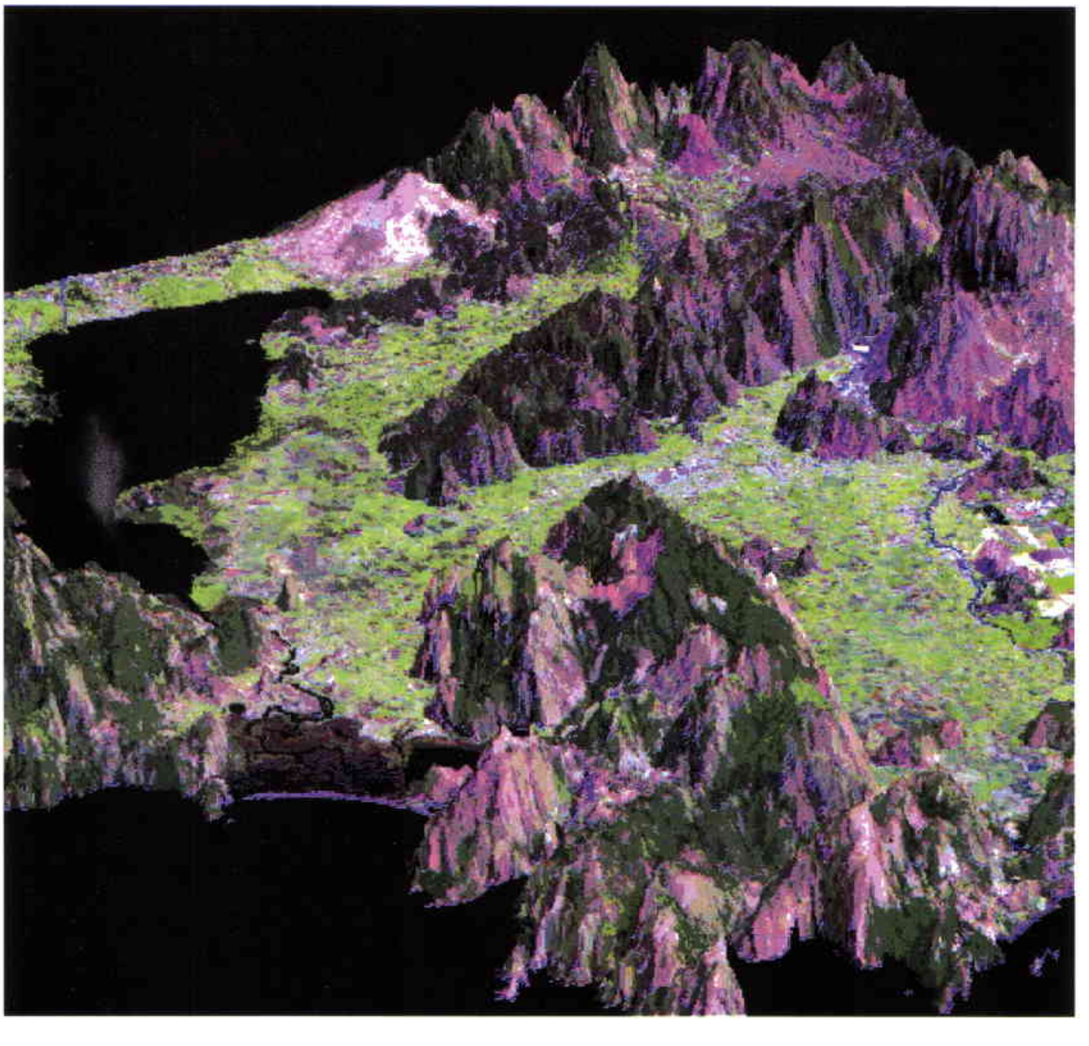


Figure 2b. An oblique view of the study area based on an irregular Triangulated Network (TIN) model and with Landsat Thematic Mapper (TM) data superimposed

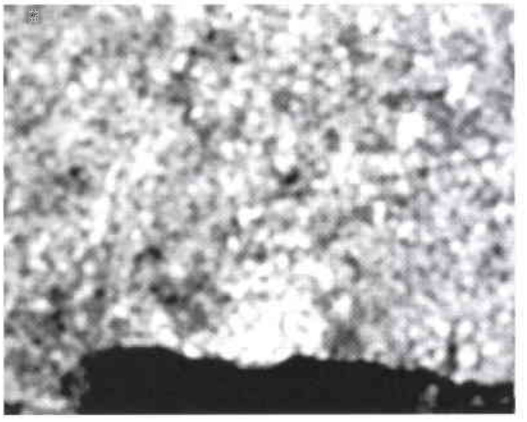


Figure 2c. Urban areas are characterised by points with very high backscattering values, due to the effects of 'corner reflectors', during all observation periods

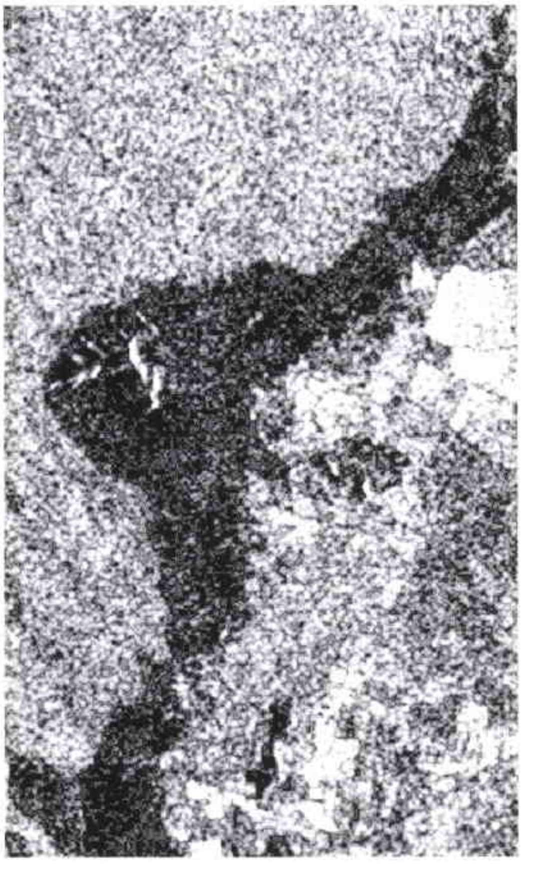
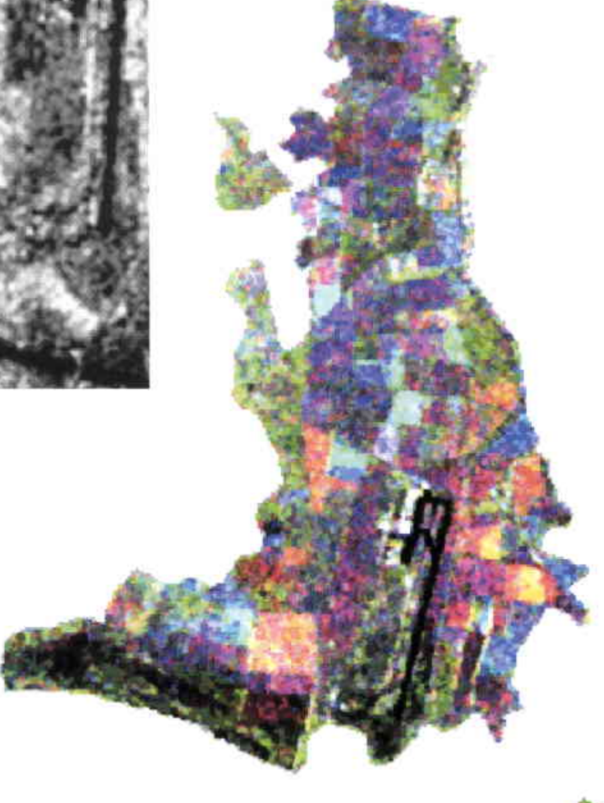


Figure 2d. Reeds along the lake shore can hide a rough water surface and hence appear in dark tones

Figure 2e. Pronounced linear features in a SAR image are often man-made structures, such as roads, airports and canals



a

b

Figure 2f. (a) Multi-temporal SAR image of the land-use-mapping test area (red: data acquired in August, green: in March, blue: in May); (b) Classification results

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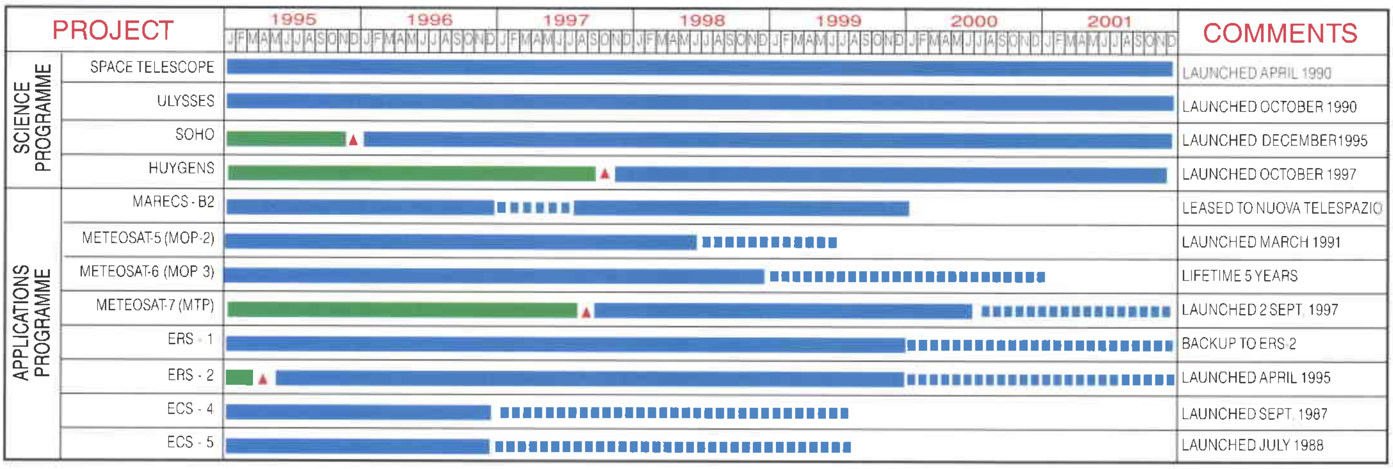
(status end March 1999)

In Orbit / En orbite



Under Development / En cours de réalisation

■ DEFINITION PHASE ■ MAIN DEVELOPMENT PHASE ▲ LAUNCH/READY FOR LAUNCH

■ OPERATIONS ■■■ ADDITIONAL LIFE POSSIBLE ▼ RETRIEVAL ▮▮▮▮▮ STORAGE

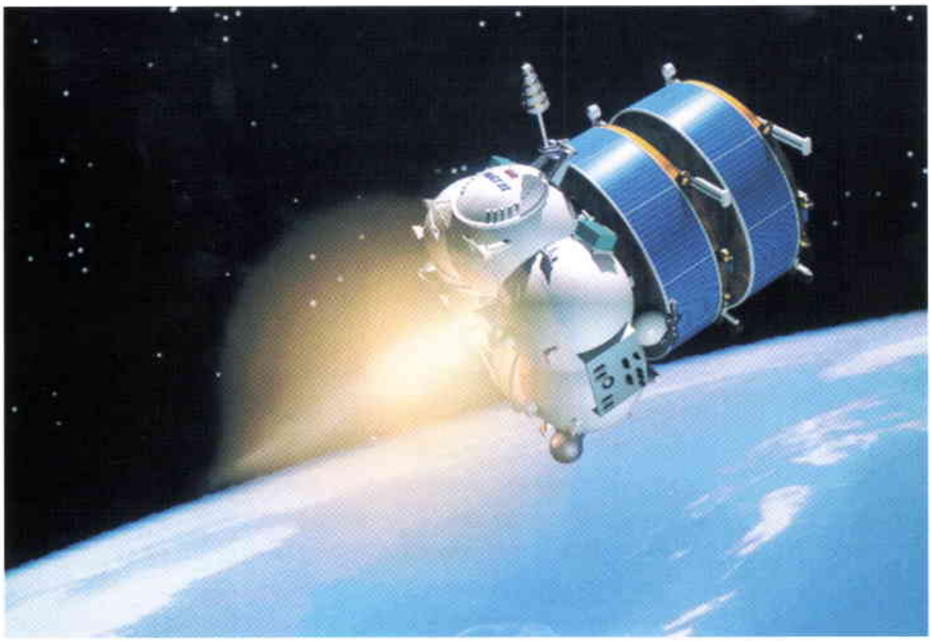
Cluster-II

La mise en œuvre du programme se déroule selon le calendrier établi, qui prévoit que les quatre satellites seront lancés deux par deux, à un mois d'intervalle, vers la mi-2000.

Le premier modèle de vol (FM6) a été intégré avant de quitter les installations de Dornier, à Friedrichshafen (D), pour celles de IABG, à Munich (D) afin d'y subir des essais d'ambiance. Les essais acoustiques ont été à ce jour réalisés avec succès, et doivent être suivis par des essais thermiques sous vide et des essais de caractéristiques de masse et de propriétés magnétiques. L'intégration du deuxième modèle de vol (FM7) est à mi-parcours, l'ensemble des éléments de la charge utile affichant un fonctionnement normal. Ce modèle devait rejoindre son prédécesseur chez IABG à la fin du mois de mai.

Le transfert de l'antenne au sol d'Odenwald (D) à Villafranca (E) se déroule également selon le calendrier prévu. La parabole mécanique a été complètement installée en Espagne et l'ensemble du système d'antenne sera prêt à fonctionner début septembre.

Le programme de qualification au sol de Frégate, le nouvel étage supérieur de Soyouz, progresse normalement et de nombreux essais ont d'ores et déjà été réalisés. Deux lancements utilisant cet étage supérieur devront avoir été accomplis avant la mise en orbite de Cluster-II. Le premier doit avoir lieu en janvier 2000 et le second en mars de la même année. Starsem commercialise aujourd'hui Soyouz avec succès auprès des clients occidentaux et compte déjà deux lancements à son actif.



Artist's impression of two Cluster-II spacecraft on the Fregat upper stage

Image conceptuelle d'un couple de Cluster-II sur l'étage supérieur Frégate

XMM

Les essais auxquels ont été soumises chacune des deux moitiés du modèle de vol du satellite ont été achevés en mars. Plusieurs équipements de vol ont été retirés du module de service afin de subir des modifications qui amélioreront leur résistance aux changements d'état ponctuels. Ces modifications ont été décidées à la lumière des conclusions de l'enquête sur Soho.

Le télescope du moniteur optique a été démonté afin d'être remis en état à la demande du responsable de recherche. Après le remplacement de certains éléments déficients, on a découvert un nouveau défaut dans ses équipements électroniques, ce qui risque de peser de manière critique sur le calendrier de livraison de l'instrument avant le lancement.

La prochaine étape majeure dans le domaine des essais d'ambiance consistera à préparer les essais acoustiques que doit subir en juillet l'ensemble du satellite dans la Grande chambre européenne d'essais acoustiques (LEAF) de l'ESTEC. Les essais électriques des différentes fonctions du satellites, entrepris parallèlement aux essais d'ambiance, ont permis de confirmer le fonctionnement normal de tous les systèmes.

Les essais de recette de l'exemplaire de rechange du module miroir de vol ont été achevés au Centre spatial de Liège (CSL, B). Le module est désormais placé dans l'installation Panter de l'Institut Max-Planck de Garching (D) où l'on procédera à l'étalonnage de son fonctionnement dans le rayonnement X. Les trois modèles de vols du module miroir sont désormais installés à bord du satellite.

Les groupes 'instruments', déjà étroitement associés à la campagne d'essais fonctionnels et d'ambiance réalisés à l'ESTEC, se consacrent aujourd'hui à la finalisation des logiciels et de la documentation nécessaires pour préparer l'exploitation de leurs instruments.

La version définitive du logiciel de contrôle mission a été livré en mars à l'ESOC pour y subir ses essais de recette. Les premiers essais de validation au niveau système ont été réalisés en utilisant cette dernière version, permettant au opérateurs du système de contrôle mission de l'ESOC de contrôler entièrement, pour la première fois, l'ensemble du satellite.

La communauté scientifique a été, pendant ce temps là, invitée à soumettre une première série de demandes d'observation pour la mission XMM, en utilisant à cette fin le système de 'télé-soumission' proposé par l'Agence. Cette procédure devait s'achever fin avril.

Intégral

La réalisation d'essais fonctionnels au niveau système a marqué la fin, à la mi-février, de la première grande étape de fabrication du modèle d'identification du satellite. Bien que les instruments de la charge utile aient été installés dans une configuration réduite ou simplement simulés, ces essais ont permis de

Cluster-II

The project is still going according to schedule, aiming for the four spacecraft to be launched in two pairs, one month apart, in the middle of 2000.

The first flight model (FM6) has been successfully integrated and transported from Dornier in Friedrichshafen (D) to IABG in Munich (D) for environmental testing. So far, the acoustic test has been successfully performed, and this will now be followed by thermal vacuum, magnetic and mass property tests. The second flight model (FM7) is half way through its integration with all payload units operating nominally. This model will follow FM6 to IABG at the end of May.

The move of the ground antenna from the Odenwald (D) to Villafranca (E) is also going according to plan. The mechanical dish has been fully installed in Spain and the complete antenna system will be ready by early September.

The ground qualification programme for the new Fregat upper stage for the Soyuz launch is progressing and many tests have already been successfully completed. Before the Cluster-II launch, two successful launches using this upper stage must take place - one in January 2000 and one in March 2000. The commercialisation by Starsem of the Soyuz rocket to be used by Western customers is now well-proven, with two successful launches having already taken place.

XMM

The two halves of the flight satellite completed their individual test sequences in March. Some flight equipment was taken off the service module to undergo technical modifications in order to increase the equipment's resistance to single-event upsets. The decision to implement these modifications was taken following the lessons learnt from the SOHO investigation.

The Optical Monitor Telescope was dismounted for refurbishment at the request of the Principal Investigator. After the replacement of deficient parts in the optical system, another shortcoming in the electronics was discovered, making the instrument's delivery critical for the launch.

The next major step in the environmental test sequence is the preparation for the acoustic testing of the whole spacecraft in the Large European Acoustic Facility (LEAF) at ESTEC, planned for July this year. The electrical testing of the various satellite functions is being conducted in parallel with the environmental tests and confirms the nominal performance of all systems.

At Centre Spatial de Liège (CSL, B), the acceptance testing of the spare flight mirror module has been completed. The mirror module is now installed in the Panter test facility at the Max-Planck Institute in Garching (D) for the calibration of its X-ray performance. The three flight mirror modules are already installed in the spacecraft.

In addition to their close involvement in the environmental and functional test campaign at ESTEC, the efforts of the instrument groups are currently focused on finalising software and documentation to prepare for the operation of their instruments.

The final release of the mission-control software was delivered to ESOC in March for acceptance testing. The first system-level validation test making use of this new release has been run successfully, with the spacecraft fully controlled from ESOC by the mission control system for the first time.

In the meantime, the scientific community has been invited to submit the first batch of observation requests for the XMM mission using the remote proposal-submission system. This process will last until the end of April.

Installation of the third flight-model mirror in the XMM service module

Installation du 3ème miroir de vol sur le module de service du satellite XMM

démontrer :
- que les modules de servitude et de charge utile fonctionnaient correctement,
- que les équipements de soutien au sol étaient opérationnels et en mesure de réaliser une simulation dynamique,
- que les procédures d'essais répondaient aux besoins et permettait d'enchaîner normalement les étapes de développement prévues pour la mission,
- que l'on pouvait exploiter les instruments sur le satellite.

Le programme de développement du modèle d'identification devait reprendre en avril, après amélioration des modèles de charge utile – et notamment de certains éléments des capteurs – permettant de mieux refléter la configuration de vol. Le modèle d'identification devrait être achevé fin juillet 1999.

Le programme de réalisation du modèle de vol a parallèlement débuté, avec la livraison de différents éléments électroniques et de structure et les premières étapes d'intégration du module de servitude. La principale inquiétude concerne la livraison de la chargeutile du modèle de vol, les prévisions actuelles interdisant que l'on puisse procéder au lancement en avril 2001. Sous réserve de nouvelles estimations, la première possibilité se situe désormais au début du créneau de lancement automnal, en septembre 2001.

