# esa bulletin


number 82

may 1995

esa

## 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: P.G. Winters

Director General: J.-M. Luton.

## agence spatiale européenne

*L'Agence Spatiale Européenne est issue des deux Organisations spatiales européennes qui l'ont précédée — l'Organisation européenne de recherches spatiales (CERS) et l'Organisation européenne pour la mise au point et la construction de lanceurs d'engins spatiaux (CECLES) — dont elle a repris les droits et obligations. Les Etats membres en sont: l'Allemagne, l'Autriche, la Belgique, le Danemark, l'Espagne, la 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: P.G. Winters*

*Directeur général: J.-M. Luton.*

# esa bulletin

no. 82 may 1995


**contents**/sommaire

Cover: Launch of ERS-2 on Ariane flight 72




**Editorial/Circulation Office**
ESA Publications Division
ESTEC, PO Box 299, Noordwijk
2200 AG The Netherlands

Publication Manager
Bruce Battrick

Editors
Bruce Battrick
Duc Guyenne
Clare Mattok

Layout
Carel Haakman

Graphics
Willem Versteeg

Montage
Keith Briddon
Paul Berkhout

Advertising
Brigitte Kaldeich





Printed in The Netherlands ISSN 0376-4265

**european space agency**

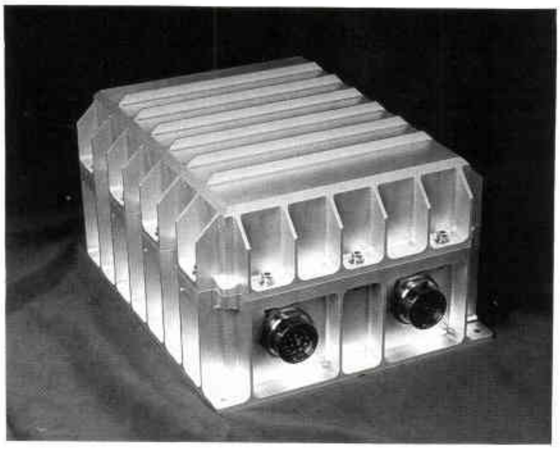
AMP TEK®

# SPACEFLIGHT DATA RECORDER

# FDR-8000

**Product Spotlight**

| | |
|---|---|
| Model: | FDR-8500C |
| Capacity: | 5 Gigabytes (uncompressed)<br>10 Gigabytes (2:1 compression)<br>250 Gigabytes (50:1 compression) |
| Date Rate: | 10 Mbit/s per channel (burst)<br>4 to 12 Mbit/s total (sustained) |
| Weight: | 16 lbs (7.3 kg) |
| Power: | 18 Watts @ 28VDC |
| Size: | 11.8" x 9" x 6"<br>(300mm x 229mm x 152mm) |
| Interface: | RS-422 |



**FDR-8000** series recorders are flight-proven, high performance data storage units built for operation within the Space Shuttle bay, on the aft flight deck, and aboard space platforms. Designed with 8mm helical scan technology, the FDR-8000 line provides economical mass data storage. These recorders' unique characteristics make them equally useful in avionics and satellite applications.

## Capacity

The newest member of the FDR-8000 family is the FDR-8500C. The capacity of the FDR-8500C is 5 Gigabytes of uncompressed data. Hardware compression is typically 2:1, yielding 10 Gigabytes of storage space. Depending on data content, compression rates of 50:1 are attainable. Peak data rates are 10 Mbit/s per channel into a 4 Mbit buffer. Multiple input models are available. Total sustained data rates from combined channels are from 4 Mbit/s to 12 Mbit/s depending on compression efficiency. The error rate is less than one in $10^{13}$ bits read.

## Mechanical

The FDR-8000 enclosure is a sealed box purged with nitrogen. The inert gas provides an air cushion around the recording head and protects the tape from common corrosive gases during long term storage. Internal heaters activate below +10°C. During initialization, recording is disabled until heaters can stabilize the internal environment above 0°C. Shock and vibration isolation allow the tape transport assembly to surpass Shuttle launch and landing requirements.

The recorder's footprint measures 11.8" x 9" (300mm x 229mm), with a height of 6" (152mm). The mounting hole pattern is on 70mm centers for easy interfacing with ESA cold plates and Hitchhiker pallets. Total weight is 16 lbs (7.3 kg).

## Electrical

Power dissipation is 18 Watts at 28V. Each recorder contains its own DC/DC power converter. An internal controller supports serial data transfer, file structures, error recovery, and regulation of the recorder's operating environment.

## Interface

Communication with the FDR-8000 is provided via RS-422 compatible channels. The command channel is asynchronous at 1200 baud. The data channel is synchronous from DC to 10 MHz.

Let Amptek provide the solution to your high-capacity data storage needs.

AMPTEK, INC. 6 DE ANGELO DRIVE, BEDFORD, MA 01730 U.S.A. TEL 617/275-2242 FAX 617/275-3470

# Has Space a Future?*

**P. Creola**
Advisor on European Space Cooperation, Federal Department of Foreign Affairs, Bern, Switzerland

Ladies and Gentlemen,

Has Space a future? Many of you would answer yes without hesitation, others may have doubts. But how do matters stand beyond these four walls, out there in the world of politics and economics, where priorities are set and money allocated? I have twenty minutes in which to give you my own answer. You, for your part, will either confirm your initial positive response or emerge with even greater doubts.

The idea of the conquest of space is as old as the human brain. Long before Kepler discovered the laws of celestial mechanics that make interplanetary travel conceivable, an intensive space traffic existed in myth and legend. Men rose into the heavens and gods visited the Earth in chariots of fire. The first space novel was written in 160 AD. The first solid-fuel rockets flew in ancient China, and medieval Europe had not only fireworks but artillery rockets. The first technical drawing of a three-stage rocket dates from . . . 1526!

Do you have the feeling you're in the wrong lecture theatre, listening to a talk on the Middle Ages rather than one on the future of space? Let me reassure you: without reference to the past, the future makes no sense. The past is much more than just the past: it is the only known collection of earlier futures. It should encourage us to reflect on today's futures. Our rich range of ideas about the future feed into the evolutionary mill, are pressed into the present, and emerge as the past, once evolution has made its inexorable choice. Only futures past will show which of today's futures was the right one.

Many people see the space endeavour as a thing of the past – a by-product of the Cold War, a piece of machinery left over from a no longer existing worldwide ideological confrontation that will soon come to a standstill.

That conclusion is not only hasty but demonstrably incorrect. Anyone who watches the numerous daily weather forecasts (even if they are not always accurate), telephones to the far ends of the Earth, or steers a boat with the aid of a GPS receiver, is using space technology that has become commonplace. And so are the people who, from a range of thirty television programmes, delight in choosing the most stupid one of all!

Commonplace space technology is even writing history. It is quite plausible that the fall of the Soviet Empire and the breakdown of dictatorships of all kinds was and will be considerably hastened by a flow of information that, thanks to mobile ground stations, can no longer be stemmed. We have satellites for meteorology, telecommunications, mobile broadcasting, navigation, and remote sensing. Whole branches of the economy live with and through space services that have become part of daily routine. Whether they are operated by private or public bodies, their value to the economy as a whole now far outweighs the cost of their development and operation. Yet without the conviction of the pioneers of space and without the politically motivated initial investment, they would never have been conceived, let alone developed.

Perhaps we can draw a preliminary conclusion here. The space sector as a provider of services quite definitely has a future. It is inseparably and irrevocably bound up with our knowledge of Planet Earth – connecting people, events and information in instantaneous discourse. Of course, this also has its drawbacks. But it nevertheless seems to me absolutely essential if people are to learn at long last, and never forget, that everything which happens, happens just round the corner, and that everything they do has repercussions, even in the most far-flung corners of the Earth.

No category of satellites brings this home as clearly as remote-sensing satellites – an area

* Address to the Annual Meeting of the Swiss Academy of Technical Sciences, Bern, 22/23 September 1994.

# L'Espace a-t-il un avenir?*

**P. Creola**
Conseiller pour la coopération spatiale européenne,
Département fédéral des affaires étrangères, Berne, Suisse

Mesdames et Messieurs,

L'Espace a-t-il un avenir? Beaucoup d'entre vous répondraient certainement oui sans hésiter, d'autres peuvent douter. Mais comment les choses se passent-elles en dehors de cette enceinte, dans le monde de la politique et de l'économie, là où les priorités sont fixées et l'argent réparti? J'ai vingt minutes pour vous exposer ma réponse personnelle. Pour vous, il s'agira de renforcer encore votre oui initial ou au contraire de voir vos doutes affermis.

L'idée de la conquête de l'espace est aussi vieille que le cerveau de l'homme! Longtemps avant que Kepler ait établi les lois de la mécanique céleste applicables aux voyages interplanétaires, un intense trafic spatial régnait dans les contes et les mythes. L'homme s'élevait dans les espaces célestes et les dieux visitaient la Terre à bord de vaisseaux de feu. Et le premier roman spatial parut en l'an 160! Les premières fusées à poudre sillonnaient déjà le ciel de la Chine antique, et dans l'Europe du Moyen-âge existaient à côté des pièces d'artillerie des batteries de fusées. Et savez-vous à quelle année remonte la première étude d'une fusée à trois étages? A l'an 1526!

Pensez-vous vous être trompés de conférence? Entendre un exposé sur le Moyen-âge au lieu de l'avenir de l'espace? N'ayez crainte: sans référence au passé, l'avenir n'a pas de sens. Le passé est bien plus que le passé: c'est la seule collection connue d'avenirs d'autrefois. Son étude doit nous inciter à réfléchir sur les avenirs d'aujourd'hui. C'est dans l'éventail bariolé de nos idées sur l'avenir que l'évolution opère inexorablement son choix, le condense pour en faire le présent et le restitue sous forme de passé. Seul le passé de demain nous montrera donc lequel des avenirs d'aujourd'hui était le bon!

Nombreux sont ceux qui ne veulent attribuer à l'espace qu'une place dans le passé. Ils ne voient en lui qu'un effet pervers de la guerre froide et qu'une machine de la confrontation idéologique mondiale, aujourd'hui dépassée et courant à sa fin certaine.

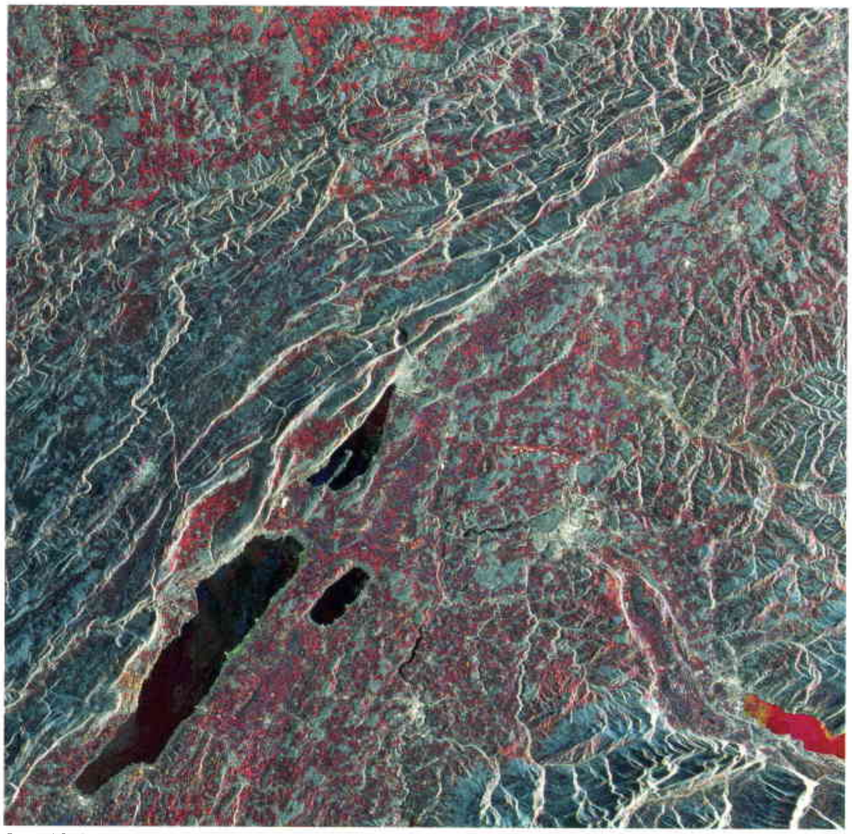
Une telle conclusion, non contente d'être hâtive, est en outre notoirement injustifiée. Quiconque consulte les nombreux bulletins quotidiens de la météorologie – même s'ils ne sont pas toujours vérifiés – téléphone avec les points les plus reculés de la Terre ou pilote son bateau à l'aide d'un récepteur GPS, utilise des techniques spatiales devenues courantes. C'est naturellement aussi le cas de tous ceux qui, parmi trente programmes de télévision, choisissent finalement avec délectation . . . le plus stupide.

On peut dire de l'espace au quotidien qu'il contribue aussi à écrire l'histoire: il semble plausible que l'effondrement de l'empire soviétique et la chute de dictatures de toutes sortes ont été et seront encore notablement accélérés par un flot d'information qu'il est devenu impossible de censurer du fait des stations mobiles au sol. Satellites de météorologie, de télécommunications, de radiodiffusion, de navigation, de télédétection; aujourd'hui, des branches entières de l'économie vit et se sert de ces services spatiaux intégrés dans le quotidien. Leur utilité au plan de l'économie générale, qu'ils soient gérés par des organismes privés ou publics, dépasse aujourd'hui largement leur coût de réalisation et d'exploitation. Mais sans la conviction des pionniers de l'espace et sans les investissements initiaux qui ont été motivés par des considérations politiques, leur création eût été impossible et ils n'auraient certainement pas été réalisés.

Pouvons-nous tirer un premier bilan? La fonction de 'prestation de services' de l'espace a incontestablement un avenir!

* Communication prononcée devant la session annuelle de l'Académie suisse des sciences techniques, Berne, 22/23 septembre 1994.

of space technology in which Europe plays a leading role. The eye of the satellite sees night and day, clouds or no clouds. It alerts us to icebergs, floods and swarming locusts, and will soon be able to warn us of volcanic eruptions and earthquakes. It monitors the burning of the rain forests, detects oil slicks from leaking tankers, and measures the shrinkage of the ozone layer. Since knowledge is the prerequisite for all action, the eye of the satellite shows us the way and will hopefully at long last provide us with legs on which to tread more carefully around our planet in the next century. The most important thing is careful management of the Earth's biological, fossil and mineral resources. Remote-sensing satellites should not only enable us to compile an increasingly comprehensive inventory of our natural resources, but should also help us to understand more clearly the finite nature of those resources and incite us to better housekeeping.


Central Switzerland seen from the ERS-1 satellite/*La région centrale de la Suisse vue par le satellite ERS-1*

Thinking about what has been said so far, we can see that we have dealt only with aspects of space activities that in a sense have little to do with spaceflight or space as such. Virtually all satellites function in relation to the Earth – whether as telecommunications relays, fixed points for navigational bearings, or observation platforms.

Let us turn now to flight away from the Earth, towards the other bodies in our Solar System and beyond into the depths of space. That is what has fascinated humankind for thousands of years. Has such spaceflight a future? In 1994 there is no better keyword on that subject than 'Apollo'. A quarter of a century ago, the rivalry between the two superpowers culminated in man's first steps on the Moon. The United States had overcome its humiliation at the flight of the first Sputnik in 1957 and the first cosmonaut, Yuri Gagarin, in 1961, and shown the world its striking technological superiority over the Soviet Union. The two giants had played for very high stakes, and tacitly agreed to turn to other games.

In the space sector, the Soviet Union concentrated on building a manned space station in orbit, while the United States embarked on the development of the ultimate and most fascinating flying-machine of all time: the Space Shuttle. How symbolic that in 1995, only a year after the twenty-fifth anniversary of the first Moon landing, a Shuttle will be docking for the first time with the Mir Station. Once again, the world is a witness – the rivals have become partners. Their aim now is to build an international space station with contributions from Europe, Japan and Canada, who are already involved with the United States. The station will have many different tasks, with the accent on materials and life sciences, and Earth observation. The overriding goals are the integration of separately developed elements in a functioning whole and the establishment of multinational management. For what purpose? Will man ever again blast out of Earth orbit towards the Moon or another planet? Many think not. Manned spaceflight bears the brunt of the criticism directed at the space sector – whether justified or shortsighted. At the heart of the matter is the future division of labour between man and machine or, more correctly, man and robot.

In the spring of 1994, the first International Lunar Workshop was held in Beatenberg, at Switzerland's and ESA's initiative. For the first time, representatives of all the major space powers discussed a return to the Moon, this time conceived not in terms of competition but as an internationally coordinated project divided into logically connected phases. ESA's idea had met with widespread approval. After a series of exploratory satellites, the next stage will be a 'permanent robotic presence' on the Moon. Most of you will have seen pictures of earthbound prototypes. Weighing from a few tens of kilos to a few hundred, they clamber over the crevices and fissures of the lunar-like landscape, powered by curiosity, descending

L'espace appartient de façon indissociable et irrévocable à la prise de conscience de la planète Terre. Il réunit les hommes, les événements et les informations dans une communauté de l'immédiat. Une telle évolution n'a certainement pas que des aspects positifs. Il me semble toutefois qu'il y a là une condition indispensable pour que les hommes apprennent enfin et n'oublient plus jamais que tout ce qui se passe se produit au coin de la rue, et que tout ce qu'ils font a une répercussion, même aux antipodes. Aucune catégorie de satellites ne montre cela plus clairement que les satellites de télédétection, domaine de la technique spatiale dans lequel l'Europe a pris une position en flèche: l'oeil du satellite voit de jour comme de nuit et traverse les nuages. Il prévient du danger d'icebergs, d'inondations et d'invasions de sauterelles, et pourra prochainement annoncer les éruptions volcaniques et les mouvements sismiques. Il garde trace de la destruction par le feu des forêts tropicales, découvre le rejet pétrolier d'un tanker négligent et mesure la réduction de la couche d'ozone. Etant donné que la connaissancé est à l'origine de toute activité, l'oeil du satellite nous aide à rester sur la bonne voie et, peut-on l'espérer, nous donnera finalement des jambes pour nous occuper plus attentivement de la planète Terre au prochain millénaire. Sur ce plan vient avant tout à l'esprit la gestion économe des ressources biologiques, fossiles et minérales de la planète. Les satellites de télédétection doivent non seulement faire un inventaire de plus en plus complet de ces biens naturels, mais aussi mieux faire saisir leur caractère précaire et, de ce fait, nous guider vers une meilleure gestion de la Terre.

Si nous revenons rapidement sur ce qui a été dit jusqu'ici, nous nous apercevons que nous n'avons abordé pour le moment que des aspects de l'activité spatiale qui, dans un certain sens, ne sont aucunement des vols spatiaux. La quasi-totalité de ces satellites ont des fonctions liées à la Terre: relais de télécommunications, points fixes pour la navigation, plates-formes d'observation.


Voyons maintenant ce qu'il en est des voyages spatiaux loin de la Terre, vers d'autres objets de notre système solaire et, au-delà, les profondeurs du cosmos. C'est cette forme de l'espace qui fascine l'homme depuis des siècles. A t-elle un avenir? 1994 ne peut apporter à cette question de meilleure mot clé que: 'Apollo'. Il y a un quart de siècle, la compétition entre les deux super puissances culminait avec les premiers pas d'un homme sur une autre planète. Les Etats-Unis avaient surmonté l'humiliation provoquée par le lancement du premier Spoutnik en 1957 et du premier cosmonaute, Youri Gagarine en 1961, et démontré au monde qu'ils avaient repris leur éclatante supériorité technologique par rapport à l'Union soviétique. Les deux géants avaient misé très haut – et s'accordèrent en silence pour se tourner vers d'autres jeux.

Dans le domaine spatial, l'Union soviétique s'est attachée à la construction d'une station spatiale habitée sur orbite terrestre et les Etats-Unis à la réalisation de la machine volante la plus fascinante et la plus folle de tous les temps: la navette spatiale. Quel symbole de songer qu'un an après ce jubilé lunaire, en 1995, une navette ira s'amarrer pour la première fois à la station Mir! Mais cette démonstration vaut pour l'ensemble du monde: les rivaux sont devenus partenaires. Ils ont pour objectif d'édifier une Station spatiale internationale avec la participation des Européens, des Japonais et des Canadiens, déjà associés aux Etats-Unis. Ses tâches seront multiples: biologie et science des matériaux et observation de la Terre sont les maîtres-mots. A une plus grande échelle, il s'agit d'intégrer en un système fonctionnel global des éléments mis au point séparément et de mettre en place une gestion multinationale. A quelle fin? Les hommes vont-ils jamais se catapulter à nouveau hors des orbites terrestres en direction de la Lune ou d'une autre planète? Beaucoup le nient. Les vols spatiaux avec équipage sont la principale cible des critiques de l'espace, aussi bien critiques fondées que visions à court terme. Au coeur du débat se trouve la question de la future répartition entre l'homme et la machine, ou plus exactement entre l'homme et le robot.

Au printemps de 1994 s'est tenu à Beatenberg, à l'initiative de la Suisse et de even into the craters of active volcanoes and reporting back eagerly on everything they see, the state of the terrain, and what can be extracted from it. Thanks to progress in electronics and micromechanics, these robot researchers, working partly under remote control and partly autonomously, are becoming increasingly agile and intelligent. The next robot generation, at the latest, will outgrow practice on Earth and push out into space. And unlike the Apollo astronauts, they will not have to wait for the development of giant launchers – conventional launchers like ESA's Ariane-5 can already land them on the Moon, or on comets, asteroids and Mars.


The Moon/*La Lune*

Will tomorrow's astronauts then be armchair adventurers, sitting back comfortably with a glass of beer in easy reach and exploring the Solar System through permanent contact with a horde of robots? I am convinced that an organic division of labour will emerge. The only logical follow-up to the international space station is a permanent manned research base on the Moon. The Apollo astronauts are already grandfathers. It seems to me unthinkable that their great-grand-children, in the years 2010 to 2030, with technology fifty years younger than that of Apollo, will not return to the Moon, at greatly reduced overall cost, to live and work.

Never forget that the Moon is literally in our own backyard. In terms of distance, ten revolutions around the Earth would take the international space station to the Moon – provided it was on the right trajectory! The Moon's scientific and perhaps economic potential as a natural space station is practically limitless. It is the perfect condensed record of the development of our Solar System, a gigantic laboratory for life away from Earth, and its far side is the ideal platform from which to conduct astronomical observations free of all terrestrial influences. An impressive list of Moon-based research activities is included in a report by an international working party headed by Professor Balsiger of Bern, which has attracted a great deal of attention.

And after the Moon? Mars is certainly the most fascinating target. It is of course a hundred times more distant than the Moon, but it is an independent planet with a history that is both mysteriously different and at the same time fascinatingly similar to that of the Earth. The hypothesis, based on our present under-standing, that life developed on Mars long ago and subsequently disappeared, is bound up with the mother of all questions: Are we alone in the Universe? If so, why? And if not, where are the others and shall we ever encounter them?

Whether Mars will be the object of manned expeditions in the foreseeable future is much harder to say than in the case of the Moon. But our clever little robots will certainly explore it. Perhaps the flood of messages they will be sending us will finally crystallise into an urgent summons: 'On your feet, you armchair astronauts. This is something you simply have to see for yourselves!'

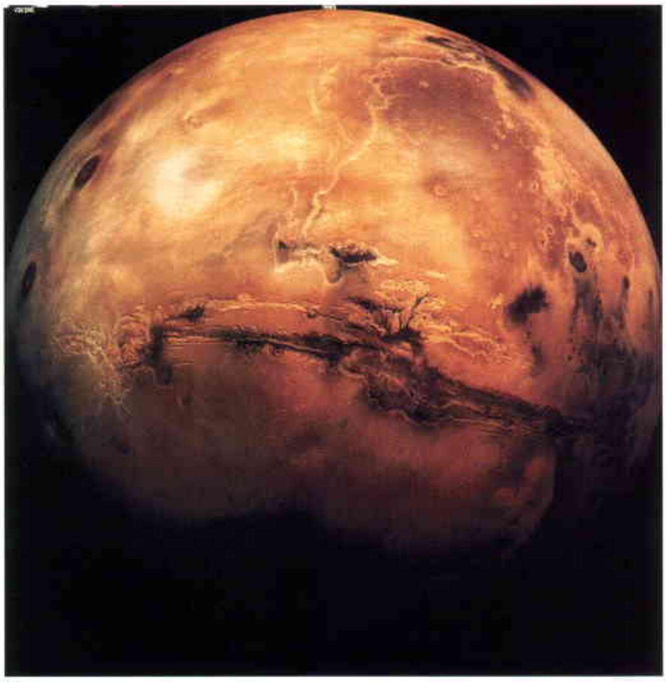
And beyond Mars? As I speak to you, ESA's Ulysses probe, carrying an experiment from the University of Bern, is making the first ever flyby of the Sun's south pole. In Vevey and Zurich, people are building the structure for ESA's Huygens probe, which will land on Saturn's moon Titan in 2004. And in our institutes of technology, more Swiss teams are working on instruments and observation systems for other highly interesting projects in ESA's Science Programme, such as ISO, XMM and Integral, designed to observe distant stars, galaxies and the more exotic celestial objects in the infrared, X-ray and gamma-ray ranges. Those are examples of space missions in which direct human involvement is forever barred by the laws of physics as we know them today. However, visions of what might be are not only permissible but necessary. They air the dusty corridors of our brains, keep them young and fresh, and – an enormous l'ESA, le premier Séminaire international sur la Lune. Pour la première fois, les représentants de toutes les grandes organisations spatiales ont examiné les plans d'un retour sur notre satellite, non plus basés sur la concurrence, mais coordonnés au plan international et divisés en phases logiquement liées entre elles. Cette idée de l'ESA a recueilli un large écho. Après une série de satellites d'exploration de la Lune doit d'abord être mise en place une 'présence robotisée permanente'. Pour la plupart d'entre vous, vous avez déjà vu des images de prototypes de tels petits "bonshommes." Pesant de quelques dizaines à quelques centaines de kilogrammes, ils crapahutent les yeux à l'affût sur des terrains crevassés, grimpent dans le cratère des volcans en activité et transmettent sans tarder ce qu'ils voient, comment le terrain est fait et ce que l'on pourrait en tirer d'une façon ou d'une autre. Ces chercheurs robotisés qui travaillent partiellement sous télécommande et partiellement de façon autonome seront, grâce aux progrès de l'électronique et de la micro-mécanique, toujours plus agiles et plus intelligents. Ceux de la prochaine génération au plus tard ne se contenteront plus de travaux fastidieux ou dangereux sur la Terre, mais fileront dans l'espace. Et ils n'auront plus besoin, comme en leur temps les astronautes d'Apollo, que l'on mette au point une fusée géante: des lanceurs classiques, comme par exemple l'Ariane-5 de l'ESA, peuvent sans difficulté les transporter jusqu'à la surface de la Lune, ou des comètes, des astéroïdes et de Mars.

Les astronautes de demain seront-ils donc des fonctionnaires qui, un verre à portée de main, paresseront dans une chaise longue sur la Terre et exploreront notre système solaire par l'entremise d'une nuée de robots? Pour ma part, je suis convaincu qu'une répartition organique des tâches se mettra en place. Le seul successeur logique de la Station spatiale internationale est le projet d'une base de recherche permanente, occupée par l'homme, sur la Lune. Aujourd'hui, les astronautes d'Apollo sont déjà grand-pères. Il me semble impensable que leurs petits-fils et leurs petites-filles, entre 2010 et 2030, et avec une technologie plus jeune d'un demi-siècle que celle d'Apollo, ne s'envolent pas à nouveau vers la Lune moyennant un coût total largement inférieur afin d'y vivre et d'y travailler.

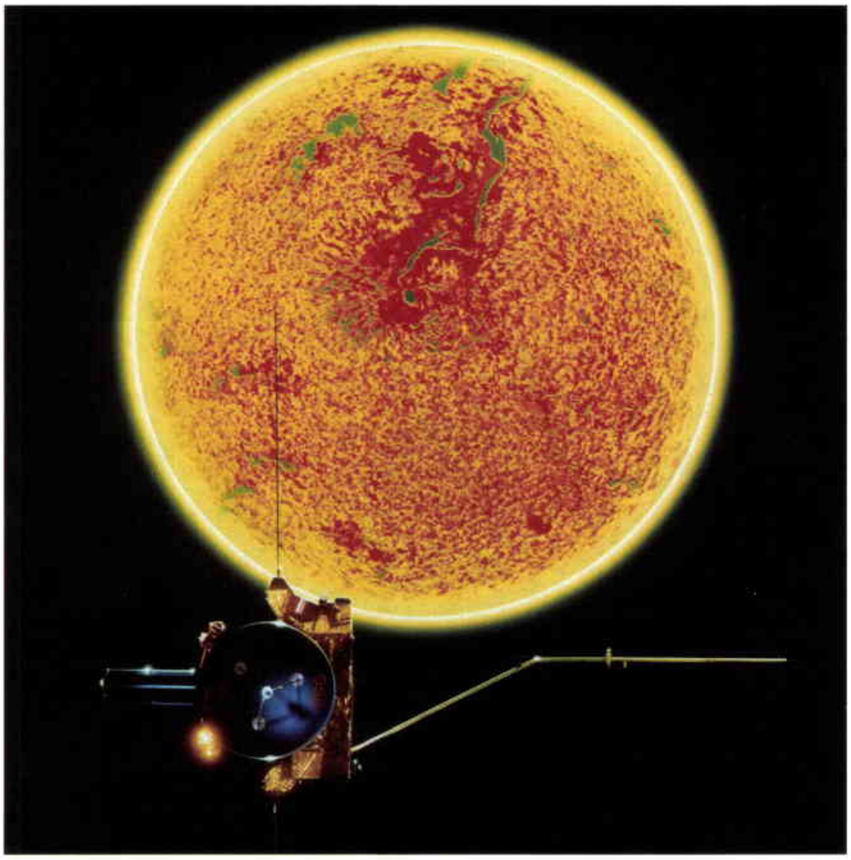
N'oubliez jamais que la Lune est littéralement à notre porte. En termes de distance, il suffirait à la Station spatiale internationale d'une dizaine de révolutions autour de la Terre pour atteindre la Lune – à la condition d'être placée sur la bonne trajectoire! Le potentiel scientifique, mais peut-être également économique, de la Lune en tant que station spatiale naturelle est purement et simplement inépuisable: c'est un condensé des archives de la création de notre système solaire, c'est un gigantesque laboratoire pour vivre en dehors de la Terre, et sa face cachée est la plate-forme idéale pour les observations astronomiques, à l'abri de toutes les influences de la Terre. Un groupe de travail international, placé sous la direction du Prof. Balsiger, de Berne, a fait un rapport très apprécié de l'impressionnante liste de ces activités de recherche.

Et au-delà de la Lune? L'objectif suivant le plus probable est certainement Mars. En termes de distance, il est vrai qu'elle est cent fois plus éloignée que la Lune. Mais en revanche, c'est une planète autonome, avec une histoire qui est à la fois mystérieusement différente et, ce qui nous fascine, similaire à celle de notre Terre. Que la vie s'y soit développée il y a longtemps et que depuis, selon nos connaissances actuelles, elle se soit évanouie, voilà la question primordiale entre toutes: sommes-nous, nous les humains, seuls dans l'Univers? Si oui, pourquoi? Et si tel n'est pas le cas, où sont les autres et les rencontrerons-nous jamais?

Que Mars soit dans un délai prévisible l'objectif d'expéditions humaines, voilà qui, à la dif-



Mars



Ulysses/*Ulysse*

advantage by today's standards – cost nothing at all.

Mention of 'cost', the keyword in this context, brings us down to Earth . . . 'Spaceship Earth' an image from the Apollo years. Right enough, the Earth is a spaceship – and a highly developed one. Racing through the Solar System at 100 000 kilometres an hour, its velocity through the Galaxy, in the company of the Sun, is no less than nine times as great. Nevertheless, it is in a sorry state. The crew are plundering the ship's supplies, tinkering with the temperature and life-support controls, and haven't yet managed to get hold of the instruction manual. Apparently, they haven't had time to look for it yet, since they have nothing better to do than engage in bloody skirmishes in every corner of the vessel, while increasing the size of the crew, week in week out, by a further two million.

Given these problems, isn't Space a cynical flight away from the urgent agenda on Earth? We must not dodge this question. Let me sketch out an answer in three parts:

Firstly, regarding the state of Planet Earth. I have already referred to the role of remote-sensing satellites in environmental monitoring and better management of natural resources. How can we expect to prevent environmental disasters, to avoid – and in emergencies survive – conflicts over the distribution of resources among a world population growing by a hundred million every ten years, and to counter all manner of threats to our free, pluralistic civilisation, unless we know more and more about the overall state of the planet and are constantly aware of what is going on and where? We have to ensure that we have unrestricted access to the only place from which an overall and real-time view of the planet is possible – the space around the Earth.

Secondly, on the matter of cost. We have already seen that Earth-oriented satellite services not only pay their way, but are generating more and more profit for the general economy. What of the costs of scientific research in space? Like every other form of basic research, it is an investment in the future that not only leads to innovations, but also stimulates the production of antibodies against irrational ideologies. As for the cost of much-maligned human spaceflight, which will apparently require such inordinate sums of money, just think for a moment of the other areas, apart from basic material needs, in which enormous amounts are spent year-in year-out – sports of all kinds, cars of all colours, drinks of all sorts. The German market in esoteric products alone is estimated at twelve to eighteen billion marks per year. For a tenth of that amount, the Germans could almost finance their own lunar base. There would be plenty left for the exponents of esoteric philosophies, while those more attracted by the unfathomable mysteries of the Universe would no longer be dismissed as idle dreamers.

Thirdly, and lastly, a few thoughts about long-term survival on this planet. We recently witnessed the spectacular collision of Comet Shoemaker-Levy with Jupiter. The probability of a similar collision with the Earth over the next 150 years is estimated at 1 in 10 000. Do you find this probability too small to worry about? Enormous sums of money are spent on technical measures and insurance against lesser risks originating on Earth. Nor does it have to be a whole comet. Every ten years, statistically speaking, as in 1908 in the Siberian taiga and in February 1994 in the western Pacific, the Earth is struck by a meteorite with a force equivalent to 10 to 100 times that of the atomic bomb dropped on Hiroshima, easily capable of flattening one of the world's largest cities. Only space technology could give us the possibility of diverting such dangerous debris from its trajectory.

férence de la Lune, est bien plus difficile à pronostiquer. Mais nos robots astucieux pourront l'explorer sans risques. Dans le flot ininterrompu de leurs messages, peut-être entendrons nous un jour cette appel impérieux: 'Venez donc, espèces d'astronautes qui paressez dans vos chaises longues, voilà une expérience que vous devez vivre vous-mêmes!'.

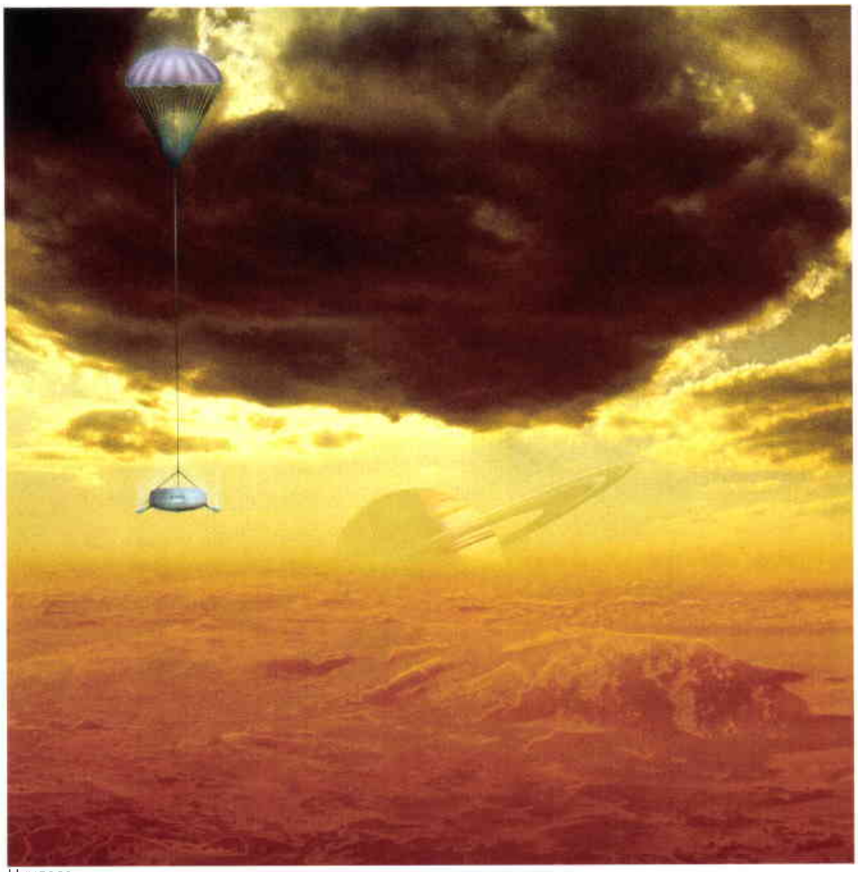
Et au-delà de Mars? Pendant que je vous parle, la sonde Ulysse de l'ESA est le premier véhicule spatial à survoler, avec à son bord une expérience de l'Université de Berne, le pôle sud du Soleil. A Vevey et à Zurich, on travaille à la structure de la sonde Huygens de l'Agence qui doit atterrir sur Titan, le satellite de Saturne, en 2004. Et dans nos grandes écoles, d'autres équipes de Suisses travaillent sur des instruments et des projets d'observation destinés à d'autres projets passionnants du programme scientifique de l'ESA, comme ISO, XMM et Integral, engins qui iront analyser dans les domaines du rayonnement infrarouge, X et gamma, des étoiles lointaines, des galaxies et des objets célestes encore inconnus. Voilà des exemples de missions spatiales auxquelles, selon les lois de la physique énoncées jusqu'ici, l'accès direct de l'homme reste pour toujours fermé. Mais il n'est pas interdit d'avoir des visions, elles sont même nécessaires, car elles aèrent les circonvolutions de notre cerveau, nous gardent jeunes et – avantage majeur de nos jours – ne coûtent rien!

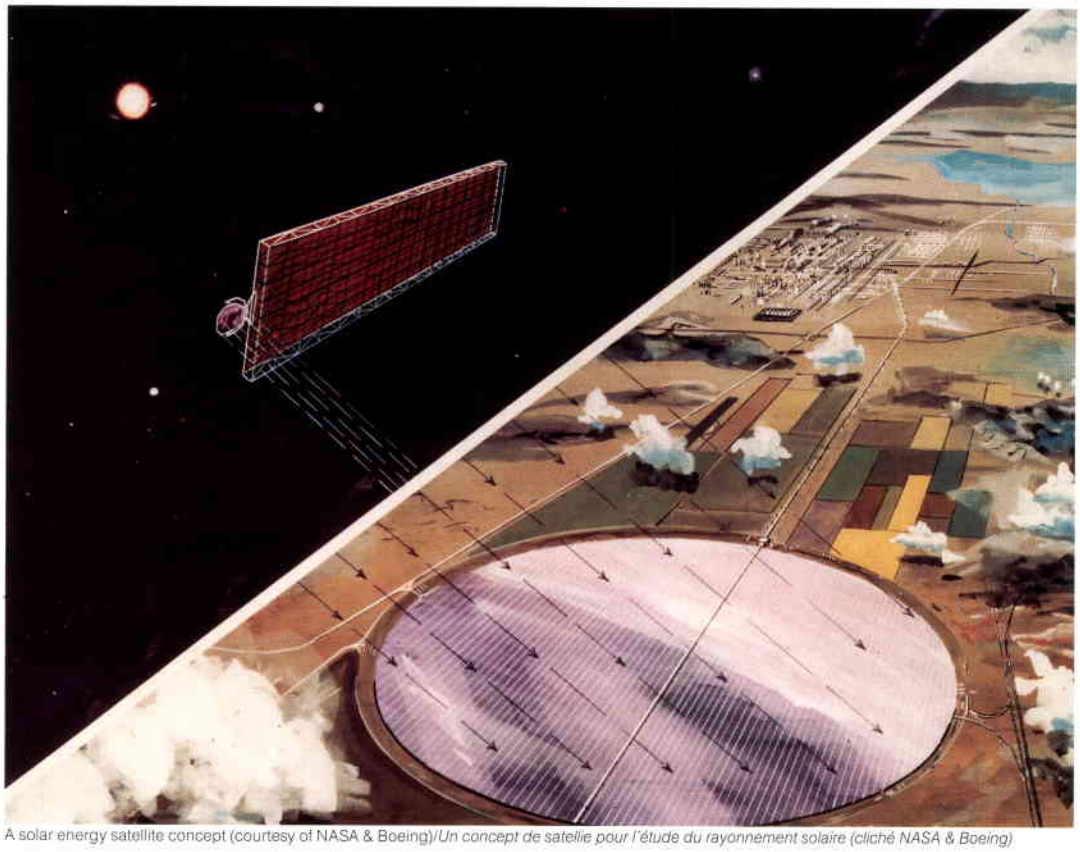
Le mot clé, 'coût', nous ramène sur Terre. 'Le vaisseau spatial Terre'... une image du temps d'Apollo. C'est vrai, la Terre est un vaisseau spatial et, qui plus est, hautement développé: avec 100 000 kilomètres à l'heure, il file à travers le système solaire et, en tant qu'ensemble lié au Soleil, à 900 000 kilomètres à l'heure à travers notre Galaxie. Et pourtant il est en bien triste état. L'équipage gaspille les réserves du bord, tripote les boutons du système de régulation thermique et de soutien vie, et n'a même pas encore trouvé le manuel de vol de son propre véhicule. Manifestement, il n'a pas trouvé jusqu'ici le temps de le chercher. Car il ne semble rien avoir de plus intelligent à faire que de livrer des escarmouches sanglantes dans tous les recoins du navire, alors qu'en même temps, le nombre de ses membres augmente chaque semaine de deux millions.