Un examen du secteur sol a été réalisé en janvier. L'état d'avancement des différents éléments a été jugé satisfaisant pour cette phase du projet.

Les progrès des démarches entreprises par l'Agence spatiale russe pour obtenir de son gouvernement l'autorisation de fournir un lanceur Proton ont permis l'entrée en vigueur de l'arrangement de coopération. Cette évolution positive a permis à l'équipe de projet de finaliser le contrat d'adaptation à conclure avec l'industrie russe, portant sur les éléments spécifiques à Intégral non-inclus dans l'arrangement.

Rosetta

On finalise actuellement la conception détaillée du satellite et la majeure partie de ses éléments et sous-systèmes ont déjà fait l'objet de revues de conception préliminaire.

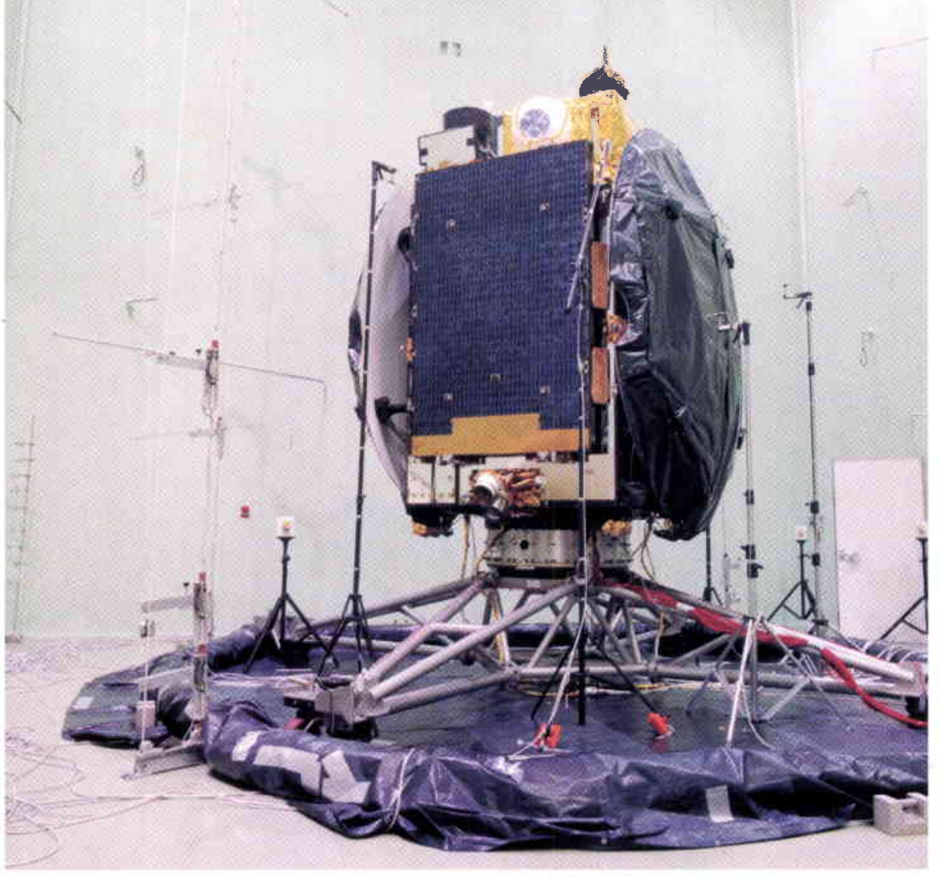
Les caractéristiques particulières à une mission dans l'espace lointain comme celle de Rosetta ont conduit l'ESOC, la direction technique de l'ESTEC et l'industrie à se pencher attentivement sur la mise au point du logiciel de bord. Il a fallu imaginer de nouvelles solutions pour garantir une exploitation sûre et autonome du satellite à des distances très éloignées du Soleil, en tenant compte de la difficulté d'établir une liaison radio fiable et de la lenteur de propagation du signal (plus de 90 minutes). Ces travaux de conception sont aujourd'hui bien consolidés, ce qui a permis de réaliser avec succès, fin mars, une revue des impératifs du logiciel.

La réalisation du modèle structurel et thermique (STM) progresse également de manière satisfaisante. La fabrication du cylindre central du satellite est achevée et l'on a commencé celle des panneaux latéraux. Plusieurs STM d'expériences sont prêts à être livrés. Le STM de l'atterrisseur de Rosetta a été complètement intégré et il était prévu de l'expédier le 29 mars chez IABG pour y entamer des essais d'ambiance.

A la suite d'une recommandation de la commission de revue de la conception du système de mission début décembre 1998, on a décidé d'installer un dispositif supplémentaire de commande du satellite utilisant une liaison radiofréquence en bande X. Cela permettra d'éviter toute interférence potentielle avec de futurs systèmes de téléphonie mobile. On envisage, pour la même raison, de rechercher un nouveau lieu d'implantation pour l'antenne au sol de 35 mètres qu'il était prévu à l'origine d'installer à Perth, en Australie. Une petite vallée, située à quelque 100 km au nord du centre de la ville australienne, parait offrir la solution de remplacement la plus souhaitable.

Artémis

Plusieurs étapes importantes ont été franchies dans le programme d'essais du satellite Artémis actuellement mené à



Artemis during acoustic testing at ESTEC

Artémis aux essais acoustiques à l'ESTEC

Integral

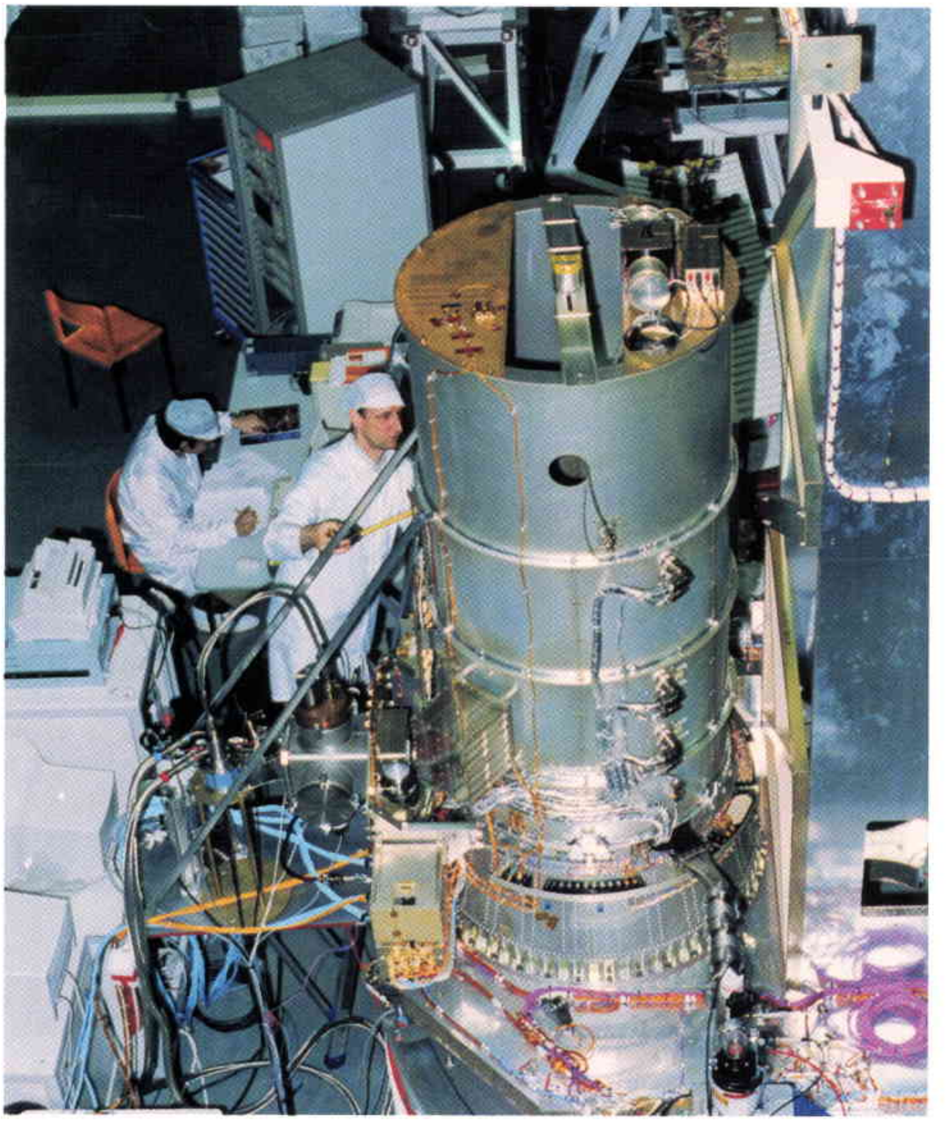
The first main milestone for the satellite engineering model was achieved in mid-February with the completion of a system functional test. Although the payload instruments were either simulated or present in a reduced configuration, the test demonstrated that:
- the Service and Payload Modules are functioning correctly
- the ground-support equipment is operating and able to perform a dynamic simulation
- the test procedures are working and able to step the satellite through the nominal mission sequence
- the instruments can be operated within the satellite.

The engineering-model programme is expected to resume in April, following improvement of the payload models, including detector elements, to better represent the flight configuration. It is planned to complete the engineering model by the end of July 1999.

In parallel, the flight-model programme has started with the delivery of various structural and electronic units and the first steps in the Service Module's integration. The main concern is the availability of the flight-model payload, and current delivery forecasts have ruled out an April 2001 launch. Pending further review, the earliest launch opportunity is now at the start of the fall launch window in September 2001.

A ground-segment review was completed in January. In general, the development status of the various ground-segment elements was found adequate for this phase of the project.

The Russian Space Agency has made some progress in seeking government approval for the provision of the Proton launcher, leading to the entry into force of the co-operation arrangement. Based on these positive signals, the project team is finalising the adaptation contract with Russian industry for the Integral-specific items not covered under the arrangement.



The Integral spectrometer engineering model under test at Alenia (I)

Le modèle technologique du spectromètre d'Integral en cours d'essais chez Alenia (I)

Rosetta

The spacecraft's detailed design is being finalised and Preliminary Design Reviews have been held for most of the spacecraft units and subsystems.

Due to the particular characteristics of a deep-space mission like Rosetta, the design of the on-board software has required an intensive effort, involving Industry, ESOC and the ESTEC Technical Directorate. Innovative solutions have had to be found to ensure safe autonomous operation of the spacecraft at distances far from the Sun, taking into account the difficulty of establishing a reliable radio link and the long signal-propagation delays (more than 90 min). The software design is now well consolidated and the Software Requirements Review was successfully concluded at the end of March.

The Structural and Thermal Model (STM) programme is also making good progress. Manufacture of the spacecraft central cylinder is complete and production of the lateral panels has started. Several experiment STM models are ready for shipment. The Rosetta Lander STM model has been fully integrated and its delivery to IABG for the start of environmental testing is planned for 29 March.

Following a recommendation from the Mission System Design Review Board in early December 1998, an additional capability to command the spacecraft using the X-band radio-frequency link is being implemented. This will avoid potential interference problems with future mobile telephone systems. For the same reason, a more suitable location is being considered for the 35 m ground antenna *l'ESTEC. On a notamment achevé les essais mécaniques d'ambiance, avec – venant s'ajouter aux essais traditionnels d'excitation acoustique et de vibration sinus – un essai aux microvibrations qui a permis de vérifier que l'environnement du satellite était compatible avec les impératifs très stricts du terminal de communications optiques Silex.*

Outre les essais du satellite, ont procède actuellement à l'intégration finale des installations de contrôle de Fucino (I) et à une modification des installations de Redu (B) pour qu'elles puissent être utilisées par les satellites de la NASDA devant bénéficier du soutien d'Artémis.

EOPP

Stratégie et programmes futurs

Les dernières semaines ont été essentiellement consacrées à préparer, avec le Conseil directeur (PB-EO), la Déclaration de programme et le Règlement d'exécution du Programme-enveloppe d'observation de la Terre. On se prépare également à travailler avec l'industrie à la définition d'un éventuel réseau d'information européen de données de télédétection.

Missions futures

Les études de phase-A des quatre missions de base d'exploration de la Terre se poursuivent avec pour objectif de procéder à la définition d'une formule de référence définitive. On prépare actuellement le choix de deux missions pour la fin de l'année.

Les vingt sept propositions de missions de circonstance d'exploration de la Terre reçues en décembre dernier ont été évaluées et l'on a déjà publié les recommandations de l'ESAC à ce sujet.

Campagnes

Les campagnes 1999 ont été avalisées par le DOSTAG et l'on procède actuellement à leur phase de définition.

Envisat/Plate-forme polaire

Système Envisat

La définition des opérations entrant dans le cadre de la vérification d'ensemble du secteur sol (GSOV) a été achevée et les activités correspondantes ont débuté avec l'industrie.

On progresse dans la préparation des activités d'étalonnage et de validation après lancement: les équipes sont en cours d'organisation et l'on évalue les offres d'étalonnage et de validation reçues dans le cadre de l'avis d'offre de participation relatif à l'exploitation des données.

Activités liées au satellite

Les activités portant sur le modèle d'identification du satellite Envisat ont considérablement progressé, avec la réalisation des essais de compatibilité radiofréquence et électromagnétique. On travaille actuellement sur les quelques cas de non-conformité qui ont été constatés. Des essais de validation du système, permettant à l'ESOC de vérifier la compatibilité du logiciel du centre de contrôle des opérations en vol avec le satellite, ont été réalisés avec succès. Il ne reste plus que quelques essais supplémentaires à effectuer pour achever les travaux liée au modèle d'identification du satellite.

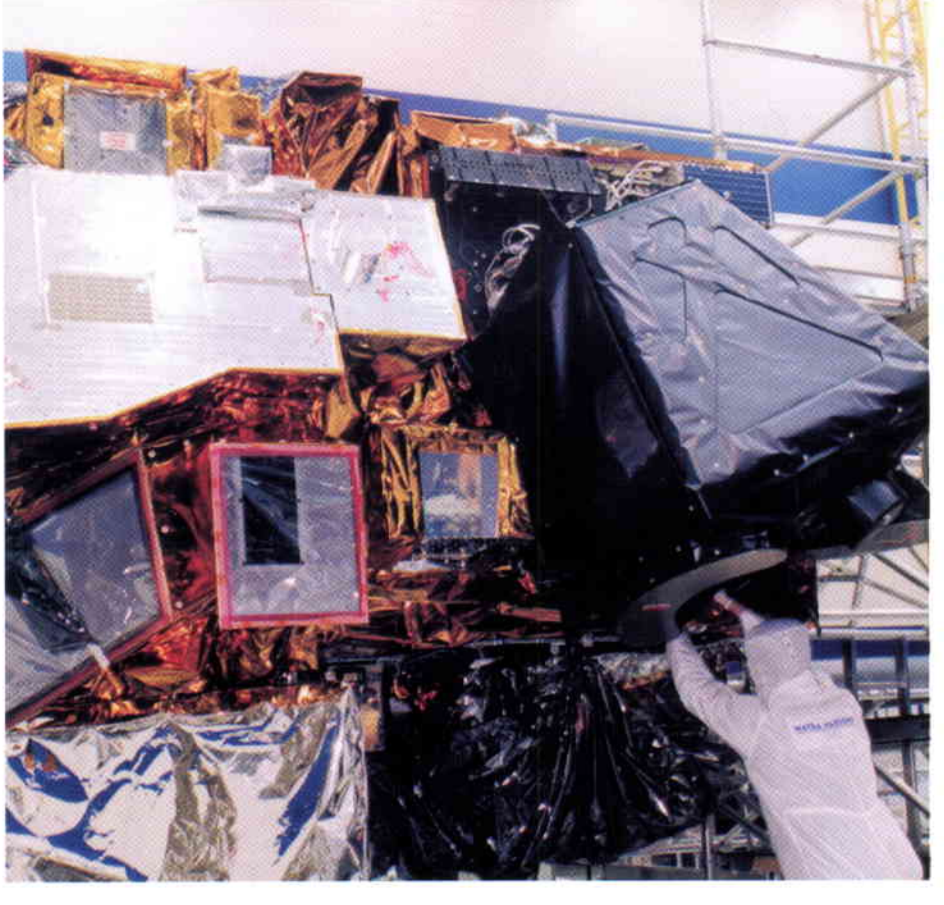
Les activités d'assemblage, d'intégration et d'essais (AIT) du modèle de vol se sont accélérées avec l'intégration des différents instruments. L'altimètre radar (RA-2) et les éléments électroniques de l'ASAR (CESA), du MTSR et du SCIAMACHY ont été totalement intégrés, et l'électronique du modèle de vol du MIPAS a été couplée à l'unité optique du modèle d'identification. Le modèle d'identification du MERIS a été retiré du modèle d'identification du satellite pour être intégré au modèle de vol. L'enregistreur a état solide a également été intégré dans le module de charge utile. L'intégration du modèle de vol progresse normalement à ce jour, et la préparation des essais de bilan thermique et d'ambiance thermique sous vide se déroule selon le calendrier prévu.

La préparation de la revue de qualification du satellite Envisat est en cours.

Charge utile Envisat

Le modèle de vol de l'instrument AATSR a été livré début février.

La revue de qualification officielle de



MIPAS and AATSR mounted on the Envisat Payload Module flight unit

Montage de MIPAS et AATSR sur l'unité de vol du module de charge utile d'Envisat originally planned to be installed in Perth (Australia). The most likely alternative is a small valley some 100 km north of the city centre.

Artemis

The Artemis satellite test programme is continuing in ESTEC, with several major milestones in the test campaign having now been achieved. In particular, the mechanical environmental testing has been successfully completed. This has included, in addition to the conventional testing with acoustic excitation and with sine vibration, a microvibration test to verify that the spacecraft environment is compatible with the stringent requirements of the Silex optical communications terminal.

In addition to the satellite testing, work is also proceeding on the final integration of the satellite control facilities in Fucino (I), and on the modifications to the facilities in Redu (B) to make them suitable for utilisation by the NASDA satellites to be supported by Artemis.

EOPP

Strategy and future programmes

The main emphasis in recent weeks has been on establishing the Programme Declaration and Implementing Rules for the Earth Observation Envelope Programme with the Programme Board (PB-EO). In addition, progress has been made towards working with Industry to define a potential European Remote-Sensing Information System.

Future missions

The four Phase-A studies of candidate Earth Explorer Core Missions have progressed towards final baseline definition. Work is now in progress to prepare for the selection of two missions at the end of the year.
The twenty-seven Earth Explorer Opportunity mission proposals received last December have now been evaluated and the recommendations of the ESAC have been published.

Campaigns

The 1999 campaigns have been agreed by DOSTAG and are now in the definition phase.

Envisat/Polar Platform

Envisat system

The definition of the Ground Segment Overall Verification (GSOV) has been completed and the corresponding activities are being initiated with industry.

Organisation of the post-launch calibration/validation activities is in progress: the teams are being organised, including the evaluation of calibration/validation offers received via the Announcement of Opportunity (AO) for data exploitation.

Satellite activities

The Envisat satellite engineering-model programme has progressed significantly with the successful completion of the electromagnetic and radio-frequency compatibility tests. A few limited non-conformances have been identified which are currently being worked on. In addition, a system validation test permitting ESOC to verify compatibility of the Flight Operations Control Centre software with the satellite has been successfully executed. A few additional tests remain in order to complete the engineering-model satellite programme.

The flight-model Assembly, Integration and Test (AIT) activities have gained further momentum with the continuation of instrument integration. The flight-model Radar Altimeter (RA2), the flight-model ASAR electronics (CESA), the MTSR and the SCIAMACHY electronics have all been integrated, and the MIPAS flight-model electronics coupled to the engineering qualification model optical unit. The MERIS engineering model was removed from the engineering-model satellite to be integrated on the flight model. The Solid State Recorder was also integrated into the Payload Module. So far, the flight-model integration is progressing well, and preparations for the thermal-balance/thermal-vacuum test are on schedule.