Au vu de ces problèmes, la recherche spatiale n'est-elle pas une fuite cynique loin de ce qui reste à faire sur la Terre? Nous ne devons pas éluder cette question. J'aimerais malgré tout esquisser devant vous une réponse en trois parties:

Premièrement, en ce qui concerne l'état de la planète Terre, j'ai déjà évoqué les satellites de télédétection, instruments de la surveillance de l'environnement et d'une meilleure gestion de nos richesses naturelles. Comment pourrons- nous prévenir les catastrophes environnementales, comment pourrons-nous éviter ou au moins survivre les conflits qu'occasionne le partage des richesses au sein d'une population qui croît chaque décennie d'un milliard d'habitants, comment pourrons-nous – et ici je pense incontestablement à notre civilisation de type libéral et pluraliste – faire face aux menaces de toute nature si nous ne connaissons pas de mieux en mieux l'état général de la planète et si nous ne savons pas à tout moment ce qui s'y passe et où? C'est pourquoi nous devons nous assurer le libre accès au seul lieu qui garantit une vue générale du globe, l'espace qui entoure la Terre!

Deuxièmement, à propos du coût des activités spatiales: que les satellites d'application axés sur la Terre ne se contentent pas de couvrir leurs frais, mais apportent de plus en plus de profits dans la caisse de l'économie générale, c'est une vérité que vous connaissez déjà. Qu'en est-il du coût de la recherche scientifique dans l'espace? Comme pour toute recherche fondamentale, il s'agit d'un


Huygens



A solar energy satellite concept (courtesy of NASA & Boeing)/*Un concept de satellie pour l'étude du rayonnement solaire (cliché NASA & Boeing)*

Another example is global warming, the number one issue at climate conferences. However, the battle now raging about natural versus human causes is likely to prove futile, not only because our increasing greed for energy will probably impel us to send all our reserves of fossil fuel up in smoke anyway, but also because there is more and more evidence that abrupt swings of temperature have occurred in the past, even within the larger climatic cycles, which would have had a catastrophic effect on our highly technically developed and highly regionally concentrated civilisation. Although ridiculed today, the idea of positioning a filter at the libration point between the Earth and the Sun in order to regulate the amount of solar radiation reaching our planet, or other devices for active climate control could become a real life-saving proposition in no more than a few decades.

Large structures in space – and it would take a whole symposium to discuss them properly – could also become a real possibility in the form of solar-energy satellites, long rejected as unrealistic. By the middle of the next century, when all fossil-fuel reserves have been exhausted, the Sun will have to make a much larger contribution to the Earth's energy supply. The Earth itself receives less than a billionth of the energy which our star pours out into the Universe free of charge, noise and exhaust fumes. What would be more natural than to divert a further small fraction from the immediate environment between the Earth and the Moon for our own purposes?

My time is up. I would like to encourage you to formulate your own answers to the question of whether Space has a future in the light of the thoughts I have offered. Give a future including Space the chance to undergo the strict selection procedure of evolution on terms at least equal to those of other possible futures. Have the courage to be visionary. If you don't, others will.

My own answer to the question, 'Has space a future?', will not surprise you. 'Without space, there is no future!' If you share this view, then spread it in the outside world, where policies are made and money allocated. No opportunity is too small and no event too impressive for you to put your case with convincing arguments and with that inner fire that is the mark of youth.

Thank you.

investissement sur l'avenir, qui est à l'origine d'innovation mais stimule également la production d'anticorps contre les idéologies irrationnelles. Et les coûts des vols habités tant décriés, qui exigent apparemment des sommes disproportionnées? Réfléchissez un moment aux autres domaines dans lesquels, au-delà de la satisfaction de leurs besoins matériels, les humains dépensent annuellement des sommes colossales: sports de toute nature, autos de toute couleur et boissons de toute sorte. A lui seul, le marché de l'ésotérisme est estimé en Allemagne à 12 à 18 milliards de marks par an. Avec un dixième de cette somme, les Allemands pourraient financer une base lunaire presque seuls. Il en resterait encore largement assez pour les voyants extra-lucides! Et ceux qui préfèrent les miracles insondables de l'Univers ne seraient plus rejetés comme d'irresponsables rêveurs.

Troisièmement, une dernière pensée pour la survie à long terme sur cette Terre: vous avez suivi la spectaculaire collision de la comète Shoemaker-Levy avec Jupiter. La probabilité d'une catastrophe semblable sur la Terre au cours des 150 prochaines années est évaluée à 1:10 000. Pensez-vous que cette probabilité soit trop petite pour que l'on s'en soucie? Mais contre de faibles risques de caractère terrestre, on dépense des sommes gigantesques sous forme d'assurances et de mesures techniques. Il est d'ailleurs inutile qu'il s'agisse d'une comète entière. En 1908 dans la taïga sibérienne, en février 1994 dans l'ouest du Pacifique et, statistiquement, tous les dix ans, des météorites se précipitent sur la Terre avec une énergie équivalente à 10 à 100 bombes d'Hiroshima, catastrophe qui pourrait anéantir sans difficulté l'une des capitales mondiales. Seules les techniques spatiales nous donneraient les moyens de faire dévier à temps de leur trajectoire d'aussi dangereux débris.

Autre exemple: le danger d'un réchauffement global figure au premier point de l'ordre du jour des conférences sur le climat. La lutte fait rage pour partager les causes d'origine naturelle et les causes créées par l'homme. Il s'agit à long terme d'une controverse sans doute futile. D'une part, parce que l'humanité, avec sa soif toujours croissante d'énergie, va vraisemblablement envoyer dans l'atmosphère d'une façon ou d'une autre la totalité des combustibles fossiles, et d'autre part, parce que tout montre que, également dans le passé, sont apparues de relativement brusques variations des températures à l'intérieur des grands cycles climatiques, variations qui auraient un effet particulièrement brutal sur notre civilisation hautement technologique et sur des populations par endroits extrêmement denses. C'est aujourd'hui une hypothèse dont on sourit, mais dans quelques décennies, l'idée d'un diaphragme mis à poste au point de libration entre la Terre et le Soleil afin de régulariser dans le long terme le rayonnement de l'astre sur notre Terre, ou d'autres moyens d'intervention climatique pourrait devenir d'actualité. De grandes structures spatiales – il faudrait tout un symposium pour traiter la question en détail – pourraient également prendre la forme de satellites d'énergie solaire, longtemps repoussés comme irréalistes.

Lorsque les combustibles fossiles auront été épuisés au milieu du prochain siècle, le Soleil devra fournir une contribution beaucoup plus élevée à la consommation en énergie de la Planète. La Terre elle-même reçoit moins d'un milliardième de l'énergie que produit gratuitement, silencieusement et sans émission de gaz notre centrale solaire, ce qui nous inciterait à en prélever une part supplémentaire dans les régions proches de l'espace entre la Terre et la Lune.

J'arrive à la fin de mon temps de parole. Je voudrais vous encourager à formuler vous-mêmes votre propre réponse à la question de l'avenir de l'espace à la lumière de ce kaléidoscope de réflexions. Parmi les nombreux avenirs possibles, donnez aussi une chance à celui de l'espace, une chance au moins équivalente aux autres dans le difficile processus de choix de l'évolution. N'ayez pas peur d'avoir des visions. Autrement, d'autres les auront à votre place.

Ma réponse personnelle à la question: 'l'Espace a-t-il un avenir' ne vous étonnera pas: 'Sans espace, pas d'avenir!'. Si c'est également la vôtre, transmettez-la dans le monde où se fait la politique et où se répartit l'argent. Aucune occasion ne sera trop banale et aucune réunion trop huppée pour défendre votre conviction avec des arguments solides et avec un certain feu intérieur, celui de la jeunesse.

Je vous remercie.

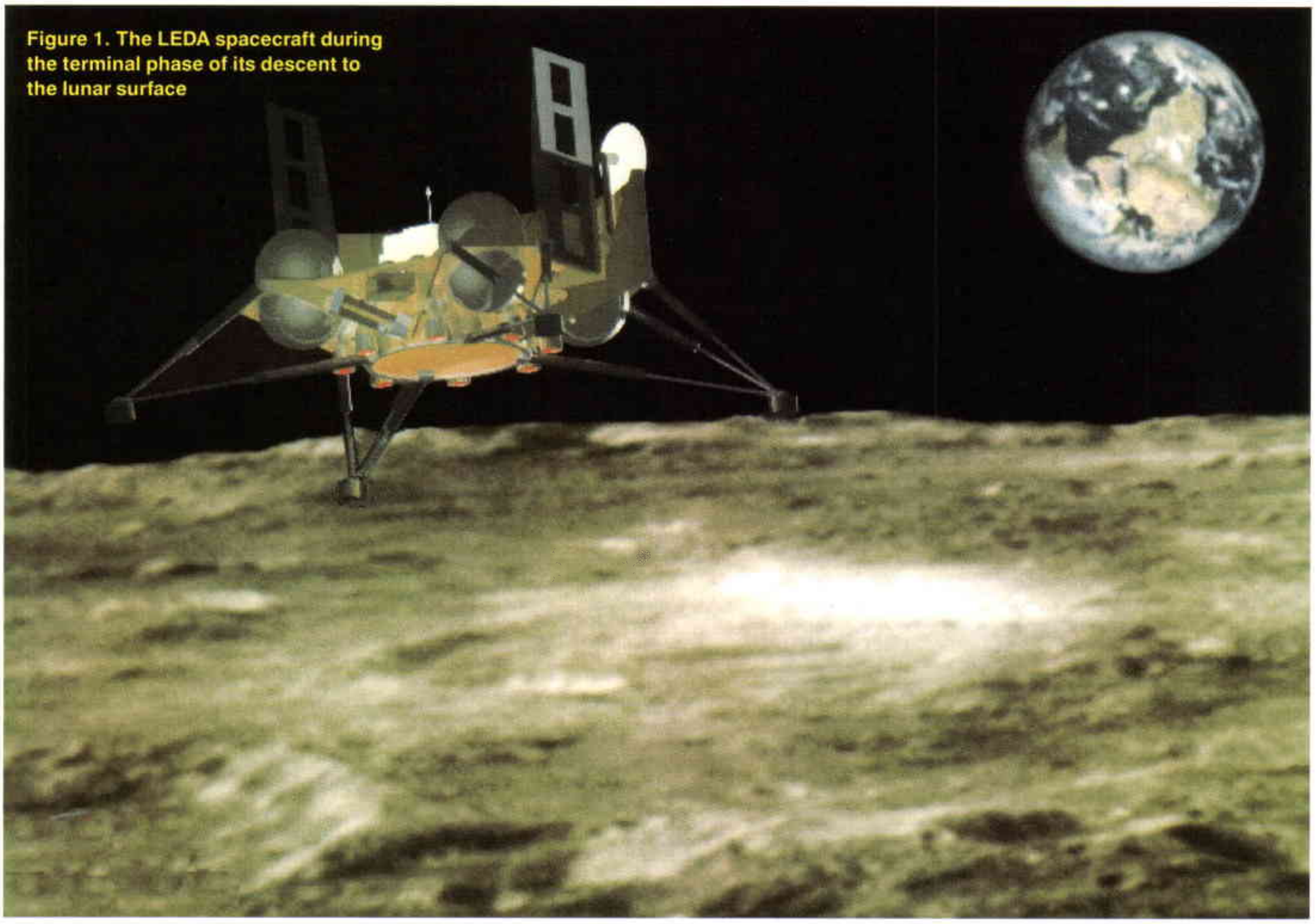


Figure 1. The LEDA spacecraft during the terminal phase of its descent to the lunar surface

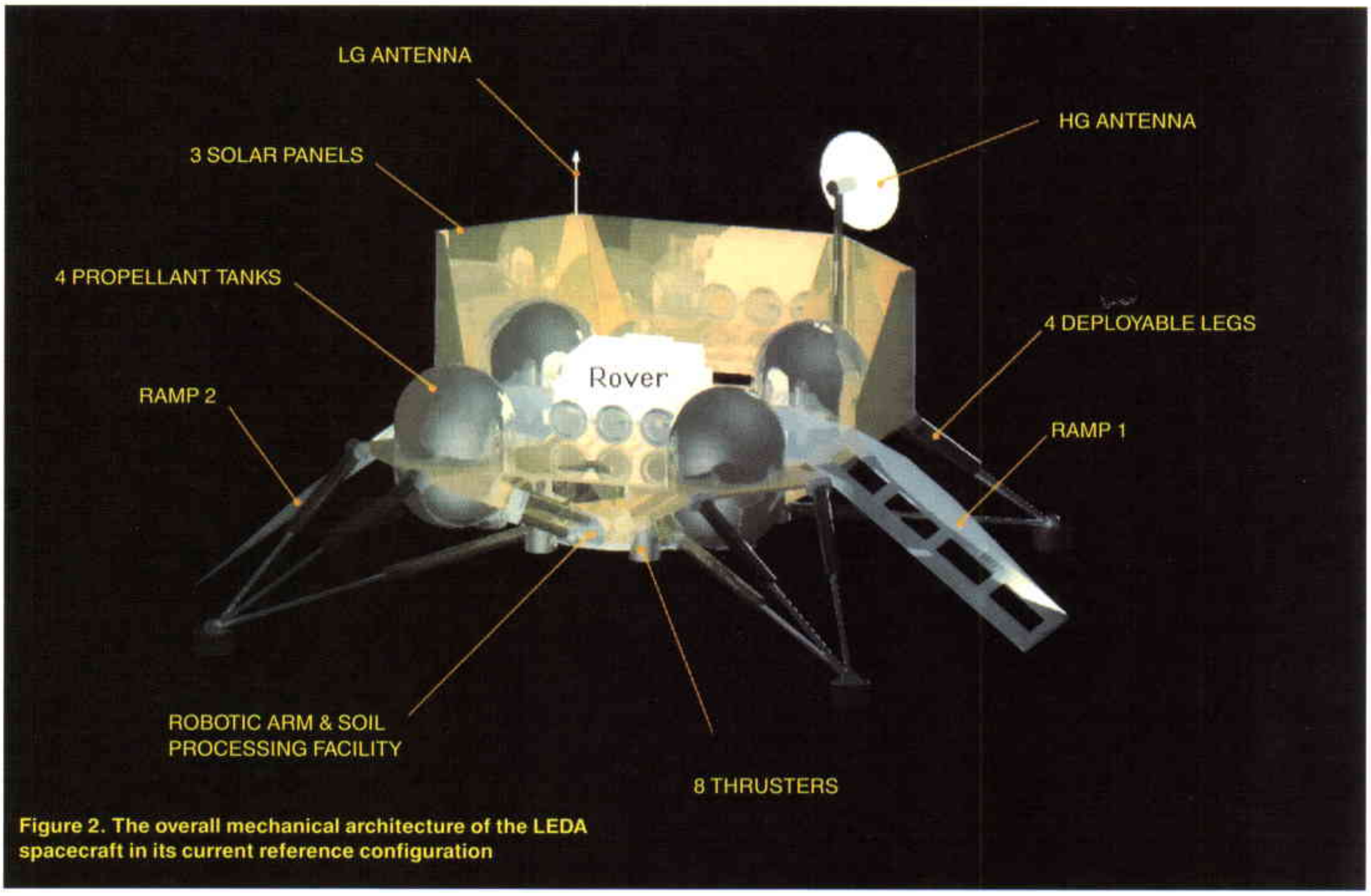



Figure 2. The overall mechanical architecture of the LEDA spacecraft in its current reference configuration

# LEDA – A First Step in ESA's Lunar Exploration Initiative

**D. Kassing & M. Novara**
System Studies Division, European Space Research & Technology Centre (ESTEC), Noordwijk, The Netherlands

**The proposed ESA Moon Programme is based on a phased approach. The current end goal is the establishment – in Phase 4 – of a lunar outpost to serve science and the utilisation of lunar resources. The first phase of this programme of lunar exploration would make a survey of unexplored regions on the lunar surface and an inventory of lunar resources by means of remote sensing and by in-situ measurement. It would also develop a range of technologies of direct benefit for the later phases of the lunar programme. This article summarises the initial results of an ESA study being performed in cooperation with CNES (F) and ASI (I).**

### Why to the Moon?

The first International Lunar Workshop held in June last year in Beatenberg, Switzerland, defined the overall objectives for a staged, but evolutionary Moon Programme. About 140 representatives of space agencies, scientific institutions and industry from around the World considered plans for the implementation of internationally coordinated programmes for robotic and human lunar exploration. It was agreed that the time is right – scientifically, technologically and financially – to initiate the first phase involving Moon orbiters and landers with roving robots to prepare for 'Science of the Moon' (illuminating the history of the Earth – Moon system), 'Science from the Moon' (for astronomical projects) and 'Science on the Moon' (biological reactions to low gravity and the unique radiation environment). The details are to be found in ESA Special Publications SP-1150 and SP-1170 (available from ESA Publications Division).

The enthusiasm expressed in Beatenberg about the rich opportunities offered by the exploration and utilisation of the Moon was really the trigger for LEDA, ESA's study of a 'Lunar European Demonstration Approach'. It includes a series of in-house and external activities to define an exploration mission consisting of a spacecraft that would soft-land, in the year 2002, on the lunar surface after having been put into orbit by Europe's Ariane-5 launcher. This spacecraft (Figs. 1 & 2) would carry a payload consisting of a rover, a robotic arm, a soil-processing test facility and a number of instruments for making in-situ measurements in the lunar environment (Table 1). All of this must be accomplished within the budget of a medium-sized ESA mission.

A range of mission options, landing sites, spacecraft/rover design concepts and technologies are presently being assessed by a working team of experts from ESA, the French Centre National d'Etudes Spatiales (CNES) and the Agenzia Spaziale Italiana (ASI).

### Mission design

Lander missions to the surface of the Moon require a total velocity increment (delta-V) of 3 km/s or more from the initial orbit into which the launcher delivers the spacecraft. Ideally, this initial orbit is a Lunar Transfer Orbit (LTO) with its apogee in the vicinity of, or beyond the Moon. However, the need to transport a significant useful payload to the Moon, combined with the high velocity increment required, implies that relatively large launch masses are needed for this kind of mission (in the order of 3 t or more). One way of containing the launch cost for such spacecraft is to share a launch with a commercial payload bound for geosynchronous orbit; this permits a saving of one third of the cost in the case of an Ariane-5 launch. The lunar lander would be delivered into a 620 x 35 883 km Geostationary Transfer Orbit (GTO) inclined at 7° to the Earth's equator. The available payload mass with a standard Ariane-5 launch, assuming 58% of the total were allocated to LEDA, would be 3330 kg.

Depending on the relative orientations of the apsidal line of the GTO and the line of nodes of the Moon's orbit, the delta-V required for the subsequent transfer varies over a year, as shown in Table 2 (where the corresponding velocity increment for a direct LTO injection is also indicated). Under the most unfavourable conditions, the duration of the transfer is also

**Table 1. LEDA mission summary**

| | |
|---|---|
| Objectives | - Europe to soft-land a spacecraft on the lunar surface using ARIANE 5<br>- Carry a payload to undertake investigations pertinent to future phases of ESA programme<br>- Budget of a medium size mission |
| Spacecraft | - Mass: 3330 kg in GTO, 1007 kg on Moon surface<br>- Size: diameter 4.1 m, height 2 m<br>- Propulsion: 7 × 400 N, 8 × 10 N thrusters, pulsed-mode operation for thrust modulation during descent<br>- Power: 300 W bus power from 5 $m^2$ GaAs fixed solar panels (207 $W/m^2$), 16 kg $Ni\text{-}H_2$ batteries (60 Wh/kg), 5 kg RHUs<br>- Thermal Control: passive + active (radiator louvres)<br>- GNC: 3-axis stabilisation, coarse sun sensor, Inertial Measurement Unit, radar altimeter, Doppler radar, camera vision system<br>- Data: 8 Gbit MMU (video sequence storage)<br>- Communications: 20-W S-band transponder, omni antennas for orbit and landing, 0.5 m high-gain antenna for surface operations<br>- Landing: 4 legs, 0.5 m stroke, 5 m/s vertical speed, <5 g landing shock |
| Payload | - Payload mass: 200 kg<br>- Payload may include rover, robotic arm, soil processing test facility<br>- In situ measurement payload: soil characterisation, imaging, operational environment evaluation |
| Launch & Orbit | - Shared ARIANE 5 into GTO (58% of launch mass capability)<br>- Manoeuvres to LLO: perigee, mid-course, lunar orbit injection (total $\Delta V$ = 1734 m/s)<br>- Duration 81 days from launch to landing (including lunar orbital phase)<br>- Lunar polar orbit at 100 × 100 km altitude, period 2 hours<br>- Orbit lowering to 15 × 100 km, 1-2 orbits prior to landing, for site survey<br>- Descent & landing ($\Delta V$ = 2000 m/s) in Moon South Pole region, 83-85° S, 0-20° W |
| Operations | - Communications: S-band (2,076/2,255 MHz)<br>- Data volume: 44 kb/s to 4.4 Mb/s, on-board 1:4 video data compression, 2 ESA 15-m ground stations<br>- ESOC operations centre<br>- Operational lifetime: 4 lunar days on Moon surface<br>- No orbital relay, direct communications to Earth (<73% of time) |
| Programmatics | - ESA cost <350 MAU<br>- Phase C/D start in January 1998, launch in November 2002<br>- Based on European capability alone (except RHUs)<br>- ESA provides shared ARIANE 5 launch<br>- Payload contributed by National Agencies |

**Table 2. Comparison of velocity increments for various lunar transfer strategies**

| Manoeuvre | Strategy | | |
|---|---|---|---|
| | Via GTO Short Transfer | Via GTO Long Transfer | Direct to LTO |
| GTO to LTO Injection | 720 | 750 | 0 |
| Mid-Course Correction | 120 | 310 | 0 |
| LTO to LLO (100 × 100 km) | 874 | 854 | 874 |
| Lowering of Periselenum (15 × 100 km) | 20 | | |
| Descent Manoeuvre | 35 | | |
| Landing | 1965 | | |
| Total | 3734 | 3934 | 2894 |
| | [m/s] | [m/s] | [m/s] |
| Duration of Transfer to LLO | <29 days | <77 days | 3-5 days |

significantly longer. Up to 50 days may be required to compensate for the Moon's declination above the Earth's equator, plus up to one lunar sidereal period of 27.3 days for phasing with the Moon's angular position. A four-week window occurs just twice per year during which a 'short transfer' is possible (Fig. 3); the corresponding GTO launch mass can be reduced by 7%, and the transfer duration may be up to 50 days shorter, with a somewhat reduced choice of potential launch companions. It is presently considered that the LEDA mission should take advantage of this window.

Other strategies have been considered to optimise transportation to the Moon, including:

- A dedicated launch directly into LTO. Although technically sound, this alternative would be quite expensive, unless a cheaper launcher, such as a Russian Proton, were to be made available.
- A shared launch into GTO with the upgraded Ariane-5 Evolution vehicle (Ariane-5E), which would allow two 3.7 t spacecraft to be delivered to GTO for the same target cost as a basic Ariane-5.
- A shared Ariane-5 launch directly into LTO, together with an exploratory spacecraft bound for the Moon or its vicinity (e.g. for a lunar swingby manoeuvre).
- A shared Ariane-5 launch into Low Earth Orbit (LEO), with a companion bound for the International Space Station, e.g. by sharing a ride with an Automated Transfer Vehicle (ATV).

None of the above options is currently a clear-cut winner, since the most promising ones in terms of performance and cost rely on other, as yet unapproved, Agency programmes (e.g. Ariane-5E or one of the M3 scientific missions). The basic Ariane-5 launch into GTO has therefore been analysed in detail as the reference mission model.

Having reached the vicinity of the Moon, the currently foreseen strategy for LEDA would be to enter a 100 x 100 km polar Low Lunar Orbit (LLO), which would provide the best opportunities for remote sensing and landing-site access. The landing-site area must be known within a given uncertainty (typically, an ellipse of 5 x 10 km). Once the ground track of the spacecraft's orbit comes close to, or crosses this area, the periselenum could be taken down as low as 15–25 km. Overflying the landing area at this altitude for the last one or two orbits before descent would allow an onboard vision-based navigation system to assess the morphology of the terrain to a resolution of better than 1 m, so that an obstacle-free spot could be targeted for the landing.

A further burn would initiate the descent trajectory, bringing the spacecraft down to within a few kilometres of the landing site. A terminal burn phase would then begin, during which the spacecraft could be steered towards the target site by the onboard cameras, matching their images against the landing-site images previously stored from orbit. When objects as small as 0.5 m or less are discerned, some hovering could take place, allowing the lander to avoid such obstacles (Fig. 4). Finally, the engines would be cut and the lander dropped from a height of a few metres for a soft landing, with a vertical speed of less than 5 m/s and a shock of no more than 5–10 g contained by the landing-gear design.

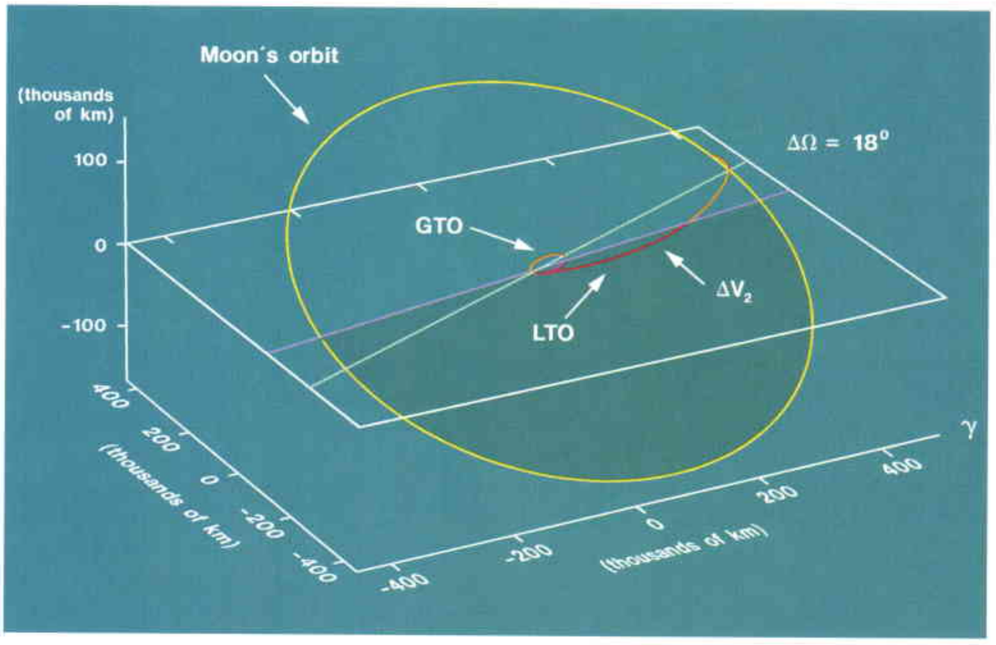



**Figure 3. Orbital transfer manoeuvre from GTO to the Moon. When the angle between the GTO apsidal line and the line of nodes of the Moon's orbit is small (18° in this figure), the delta-V required for the manoeuvre is minimised. This condition occurs twice per year for periods of about four weeks**

## Landing-site selection

The Moon was extensively visited during the 1960s and 1970s by both automatic and piloted missions. Nevertheless, there are still many sites which were not, or were only summarily investigated and are deemed to be of great interest to the scientific community. For example:

- The polar areas are little known. No lander missions were ever flown at high or polar latitudes, and even orbiter data are scanty for those areas; the Clementine imagery, for example, is limited to a resolution of 100 m and no altimetry data were obtained. Scientific interest in these areas is manifold, ranging from the search for water ice, residue from cometary impacts, which may have survived in the permanently shadowed areas that are likely to exist near the lunar South Pole, to the possibility of installing infrared interferometry devices in these same shadowed, and thus extremely cold, areas. Access to unique geological features, such as the Aitken Basin (covering a large portion of the south polar region) is also a highly regarded opportunity.

- Research into the Moon's volcanic history, radiometric age, and heat flow are areas of investigation not previously pursued, and ones for which the lava-flooded areas to be found at medium/high lunar latitudes (up to 70°) are ideal sites.

Besides the scientific and exploratory interest, technical and operational considerations affect the choice of landing site. The south-polar region, which is of the highest interest, is not very well known, but it appears to be considerably rougher, in general, than lower-latitude sites. Such morphology has several consequences:

- The risk of not finding a suitable, obstacle-free landing site is higher.
- Both the Sun and the Earth will be visible at very low elevations from the landing site, so that both the availability of sunlight and communications with Earth will be very much impacted by local features (peaks, valleys, etc.).
- Operation of a mobile payload (a mini-rover) on the surface will be constrained by the difficult local terrain (slope, size of boulders), and also by the fact that sight of the lander maybe lost very soon after moving away from it.

In particular, it has to be remembered that the regions around the Moon's poles (beyond approx. 83° latitude) periodically disappear from sight for an observer on Earth (the so-called 'optical libration phenomenon'). This phenomenon lasts for half a lunar day, i.e. about 14 Earth days, at the pole itself. Given that the lunar night also has a comparable duration of 14 Earth days, there is an annual periodicity pattern during which the Earth can be seen from the Moon's polar regions during local daytime, as shown in Figure 5. The best conditions only occur for about four months per year, and this would seem to determine the maximum duration for a surface mission to the poles, as well as imposing a 'landing window' at the beginning of the four-month period. Given that there is already a launch-window constraint for a shared launch to GTO, a waiting time in lunar orbit for phasing purposes would thus be necessary.

The low elevation of the Sun also means that solar generators would be required to cope with the full 180° azimuth variation of sunlight direction in order to receive sufficient energy (while at lower latitudes a simple, flat, horizontal solar array may suffice). Also, long shadows reduce visibility, implying that a vision-based landing could only take place around local noon, thereby losing surface-operations time during the preceding morning.

The fact that no high-resolution mapping of polar regions is available to a sufficient level of detail is also a concern. Imaging to better than 10 m resolution will be required to select the areas that are of highest exploratory interest. A digital elevation model, from either stereoscopic imaging, laser or microwave altimetry, is required to assess the safest landing-site conditions. If the mission is to include a search for particular chemical

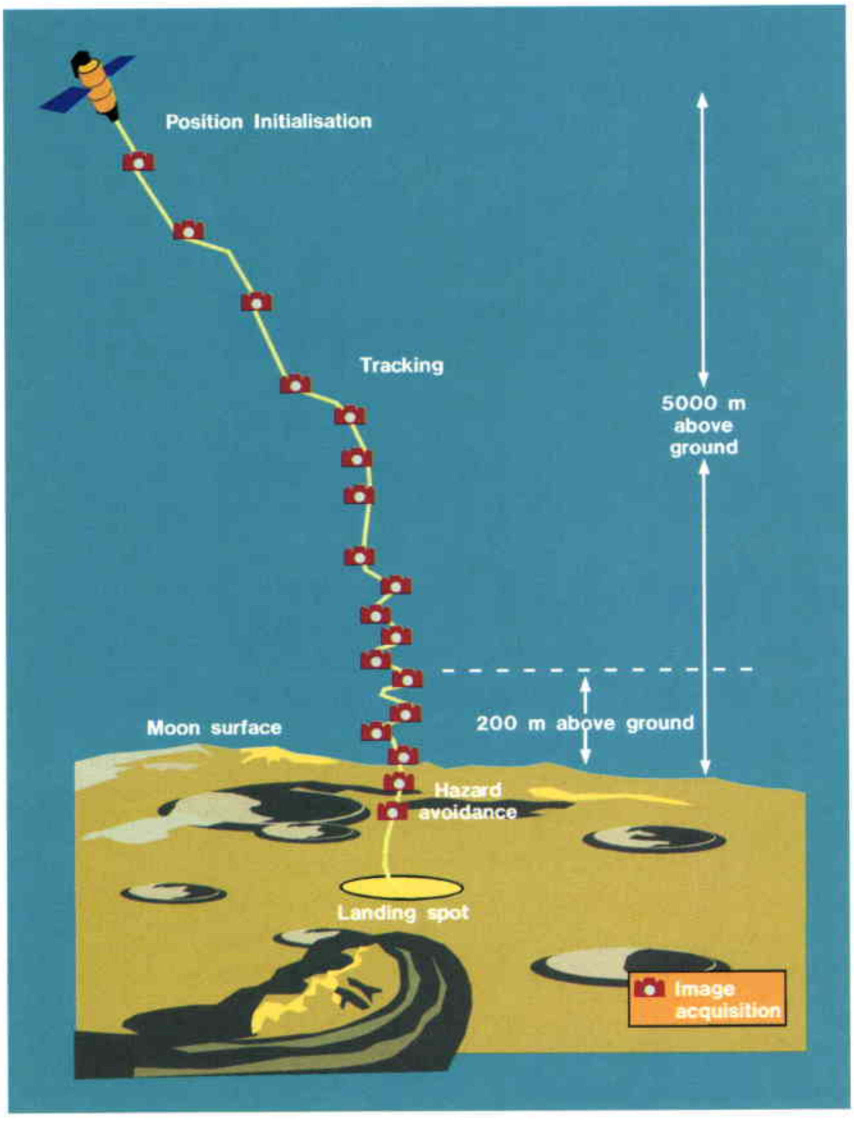



**Figure 4. LEDA relies on a vision-based navigation system during the final descent phase. From an altitude of 5000 m, the onboard cameras track a pre-determined landing spot. At 200 m above ground, when obstacles as small as 0.5 m become visible, the navigation system steers the lander to a safe touchdown in a hazard-free area**

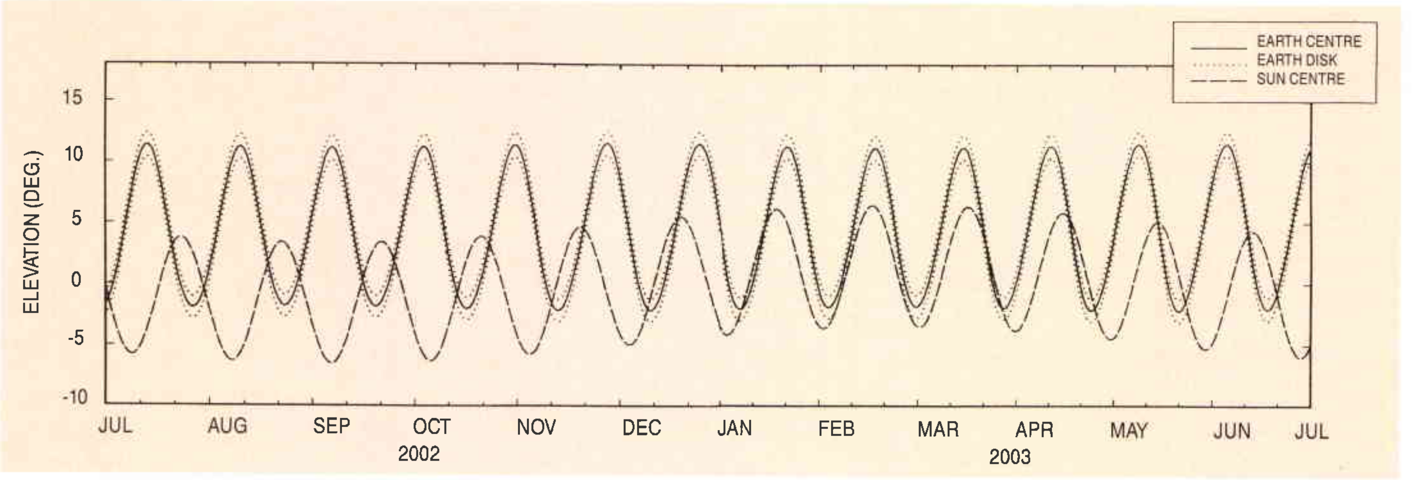



**Figure 5. Visibility of Earth and Sun from a lunar landing site at 85° latitude. Elevation of both Earth and Sun over the Moon's horizon varies slightly in different periods, so that simultaneous visibility of both occurs for periods of about 4 months, once a year (e.g. January to April 2003)**

species that are rarely found on the lunar surface (e.g. water ice), then remote sensing from orbit will be needed to pinpoint the locations of such species (e.g. neutron detection for the search for hydrogen). Otherwise, the probability of finding them within the limited surface mobility range of the LEDA mini-rover, which is expected to be just a few tens of kilometres, is unacceptably low.

The recently announced NASA 'Lunar Prospector' mission, planned for a 1997 launch, may provide lunar geochemical information crucial to LEDA mission planning. If no other orbital missions to the Moon can be flown to obtain the necessary high-resolution mapping beforehand, LEDA would be required to carry out its own remote sensing. This would have to be limited to the latitude of specific interest, since a global mapping would require a different spacecraft design (i.e. Moon-pointing, instead of Sun-pointing attitude). The 83 – 85° latitude band is currently being taken as a reference, this being the lowest at which access to permanently shadowed areas and to Aitken Basin features appears possible. The landing site would in any case be as close as possible to 0° longitude (near side) for best Earth-visibility conditions.

Should the South Pole landing site turn out to be too risky from an operational point of view, a less demanding site at latitudes lower than 70° could be chosen. It would allow the validation of technologies and operational capabilities required to perform complex tele-operated or automated robotic tasks. Landing on the far side of the Moon (in regions not visible from Earth) would require a Moon-orbiting data-relay satellite and is not financially realistic for Phase 1 of the Moon Programme.

The main characteristics and constraints associated with the various landing sites are summarised in Table 3.

It is therefore clear that, to cope with such a challenging landing site as the South Pole region, a thorough assessment of the technologies required for both survival and operations is a prerequisite before committing to the mission. Whether LEDA would be able to tackle the hurdles posed by the prime landing area near the South Pole, or a safer approach should be taken in a first mission, is an issue central to the current investigations.

**Table 3. Comparison of lunar landing-site characteristics**

| | Thermal Environment | Earth Visibility | Sunlight (Energy) | Landing Opportunities | Exploration Opportunities | Required Data Base |
|---|---|---|---|---|---|---|
| Polar Regions (80°-90° N/S) | -230°/-40° C | Intermittent (50% -100% of the time) | Very low elevation (affected by topography) | 14/28-day intervals 4 months per year | Geology Environment Water ice | Mapping Thermal Chemical |
| High-Latitude Regions (70°-80° N/S) | -160°/+60° C | Direct | Low elevation | 14/28-day intervals from polar orbit | Geology Volcanism Environment | Mapping (Clementine) |
| Equatorial Regions (0°-10° N/S) | -160°/+130° C | Direct | Near zenith (no shadows) | Continuous from equatorial orbit | Geology Environment Historical | APOLLO |
| Limb/Farside (>80° E/W) | Function of latitude | Intermittent/ Indirect | Function of latitude | Function of latitude | Geology Environment Access to EM-quiet cone | Function of latitude |

## Payload

The need for a large velocity increment in order to land on the lunar surface implies that the mass available for the useful payload – whether of a scientific, exploratory or technology-demonstration nature – is thereby limited. Choices therefore have to be made and the hardware that is flown should have the maximum possible performance-to-weight ratio.

A mini-rover (Fig. 6) weighing 100 to 200 kg is regarded as the primary LEDA payload, essentially because:
- a range of a few tens of kilometres from a safe landing site is necessary, in order to explore more difficult but interesting terrain
- surface mobility constitutes one of the most important technology demonstrations in preparing for subsequent Moon Programme phases.

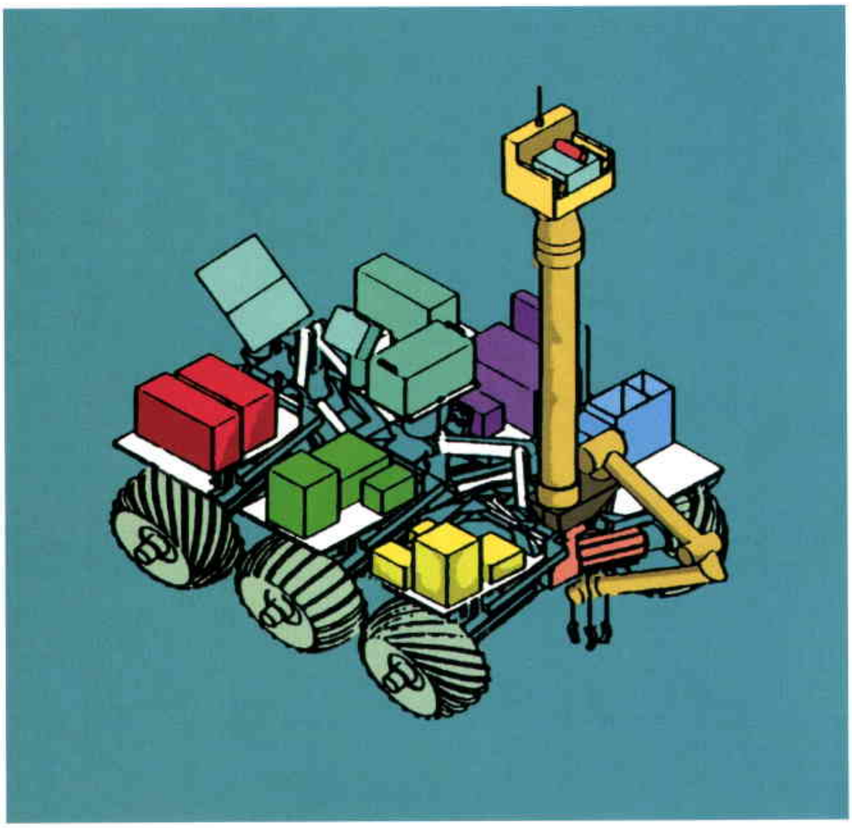


**Figure 6. The ground demonstrator IARES (Illustrateur Autonôme de Robotique Mobile d'Exploration Spatiale), a programme by the French Agency CNES, which will help develop some of the critical technologies needed for the LEDA mini-rover**

The main mission requirements for the mini-rover are highlighted in Table 4. A typical payload to be carried by the rover has been defined as a reference for the study, as shown in Table 5.

Depending upon the available payload mass, additional hardware may also be installed on the lander itself and operated in a stationary mode. Candidate facilities include:
- Instruments for geochemistry, environmental measurements and imaging, some of which could be back-ups to those carried on the rover, mass allocations permitting.
- A robotic manipulator, which may be used in support of other payload items (e.g. pick-up/deployment tasks, soil-sample feeding), but which would be flown primarily to demonstrate the technology needed for tasks for later missions, such as structural assembly.
- A drilling unit, able to penetrate 0.5 – 1 m (and possibly 2 – 3 m) beneath the surface for thermal-probe installation.
- A soil-processing test facility, aimed at evaluating the critical technologies (e.g.

**Table 4. Summary of lunar-rover mission requirements**

| | |
|---|---|
| Exploration | Over 4 lunar days, about 50 km radius off the lander |
| | Including the (presumed) permanently shadowed areas |
| In Situ Measurement Support | Mostly while rover is stationary |
| | Minimum of 6 stations per lunar day, minimum of 10 hours each |
| | Position instrument sensor heads |
| | Feed samples to analysis instruments |
| Technology Demonstration | Assess performance of critical subsystems (locomotion, communications, power, control) |
| | Test lunar survival skills (maintaining communications, use of natural or artificial shelters) |
| | Demonstrate key capabilities for future missions (assembly, maintenance, repair of infrastructure) |
| Information and Education | Allow teleoperated locomotion control, camera positioning, robot manipulation |
| | Downlink sufficient imaging data (not necessarily in real time) to reconstruct environment for "virtual reality" model on Earth (for scenario and path planning, simulation, training, public utilisation) |

chemical reactions in hypogravity) needed for such future applications as oxygen production from lunar soil.

The application of virtual reality and tele-presence to lunar-surface payload operations is important for exploration, in-situ measurement, technology demonstration, and information coverage. It provides a powerful user interface to rover, robot and scientific-instrument operations. It offers 'sensory' feedback (images of environment and spacecraft, rover and robot states, instrument measurements), either on- or off-line (stored). It grants an interaction capability (commanding at various levels), either on-line (immediate execution) or off-line (planning in simulated environment, validation, later execution). In terms of public information and education, such tele-presence involvement can be offered on a worldwide scale to participants ranging from scientists and experts to students and the general public.

The constraints to be faced are essentially:
- the communications time delay (up to 10 s), which requires interaction at a sufficiently high level and the implementation of sufficient onboard autonomy
- limited telemetry bandwidth (less than 0.5 Mbit/s): only critical for image data, requiring on-board data compression, low refresh rate (but compatible with dynamics of scene and level of interaction!)
- rover operational limitations (power, control): very low speeds (less than 1 km/h), long pauses may cause operator boredom and fatigue.

Possible user interfaces to the payload in a tele-presence mode include:
- 'augmented reality' (virtual image of predicted rover position in real video image) for tele-operation
- fully simulated scenes (virtual rover in virtual world, alternative viewing points) for planning, supervision of autonomous execution
- offline replays of (condensed) real data in virtual environment (for analysis, planning, training, validation of new algorithms, simulation of future operations, research, teaching, entertainment, etc.)
- 'virtual dome' from real images for users to move around and explore ('hot spots' for interaction) as depicted in Figure 7.

A long-ranging result of tele-presence applications is the possibility of winning and maintaining public support, stimulating multi-disciplinary participation in lunar exploration and utilisation (exhibits, contests). Media products could eventually be derived from the development and operations tools and scientific data made available by a lander/rover mission, e.g. 'Moon Rover Rides' (like today's flight simulators) for education and entertainment.

**Table 5. Potential complement of rover-mounted instruments**

| Rover-Mounted Instruments | | | Mass [kg] | | Power [W] | Data Rate [kbit] |
|---|---|---|---|---|---|---|
| | | | Sensor Unit | Electronics | | |
| Geochemical Analysis | APX | Alpha-Proton-X-ray Spectrometer | 0.25 | | 0.3 | 32 / sample |
| | GRS | Gamma-Ray Spectrometer | 0.5 | 0.4 | 1.0 | 8 / sample |
| | NED | Neutron Detector | 0.1 | 0.2 | 0.2 | 0.032 / sample |
| | EGA | Evolved Gas Analyzer | 0.5 | 0.2 | 8.0 | 1000 / sample |
| | CPM | Complex Permittivity Meter | 3.0 | | 1.5 | 0.016 / min |
| | GPR | Ground Penetrating Radar | 5.0 | | 10.0 | 1 / s |
| | SAS | Sample Acquisition System | 2.0 | | 5.0 | - |
| Environmental Measurements | TAP | Thermal Array Probes (2x) | 0.15 | 0.2 | 1.0 | 0.05 / 2 |
| | RDM | Radiation Dose Monitors (2x) | 0.2 | 0.25 | 2.0 | 0.4 / meas. |
| Imaging | PCS | Panoramic Camera System | 0.75 | 0.75 | 4.0 | 512/ image |
| | CUI | Close-up Imager | 0.1 | 0.2 | 4.0 | 512 / image |
| Total | | | <15 | | | |

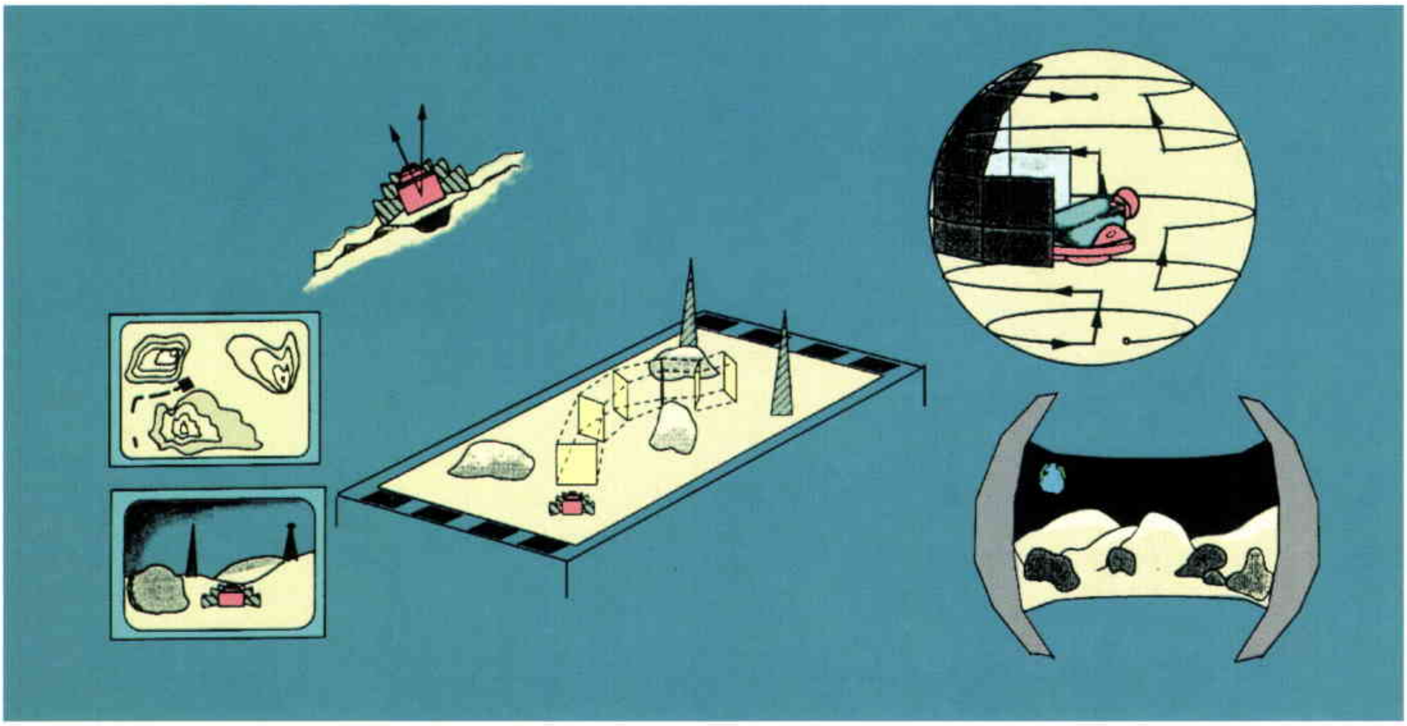


Figure 7. Virtual-reality applications to the rover mission on LEDA. Rover orientation and localisation can be performed by a ground operator by switching between various viewpoints in a virtual environment, and by adding 'widgets' (e.g. target points) to the landscape. The rover's path can be shown on conventional monitors, or on a horizontal planar screen with stereoscopic vision. A 'virtual dome' can be created by reconstructing the landscape observed around the rover by a movable camera

## Technologies

A reference configuration for the LEDA spacecraft has been established (Fig. 2) to assess the critical technologies needed. The technologies will be driven by the two main phases of the LEDA mission, namely the transfer to the Moon up to the landing, and the subsequent lunar-surface operations.

### Propulsion and landing technologies

The most critical subsystems for a successful landing are:
- propulsion
- guidance, navigation and control
- landing gear.

All three require innovative technologies in which Europe has no, or only limited experience to date. Other subsystems – such as communications, data-handling, power and thermal-control – are comparable to those of a more conventional satellite, apart from the process of landing.

The propulsion subsystem is the heaviest item on the spacecraft (consuming up to 27% of the total lander dry mass), because it has to provide such a large velocity increment. In addition, a wide range of thrusts are needed – a maximum at the beginning of descent from lunar orbit (minimum deceleration of 1.5 $m/s^2$), and significantly less (reduced by 50%) during final hovering. This calls for a propulsion system delivering in excess of 2.4 kN, but with the possibility of 'throttling back' to 1.3 kN. There is currently no such engine available in Europe, although a 3 kN non-throttlable engine developed previously may serve as a technology base for further development.

LEDA requirements could also be fulfilled by using a set of smaller engines (7 x 400 N) that are already available and space-qualified in Europe. Thrust reduction can then be achieved by a combination of switching off three or four engines during hovering, and operating the remainder in a pulsed mode (for which a small extra qualification effort is needed). This design is strictly applicable only to relatively small and unambitious landers such as LEDA, while further missions would require a newly developed system.

A number of other solutions are also still under investigation with a view to increasing the payload mass that can be landed by reducing the mass consumed by the propulsion plant, including:
- dual-mode propulsion ($N_2H_4/N_2O_4$), using hydrazine monopropellant for attitude control
- two-stage bipropellant (both lander and transfer stage)
- two-stage bipropellant lander and solid kick stage for trans-lunar injection.

The landing gear has to ensure a stable landing in the correct orientation (within a given range), as well as keep the landing shock below a specified maximum. This essentially involves a trade-off between the maximum allowable residual shock and the length of the landing-gear stroke. The latter, in turn, may influence the overall lander configuration in terms of height of the centre of mass and payload accessibility to the lunar soil. The current baseline foresees four deployable hinged legs with crushable dampers, which have been traded-off against alternatives such as air bags and crushable cushions.

The guidance, navigation and control system controls the spacecraft's trajectory relative to the landing site during descent, hovering and landing, by means of a radar altimeter (range-to-surface measurement), a three-beam Doppler radar (three-axis velocity measurement) and an Inertial Measurement Unit (IMU) combining gyros and accelerometers (for attitude and position determination). Accuracy and safety in landing are accomplished by using a vision-based navigation system. Stability and pointing requirements allow concepts for attitude stabilisation and measurement relying entirely on the use, respectively, of a set of eight 10 N attitude-control thrusters, and of the vision-based navigation cameras as Moon horizon sensors (combined with a coarse Sun sensor). This synergy between the various equipment items has been devised to minimise both power and mass requirements.

The radar altimeter and the Doppler radar represent new developments for Europe for this application, although the radar experience with the Huygens project can be exploited to good effect. The vision-based navigation system also represents a new development, particularly in terms of onboard software required. Microcameras, which are already under development in Europe for other applications, will be needed. Fibre-optic gyroscopes are also an interesting new development that promises further mass reduction.

### Technologies for lunar-surface operations

Two main critical issues immediately spring to mind in this context, namely lunar nighttime survival and surface mobility.

The lunar night of 14 Earth days (with a seasonal variation between 10 and 18 days at the LEDA target landing sites) constitutes a major challenge for the designer. No solar power is available during this period, and the temperature of the surrounding lunar-surface environment drops to well below −160°C (temperatures as low as −230°C have been predicted for polar locations, although these have never been measured). There are essentially three design strategies for facing this problem:

- highly efficient thermal control to dramatically reduce heat leaks during nighttime, a solution affected by residual uncertainties in terms of both system performance and the surrounding environment
- adoption of equipment that is qualified to survive, and even operate, at extremely low temperatures, typically in the range −50 to −100°C; availability of such equipment (especially electromechanical items such as motors) is currently quite limited and

**Table 6. Comparison of energy-storage systems for nighttime survival**

| | Use for LEDA | Other Users | Technology Issues | Procurement |
|---|---|---|---|---|
| RFC | • Electrical power for nighttime survival<br>• Possibly: electrical power for locomotion and operations in darkness (but mass appears prohibitive) | • Uncertain | • High mass (>150 kg for 100 W) increases launch cost<br>• Power can be distributed by electrical heater system<br>• Very complex, contains water, requires high operational temperature | • European technology available<br>• No off-the shelf system (specific low-power adaptation to LEDA needed)<br>• Alternative US and Russian suppliers |
| RHU | • Heat for nighttime survival<br>• No use for locomotion or payload operations in darkness | • Used on GALILEO, CASSINI/HUYGENS, MARS-96<br>• Some interest for planetary missions | • Extremely mass efficient (5 kg for 100 W)<br>• Simple technology<br>• May give problems with unplanned re-entry<br>• Concentrated heating source, requires heat distribution<br>• Requires daytime heat rejection capability | • European development envisageable (large effort)<br>• US source disappearing from market<br>• Alternative Russian supplier |
| RTG | • Electrical power for nighttime survival<br>• Electrical power for locomotion and operations in darkness<br>• Rover only (excessive for lander application) | • Used on GALILEO, ULYSSES, CASSINI, MARS-98 rover<br>• High interest for planetary missions | • Proposed PLUTO EXPRESS device (16 kg, 90 W) very interesting for LEDA<br>• Power can be distributed by electrical heater system<br>• Requires daytime heat rejection capability | • No European know-how<br>• European development too costly, too long (>15 years)<br>• US source disappearing from market, anyway high recurring cost<br>• Alternative Russian supplier |

considerable qualification efforts would be required

- use of highly efficient energy-storage systems appears to be the safest and most flexible solution, but no optimum system has yet been identified; conventional systems such as chemical batteries are too heavy, given the LEDA requirement of some 40 kWh per lunar night, and the most interesting candidates appear to be regenerative fuel cells or radio-isotope-based sources (Table 6).

The mobility issue will focus on the design of the mini-rover's chassis, including the locomotion, control and power subsystems. The availability of a suitable locomotion subsystem, able to cope with the terrain of the target South Pole landing areas, currently relies on a further development of the Russian Marsokhod rover chassis designed for the Mars-98 mission. However, the adaptations needed for lunar operations are numerous and drastic. The control subsystem requires critical developments in terms of miniature navigation sensors (cameras, Sun and star sensors) and onboard software for full, or at least partial, autonomy. The power subsystem faces extreme requirements in terms of low-mass energy storage.

**Conclusions**

The LEDA Assessment Study has shown that it is within the capabilities of ESA, working together with other European agencies, to undertake a lander mission to the Moon early in the 21st Century, and to demonstrate safe and effective landing and surface operations. A number of mission options and critical technologies, for which either a development activity in Europe or procurement from a foreign source is required (e.g. radio-isotope power systems), have not been finalised at this stage. However, the available information concerning the various options and technologies provided by the LEDA study should allow the managements of ESA and the national agencies to generate programmatic directives and to initiate the necessary agreements on cooperative undertakings.

**Acknowledgement**

The authors gratefully acknowledge the substantial contributions of a large number of specialists from ESA's Technical, Scientific, Operations and Administrative Directorates who have participated in the LEDA Assessment Study, and in particular G. Janin, M. Lang, P. Putz and J.-C. Salvignol for their contributions to this article.

# Future Perspectives for Europe in Space

**A. Atzei, K. Pseiner & D. Raitt**
Systems Studies Division, ESTEC, Noordwijk, The Netherlands

**The events of 1989, symbolised by the fall of the Berlin Wall, presented Europe as a whole with its greatest challenge of recent years. The adaptation process to cope with this new continental order has now entered a critical phase and for space activities too the context for current and future plans is changing rapidly for various reasons:**

- **The end of the Cold War has eliminated the principal structuring feature of the international space environment and precipitated a dramatic contraction in defence budgets.**
- **International economic competition has become a central issue in international affairs.**
- **Economic and political constraints now require that space agencies adapt the ambitious plans put forward in the 1980s to the realities of the 1990s and beyond.**

**It was with these factors in mind that in 1993 ESA initiated a study called 'Space 2020', to examine how such issues might impact on space activities in the next 25 years. This article provides an overview of the objectives of 'Space 2020' and the scenarios considered possible at that time, as well as a discussion of some of the areas specifically relevant to the future of European space endeavours.**

## Introduction

ESA's 'Space 2020' study has attempted to provide a programme-independent view of the possibilities and constraints for the European space sector, and for ESA in particular, by interacting with external consultants from all major disciplines to derive a strategic assessment. This independent view is of the utmost importance in covering the complex network of factors influencing future prospects for the space sector.

The 'Space 2020' study constitutes both a projection and an evaluation of potential developments not only in space activities in general, but also within ESA itself, with the objective of anticipating and preparing the possible future infrastructures of a dynamic and efficient Agency with a competitive industrial organisational base.

This objective is the focus of the following questions:

- Can space respond better to the essential needs and aspirations of society?
- Can the space sector support more valuable and competitive services?
- Can the progress of technology, the efficiency of space industry, the visions of space organisations, as well as the political, social and economic awareness of governments, support a strategic and stable long-term development of the space sector?

Answering the above questions calls for an assessment of methodologies and organisational structures that could contribute substantially to a visible improvement in efficiency and thus in the competitivity of space-based services.

## The scenarios

In the first phase of the Space 2020 study, two important scenarios were selected as the reference models for the time horizon chosen: the 'Greater Europe Scenario' and the 'Little Europe Scenario' (see sidebar). Regardless of which of these two scenarios proves to reflect more accurately the situation prevailing by the year 2020, it is expected that the major challenges for the European space sector are likely to stem from the mounting needs for commercial services in the most dynamic regions of the world. There is general agreement that the role of public authorities in the economy will be reduced and that a free market will be the dominant feature of the economic order up to 2020 and beyond.

### Greater Europe Scenario

Around the end of the decade, the European Union will, in principle, have monetary union, convergence of economic policies, an integrated defence system and a common foreign policy.

### Little Europe Scenario

In this scenario, no real progress towards European integration is expected up to the end of the decade, particularly as far as monetary union and the convergence of foreign and defence policies are concerned.

Space activities have so far been driven mainly by the programmes and initiatives of national governments and/or European institutions such as ESA. Sometimes these efforts have been motivated more by national prestige rather than more altruistic goals. In the future, such motivations will gradually fade, with increased cooperation and competition. Companies will come under increasing pressure to find new outlets and applications for their products and services, and this growing dynamism has important implications for the space industry.

For the European space sector, and ESA in particular, the political future of the European Union (EU) will have a major impact. Within a Greater Europe scenario, the space sector would gain additional momentum from an economic as well as from a technological push. ESA could be proposed as an integrative agency not only for the continuation of the existing mandate, but could also evolve to incorporate the former COMECON countries and so extend its international influence with respect to the USA, Russia and the Far East. Furthermore, ESA could strengthen its ties with other countries with fledging space industries in a number of ways.

On the other hand, if no real progress is made towards European integration up to the end of this decade, the space sector will split up into several regional alliances to serve the commercial and national demands. Strong competition from the USA and the Far East would be imposed on the key players and ESA would be faced with permanent struggles for budgets and a limited political consensus on its mandate.

Table 1 shows four scenarios for the European space sector including ESA. Here the two major scenarios of Greater Europe and Little Europe are further subdivided into scenarios for strong economic growth (GNP growth above 3% = low budget constraints) and a scenario assuming low economic growth (GNP growth below 3% = high budget constraints).

## International cooperation vs competition

To remain appropriate, space activities must take place within a new world order of different political, economic, military, social and environmental structures, where sustainable development, quality of life, and stability become paramount. The global, interlinked nature of many of today's problems and possibilities points to international cooperation as the best course.

The objective of international cooperation is not merely the exchange of existing data and information; it is also a medium for the acquisition of new knowledge through a common programme of research in which the different partners agree to pool their intellectual, financial and logistic resources.

Today, space can be considered the epitome of international cooperation – especially where

**Table 1. Scenarios for the European space sector and ESA**

| | GREATER EUROPE - ABOVE 3% GROWTH | GREATER EUROPE - UNDER 3% GROWTH | LITTLE EUROPE - ABOVE 3% GROWTH | LITTLE EUROPE - UNDER 3% GROWTH |
|---|---|---|---|---|
| EXPLORATION (Public funded) | - International cooperation with Europe in the lead<br>- Long term space exploration including a human return to moon/mars<br>- Space as a research lab (e.g. microgravity) | - A human return to moon is excluded<br>- Unmanned missions still in the range of possibilities but strong competition from terrestrial institutes on the available budgets | - Limited to unmanned missions<br>- Space at best as a private lab for closed groups (chemistry, physics, electronics etc.) | - Strong diminishing of expenditure for exploration missions |
| SCIENCE & PUBLIC SERVICES (Public funded) | - Contribution to developing and controlling the new power structures<br>- Europe leads in environmental monitoring, disaster relief, etc.<br>- Emphasis is on "quality of life" together with defense = surveillance | - Some environmental programmes decided by EU<br>- Surveillance organised and dominated by defense<br>- Subsidiarity is the key word | - Only limited survival functions - subsidiarity controlled by a central agency<br>- Defense bilateral<br>- Research for cohesion is the key word | - Scientific missions remain the only "recognised" space activity |
| COMMERCIAL | - The need for "mobility" raises many value added applications for new users<br>- ESA has strong influence on the network | - Demand size is strongly dominated by EU<br>- Organisational principle = subsidiarity | - Many newly emerging self organised users ( cities insurance, etc.)<br>- Private sector uses space eg as Microsoft projects) | - Only few new users (cities, regions, bilateral groups) |
| LAUNCHERS | - New coherent projects (including manned programmes) favour new developments, e.g. upgrading of Ariane 5<br>- New systems concepts emerging | - Europe will try to maintain its market share<br>- Strongly dependent on the demand pull from Asian countries versus their competition | - Search for small private launch facilities (cost per kilo in orbit decisive)<br>- European market share is fragile: some European countries no longer using European launch pads | - Europe loses out depending on the Asia/US competitive success |

*From 'Space 2020 Phase-2, Synthesis Report'* new large and expensive or globally-reaching programmes are concerned. The 'success story' of international cooperation in space is exemplified by Space Science, and the opportunity to develop further international cooperative ventures in space applications of existing and evolving technology has never been better. However, it is by no means certain that a comparable degree of cooperation can be reached in other areas of space activities in the foreseeable future, because of the growing risk of commercial conflicts (e.g. in the telecommunications satellite market). The balance between cooperation and competition is thus subtle and continually evolving.

**Evolution of R&D policy in Europe**

Until the beginning of the 1980s, European policy for science and technology relied on the so-called 'linear model of innovation'. According to this model, financing the upstream process of innovation (basic science) will progressively generate new products, markets and opportunities for growth downstream. Moreover, there was a broadly accepted principle that governments should participate strongly in research funding because of the lack of incentives from the private sector.

Certain areas, such as nuclear and high-energy physics and space activities, were considered 'big science' and thus prime candidates for government funding because they had high fixed costs, results and output were remote from markets, and activities required a high degree of collaboration between countries. While early evaluations of such R&D programmes provided positive evidence for continuing government-funded big-science projects, the situation nowadays is being reconsidered, particularly for space programmes.

Even if some parts of space activities exhibit the features of big science (ever-increasing fixed costs and infrastructure), space is being considered as an activity the essence of which is to integrate a wide range of other activities and technologies – from pure basic research to advanced technical developments. There is thus not only reason to expect spin-off from space projects, but also 'spin-in', i.e. the fact that space should be considered as something that pulls together other activities. To a large extent, it appears that space has hitherto been thought of as a closed sector developing in isolation from other sectors. Future R&D policy for space should correct this assumption and ensure that space activities are open to these other areas.

**Technological breakthroughs**

New technologies are increasingly being developed in all areas. As far as the space segment is concerned, it is widely accepted that the miniaturisation of systems is a vitally important breakthrough which will allow the launch of extremely high performance systems within a reduced envelope in terms of size, mass, power and cost compared with today's systems. Technology advances in the USA have already enabled the miniaturisation of satellites (particularly for science and earth observation), and a target reduction by a factor of ten is planned for the next decade. Several missions will be accomplished using satellites weighing no more than a few tens of kilogrammes by 2020. State-of-the-art technology will permit the development of smaller platforms, as well as smaller instruments. Onboard data compression, fibre optics, lightweight large-capacity recorders, artificial intelligence, etc. will allow flexible mission designs with fast reaction times and improved scientific and operational returns.

In the ground-segment area, technological advances will also embrace both hardware and software. Fibre-optic networks, data-dissemination satellites and information superhighways will revolutionise the distribution and exchange of data, and thus the structure of the value-added service market.

**Access to space**

Present developmental activities for future space launchers (of classical concepts) are targeted towards low-Earth-orbit (LEO) missions. These developments usually go in the direction of capacity improvements by increasing tank sizes, increasing the thrust of the engines, and providing launch-assist strap-on boosters to create 'families' of launchers. There are also a number of hypersonic technology programmes related to aerospace planes in Germany, the UK and the USA. Since several of these concepts are based on technologically-advanced air-breathing hypersonic engines, performance and cost projections are not firm. It can be assumed, however, that the technological problems of hypersonic flight are too difficult to be solved within the next two decades, and thus expectations for commercial satellite launches using novel aerospace planes by the 2020 timeline are low.

The satellite launching market is expected to be even more competitive in the future in that:

- newcomers will enter the market
- communications satellites will experience strong competition from terrestrial fibre-optic networks, and

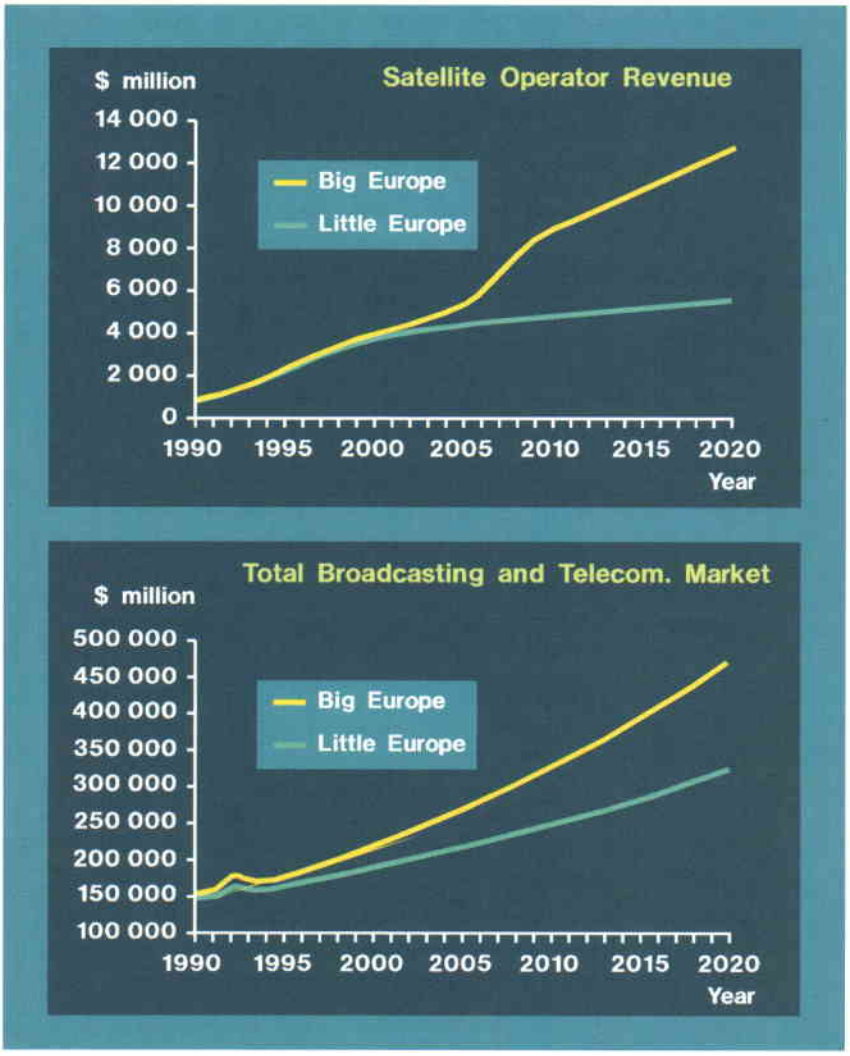
– satellites will have longer operational lifetimes.

An analysis of the present space launch-vehicle situation indicates several important reasons why Europe's Ariane should continue to maintain a large market share:

- an ideal launch location in Kourou
- optimisation for transportation to geostationary transfer orbit (GEO)
- availability of a launcher family
- use of an optimum-sized high-energy upper stage.

Europe's strongest rival for future commercial satellite launch services is likely to be Japan. Russia is seeking financially-strong partners and thus that country can be viewed either as a future rival or a future partner with excellent launchers. China is not seen as a serious rival in the long-term, but does have good launchers and is also looking for cooperation – possibly with Brazil with its optimal launch location. The US launcher fleet needs improvements to its existing models, but this will probably not lead to vehicles superior to Ariane-4/5.

**Figure 1. Total broadcasting and telecommunications market**




**Space science**
Space science is a field that seems to have a more or less permanent base of support from a public interested in learning more about the space frontiers and tantalised and intrigued by the prospect of finding life on other worlds. On the other hand, preoccupation with personal and social problems means that public sympathy for space-science funding is not always as great as it could be. While space-science research has been conducted in universities and research establishments for many years, the creation of space agencies has given rise to other programmes, with a consequent reduction in the amount spent on space-science projects despite the overwhelming successes in this area.

These achievements are, however, no longer sufficient to mobilise enough support in the face of mounting budgetary pressures. The long-term trend, certainly in the USA, seems to be a move away from large expensive space-science missions (only two are currently foreseen within the next ten years) in favour of a greater number of cheaper missions using small spacecraft. This plan is being followed not only by NASA (with its Discovery programme), but also by various universities which are again beginning to take the lead in space science.

In Europe, the Horizon 2000 and Horizon 2000+ Programmes are paving the way for Space 2020 in space science and the relative financial stability of the European programmes means that space science may not suffer from the problems encountered in the USA. However, in the long term, Europe too will require a more cost-effective strategy if it wants its space-science programmes to survive what is thought to be an inevitable decrease in government funding. The trend towards smaller and cheaper space-science missions will also occur in Europe because of the competitive pressure from the rest of the world, where the requisite technologies are already being developed for other applications.

**Space exploration**
It is only through international cooperation and coordination between the various space agencies throughout the world that sufficient resources can be mustered to accomplish the goal of space exploration.

The initial (unmanned) exploration of Mars will require landers, rovers, balloons and a new generation of technologies, since planetary exploration places uniquely stringent constraints on the mass, power and data rate of the equipment used.

Closer to Earth, the Moon also offers opportunities for exploration and scientific utilisation:

- as a research field in itself, to improve our knowledge of the unique Earth – Moon system
- as a laboratory for the development of resources and biological systems, and
- as a platform for astronomy.

A Moon Programme would be based on long-term objectives and on the principle of a phased approach, with international cooperation becoming increasingly important. Its implementation must comply with the availability of financing, starting with small, low-cost, automatic missions and progressing to more complex robotic endeavours, and eventually to manned missions. Such a phased evolutionary approach allows uncertainties over the role of humans in space and the economic utilisation of the Moon to be assessed later, in the light of results from the earlier phases.

**Space and the information society**

The commercial telecommunications satellite market is the most mature of the space markets. It is currently dominated by world and regional systems and by American private operators. Each satellite application has specialised service providers and a particular terrestrial competitor. The frequency spectrum is a scarce resource normally allocated by licence rather than in an open market.

By 2020, however, the present-day communications and media/entertainment industries will have merged in the multimedia revolution. Voice, data and visual-image services are likely to be offered through a single digital distribution system which will be interactive and narrowcast rather than broadcast in nature. Already, many experimental interactive television services are either operational or planned. Key emerging services that appeal to mass users are home shopping, video or movies on demand, tele-banking, sport and games, and mobile services (such as vehicle tracking and communications, and personal communications). It should be noted, however, that the likely focus for multimedia services in European homes is expected to be the personal computer, as opposed to the television set in the United States.

It is apparent that fibre-optic cable will play a major role in the provision of telematic services over the so-called 'information superhighway', though satellites will have a large part to play in feeding cable heads and in remote areas where it is not practical to install cables. The space sector will also have a major role in specific services required across a broad geographical area by end-users in niche markets, for example tele-education and distance learning, tele-medicine and tele-health, home shopping and banking, and interactive TV. The projected total market value of the broadcasting and telecommunications market and the satellite market values in 2020 are shown in Figure 1.

The key issues, then, in the development of the space service sector are a liberalisation of and demand in end-user markets in the information, entertainment and communication fields, and economic growth – both of which lead to a demand for suitable delivery mechanisms. Open access to space segments together with market-based access to orbit, spectrum resources, technological progress and R&D have an affect on the availability, cost and quality of space-based services. The availability, cost and quality of terrestrial cable networked services are also important factors.

In summary, it can be concluded that:

- without improved economic efficiency throughout the European satellite service industry, there will be a progressive loss of competitiveness vis-a-vis alternative delivery mechanisms, such as cable and terrestrial broadcasting
- regulatory change is essential to facilitate improvements in economic efficiency
- improved economic efficiency will allow satellite services to feature much more prominently in the multi-media environment that is expected to be well-established by 2020
- economies of scale and scope will give multifarious service applications the potential to flourish (see Fig. 2).

Space technologies also have enormous potential in the health and medical field. Satellite video-conferencing can be used for long-distance medical diagnosis and keyhole surgery, while remote sensing, geographic information systems and meteorological data transmitted by satellite will be used for assessing the geographical distribution and spread of infectious diseases. Satellite navigation systems will permit a more efficient transport of medical supplies, personnel and patients, while better communications will provide more effective and timely emergency medical services (e.g. the GATES concept in Fig. 3).

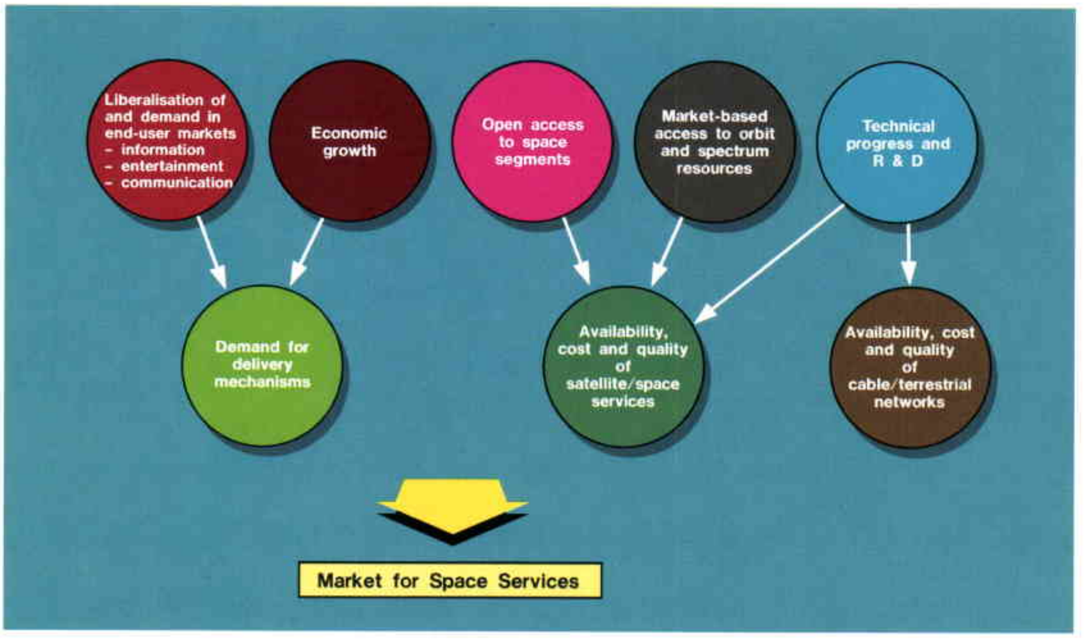



**Figure 2. Key issues in the development of the space service sector**

Satellites can transmit medical, nutritional and agricultural advice to large numbers of people in remote areas. The information can be delivered to those who need it fast, when other means (e.g. land telephone lines) may be poor or even non-existent. It has been shown that in India, for instance, huge advances in knowledge about health and hygiene, family planning and political awareness have been made via educational programmes beamed direct to small villages.

The global navigation systems are expected to be widely used by civilian aviation. For this reason, plans will be put forward to develop a civilian satellite navigation system that can be used internationally. Such a system could be developed and built with international cooperation.

Although one cannot yet fully appreciate the future development of the services made possible by the above information technology, one can expect that new frontiers for applications will open up.

## The prospects for remote sensing

The remote-sensing market is a fast-growing area with nearly triple the number of satellites being launched in the period 1992 – 1996 than in the previous five years. Although the current market value for data is in the order of $200 million, it is increasing by some 20% per year. In the long term, remote-sensing data is expected to be exploited for a wide variety of applications including arms control, environment and climate monitoring, resources exploration, land management and disaster protection.

For too many years, the Earth Observation (EO) communities have been in the situation of 'having a solution and looking for a problem'; i.e. the development of products and services has been driven by technology. This is not unique to EO technology, but it fits the pattern of introduction of most new technologies.

There are a wide range of applications relating to ecological monitoring that remain mostly untouched by remote-sensing technology. Many such applications have been discussed and potentially the biggest is cross-disciplinary and relates to treaty verification/legislation enforcement. Largely untouched at the moment, it is an area with huge potential in which EO can make practical contributions to global problems. More than anything else, the user community (governments, international organisations) still needs convincing of the value of EO data.

Closely related to the above application, the detection and monitoring of major risks (natural and technological disasters) will most likely be on the political agenda even more prominently than today. Disaster monitoring and relief capabilities may well be a major requirement for future satellite constellations.

User education and environmental awareness, and easy access to data coupled with fast delivery, are also sure to be deemed important.

## Conclusion

In recent years, it has become evident that the space community has to prepare for new challenges, both in technical areas and in the commercial sectors. Space is expected to start

## The Trends

The trends highlighted below represent a condensed summary of the major issues addressed during the Space 2020 study:

- No matter which of the scenarios proves to reflect the situation by the year 2020 more accurately, it is expected that the major challenges for the European space sector and ESA are likely to stem from the mounting needs for commercial services in the most dynamic regions of the globe. There is general agreement that the role of public authorities in the economy will be reduced and that a free market will be the dominant feature of the economic organisation up to 2020 and beyond.

- The future cooperation with the European Union (EU) will depend: on the need for greater market drive in space; on the synergy, or lack of it, between civil and military space activity; and on the political organisation of space in Europe. Working agreements with the EU will evolve (including industry and international operators) to support the development of the European informatics/telematics infrastructure and the locating network for global transportation.

- The potential for international cooperation will rely strongly on the similarity of problems which can result in the adoption of a common approach in technology applications; the nature of problems which often transcend national boundaries; the pooling of resources which could avoid duplication of effort; and the wish to increase cost benefits and to contribute jointly to sustainable development.

- In advanced and complex economies, innovation appears more as a 'demand-pull' process or even as an interactive process relying on continuous feedback between different steps in the process. Thus basic space research can no longer be considered separately from the demand side. Technology advances in the USA have enabled miniaturisation of the size and mass of satellites (particularly for science and earth observation) and a target reduction by a factor of ten is planned for the next decade. Several missions will be accomplished using satellites weighing no more than a few tens of kilos by 2020.

- The long-term trend seems to be a move away from large expensive space missions in favour of a greater number of cheaper missions based on small spacecraft. Europe will require a more cost-effective strategy if it wants its space programmes to survive what is thought to be an inevitable decrease in government funding. The trend towards small and cheap space missions will also occur in Europe because of competitive pressure from the rest of the world, which is already developing the required technologies for other applications.

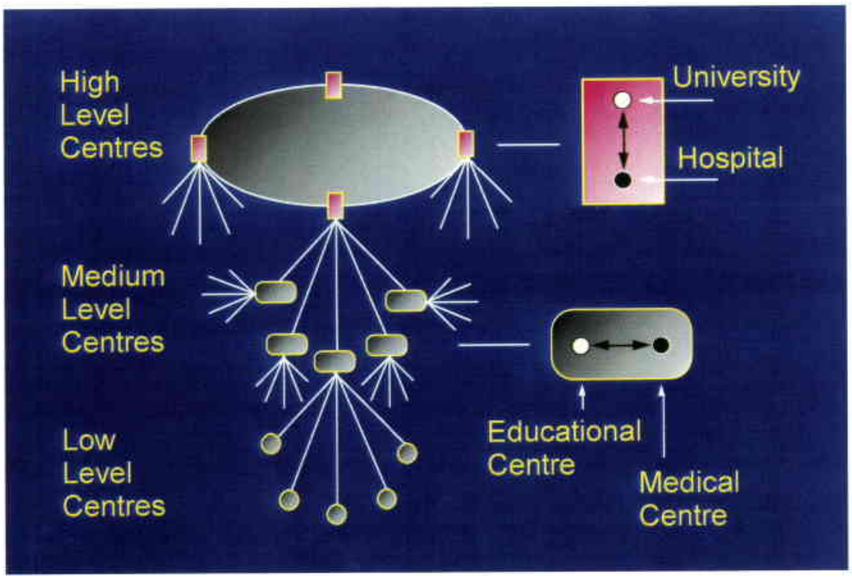
- Europe's strongest rival for future commercial satellite launch services is likely to be Japan. Russia is seeking financially-strong partners and can thus be viewed either as a future rival or a future partner with excellent launchers. The technological problems of hypersonic flight are considered too difficult to be solved within the next two decades, and thus expectations for commercial satellite launches using novel aerospace planes by the 2020 timeline are low. Nevertheless, technological research funding will support future launchers specially targeted to serve low Earth orbit (LEO) at competitive prices.