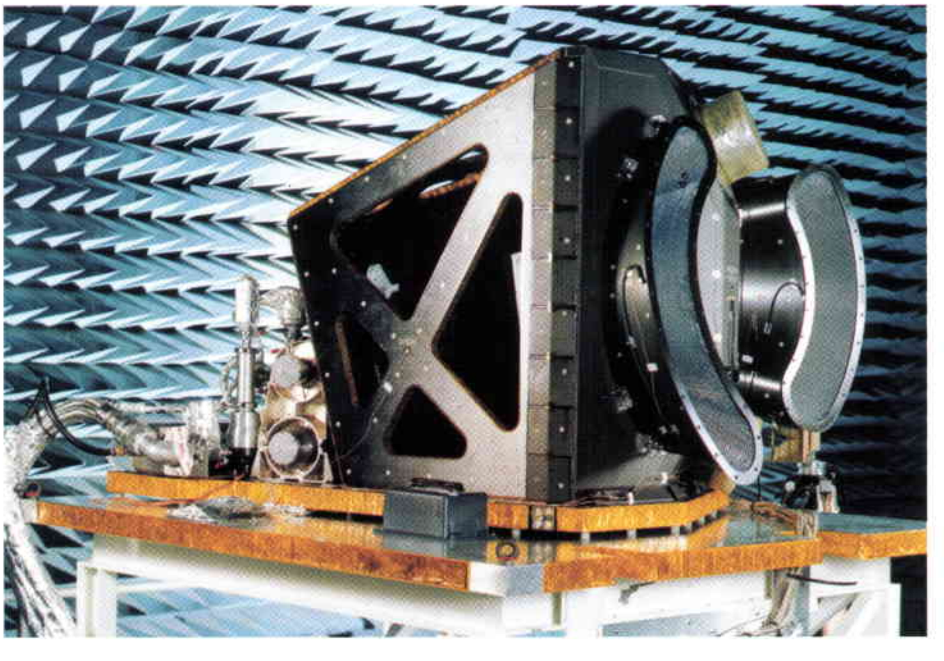
Preparations for the Envisat Satellite Qualification Review are in progress.

Envisat payload

The flight model of the AATSR instrument was successfully delivered in early February.

The SCIAMACHY instrument's formal qualification review was held in January and final integration and acceptance testing is currently in progress. The flight-model electronics have already been delivered.

Assembly of the MIPAS instrument optical flight model has been resumed and is



Flight model of Envisat's AATSR instrument during EMC testing

Le modèle de vol de l'instrument AATSR soumis à des essais EMC *l'instrument SCIAMACHY s'est déroulée en janvier et les derniers essais d'intégration et de recette sont en cours. L'électronique du modèle de vol a été livrée.*

L'assemblage du modèle de vol de l'instrument optique MIPAS a repris et devrait être achevé à la fin du mois de juillet.

Des problèmes d'étanchéité à la lumière ont été constatés dans les caméras du modèle de vol de l'instrument MERIS. Ils sont en cours de résolution.

Les essais de recette de l'antenne du modèle de vol de l'ASAR sont en cours.

Secteur sol Envisat

L'intégration du système des données de charge utile (PDS) s'est poursuivi, avec l'installation du centre de contrôle des données de charge utile sur la plate-forme de référence installée chez DATAMAT, à Rome (I). La station de traitement des données de charge utile (PDHS) est aujourd'hui entièrement installée à l'ESRIN, à Frascati (I) et subit ses essais de recette.

Après achèvement des essais de vérification du satellite, on procède actuellement, selon les plans prévus, à la revue de mise en œuvre du secteur des opérations en vol (FOS).

Métop

Une importante série de revues de conception préliminaire (PDR) ont eu lieu fin 1998 et début 1999 au niveau des différents éléments du satellite, ouvrant ainsi la voie aux PDR de niveau supérieur. La PDR du module de service (SVM) a été remplacée par une revue de conception du matériel pour tenir compte de la nature largement récurrente de cet élément. Les PDR du module de charge utile (PLM) et de l'instrument ASCAT se sont déroulées en avril et celle de l'instrument GOME-2 devrait débuter prochainement. La réalisation de l'instrument GRAS progresse de manière satisfaisante, ce qui – en dépit d'un démarrage tardif par rapport à d'autres éléments du programme – devrait permettre de réaliser la PDR de cet instrument avant celle du système.

La PDR au niveau système devrait finalement avoir lieu en mai et juin. La revue concernera la totalité des éléments du satellite Métop. La réalisation de l'ensemble du système, y compris le secteur sol et le lanceur, est placée sous la responsabilité d'Eumetsat et son domaine dépasse, en conséquence, celui des différentes revues citées ici.

Le contrat principal de développement industriel du satellite Métop prévoit la réalisation d'algorithmes et de prototypes de logiciels servant à confectionner des produits de données de niveau 1b à partir des instruments ASCAT et GRAS. Le choix du contractant chargé de cette tâche pour l'instrument GRAS devrait permettre de parachever la composition de l'équipe industrielle Métop. Le groupe industriel Métop devrait procéder au choix nécessaire à l'issue d'un appel d'offre ouvert.

Un certain nombre de raisons ont retardé jusqu'ici la signature du contrat de développement de Métop, et il a fallu – pour assurer une couverture juridique à l'industrie – publier fin mars une nouvelle autorisation d'engagement de travaux destinée à remplacer celle venue à expiration.

A la suite du séminaire ESA/Eumetsat cité dans le Bulletin ESA 97, on a entrepris de recenser les éléments développés à l'origine pour ERS et Envisat susceptibles d'être réutilisés dans le système Eumetsat EPS.

Météosat de seconde génération

Le modèle structurel et thermique (STM) du satellite a été testé avec succès avant d'être démonté. Les éléments de vol qu'il contenait (telles les structures primaires et secondaires et les réservoirs) ont été retournés à leur fabricant pour une remise en état qui doit permettre de les utiliser ultérieurement sur le modèle de vol 3. Les résultats des essais de choc basés sur les chocs induits par Ariane-5 sont toujours en cours d'évaluation.

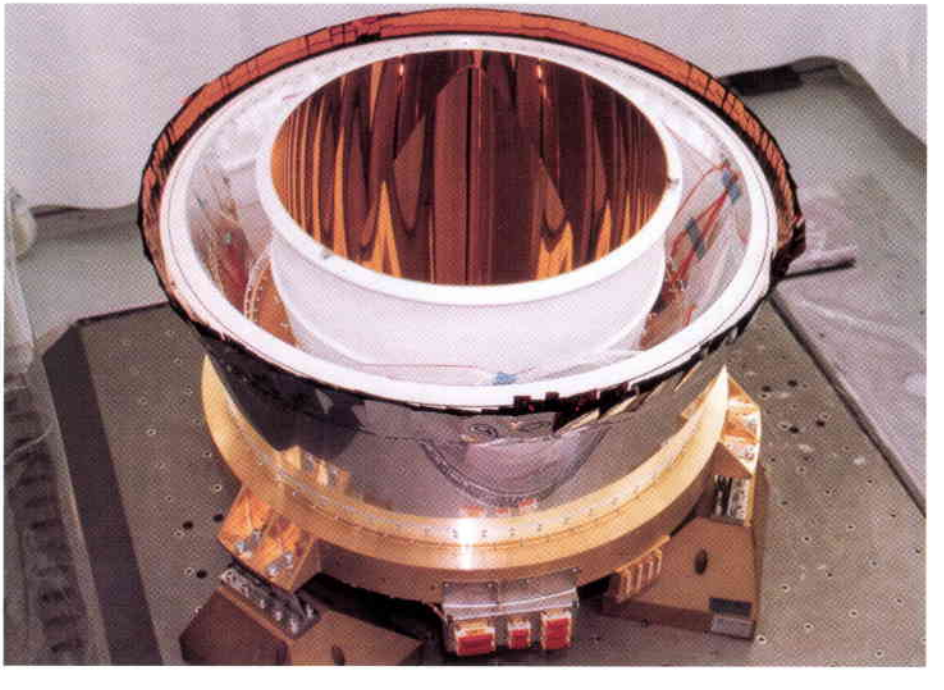
Le modèle d'identification du satellite a été intégré et attend désormais l'instrument optique SEVERI qui se trouve actuellement au Centre spatial de Liège (B) pour y subir ses derniers essais de fonctionnement.

Le modèle de vol MSG-1 du satellite est prêt pour l'intégration de l'instrument SEVERI et du sous-système de communication de la mission.

Le lancement de MSG-1 est toujours fixé à octobre 2000, en dépit d'une marge de

The MSG SEVIRI instrument's passive-cooler assembly

Le dispositif de refroidissement passif de l'instrument MSG-SEVIRI



planned to be completed by the end of July.

The MERIS flight-model cameras were all found to be suffering from light-tightness problems, which are presently being fixed.

The ASAR flight-model antenna acceptance testing is in progress.

Envisat ground segment
The Payload Data Segment (PDS) integration effort is still in progress with the setting up of the Payload Data Control Centre configuration on the Reference Platform of DATAMAT in Rome (I). The Payload Data Handling Station (PDHS) is now fully deployed at ESRIN in Frascati (I) and is undergoing acceptance testing.

Following successful completion of the Satellite Verification Tests, the Flight Operations Segment (FOS) implementation review is being performed according to plan.

Metop

The latter part of 1998 and early 1999 has seen an intensive series of Preliminary Design Reviews (PDRs) at unit level, building up to the higher level PDRs. In the case of the Service Module (SVM), the PDR has been replaced by a Hardware Design Review, in recognition of the largely recurrent nature of this element. The PDR for the Payload Module (PLM) and the ASCAT instrument is underway (April) and the GOME-2 PDR will start shortly. The GRAS instrument's development is progressing well and, despite its late start compared to other programme elements, it will also undergo a PDR prior to the System PDR.

Finally the System Level PDR will take place in May and June. This Review will encompass all elements of the Metop spacecraft itself. The ground segment and launcher are being developed under the responsibility of Eumetsat, and consequently beyond the scope of the review cycle described here.

The main industrial development contract for the Metop spacecraft includes the development of algorithms and prototype software for the generation of level-1b data products from the ASCAT and GRAS instruments. The selection of the contractor to perform this task for the GRAS instrument is one of the last open elements in terms of the Metop industrial team. Metop industry is currently conducting this selection by competitive Invitation to Tender.

The contract for Metop development has not yet been signed for a number of reasons, and with the expiry of the existing Authorisation to Proceed (ATP), which had provided coverage to industry, a further ATP was issued at the end of March.

Following the ESA/Eumetsat seminar described in ESA Bulletin 97, an effort to identify elements developed primarily for ERS and Envisat that may be reused in the Eumetsat EPS system has been undertaken.

Meteosat Second Generation

The satellite Structural and Thermal Model (STM) has, after successful testing, been dismounted and the flight elements that it contained (such as primary and secondary structures and tanks) have been returned to their manufacturer for refurbishment and later use for FM-3. Shock-test results, based on Ariane-5 induced shocks, are still under evaluation.

The engineering-model satellite has been integrated and is now waiting for the SEVERI optical instrument, which is currently at Centre Spatiale de Liège (B) for final performance testing.

The MSG-1 flight-model satellite is waiting for the SEVIRI instrument and the mission communication subsystem to be integrated.

The predicted launch date for MSG-1 remains October 2000, albeit with a diminishing margin. MSG-2 and MSG-3 remain on schedule, with a predicted launch date of 2002 for MSG-2 and an anticipated storage date for MSG-3 in 2003.

ERS

ERS system operations have continued very smoothly with excellent performances from both the satellites and the ground segment. The mission was conducted with ERS-2, with the ERS-1 payload kept in hibernation for back-up purposes.

In order to extend the ERS mission for as long as possible, the satellite operations and performances are monitored very closely. The gyroscopes are running within specification, but randomly produce low-level noise, indicating some ageing of the mechanical parts. To lower the stress on the gyroscopes and to extend their operational lifetime, a new Attitude and Orbit Control System (AOCS) using only one gyro and supported by the digital Earth sensors and reaction wheels is being developed; it should become available for implementation by October.

To maintain ERS-1 battery performance, the SAR image mode is activated once a day. This opportunity is used to perform ERS-1/2 SAR interferometry by pre-planning pairs of SAR images.

International Space Station

ISS Overall Assembly Sequence
The status of the first two ISS elements, 'Zarya' and 'Unity', launched in November and December, respectively, and assembled in orbit, is being continuously monitored by the Mission Control Centres in Moscow and Houston. The performance of all systems is reported to be satisfactory.

It is now evident that the launch of the Russian Service Module is likely to slip from July to September/October. Multilateral activities for updating the Overall Assembly Sequence will start once a firm launch date for the Service Module has been scheduled, leading to a meeting of the Space Station Control Board (SSCB) in early June.

Columbus laboratory
About two thirds of the structure Critical Design Review (CDR) closeout has been achieved and sufficient data is available for decisions to be taken regarding the recovery of the mass margins.

The pre-board meeting concerning the Environmental Control and Life Support (ECLS) subsystem CDR has stipulated the *sécurité réduite. La réalisation de MSG-2 et 3 se déroule selon le calendrier établi. La date de lancement de MSG-2 reste prévue en 2002 et la date de stockage de MSG-3 a été avancée à 2003.*

ERS

L'exploitation du système ERS s'est poursuivie sans heurts, avec d'excellentes performances des satellites et du secteur sol. Elle repose désormais sur l'utilisation d'ERS-2, la charge utile d'ERS-1 étant maintenue en hibernation pour servir de secours.

L'utilisation du satellite et son fonctionnement sont surveillés de très près, afin de prolonger la mission aussi longtemps que possible. Les gyroscopes fonctionnent dans les limites spécifiées, en produisant par intermittence un bruit de faible niveau qui est la conséquence du vieillissement de certaines pièces mécaniques. On développe actuellement un nouveau système de commande d'orientation et de correction d'orbite (AOCS) n'utilisant qu'un seul gyroscope, épaulé par les capteurs numériques terrestres et les roues de réaction. Ce système, qui pourrait fonctionner à partir du mois d'octobre, permettrait de soulager les gyroscopes et de prolonger leur durée de vie opérationnelle.

Le mode image du SAR d'ERS-1 n'est activé qu'une fois par jour afin de préserver les performances des batteries. Ce système permet de réaliser des opérations d'interférométrie SAR ERS-1/2 en pré-programmant l'acquisition de paires d'images SAR.

Station spatiale internationale

Séquence d'assemblage de l'ISS

Les centres de contrôle de la mission établis à Moscou et Houston surveillent constamment le comportement des deux premiers éléments de l'ISS,'Zarya' et 'Unity', qui ont été respectivement lancés en novembre et décembre 1998 avant d'être assemblés en orbite. D'après les rapports, l'ensemble des systèmes fonctionnent de manière satisfaisante.

Il apparaît aujourd'hui évident que le lancement du module de service russe n'aura pas lieu en juillet mais en septembre/octobre. Les activités multilatérales d'actualisation de la séquence d'assemblage commenceront dès que l'on connaîtra la date définitive de lancement du module de service. Elles devraient s'achever, début juin, par une réunion de la Commission de Contrôle de la Station spatiale (SSCB).

Laboratoire Columbus

La dernière phase de la revue critique de conception (CDR) de la structure est achevée aux deux-tiers et l'on dispose aujourd'hui de suffisamment de données pour prendre les décisions permettant de ramener la masse du laboratoire dans les limites spécifiées.

La réunion préliminaire de préparation de la revue critique de conception (CDR) du sous-système de régulation d'ambiance et de soutien-vie (ECLS) a abouti à la conclusion qu'une deuxième CDR serait nécessaire en mai pour tenir compte des résultats de la revue de conception des expériences (ECDR) menée par SECAN et SOTEREM et du changement d'un sous-traitant. Certains documents relatifs à la première partie de la CDR doivent en outre faire l'objet d'une nouvelle soumission.

Les essais de recette des équipements électriques de soutien sol (EGSE) ont révélé certains problèmes liés à la version actuelle du logiciel au sol Columbus (CGS). Les essais ont néanmoins été menés à bien et les EGSE ont été livrés. Les activités d'assemblage et d'intégration du modèle d'essais électriques (ETM) progressent en dépit de retards significatifs dans l'examen du logiciel d'ensemble du système.

Compensation du lancement de Columbus

Eléments de jonction 2 et 3

La NASA a demandé certaines modifications dans la configuration de l'élément de jonction n°3. On étudie par ailleurs la possibilité de faire pivoter l'un des mécanismes communs d'accostage (CBM) de 45 degrés afin de permettre de réviser la trajectoire d'approche de la navette vers l'ISS.

Livraisons de logiciels et d'éléments du DMS-R / Soutien technique associé fourni à la NASA

La NASA a demandé, pour l'installation de vérification des logiciels de Houston, la livraison d'éléments supplémentaires du système de gestion de données pour la Russie (DMS-R). Une extension de l'accord de compensation est actuellement à l'étude pour couvrir cet élément.

Bâtis réfrigérateurs/congélateurs de l'équipage

La NASA envisage de demander une modification des impératifs techniques et opérationnels du système de bâtis réfrigérateurs/congélateurs de l'équipage. Elle a également reporté la livraison des 3x3 bâtis réfrigérateurs/congélateurs (RFR) de novembre 2001/mars 2002 à juillet 2004. Ces changements sont dus à une évolution dans la conception du chargement et du déchargement des provisions alimentaires destinées à l'équipage et à la nécessité de reconsidérer le processus d'installation des RFR en raison du retard apporté à la réalisation du module d'habitation.

C'est la raison pour laquelle l'ESA a préféré ne lancer qu'une phase B0 de 16 mois, destinée à étudier dans le détail et à réaliser des maquettes des RFR en étroite consultation avec la NASA, plutôt que d'autoriser la mise en œuvre de la phase B/C/D de développement proprement dit des bâtis réfrigérateurs/ congélateurs. Un ensemble consolidé d'impératifs devrait être disponible début 2000.

Bâtis congélateurs cryogéniques

La documentation technique relative aux bâtis congélateurs cryogéniques a été finalisée en janvier, en coopération avec la NASA. L'équipe de projet de l'ESA a préparé l'appel d'offres qui devait être publié à la mi-mars.

Coupoles

Une réunion de démarrage, organisée début décembre, a permis de lancer officiellement le programme de réalisation des coupoles. Le contrat, d'une valeur de 20 Meuros, conclu après négociations entre l'ESA et le maître œuvre Alenia Aerospazio, a été signé le 8 février à Turin. Alenia Aerospazio coordonne les activités de six autres sociétés européennes. Elle réalisera les coupoles et assistera également l'ESA dans ses rapports avec la NASA.

Véhicule de transfert automatique (ATV)

L'industrie a proposé une solution

need for a second CDR in May to reflect the closure of SECAN and SOTEREM ECDR and the change of one subcontractor. In addition some CDR-part-1 documents have to be resubmitted.

During the Electrical Ground Support Equipment (EGSE) acceptance tests, problems with the current CGS version were experienced. The acceptance tests have been completed and the EGSE has now been delivered. The assembly and integration of the Electrical Test Model (ETM) is progressing, albeit subject to significant delays in scrutinising the overall system software.

Columbus launch barter

Nodes-2 and -3

Further re-engineering changes have been received from NASA for Node-3. A request to evaluate the feasibility of rotating one Cargo Berthing Mechanism (CBM) by 45 deg to enable a revised Shuttle approach path to the ISS is being worked on.

Software Deliveries/ DMS-R Items / Associated Sustaining Engineering for NASA

NASA has requested additional Data Management System (DMS-R) hardware to support the Software Verification Facility in Houston. A possible expansion of this part of the barter is under discussion.

Crew Refrigerator/Freezer Racks

NASA's plans call for a change in the technical and operational requirements for the Refrigerator/Freezer Rack System. It has also shifted the delivery of the 3x3 Refrigerator/Freezer Racks (RFRs) from the November 2001/March 2002 period to July 2004. These changes are related to conceptual changes in the crew food up and down-loading and to re-accommodation needs for the RFR, caused by the delay in availability of the Habitability Module.

This is why, instead of authorising the full Phase-B/C/D development effort, ESA has started only a 16 month detailed RFR study and breadboarding Phase-B0, which will be closely monitored by NASA. A consolidated set of requirements is expected to be available early in 2000.

Cryogenic Freezer Racks

The technical documentation for the Cryogenic Freezer Racks was finalised in January in co-operation with NASA. The ESA project team prepared the Invitation to Tender (ITT) for release in mid-March.

Cupola

The Cupola activities were formally started in early December with a 'kick-off meeting'. Following successful completion of negotiations, the 20 MEuro Cupola contract between ESA and Alenia Aerospazio, the prime contractor, was signed on 8 February in Turin. Alenia Aerospazio is co-ordinating an industrial team of six other European companies. In addition to developing the Cupolas, Alenia will assist ESA in interfacing with NASA.