- Without improved economic efficiency throughout the European satellite-service industry, there will be a progressive loss of competitiveness vis-a-vis alternative delivery mechanisms, such as cable and terrestrial broadcasting. Regulatory change is essential to facilitate improvements in economic efficiency. The latter will allow satellite services to feature much more prominently in the multi-media environment that is expected to be well-established by 2020. Economies of scale and scope will give multifarious service applications the potential to flourish.

- Considering the present evolution in technologies and products, it is expected that by 2020 public-supported earth-observation programmes will mostly be concerned with science and defence, while all other applications, whether operational or commercial, will in the main be privately run. Yet to be established environmental policies (executed via the newly founded European Environmental Agency) will lead to a demand pull for space-based monitoring services.

- Substantial technological progress will be achieved (especially from terrestrial expertise) in miniaturisation, automation and high-level simulation (including virtual-reality applications), as well as in the field of added-value techniques for remote-sensing data.

- Modularisation, standardisation, miniaturisation and intelligent software will characterise future satellite engineering. The introduction of mass-market components will enable the development of 'mass market' LEO turn-key systems at competitive prices. The ground segment will benefit earlier from these mass-market technologies: smart and mobile mini-terminals will further improve, contributing to more efficient utilisation of satellite services. Within this new environment, space commercialisation will have the potential to flourish.



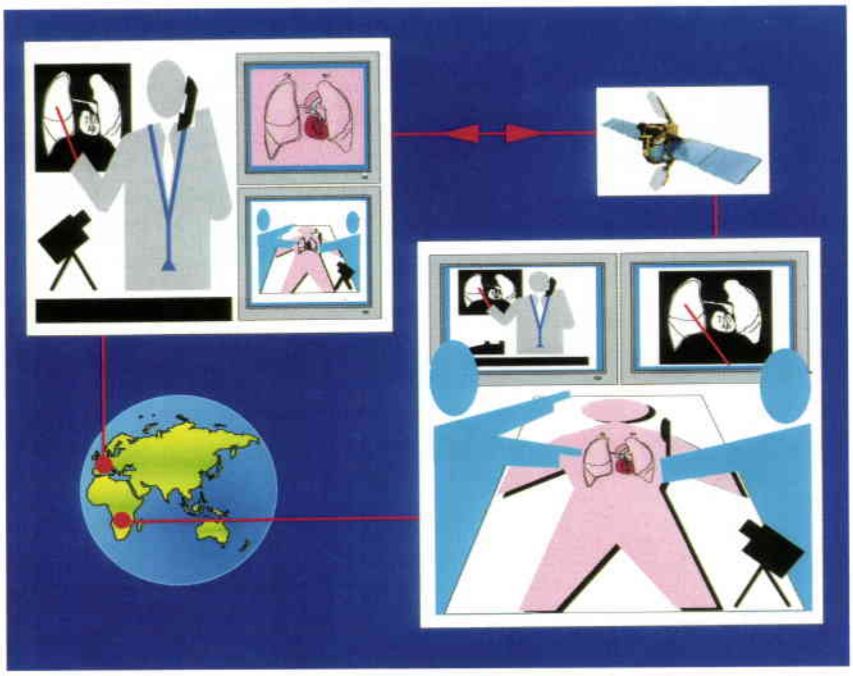



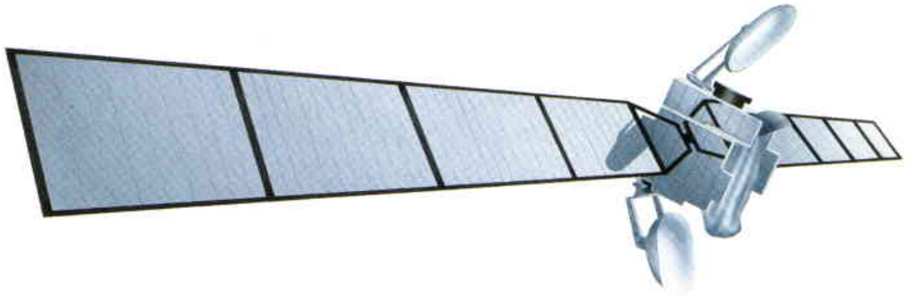
**Figure 3. Tele-medicine scenario (GATES concept)**

the transition from an undisputed government-supported engagement (tele-communications excluded) to a service-on-demand type of business. There are various reasons for this:

- Firstly, the budget deficits of many European governments are at a critical level.
- Secondly, ground-based systems are competing directly with space-based infrastructures.
- Thirdly, it takes too long (especially in Europe) to convert research into applications, then into a real service and finally into a globally competitive service.

The space sector clearly needs innovative ideas and a visionary spirit, to broaden the scope and the destination of space services and at the same time reduce their cost. How can we encourage private investment in economically convincing services? How can public services with more convincing social benefits be provided to governments?

The innovations in technologies and methodologies are emerging as a future challenge for space agencies, industries and operators. The technological challenges lie primarily in low-cost launchers and low-cost autonomous spacecraft, probably much smaller in size and benefiting from commercial mass-market technologies, as already evident in the computer, automobile and communications sectors. Technology transfer, synergy and cooperation are certainly key factors for achieving 'more with less' at the global level. It is likely, however, that in order to make space more accessible for both public and private operators, some kind of technical and cultural revolution has to take place. Therefore there has to be a systematic effort to explore innovative concepts and the frontiers of technological research. In addition, the problems of funding of research and development – by both the governmental and private sectors – have also to be addressed in a spirit of mutual trust and cooperation.



# Three Missions, Three Launches, Six Spacecraft for Science in 1995

**J. Credland, F. Felici, M. Grensemann & J.A. Steinz**
ESA Directorate of Scientific Programmes, ESTEC, Noordwijk, The Netherlands

**If everything goes according to plan – and there are no indications to the contrary so far – the second half of this year will see an unprecedented series of events in ESA's Scientific Programme. Three launches are scheduled in the period September to November, sending a total of six scientific spacecraft into orbit around planet Earth to explore its magnetosphere, the Sun and the infrared radiation sources deep in outer space.**

**These missions will demonstrate the high technical standards of ESA and European Space Industry, the desire of European scientists to explore the Universe with their state-of-the-art instrumentation, and the merits of successful cooperation with other international space agencies such as NASA and Japan's Institute of Space and Astronautical Sciences (ISAS).**

## Introduction

The first mission 'to go' will be the Infrared Space Observatory (ISO), launch of which is scheduled for September 1995. With its scientific instruments cooled to the temperature of superfluid helium, ISO will observe the heat radiation from very weak celestial sources out to extreme extragalactic distances. Launch will take place from Kourou in French Guiana, on an Ariane 44P rocket.

This launch will be followed by that of the Solar and Heliospheric Observatory (SOHO) at the end of October 1995. SOHO will be placed into a halo orbit around the first Lagrangian point, between the Earth and the Sun, about 1.5 million km from Earth. This special orbit will be ideal for the mission's scientific objective of continuous study of the Sun, including the solar corona, the solar wind and the solar interior structure. Being a cooperative programme with NASA, SOHO will be put into orbit from the Kennedy Space Center in Florida by an Atlas Centaur IIAS launcher.

The year will be rounded off with another major highlight for the Scientific Programme with the launch of the Cluster mission: for the first time in the Agency's history, four identical scientific spacecraft will be put into orbit by a single launcher. It will be the first qualification flight (V501) of Europe's biggest launcher, Ariane-5, that will carry the four Cluster satellites into space. The four spacecraft will fly in formation in a near-polar orbit, in one of the most ambitious space missions attempted so far. They will chart, in three dimensions, the tenuous plasma structures that fill the Earth's immediate space environment.

## The Infrared Space Observatory (ISO)

### The mission

ISO, the Infrared Space Observatory, is a telescope facility to be placed in orbit around the Earth for use by astronomers in Europe, the USA and Japan to make scientific observations of very weak celestial sources of heat radiation (Fig. 1). The observatory has to be put in space to avoid the Earth's atmosphere, as it masks almost all of the weak infrared radiation from space. ISO will be used to study a very large variety of infrared radiation sources in every field of astronomy from solar system objects, through the birth and death of stars, to the most distant extragalactic sources.

The first major step in this direction was taken with the Infrared Astronomical Satellite (IRAS), which surveyed almost the entire sky in the 8 – 120 micron wavelength range in 1983. Compared with IRAS, ISO will have a longer operational time, wider wavelength coverage (2.5 – 200 microns), better angular resolution, more sophisticated instruments, and a sensitivity gain of several orders of magnitude. Most importantly, ISO will be operated as an observatory, able to point to specific objects in space and observe them continuously.

The ISO mission was approved by ESA's Science Programme Committee (SPC) in March 1983. The design and development phase of the project started in early 1987. The project is currently in the final system-testing phase and is getting ready for the launch from Kourou in September.

The satellite will be operated from ESA's Villafranca ground station, near Madrid, for at least 18 months. A second ground station, at

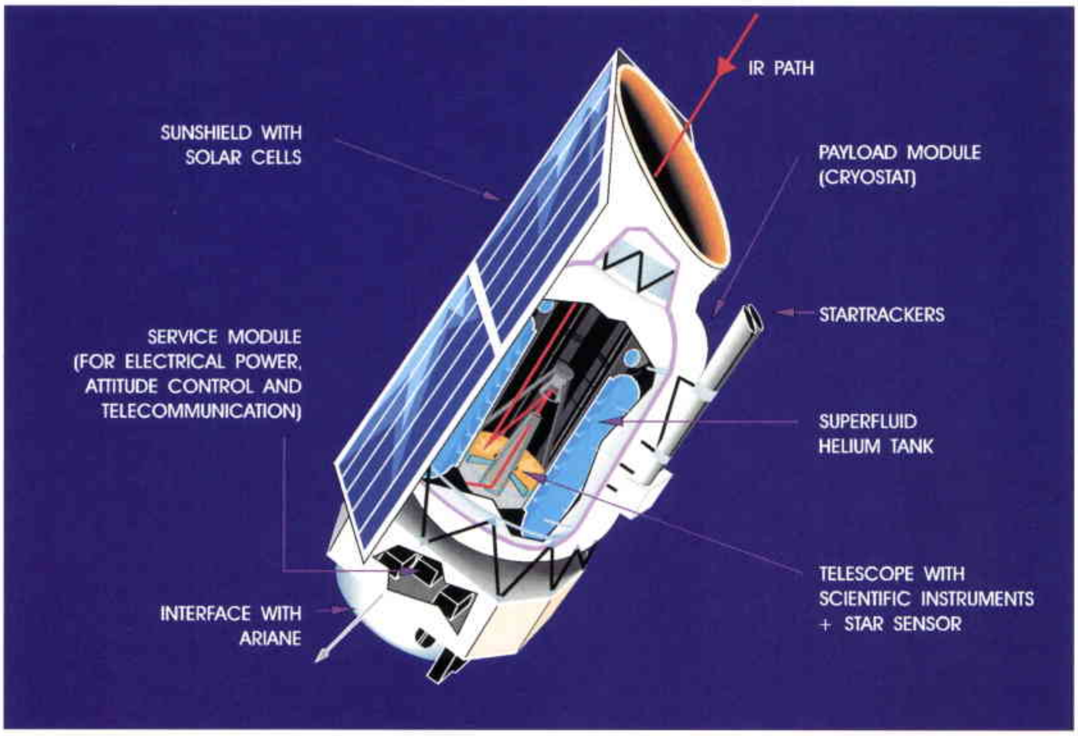



**Figure 1. Configuration of the ISO satellite**

Goldstone in the USA, will be used to relay telecommands and telemetry for some time each day.

## The spacecraft

The spacecraft has to provide an extremely cold environment for the telescope and its instruments to detect and measure extremely weak heat sources. In the case of ISO, this is done by placing both the instruments and the telescope in a large, thermally insulated vacuum vessel filled with superfluid helium at a temperature of less than 2 K (about −271 °C). The helium slowly evaporates to provide the necessary cooling, and is vented to space. The initial volume of helium in the tank therefore determines the satellite's lifetime.

The spacecraft consists of a payload module (the upper cylindrical part in Fig. 1) and the service module (below) with its interface to the Ariane launch vehicle. The main characteristics of the ISO spacecraft are summarised in Table 1. Figure 2 shows the flight-model spacecraft during testing at ESTEC.

*Table 1. ISO spacecraft characteristics*

| | | |
|---|---|---|
| Dimensions: | height | 5.3 m |
| | width | 3.5 m |
| Total mass | | 2500 kg |
| Superfluid helium (2 K) | | 2100 l |
| Telescope aperture | | 600 mm |
| Pointing accuracy (jitter) | | 2.7 arcsec |
| Electrical power | | 580 W |
| Telemetry rate (S-band) | | 32 kbit/s |

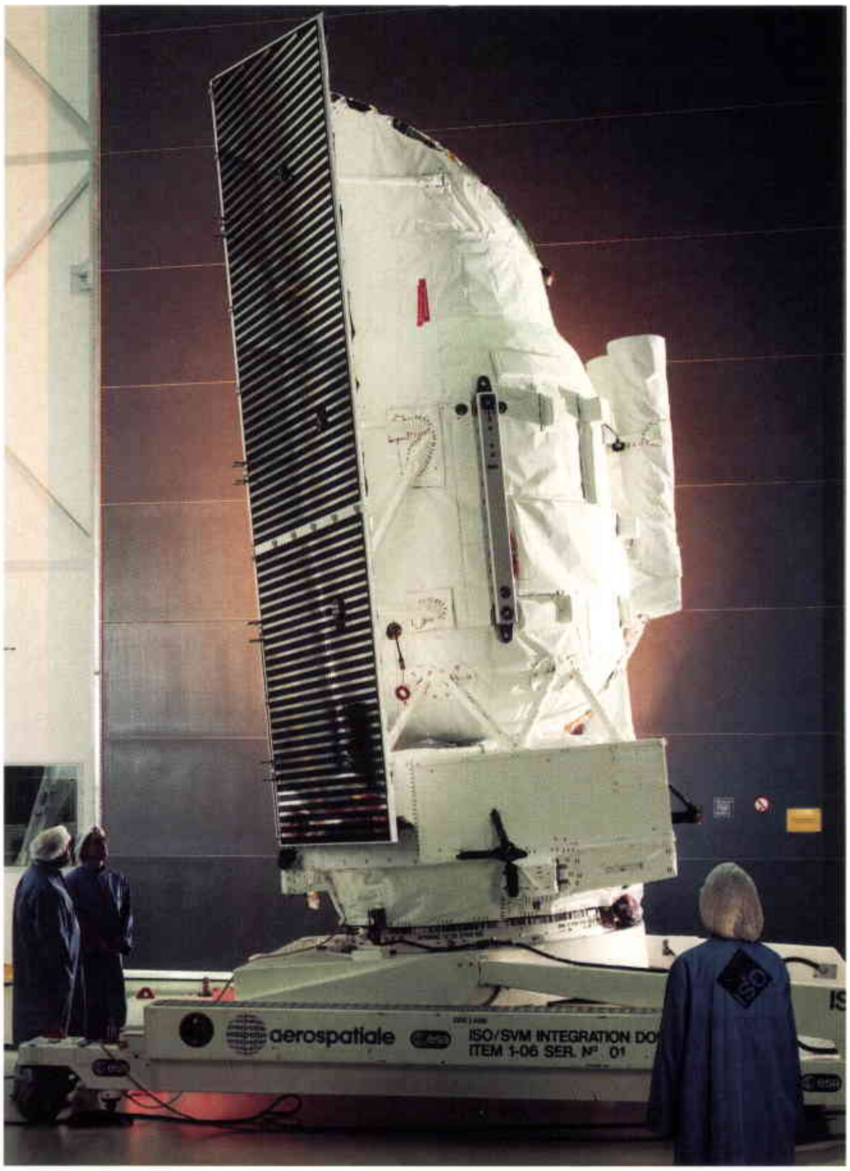



**Figure 2. The ISO flight-model satellite after mechanical/ environmental testing at ESTEC in Noordwijk (NL)**

The payload module is essentially a large cryostat, with a long toroidal tank filled with superfluid helium. In the centre of the cryostat is mounted a 60 cm-diameter telescope. The scientific instruments are mounted behind the telescope's primary mirror. Some instrument detectors are strapped directly to the liquid-helium tank to keep them at very cold temperatures (2 – 4 K). Infrared radiation from an object in space passes through the telescope and into the instruments as indicated by the red arrows in Figure 1. The payload-module cryostat is well-insulated with thermal blankets and the sunshield mounted on the side protects it from direct heating by the Sun.

The service module at the bottom of the spacecraft provides the traditional spacecraft functions, such as power conditioning, data handling, telecommunications and attitude control. The attitude-control subsystem can point the satellite with an accuracy of a few arcseconds. The onboard computer system also provides for safe autonomous satellite operations (in the event of loss of control from the ground) for at least three days. This system ensures that the telescope will never be pointed towards the Sun or the Earth, to avoid damaging the scientific instruments.

The spacecraft design employs very advanced technologies and therefore demanded an extensive development programme, especially for the payload module's cryogenic system and telescope. Special development models of the cryostat and telescope were built and tested. Similarly, the attitude-control system is very complex and its development was also highly demanding. Considerable effort and care were dedicated over several years to the development of these three critical-technology areas in order to solve all potential problems prior to the assembly and testing of the flight-model satellite. The approach taken was very successful: the final flight-model test programme was a great success and was completed on schedule and without any major problems.

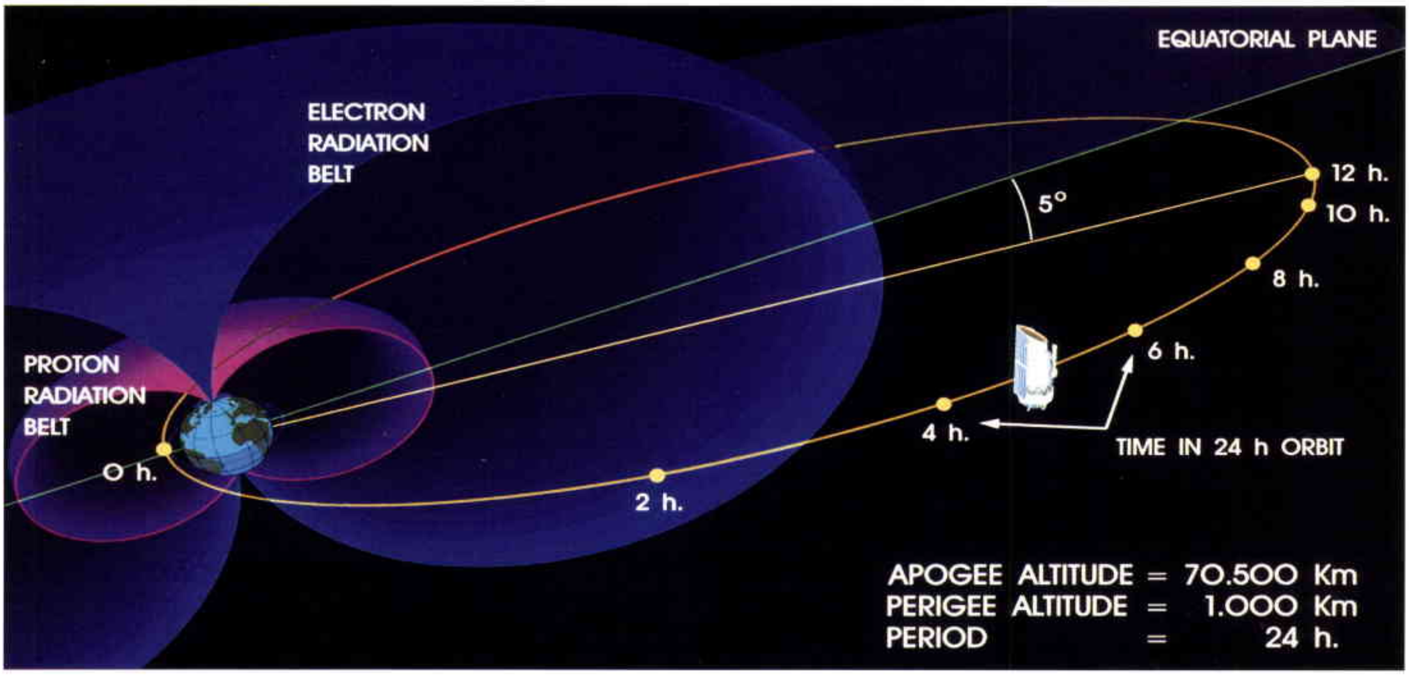
### The scientific instruments

The ISO instrument complement consists of a camera, an imaging photopolarimeter and two spectrometers (Table 2). Each instrument was developed by an international consortium of institutes using national funding, and then delivered to ESA for integration into the satellite. These instruments are all very sophisticated and have been optimised to form a complete, complementary and versatile common-user facility.

*Table 2. ISO scientific instruments*

| Instrument | Wavelength (microns) | |
|---|---|---|
| Camera and polarimetry Isocam, Saclay (F) | 3 – 17 | Two channels 32 × 32 element detector array |
| Imaging photopolarimetry Isophot, Heidelberg (D) | 3 – 200 | (I) Photo-polarimeter (3 – 110 μm)<br>(II) Far-infrared camera (30 – 200 μm)<br>(III) Spectrophotometer (2.5 – 12 μm) |
| Short-wavelength spectrometer SWS, Groningen (NL) | 3 – 45 | Two gratings and two Fabry-Perot interferometers |
| Long-wavelength spectrometer LWS, London (UK) | 45 – 180 | Gratings and two Fabry-Perot interferometers |

**Figure 3. ISO's orbit**



The development of these instruments was also highly challenging and took place over many years, starting before the satellite Phase-B. The result of these efforts is a set of advanced instruments which perform very well in the flight-model satellite, and the scientific community is already eager to exploit them.

### Orbit and operations

ISO will be launched by an Ariane-44P vehicle into transfer orbit and its hydrazine reaction-control system will then be used to attain the operational orbit. This will have a 24 h period, a perigee height of 1000 km, an apogee height of 70 000 km, and an inclination to the equator of 5°. The scientifically useful time in this orbit (Fig. 3) is that spent outside the Earth's radiation belts, namely about 16 h per day. Instrument performance is generally degraded when in the radiation belts, where operations are therefore generally restricted to satellite and instrument setup, etc.

ISO will be operated from ESA's Villafranca ground station, near Madrid, Spain. A second ground station, at Goldstone in California (USA) will be dedicated to ISO under a cooperative agreement with NASA and the Japanese Institute of Space and Astronautical Sciences (ISAS). In return for the support given, both NASA and ISAS may each use ISO for 0.5 h per day. Over one third of ISO's scientifically useful time is guaranteed time for the parties involved in the development of the scientific instruments, and the remaining time is available to the general astronomical community.

The concept for ISO operations is shown in Figure 4. Astronomers submit their proposals, which are screened by peer review groups. Following selection, the full proposals are entered electronically, scheduled taking into account all relevant constraints, and then executed by the satellite, which sends the data that has been gathered to the ground.

The observing programme is currently being established. The guaranteed time, for those scientists involved in the construction and operation of the facility, involves some 13 000 observations. Approximately 1000 proposals for the open time have been received, which have been ranked in order of priority. Some 500 proposals have been recommended, and the average time alloted per proposal is about 6 h; this may entail in the order of several tens of thousands of individual observations. Clearly, there is very high interest in the astronomical community in using ISO.

### Status and outlook

The flight-model satellite, with its scientific instruments, has successfully concluded all of its system environmental tests. The satellite operations interfaces with the ground segment have also been successfully tested. The total satellite and ground-segment system will be finally tested in April before ISO is packed for shipment to Kourou.

All efforts are geared to a successful launch campaign over the summer months for the intended launch in September 1995.

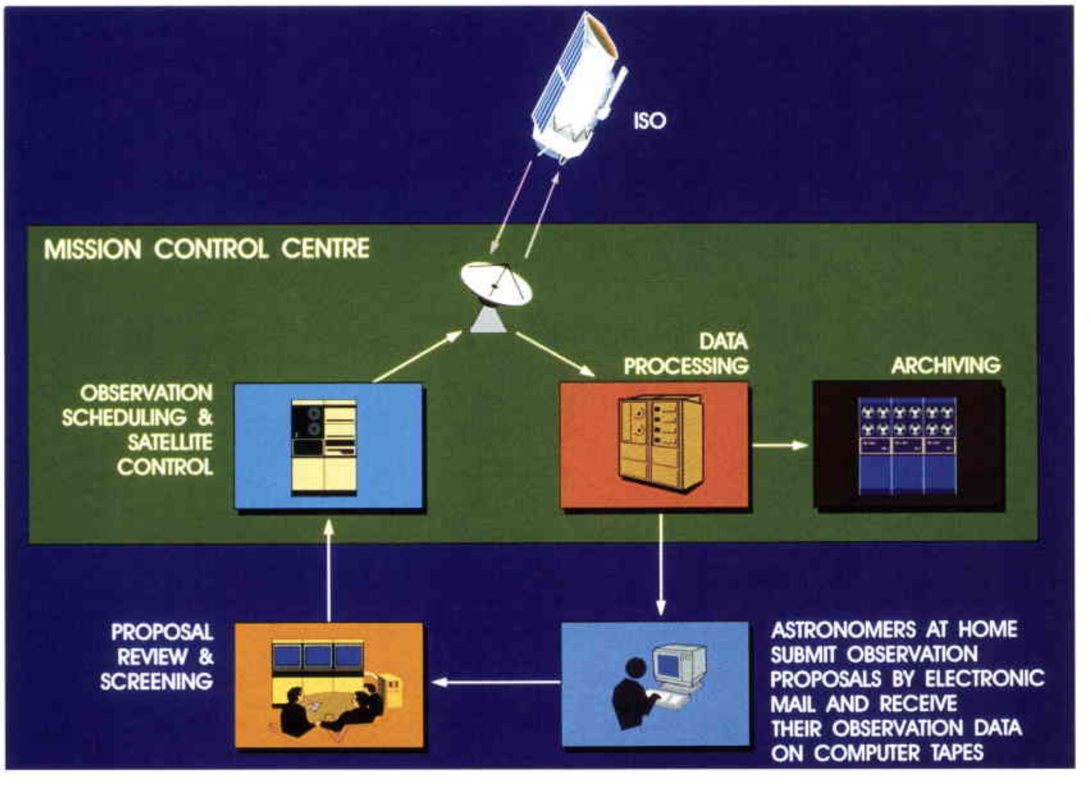



**Figure 4. ISO mission operations concept**

## The Solar and Heliospheric Observatory (SOHO)

### The mission

The Solar and Heliospheric Observatory, or SOHO, is a spacecraft that carries many international experiments to observe the Sun and measure the particles it generates from a special vantage point, the so-called 'Lagrangian first equilibrium point (L1)' between the Earth and the Sun, 1.5 million km from Earth. It will orbit for at least two years (possibly up to six) in a 'halo' orbit around L1, which will allow uninterrupted observation of the daylight star for the first time in solar-physics investigations.

SOHO is one of the two missions – the other being Cluster – making up the Solar Terrestrial Science Programme (STSP), the first 'Cornerstone' of ESA's Horizon 2000 Programme. The SOHO heritage comes from the initial solar missions of OSO and Skylab's Apollo Telescope Mount Mission of the 1970s, which were followed by several European/American proposals (GRIST, DISCO).

The SOHO mission was proposed in 1982 and approved by ESA's Science Programme Committee (SPC) in February 1986. The payload composition was announced, after the selection process, in March 1988; the industrial Phase-B contract was awarded to MMS-F (then Matra Espace) in late 1989; the Phase-C/D contract was kicked-off in May 1991. The launch, planned at mission selection for summer 1995, is foreseen for 30 October this year. The launch vehicle, supplied by NASA, will be an Atlas IIAS, lifting off from Kennedy Space Center in Florida.

ESA retains overall mission responsibility for SOHO and the interfaces with the NASA centres – Goddard Space Flight Center (GSFC), Kennedy Space Center (KSC) and Lewis Research Center (LeRC) – in implementing this responsibility. NASA will in particular implement the operations, SOHO being controlled in this phase from GSFC.

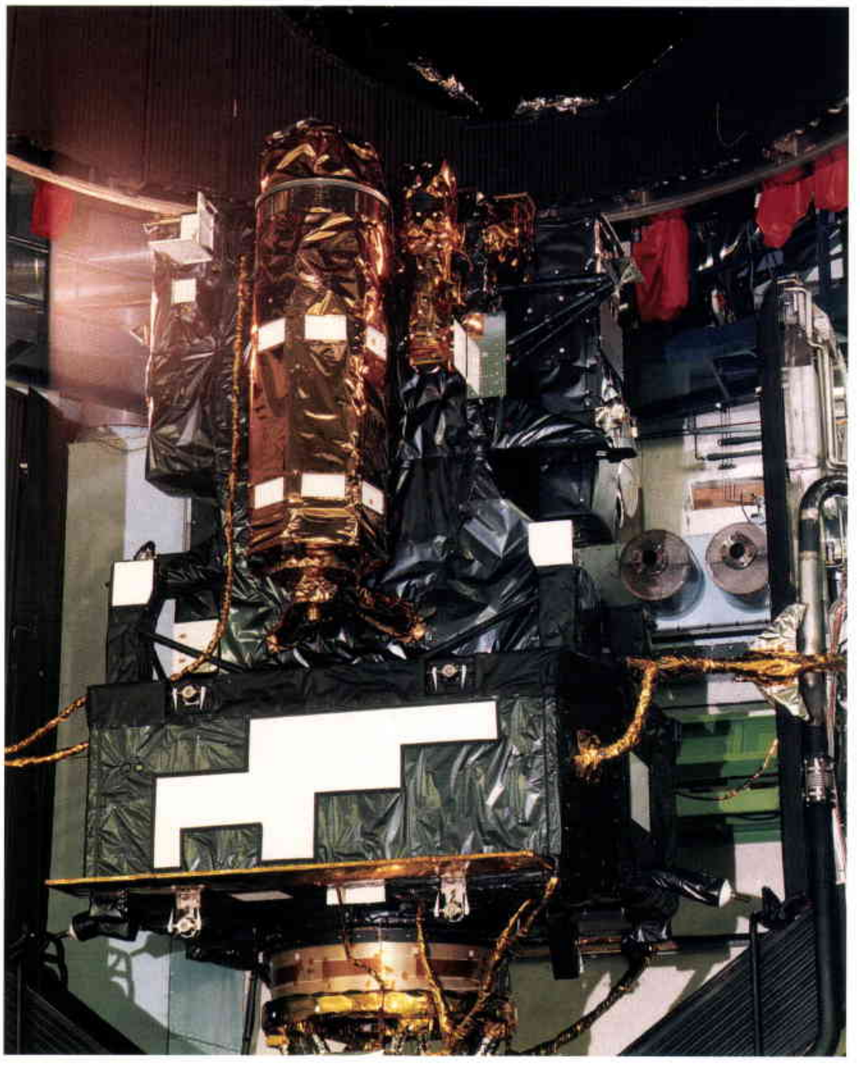


**Figure 5. The complete SOHO spacecraft just before thermal-balance testing at Intespace in Toulouse (F) in December 1994**

### The spacecraft

The SOHO spacecraft in launch configuration will weigh about 1875 kg (Fig. 5 and Table 3). It consists of a lower section, the service module (Fig. 6), which houses all the services and its single large propellant tank containing 235 kg of hydrazine at launch. The upper section is the payload module (Fig. 7), around which all instruments are clustered; the large coronal instruments in particular cover the sides of this module in carefully engineered installations.

Three main elements have driven the design of the satellite: pointing stability, both short- and

*Table 3. SOHO spacecraft characteristics*

| | |
|---|---|
| Launch mass | 1875 kg (650 kg of instruments & 235 kg of propellant) |
| Pointing stability | Three-axis stabilised, Sun-pointing: 1 arcsec stability over 1.5 min<br>10 arcsec stability over 6 months |
| Power | 1500 W from solar cells<br>950 Wh from NiCd batteries |
| Telemetry | S-band<br>220 kbit/s down-link<br>1 Gbit storage capability |
| Lifetime | 2 years |
| Operations | Deep Space Network (NASA)<br>GSFC Control Centre<br>48 h autonomy with no ground contact |

long-term; modularity, to allow maximum parallel processing for the service module and the payload module with its extremely complex and heavy payload; and finally cost and schedule. The uniquely stable thermal environment in the operational halo orbit has allowed aluminium-alloy structures to be used also for the payload module, which supports the large optical instruments. A finely tunable thermal-control system provides an overall platform stability of 1 arcsec over 15 min (short-term stability) including attitude control contributions, and 10 arcsec over 6 months (absolute stability).

The attitude-control system is principally based on a very accurate fine-pointing Sun sensor for pitch and yaw and two starmappers for roll control. Four reaction wheels allow a long period (8 weeks) of undisturbed operations before momentum off-loading. Both housekeeping telemetry and most scientific data are to be stored onboard on a solid-state recorder (a European development) and a NASA-supplied tape recorder and transmitted to the ground station via the steerable high-gain antenna at the rear of the spacecraft, facing Earth. The solar-array wings will deliver 1.5 kW of power.

Special attention has been paid to minimising all disturbance sources that could lead to high-frequency 'blurring' of the pointing performance. Key sources for possible disturbances (reaction wheels, tape recorders, experiment mechanisms, etc.) have been analysed and balanced as much as possible during the spacecraft's development and correlated with specific measurements on available flight elements.

The system development effort for SOHO has been limited to a structural/engineering model (1993) and a flight model, which underwent the only thermal-vacuum/thermal-balance test of the development programme at the end of last year.

Specific attention has also been paid to the extremely stringent cleanliness requirements, dictated in particular by the presence of ultraviolet optics, both during the assembly and testing of the flight-model spacecraft and for in-orbit operations. This has been achieved on the ground without resorting to specially-built facilities, by applying a careful combination of nitrogen purging, protections (doors) on the most sensitive payload elements, and the use of industry-standard clean rooms and laminar-flow tents (at MMS-F, MMS-UK and Intespace).

**Figure 6. The SOHO service module entering the SIMLES solar-simulation facility at Intespace in Toulouse (F)**

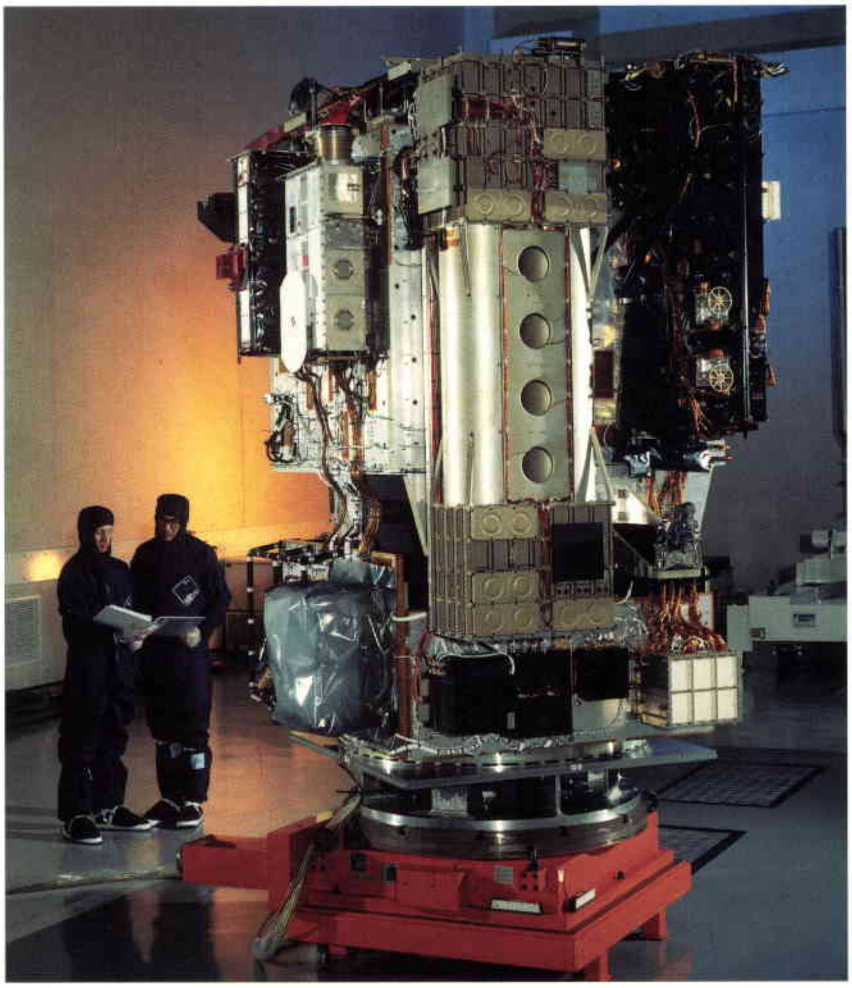


**Figure 7. The SOHO payload module, without thermal blankets, at the end of its integration and testing at MMS in Portsmouth (UK)**

*Table 4. SOHO scientific instruments*

| Scientific Objectives | Instruments | Principal Investigators | Measurements |
|---|---|---|---|
| Solar Atmosphere Remote Sensing | Solar Ultraviolet Emitted Radiation (SUMER) | K. Wilhelm, Max Planck Institute, Germany | Plasma flow characteristics |
| | Coronal Diagnostic Spectrometer (CDS) | B.E. Patchett, Rutherford Appleton Laboratory, UK | Transition region and corona temperature and density |
| | Extreme-Ultraviolet Imaging Telescope (EIT) | J.P. Delaboudinière, IAS/CNRS, France | Evolution of chromospheric and coronal structures |
| | Ultra-Violet Coronograph Spectrometer (UVCS) | J.L. Kohl, Smithsonian Astrophysical Observatory, USA | Electron and ion temperatures, densities and velocities in corona |
| | Large-Angle and Spectrometric Coronograph (LASCO) | G.E. Brueckner, Naval Research Laboratory, USA | Structures evolution, mass, momentum and energy transport in corona |
| | Solar-Wind Anisotropies (SWAN) | J.L. Bertaux, CNRS, France | Solar-wind mass flux anisotropies and temporal variations |
| Solar Wind 'In Situ' | Charge, Element and Isotope Analysis (CELIAS) | D. Hovestadt, Max Planck Institute, Germany | Ionic energy distribution and composition |
| | COSTEP/ERNE Particle Analyser Collaboration (CEPAC) | ENRE: J. Torsti, University of Turku, Finland<br>COSTEP: H.Kunow, University of Kiel, Germany | Energy distribution of particles, energy spectrum and composition |
| Helioseismology | Global Oscillations at Low Frequencies (GOLF) | A. Gabriel, IAS/CNRS, France | Global velocity and magnetic-field oscillations (low degree modes) |
| | Variability of Solar Irradiance and Gravity Oscillations (VIRGO) | C. Froehlich, PMOD/WRC, Switzerland | Irradiance oscillations (low degree modes) and solar constant |
| | Michelson Doppler Imager (MDI) | P.H. Scherrer, Stanford University, USA | Velocity oscillations (high degree modes) |

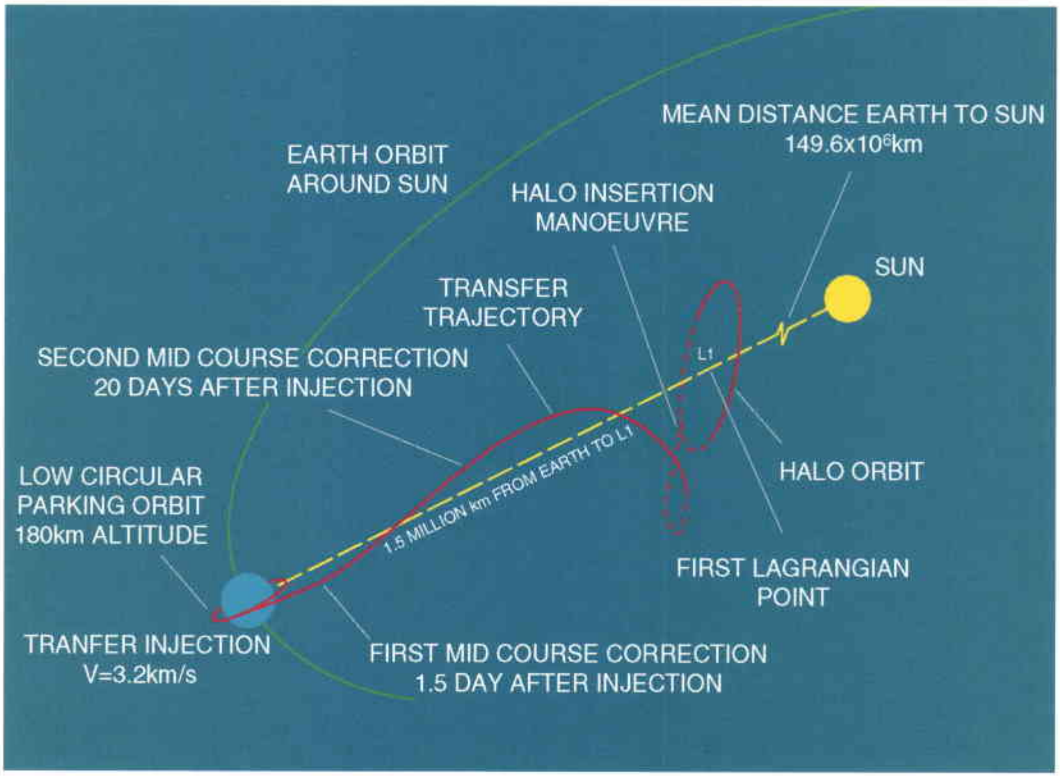



**Figure 8. The SOHO mission phases**

### The scientific instruments

The SOHO payload is by far the most complex and heaviest payload produced so far by a scientific community for an ESA mission, with its 650 kg and 11 state-of-the-art instruments involving 39 international institutes and a total of 33 separate units.