Automated Transfer Vehicle (ATV)

Industry has proposed an attractive 'star tracker' option to replace the Sun/Earth sensors, particularly for the perigee-raising manoeuvre that will be executed after the Ariane-5 launch injection. This proposal is under evaluation.

Alenia has reached an 'agreement in principle' on the procurement of Russian hardware through a normal procurement contract with RSC-Energia.

Assessment of the impact of two major technical issues linked to ISS requirements has been completed:

- limitations on the power available to the ATV from the ISS during the attached phase, which might lead to bigger and rotating solar arrays
- possible modification of the propulsion architecture, with thrusters on top of the cargo carrier in order to improve the ATV's controllability during the rendezvous phase, as well as the robustness of the ATV system with respect to further ISS technical changes.

A full Request for Quotation (RFQ) for ATV integration activities has been released to RSA/RSC-Energia and a first clarification meeting was held in Moscow in the last week of January. The proposal from RSA/RSC-Energia is now expected during May. In parallel, a number of technical meetings took place in March to consolidate the ATV/Russian Segment technical baseline and a series of contractual meetings were held to clarify and finalise the text of the draft contract.

X-38/CRV and Applied Reentry Technology (ART)

The previously reported 'CRV observation period' at NASA/Johnson Space Center is in progress with five companies, including MAN-Technologie. In January NASA released its draft Request for Procurement (RFP) of the operational CRV. The RFP update is targeted for release in April.

The X-38 drop tests from a B52 aircraft with vehicle V131 were successfully completed in February. Earlier problems relating to parafoil deployment appeared to have been fully overcome, and the descent and landing were nominal. A second X-38 drop test with vehicle V132 was completed successfully in early March. For this test, the flight control system was active throughout the descent phase.

The aft structure flight articles, already delivered to NASA for the orbital test vehicle (V201), have now been integrated into the overall vehicle structure

Atmospheric Reentry Demonstrator (ARD)

The ARD arrived back at Aerospatiale in Bordeaux (F) on 18 January. The initial visual inspection indicated no significant degradation of the capsule. The level-0 data exploitation was completed in February. Following the review of the preliminary level-0 results, the Request for Quotation (RFQ) for the full data exploitation was released to Aerospatiale during February.

A presentation for the press of the ARD and the first mission results was made in Bordeaux on 22 February.

Ground-segment development and operations preparation

At its December meeting, the ESA Council decided to locate the Columbus Control Centre at GSOC in Oberpfaffenhofen (D) and the ATV Control Centre at CNES in Toulouse (F). The Executive is now preparing the necessary procurement actions in line with this decision.

At the same Council meeting, the Executive was requested to submit, in the spring, a proposal for the distribution of tasks and the location of the Operations Support Functions. A preparatory meeting with Germany and Italy at Director General/Heads of Agencies level was held early in February, at which the Executive proposed concentrating the major *intéressante consistant à remplacer les capteurs Terre/Soleil par un 'suiveur d'étoiles', notamment pour la manœuvre de rehaussement du périgée qui doit être réalisée après l'injection sur orbite par Ariane-5. Cette proposition est en cours d'examen.*

Alenia est parvenu à un accord de principe sur l'approvisionnement de matériels russes par le biais d'un contrat d'approvisionnement normal conclu avec RSC-Energia.

Deux importantes questions techniques, liées aux spécifications de l'ISS, ont fait l'objet d'une évaluation :

- *Le choix éventuel de générateurs solaires tournants et de plus grande taille pour répondre à une limitation de la quantité d'énergie susceptible d'être fournie par l'ISS à l'ATV pendant la phase de jonction,*
- *La modification éventuelle de l'architecture du système de propulsion, avec des propulseurs placés sur le dessus du conteneur de fret permettant d'améliorer la manœuvrabilité de l'ATV durant la phase de rendez-vous et d'accroître la robustesse du système en prévision de nouvelles modifications techniques de l'ISS.*

Une demande de prix complète concernant les activités d'intégration de l'ATV a été adressée à RKA/RSC-Energia et une première réunion de clarification a été organisée à Moscou, au cours de la dernière semaine de janvier. La proposition de RKA/RSC-Energia était attendue au cours du mois de mai. Une série de réunions techniques se sont parallèlement déroulées en mars afin de consolider la base de référence technique ATV/composante russe et une série de réunions ont été organisées dans le but de clarifier et de finaliser le texte du projet de contrat.

X-38/CRV et application des technologies de rentrée (ART)

La 'période d'observation' précédemment évoquée pour le CRV est en cours au Centre spatial Johnson de la NASA, avec la participation de cinq sociétés dont MAN-Technologie. La NASA a publié en janvier un projet d'appel d'offres relatif au CRV opérationnel. L'appel d'offres définitif devait être publié en avril.

Les essais de largage du X-38/V-131 à partir d'un B-52 se sont déroulés avec succès en février. Les problèmes liés au déploiement du parachute semblent avoir été totalement résolus, et la descente comme l'atterrissage se sont déroulés normalement. Un second essai de largage a été réalisé début mars avec le véhicule V132. La chaîne de pilotage a été activée à cette occasion, pendant la phase de descente.

Les éléments de la structure arrière du véhicule d'essais en orbite (V201) déjà livrés à la NASA ont été intégrés dans la structure d'ensemble.

Démonstrateur de rentrée atmosphérique (ARD)

L'ARD a fait son retour chez Aérospatiale à Bordeaux (F), le 18 janvier. Un premier contrôle visuel n'a révélé aucune dégradation significative de la capsule. L'exploitation des données de niveau 0 a été achevée en février. Après examen des premiers résultats de niveau 0, une demande de prix relative à l'exploitation complète des données a été adressée à Aérospatiale en février.

L'ARD et les premiers résultats de la mission ont été présentés à la presse, le 22 février à Bordeaux.

Réalisation du secteur sol et préparation de l'exploitation

Lors de sa réunion du mois de décembre, le Conseil de l'ESA a décidé d'installer le Centre de contrôle de Columbus au GSOC, à Oberpfaffenhoffen (D) et le Centre de contrôle de l'ATV au CNES, à Toulouse (F). L'Exécutif prépare actuellement les activités d'approvisionnement liées à cette décision.

Lors de la même réunion du Conseil, il a été demandé à l'Exécutif de soumettre au printemps une proposition de répartition des activités et des lieux d'installation des différentes fonctions de soutien des opérations. Une réunion préparatoire à été organisée en au niveau du Directeur général et des directeurs d'agences représentant l'Allemagne et l'Italie. L'Exécutif a proposé de répartir les principales fonctions de soutien des opérations en deux blocs. Le premier bloc, conduit par l'industrie allemande, couvre les activités de soutien technique continu de Columbus et d'intégration des charges utiles Columbus. Le second bloc, placé sous la conduite de l'industrie italienne, couvre la logistique d'ensemble des éléments ESA de l'ISS et l'intégration de la cargaison de l'ATV. L'Allemagne a accepté cette proposition à la condition que l'Italie en fasse autant. Une réunion a été organisée le 10 mars avec les représentants de l'ASI et des progrès ont été accomplis sur nombre des questions encore en suspens. Ces discussions se poursuivent.

Utilisation

Promotion

Les activités de promotion des applications de la microgravité (MAP) ont pour principal objectif de favoriser le développement d'une première génération de projets pour l'ISS, orientés vers les applications et entrepris avec la collaboration de l'industrie. Elles doivent permettre de confirmer l'utilité de la recherche et du développement en microgravité dans le domaine industriel. Les projets seront préparés par des expériences préliminaires, utilisant les porte-instruments et les possibilités normalement prévues dans le cadre de l'utilisation initiale de la Station spatiale.

Les projets actuellement en cours ou en préparation concernent des sujets tels que l'ostéoporose, la croissance des cristaux de tellure de cadmium (CdTe) et de composés associés, la diffusion Soret dans la récupération des hydrocarbures, la mesure ultra précise du temps, les horloges atomiques, la recherche avancée sur la combustion, la diffusion et les flux dans les milieux poreux et la stabilité des mousses. Quinze groupes de travail ont en outre été constitués pour évaluer la pertinence d'autres sujets d'expériences et entamer des consultations avec des partenaires industriels potentiels.

Plus de 120 propositions avaient été reçues fin février, date limite du dépôt, en réponse à l'avis d'offre de participation lancé en octobre 1998 sur Internet.

Préparation

L'élaboration des règles d'accès des utilisateurs de la Station spatiale a considérablement progressé. La réunion des participants potentiel au programme d'exploitation de l'ISS, organisée le 24 janvier, et les discussions auxquelles elle a donné lieu entre les délégations, a permis de simplifier considérablement les différentes catégories d'utilisateurs, et il operations support functions in two blocks. The first block, to be led by German industry, covers Columbus Sustaining Engineering and Columbus Payload Integration; the second block, to be led by Italian industry, covers the overall logistics function for all ESA ISS elements and ATV Cargo Integration. Germany subsequently endorsed this proposal on condition that Italy also accepts it. A meeting was held with ASI on 10 March and some progress was made in resolving a number of open points. Discussions are continuing.

Utilisation

Promotion

The Microgravity Application Promotion (MAP) activities have, as their primary objective, the fostering and development of a first generation of applications-oriented projects for the ISS with involvement from industry. They should demonstrate that microgravity is indeed a useful tool for industrial R&D. These projects will be prepared with precursor experiments using traditional carriers and opportunities associated with the early utilisation of the ISS.

Projects already underway and in preparation cover such areas as: osteoporosis, crystal growth of CdTe and related compounds, Soret diffusion related to oil recovery, ultraprecise measurements of time, atomic clocks, advanced combustion research, and diffusion, flow in porous media and foam stability. In addition, some 15 working groups have been created to evaluate the relevance of other topics and to start the dialogue with potential partners from industry.

By the end-February deadline for their submission, more than 120 proposals had been received in response to the Announcement of Opportunity issued via the Internet in October 1998.

Preparation

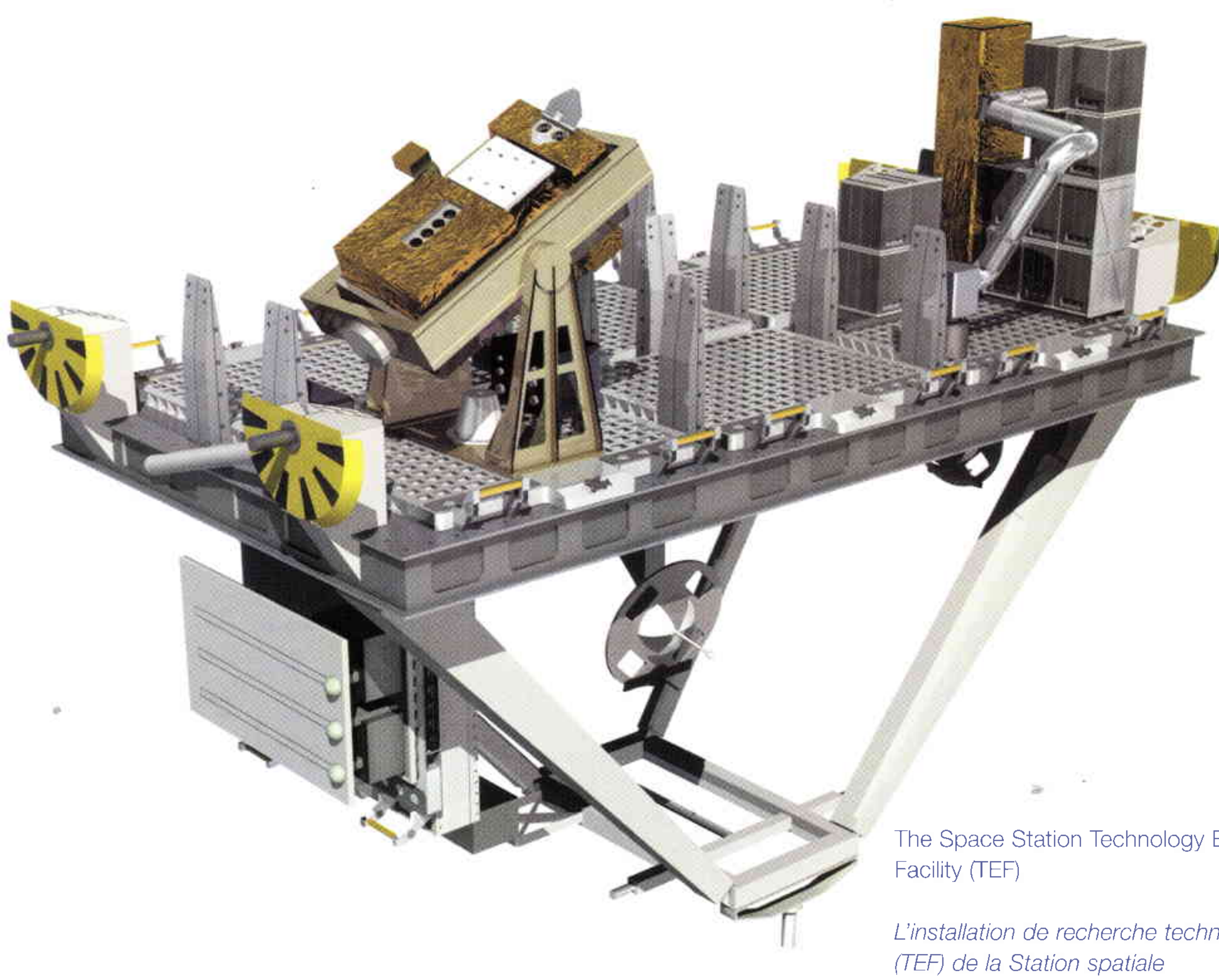
Considerable progress was achieved in establishing rules for users to gain access to the Space Station. Discussions with Delegations at an Exploitation Programme Potential Participants Meeting on 24 January resulted in a considerable simplification of user categories and left only minor points to be resolved.

At a meeting of the Space Station User Panel (SSUP) in mid-February, the Executive's proposals for the Exploitation Programme and the means for encouraging full utilisation of the Space Station by industrial/commercial users were examined. User access rules were discussed, as were the roles of SSUP and European Utilisation Board (EUB) during the exploitation phase. Brochures covering both the European research planning for Space Station and its planned utilisation by European industry have been published by ESA Publications Division (ESA BR-137 and ESA BR-141 + Appendix).

Hardware development

The contract for Phases-B/C/D for the Technology Exposure Facility (TEF) for Space Station Early Utilisation has been awarded to Carlo Gavazzi (I) and work started in January.

The Critical Design Review (CDR) of the Microgravity Science Glovebox (MSG) has been closed-out and the Preliminary Design Review (PDR) of the Hexapod pointing system is in progress. A



The Space Station Technology Exposure Facility (TEF)

L'installation de recherche technologique (TEF) de la Station spatiale *ne reste plus que quelques détails mineurs à résoudre.*

Les propositions de l'Exécutif concernant le programme d'exploitation et les moyens d'encourager les clients industriels et commerciaux à utiliser pleinement la Station spatiale ont été examinées au cours d'une réunion du Groupe 'Utilisateurs de la Station spatiale' (SQSUP) organisée à la mi-février. On y a discuté des règles d'accès des utilisateurs ainsi que du rôle du SSUP et de la Commission européenne de l'utilisation (EUB) au cours de la phase d'utilisation. Des brochures évoquant tout à la fois le programme de recherche européen pour la Station spatiale et l'utilisation de celle-ci par l'industrie européenne ont été publiées par la Division des publications de l'ESA (ESA BR-137 et ESA BR-141 + appendices).

Réalisation des matériels

Le contrat relatif aux phases B/C/D de l'Installation d'exposition au milieu spatial pour les recherches technologiques (TEF) a été attribué à Carlo Gavazzi (I) et les travaux ont débuté en janvier.

La revue de conception critique (CDR) de la boîte à gants pour la recherche en microgravité (MSG) a été achevée et la revue de conception préliminaire (PDR) du système de pointage Hexapod suit son cours. L'ESA et la NASA ont entrepris des discussions sur les performances thermiques du congélateur de laboratoire à –80°C (MELFI). La livraison aux utilisateurs des éléments du modèle d'identification de l'équipement complémentaire des charges utiles standard (SPOE) a débuté.

Activités des astronautes

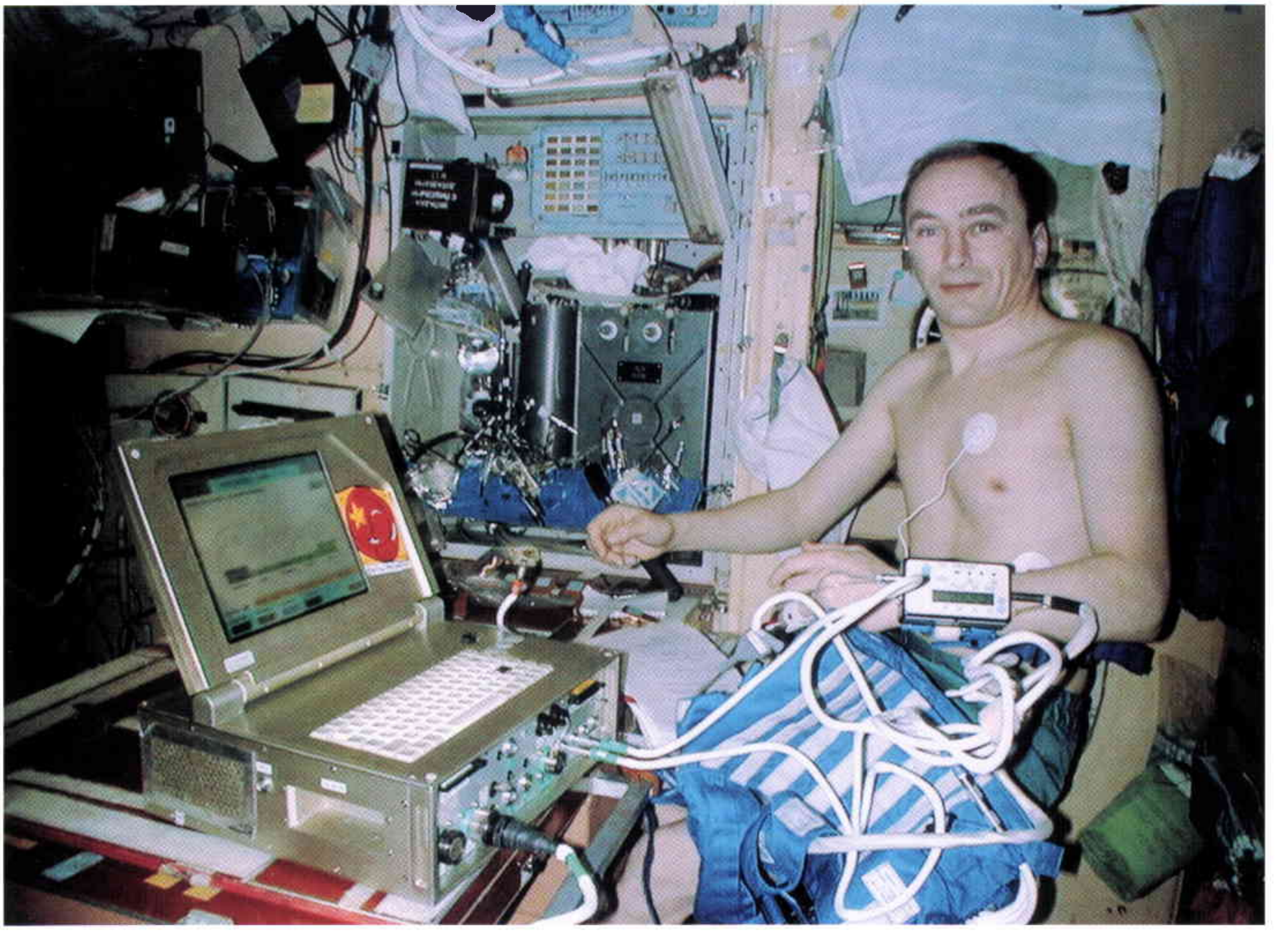
L'astronaute de l'ESA J-P. Haigneré s'est envolé le 20 février à bord d'une capsule Soyouz pour un séjour de six mois dans la station Mir. Cette mission franco-russe, baptisée 'Perseus', lui permettra de réaliser un programme scientifique spécialement conçu pour ce séjour de longue durée. L'astronaute effectuera au moins une sortie dans l'espace. L'une des expériences conçues par l'ESA pour ce vol permettra de surveiller les modifications subies par la structure osseuse des astronautes et d'évaluer les contre-mesures possibles. Les astronautes utiliseront également un certain nombres d'outils opérationnels fournis par l'ESA, et notamment le MIRSUPIO, un sac spécial polyvalent conçu au Centre des astronautes européens (EAC) de l'Agence.

L'astronaute de l'ESA U. Guidoni sera le premier européen à se rendre dans la Station spatiale internationale en tant que membre d'équipage de la première mission (5A.1) du Mini-module logistique pressurisé (MPLM). La nouvelle a été annoncée conjointement par le Directeur général de l'ESA, l'Administrateur de la NASA et le Président de l'Agence spatiale italienne, le 9 février à Rome.

On a annoncé le 11 mars que les astronautes de l'ESA J-F. Clervoy et

ESA astronaut J-P. Haigneré at work aboard Mir, in March 1999

L'astronaute J-P. Haigneré à bord de Mir, en mars 1999



discussion between ESA and NASA on the thermal performance of the -80°C Freezer (MELFI) is underway. Delivery of Standard Payload Outfitting Equipment (SPOE) engineering-model items to users has commenced.

Astronaut activities
On 20 February, ESA astronaut J.-P. Haigneré was launched onboard a Soyuz capsule for a six-month stay on the Russian space station Mir. During this French-Russian flight, called 'Perseus', Haigneré will carry out a programme of scientific research designed to take advantage of the long duration of the flight. He will make at least one spacewalk outside Mir. Among the studies that Haigneré will perform is an ESA experiment to measure changes in bone structure in astronauts and assess possible countermeasures. During the mission, the astronauts will use a number of ESA-provided operational tools, including MIRSUPIO, a special multipurpose bag, designed at ESA's European Astronaut Centre (EAC).

ESA astronaut U. Guidoni will become the first European to visit the International Space Station as a crew member of the first Multi-Purpose Logistics Module (MPLM) mission (5A.1). This was announced jointly by ESA's Director General, the NASA Administrator, and the President of the Italian Space Agency, on 9 February in Rome.

On 11 March, it was announced that ESA astronauts J-F. Clervoy and C. Nicollier will be part of the crew of the Hubble Telescope maintenance and repair mission (STS103). During the mission, which has been advanced to October this year, C. Nicollier will also perform an EVA. This will be the third Shuttle mission for Clervoy and the fourth for Nicollier.

The instructor-training programme for the International Space Station has been initiated at EAC with a first group of instructor candidates.

Early deliveries
Data Management System for the Russian Service Module (DMS-R)
During recent integrated testing of the Service Module, a new bug was identified in the DMS-R ERC32 chip. This causes failures during the floating-point calculations that are needed in support of navigational computation. Industry has been tasked with numerous corrective actions and a corrective action plan has been agreed with RSC-Energia in order to restore the DMS-R subsystem to full serviceability and to minimise the impact on the ongoing Service Module testing. A software patch to overcome the problem has already been developed and agreement has been reached with RSC-Energia and NASA to use this patch for the Service Module launch, with a final confirmation to be given in early-May following completion of testing in Moscow. In parallel, urgent actions are underway to establish a fallback option of replacing existing printed-circuit boards with boards carrying a later version of the ERC32 chip in which this particular bug has been corrected, should the software patch not be successful.

MPLM-ECLSS Environmental Control and Life Support Subsystem (ECLSS)
The close-out of the MPLM ECLS subsystem Qualification Review is in progress. An out-of-limit leakage at cold temperatures occurred after the engineering qualification model thermal-vacuum test on the Inter-Module Ventilation (IMV) shut-off valve. After re-adjustment, the engineering-qualification and flight models were successfully re-tested.

The structural analysis of the Duct Smoke Detector (DSD) has been updated and reviewed. Special attention is being paid to the power-transformer mounting, where a potential for failure was identified.

European Robotic Arm (ERA)
A plan for implementing corrective action to overcome the component test failures of the US-sourced encoder has been agreed with the supplier (BEI), and new delivery dates for the re-supply of these parts have been agreed. This should now enable Sabca to establish firm planning for outstanding deliveries to Fokker Space.

Efforts to settle the financial and schedule difficulties being experienced by Sabca have been successful and an agreement between ESA, Fokker Space and Sabca was signed on 23 March.

The On-Board Computer Operating System delivered by DASA for the engineering qualification model testing has exhibited numerous previously unreported non-conformances and bugs. A major re-coding effort has been initiated to bring the software up to an acceptable standard.

The overall ERA schedule is under continuous review and updating, reflecting the delays being encountered in subsystem deliveries. It is now expected that the delivery of the ERA flight model will be delayed to the last quarter of 2000. Based on the latest discussions with RSA/RSC-Energia, this delivery date remains just within the need date for the Science Power Platform, which is also delayed due to funding shortfalls on the Russian side.

The overall programmatic impact of the various technical problems and delivery delays is being assessed.

Microgravity

EMIR-1 and EMIR-2
Flight of ESA payloads on STS-95/Spacehab in October 1998
The Microgravity Programme facilities – Advanced Gradient Heating Facility (AGHF), Advanced Protein Crystallisation Facility (APCF), Biobox, Facility for Adsorption and Surface Tension (FAST) and Morphological Transitions in a Model Substance (MOMO) Facility – which were flown on STS-95/Spacehab last October were returned to Europe and all experiments have been handed-over to their respective investigators for evaluation.

Flight of ESA payloads on STS-107/Spacehab in December 2000
In February, the conditions for the flight of ESA payloads on STS-107/Spacehab in December 2000 were negotiated with NASA and industry. Under the arrangement with NASA, and following flight STS-95, ESA will perform re-flights of Biobox-5, FAST-2 and one of the APCF flight models.

For Biopack, still in Phase-B, and for ARMS (Advanced Respiratory Monitoring System), presently in final manufacture, it will be the maiden flight. The PDR data package of Biopack is in preparation and the PDR will begin on 13 April 1999. The acceptance review for ARMS will be performed in the summer of 1999.

C. Nicollier participeraient à l mission STS-103 de maintenance et de réparation du télescope Hubble. Claude Nicollier effectuera lui aussi une sortie dans l'espace (EVA) à l'occasion de cette mission qui a été avancée au mois d'octobre de cette année. Ce sera sa quatrième mission à bord de la navette, et la troisième pour J-F. Clervoy.

Un premier groupe de candidats instructeurs aux activités de la Station spatiale internationale a entamé à l'EAC le programme de formation qui lui est destiné.

Livraisons à court terme

Système de gestion de données pour le module de service russe (DMS-R)

Un nouveau défaut de fonctionnement a été constaté dans la puce ERC32 du DMS-R au cours des récents essais intégrés du module de service. Cette anomalie provoque des défaillances dans les calculs en virgule flottante nécessaires aux opérations de navigation. L'industrie s'est vue confier plusieurs actions correctives et un plan d'action a été adopté avec RSC-Energia afin de restaurer totalement les fonctions de ce sous-système du DMS-R et minimiser les conséquences de ce défaut sur les essais en cours du module de service. On a d'ores et déjà développé un programme de correction et l'on est parvenu à un accord avec RSC-Energia et la NASA pour l'utiliser lors du lancement du module de service. La confirmation de cette décision devait intervenir début mai, après achèvement d'un certain nombre d'essais à Moscou. Pour répondre à un éventuel insuccès du programme de correction, on prépare parallèlement, et en urgence, une solution de repli qui consisterait à remplacer les cartes à circuits imprimés existantes par de nouvelles cartes comprenant une version évoluée de la puce ERC32 dans laquelle le défaut de fonctionnement aura été corrigé.

Sous-système de régulation d'ambiance et de soutien-vie (MPLM-ECLSS)

La revue de qualification du sous-système de régulation d'ambiance et de soutien-vie MPLM-ECLSS approche de son terme. Les essais thermiques sous vide réalisés sur le modèle de qualification et d'identification ont révélé une fuite aux froides températures dans la vanne d'isolement du système de ventilation inter-modules (IMV). Les ajustements nécessaires ont été réalisés et les essais ont repris avec succès sur le modèle de qualification et d'identification comme sur le modèle de vol.

L'analyse structurelle du détecteur de fumée (DSD) a été mise à jour et réexaminée. Une attention particulière a été accordée au support du transformateur d'alimentation qui est susceptible de présenter des défaillances.

Bras télémanipulateur européen (ERA)

Les essais ont révélé des défaillances dans certains composants du codeur de provenance américaine. Des mesures correctives ont été décidées avec le fournisseur (BEI) et l'on s'est mis d'accord sur les dates de fourniture des nouvelles pièces. Cela devrait permettre à Sabca de fixer définitivement les dates de livraison des derniers éléments à Fokker Space.

Des efforts ont été accomplis pour résoudre les difficultés financières et de calendrier rencontrées par Sabca. Ils ont abouti, le 23 mars, à la signature d'un accord entre l'ESA, Fokker et Sabca.

Le système d'exploitation de l'ordinateur de bord livré par DASA pour les essais du modèle d'identification et de qualification a révélé de nombreuses anomalies et non-conformités, jamais signalées auparavant. On a entrepris de réécrire le programme afin qu'il puisse répondre aux normes fixées.

Le calendrier d'ensemble de l'ERA fait l'objet de réexamens et de remises à jours continuelles, témoignant des retards rencontrés dans la livraison des sous-systèmes. On estime aujourd'hui que le modèle de vol du bras télémanipulateur ne pourra être livré avant le dernier trimestre 2000. Les dernières discussions organisées avec RKA/RSC-Energia ont permis d'établir que cette date de livraison demeurait compatible avec les besoins de la plate-forme science et énergie, dont la livraison est également retardée en raison de difficultés de financement du côté russe.

Les conséquences programmatique d'ensemble des différents problèmes techniques et retards rencontrés sont en cours d'évaluation.

Microgravité

EMIR-1 et EMIR-2

Emport de charges utiles ESA sur STS-95/Spacehab en octobre 1998

Après avoir participé à la mission STS-95/Spacehab en octobre dernier, le Four à gradient de haute technologie (AGHF), l'Installation de cristallisation des protéines de pointe (APCF), le Biobox, l'Installation d'études de l'adsorption et de la tension de surface (FAST) et l'Installation d'études morphologiques sur des substances modèles (MOMO) ont été ramenés en Europe et remis pour évaluation aux différents chercheurs concernés.

Emport de charges utiles de l'ESA sur STS-107/Spacehab en décembre 2000

L'ESA a négocié en février, avec la NASA et l'industrie, les conditions d'emport de plusieurs de ses charges utiles au cours de la mission STS-107/Spacehab, prévue en décembre 2000. Après le vol STS-95, et aux termes de l'arrangement conclu avec la NASA, l'Agence procédera à cette occasion à un nouvel emport dans l'espace du Biobox-5, de FAST-2 et de l'un des modèles de vol de l'APCF.

Ce nouveau vol constituera un baptême pour le Biopack, toujours en phase B, et pour le Système de surveillance respiratoire de pointe (ARMS). La revue de conception préliminaire devait être lancée le 13 avril 1999, après constitution du dossier nécessaire. La revue de recette de l'ARMS sera réalisée au cours de l'été 1999.

La remise à neuf de l'Installation d'études de l'adsorption et de la tension de surface (FAST) en vue d'un nouveau vol et son adaptation à de nouvelles recherches débuteront dès l'adoption de la liste complémentaire d'expériences prévue pour l'appareil.

L'Installation de cristallisation des protéines de pointe (APCF) a été attentivement inspectée et testée après le vol STS-95 en vue de l'approbation d'une nouvelle série d'expériences en juin 1999. Les propositions industrielles pour une remise à neuf de l'appareil et son soutien lors de son sixième vol sont attendues d'ici juillet.

Installations de l'ESA sur Foton-12

Le lancement de la capsule récupérable russe Foton-12 a été contractuellement

The refurbishment and adaptation to new experiments for a re-flight of the Facility for Adsorption and Surface Tension (FAST) will start as soon as an experiment complement has been approved.

Having carefully inspected and tested the Advanced Protein Crystallisation Facility (APCF) after flight STS-95, and after approval of new experiments in June 1999, the submission of industrial proposals for the refurbishment of, and support to the sixth flight of APCF are expected by July.

ESA facilities on Foton-12
The launch of the retrievable Russian capsule Foton-12 has been set contractually, in consultation with the Russian Space Agency (RSA), CNES and DLR, for 1 September. The ESA facilities on Foton-12 consist of FluidPac, including its TeleSupport Unit, Biopan-3, and four autonomous experiments including Stone. The FluidPac and TeleSupport Unit are scheduled for acceptance in May and for delivery for Foton-12 integration in early June. The mass dummy units forFluidPac and TeleSupport were delivered to the Russian Foton contractor in January in order to proceed with the balancing of the spacecraft.

The Biopan-3 experiment hardware has been tested, fit-checked with the facility, and accepted for flight. Biopan-3 has received a new heat shield and the software has been upgraded to cope with the Foton-12 operating scenario. The Flight Acceptance Review took place in mid-March.

Protein Crystallisation Diagnostics Facility (PCDF)
The PCDF Phase-B study and related breadboarding have been successfully completed. The RFQ for Phase-C/D was issued at the end of January. A proposal from the industrial consortium led by DASA/Dornier was received end-March, and is presently under evaluation.

Parabolic flights
The 26th ESA parabolic-flight campaign - the third ESA campaign to use the Airbus A300 aircraft - is currently being prepared and will take place between 25 May and 4†June. Experiments with an emphasis on life sciences are in preparation.

Sounding rockets
Maser-8, with four microgravity experiments, has been prepared for launch from Esrange (S) in early May. Two Texus flights, Texus 37 and 38, with four ESA microgravity experiments are in final development for launch in November 1999.

Microgravity Facilities for Columbus (MFC)
The Biolab safety review and system Preliminary Design Review (PDR) were successfully concluded in January. The release of the Invitation to Tender (ITT) for Phases-B/C/D for the Experiment Preparation Unit (EPU) is planned for mid-1999.

The system PDR for the Fluid Science Laboratory (FSL) started in January as planned and should be completed by April. It has been decided to introduce the Microgravity Vibration Isolation System (MVIS) developed by the Canadian Space Agency (CSA) in two steps. The first step, to be carried out in July, is an in-depth assessment of the technical/programmatic impacts. The second step, consisting of the implementation of the MVIS into the FSL project, will be carried out if the identified impacts are affordable.

Subsequent to the signature in November 1998 of the development contract for the Materials Science Laboratory (MSL) in the US Lab, the implementation of subcontracts will be completed in March 1999. Both the PDR at subcontractor level, which started in December 1998, and the system PDR, which started mid-March will be completed in June.

The release of the Request for Proposals for the SQF development is planned for October and the work should start before end-1999.

The Invitation to Tender for Phases-B/C/D of the European Physiology Modules (EPM) was released to Industry at the end of 1998 and proposals are expected in March. The Agency has planned a highly compressed evaluation in order to cope with the very tight development schedule. Contract kick-off is expected in April.

Discussions with national agencies providing modules to the EPM should be completed by end-May, prior to the kick-off of the EPM contract. Discussions with NASA concerning the EPM's co-location with the Human Research Facility (HRF) as well as the harmonisation of the respective science equipment are proceeding. The goal is to achieve preliminary agreements in April. esa *fixé au 1er septembre, après consultations avec l'Agence spatiale russe (RKA), le CNES et le DLR. Les installations de l'ESA embarquées à bord de la capsule comprendront le Fluidpac, avec son unité de téléscience, le Biopan-3, et quatre expériences autonomes, dont l'expérience Stone. La recette du Fluidpac et de son unité de téléscience était prévue pour le mois de mai. Les appareils devraient être ensuite livrés pour intégration début juin à bord de Foton-12. Les modèles de masse du Fluidpac et de son unité de téléscience ont été livrés en juillet au maître d'œuvre russe de Foton afin que celui-ci puisse procéder à l'équilibrage du satellite.*

Le matériel d'expérimentation du Biopan-3 a été accepté pour le vol après avoir été testé et après vérification de sa parfaite compatibilité avec l'installation. Biopan-3 a été doté pour sa part d'un nouveau bouclier thermique et son logiciel a été mis à niveau afin de répondre au scénario d'exploitation de Foton-12. La revue de recette pour le vol s'est déroulée à la mi-mars.

Installation de diagnostic pour la cristallisation des protéines (PCDF)
L'étude de phase-B du PCDF, avec ses montages sur table, a été menée à bien. La demande de prix relative à la phase C-D a été adressée fin janvier. Le consortium industriel dirigé par DASA/Dornier a adressé une proposition à la fin du mois de mars. Elle est actuellement en cours d'évaluation.

Vols paraboliques
La 26 ème campagne de vols paraboliques de l'ESA – la troisième à utiliser un Airbus A-300 – est en cours de préparation et devrait se dérouler entre le 25 mai et le 4 juin. Les expériences préparées portent plus particulièrement sur les sciences de la vie.

Fusées-sondes
La fusée Maser-8, emportant quatre expériences en microgravité, a été préparée en vue d'un lancement début mai à Esrange (S). On met actuellement un point final à la préparation des vols Texus-37 et 38, emportant quatre expériences ESA de recherche en microgravité. Leur lancement doit avoir lieu en novembre 1999.

Installations de recherche en microgravité pour Columbus (MFC)
La revue de sécurité et la revue de conception préliminaire (PDR) du Biolab au niveau système se sont achevées en janvier. La publication de l'appel d'offres relatif aux phases B/C/D de l'unité de préparation des expériences (EPU) est prévue à la mi-1999.

La PDR système du laboratoire de science des fluides (FSL) a débuté comme prévu en janvier et devait s'achever en avril. Il a été décidé de diviser le programme de réalisation du système d'isolation contre les vibrations en microgravité (MVIS) conçu par l'Agence spatiale canadienne en deux étapes. La première, lancée en juillet, consisterait en une évaluation approfondie de l'impact technique et programmatique du projet. La seconde, couvrant la mise en œuvre du MVIS dans le cadre du FSL, serait lancée si l'impact du projet est jugé acceptable.

Les sous-contrats découlant de la signature, en novembre 1998, du contrat de développement du laboratoire de sciences des matériaux (MSL) destiné au laboratoire américain devaient être conclus en mars 1999. Les PDR au niveau des sous-traitants, lancés en décembre 1998, et la PDR au niveau système, lancée à la mi-mars, devraient être achevés en juin.

La diffusion de la demande de proposition relative au développement du Four de solidification avec trempe (SQF) est prévue en octobre, les travaux devant débuter avant la fin de 1999.

L'appel d'offres relatif aux phases B/C/D des modules de physiologie européens (EPM) a été lancé fin 1998 auprès de l'industrie, et les propositions étaient attendues en mars. L'Agence prévoit de raccourcir au maximum procédure d'évaluation afin de répondre à un calendrier de développement très serré. Le lancement du contrat était prévu en avril.

Les discussions engagées avec les agences nationales fournissant des modules EPM devaient s'achever avant le lancement du contrat. Les discussions relatives à la co-implantation de l'EPM et de l'Installation de recherche sur l'Homme (HRF) et à l'harmonisation des équipements scientifiques respectifs se sont poursuivies avec la NASA, avec pour objectif de parvenir à un accord préliminaire en avril.

In Brief

139th ESA Council Meeting

The 139th Council meeting was held from 7 to 9 April in Longyearbyen, a town of 1500 inhabitants on Spitsbergen, the largest island of the Svalbard archipelago 1200 km from the North Pole. The ESA Delegations and Executive were there at the invitation of Hugo Parr, Chairman of Council. This first 'far-North' Council meeting was organised by the Norwegian authorities and the Norwegian Space Centre. The exceptional venue undoubtedly made this a very special Council meeting.

The following main decisions were taken:
- The date of the next Ministerial Meeting was confirmed for 11-12 May (see page 8 of this Bulletin) and a final draft agenda for the ministerial meeting was agreed.
- After lengthy discussion, draft Resolutions 1 and 2 on 'Shaping the Future of Europe in Space' and 'The Agency's Evolution and Programmes' were finalised by the delegations for submission to the ministers.
- Council unanimously adopted the Resolution on the ESA contribution to the European Union's Galileo initiative, marking the first official step in undertaking a new ESA optional programme: GalileoSat. The Resolution reaffirms the key role and competence of the Agency in the technical management of the definition, development and validation of the space and related ground segment of a European satellite navigation system. The programme will be carried out in cooperation with the EU on the basis of joint funding. Programme definition activities will start following the May Ministerial Meeting, at which ESA Member States are expected to subscribe for the ESA part of the programme. The decision on the corresponding EU funding is expected to be taken by EU transport ministers in June.