The SOHO payload covers three solar-physics disciplines simultaneously for the first time: investigations of the solar atmosphere, helioseismology and solar-wind in-situ measurements (see Table 4). Through its payload complement, SOHO will be able to offer solar scientists a unique opportunity to examine and understand the structure and dynamics of the interior of the Sun (helioseismology), the chromosphere, transition zone and corona (coronal instruments) and the solar wind which will stream around SOHO a few days after originating at the Sun.

Each experiment has been developed by an international consortium of scientists, funded by their own national bodies, and led by Principal Investigators (PI), three of whom lead the NASA contribution to the scientific payload.

### Orbit and operations

SOHO will be launched by an Atlas IIAS, the most powerful version of the Atlas-Centaur family, and will be injected initially into a low Earth orbit. After a short coast phase of at most 110 min, the Centaur stage will be restarted and will inject SOHO into a transfer orbit towards the Lagrangian point, 1.5 million km from Earth (Figs. 8 & 9). After a four-month transfer phase, the 'halo' orbit will be reached with a further series of manoeuvres before the nominal mission can begin.

In general, one pass of 8 h and two passes of 1.3 h are foreseen with the Deep Space Network (DSN) each day for real-time solar observations and the dumping of data stored on board. For two months each year the DSN coverage will be continuous. An Experiment Operations Facility, headed by the ESA Project Scientist, has been set up at GSFC to host all of the scientific teams involved. There they will operate their experiments in orbit in close coordination with the Flight Operations Team, which will operate the spacecraft.

If the spacecraft's health permits and resources are sufficient at the end of the nominal two-year mission, further mission extensions to up to six years may be considered.

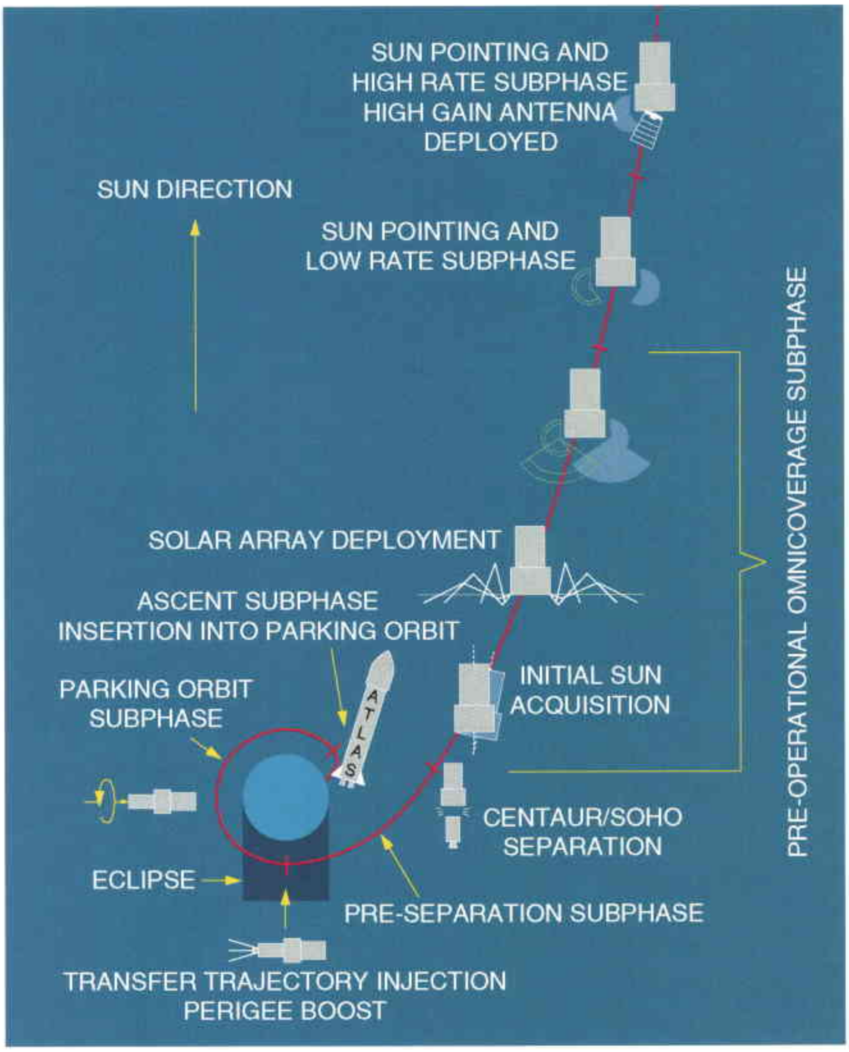



**Figure 9. The SOHO launch and early orbit phases**

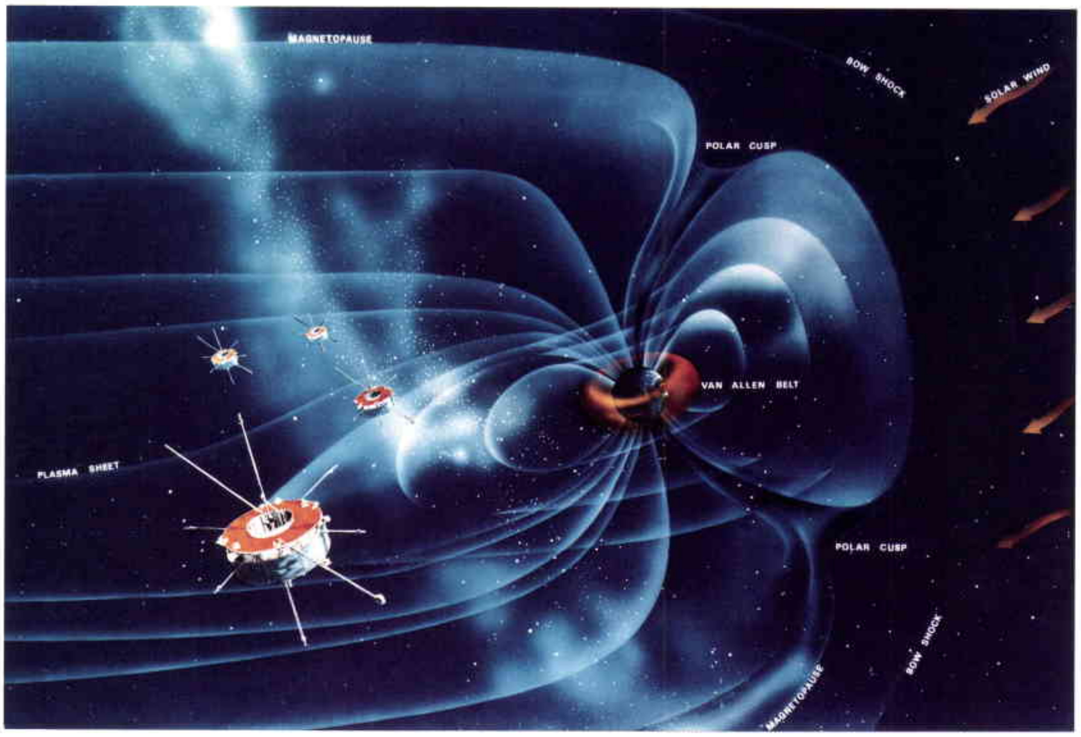
## Cluster

### The mission

Earlier space missions to explore the Earth's magnetosphere have shown how dramatic the interaction can be between near-Earth space and the continuous stream of plasma ejected by the Sun, known as the 'solar wind' (Fig. 10). An incredible range of phenomena have been observed – such as the shorting out of satellite components in orbit, power surges in long transmission lines, and disturbances in short-wave radio broadcasting. Auroras are probably the most spectacular visible manifestation of plasma processes in space.

Cluster will address the structure of electromagnetic fields and the distribution of particles in the solar wind and in the Earth's magnetic field in unprecedented detail. For the first time ever, it will provide the means to investigate the full extent of interesting phenomena in three dimensions. A minimum of four identical spacecraft in carefully designed orbits are required to achieve this, as they must fly in scientifically meaningful configurations. The relative distances between the four spacecraft will be varied between 200 and 18 000 km during the course of the mission (Fig. 11).

Figure 10. The Cluster mission concept

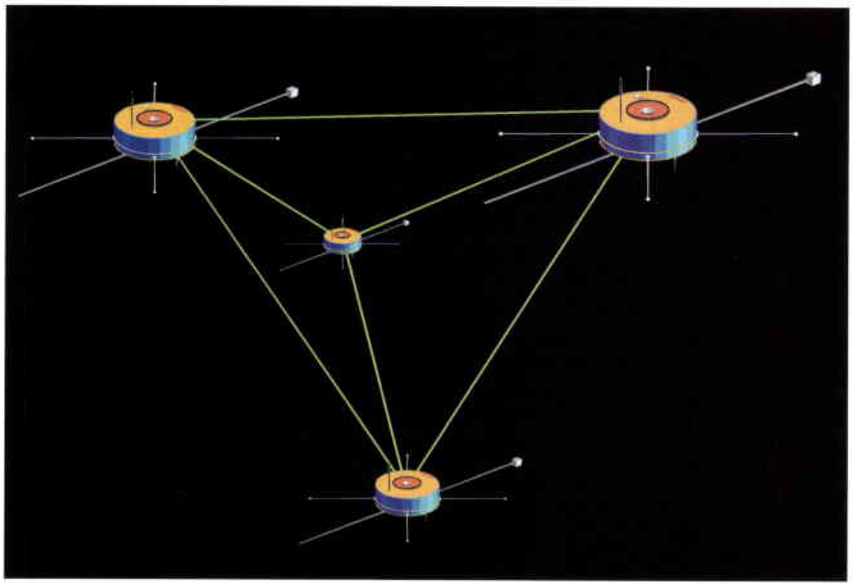



The Cluster project was approved by ESA's Science Programme Committee in February 1986, within the framwork of the Solar Terrestrial Science Programme, together with the SOHO project. The design and development phase started in October 1989. All four spacecraft have now been manufactured and are undergoing final testing, ready to be shipped to the Kourou launch site in July for their November 1995 launch.

### The spacecraft

Each of the four Cluster spacecraft will carry a full complement of state-of-the-art instruments to measure electromagnetic fields and particles. Each payload consists of eleven instruments and includes six booms, four of which are 50 m-long wire booms and the remaining two are rigid 5 m booms (Fig. 12). Active sensors mounted at the tips of the 50 m booms will detect the ambient electric fields. The short booms carry the sensors for the magnetic-field instruments. The remaining instruments are mounted inside the spacecraft's cylindrical body, with their sensors protruding through the outer skin.

Figure 11. Orbital configuration of the four Cluster spacecraft



Each payload will constitute about 72 kg of the spacecraft's 550 kg dry mass, and some 650 kg of onboard fuel will be needed to meet the scientific requirements in terms of orbits and orbital separation manoeuvres. The launcher requirement to carry one satellite on top of another in a dual-launch configuration, and the accommodation of the onboard fuel, represented major design drivers.

Each of the 2.9 m-diameter and 1.3 m-high cylindrical spacecraft will be spin-stabilised. They will be powered by solar arrays covering most of their cylindrical surface. Five batteries will ensure survival during eclipses by powering heaters for the most critical components.

The Cluster spacecraft have been designed and built by a European consortium of space industries, led by Dornier GmbH (D) as Prime Contractor (Fig. 13).

### The launch, ground segment and operations

All four spacecraft will be launched on Ariane-5's maiden flight and delivered into a standard Geostationary Transfer Orbit (GTO). Immediately after their separation from the launch vehicle, the four spacecraft will be controlled from ESA's European Space

Operations Centre (ESOC) in Darmstadt, Germany (Fig. 14). Over the following three-week period, the spacecraft will be transferred from their geostationary transfer orbit into their routine mission orbit.

This transfer will require a total of twenty manoeuvres to bring the satellites from the original 8° Ariane-5 delivery inclination to a 90° inclination, and then finally to the routine elliptical polar orbit (4 x 19.6 $R_E$). A strategy has been developed to manoeuvre and control the four satellites in pairs during this initial phase, and to reach the mission-phase orbit in the desired tetrahedral configuration with predefined separation distances between the spacecraft when crossing the scientific regions of interest. This spatial configuration will be adjusted for different phases of the mission.

Eleven Principal-Investigator teams will be located at ESOC for a two-month period following launch, in order to commission their experiments, a total of 44 instruments. The combined operation of four spacecraft

*Table 5. Cluster spacecraft characteristics*

| | | |
|---|---|---|
| Dimensions | | |
| diameter | 2.9 m | |
| height | 1.3 mm | |
| Launch mass | 1200 kg | |
| payload | 72 kg | |
| spacecraft (dry) | 478 kg | |
| propellant | 650 kg | |
| Power allocated to payload | 47 W | |
| Total available power at EOL | 224 W | |
| Pointing/alignment | 0.25 deg design goal | |
| Spin rate | 15 rpm ± 10% | |
| Rigid radial booms | two, each approx. 4.5 m long | |
| Wire booms | four, each approx. 50 m long | |
| Telemetry rates (kbit/s): | downlink | 'real data' |
| housekeeping data | 2 | 1.7 |
| science data | 22 | 17 |
| tape-recorder dump | 131 | 107 |
| tape-recorder dump | 262 | 214 |
| DSN transmission | 262 | 220 |
| RF output | 3/10 W at HPA, 2/6 W at antenna | |
| Telecommand rate | 2 kbit/s | |

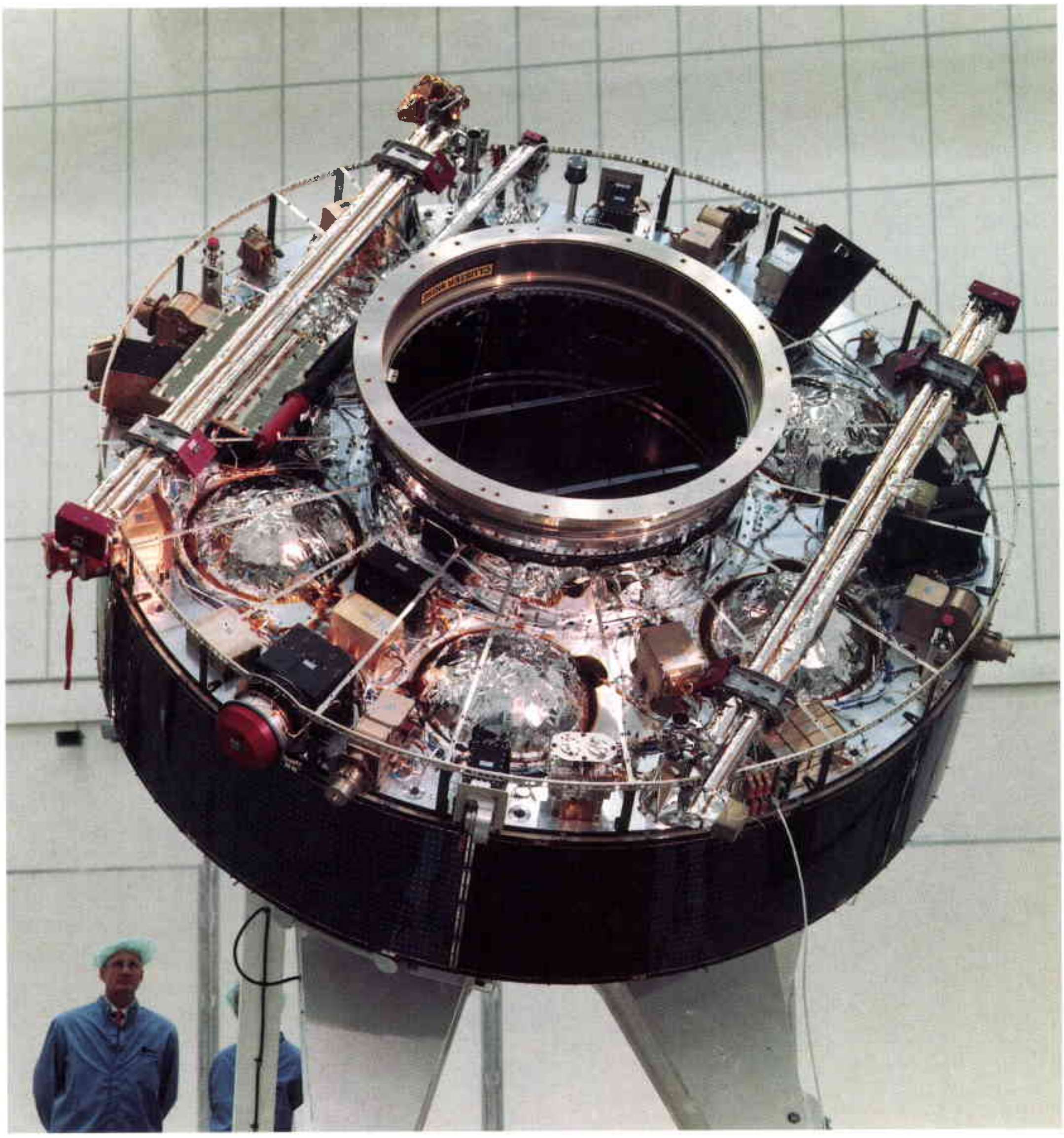


**Figure 12. Cluster flight-model spacecraft number 3**

*Table 6. Cluster scientific instruments*

| Instrument | Principal Investigator | Experiment |
|---|---|---|
| Active Spacecraft Potential Control (ASPOC) | W. Riedler, IFW, Graz (A) | Spacecraft potential control by ion emission |
| Cluster Ion Spectrometry (CIS) | H. Rème, CESR, Toulouse (F) | Ion spectrometry using a composition and distribution functions analyser and a hot ion analyser |
| Electron Drift Instrument (EDI) | G. Paschmann, MPI, Garching (G) | Electron emission and beam return using two gun/detector assemblies |
| Fluxgate Magnetometer (FGM) | A. Balogh, Imp. College, London (UK) | Three-axis fluxgate magnetometers |
| Plasma Electron & Current Analyser (PEACE) | A. Johnstone, Mullard SSL (UK) | High- and low-energy electron analysers |
| Research with Adapt. Particle Imag. Det. (RAPID) | B. Wilken, MPAe, Lindau (G) | Imaging ion mass-spectrometer and imaging electron spectrometer |
| Digital Wave Processor (DWP) | L. Woolliscroft, Univ. Sheffield (UK) | Data compaction and compression, event selection and particle/wave correlation |
| Electric Fields and Waves (EFW) | G. Gustafsson, Uppsala (S) | Two pairs of wire booms, 100 m tip-to-tip, measuring electric field and wave form |
| Spatio-Temporal An. of Field Fluct. (STAFF) | N. Cornilleau-Wehrlin, CRPE, Paris (F) | Three-axis search-coil magnetometer on 5 m boom |
| Wide Band Data (WBD) | D. Gurnett, Univ. Iowa (USA) | Measuring transmission of electric-field wave form up to ca. 100 kHz |
| Waves of High Freq. and Sounder for Probing of Density by Relax. (WHISPER) | P. Decreau, LPCE, Orleans (F) | Sounder to actively measure the total electron density and also the natural plasma |

throughout their in-orbit lifetime (a minimum of 24 months for science product generation) will be performed by ESOC via two ground stations at Redu (B) and Odenwald (D), in conjunction with a Joint Science Operations Centre at RAL (UK) providing scientific mission-planning inputs and command requests originating from the Principal Investigators.

The control concept for the Cluster mission foresees all payload operations being pre-planned and executed from the onboard master schedule, whereby the onboard execution may occur up to 30 h later, because periods with no ground-station coverage can be encountered due to the characteristics of the orbit. For the same reason, data generated

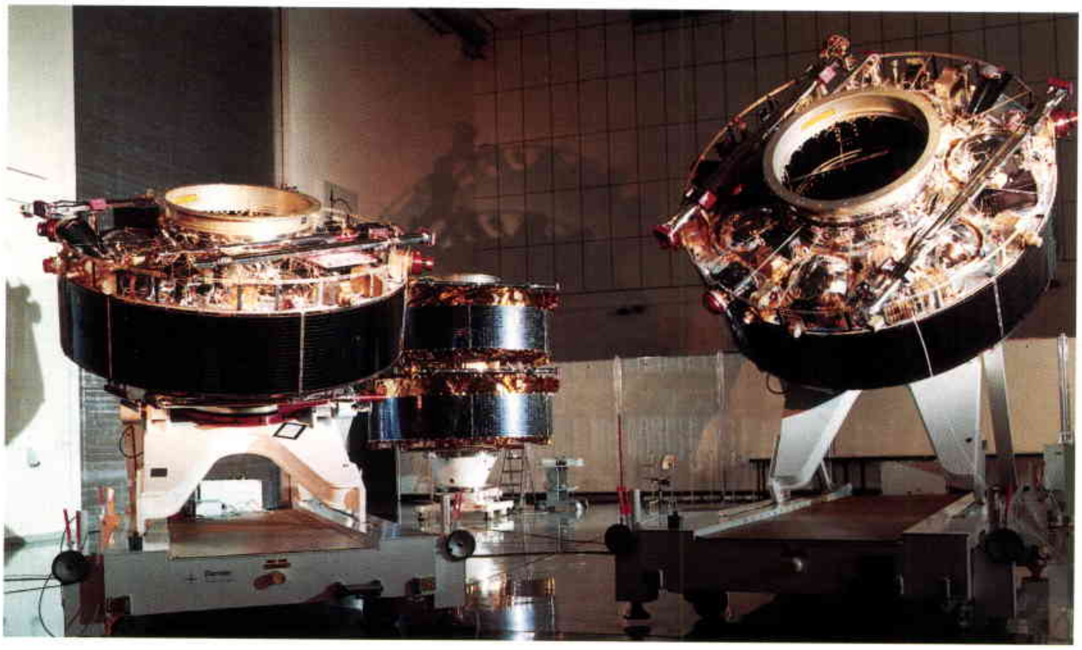


**Figure 13. The four flight-model Cluster spacecraft photographed together at IABG, Munich (D)**

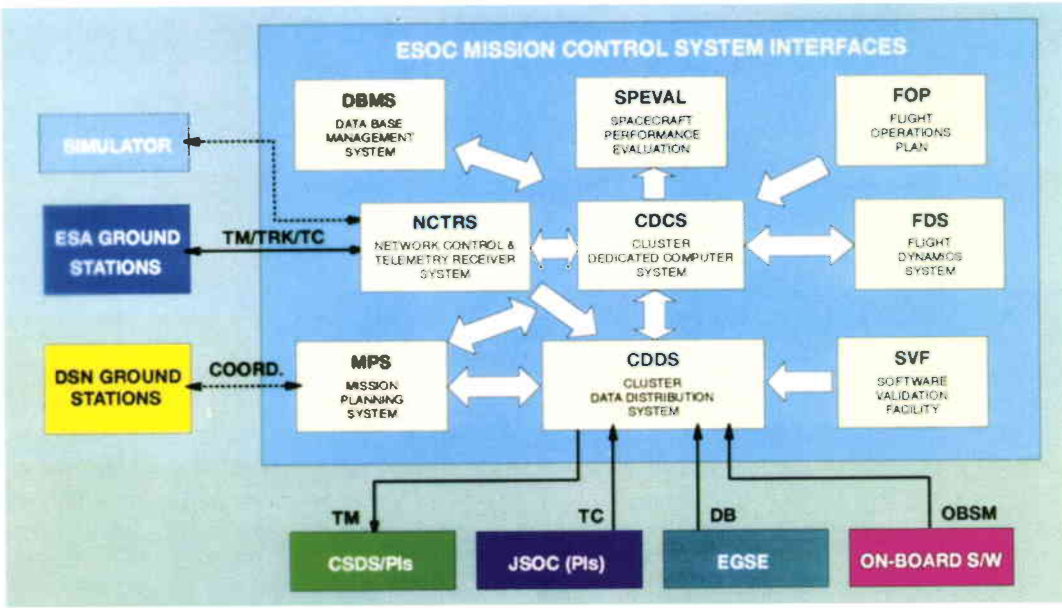



Figure 14. The Cluster mission-control system

onboard are only occasionally directly transmitted to ground (when visibility permits), but will primarily be recorded by the onboard solid-state recorders for dumping to ground at a later time. Upon receipt at the ground station(s), the real-time telemetry data will be sent directly to ESOC, permitting access in near-real-time, whilst the transmission of playback data will occur within 24 h of reception at the ground station.

The scientific data will be distributed on CD-ROM, although the Principal Investigators will also have access to quick-look data via an electronic network.

## The Science Data Centres

Scientific operation of the Cluster spacecraft will be co-ordinated through the Joint Science Operations Centre in the United Kingdom. The commanding of the four payloads and the scientific analysis of the data downlinked from them will be supported by the Cluster Science Data System (Fig. 15). Major national data centres installed in Austria, France, Germany, Hungary, Sweden, the United Kingdom and the United States will be computer-networked to ensure fast and reliable data exchange. A data centre in China will also participate in this data system.

## Expected benefits

The Cluster mission will contribute significantly to our understanding of the complex interaction between the solar wind and our environment here on Earth. In the future, 'space weather' predictions will be important to warn, for instance, operators of telecommunications satellites and power grids of potential problems ensuing from disturbances at Earth which have their origin in explosive releases of energy at the surface of the Sun. Even airlines could be forewarned to avoid exposing their passengers to excessive doses of radiation from space when flying at high geographic latitudes.

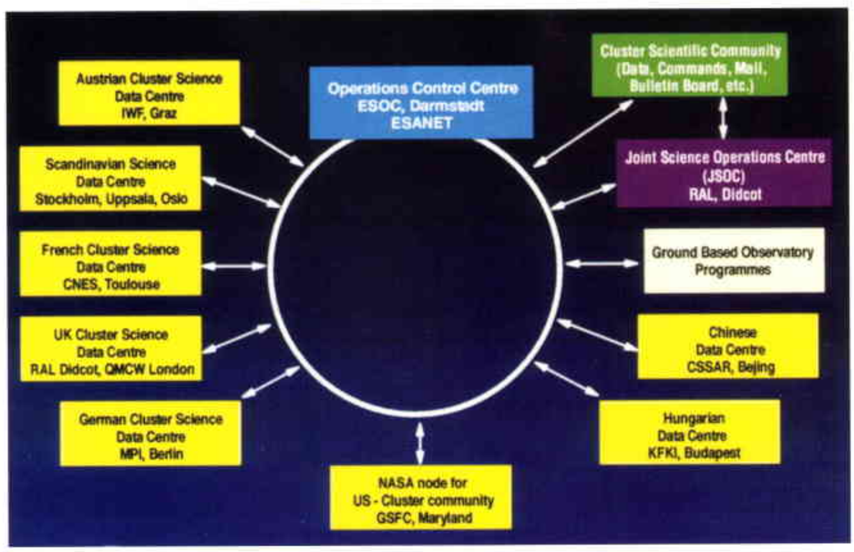



Figure 15. The Cluster Science Data System

## Status and outlook

All four flight-model spacecraft, with their scientific instruments, have successfully concluded all of their system environmental tests. They are now in the process of final refurbishment with the flight sensors for the instruments and will be ready for packing and shipping to Kourou in July. The satellite-operations interfaces with the ground segment have also been successfully tested.

The long launch campaign starts in the summer with final checkout of the payload and subsystems, followed by the filling with more than 2 tons of propellant. Final assembly of the four spacecraft with the launch vehicle will then take place, with launch scheduled for late November 1995.

# Ulysses Explores the South Pole of the Sun

**R.G. Marsden**
Ulysses Project Scientist, ESA Space Science Department,
ESTEC, Noordwijk, The Netherlands

**On 13 September 1994, the joint ESA – NASA Ulysses mission passed a major milestone on its journey of exploration through the 'third dimension' of the Sun's environment, the heliosphere. Nearly four years after its launch by the Space Shuttle 'Discovery', the European-built spacecraft reached the most southerly point on its out-of-ecliptic orbit, 80.2° south of the Sun's equator, at a distance of 2.3 AU (345 million km) from the Sun. Although it will take scientists many months to unravel fully the new and exciting data acquired by Ulysses, several important results have already emerged.**

## Introduction

The international Ulysses mission, a joint undertaking by ESA and NASA, is currently surveying the unexplored region of space above the poles of the Sun. Following a unique trajectory (Fig. 1) that allows it to escape the confines of the ecliptic plane (in which the Earth and most of the planets orbit the Sun), the Ulysses spacecraft and its payload of interplanetary particle and field instruments (listed in Table 1) are returning data of exceptional quality. Data coverage throughout the mission to date has been very high, exceeding 95% on average (Fig. 2). This comprehensive data set, representing one of the most complete records of interplanetary phenomena ever obtained, is enabling scientists to accomplish successfully the primary goal of the mission, namely the first-ever study of the Sun's environment from the equator to the poles.

Even before embarking on the key, out-of-ecliptic phase of its mission, Ulysses had already demonstrated its excellent scientific capabilities. Launched in October 1990 from the Space Shuttle 'Discovery', Ulysses needed a gravity assist by the giant planet Jupiter to achieve its final, high-inclination orbit. En route to Jupiter, Ulysses collected a detailed set of in-ecliptic interplanetary measurements (see ESA Bulletin No. 67), while the two-week passage through Jupiter's magnetosphere in February 1992 also produced new and exciting data (see ESA Bulletin No. 72).

This article focuses on the results obtained during the first high-latitude pass.

## The south polar pass

The launch energy provided by the Space Shuttle and three powerful upper-stage rockets, combined with the gravity-assist manoeuvre at Jupiter, placed the Ulysses spacecraft in a Sun-centred, elliptical orbit inclined at 80° with respect to the Sun's equator. Important design requirements for the mission were to maximise the time spent at high solar latitudes and to achieve the highest possible latitude. Owing to the relative positions of the Earth, Sun and Jupiter at the time of the planetary swingby, a south-going out-of-ecliptic trajectory best met these requirements.

On 26 June 1994, 28 months after leaving Jupiter, Ulysses began its passage over the Sun's southern polar cap. The Ulysses polar passes are defined to be the segments of the trajectory corresponding to solar latitudes greater than or equal to 70° in either hemisphere. The south polar pass lasted 132 days, equivalent to five solar rotations. During this time, the distance from the spacecraft to the Sun decreased from 2.8 to 1.9 AU (1 AU = 150 million km). The spacecraft reached its most southerly point, 80.2° south of the solar equator, on 13 September 1994, at a distance of 2.3 AU from the Sun. An overview of the Ulysses polar passes is presented in Table 2.

## Scientific highlights

### Solar wind and magnetic field

The polar passes of Ulysses take place near the minimum in the current activity cycle of the Sun. The structure of the corona near solar minimum is dominated by the appearance of large coronal holes, cool regions in the Sun's corona, at the north and south poles with relatively few transient disturbances. From remote-sensing observations over many years (utilising, for example, the scintillation of distant radio sources), it was expected that Ulysses would encounter fast solar wind from the coronal holes over the poles. Fast streams of solar wind are also observed in the ecliptic at times when coronal holes extend to low latitudes. Observations from Ulysses, the first ever to be made in-situ in the solar wind flowing from the polar caps, have confirmed this expectation.

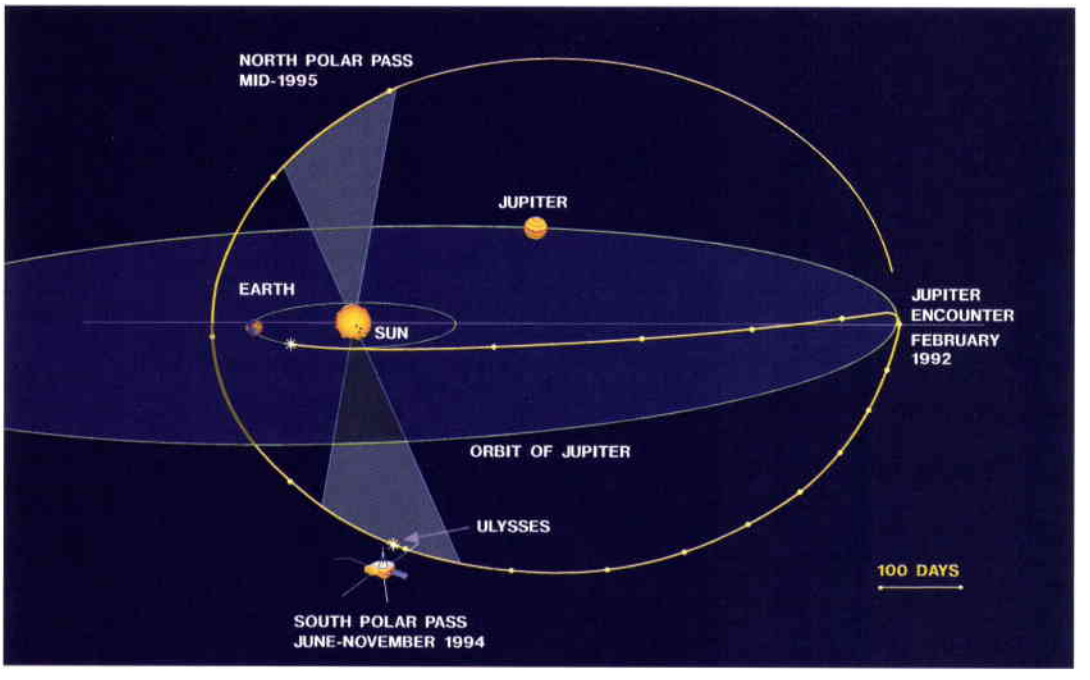



**Figure 1. The Ulysses flight path viewed from 15° above the ecliptic plane. The north and south polar passes, defined to be the segments of the trajectory above 70° solar latitude, and the position of Ulysses at its most southerly point are shown.**

From July 1992 until April 1993, the solar wind flow at Ulysses was dominated by the appearance of a single high-speed stream once per solar rotation, with slower solar wind in between (Fig. 3). The fast stream was traced back to an equatorward extension of the southern polar coronal hole, while the slower wind originated in the so-called 'coronal streamer belt' that encircles the Sun's magnetic equator. Starting in May 1993, this recurrent pattern underwent a change. While the dominant high-speed stream remained visible in the data, the speed of the wind in the inter-stream regions increased, significantly reducing the peak-to-valley excursions. As a consequence of its increasingly southern position at this time, Ulysses was no longer exposed to solar wind from inside the streamer belt, only to wind from the boundary region between the belt and the coronal hole and to fast wind from the hole itself.

Once above 40° latitude, Ulysses became totally immersed in fast solar wind from the polar coronal hole flowing continuously at an average speed of 750 km/s. These conditions

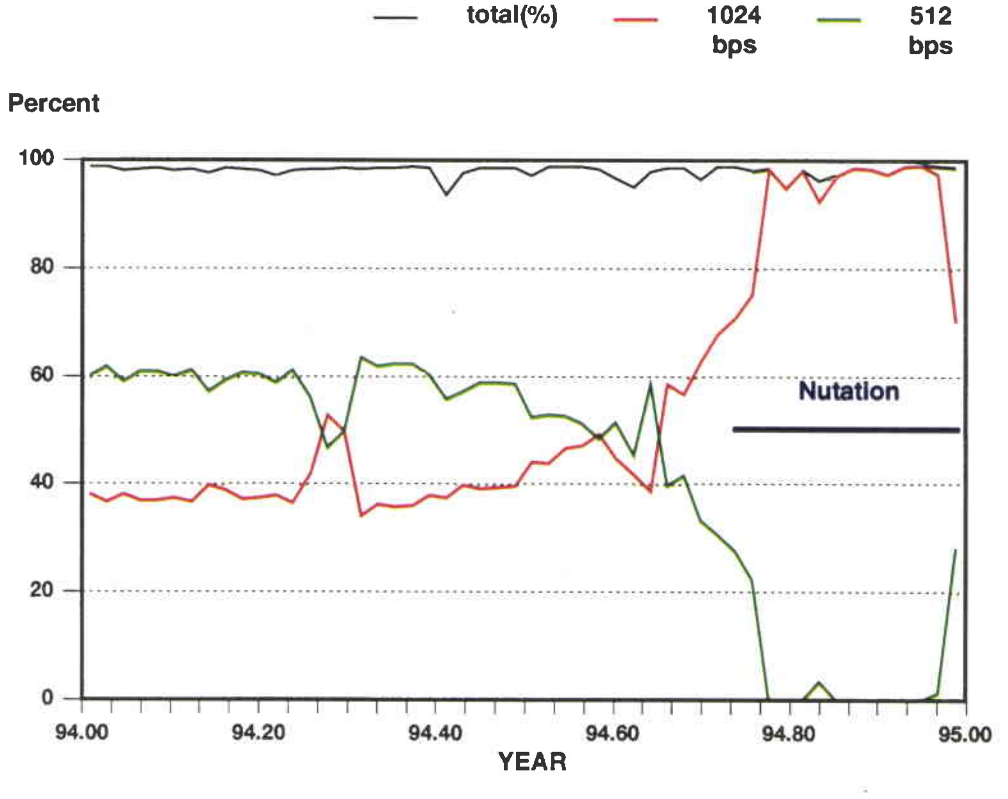



**Figure 2. Data coverage during 1994, showing the percentage of real-time (1024 bit/s) and playback (512 bit/s) data.**

*Table 1. The Ulysses scientific investigations*

| Investigation | Acronym | Principal Investigator | Institute |
|---|---|---|---|
| Magnetic field | VHM/FGM | A. Balogh | Imperial College, London (UK) |
| Solar-wind plasma | SWOOPS | J.L. Phillips | Los Alamos Nat. Lab. (USA) |
| Solar-wind ion composition | SWICS | J. Geiss<br>G. Gloeckler | Univ. of Bern (CH)<br>Univ. of Maryland (USA) |
| Radio and plasma waves | URAP | R.G. Stone | NASA/GSFC (USA) |
| Energetic particles, interstellar neutral gas | EPAC/GAS | E. Keppler | MPAe, Lindau (D) |
| Low-energy Ions and electrons | HI-SCALE | L.J. Lanzerotti | AT&T Bell Labs. (USA) |
| Cosmic rays and solar particles | COSPIN | J.A. Simpson | Univ. of Chicago (USA) |
| Solar X-rays and cosmic gamma-ray bursts | GRB | K. Hurley | UC Berkeley (USA) |
| Cosmic dust | DUST | E. Grün | MPK Heidelberg (D) |
| **Radio science** | | | |
| Coronal sounding | SCE | M.K. Bird | Univ. of Bonn (D) |
| **Interdisciplinary studies** | | | |
| Directional discontinuities | | M. Schulz | Lockheed Palo Alto Res. Lab. (USA) |
| Mass loss and ion composition | | G. Noci | Univ. of Florence (I) |
| Solar wind outflow | | A. Barnes | NASA/ARC (USA) |
| Comets | | J.C. Brandt | Univ. of Colorado (USA) |
| Cosmic rays | | J.R. Jokipii | Univ. of Arizona (USA) |
| Shocks | | C. P. Sonett | Univ. of Arizona (USA) |

*Table 2. Key dates during the Ulysses mission*

| Event | | Year | Mo | Day |
|---|---|---|---|---|
| Launch | | 1990 | 10 | 06 |
| Jupiter flyby | | 1992 | 02 | 08 |
| 1st Polar Pass | start | 1994 | 06 | 26 |
| | max. latitude (80.2°S) | 1994 | 09 | 13 |
| | end | 1994 | 11 | 05 |
| Perihelion | | 1995 | 03 | 12 |
| 2nd Polar Pass | start | 1995 | 06 | 19 |
| | max. latitude (80.2°N) | 1995 | 07 | 31 |
| | end | 1995 | 09 | 29 |
| Start of 2nd Solar Orbit | | 1995 | 10 | 01 |
| 3rd Polar Pass | start | 2000 | 09 | 08 |
| | max. latitude (80.2°S) | 2000 | 11 | 27 |
| | end | 2001 | 01 | 16 |
| Perihelion | | 2001 | 05 | 26 |
| 4th Polar Pass | start | 2001 | 09 | 03 |
| | max. latitude (80.2°N) | 2001 | 10 | 13 |
| | end | 2001 | 12 | 12 |
| End of Mission | | 2001 | 12 | 31 |

persisted throughout the south polar pass, continuing at least up to the end of 1994. However, given the much more rapid change in spacecraft latitude during the pole-to-pole segment of the trajectory than during the intial climb out of the ecliptic, it is to be expected that soon Ulysses will once more encounter a recurrent pattern of fast and slow solar-wind streams similar to that seen at lower latitudes prior to the south polar pass.

The profile of solar-wind speed shown in Figure 3 is a very useful 'road map' of Ulysses' first excursion to high latitudes. Many of the phenomena studied exhibit features that can be related to the same broad regions found in the solar-wind data.

The continuous exposure to fast solar wind over a period of many months has enabled Ulysses to study the characteristics of high-speed flows in unprecedented detail, leading to a very clear understanding of the fundamental differences between fast and slow wind. Fast wind from the poles originates in a region of the solar atmosphere that is several hundred thousand degrees cooler than the 1.8 million degree source region of the slower wind at the equator. Fast wind also has a different chemical composition from slow wind, being richer in elements such as oxygen that are relatively hard to ionise.