  Luc Tytgat, the Administrator for GNSS policy at the Commission's DG VII (Transport) and the EU representative attending the meeting at Council's invitation, confirmed that a budget was available for the Galileo programme. This followed the adoption of Agenda 2000, including the trans-European and transport network, and the Fifth Framework Programme by the Council and Parliament of the European Union.
- Lastly, a number of delegations expressed interest in the Lunarsat project but asked that the matter be examined further at a future Council meeting.

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Hugo Parr, Chairman of Council (left) and Antonio Rodotà, ESA's DG, enjoying the rugged scenery of Longyearbyen, Norway, site of the 139th Council Meeting

Go-ahead for ESA's New Millennium Space Observatories: Planck and FIRST

European scientific institutes have been given the go-ahead for the development of instruments for two major ESA missions for the new millennium: Planck, a satellite to study the radiation considered to be the 'echo' of the Big Bang and FIRST, an infrared space telescope. ESA's Science Programme Committee (SPC) approved on 17 February the scientific instruments for both missions, which will be built by more than 80 institutes from all over Europe. The go-ahead will also allow ESA and European industry to begin in earnest the development of the Planck and FIRST spacecraft to be launched together in 2007.

Planck is a cosmology mission, designed to test the models describing the origin and evolution of the early Universe. It will study the Cosmic Background Radiation, a light emitted shortly after the Big Bang that fills the whole Universe and can be detected today, like an echo of the primeval explosion. Astronomers consider it a 'fossil' radiation, since it holds a lot of information about both the past and the future of the Universe.

"Planck will determine fundamental characteristics of the Universe, such as its geometry, its density, and the rate at which it expands. It will also provide important clues as to the kind of matter that fills the Universe", explains Planck Project Scientist Jan Tauber, at ESA's European Space Research and Technology Centre (ESTEC). More precisely, the task of Planck will be to measure the temperature of the echo. Though at the time of its emission the Cosmic Background Radiation was very hot, some 3000°C, it has since expanded and cooled, together with the entire cosmos, to a much lower temperature, about -270°C (3° Kelvin). Planck will look for differences in this temperature as slight as a few microkelvin, thin variations like clots that are, in fact, the 'seeds' of the huge condensations of matter in today's Universe. *"It will be like watching the birth of the galaxies, the galaxy clusters, all the large-scale structures that we observe today",* Tauber says.

The two instruments on board Planck, now approved by ESA, are the Low Frequency Instrument (LFI) and the High Frequency Instrument (HFI). They will cover a very broad range of frequencies (between 30 and 857 Gigahertz). The HFI will be designed and built by a consortium of about 20 institutes led by Jean-Loup Puget of the Institut d'Astrophysique Spatiale in Orsay (F). The LFI will be designed and built by a consortium of about 20 institutes led by Reno Mandolesi of the Istituto di Tecnologie e Studio delle Radiazioni Extraterrestri in Bologna (I).

FIRST, the 'Far InfraRed and Submillimetre Telescope', is the successor to ESA's Infrared Space Observatory ISO. It will be more powerful than any of its predecessors, with a primary mirror 3.5 m in diameter – the largest ever for an infrared space telescope. It will observe at wavelength ranges never covered before (from 80 to 670 microns). Like Planck, it will be located about 1.5 million km away from Earth.

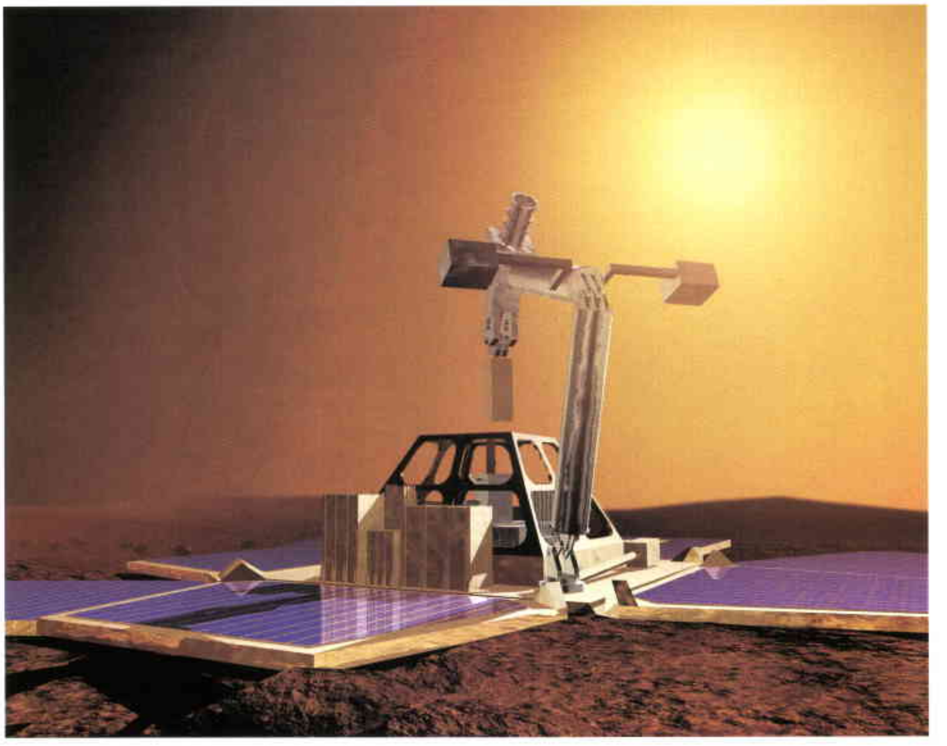
FIRST will look for planetary systems and study processes like the evolution of galaxies in the early Universe. It will provide detailed information about the coldest objects in the Universe, and those shrouded by dust. The pre-stellar cores from which the stars hatch at nearly -260°C, or the dusty distant galaxies undergoing violent collisions, are some examples. Also, FIRST will show the composition, temperature, density and motion of the gas and dust of the clouds in the interstellar space.

Its payload will consist of three instruments: two cameras called PACS and SPIRE, and HIFI, a high-resolution spectrometer. *"They are real technological challenges. Instruments like these have never been used in a space telescope",* says FIRST Project Scientist Göran Pilbratt at ESTEC. To avoid the 'noise' caused by the emission of the instruments themselves, a cryostat full of superfluid liquid helium will cool them down to a temperature below -271°C, very close to the absolute zero (at -273°C).

The Heterodyne Instrument for FIRST (HIFI) takes very high-resolution spectra of the astronomical objects in thousands of frequencies simultaneously. It will be designed and built by a consortium led by Thijs de Graauw, SRON, Groningen (NL). The Photo-conductor Array Camera and Spectrometer (PACS) instrument is an infrared camera and a spectrometer that will be developed and built by a consortium led by Albrecht Poglitsch, MPE, Garching (D). The Spectral and Photometric Imaging REceiver (SPIRE) is also a camera and spectrometer, but will observe at longer wavelengths than PACS. It will be developed and built by a consortium led by Matt J. Griffin, Queen Mary and Westfield College, London (UK). esa

The Far InfraRed and Submillimetre Telescope, FIRST, is the successor to ESA's Infrared Space Observatory, ISO

Mission to Mars



Artist's impression of the Mars Express lander, Beagle 2, on the red planet (credit: ESA/MediaLab)

On 30 March, ESA signed a contract with Matra Marconi Space (MMS), that pioneers a more flexible way of building space science missions and is, in this respect, the first trial as an element of a new and ambitious implementation concept which is currently under development for ESA's Scientific Programme. The contract, worth about 60 million Euro, is to design and build the Mars Express spacecraft in time for launch in June 2003. Mars Express will allow European space scientists to investigate whether there is, or ever was, life on the red planet.

ESA took the decision in principle to send a mission to Mars shortly after the loss of the Russian spacecraft Mars '96 with several European experiments on board. The Agency wanted to build on the Mars '96 payload experience to design a mission that would put Europe at the leading edge of Mars exploration and it had to act quickly. Major space missions can take up to 11 years from concept to launch, and there was little more than six years to go before the positioning of the planets in 2003 would offer the shortest travel time to Mars with the highest payload. Budgetary pressures were also forcing ESA to look for cheaper ways of building spacecraft. A Mars mission therefore seemed a good candidate to explore cheaper and faster working methods.

Mars Express (so called because of the streamlined development time) is the first of a new type of 'flexible' missions in ESA's long-term scientific programme, which should be built and launched for about half the budget for previous, similar missions. The global budget for Mars Express will actually be only 150 million Euro including spacecraft development, launch by a Russian Soyuz/Fregat launcher, operations, testing and management costs. Costs are being saved by shortening the time from original concept to launch, re-using existing hardware, adopting new project management practices, and having access to reduced launcher costs.

Selection of the scientific payload by ESA's scientific advisory bodies and mission definition by industry have been performed simultaneously, instead of sequentially as in previous missions. This has cut the time from concept to the awarding of today's design and development contract from about five years to little more than one year. The design and development phase will take under four years, compared with up to six previously.

Mars Express is making maximum use of pre-existing technology, which is either 'off-the-shelf' or has already been developed for the Rosetta mission (also due for launch in 2003). This strategy, in fact, only works when a second mission (i.e. Mars Express), can use, in a recurring manner, technology already applied in a previous mission (i.e. Rosetta). In future, ESA plans to develop new technologies needed for innovative and ambitious missions also in separate, small technology missions called SMART.

It is indeed a totally new concept where programme cornerstones may now become industrial themes spanning over several missions. New technologies are first tested in a small technology mission, then applied in a major mission, whose design and hardware can be utilised in following flexible missions. An industrial cycle is created in this way that gives more launch opportunities and that will also allow implementation in the long term of a global and coherent industrial return for the participants.

A further advantage of this concept applied to Mars Express is that commonalities with Rosetta make it possible to reduce operations costs at ESOC and to streamline project-management by handing over more responsibility to industry. *"European space industry is now sufficiently mature, thanks largely to previous experience with ESA missions, to take on these aspects of Mars Express as well as the associated risks"* says Rudolf Schmidt, ESA Mars Express Project Manager. MMS (Toulouse) is therefore interacting directly with the principal investigators for the scientific payload and with possible launch suppliers to ensure that technical interfaces are compatible. *"Before, ESA was taking the interface role. For Mars Express we have meetings directly with the scientists. This means that we can agree on the solution to any problem very rapidly"* says Philippe Moulinier, Mars Express Spacecraft Manager at MMS.

The use of previously-developed technology means that the number of models can be reduced without substantially increasing risk. This will also shorten the schedule and limit costs. *"Before we were developing every new system. Now we are using off-the-shelf and Rosetta technology which means we can offer both low cost and low risk"*, says Moulinier.

For further information on the Mars Express mission, see pages 56-66 of this Bulletin

ESA Astronauts Selected for HST Servicing Mission

ESA astronauts Claude Nicollier and Jean-François Clervoy have been selected to join a team of Shuttle astronauts on an earlier-than-planned mission to service the orbiting Hubble Space Telescope (HST) in October. Although the HST is operating normally and continuing to conduct its scientific observations, its pointing system has begun to fail.

Nicollier and three NASA astronauts, who had already been training for a Hubble servicing mission planned for June 2000, have been reassigned to this earlier mission (STS-103). Clervoy and two other NASA astronauts will complete the STS-103 crew.

The repairs and maintenance of the telescope will require many hours spent working outside the Shuttle and will make extensive use of the Shuttle's robotic arm.

Nicollier, of Swiss nationality and making his fourth flight, will be part of the team performing the 'spacewalks'. An astronomer by education, he took part in the first Hubble servicing mission (STS-61) in 1993, controlling the Shuttle's robotic arm (RMS) while astronauts on the other end performed the delicate repairs to the telescope. He also served on STS-46 in 1992 using the robotic arm to deploy ESA's Eureca retrievable spacecraft from the Shuttle, and on STS-75 in 1996 with the Italian Tethered Satellite System. Nicollier is currently the chief of the robotics branch in NASA's astronaut office and ESA's lead astronaut in Houston.

Clervoy, of French nationality and making his third flight, will have the lead role in the operation of the robotic arm for this mission. He previously served on STS-66 in 1994 using the robotic arm to deploy and later retrieve the German CRISTA-SPAS atmospheric research satellite, and on STS-84 in 1997, a Shuttle mission to the Russian Mir space station.

The other STS-103 crew members are: Commander Curtis Brown, pilot Scott Kelly, and mission specialists Steven Smith, Michael Foale and John Grunsfeld.

During the flight, the astronauts will replace Hubble's failing pointing system, which allows the telescope to aim at stars, planets and other targets, and install other equipment that will be ready for launch at that time. A second mission to complete the previously-scheduled Hubble refurbishment work is foreseen at a later date. The crew for that mission has not yet been assigned.

ESA astronaut Claude Nicollier at RMS controls on the Shuttle's aft flight deck during the first HST servicing mission, STS-62

The Hubble Space Telescope, launched in 1990, is one of the most powerful optical telescopes available to astronomers today, producing images and spectral observations at the forefront of astronomy. ESA contributed a 15% share to the development of Hubble and European astronomers receive in return a guaranteed 15% share of observing time (and 20% on average in practice).

For more information, see the following web pages:

- Biographies of ESA astronauts: <http://www.estec.esa.int/spaceflight/astronaut>
- Biographies of NASA astronauts: <http://www.jsc.nasa.gov/Bios>
- Hubble servicing missions: <http://station.nasa.gov/shuttle/future/sts-103.html>
- Hubble Space Telescope: <http://sci.esa.int/hubble>

esa

Waiting for the Leonids

Once a year, the Earth passes close to the orbit of comet 55P/Tempel-Tuttle. Dust from the comet enters the Earth's atmosphere in the night from 17 to 18 November creating the Leonid meteor shower. For 1998, an extremely high meteor rate was predicted – a so-called 'meteor storm' – the same is expected for 1999.

Last year enhanced activity was indeed observed at the predicted time, but with lower rates than expected. In addition, the previous night (16 November) presented us with a wonderful display of extremely bright meteors.

Current models predict storm level activity for this year, with the best visibility in Europe. While this is no threat on Earth, a particle impact on a satellite could cause severe damage. Spacecraft operators have taken precautions for near-Earth satellites. In addition, scientists of the Solar System Division in ESA's Space Science Department will set up a ground-based observing campaign from the Sierra Nevada Observatory (OSN) and the German-Spanish Astronomical Centre at Calar Alto (CAHA), both in southern Spain. Equipped with intensified video cameras they will study the physical properties of the cometary dust particles. The two stations will allow stereoscopic observations for precise triangulation of the meteor paths. With the OSN telescope, scientists will perform a spectroscopy of the glow that is visible after the meteor disappeared, the persistent 'train'. One video camera will be dedicated to public relations activities.

In 1998, ESA recognised the public interest for this event. Still images of the night sky were transmitted from an observation site near Utrecht (NL) and a group of scientists was available for interviews, conveying the excitement of the observations.

For the upcoming event in November 1999, we are aiming at:
- having mobile, light-weight, easy to carry equipment
- not being dependent on external infrastructure, in particular all equipment should run on 12 V
- transmitting compressed video frames in real time
- having a low-cost, reusable solution
- directly feeding a real-time video stream to the world wide web (WWW).

To fulfil these requirements, a bandwidth of at least 30 kbits/s is needed. While a Global System for Mobile Communication (GSM) data modem offers the flexibility required, the data rate is still restricted to 9660 Kbit/s and the next generation of GSM data modems will not be available this year. Alternative solutions such as ISDN connections or satellite communication are either quite expensive or do not offer the flexibility and mobility we would like to see. Mobile connect GmbH, Germany, offered a solution using 4 GSM data modems. The Solar System Division and the Science Programme Communications Service will implement this solution in a collaborative effort.

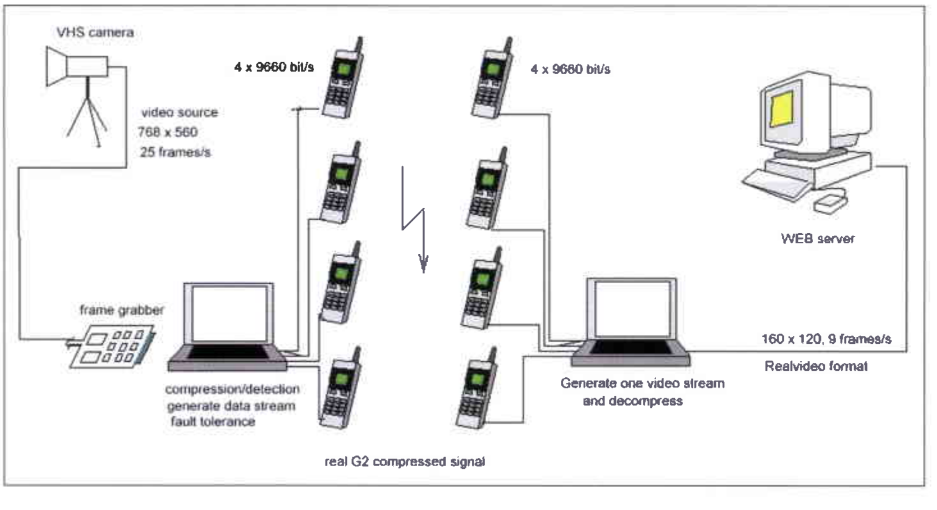
From 11 to 18 November we will operate an image-intensified video camera for public relations purposes from the Calar Alto site. It will provide a wide-angle view of the night sky. This video stream is compressed and transmitted by the four data modems in parallel. The Science Communications Service will operate four data modems at ESTEC, receiving and merging the data streams together. The collected video sequences will be published on the Science web server and can then be watched with the freely-available RealVideo viewer on the Internet.

Using standard compression algorithms, we expect a data rate of 160x120x3 (width x height x frames/s), with a transmission aim of up to 8 frames/s, taking into account the image characteristics of the night sky and the meteors. The necessary algorithms are being developed and implemented in the Space Science Department.

Having decided on this solution, we realised that the setup is flexible and mobile enough to be used as a general communication tool within the Space Science Department for a variety of astronomical events, the first one being the solar eclipse on 11 August. **esa**

A Perseid meteor recorded by an intensified video camera

Collected video sequences of the Leonids will be available at: <http://sci.esa.int>



ESA Successful in Advanced Space Robotics Experiment

A team of ESA staff and contractors, operating from Japan, has successfully performed a novel experiment in space robotics. From an ESA control station in the National Space Development Agency of Japan (NASDA) Tsukuba Space Centre, they commanded the robot arm on the Japanese Engineering Test Satellite 7 (ETS-VII) using several advanced techniques, which will be essential in future applications of space robotics. The experiment data collected will provide a basis for quantifying the performance that can be achieved using these control modes.

ETS-VII is the latest in NASDA's series of engineering test satellites. It is dedicated to the in-orbit assessment and demonstration of novel technologies in rendez-vous/docking and space robotics. ETS-VII is, in fact, a pair of satellites, a larger chaser and a smaller target satellite. The larger satellite carries a robot arm with a stretched length of about 2 m and a set of experimentation equipment to test the robot's capabilities: a task board on which typical robot manipulation activities can be performed and measured, an Orbital Replacement Unit (ORU) to be removed and reinstalled, a truss structure to be erected, an antenna assembly mechanism to be actuated, and an advanced robot hand.

The ESA experiments concern advanced schemes for planning, commanding, controlling and monitoring the activities of a space robot arm system. One set of experiments tests an operational mode called 'interactive autonomy', whereby the robot motions are split into typical tasks of medium complexity. Ground operators can interact with the tasks (parameter-ising, commanding, rescheduling, monitoring, interrupting them as needed), relying on the fact that each task will be autonomously executed using appropriate sensor-based control loops (it having been programmed and extensively verified in advance by simulation). This signifi-cantly reduces the amount of data traffic over the space link. In fact, ETS-VII offers only a few short communications windows per day. Data from ESA experiments will be used to assess the performance of tasks executed with 'interactive autonomy' compared with the more traditional tele-manipulation at lower control levels.

The second group of experiments concerns vision-based robot control. Using the Japanese-provided onboard vision system (which includes one hand camera and one scene-overview camera), it has been demonstrated that reliable automatic object localisation and grasping can be performed even without the artificial markers which are typically used to guide tele-manipulation. This is an important capability for robotically servicing 'non-cooperative' targets.

The success of these experiments is an important step towards the development of a number of ESA space robot systems which will be launched and installed on the International Space Station in the next few years. Looking beyond the ISS, the functional demonstration of satellite capture by robotic means could also inspire novel applications for space robotics on free-flying servicing vehicles.

Development work for the ESA experiments was funded by Belgium under the ESA Technology Demonstration Programme (TDP) and the ESA General Support Technology Programme (GSTP). After competitive tendering, the contract was awarded to a team led by TRASYS Space with SAS and two institutes at the Catholic University (KUL) in Louvain, Belgium as subcontractors.

ETS-VII was launched in November 1997. It operates in a circular orbit at an altitude of 550 km and is controlled from the Tsukuba Space Centre via NASA's Tracking and Data Relay Satellite. In the course of 1998, NASDA successfully performed a range of experiments in space robotics and rendez-vous/docking.

In an effort to strengthen international cooperation NASDA offered ESA an opportunity to participate in the ETS-VII experiments. ESA responded positively with several proposals and, in 1997, an ESA/NASDA Memorandum of Understanding was concluded concerning the joint robot experiment.

Spacelab: A Piece of Space Heritage Returns to Europe

After 22 trips into space, Spacelab – Europe's first step into human spaceflight – has returned to Europe. On 16 April, NASA Administrator Daniel Goldin officially handed the space laboratory over to ESA's DG, Antonio Rodotà, in the presence of German Chancellor Gerhard Schröder, during a ceremony at Bremen airport in Germany, the city where the module was built more than two decades ago.

The laboratory, to be housed in a special exhibition hall at the airport, will be the 'foundation stone' for the Space Academy Bremen, a new educational venture between DaimlerChrysler Aerospace and Bremen University. The academy will give students and the general public the opportunity to learn first-hand about Europe's achievements in the human exploration of space.

Europe's involvement in human spaceflight began shortly after the Apollo moon landings in 1969 when the future of space exploration was being determined. Europe and the US agreed that NASA would build a re-usable space plane, the Space Shuttle, while ESA would contribute the laboratory carried in the Shuttle's cargo bay where astronauts could conduct scientific research in the unique environment of space. ESA entrusted the development of Spacelab to a consortium of European companies led by ERNO of Bremen, today a part of DaimlerChrysler Aerospace.

Two Spacelab flight units were built. The laboratory returned to Europe flew on the final Spacelab flight, the Neurolab mission in April 1998, and was used for both German Shuttle missions, D-1 and D-2, among others. The second flight unit, which flew on Spacelab's maiden mission in 1983, will be preserved along with other pieces of American space history at the Smithsonian Institute's National Air and Space Museum in Washington, D.C.

Europe's experience with building Spacelab has inspired the Columbus laboratory, to be added to the International Space Station in 2003. Columbus is based on the same concept and technologies, but in contrast to Spacelab's eight-day to two-week missions, it will serve as an outpost for continuous research in orbit.

For online information on ESA and its manned spaceflight activities see: <http://www.esa.int/spaceflight/>

On Spacelab D-1 (STS-61A), astronauts conducted 75 individual experiments on material science, fluid physics, biology and medicine. Working on experiments here are Wubbo Ockels, ESA, and Bonnie Dunbar, NASA.

XMM – One Step Closer to Lift-off

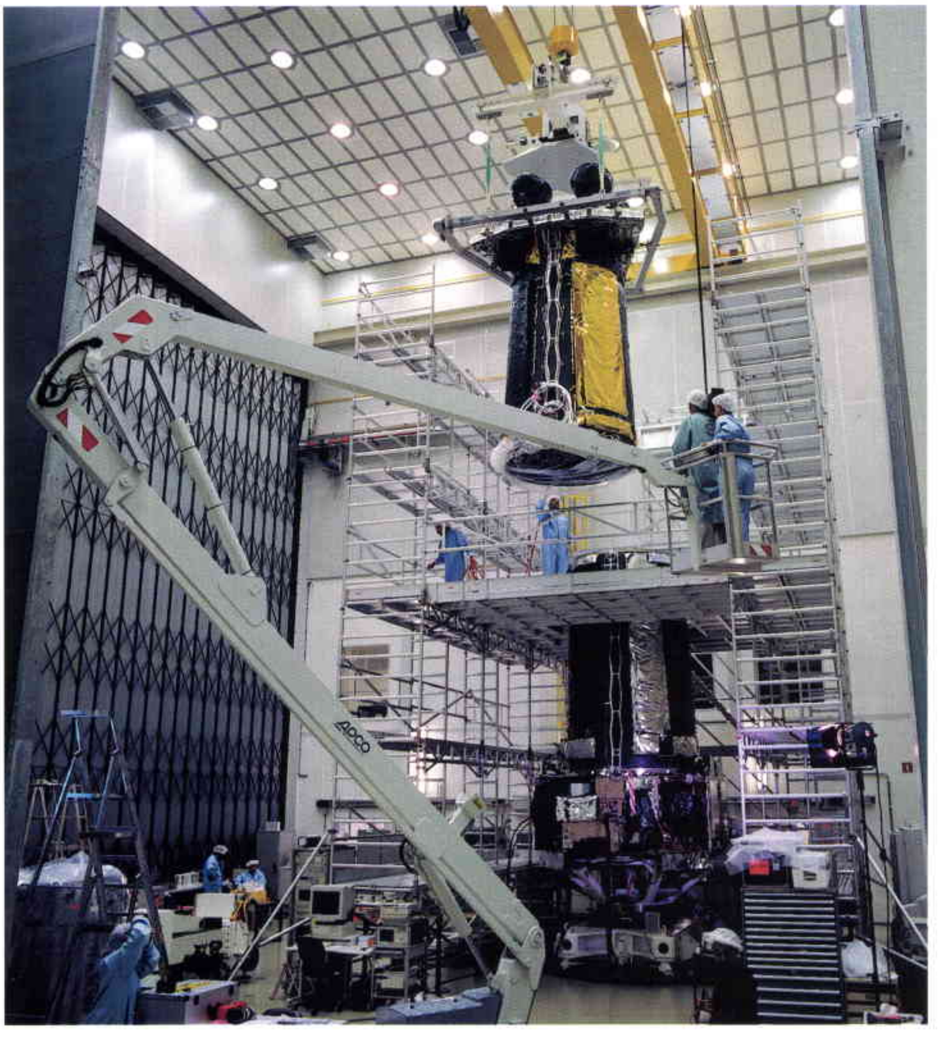
With the most sensitive X-ray space telescope ever conceived, ESA's X-ray astronomy mission, XMM, is about to revolutionise X-ray astronomy. The XMM mission will conduct prolonged observations of more than one million X-ray sources in the universe, violent and changing places such as black holes, binary stars and vestiges of supernovae, where temperatures reach millions of degrees.

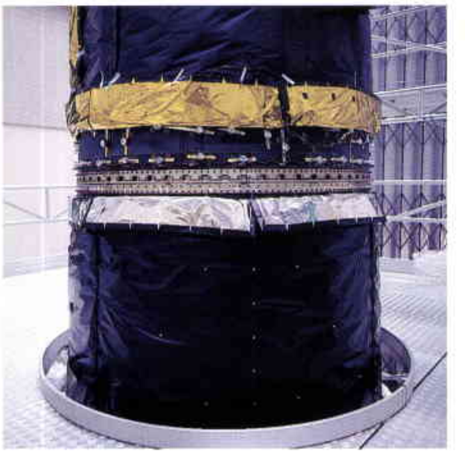
Over the past months, both parts of the spacecraft – its focal plane assembly and the module with its mirror support platform, each with a section of the 7.5m telescope's central tube – have independently and successfully completed their environmental tests at ESTEC. The three mirror modules and an optical telescope were also installed.

On 26 May, the two halves of XMM, both approximately 5 m long, were mated at ESTEC in the XMM integration area. The upper focal plane assembly was hoisted by a gantry crane above XMM's lower section, itself surrounded by scaffolding. As it slowly descended, controlled with infinite caution by specially-trained technicians, the scene was watched from a visitors gallery by members of the XMM team, several of the mission's principal investigators and representatives from Arianespace, including Arianespace XMM mission manager Daniel Biedermann.

After being lowered into place, the first of 64 bolts around the 6 m diameter interface plane was inserted. To mark this new milestone in the programme, three years after the start of construction of flight hardware, a special 'golden bolt' was positioned by Dr Hubert Hofmann, Executive Vice President Science, Earth Observation and Meteorological Satellites, Dornier Satellitensysteme, the XMM prime contractor:

"It is an exciting moment to see the XMM satellite ready for the last tests in Europe. I would like to thank all members of the XMM team for reaching this significant milestone. I'm convinced that the upcoming launch campaign will also be conducted in a positive spirit. I'm sure that XMM will deliver excellent data to the scientific community", Dr Hofmann said.

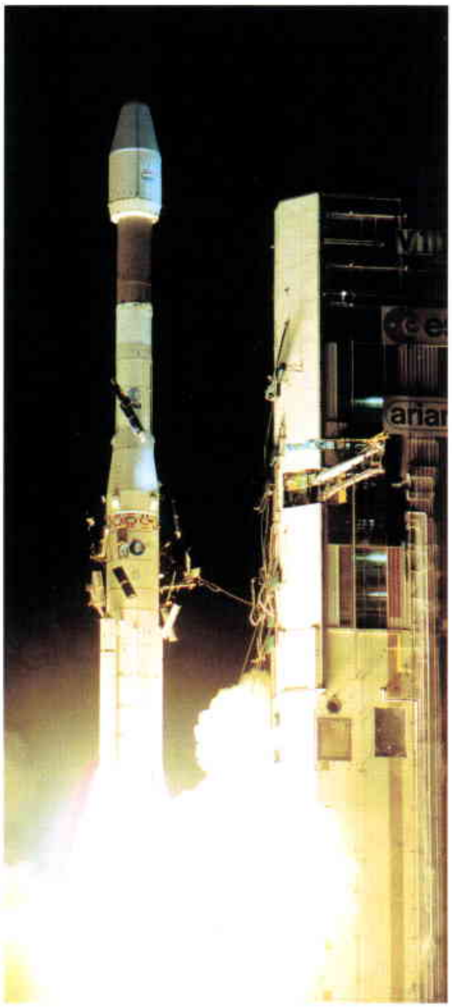




(top) Infinite precaution is taken during the mating of the upper and lower halves of ESA's X-ray astronomy satellite, XMM, at ESTEC
(middle) The two halves are sealed by 64 bolts around the 6 m diameter interface plane
(bottom) To mark this new milestone, the first of the 64 bolts, specially made of gold, is inserted by Dr Hubert Hofmann (right) of Dornier Satellitensysteme, assisted by Robert Lainé, ESA's XMM Project Manager

Robert Lainé replied: *"I would like to congratulate everybody at Dornier. It's an exceptional achievement to have built such a large spacecraft and to have reached this stage only three years and two months after we signed the industrial contract"*.

The fully-assembled satellite is currently undergoing acoustic tests at ESTEC. Final verifications will last virtually until it is time to pack XMM for its journey to French Guiana. The present schedule is to have the satellite in Kourou by end September, with a campaign leading to a launch at the end of this year. esa



Ariane V116 launched on Friday 26 February carrying satellites Arabsat 3A and Skynet 4E

3 Satellites Successfully Launched

The 116th Ariane launch (V116) took place on Friday 26 February at 07:44 p.m. Kourou time. An Ariane 44L vehicle (equipped with four liquid strap-on boosters), lifting off from the Guiana Space Centre, placed into geostationary transfer orbit Arabsat 3A for the Arab League and Skynet 4E for the British Ministry of Defence.

The 117th Ariane launch (V117) lifted off on Friday 2 April at 07:03 p.m. Kourou time. The launcher, an Ariane 42P (equipped with two solid-propellant strap-on boosters) placed into geostationary transfer orbit the Indian telecommunications and meteorology satellite, INSAT 2A. The flight marked the 44th successful launch in a row for Ariane-4.

Beyond 2000: Investing in Space for Europe

Why should Europe invest in space? What challenges lie ahead? What is Europe doing and could it do in areas such as: the search for Earth-like planets, cheaper access to space, disaster warning from space, the threat of cosmic collisions, space energy and space tourism? These and many other questions are explored in the second report drawn up by ESA's Long Term Space Policy Committee (LSPC).

The report, intended to give ESA's Member States a framework for long-term strategic thinking and decisions on space activities, was recently completed and presented at a press briefing on 21 April at ESA Headquarters.

Peter Creola, Chairman of the Long Term Space Policy Committee, Jean-Jacques Dordain, ESA's Director for Strategy and Technical Assessment, and Géraldine Naja, in charge of European Policy and Prospective Studies at ESA, illustrated the content of the report and outlined the initiatives which the Committee would like ESA to pursue.

The report (ESA SP-2000) identifies three challenges which Europe will have to face as it enters the next century: independence, planetary management and expansion beyond present-day horizons. The Committee considers that Europe needs an ambitious space policy and programmes to respond effectively to these challenges and to continue playing a worldwide role commensurate with its economic weight and cultural heritage.

ESA Medals Mark the Hipparcos Revolution in Astronomy

At a gathering of top space scientists on 20 May, ESA's Director of Science, Roger Bonnet, conferred medals on four European astronomers for their leading roles in the Hipparcos mission. This pioneering project in space astrometry fixed the positions of the stars far more accurately than ever before.

Catherine Turon and Jean Kovalevsky from France, Lennart Lindegren from Sweden and Erik Høg from Denmark each received a Director of Science Medal. The occasion was a meeting in Bern, Switzerland, of the Science Programme Committee, which brings together senior representatives of space science in the 14 Member States of ESA.

The Director of Science Medal is a new award introduced to recognise extraordinary efforts and achievements by scientists and engineers from universities and research institutes who participate in ESA's space science missions. This year's awards are a tribute to non-ESA scientists' contributions – indispensable to a successful project.

"ESA's Director of Science's very first medals for science are awarded for work with Hipparcos, one of our most distinctive all-European missions," said Roger Bonnet. *"No other agency has attempted anything like it. From the vastly improved positions, distances and motions of stars which Hipparcos provided, scientists all around the world are now making discoveries every day. As team leaders, our medallists were responsible for the largest computing task in the history of astronomy. ESA says thank you to them and to the many other scientists who devoted 20-30 years of their working lives to making Hipparcos a success."*

Conceived and built in Europe, Hipparcos operated in space from 1989 to 1993, repeatedly measuring angles between pairs of stars in widely separated positions in the sky. Before it flew, multinational teams of scientists identified the target stars and prepared the computing techniques that would make sense of a million bits of data coming from the satellite. Motions of the Earth and of the stars themselves, and even the effect of the Sun's gravity on starlight, had to be reconciled in a consistent and precise map of the entire sky.

Nearly 120 000 target stars for Hipparcos were chosen by the Input Catalogue Consortium (INCA) headed by Catherine Turon. Two other medal winners, Jean Kovalevsky and Lennart Lindegren, led the FAST (Fundamental Astronomy by Space Techniques) and NDAC (Northern Data Analysis) Consortia, which independently calculated the positions, distances and motions of these stars, from the space observations with the main instrument on Hipparcos. Using an auxiliary star mapper, the TDAC (Tycho

Data Analysis Consortium) produced a further catalogue of a million stars with lesser but still remarkable accuracy, under the leadership of Erik Høg.

Calculations continued for three years after the space operations ended. In 1997, ESA's Hipparcos Catalogue and Tycho Catalogue made the results available to all the world's astronomers, professional and amateur. The American astrophysicist, Philip Morrison, wrote of the outcome: *"Our galactic star precinct has just been well mapped for the first time, ready for a century of searching stars for the promise of life."*

JEAN KOVALEVSKY (Observatoire de la Côte d'Azur): *"Altogether thirty years elapsed until our work was completed by the publication of the Hipparcos Catalogue. For individuals involved from the beginning, it was an extraordinary commitment within the human lifetime. Yet thirty years was a short time in the history of science, to achieve a revolution that has affected every branch of astronomy."*

ERIK HØG (Copenhagen University Observatory): *"In 1981 we were considering the performance of ground-based instruments that would help in preparing the Input Catalogue. That was when I realised that even the auxiliary star mapper on Hipparcos would give far better star positions. But I found it a little embarrassing that we were going to put those helpful ground-based instruments out of business, as far as all the brightest stars were concerned."*

ESA's Director of Science, R. Bonnet, offering the new Director of Science Medal to Erik Høg (DK). Other medal recipients were (background, left to right) Catherine Turon (F), Jean Kovalevsky (F) and Lennart Lindegren (S)

CATHERINE TURON (Observatoire de Paris-Meudon): *"In mid-1985 we presented our colleagues with an incredibly long list of stars that had to be freshly measured from the ground to provide starting positions good enough for Hipparcos. It was a big effort for the project, and bad weather at the observatories did not help us. But with tremendous goodwill, a task that might have taken some decades in normal circumstances was finished in time for the launch of the satellite."*

LENNART LINDEGREN (Lund Observatory): *"The Hipparcos Catalogue is not the end of the story. The revolution in astrometry has only just begun. By conceiving the GAIA spacecraft, which could outperform Hipparcos as thoroughly as Hipparcos beat the ground-based instruments, we are now offering ESA the chance to maintain its world leadership in space astrometry."*

Pictures of the medallists, more information about their contributions to Hipparcos, and brief personal histories, are available on the web at: <http://sci.esa.int/hipparcos>

Total Eclipse of the Sun

The last solar eclipse of the millennium will take place on 11 August 1999 with a range of visibility stretching slightly more than one-third of the Earth from Nova Scotia (Canada) to the Bay of Bengal (India).

The zone of totality will begin at sunrise south of Nova Scotia. By about 11:00 (GMT) it will be visible in the southwest of England. Next it travels to northern France, Belgium, Luxembourg, Germany, Austria, Hungary and Romania, where it will be visible the longest. The zone continues through eastern Turkey, northern Iran, Iraq, south Pakistan and central India, ending at sunset in the Bay of Bengal.

In the few minutes leading up to total eclipse, it will be possible to see the shadow of the moon racing westerly, the famous 'Bailey Beads' (the necklace effect of the Sun's light around the moon's mountains, valleys and craters) and the 'diamond ring' (the last visible point of light).

During total eclipse, there will be a glow of light on the horizon where the Sun's light is reflected off the parts of the Earth outside the zone of the eclipse. Planets and stars will be clearly visible. The ring of the Sun's corona will reach out from behind the dark lunar disc and it may be possible to identify the Sun's 'flares' (arched corona structures near the Sun's equatorial area).

Path of totality for the 11 August solar eclipse

The solar eclipse is a spectacular event not to be missed. More information can be found on the ESA Science Programme website: <http://sci.esa.int>.