Ulysses' measurements at middle latitudes, where both slow and fast wind were sampled once per solar rotation, have also shown that the boundaries between these two kinds of solar wind are quite sharp and well-defined, even at the relatively large distance of Ulysses (Fig. 4). Even more surprising is the degree to

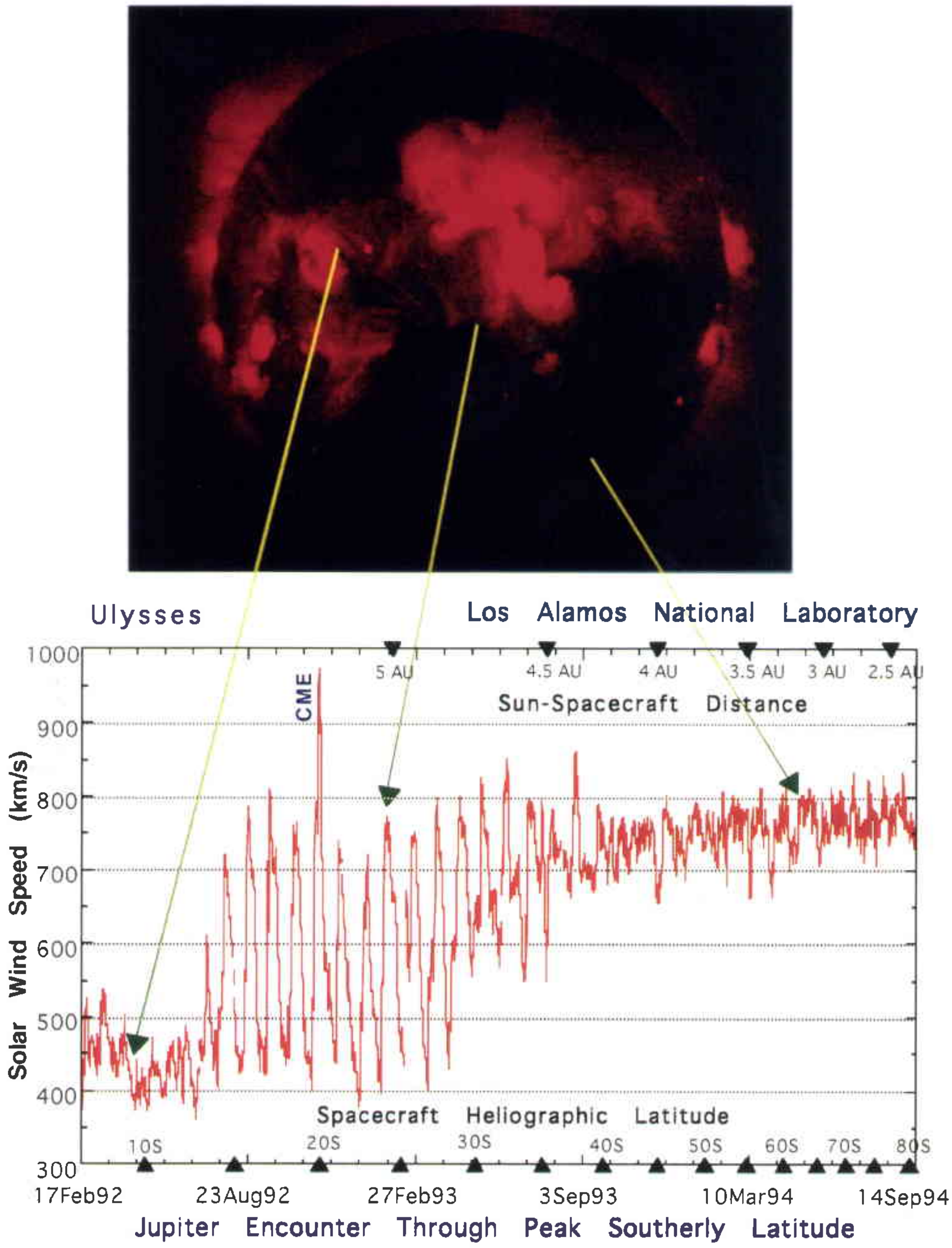



**Figure 3. Solar-wind speed as a function of time and latitude since Jupiter flyby as measured by the SWOOPS experiment on board Ulysses, together with an X-ray image of the Sun from the Japanese Yohkoh satellite (Courtesy of the Los Alamos National Laboratory and ISAS).**

which the 'temperature boundaries' and the 'composition boundaries' observed by Ulysses match, since the former must be established in the corona, whereas the latter are created in the chromosphere, below the solar atmosphere. This apparent relationship between conditions in the corona and processes in the chromosphere is expected eventually to shed light on the still-unanswered question of how the solar wind is created.

A surprising phenomenon identified by the solar-wind plasma experiment on board Ulysses was a new class of so-called 'coronal mass ejections' (CMEs) in the fast-moving solar wind at high latitudes. CMEs are large bubbles of gas, often having masses of $10^{13}$ kg (equivalent to 100 000 large aircraft carriers!), propelled into space from the corona by magnetic forces at the Sun. CMEs near the ecliptic are known to 'plough into' slow solar wind ahead of them, creating a shock wave in the plasma, rather like a supersonic aircraft in the Earth's atmosphere. The high-latitude CMEs observed by Ulysses behave quite differently from their ecliptic cousins. They travel at the same high speed as the polar solar wind in which they are embedded and expand rapidly (apparently as a result of high internal pressure). The rapid expansion of the high-latitude CMEs drives a pair of shock waves, one towards and one away from the Sun. Since it has been demonstrated that CMEs are the main culprits for causing major magnetic storms on Earth (which in turn can disrupt technological systems like electrical power grids and satellites in orbit), it is important to gain a full understanding of these manifestations of the restless Sun.

Observations from Ulysses have confirmed that the large-scale structure of the magnetic field in the polar regions is, on average, organised according to the model predictions made by the 'father' of the solar wind, Prof. Gene Parker, more than three decades ago. In this model, the field is shaped by the combined effects of the solar wind, which carries the field, flowing radially outward, and the rotation of the Sun to which the footpoints of the field lines are anchored (Fig. 5). The field is wound into a spiral which is tighter at the equator than at the poles. There are, however, significant – and in many cases unexpected – variations on all time scales (Fig. 6). Detailed study of these variations, which can be interpreted in terms of a variety of both dynamic and spatial structures in the solar wind, have revealed a striking similarity to features observed on occasion in fast solar wind in the ecliptic and much closer to the Sun (0.3 AU) by the Helios spacecraft. Both sets of observations point to solar-wind plasma that has undergone relatively little change during transit from the Sun. The surprise is that the polar solar wind retains this unevolved character out to distances of 2 AU or more. The observations also suggest that the fast solar wind seen in the ecliptic has its origin at higher latitudes, again indicating the influence of non-radial effects.

A surprising result to emerge from the observations of the heliospheric magnetic field over the poles concerns the strength of the field. It was expected that the Ulysses data acquired at high latitudes would contain evidence of a dipole-like field (similar to a bar magnet) with a clear concentration of magnetic flux corresponding to a south magnetic pole. This expectation was based on an extrapola-

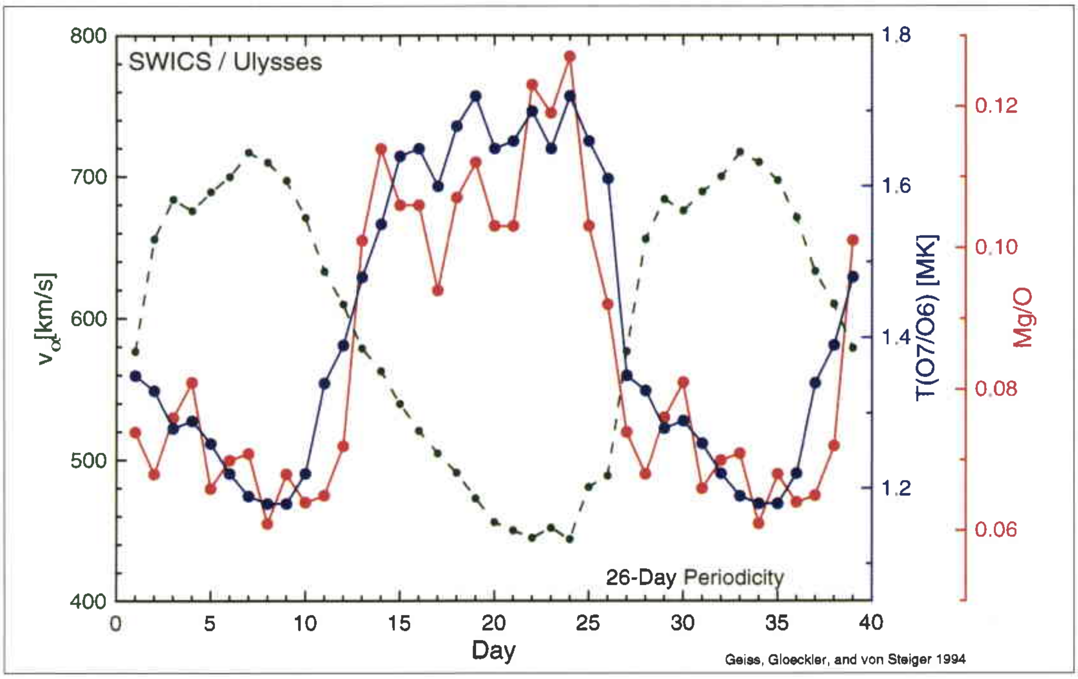



**Figure 4. Data from the SWICS experiment on board Ulysses showing measurements of fast and slow solar wind. Note the correlation between the inferred source temperature in the corona and the relative abundance of magnesium to oxygen, both of which are anti-correlated with solar-wind speed. (Courtesy of J. Geiss, University of Bern)**

tion of the Sun's surface (photospheric) magnetic field, as measured routinely from the Earth using spectroscopic techniques. The surface field at solar minimum clearly resembles a dipole with its axis tilted by 10 – 20° with respect to the Sun's rotation axis. Scientists believed that an imprint of this field would be carried out by the magnetised solar wind. What Ulysses found, however, was a rather uniform field with no concentration of magnetic flux at high latitudes. Clearly, scientists have to re-think their ideas concerning the way in which the Sun's surface magnetism is carried into the solar wind. One possibility is that magnetic stresses acting close to the solar surface are able to redistribute the field.

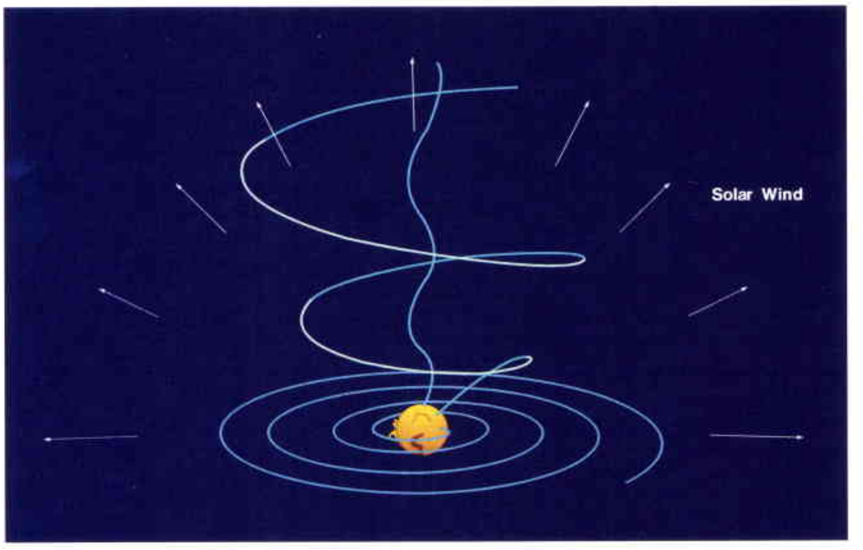



Figure 5. Simplified representation of the heliospheric magnetic field as predicted prior to the Ulysses mission.

## Energetic particles and cosmic rays

Ever since a mission to explore the third heliospheric dimension was conceived, scientists have been intrigued by the possibility of being able to detect a more complete sample of cosmic-ray particles – high-energy nuclei thought to be created in supernova explosions – over the solar poles. The reasoning is rather simple: since the heliospheric magnetic field at the poles is much less tightly wound by solar rotation and presumably less disturbed than near the equator, cosmic-ray particles (which are electrically charged and therefore bound to follow the magnetic field) ought to have an easier access to the inner heliosphere over the poles. In that case, particles entering the heliosphere through such 'cosmic-ray funnels' would reach a solar-polar orbiting spacecraft like Ulysses with very little loss in energy. This in turn would allow scientists to study the properties of the cosmic rays (e.g their composition and energy distribution) over a much broader energy range than is possible in the ecliptic, where the tightly-wound magnetic field and turbulent solar wind form an effective barrier to low-energy cosmic rays.

In fact, although Ulysses detected an increase in the cosmic-ray flux over the south pole compared with the fluxes measured in the ecliptic, the increase was much smaller than expected (Fig. 7), particularly at low energies. It is now thought that the irregularities in the magnetic field seen over the pole are able to scatter the incoming cosmic-ray particles, making the 'funnel' less effective.

A topic of great interest during the first polar pass has been the variation in the energetic-particle fluxes with latitude. Prior to Ulysses, it was generally expected that fluxes of

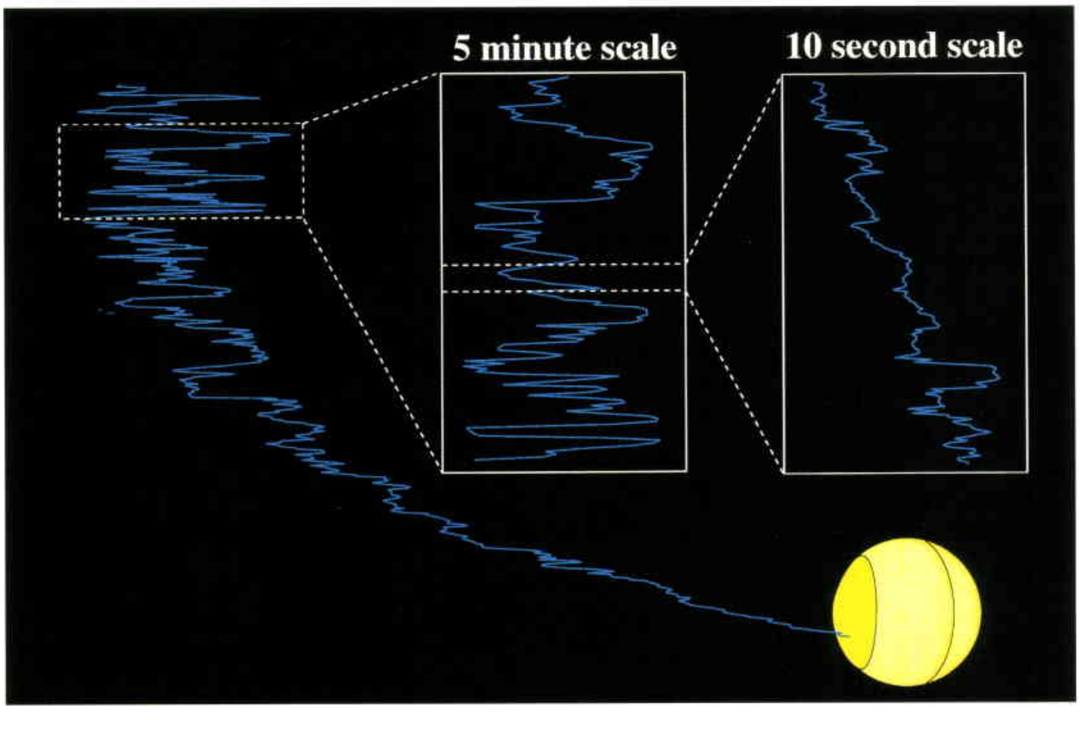



Figure 6. Data from the magnetometer experiment on board Ulysses, showing the high degree of variability in the field measured over the south pole.
(Courtesy of T. Horbury, Imperial College London)

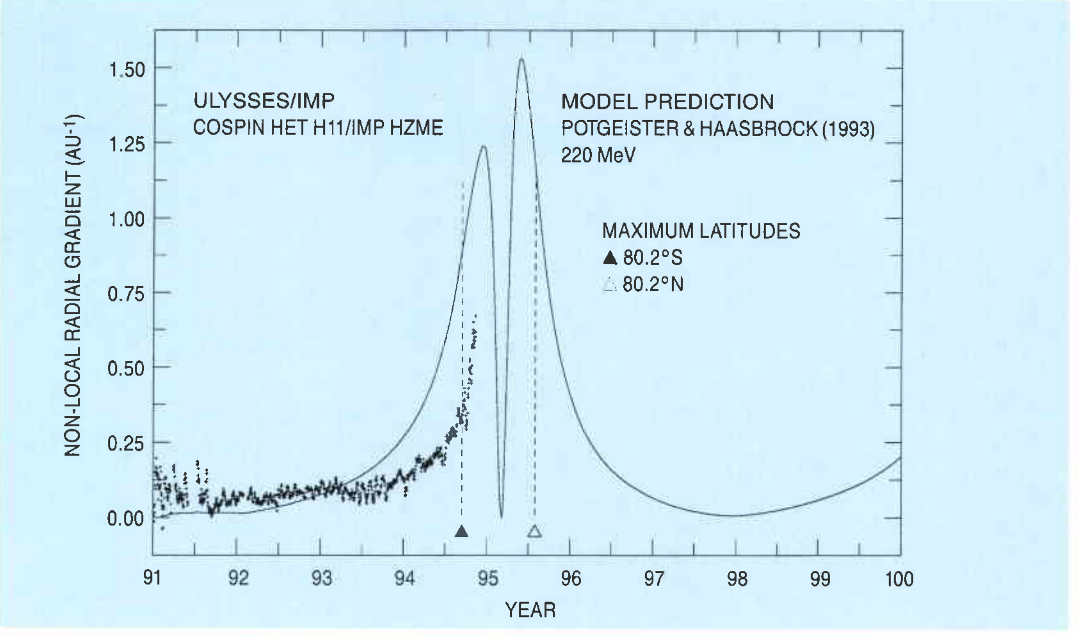



**Figure 7. Cosmic-ray data from the Ulysses/COSPIN HET experiment showing the smaller-than-expected increase in the number of cosmic-ray particles arriving over the south pole compared with model predictions. (Courtesy of R.B. McKibben, University of Chicago)**

solar and interplanetary energetic particles would be low over the poles near solar minimum, principally because of the lack of high-latitude acceleration sites. Surprisingly, the recurrent increases in particle intensity observed at low latitudes in association with corotating shock waves formed by the interaction of long-lived fast and slow solar-wind streams, continued to be seen up to 70° latitude, even though the shocks themselves were not detected at the location of the spacecraft. During the south-polar pass itself, and almost up to the end of the year, the fluxes showed very little variation, remaining essentially at background levels (Fig. 8).

One possible explanation of the Ulysses energetic-particle results is as follows. Co-rotating shocks, i.e. particle acceleration sites, do form at high latitudes, but at greater distances from the Sun than Ulysses. The recurrent flux enhancements observed at moderately high latitudes presumably originated at these more distant locations. However, a source of low-energy particles is also required as input to the acceleration process. An obvious candidate in this regard would be a solar flare. If no solar flare (or other) source is present, the acceleration process will probably be less efficient. In fact, no energetic flares occurred on the Sun during the Ulysses south-polar pass, which would provide one explanation for the lack of recurrent particle increases over the pole. Observations over the north pole will help to substantiate this picture.

### Interstellar ions

Another area of research using Ulysses high-latitude data that has proved to be very fruitful is the study of interstellar pick-up ions. These particles flow into the heliosphere as neutral atoms of interstellar gas, are subsequently ionized, and 'picked up' by the outflowing solar wind. Unique results in this field have been obtained by the solar-wind ion composition spectrometer on board Ulysses

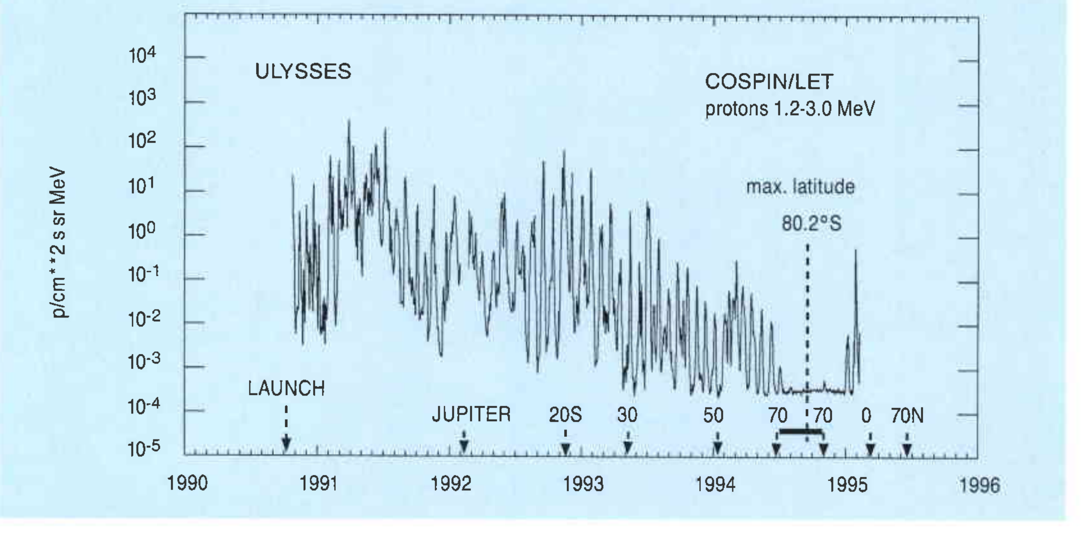



**Figure 8. Energetic-particle data from the Ulysses/COSPIN LET experiment showing the absence of periodic enhancements above 70° latitude during the south polar pass. (Courtesy of T. Sanderson, ESA Space Science Dept.)**

(Fig. 9). Oxygen, nitrogen and neon pick-up ions of interstellar origin have been detected for the first time, permitting estimates of the relative atomic abundances of the interstellar gas. In addition, by using simultaneous measurements of the fluxes of doubly-ionized helium of both solar-wind and interstellar-pick-up origin, a new method has recently been developed for determining the absolute abundance of neutral helium in the local interstellar medium. Preliminary analysis indicates a value close to 0.01 atoms/cm$^3$.

**The future**

Having crossed the ecliptic, Ulysses is now en route to the north polar regions, which it will begin to explore on 19 June. Given the wealth of new data – and several unexpected puzzles – that have been generated during the exploration of the south pole, the Ulysses investigators are eager to see what surprises are in store above the Sun's north pole. Whatever is found, Ulysses has already altered our view of the heliosphere for ever.

Looking even further ahead, the prospects for continuing the mission after the north polar pass are very good. The ESA Science Programme Committee has approved the Agency's participation in the mission until 2001, corresponding to a full second orbit of the Sun. NASA has also expressed its intention to continue the mission, on the understanding that the NASA budget-approval procedures operate on a shorter-term basis than in ESA.

A technical evaluation has shown that the spacecraft is capable of operating until the end of 2001, albeit with certain constraints during the last few months of its lifetime. The limiting factor is the power output of the radioisotope thermoelectric generator (RTG), which will have decreased to the point where it can no longer supply sufficient electrical power to maintain the attitude-control fuel above its freezing point.

Scientifically, the second solar orbit is highly desirable, since the polar passes in 2000 and 2001 (see Fig. 10 and Table 2) will occur when the Sun is at its most active. This will permit scientists to extend their survey of the three-dimensional heliosphere to cover the full range of solar activity conditions.

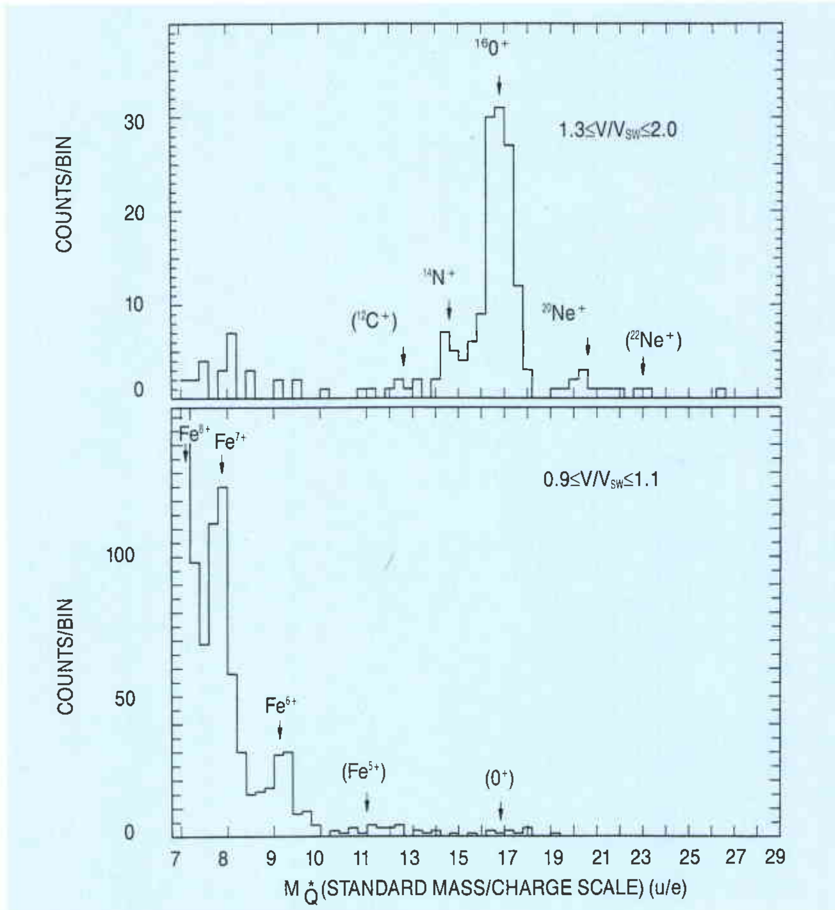



**Figure 9. Interstellar pick-up ions detected by the SWICS experiment on board Ulysses. (Courtesy of J. Geiss, University of Bern, and G. Gloeckler, University of Maryland)**

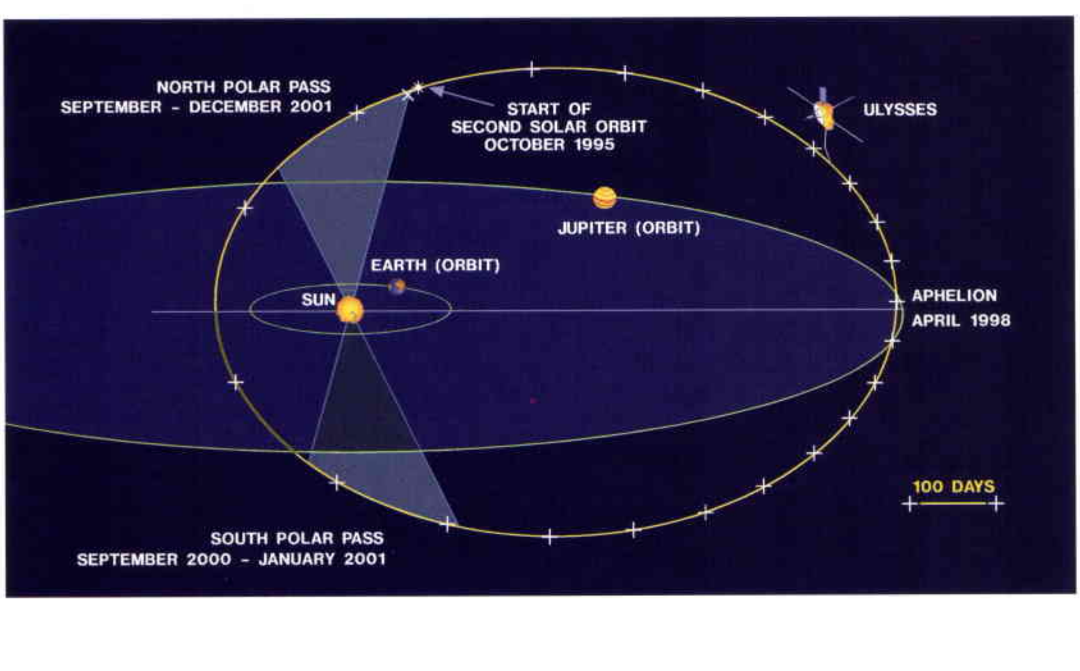
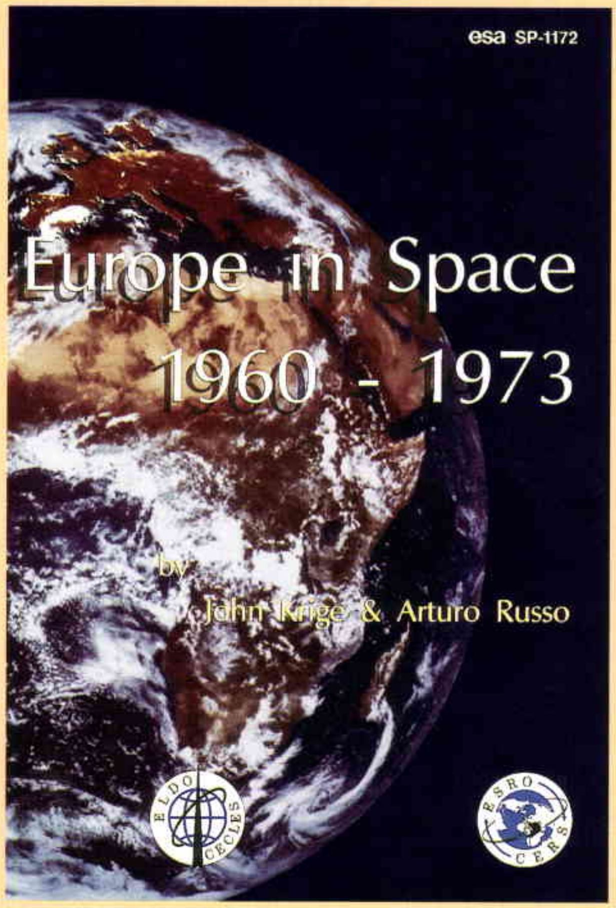



**Figure 10. The flight path of the Ulysses spacecraft during its second orbit of the Sun. Also shown are the polar passes in 2000 and 2001**




## EUROPE IN SPACE 1960 – 1973

***by John Krige & Arturo Russo***

This is the first part of a two-volume history covering Europe's cooperative space efforts, which traces their beginnings from the late 1950s and the subsequent developments of a European space programme from that time up to the early 1970s. It recounts the efforts of the fledgling space community that launched ESRO (the European Space Research Organisation) and ELDO (the European Launcher Development Organisation), with much government support, and shows how those two organisations gradually evolved, and how the foundation was laid for a single European Space Agency.

Drawing on the ESA documentation in the Historical Archives of the European Community at the European University Institute in Florence, and the many interviews with key players involved in the build-up of the European space programme, John Krige and Arturo Russo provide a lively picture of the complex and at times dramatic process of Europe's slow, but determined, efforts in establishing a cooperative space programme.

'This volume provides an important contribution to our understanding of the development of science and technology in postwar Europe. It should thus be of interest not only to those who were directly involved in Europe's fascinating venture into space, the space scientists, and those concerned with the organisation and implementation of the space projects in government and industry, but also to the general public who watched, and simply by virtue of their support became participants in, one of the most remarkable successes of European integration.

I hope that the reader will get a feel for what drove the pioneers in their efforts to set up a European space programme and their enthusiasm for that cause, and will read this fascinating story with a similar sense of attachment and participation as I have read it and look forward to the second volume of the study.'

*Reimar Lüst*
*Chairman of the Advisory Committee to the ESA History Study*

***Europe in Space 1960-1973, ESA SP-1172***

Published by ESA Publications Division
ESTEC, Postbus 229
2200 AG Noordwijk
The Netherlands

Price Dfl 70

esa

# Microgravity Research During Aircraft Parabolic Flights: The 20 ESA Campaigns

**V. Pletser**
Microgravity Projects Division, Manned Spaceflight and Microgravity Directorate, ESTEC, Noordwijk, The Netherlands

**Aircraft parabolic flights provide repeated periods of up to 20 seconds of reduced gravity during ballistic flight manoeuvres, preceded and followed by 20 seconds of 1.8 g. Such flights are used to conduct short microgravity investigations in physical and life sciences, to test instrumentation and to train astronauts before a spaceflight.**

**Since 1984, ESA's Microgravity Projects Division has organised 20 parabolic flight campaigns using three different types of aircraft. More than 1700 parabolas have been flown, representing nine and half hours of microgravity in slices of 20 seconds, or equivalently, six low Earth orbits. A total of 235 experiments have been performed using this unique microgravity tool.**

Some highlights of ESA's parabolic flight campaigns over the past 10 years

- More than 1700 parabolas have been flown, representing approximately 9.5 hours of weightlessness or six low Earth orbits
- Three airplanes have been used in 10 years: the NASA KC-135, the CNES Caravelle and the Russian Ilyushin IL-76 MDK
- 235 experiments have been performed, with an average of 11 experiments per campaign
- More than 1000 scientists and engineers from 20 different countries (the 14 ESA member states, USA, Canada, Japan, Australia, Russia and Poland) have flown
- Astronauts from ESA, NASA, CNES, DLR and the Canadian Space Agency have participated either as pilots, investigators, experiment operators, or subjects for human physiology experiments
- More than 30 European journalists have participated and reported to the public on the research activities.

## Introduction

Aircraft parabolic flights are a useful tool for performing short-duration scientific and technological experiments in reduced gravity. Their greatest value is that they allow verification tests of experiments to be conducted before they are flown in space, in order to improve the experiment's quality and success rate, and after a space mission to confirm or invalidate the sometimes conflicting results obtained from space experiments.

For these purposes, ESA's Microgravity Projects Division has organised 20 parabolic flight campaigns since 1984, within the framework of the ESA Microgravity Programme.

The main advantages of parabolic flights for microgravity investigations are:

- the short turnaround time (typically of a few months between the experiment proposal and its performance)
- the low cost involved (ESA provides the flight opportunity free of charge)
- the flexibility of the experimental approach (laboratory-type instrumentation is most commonly used)
- the possibility of direct intervention by investigators on board the aircraft during and between parabolas
- the ability to modify the experiment set-up between flights.

## Microgravity-providing carriers

Microgravity is created in free-falling carriers when the sum of all forces acting on the carrier, other than gravity, is nil or strongly reduced. Scientific and technological experimentation in microgravity can be conducted in different carriers either on Earth or in orbit. Generating a weightless environment on Earth imposes practical constraints on the level and duration of the microgravity required for investigations and on the cost at which this environment is obtained.

Depending on the carrier's initial velocity, the free-fall trajectory is either linear vertical for drop facilities, parabolic for aircraft flights and sounding rockets, or circular and elliptic for orbital platforms. The characteristics of the different types of microgravity carriers are compared in Table 1.

Aircraft parabolic free-fall flights attain reduced g levels, in the range of $10^{-2}$ to $10^{-3}$ g, with the added advantage of allowing human intervention while the experiment is in progress in reduced gravity. The total available working volume in which reduced gravity is attained can be as large as the aircraft cabin.

*Table 1. Characteristics of microgravity-providing carriers*

| | μ-g level (g) | Duration of μg | Working volume | Human interaction | Preparation time |
|---|---|---|---|---|---|
| *Earth-based facilities* | | | | | |
| Drop facilities | $10^{-3}-10^{-6}$ | max 5 s | $< 1\ m^3$ | indirect | few days |
| Aircraft flights | $10^{-2}-10^{-3}$ | 20 – 25 s | $> 10\ m^3$ | direct | few months |
| Sounding rockets | $10^{-4}-10^{-5}$ | 5 – 7 min | $< 1\ m^3$ | indirect | ≈1 year |
| *Orbital platforms* | | | | | |
| Manned | $10^{-2}-10^{-5}$ | days/years | $> 1\ m^3$ | direct | several years |
| Automatic | $\approx 10^{-5}$ | weeks/months | $> 1\ m^3$ | indirect | several years |

Space missions with sounding rockets and orbiting platforms need relatively long preparation times and must be considered for long-duration experiments. In comparison, aircraft parabolic flights offer the possibility of performing microgravity experiments within 20 to 25 seconds, with a short turnaround time of a few months. Their use must be considered as complementary and preparatory to space missions.

Aircraft parabolic flights are also the only sub-orbital microgravity carrier that provides the opportunity to perform medical experiments on human subjects in real weightlessness, complementing studies conducted in simulated weightlessness, such as immersion and bedrest studies.

**Objectives of parabolic flights**

Parabolic flights provide investigators with a laboratory for scientific experimentation in which the gravity levels change repeatedly, with successive short periods of microgravity and high gravity. ESA and the scientists invited by ESA undertake such flights in pursuit of two objectives: scientific and technical.

*Scientific objectives*

From a scientific point of view, the objectives are as follows:

— To perform short experiments in which the reduced gravity is low enough to allow:
  — qualitative experiments of the 'look and see' type, based on simple ideas and using laboratory-type equipment to observe and record phenomena in microgravity
  — quantitative experiments to measure phenomena in microgravity and yielding direct, quantitative and exploitable results.

— To allow the experimenters themselves to perform their own experiments in microgravity with the ability to intervene directly while the experiment is in progress during the low g periods and to change experiment parameters between the reduced gravity periods.

— To study transient phenomena occurring during the changeover from high to low g and from low to high g phases.

Scientists have identified this last aspect as being one of the major advantages of the experimental environment attainable during aircraft parabolic flights for investigations in several disciplines such as combustion and human physiology.

Furthermore, for scientific experiments that will be performed during space missions, the following goals can be pursued during parabolic flights:

— Preliminary results of a newly proposed experiment can be obtained in order to improve the final design of the experiment hardware.

— The critical phases of an experiment on which the experiment's success depends can be tested.

— For human physiology experiments to be conducted on astronauts in space, a broader microgravity data baseline can be obtained by conducting parts of the experiments on a group of subjects other than the astronauts, either before or after the space mission.

— Parts of experiments that were not fully satisfactory in space or that yielded conflicting results, can be repeated shortly after a space mission to provide indications on how to interprete the results of the space experiment.

*Technical objectives*

With respect to the preparation of experiment hardware for manned or automatic space missions, the following objectives can also be achieved during parabolic flights:

- Equipment hardware can be tested in a microgravity environment.
- The safety aspects of an instrument's operation in microgravity can be assessed.
- Science astronauts can be trained on experiment procedures and instrument operation.

### Types of aircraft used in ESA parabolic flights

Since 1984, ESA has used three different airplanes to conduct its parabolic flight campaigns:

- NASA's KC-135 A (Fig. 1a), operated by the Reduced Gravity Office of the NASA Johnson Space Center
- CNES's Caravelle (Fig. 1b), operated by the French test flight centre, Centre d'Essais en Vol (CEV)
- the Russian Ilyushin IL-76 MDK (Fig. 1c) operated by the Yu. Gagarin Cosmonaut Training Centre (CTC) at Star City, near Moscow.

The characteristics of the three types of aircraft and the locations used during ESA campaigns are compared in Table 2. The ground infrastructure includes a hangar room for equipment set-up and check-out and office rooms for experiment preparation.

The three airplanes have similar parabolic flight profiles and provide a microgravity environment with similar characteristics. The microgravity environment is created in an aircraft flying the following manoeuvres (illustrated in Figure 2 for the Caravelle):

- From a steady horizontal flight, the aircraft climbs at 50° (pull-up) for about 20 s, with an acceleration of 1.8 to 2 g.
- The thrust of all aircraft engines is then strongly reduced for about 20 to 25 s, compensating the effect of air drag (the parabolic free-fall).
- The aircraft dives at 50° (pull-out), accelerating at about 1.8 to 2 g for approximately 20 s, to come back to a steady horizontal flight.

These manoeuvres can be flown either consecutively in a roller-coaster fashion for the KC-135 and the Ilyushin, or separated by intervals of several minutes for the Caravelle, the KC-135 and the Ilyushin. The duration of the intervals between parabolas is determined prior to the flight to give the investigators enough time to change the experimental set-up. A typical flight lasts about two and half hours, allowing for 20 to 40 parabolas to be flown, depending on the requested interval


1a

1b

1c

**Figure 1. The three aircraft used in ESA's 20 parabolic flight campaigns:**

**a. The NASA KC-135 during the pull-up manoeuvre at 45° (Photo: NASA)**

**b. The Caravelle during the pull-up manoeuvre at 50°**

**c. The Ilyushin IL-76 MDK**

*Table 2. Characteristics of the three airplanes used by ESA*

| | KC-135 A | Caravelle | Ilyushin |
|---|---|---|---|
| *Aircraft* | | | |
| Type | 4 engines<br>modified Boeing 707 | 2 engines<br>Caravelle 6R-234 | 4 engines<br>Ilyushin IL-76 MDK |
| Length | 46 m | 32 m | 46.59 m |
| Wing span | 44 m | 34.3 m | 50.50 m |
| Height | 14.10 m | 9.80 m | 14.76 m |
| *Cabin* | | | |
| Size (l × w × h) | 18 × 3.25 × 2 m | 12.5 × 2.7 × 1.9 m | 14.2 × 3.45 × 3.4 m |
| Section | half-circular | half-circular | approx. rectangular |
| Doors | side cargo door<br>1 passenger door | 3 passenger doors | aft cargo door<br>2 passenger doors |
| *Facilities* | | | |
| Electrical power | 110 V 60 Hz | 220 V 50 Hz | 220 V 50 Hz |
| Supply lines | 110 V 400 Hz<br>28 VDC | 220 V 400 Hz<br>28 VDC | 208 V/115 V 400 Hz<br>27 VDC |
| Overboard venting | yes | yes | no |
| Lighting | 20 halogen lamps<br>during parabolas | neon light<br>continuous | 20 halogen lamps<br>during parabolas |
| Padding | on floor and walls | on floor and walls | floor mats |
| *Operated* | | | |
| By | NASA-JSC | CEV | CTC |
| From (for ESA campaigns) | Ellington Air Force base<br>Houston, USA | CEV base<br>Brétigny, France | Schönefeld airport<br>Berlin, Germany |
| In air zones over | Gulf of Mexico | land or Channel | land in Berlin area |

between parabolas. During ESA campaigns, 30 parabolas are usually flown in sets of three with two-minute intervals between parabolas and with four to five minutes between sets of three parabolas.

Figure 3 shows typical acceleration levels for the Caravelle aircraft Z-axis (floor to ceiling direction), measured during a parabola with ESA's micro-accelerometers strapped to the cabin floor structure. During the reduced gravity period, a transitory phase of about 5 s appears first, with variations of about $10^{-1}$ g in the Z direction, followed by a period of approximately 20 s with acceleration levels of a few $10^{-2}$ g, while accelerations along the aircraft longitudinal X-axis (aft to front) and transversal Y-axis (right to left) are less than $10^{-2}$ g. Similar values were measured for the KC-135 and the Ilyushin.