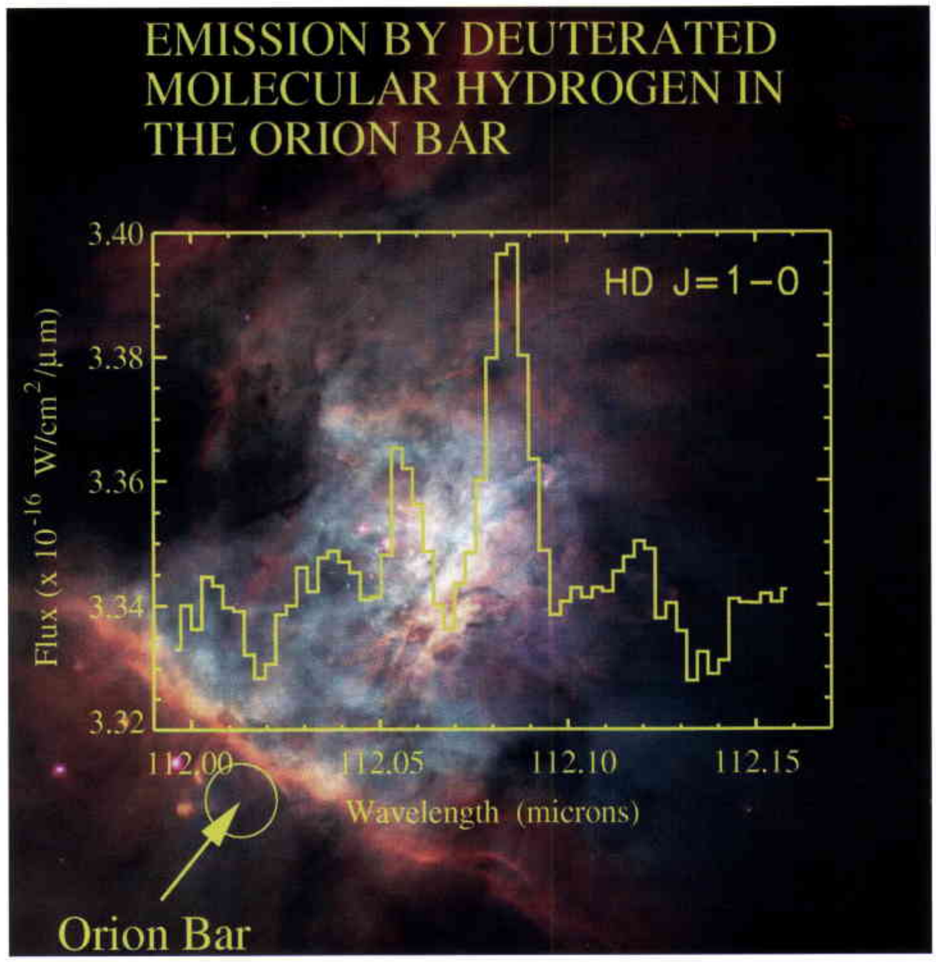
ISO – Latest Results

From near-Earth asteroids to water on Mars

Near-Earth Asteroids – asteroids whose orbits bring them close to Earth – very likely originate from collisions between larger asteroids that orbit the Sun between the planets Mars and Jupiter. This result, obtained by ESA's infrared space telescope ISO, was presented on 10 May at the workshop on ISO results on the Solar System, held at ESA's Villafranca Satellite Tracking Station in Spain. Other findings related to the atmosphere of Mars and the giant planets – Saturn, Jupiter, Neptune and Uranus – were also presented during a press conference on the same day.

Astronomers debate diamonds in space

Most chemical elements in the Universe are produced in the stars, and thus the stars' environments act as huge chemical factories. ISO has detected, in the dust surrounding a star, the chemical signature of a mysterious compound made of carbon, whose nature is being actively debated by astronomers all over the world. While some say it could be a very tiny diamond, others think it is the famous football-shaped molecule called 'fullerene' or 'buckyball'. If either of these hypotheses is confirmed it will be interesting news for industry as well.



The element deuterium has been detected for the first time in an active star-forming region, in the Orion Nebula about 1500 light-years away. The 'signature' of the element appears in the spectra overlaid on the optical image of the Orion Nebula. (Spectra: ESA/ISO/LWS & E. Dishoeck, C. Wright et al.; Optical image: NASA/ESA/HST, O'Dell & S.K. Wong (Rice University))

There is not enough normal matter in the Universe to cause a 'Big Crunch'

The fate of the Universe depends on the total amount of existing matter. New clues on this value have been obtained by an international team of astronomers, using ISO, by measuring for the first time the abundance of a particular chemical element, deuterium, in a very active star-forming region in the Orion nebula. Their result confirms that the total amount of normal matter is insufficient to stop the expansion of the Universe and cause it to collapse into a 'Big Crunch' in the future.

Online information on these topics and more can be found at:
<http://www.iso.vilspa.esa.es>
<http://sci.esa.int/iso>

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ESA Council Elects New Chairman

Mr Alain Bensoussan, currently President of the French Space Agency CNES (Centre National d'Etudes Spatiales), will be the next Chairman of the ESA Council, for two years from 1 July 1999.

Mr Bensoussan was elected at the 142nd Meeting of the ESA Council, held at the Agency's Headquarters in Paris on 23 and 24 June. He will take over from Hugo Parr, Director General in the Norwegian Ministry of Trade and Industry, who has presided over the ESA Council for the last three years and whose term of office ends on 30 June.

Alain Bensoussan, born on 12 May 1940, is an engineer by training. He graduated from the 'Ecole Polytechnique' and the 'Ecole nationale de la statistique et de l'administration économique' and holds a doctorate in mathematics. He is a correspondent Member of the French Academy of Sciences. Prior to becoming President of CNES in 1996, he was President of INRIA (Institut national de recherche en informatique et en automatique), from 1984 to 1996. He has been a member of the ESA Council since 1996.

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European Space Activities on Show 'Under One Roof' at Le Bourget

For the first time in the long history of the Paris Air Show, ESA, CNES and Arianespace joined forces this year in setting up a 2000 m^2 Pavilion in order to present together the many accomplishments – past, present and future – of European space efforts.

Some of the highlights of this joint exhibition, lasting from 12 to 20 June, were: the display of the Atmospheric Reentry Demonstrator (ARD), the capsule launched on the Ariane-503 flight and returned to Earth on 21 October 1998; full-scale models of several satellites, including Envisat, and of the Ariane-5 launcher; scale models of the International Space Station and Artemis; plus other attention-grabbing exhibits and demonstrations devoted to European space activities in the fields of telecommunications, satellite navigation, Earth observation and technology transfer.

The joint Pavilion opened its doors to the general public at the weekend on 13, 19 and 20 June, whilst during the week it was open solely to aerospace professionals and the media. Sunday 13 June was designated 'Astronauts Day', and several

The 'Europe in Space' Pavilion

The full-scale models of Envisat and Ariane-5 outside the Pavilion

Envisat

Interior of the Pavilion, with the Atmospheric Reentry Demonstrator (ARD) on the right

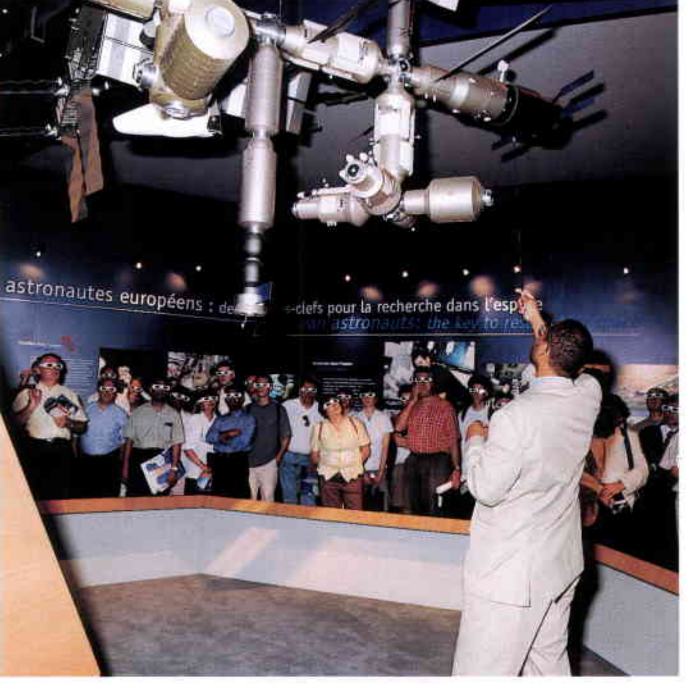
European astronauts were on hand to give presentations to the public, and to talk to the many children present.

A special effort was made to provide media representatives with plenty of opportunities to meet ESA, CNES and Arianespace directors and managers at a series of Press Conferences/Briefings and Round Tables scheduled throughout the week. The Press Conference on 16 June, for example, had the theme 'Satellite Navigation for Europe: The Galileo Programme'. It was followed later that same afternoon by the signature of the industrial contract for EGNOS – the European Geostationary Navigation Overlay Service (see accompanying photograph). The Press Briefing on 17 June on atmospheric reentry technologies and the initial results of the Atmospheric Reentry Demonstrator (ARD) mission was followed by an Appreciation Award ceremony in which the ARD heads of project and their teams were recognised for their outstanding contributions (see accompanying photograph).

Distinguished visitors to the Pavilion during the week included Mr Claude Allègre, France's Minister for Education, Research and Technology.

The accompanying photographs show just a small selection of the activities that took place within the ESA-CNES-Arianespace Pavilion at this unique biennial gathering catering to both the professional aerospace community and the general public.

General view of the interior of the Pavilion



'Three-dimensional' presentation of the International Space Station Programme, by Eric-Joseph Gabriel (ESA)

The 'Earth Observation: Europe for a Living Planet' Press Conference on 16 June; from left to right: Marc Pircher (CNES), Guy Duchossois (ESA) and Philippe Munier (Spot Image)

The visit of Minister Allègre (second from right) to the 'Europe in Space' Pavilion

The 'Satellite Navigation for Europe' Press Conference, being addressed by Claudio Mastracci, ESA's Director of Application Programmes

Signature of the industrial contract for the development of EGNOS, Europe's first-generation regional contribution to GNSS, by Jean-Claude Husson (seated left), President and Chief Executive Officer of Alcatel Space Industries, and Antonio Rodotà, ESA's Director General

The Round Table on 'Space Developed Technologies and Technology Transfer', hosted by Hans Kappler (extreme left), ESA's Director of Industrial Matters and Technology Programmes

The ARD Appreciation Award ceremony. The five recipients were, from left to right: Patrice Amadieu, ESA; Gérard Lagrenée, CNES; Gérard de Wailly, French Navy; Gérard Bréard, Aerospatiale Matra; and Christian Cazaux, ESA. Holding the microphone is Pierre Moskwa, Director of Space Techniques at CNES, and on the extreme right is Jörg Feustel-Büechl, Director of ESA's Manned Spaceflight and Microgravity Programme

Publications

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

ESA Annual Report

ANNUAL REPORT '98 (MAY 1999)
BATTRICK B. (ED.)
NO CHARGE

RAPPORT ANNUEL '98 (JUIN 1999)
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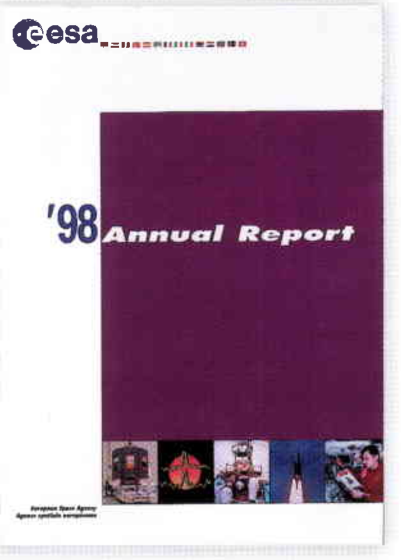

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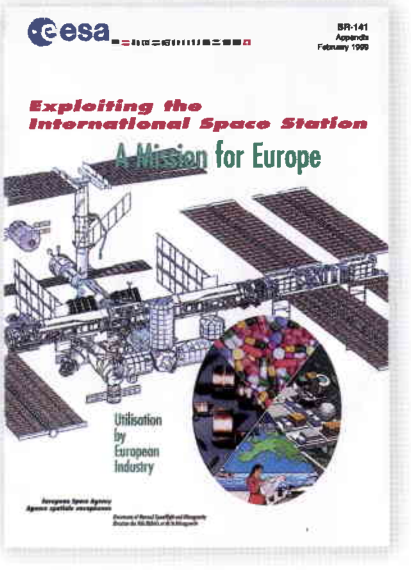

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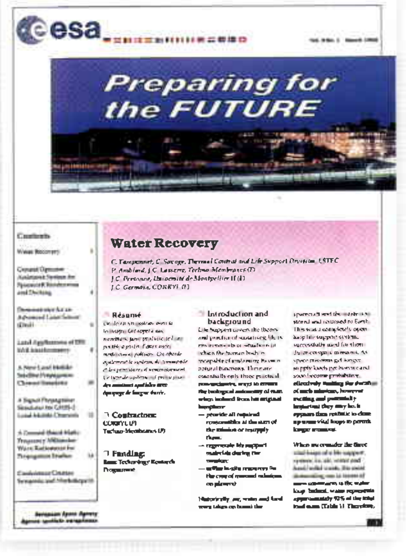

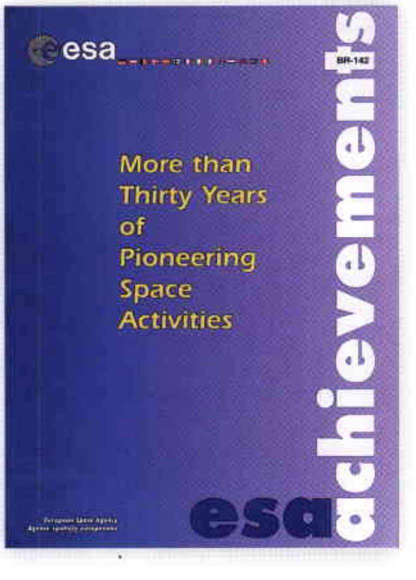

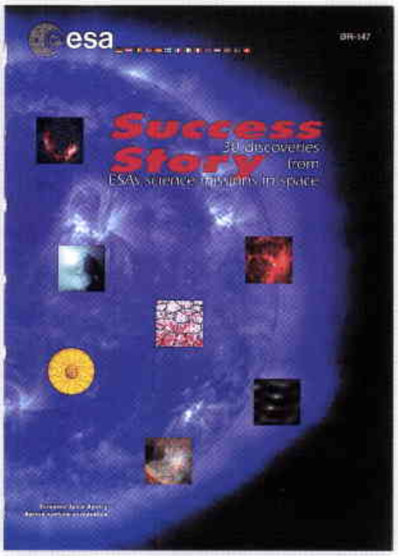

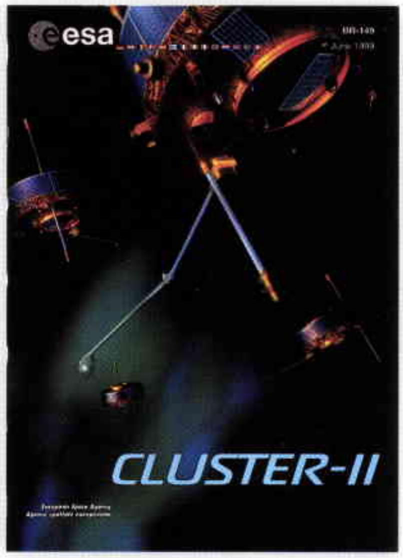

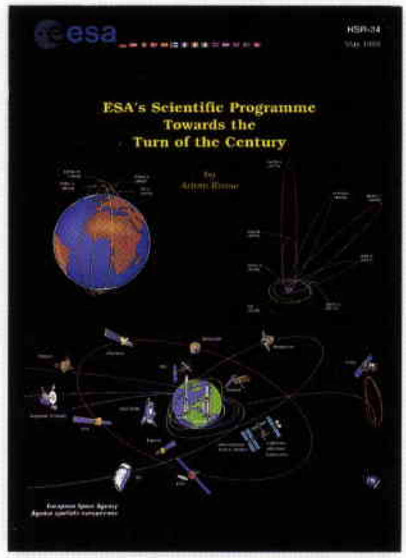

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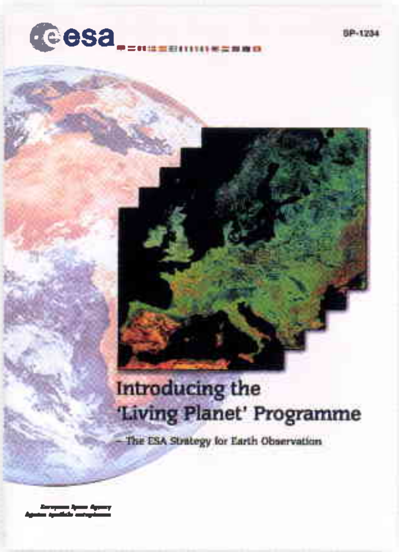

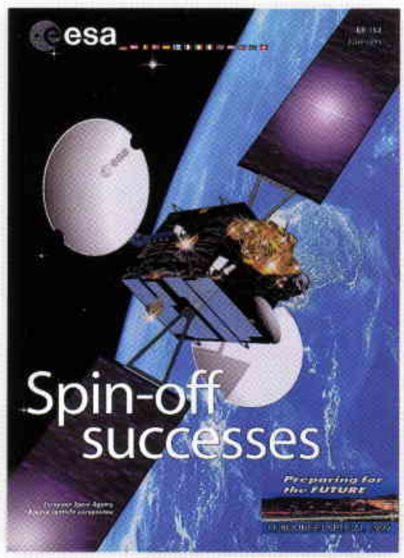

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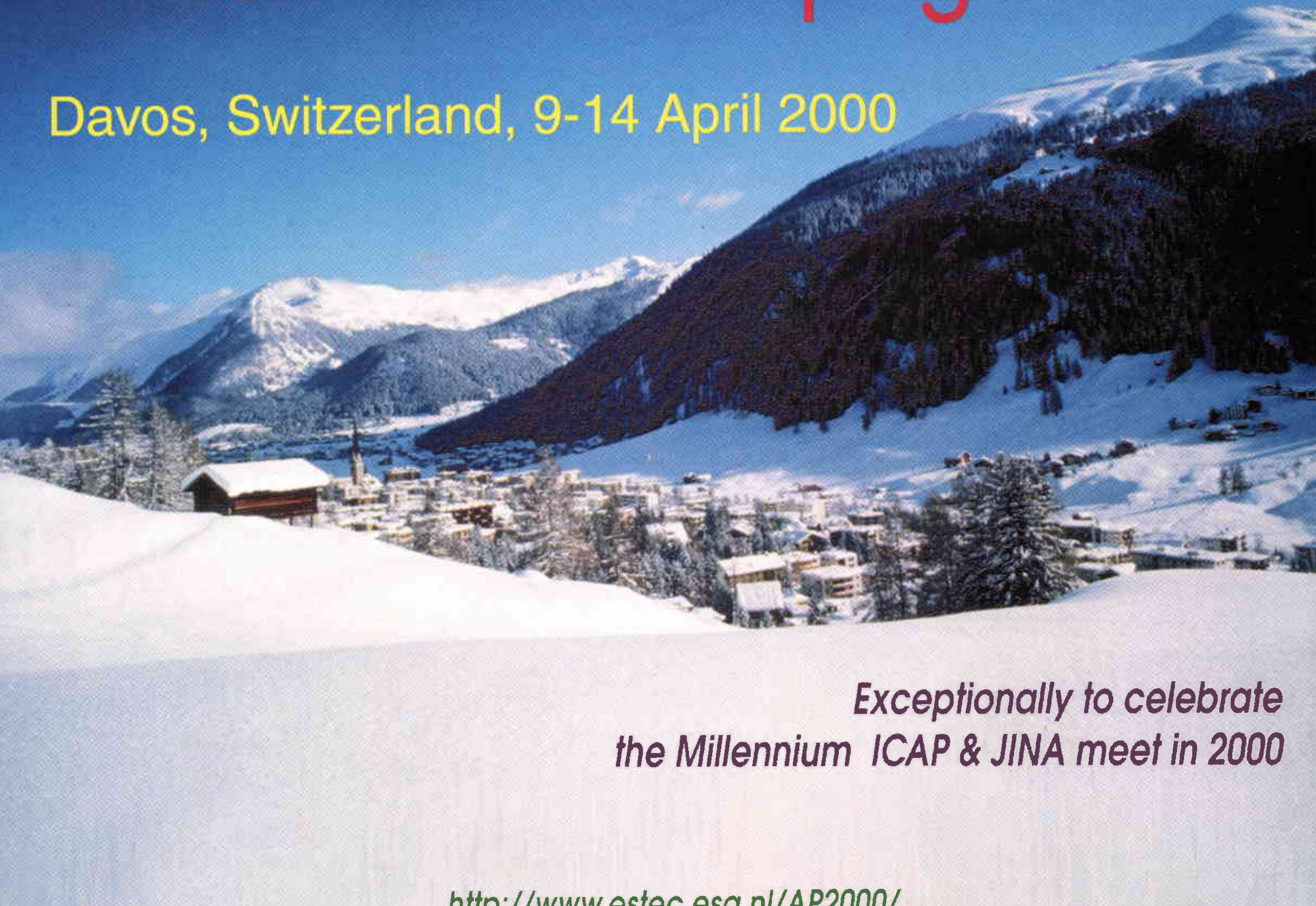

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