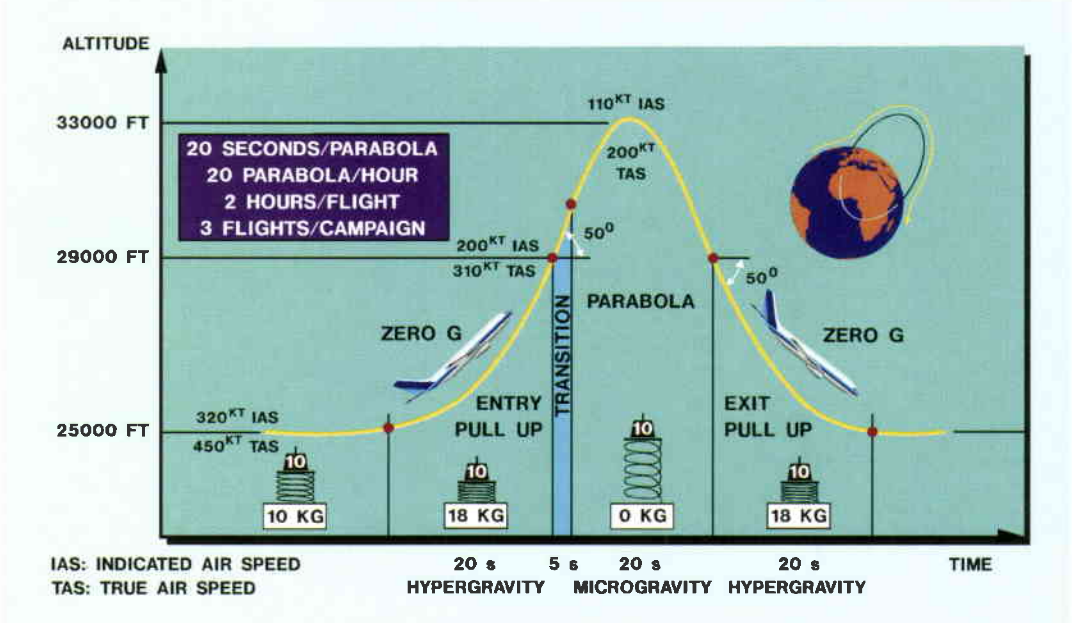



**Figure 2. The Caravelle parabolic flight manoeuvre**

The residual accelerations sensed by experimental set-ups attached to the aircraft floor structure are typically in the order of $10^{-2}$ g, while for an experiment left free floating in the cabin, the levels can be improved to typically $10^{-3}$ g.

For the three airplanes, the piloting is done manually along the X-axis by adjusting the engines thrust, and along the Z-axis using visual references provided by a coarse (+2 to −2 g) and a fine (+0.1 to −0.1 g) accelerometer. With the Caravelle, the aircraft can be piloted using another method to provide dedicated free-floating experiments with levels in the order of $10^{-3}$ g for up to 10 s. This method aims at reducing the relative displacement of the free-floating package by providing the pilot with visual information on the free-floating state through a closed TV circuit, allowing to pilot the aircraft 'around' the free-floating package.

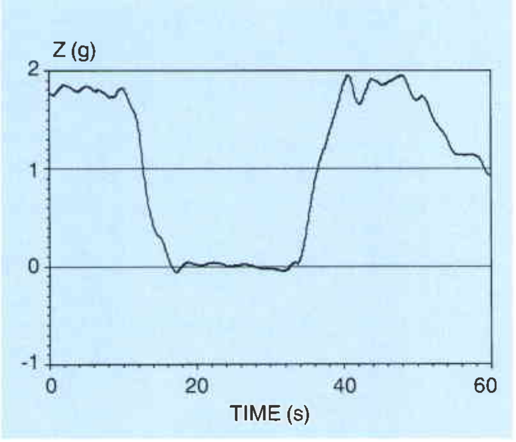



**Figure 3. Acceleration levels during a parabola on board the Caravelle. The measuring equipment is attached to the aircraft's floor structure (sample rate of 10 Hz).**

## Safety and medical aspects of operations during parabolic flights

Since aircraft parabolic flights are considered to be test flights, specific precautions must be taken to ensure that all flight operations are performed safely and that flying participants are adequately prepared for the repeated high and low gravity environment.

Prior to a campaign, ESA provides support in the design of the test equipment and in related safety aspects. Several months before the campaign begins, experts review all experiments to be performed and all equipment to be installed on board the aircraft from the structural, mechanical, electrical, safety and operational points of view. Technical visits are made to the experimenters' institutes to check the equipment. A safety review is then held one month before the campaign to assess the overall safety of the campaign. Finally, before the first flight, a safety visit of the aircraft is made to verify that all installed equipment complies with the safety standards.

All experimenters that ESA invites to participate in parabolic flights must pass a medical examination (FAA Class III) and a hypobaric chamber physiological test. All certifications are verified prior to the first flight of the campaign. For experiments to be conducted on human subjects, the ESA Medical Board reviews the medical protocols submitted by the investigators two months prior to the campaign to ensure that the proposed research is conducted according to the ethical and safety rules for spaceflights. In particular, all interfaces applied to human subjects are verified and procedures to be followed in nominal and non-nominal situations are reviewed. Human subjects are made aware of the purpose of the research and are informed that they can withdraw at any moment from the investigation, as long as their withdrawal does not present any risk.

For the Caravelle campaigns, the ground infrastructure at the CEV includes the Laboratoire de Médecine Aérospatiale (LAMAS) which provides medical facilities and on-site support for the preparation of experiments involving human subjects.

During the flights, specialised personnel supervise and support the in-flight experiment operations. In addition, a flight surgeon participates in all ESA flights to supervise the medical aspects of in-flight operations and to assist flying participants in case of motion sickness. Due to the sequence of flight phases of low and high gravity, motion sickness is quite common among participants in parabolic flights, sometimes hindering them from conducting their tasks. Anti-motion sickness medication is made available to flying participants, on request, before the flights.

## ESA parabolic flight campaigns

In 10 years of parabolic flight campaigns organised by ESA, 235 experiments have been performed. Table 3 gives an overview of the number of experiments undertaken per campaign and in each scientific field. In general, the type of microgravity experimentation conducted during parabolic flights follows the trend of research conducted during space missions and prepares experiments for orbital microgravity laboratories, either manned (Spacelab, Mir space station) or unmanned (EURECA).

ESA's 10 years of utilisation of parabolic flights can be divided into five periods.

*1984 – 88, Campaigns No. 1 to 6*
From December 1984 to August 1988, six ESA campaigns were organised. NASA's KC-135 aircraft was used, flying from Houston. The first two campaigns were devoted to preparing for the Spacelab-D1 (SL-D1) mission. ESA and DLR science astronauts tested the hardware and experiment procedures for the Fluid Physics Module (FPM) (Fig. 4). Investigators involved in the SL-D1 mission performed preliminary tests to prepare for their fluid physics (Fig. 5), biological and vestibular experiments respectively with the FPM, Biorack and SLED facilities developed by ESA.

Shortly after those two campaigns, the importance of preparing space experiments during parabolic flights was recognised and the scientific interest in performing short microgravity investigations (within 20 s) increased.

After SL-D1, during the third campaign, an experiment on surface forces between two colliding solid bodies (Fig. 6) was prepared for the Eureca mission. The first European microgravity combustion experiment was performed and other experiments were carried out, mainly in fluid physics and on the vestibular system (Fig. 7) to complement results obtained during SL-D1.

For the subsequent campaigns, ESA invited European scientists to perform their experiments on board the KC-135. Several theme campaigns were organised. The fourth campaign was dedicated to seven microgravity combustion experiments with other

*Table 3. ESA parabolic flight campaigns*

| Aircraft/Location | ESA Campaigns | Dates | Number Parabolae | Fluid Physics | Combustion Physics | Material Sciences | Technology | Human Physiology | Biology | Technology | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| KC-135 | 1 | Dec. 84 | 44 | 11 | – | 2 | – | 3 | 2 | – | 18 |
| Houston | 2 | Jun. 85 | 51 | 14 | – | – | – | 7 | 2 | – | 23 |
| | 3 | Mar. 86 | 75 | 6 | 1 | 1 | – | 2 | – | – | 10 |
| | 4 | Apr. 87 | 75 | – | 7 | – | 1 | 2 | – | – | 10 |
| | 5 | Oct. 87 | 75 | 2 | 1 | – | 2 | 11 | 1 | – | 17 |
| | 6 | Aug. 88 | 75 | 6 | 1 | 1 | 2 | 4 | 2 | – | 16 |
| Caravelle | Demo | Feb. 89 | 30 | – | – | – | 2 | 1 | – | – | 3 |
| Bretigny | 7 | Mar. 89 | 92 | 2 | 1 | – | 2 | 4 | 1 | – | 10 |
| | 8 | Oct. 89 | 92 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 10 |
| | 9 | Apr. 90 | 90 | 2 | 1 | – | – | 2 | – | 5 | 10 |
| | 10 | Jul. 90 | 90 | 2 | – | 1 | – | 2 | – | 3 | 8 |
| | 11 | Oct. 90 | 87 | 2 | – | – | 1 | 2 | – | 3 | 8 |
| | 12 | Feb. 91 | 90 | 2 | – | – | 2 | 5 | – | 2 | 11 |
| | 13 | Jun. 91 | 93 | 4 | – | 2 | 1 | 2 | 1 | – | 10 |
| | 14 | Sep. 91 | 75 | 1 | – | 1 | 3 | 1 | – | 2 | 8 |
| | 15 | Mar. 92 | 90 | 5 | 1 | – | 1 | 3 | – | – | 10 |
| | 16 | Jan. 93 | 92 | 6 | 1 | 1 | – | 2 | 2 | – | 12 |
| | 17 | Nov. 93 | 93 | 2 | 1 | – | – | 5 | 3 | – | 11 |
| | 18 | Mar. 94 | 80 | 1 | 1 | 1 | – | 1 | 3 | 1 | 8 |
| IL-76 | Demo | May 94 | 35 | – | – | – | 1 | – | – | – | 1 |
| Berlin | 19 | Jul. 94 | 90 | 1 | – | – | 1 | 6 | – | 2 | 10 |
| Caravelle Bretigny | 20 | Oct. 94 | 93 | 6 | – | 1 | 1 | 3 | – | – | 11 |
| Total | | | 1707 | 76 | 17 | 12 | 21 | 70 | 19 | 20 | 235 |

1707 parabolae ≈ 9.5h ≈ 6 orbits

# Campaigns using the KC-135

Figure 4. ESA astronaut Ulf Merbold training on the engineering model of the Fluid Physics Module (FPM) (1st ESA campaign, Dec. 1984) (Photo: NASA)

Figure 5. J.C. Legros (University of Brussels, B) performing a test on stability of a fluid interface within a cell, in preparation for his SL-D1 experiment with the FPM (1st ESA campaign, Dec. 1984) (Photo: NASA)


Figure 6. G. Poletti (University of Milan, I) monitoring his experiment on surface forces between contacting solids within a prototype of the Surface Force Assembly (SFA), later flown on Eureca. The equipment is installed in a confining structure with a protective net. (3rd ESA campaign, Mar. 1986) (Photo: NASA)

Figure 7. ESA astronaut Wubbo Ockels repeating an experiment with a Video-Oculographic (VOG) mask from the University of Mainz (D) (3rd ESA campaign) (Photo: NASA).

add-on experiments. The fifth campaign was devoted to life sciences with 11 human physiology investigations on the vestibular, respiratory and cardiopulmonary systems. For the first time, a multi-goal physiology experiment was conducted with several investigators measuring different physiological parameters on a single subject.

The sixth campaign saw the performance of 16 experiments in various fields, some of them being follow-ons to experiments conducted on previous campaigns by the same or other investigator teams.

*1989 – 91, Campaigns No. 7 to 14*
At the end of 1988, ESA accepted CNES's offer to use its newly refurbished Caravelle aircraft to conduct parabolic flights in Europe. This new opportunity made the flights geographically closer and easier to organise. Between 1989 and 1991, three campaigns were organised per year with mixed payloads of physical and life science experiments.

Microgravity experimentation during parabolic flights evolved significantly, demonstrating the importance of that tool for microgravity research and attesting to the growth of the microgravity parabolic flight community. Experimental equipment became more sophisticated, with precise optical diagnostic means being introduced. Other experiments of the 'look and see' type, however, were also still being performed. Large experimental set-ups were flown on several campaigns to allow 'repeat data' to be collected. Experiments were also repeated over several campaigns but with some parameters changed. The results were compared with those obtained using other microgravity carriers such as drop towers, sounding rockets, and Spacelab missions, as well as with results obtained in normal gravity on ground and in hypergravity with centrifuges.

Investigations continuing and extending those previously conducted were carried out in fluid physics, mainly on liquid/liquid and liquid/gas interfaces, on bubbles and drops, and on critical point phenomena, in combustion on pre-mixed flames and on burning droplets, and in human physiology, mainly on the vestibular (Fig. 8), respiratory and cardiopulmonary systems. In parallel, new experiments in material sciences were performed: attempts were made to grow small crystals and processing alloys. New and more daring experiments were conducted in human physiology, using invasive methods (catheters were inserted in the veins of subjects' arms to measure the central cardiac pressure, and esophageal pressure probes inserted through the nose were used for respiratory experiments) and a growing number of multi-goal physiological experiments with simultaneous measurements. For example, during one experiment, the following parameters were recorded on a subject pedalling on an ergometer: ECG, heart rate, transthoracic impedance, ergometer work rate, venous lactate concentration, blood pressure, cerebral artery flow velocity by Doppler method, respiratory flow and expired $CO_2$ concentration) (Fig. 9).

Preliminary experiments were still conducted to prepare for the Spacelab IML-1 and D2 missions for the Advanced Fluid Physics Module (Fig. 10), Anthrorack and Biorack facilities developed by ESA. Preliminary tests were performed for the Bubble Drop, Particle Unit (BDPU) facility in view of the IML-2 mission.

Microgravity technology and ergonomy investigations were also developed during this period. Starting in 1989, ESTEC's Columbus Utilisation Department began testing on board the Caravelle, crew support equipment to be used by astronauts on board the future International Space Station (Fig. 11). After having participated in several campaigns organised by the Microgravity Projects Division, the Columbus Utilisation Department organised two separate campaigns dedicated to tests of Hermes and Columbus systems in addition to those reported in Table 3.

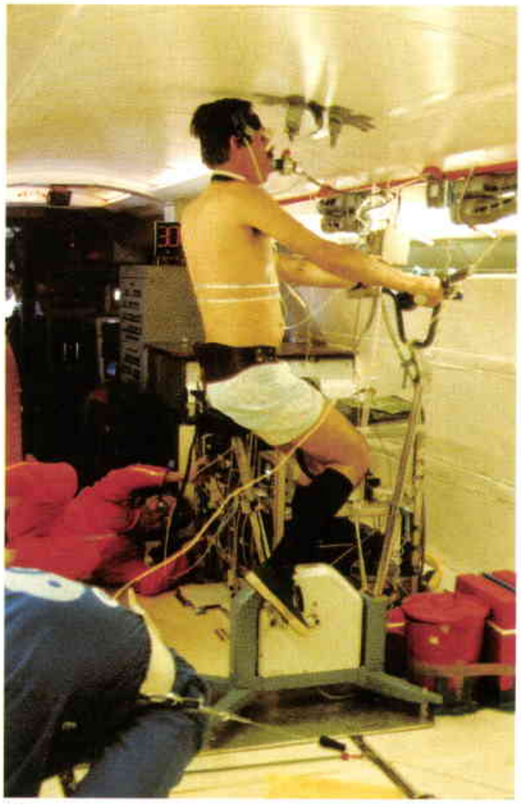
*1992 – Early 1994, Campaigns No. 15 to 18*
In 1992, ESA's policy on manned spaceflight policy changed, resulting in reduced parabolic flight activities. One to two campaigns were organised per year.

Investigations continued in fields previously explored in fluid physics, mainly on Marangoni convection and interface driven phenomena, and on bubbles and drops; in combustion on flames and combustion of dust; and in human physiology on vestibular, respiratory and cardiac systems (Fig. 12, 13). For the first time, a fluid physics experiment on heat pipe performance in microgravity was conducted on board the Caravelle for the RADIUS (Research Associations for the Development of Industrial Utilisation of Space) programme.

New biology experiments were initiated on animals and on osteoblast cells. The BDPU facility was actively prepared for the Spacelab IML-2 mission with several tests of the bubble/droplet injection and release systems.

# Campaigns using the Caravelle

(8)



(9)

Figure 8. W. Oosterveld (University of Amsterdam, NL) monitoring a subject after injection of hot water (at 44°C) in his inner ear, for an experiment on the vestibular caloric stimulations and nystagmus. Eye rotatory motion is recorded by electrodes around the eye. (11th ESA campaign, Oct. 1990)

Figure 9. P. di Prampero (University of Udine, I) pedalling an ergometer while breathing through a mouthpiece for an experiment on the cardiopulmonary function during exercise (10th ESA campaign, July 1990)

(10)

(11)

Figure 10. A prototype of the Wet Satellite Model (WSM), the experiment of J. Vreeburg (NLR Amsterdam, NL), being tested in free float. The engineering model of the Advanced Fluid Physics Module (AFPM) in the background is used to rehearse crew handling procedures in preparation for the Spacelab D2 mission. (13th ESA campaign, June 1991)

Figure 11. ESA astronaut Jean-François Clervoy assessing the two-person procedure for removing a 1/1 scale mock-up of a Columbus rack from its stand (11th ESA campaign, Oct. 1990)

(12)

**Figure 12. W. Oosterveld (University of Amsterdam, NL), sitting on a rotating chair, is the subject of his own experiment on vestibular rotatory stimulations nystagmus. Eye rotatory motion is recorded by electrodes around the eye. (15th ESA campaign, March 1992)**

**Figure 13. For the Transmural Central Venous Pressure experiment of R. Videbaek (Damec, Copenhagen, DK), a subject, lying and lightly restrained, has a 45 cm catheter with a pressure probe inserted through an arm vein up to the heart to measure left atrial cardiac pressure, and an esophageal pressure probe inserted through the nose to measure pressure variations in the esophagus. Both pressure signals are recorded on two medilogs in the two white belt pouches. Simultaneous ultrasound echocardiography is conducted on the subject to measure, during parabolas, the changing dimensions of the heart during a normal heartbeat cycle. The subject is also partaking in the experiment of V. Demaria-Pesce (Collège de France, Paris) in which activity, light exposure and body temperature are recorded on the joblog in the black belt pouch, in preparation of an experiment for the EuroMir-94 mission. (17th ESA campaign, Nov. 1993)**

(13)

Following the change in policy, no further technological investigations to prepare for the Columbus orbital facility were conducted.

*Mid-94, Campaign No. 19 with Ilyushin*

In May 1994, ESA was invited to participate in demonstration parabolic flights with the Russian Ilyushin IL-76 MDK aircraft in Berlin. During those demonstration flights, microgravity levels were measured with an ESA-developed micro-accelerometer system. The measurements showed that the levels attained during Ilyushin parabolas are approximately similar in duration and quality to those achieved by the Caravelle and the KC-135.

The next campaign, ESA's 19th, was scheduled to be conducted with the Caravelle, to prepare human physiology experiments foreseen for the EuroMir-94 and -95 missions and to test equipment under development for the EuroMir-95 mission. Because the Caravelle was not available until September 1994, this campaign could not be conducted in time for the EuroMir-94 mission of October 1994. It was decided to use the Ilyushin aircraft in Berlin again for this campaign, as a replacement. Within two weeks, the campaign was rearranged and performed in July 1994 with the participation of ESA EuroMir astronauts, to the satisfaction of the investigators (Fig. 14, 15).

*End of 1994, Campaign No. 20 with Caravelle*

Since 1993, new orientations in microgravity research paved the way for the emergence of new research themes, which are now reflected in experiments of the last campaigns and of those planned for the future.

With the Caravelle again available for parabolic flights, ESA conducted its 20th campaign, with experiments exploring new areas of fluid physics in microgravity, i.e. investigations of ferromagnetic fluids (Fig. 16) and aggregates. A second RADIUS experiment was performed on capillarity in porous media. A first preliminary experiment was carried out for the Fluid Physics Facility (FPF), a third generation ESA instrument for fluid physics research, which is now under development and is foreseen to fly on an unmanned Russian Foton satellite.

In addition to these microgravity science and technology campaigns, ESA recently undertook a new initiative proposed by students of the Delft University of Technology

# Campaigns using Ilyushin

(14)

(15)

**Figure 14. ESA Astronaut Christer Fuglesang, free floating, attempting to sit on the Munich Space Chair designed by E. Pfeiffer (Technical University of Munich, D). The chair allows an astronaut to anchor himself in front of a workstation using feet and thighs, leaving both hands free. (19th ESA campaign, July 1994)**

**Figure 15. ESA Astronaut Thomas Reiter rehearsing the donning procedures of the Analog Biomechanical Recorder (ANBRE) suit in preparation for a EuroMir-95 experiment to measure body limb positions in weightlessness.**

**On the left, the seated subject wearing a mask with two CCD cameras is performing the experiment of C. Markham and S. Diamond (University of California, Los Angeles) on torsional nystagmus (rotatory eye movements), in preparation for experiments for the EuroMir-94 and EuroMir-95 missions. (19th ESA campaign, July 1994)**

in The Netherlands, as part of the European Union's Week for Scientific Culture (see 'The First Parabolic Flight Campaign for Students' in this issue). Following a Europe-wide competition, 49 students from 11 European countries, including Poland, took part in a series of parabolic flights and performed their own experiments while in microgravity. The experiments were of a high scientific level and involved innovative ideas pertaining to several fields: general physics, fluid physics, combustion, material processing, crystal sciences, astrophysics, geophysics, biology and technology.

### Outcome of the parabolic flights

The investigators invited by ESA to perform experiments during ESA parabolic flights are asked to present their results several months after the campaign. ESA has regularly organised scientific workshops in the past 10 years where the results are publicly discussed, and the presented papers are subsequently published. The results presented during these workshops have also reflected the trend observed in the experimentation, spanning from reports of simple visual tests to presentation and discussion of scientific results acquired with laboratory instrumentation and compared to those obtained by other methods.

In November 1994, ESA and CNES organised a joint workshop in Toulouse where results of experiments conducted during the last seven

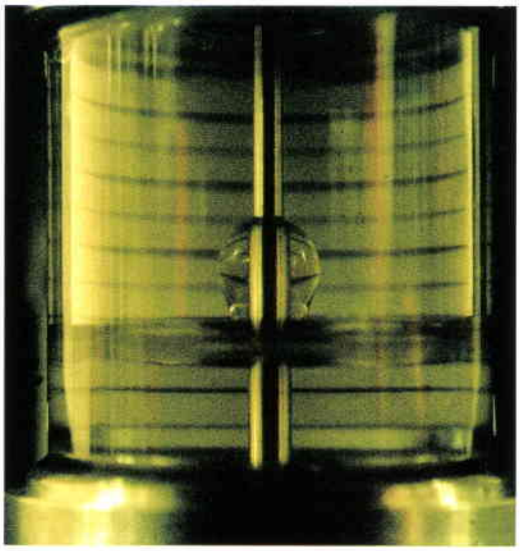


**Figure 16. During the experiment of S. Odenbach (University of Wuppertal, D), a non-Newtonian fluid (solution of oppanol B200 in heptane) climbing on a rotating shaft under microgravity. The climbing is caused by the non-Newtonian properties of the fluid. The surface tension of the liquid forces the free surface to form a sphere at the shaft. (20th ESA campaign, Oct. 1994) (Photo: University of Wuppertal)**

ESA and CNES campaigns with the Caravelle were presented. The discussions among the 100 investigators involved in CNES and ESA campaigns prompted many new ideas for future experiments to emerge. The tenth anniversary of the first ESA campaign, held in December 1984, was also celebrated on that occasion.

During those 20 campaigns, ESA staff members have contributed greatly to the success of many experiments. ESTEC's Design Office, Mechanical and Electrical Workshop, and Instrument Technology Division, in particular, have supported efficiently the preparation and the performance of several experiments.

**The future of parabolic flights**

ESA will continue to organise parabolic flight campaigns for the European scientific and technical microgravity communities. The Agency regularly invites scientists to submit proposals for microgravity experiments for the parabolic flight programme.

Three campaigns are scheduled for 1995. The 21st campaign took place in March and was devoted to the preparation of experiments to be conducted during the EuroMir-95 mission. The 22nd and 23rd campaigns, respectively foreseen for the end of April and the autumn of 1995, will be dedicated to microgravity experiments with mixed payloads of physical and life sciences. Further campaigns are foreseen for the following years at a rate of two to three per year.

Furthermore, in view of the educational and media success of the recent student campaign, a second campaign is now being organised.

As far as the aircraft used for ESA campaigns is concerned, the Caravelle is presently certified for parabolic flights until July 1995. Discussions about a replacement aircraft are presently underway in France. To bridge the gap until a new aircraft is fully operational, the flight certification of the present Caravelle could be renewed for several months.

**Conclusions**

Within specific cooperative frameworks with NASA, CNES and the Russian CTC, ESA has had the opportunity to organise campaigns for microgravity experiments with the three main airplanes in the world that are used for parabolic flights. The unique experience acquired on board the NASA KC-135, the CNES Caravelle and the CTC Ilyushin is reflected in the number of experiments successfully conducted over the last 10 years.

The quality and duration of microgravity obtained, the flexibility and variety of possibilities for experiments and tests, and the ease of flight preparation make aircraft parabolic flights a unique and versatile tool for European scientists to perform experiments in microgravity and at different g levels.

In particular, aircraft parabolic flights are highly recommended for the conducting of gravity-related physical investigations and physiological experiments on human subjects, to complement research conducted with other Earth-based carriers and to prepare for the future space station missions.

As the space agencies of the world embark on the ambitious building of the International Space Station, one can forecast that aircraft parabolic flights will be used intensively throughout the various phases of the programme. Over the next 10 years, the programme will include firstly, precursor flights on board Spacelab and Mir missions; secondly, the so-called Phase II of the International Space Station during which Europeans will participate in American and Russian experiments and European microgravity payloads will be developed; and thirdly, the period during which the ESA Columbus Orbital Facility will be available for continuous microgravity research. During all of these three phases, the preparation of experiments, the microgravity testing of payloads and the training of astronauts will still be conducted during aircraft parabolic flights.

# The First Parabolic Flight Campaign for Students

**W.J. Ockels**
Directorate of Manned Space Flight and Microgravity, European Space Agency, Noordwijk, The Netherlands, & Faculty of Aerospace Technology, Delft University of Technology, The Netherlands

**In the last week of November 1994, a different type of parabolic flight campaign took place: For the first time, students were given the unique opportunity of experiencing weightlessness. The campaign was part of the second European Week for Scientific Culture and the main goal was to motivate and educate the students rather than to obtain pure scientific and technological results as is normally the case in 'professional' campaigns.**

**Twenty student experiments were chosen in a Europe-wide competition and the winning student teams were invited to carry out the experiments during a series of parabolic flights. The experiments covered a wide variety of disciplines ranging from general and fluid physics to material processing, crystal growth, and technology research. The campaign was a great success, all experiments worked well and the students proved to be a serious and motivated workforce which performed well in the rather unsettling microgravity environment. By learning from each other's experiments and through the unique personal experience of weightlessness, the students have become ambassadors for microgravity research. Most importantly, they have shown that we can have confidence in the next generation to make good use of microgravity research opportunities, including the International Space Station, in the future.**

## Introduction

Each year, the *VSV Ruimetevaartdispuut*, the society of engineering students specialising in space technology at the Delft University of Technology in The Netherlands, organises an activity that is of significant educational value for the students but also offers great public visibility.

In early 1994, the students were intrigued by a comment made by the author during one of his lectures on crewed space flight. While discussing the various methods of simulating space conditions, including parabolic flights, he stated jokingly, 'Why don't you (the students) try to take part in such a flight?'. The comment was taken more seriously than could have been expected.

The society immediately began seeking sponsors for a parabolic flight campaign for Dutch students. Naturally, ESA was approached. ESA, however, proposed to host a campaign that would be open to all European students, and invited the Delft students to organise a Europe-wide competition whereby interested students could submit a proposal for an original experiment that they would carry out in microgravity on board the parabolic flight. Funding for the campaign was assured by ESA and the European Commission. ESA also agreed to contribute the services of staff who are regularly involved in the preparations for parabolic flights, to organise the student flight.

In March 1994, the society distributed posters and brochures advertising the competition to numerous universities. The deadline for the submission of proposals was the end of June. Forty-nine proposals were received from 11 countries. An international jury, under the author's chairmanship, selected 22 experiments as candidates to fly. The flight was set for the last week in November. The time available to the students to prepare their proposed experiments was extremely short, much shorter than is normally given for the preparation for a professional flight (three months versus typically six months to a year). In spite of the tight deadline, 20 experiments were confirmed to be ready for flight in mid-September.

## The experiments

Some 50 experiment proposals covering a wide variety of disciplines were received. The jury selected 22 on the basis of their educational value and microgravity relevance. The chosen experiments are listed in Table 1. A fair geographical distribution was reached, with 11 countries participating in the flight campaign (Table 2).

The scope of the experiments was large: they ranged from a simple demonstration of weightlessness for an educational film on the pendulum (SP-1) to new and advanced investigations on mutation rates in DNA (CH-1) and research on the stabilisation of large structures in space (I-6) (PhD work).

*Table 1. List of experiments*

| Scientific field | Experiment | Reference |
|---|---|---|
| General physics | The mean free path of a particle in a randomwalk process<br>S. Vereecke (University of Gent, B), B. Vandenbussche (University of Leuven, B) | B-2 |
| | Gravity dependent pendulum<br>E. Checa, F. Arevalo, E. Gordo, I. Fernandez (University of Madrid, SP) | SP-1 |
| Fluid Physics | Investigation of the second order Marangoni effect in transparent liquids<br>A. Griesche (Technical University of Berlin, D) | D-4 |
| | Shear cell under microgravity<br>G. Mathiak, A. Griesche, G. Welzel (Technical University of Berlin, D) | D-10 |
| | Stationary magnetic levitation experiment: SMAGLE<br>F. Huber, J. Hermann (University of Stuttgart, D) | D-9 |
| | Coupling of thermocapillary convection and fingering instability of ferrofluids in microgravity conditions<br>L. Crocco, G. Lamanna (University of Napoli, I) | I-7 |
| | Shape evolution of liquid bodies under microgravity conditions<br>P. Hofman, V. Chaturvedi (University of Nijmegen, NL), M. Pandey (University of Aachen, D), C. Harb (University of Nottingham, UK) | NL-4 |
| Combustion | Combustion of dust in microgravity<br>R. Sornek, J. Mainka, M. Blogowski, K. Benkiewicz (Technical Univ. of Warsaw, P) | P-1 |
| Material Processing | Chill casting of Al-Pb alloys in aerogel crucibles<br>G. Korekt, O. Schumacher (University of Köln, D) | D-5 |
| | Nucleation near glass transition in a low melting temperature glass<br>C. Le Deit (University of Rennes, F) | F-4 |
| Crystal Sciences | Spiral crystalline growth in chemical gardens<br>B. Stockwell, A. Hickman, E. Fell (Ashford School, Kent, UK) | GB-2 |
| Astrophysics | Collision and aggregation experiment: COLLAGE<br>G. Wurm (University of Jena, D) | D-1 |
| Geophysics | Spherical couette flow experiment: SCFE<br>M. Linek, M. Stöckert, J.R. Schmidt (University of Bremen, D) | D-12 |
| Biology | Mutation rate of DNA replication and transpositional activity in microgravity<br>S. Köchli, M. Keller (University of Basel, CH) | CH-1 |
| | Detection and identification of different expressed genes in primary osteoblasts under microgravity conditions<br>J. Tenbosch (University of Münster, D) | D-6 |
| Technology | Spin stiffened membrane antennae<br>J.M. Brindeau, S. Defer, S. Py, Y. Gourinat (ENSICA, Toulouse, F) | F-1 |
| | Proof-mass actuator systems used for active vibration control of large space structures<br>P. Vezzosi, M. Politano (University of Milano, I) | I-6 |
| | The fluid coli actuator<br>H. Yano, H. Shaw (University of Kent, UK) | GB-1 |
| | Double spin satellite simulation<br>J. Hillebrand, J. van den IJssel, P. van Niftrik (VSV, Technical University Delft, NL) | NL-6 |
| | Heat flow around printed circuit boards and heatsinks in low gravity conditions<br>P. Takala, S. Kiiskilä (University of Tampere, SU) | SU-1 |

*Table 2. Geographic distribution of the experiments*

| Country | No. of experiments Confirmed | No. of experiments Selected | Proposals received |
|---|---|---|---|
| Belgium | 1 | | 3 |
| Finland | 1 | | 1 |
| France | 2 | | 6 |
| Germany | 7 | | 20 |
| Italy | 2 | 3 | 7 |
| Norway | | 1 | 1 |
| Poland | 1 | | 1 |
| Spain | 1 | | 1 |
| Switzerland | 1 | | 1 |
| The Netherlands | 2 | | 6 |
| United Kingdom | 2 | | 2 |


Figure 1. The campaign team, including the 49 students, the pilots and the support staff

During the flight campaign, the organisers discussed each experiment with the student team to determine why the research was being undertaken — the background behind the experiment as well as the students' personal reasons for participating and the educational relevance for them.

Some experiments originated from individual initiatives, such as the experiment studying the mean free path between the collision of 400 small balls in a transparent, 30-cm sphere (B-2) (Fig. 2) and the finger-type instabilities of a ferro fluid in a magnetic field (I-7) experiment. In that last experiment, the student had taken the effort to read five-years' worth of issues of Scientific American to find 'something new' to investigate, and he did. For some other experiments, the student teams had already performed the work in the laboratory but this campaign provided an opportunity to try it in microgravity (Unidirectional casting of AlPb alloys, D-5; Gene expression in primary osteoblasts, D-6). Some other experiments were based on experiments that had already been flown in space but unexpected results had raised the need for further investigation (Cobalt nitrate crystal growth in a 'chemical garden', GB-2; Dust 'collage' study, D-1; Second-order Marangoni flow, D-4). One experiment, a geological model of the atmosphere, called 'couette flow', came from a group already performing microgravity research using a 100 m-high drop tower (D-12).

Some simple experiments proposed to study the behaviour of fluids: one experiment studied the mixing of two fluids when brought into contact (D-10), another the shape of large, spinning droplets (NL-4). The dust and filter combustion experiments (P-1) and the electric heating of a printed circuit board (SU-1) are very relevant to safety on board a spacecraft. Angular momentum effects were applied to study a model satellite with sloshing fuel tanks (NL-6). Attempts were made to change an astronaut's orientation by running water through a coil wrapped around his body (GB-1) (Fig. 3). Two quite advanced and specially designed experiments studied the magnetic levitation of an air bubble in fluid (D-9) and nucleation in low melting temperature glasses (F-4). Two students from ENSICA, a school in Toulouse (F), explored a novel way of deploying a large (1.5 m), low-mass antenna: by spinning it (F-1) (Fig. 4).

**Campaign preparation**

The campaign was set up like a regular ESA campaign, at the Centre d'Essais en Vol (CEV) base in Bretigny, south of Paris. The company Orbitics, contracted by ESA, was responsible for the accommodation of the experiments in the Caravelle aircraft and for their safety. Before the campaign began, they visited each

Figure 2. A student observes the motion of gas molecules and the mean free path between collisions using 400 balls in a sphere as a model

of the experiment development sites to inspect the experiment and to advise where necessary. The series of visits was completed by the end of October 1994.

Despite the shorter than normal time to prepare the experiments, the student teams managed, with great enthusiasm and professionalism, to have their experiments ready in time while still satisfying the safety regulations. The students, who ranged from 17 to 31 years of age, had to undergo medical and physical examinations before they could be accepted for flight.

One week before the flights, the students, some with additional 'ground support', arrived at the CEV. They stayed in a nearby hotel for two weeks, one week for the preparations, and the other for the flights. Twenty journalists from TV, radio and the written press also participated in the campaign.

In the first week, the experiments were made ready for installation in the airplane, with the enthusiastic support of the CEV technicians. 'Students tend to better listeners than professionals' was overheard.

**Figure 3. Can an astronaut's body be rotated in microgravity by pumping water through a coil? One student attempts to find out.**

### The flight week

The campaign took place during the last week of November 1994. Before the actual flight programme started, the participants were given a safety review and extensive briefings on emergency procedures. They were also given medication against motion sickness, if they requested it.

Five flights were conducted on five consecutive days, with each flight lasting about 2 hours and including 21 parabolas. Up to 20 passengers could take part in each flight: there were seats for 14 students, 2 support staff and 4 journalists. The various experiments were accommodated on four flights. The fifth flight was used as a reserve, to be used to re-fly those experiments that encountered problems and that could be improved. In that way, all experiments had a fair chance and each of the 49 students could participate in at least one flight.

The payload had to be reconfigured after each flight. The students worked until late to be ready for the flight the next day. A very strong team spirit quickly evolved, not least due to the fact that the video footage of the flights was shown and discussed each evening upon the students' return to the hotel.

The students proved to be an excellent workforce. During the flights, almost half of them became ill (typical for first-time flyers), but that did not hinder them from performing their experiments enthusiastically. All students were greatly impressed by the effect and the experience of weightlessness. Such an experience cannot not be fully anticipated. They became aware of a new environment and began to think differently about what microgravity is and how it can be used.

The press showed substantial interest in the campaign. ESA held a welcoming ceremony, which included a visit by ESA's Director General, J.-M. Luton. Some 14 journalists also had an opportunity to fly with the students.

### Some early results

The first student parabolic flight campaign was a great success. The main success was that the students experienced personally the weightlessness in which they performed their own experiments. This experience created a strong motivation for science and technology in general, and for space technology and microgravity research in particular. Many of them learned to appreciate the different fields of science. For most of them, it was also an eye-opener to learn the different ways microgravity can be used in research. All of the participants established new contacts with other European students and demonstrated a strong ability to work together as Europeans.

This campaign showed that the next generation of engineers and scientists have a strong interest in space, that they are capable of developing and performing relevant experiments, and that they have an excellent aptitude and work attitude.

Although 'science' was not explicitly the objective of the student campaign, some preliminary results are notable:

Figure 4. Another student deploys a low-mass antenna by rotating it

- The DNA polymeric chain reaction (triggered by special catalysers also used in crime investigations) resulted in more DNA production than found in normal gravity. Although the aim of the experiment (CH-1) was to observe a possible change in the mutation rate, which was not found, the possible change in the polymeric chain reaction could be very interesting.
- The fingering instability of the ferro fluid could be formed with 30% less power compared to on the ground. This effect is important when ferro fluids are used in space to prevent other fluids from flowing past a rotating axes, i.e. the ferro fluid works as a seal (I-7).
- The experiment from Cologne (D-5) showed successful casting and unidirectional solidification of aluminium-lead alloys using a method that had not been used in microgravity before. In particular, the transparent 'aerogel' crucible made it possible to take thermal pictures using an infrared camera (Fig. 5). The results of this experiment could lead to the production of better materials for bearings, leading to more energy-efficient engines.
- When an experiment prepared by the Ashford School of Kent, UK, flew on the Space Shuttle in 1992, unexpected spiral crystalline growth of cobalt silicate from salt solutions was observed. The students repeated the same experiment (GB-2) and it did show a conformation of the formation of a spiral crystal.
- The dust combustion experiments (P-1) showed the successful dispersion of dust such that flame propagation in microgravity could be observed. The results allow flame velocities for various dust and fibre materials in space to be predicted, velocities that turn out to be 3 to 5 times slower than on Earth.

The students are still analysing their data. Many of the other experiments will undoubtedly show results as interesting as the ones mentioned above. The students will meet at the next Le Bourget Airshow in Paris (in June) to discuss their latest results.

## Conclusions

The first student parabolic flight campaign was a great success. The European students who initiated the campaign, developed the experiments and conducted them personally in weightlessness, demonstrated the potential of tomorrow's microgravity science community. Those young European researchers proposed innovative ideas and implemented them in an unusually short time. The students, coming from 11 different countries, displayed a strong cooperative spirit which the supporting technicians, operators, managers and pilots welcomed warmly.

For many of the students, this campaign was a very significant experience and should have a positive impact on their future careers. The experience increased their interest in science and technology, made them aware of a large variety of other scientific disciplines, and has given each one valuable contacts with European partners.

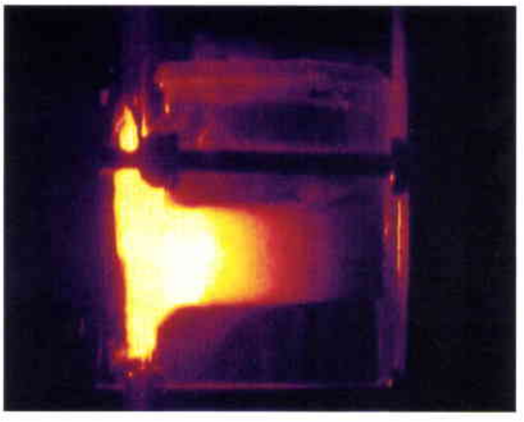


Figure 5. Unidirectional solidification of aluminium-lead alloy as seen by an infrared camera

The success of this campaign was the result of the hard work of many professionals, including engineers, technicians, pilots, and companies. The students, in particular, the initiators and organisers of the competition represented by Jasper Hillebrand of the *VSV Ruimtevaart-dispuut*, are also to be commended. It is expected that such an event will be repeated in the upcoming years. In fact, an annual Student Parabolic Flight Campaign would be well justified as a European activity to enhance our scientific and technological culture.

# Ballistocraft: A Novel Facility for Microgravity Research

**D. Mesland**
Microgravity Payload Projects Division, ESTEC, Noordwijk, The Netherlands

**D. Paris**
Trajectory Guidance and Control Section, ESTEC, Noordwijk, The Netherlands

**R. Huijser, P. Lammertse & R.Postema**
Fokker Space & Systems B.V., Leiden, The Netherlands

**One of ESA's aims is to provide the microgravity research community with various microgravity exposure facilities. Those facilities include drop towers, sounding rockets, and parabolic flights on board aircraft, in addition to orbital spacecraft.**

**Microgravity flights are usually achieved using large aircraft like the French 'Caravelle' that offer a large payload volume and where a person can be present to perform the experiments and to participate as a human test-subject. However, the microgravity community is also very interested in a flexible, complementary facility that would allow frequent and repetitive exposure to microgravity for a laboratory-type of payload. ESA has therefore undertaken a study of the potential of using a 'ballistocraft', a small unmanned aircraft, to provide a low-cost facility for short-duration (30 – 40 seconds) microgravity experimentation. Fokker Space & Systems performed the study under an ESA contract, supported by Dutch national funding.**

**To assess the ballistocraft, a simple breadboard of the facility was built and flight tests were performed. The ability of the on-board controller to achieve automated parabolic flights was demonstrated, and the performance of the controller in one-g level flights, and in flights with both zero-g and partial-g setpoints, was evaluated. The partial-g flights are a unique and valuable feature of the facility.**

## Introduction

A wide range of scientific disciplines use microgravity as a tool to investigate the influence of weight on systems. Those disciplines include both life sciences and physical sciences. The systems concerned are of highly different complexities, ranging from the whole human body to the level of molecules in fluids, for instance. The duration of the microgravity periods required by this variety of research fields varies from seconds to days, to months and even to years.

A period of uninterrupted microgravity longer than about 30 minutes can in practice only be achieved in orbital flight. Shorter periods can be obtained using ballistic rockets (5 – 15 minutes), aircraft flying parabolic trajectories (tens of seconds) and drop towers (seconds). Although they are limited in scope, many studies can be performed with only tens of seconds of microgravity. In particular, these studies involve acute changes in human physiology as well as studies in cell and molecular biology, in fluid sciences, in combustion and in solidification processes.

Although seconds of microgravity can be generated in many ways, the most attractive way from the scientific utilisation point of view is to use a facility that is available readily on a daily basis. An example of such a facility is the drop tower in Bremen, Germany, which delivers 4.7 seconds of high-quality microgravity and allows one or two experiments to be performed daily. If the microgravity 'generator' is only available during a so-called 'campaign', as with sounding rockets or manned aircraft, and a number of users must be accommodated at the same time, the facility's accessibility diminishes considerably.

These considerations were the basis of the idea for the ballistocraft, a small unmanned jet-powered aircraft that would fly through pre-programmed parabolic trajectories. It would be especially suitable for biological, fluid science, combustion and solidification studies. It would fly at relatively high altitudes, producing microgravity periods in the order of 30 to 40 seconds, and be operated on a daily basis. Passive, semi-automatic or automatic, teleoperated experiment hardware of laboratory-type quality could be carried several times per day. This would introduce a method of microgravity experimentation that resembles typical laboratory practice.

This paper describes the results of a study performed with a reduced-scale ballistocraft, a model airplane used to assess the feasibility of the ballistocraft.

**What is a parabolic flight?**

Microgravity acceleration levels are obtained by generating free-fall conditions. An object is subject to free-fall conditions when no forces other than gravity are acting on it. Those conditions can be achieved when the object is continuously free falling in orbit around the Earth on board a satellite, free falling in a sounding rocket with the engine turned off or, more simply, free falling in a drop tower. Free-fall conditions can also be generated when an aircraft flying along a ballistic trajectory, compensates for the aerodynamic forces acting upon it, namely:

— the aerodynamic drag, which is created by the air's resistance to the motion of the aircraft
— the aerodynamic lift, which enables the aircraft to sustain its weight and to fly.

Compensation for the drag is obtained by properly tuning the engine thrust. Cancellation of the lift requires proper adjustment of the control surfaces of the aircraft.

When an aircraft is subjected to free-fall conditions, it flies along a parabolic trajectory (see 'Microgravity Research During Aircraft Parabolic Flights: The 20 ESA Campaigns' in this issue). Thus, the manoeuvre is called a parabolic flight — it is a well-known way of obtaining free-floating or micro-g conditions for microgravity investigations. An important parameter is the maximum duration of the free fall. Since the drag rises proportionally to the square of the airspeed, there is a maximum speed at which the aircraft engine can cancel the drag. In theory, the maximum period of zero-gravity is obtained when the initial velocity is directed straight upward, but this is not feasible in practice using a conventional aircraft.

This limitation drives the choice of the parabolic flight sequence (the sequence is illustrated in Fig. 2 in the 'Microgravity Research During Aircraft Parabolic Flights' article). Starting from a normal level flight or a dive at maximum airspeed, the aircraft first enters a pull-up manoeuvre. At a steep climb angle (typically 50 degrees to the horizontal), the controls are set to cancel the aerodynamic forces, and the aircraft is put into a parabolic trajectory. The zero-g trajectory ends at a diving angle similar to the initial climb angle. It is followed by a pull-out manoeuvre which returns the aircraft to level flight.

During the pull-up, the aircraft is in a hypergravity state, experiencing a load factor of typically 1.8 g, i.e. its apparent weight is 1.8 times higher than its normal weight on Earth. During the parabola, the aircraft is in a microgravity condition, i.e. its payload appears to be weightless.

A classical example of a 'parabolic aircraft' is the ESA/Novespace Caravelle. That plane is flown manually through parabolas, starting at an altitude of typically 10 km and an initial speed of 600 km/h and reaching a maximum altitude of 11 km. A parabola typically lasts 20 seconds.

The Caravelle flights are executed in 'campaign mode'. Despite their low threshold of access, substantial organisation is required and many experimenters have to be served simultaneously on each flight. Compared to the normal laboratory routine, the flights are relatively infrequent and cannot be tailored to the needs of individual experimenters.

**Purpose of the study**

To assess the feasibility of a novel concept of generating microgravity conditions using the aircraft principle, ESA undertook an investigation into the use of small unmanned aircraft that perform parabolic flights in an automated way, guided by an on-board control system. A new term, 'ballistocraft', was coined for such a facility.

Such ballistocraft would provide the microgravity community with a complementary facility that could provide repeated and frequent microgravity exposure. The facility must be operable on a daily basis and must allow for the following:

— Full use of laboratory hardware in the experiments
— A 'taxi' mode of facility operation, i.e. quick turnaround based on runway landing
— Dedicated acceleration profiles, including partial-g, for each experiment.

To assess the feasibility of the concept, a simple breadboard of the facility was built. It was also used to obtain a hands-on feeling for the technical and operational possibilities. One of the aspects examined in detail was the use of the ballistocraft for generating arbitrary preset g-levels, i.e. not only microgravity conditions but also, for example, g-levels corresponding to lunar or Martian environments. The breadboard was called 'BAR-1', meaning 'Ballistocraft for Acceleration Research - 1'. Future developments will hopefully extend the BAR lineage.


Figure 1. The BAR-1 aircraft (bottom), a scaled-up version of a model aircraft, beside a Fokker 100

The main objectives of the study were to deliver the design specifications for a full-scale facility, and to estimate the cost to be charged to the user. The study was performed by Fokker Space & Systems (The Netherlands) under an ESA contract, supported by Dutch national funding (through NIVR, The Netherlands) for the breadboard development.

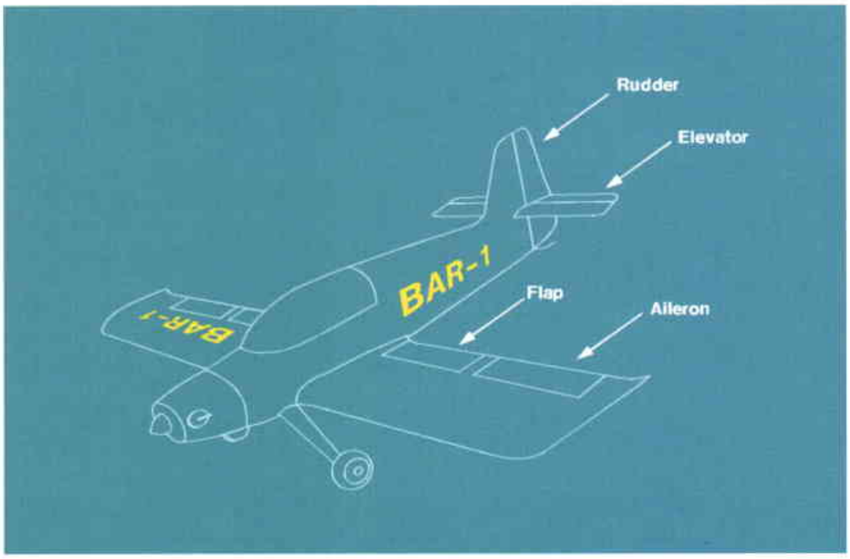
### The flying breadboard

The BAR-1 aircraft

The BAR-1 aircraft is basically a scaled-up version of an existing model aircraft design (Fig. 1). It has a conventional layout with a fixed tailwheel undercarriage.

During the non-parabolic flight phases, such as take-off and landing, the aircraft is controlled remotely via a standard model radio-control set. It carries a sensor package, an on-board controller of the IBM-PC type, and a telemetry transmitter. The on-board computer's autonomous access to the commanding of the aircraft actuators is enabled and disabled via a spare radio-control channel by the remote pilot. Autonomous flight was used for both zero-g and partial-g automated parabolic flight manoeuvres, and also for dedicated parameter identification manoeuvres such as elevator block inputs.

Figure 2. Location of the BAR-1's control actuators




Sensors were fitted to measure the following parameters during flight: accelerations and angular rates for the three control axes; true airspeed; air temperature; aircraft angle of attack; and all actuator positions. The actuators are on the engine throttle and on all aerodynamic control surfaces of the aircraft, including the flaps (Fig. 2). The on-board computer, with a control cycle of 32 Hertz, reads all sensors, performs the mode and control calculations, commands all actuators, archives sensor data and commands in RAM memory, and sends a formatted telemetry packet.

The ground equipment consists of a standard model radio control set, a telemetry receiver connected to a portable IBM-PC acting as a ground station, and a separate disk drive which can be connected to the on-board computer via an umbilical cable. The telemetry display program on the portable PC shows all measured and commanded data in real-time. Before and after flight, the portable PC doubles as a remote console for the on-board computer via the same umbilical cable connecting the disk drive. Commands can be given to start up the flight software from the disk, or to copy the RAM disk file of data collected in flight to the diskette.

Figure 3 shows a functional overview of the BAR reduced-scale facility.

Three main software modules have been developed in object-oriented Pascal. They have the following functions:

- Ground support software acting as a remote console to the on-board computer:
  - Load and start on-board software
  - Save flight-recorded data (copies on-board computer RAM disk file to diskette).
- On-board (embedded) software:
  - Perform data acquisition
  - Control the aircraft during its automated manoeuvres
  - Send the formatted telemetry to the ground.

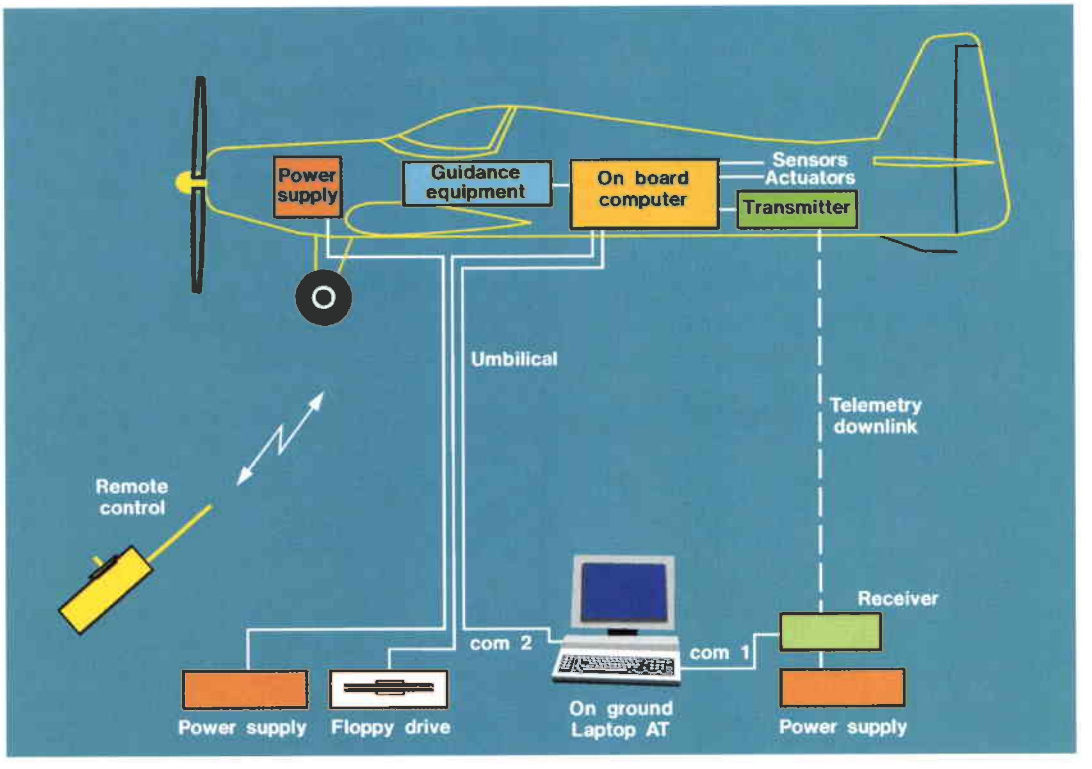



Figure 3. A functional overview of the BAR reduced-scale facility

— Ground support software for telemetry:
 — Receive (and synchronise) telemetry
 — Interpret telemetry and display to a full-screen telemetry page.
 — Save the telemetry data to disk.

The two ground station functions are performed from a single application, via a single user interface.

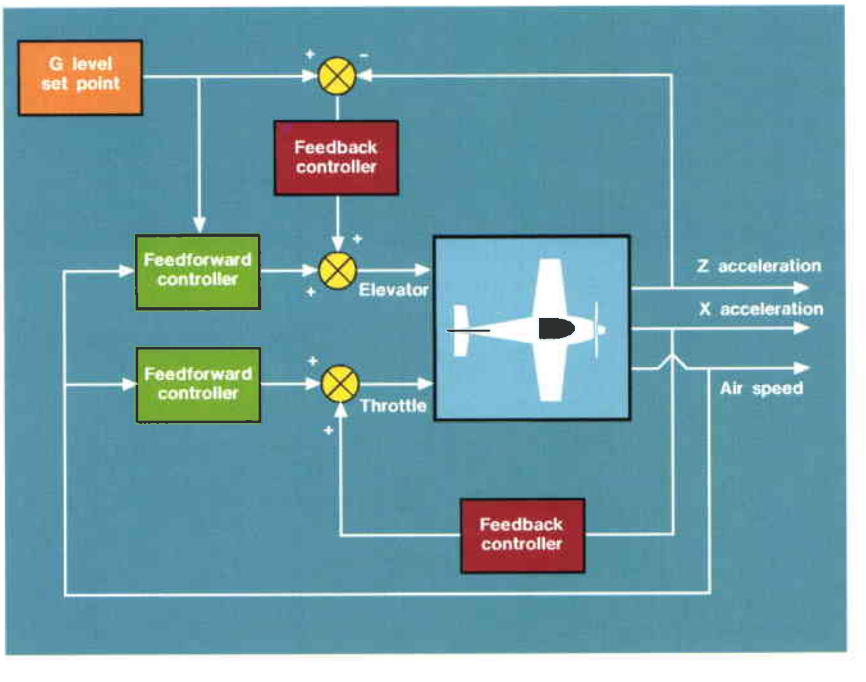
### The BAR-1 g-level control laws

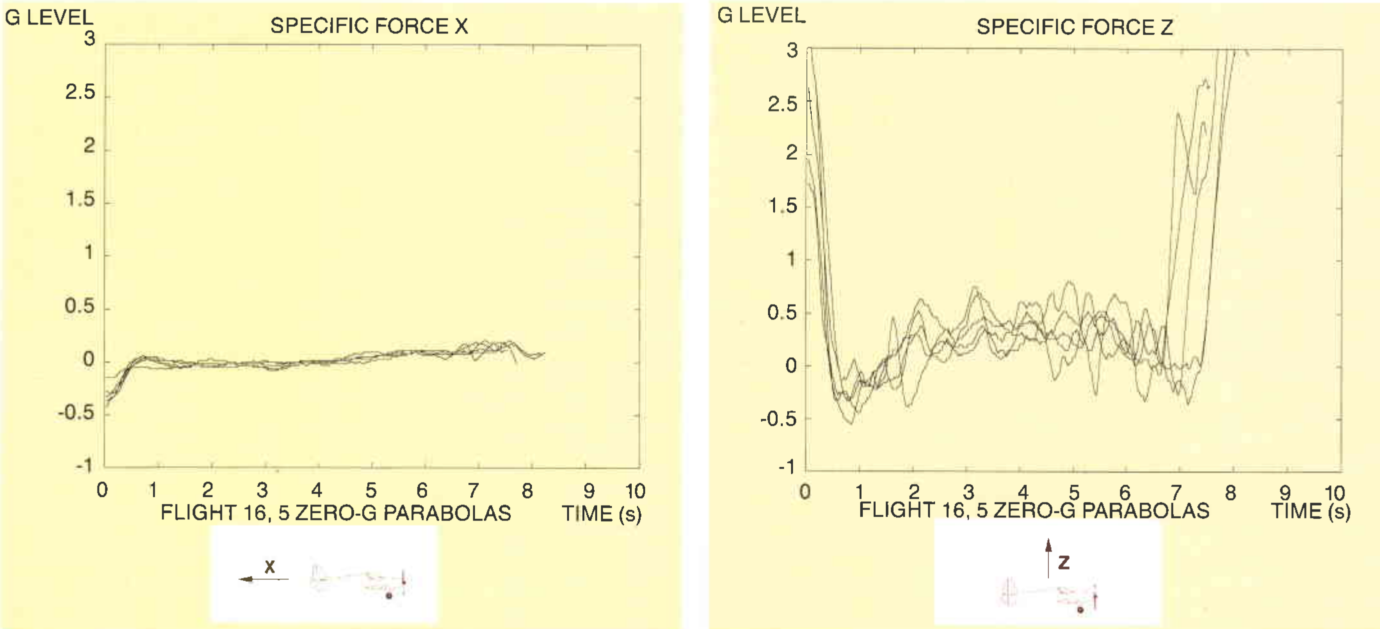
A number of control laws, i.e. different ways of controlling the aircraft, have been studied in the course of the project. The best control laws were found to be based simply on feedback of the measured accelerations. Drag compensation is obtained by tuning the throttle of the engine so that its thrust equals the aircraft drag (zero specific force along axial flight direction). Cancellation of the lift is obtained by proper control of the elevator (zero specific force along normal direction to the flight direction). Theoretical simulations have shown that g-level accuracy under ideal conditions is of the order of 0.01 g. This controller can be used to maintain any g-level setpoint, i.e. from zero-g up to maximum-g pull-ups and pull-outs.

Robustness simulations indicate that controller performance is sensitive to actuator performance, in particular to the response time and to the positioning accuracy. Since the standard radio control model actuators of the breadboard are very limited in performance, the ideal feedback control law was complemented by a feed-forward scheme based on some *a priori* knowledge of the aircraft (Fig. 4). Some test flights were devoted to determining the elevator setpoint for zero lift and to obtaining the throttle setpoint function for compensation of drag at different speeds.

Based on these measurements, a control law was implemented on BAR-1 with the following elements:
— A closed loop control over actuator positioning (to improve the accuracy of the actuator)
— An elevator setting as a function of g-level and airspeed
— A throttle setting as a function of airspeed.

Figure 4. Overview of the architecture of the BAR-1 onboard controller






(5a) (5b)

**Figure 5. Accelerations obtained along the X-axis (a) and the Z-axis (b) for a 0 g setpoint**

Control of the out-of-plane motion was not implemented; it is achieved by remote control of the aircraft ailerons.

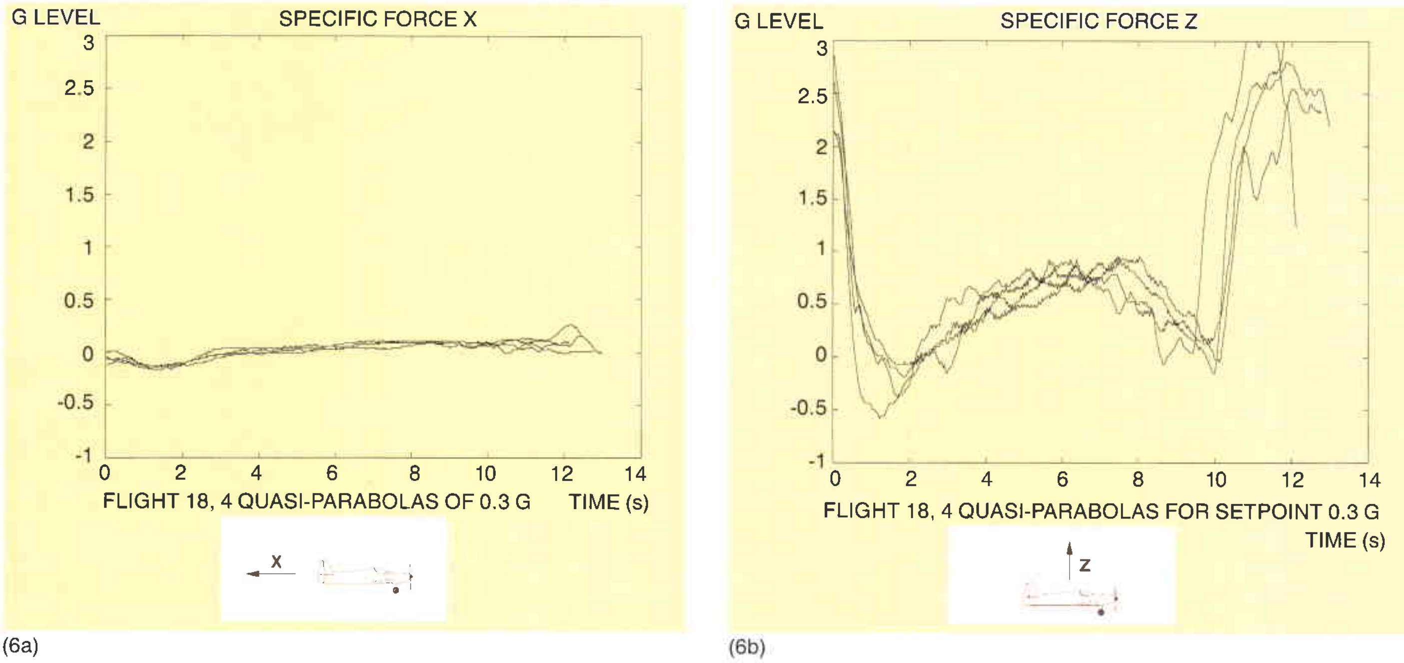
## Test flights

The BAR-1 craft was flown through 18 test flights at the Ypenburg airfield, near Delft in The Netherlands. After some flights for aircraft identification purposes, parabolic flights were successfully performed automatically by the on-board controller.

Figure 5 shows the accelerations obtained along axial (line of flight) and normal (wing lift) directions for a zero-g setpoint. Variations in g-level can be attributed directly to gust effects on the aircraft. This was confirmed by correlating acceleration data with readings obtained from the angle of attack sensor. The small size of the aircraft also makes it sensitive to gusts. In addition, the limitations of line-of-sight flying with a remote control radio set means that the flights were done at very low altitude where substantial turbulence occurs. Apart from the gust disturbances, the zero-g parabolas were quite consistent, with all recordings exhibiting the same behaviour in the acceleration profiles. The duration of the zero-g period matched that obtained in simulation exercises.

Figure 6 shows a test flight result for a setpoint of 0.3 g. The flight pattern can be repeated, but it does not show a completely constant acceleration profile. Zero-g flights appear to be easier to control than partial-g flights. This effect had been anticipated. It follows from the fact that for non-zero-g (i.e. non-zero lift) flights, the nominal elevator settings during the manoeuvre vary with the inverse of the square

**Figure 6. Accelerations obtained along the X-axis (a) and the Z-axis (b) for a 0.3 g setpoint**




(6a) (6b)

of airspeed, whereas for zero-g (and hence, zero-lift) flight, the nominal elevator setting is almost a constant value. More knowledge of the aircraft and better actuator performance is therefore needed for partial-g flight than for zero-g flight. In the present test flights, only a very simple *a priori* control law and simple actuators were implemented for the elevator channel. The resulting performance is accordingly biased.

These test flight results validated the automatic parabolic flight concept. Taking into consideration that the aircraft used is not at all optimal for flying the trajectories imposed, it was quite remarkable to obtain the g-level and durations depicted in Figure 5. Improving only the actuator response time to allow better gust suppression would already produce a small-scale facility that would be of potential interest to a number of fields of microgravity research.

These results therefore provide confidence that the envisaged full-scale facility, being a dedicated airframe capable of flying at altitudes with relatively quiet atmospheric conditions, will be able to maintain preset sub-g conditions of good quality for several tens of seconds.

### Lessons learned

The flying breadboard has provided valuable information on critical areas in the design of an unmanned parabolic flight facility. On the hardware side, actuator performance parameters (accuracy, response time) were identified as being critical to the performance of the facility.

Control algorithms and software design have been partially validated. A satisfactory performance was achieved within the limits of the hardware. Real flight experience has been shown again to be the most valuable validation tool available. Every new step in the flight programme (identification flights, zero-g flights, and partial-g flights) has yielded new information, which simulation would probably never have provided.

Practical operational experience with the aircraft has shown that a well-organised flight can be performed very quickly, and re-flights can be done in a matter of minutes. This quick turnaround time, during which the aircraft is refuelled and, if necessary, adjustments are made to the payload or a new g-level profile is loaded into the computer, resembles exactly the operational scenario foreseen for the full-scale facility. To accomplish such a scenario, it is essential that the aircraft takes off from a runway and lands on a runway using a reliable automatic system.

Such a requirement disqualifies most of the unmanned drones used for military applications, which are usually designed for rocket booster launch and parachute recovery. The full-scale ballistocraft must therefore be a dedicated platform that performs automatic runway take-offs and landings, and requires a minimum of specialist ground crew. Only then will it provide the science community with an easily accessible platform that can be used on a daily basis and at an affordable price.

## BAR Next: Toward a full-scale facility

### Requirements

The full-scale facility should be a platform capable of exposing a payload with a mass of 50 – 100 kg to a free-fall condition of 30 – 40 seconds' duration and 0.001 g accuracy. Partial g levels should also be possible.

The facility should be continuously available and not by means of organised campaigns — a so-called 'taxi' mode of operations.

The platform should accept experiment hardware of ground laboratory quality that can either be passive, semi-automatic or automatic and/or tele-operated from ground. Hence, the capability for experiment telemetry and telecommanding shall be built into the ballistocraft's design.

### Aircraft characteristics

The main performance requirements for the aircraft are that it can achieve a high maximum speed and that it has a low sensitivity to gusts. The effects of gusts can also be minimised if the aircraft is able to fly at altitudes where the air is smooth. For a conventional fixed-wing design, these requirements bias the design to the selection of a small wing area with a delta shape, and to the use of a turbojet engine.

The operational requirements for the airframe are:
- A quick turn-around time
- Re-flights are easily organised
- A minimum number of maintenance crew is required.

These requirements are best served by an aircraft capable of automatic runway take-off and landing. An example of such an aircraft is shown in Figure 7; it is the outcome of a preliminary design study undertaken jointly by the Delft Univeristy of Technology (The Netherlands), the Sir Lawrence Wackett Centre for Aerospace Design (in Melbourne, Australia), and Fokker.

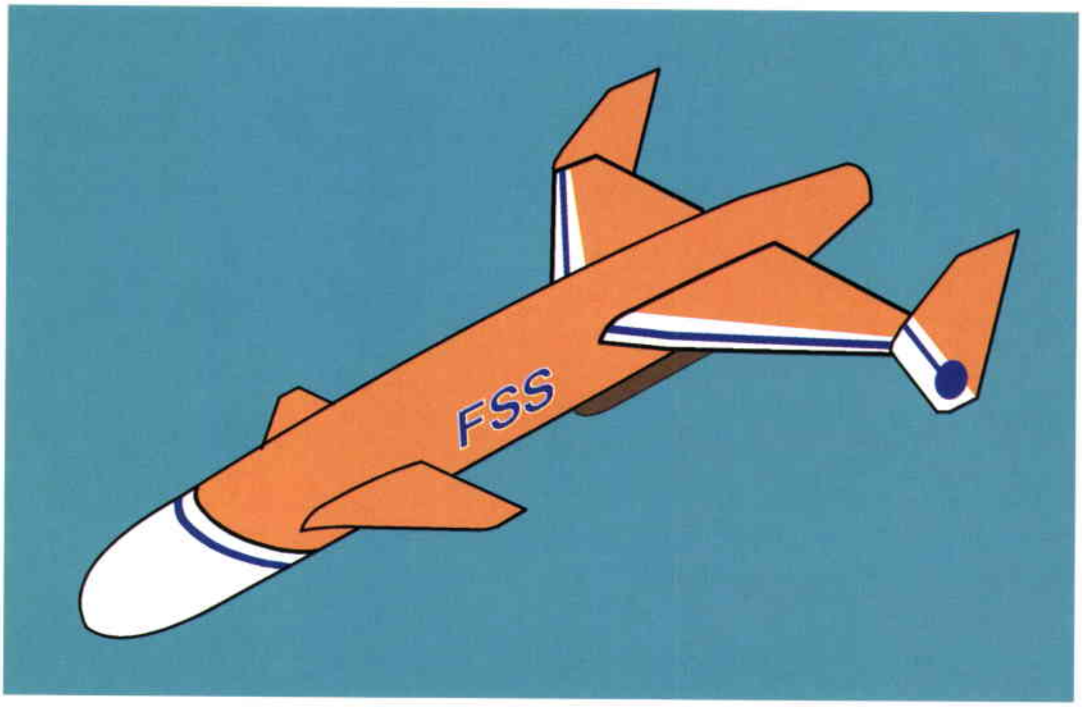



Figure 7. A proposed preliminary design for the BAR-1 Next aircraft, based on a study undertaken by the Delft University of Technology (NL), the Sir Lawrence Wackett Centre for Aerospace Design (Australia) and Fokker (NL)

The systems design of the BAR-Next craft must include:
- High-quality sensors and actuators
- A low-g fuel supply system, and engine lubrication
- Retractable landing gear
- Automated landing guidance.

The last two requirements determine the feasibility of the automatic runway landing, and are considered key items in the development of a commercially viable, full-scale, unmanned ballistocraft facility.

### Instruments and ground system

The existing flight instruments and ground systems technology is sufficient in general for the needs of BAR Next, but the quality of the instrumentation, in particular the accelerometers and actuators, should be relatively high. The automatic take-off and landing will be implemented using differential GPS (Global Positioning System) and radar altimeter, in combination with a normal inertial guidance system.

On-board control algorithms and software form an essential part in the development of the facility. Experience in flying the breadboard has strongly confirmed the general industry experience, that there is no substitute for flight-testing the actual software and hardware. Typical steps in the development are first to use simulation (preferably including hardware-in-the-loop testing), and then to test-fly the system on a manually-controlled aircraft, before integrating the guidance system into the unmanned flight platform. Fokker's current cooperation with the Delft University of Technology will be expanded into flying the envisaged hardware and software on the Cessna Citation business jet aircraft, owned jointly by Delft University and the Dutch National Aeronautical and Space Laboratory (NLR). This aircraft is currently being converted to a fly-by-wire testbed with full digital computer control, with an option to couple experimental hardware to the system.

The ground segment will make use of existing facilities, currently in use for tracking unmanned aircraft and missiles. No new developments are foreseen in this area.

### Experiment accommodation

The experimenter will be provided with a proper experiment infrastructure, both within the aircraft and on the ground. This includes such items as a power supply and a telemetry/telecommand link.

It will be very useful to provide a payload interface that is compatible with that existing for sounding rockets because of the many excellent experiment facilities that have been developed for these carriers and that serve similar short-duration microgravity studies. Investigations in cell biology, fluid dynamics and combustion could then be simply extended with ground laboratory-like research of questions requiring the periods and levels of hypogravity provided by the ballistocraft.

### Legal aspects

The accessibility of the facility will usually entail flying near populated areas. This introduces several legal aspects, including the use of airfields, operator certification, and mixing with other traffic in controlled airspace. Flying into free, uncontrolled airspace on a 'see and be seen' basis is not feasible, due to the insufficient quality and reliability of current telemetry vision systems. Flying within controlled airspace will be allowed by the authorities, provided that the aircraft carries a transponder for aircraft identification to radar stations.

A possible flying site has been identified on the Dutch coastline, near Den Helder. A flying area of restricted, controlled airspace is available directly over the North Sea; it extends from sea level to all altitudes. Other flying sites within Europe that have been considered are test ranges in Spain (CEDEA, near Huelva) and in Italy (PISQ, Sardinia).

### Financial aspects

The main factors affecting the cost of the ballistocraft facility are:

— Mission reliability and the aircraft's service life
— The size of the crew required to operate the facility.

A runway-landing drone is the enabling factor in both respects. Mission reliability and the aircraft's service life determine the hardware cost per flight. With automated runway take-offs and landings, repeated flights can be made very cheaply and safely. The only consumable needed basically is the fuel. If no landing damage occurs, the aircraft can have a long service life. The size of the crew required for a runway-landing drone is expected to be two to three persons.

These figures compare favourably with those for current, military unmanned aircraft, which typically have rocket launch and parachute recovery, entailing the extra cost of expendable booster rockets and parachute recovery. Building a runway-landing drone with the same technology will result in a system that is safe and cheap to operate and, at the same time, can make use of the existing infrastructure in terms of flying sites, ground stations and tracking equipment. The combined result is a system that will typically be cheaper to operate on a per flight basis than a manned aircraft, and which brings, as a bonus, all the other advantages of a small unmanned aircraft, including partial-g capability, quick re-flights, and easily adaptable mission profiles, in short, the 'taxi' notion of operational flexibility inherent in a small system.

## Conclusion

The study results have demonstrated the feasibility of a ballistocraft facility, emphasising the following desirable characteristics:

— The system follows the 'taxi notion', i.e. simple operation, easy access, immediate re-flight capability, and affordable operation costs.
— The system is especially suited to special mission profiles, including partial-g flight.

A flying breadboard was used to demonstrate autonomous operations and to refine the requirement description. Although the performance of the breadboard was limited by the simplicity of its instrumentation, useful operational and technical experience was gained through many autonomous flights. These flights have included various test manoeuvres and both zero-g and partial-g parabolas with automated entry and recovery (pull-up and pull-out).

Larger and faster ballistocraft, with state-of-the-art aircraft-quality instrumentation offer a promising perspective to the user community. Technical and legal feasibility seem unproblematical. Commercial feasibility is a function of the expected utilisation rate, and of the size of the crew needed. For a fully operational system, a decided cost advantage relative to manned flight is expected. In addition to this cost advantage, the system will be an attractive option in terms of flexibility and accessibility, especially for small autonomous payloads and telescience operations.

## Acknowledgements

The authors would like to thank the students M. Veltena and J.W. Zaalberg from TU Delft (The Netherlands) and I. Zago from Supaero (France) for their contributions to the study.

# The Atmospheric Reentry Demonstrator (ARD)

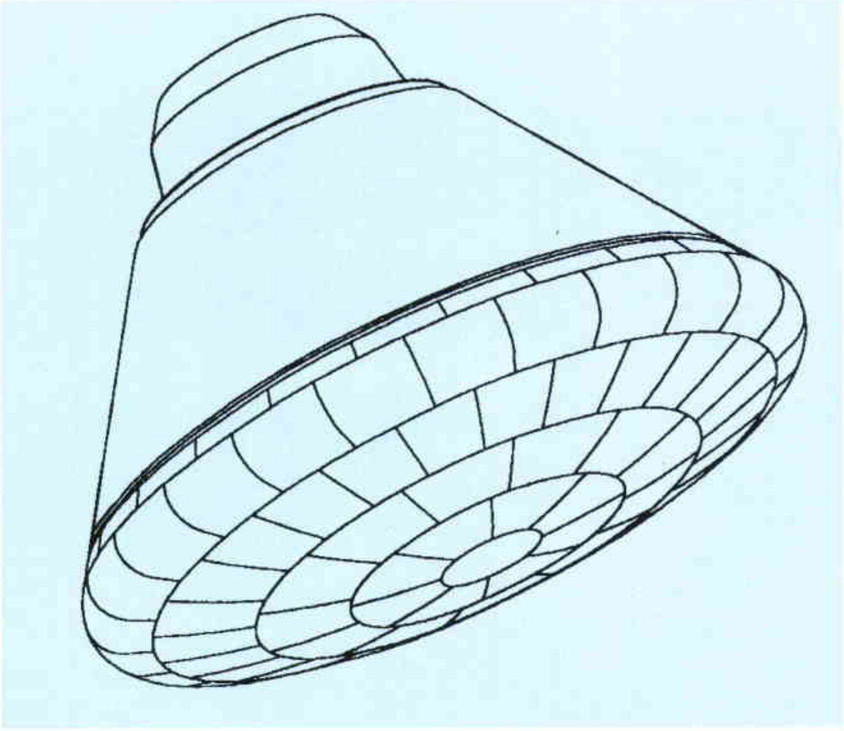
## – A Flight Experiment for Technology Qualification within the European Manned Space Transportation Programme (MSTP)

**Ch. Cazaux, Ph. Watillon, G. Durand & the ARD Team**
ESA/CNES Manned Space Transportation Programme Team, Toulouse, France

### Introduction

Although not strictly a prototype of the future European Crew Transport Vehicle (CTV), the ARD project will constitute a major step towards providing greater confidence in Europe's development capabilities. It is a simple unmanned capsule-type vehicle designed to improve our knowledge of certain critical reentry technologies.

**After several years of theoretical work on manned space-transportation systems, it has been decided to consolidate Europe's technological knowledge by conducting a flight-demonstration project within the Agency's Manned Space Transportation Programme (MSTP). The second qualification flight of Ariane-5 (V502), planned for April 1996, will carry an Atmospheric Reentry Demonstrator (ARD), for reentry technology experimentation. Industrial responsibility for the ARD project rests with Aérospatiale of France, as prime contractor**



To save time by avoiding the need for a long aerothermodynamic shape selection process, an existing shape has been selected. Dimensions and masses have been derived based on Ariane-5 performance capabilities and on ballistic reentry parameters representative of the CTV.

The technology-demonstration objectives are as follows:

- qualification of theoretical aerothermodynamic predictions
- qualification of the thermal-protection-system design and of some TPS materials
- in-flight assessment of navigation/guidance/control software performances
- in-flight assessment of parachute-system design.

Some other challenging issues stem from these primary objectives, such as:

- vehicle location and recovery
- in-flight measurement technology
- measurement telemetry and storage technology
- communication during reentry.

### Mission and overall design

The ARD vehicle has an external diameter of 2.8 m (Fig. 1) and a maximum mass of 2.8 t. After its release from the launcher, it will perform a sub-orbital ballistic flight, followed by a guided lifting reentry, ending with a final deceleration phase under parachutes and a splash-down in the Pacific Ocean (Fig. 2).

The main driving parameters of these different phases are shown in Table 1.

**Figure 1. The ARD vehicle**

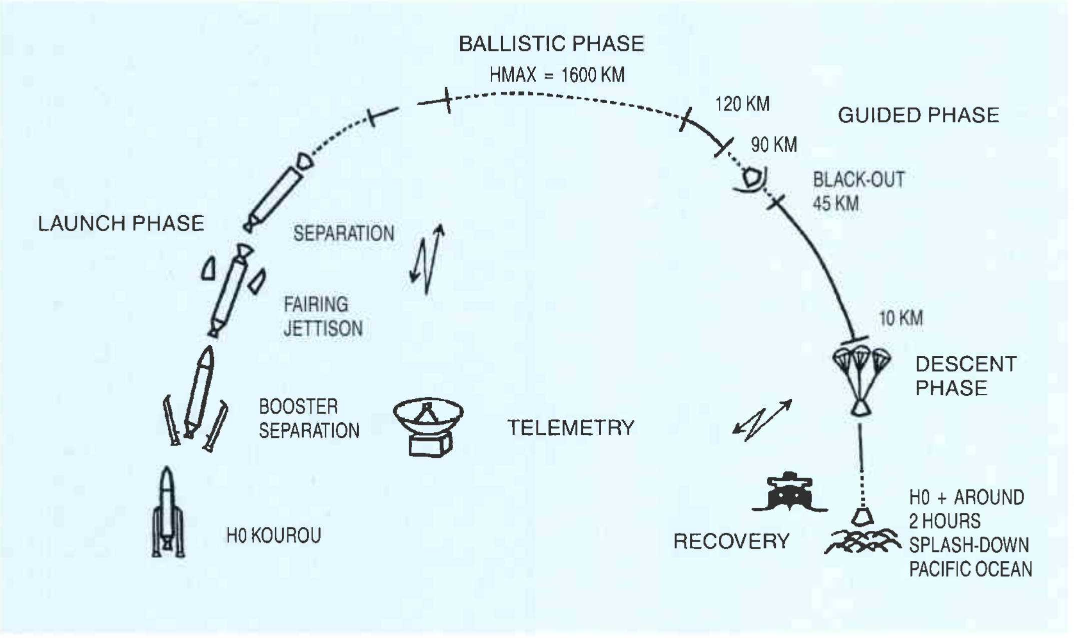



**Figure 2. The overall ARD mission**

### Structure

The pressurised, air- and water-tight structure is composed of four main elements (Fig. 3): the bulkhead structure including radial stiffeners and supporting the heat shield; the conical part carrying the Reaction Control System (RCS), including access doors to equipment items and the Ariane-5 mechanical interface frame attached via a bolted flange; the internal hexagonal secondary structure supporting all electrical equipment; and the back cover ensuring protection of descent and recovery systems during the flight.

All structural elements are made of mechanically fastened aluminum-alloy parts.

**Table 1. Main mission drivers**

*Ballistic phase*
- EPC propulsion up to 739 s and 214.8 km
- apogee 1603.4 km, perigee 36.7 km, and inclination 9.4°

*Reentry point*
- reentry at 120 km and 5791 s
- relative velocity 7737 m/s
- flight-path angle −3.0°
- longitude −121.3°
- latitude 9.4°.

*Parachute-sequence initiation*
- altitude 9.4 km at 6368 s
- relative velocity 151.2 m/s
- longitude −98.8°
- latitude 8.39°

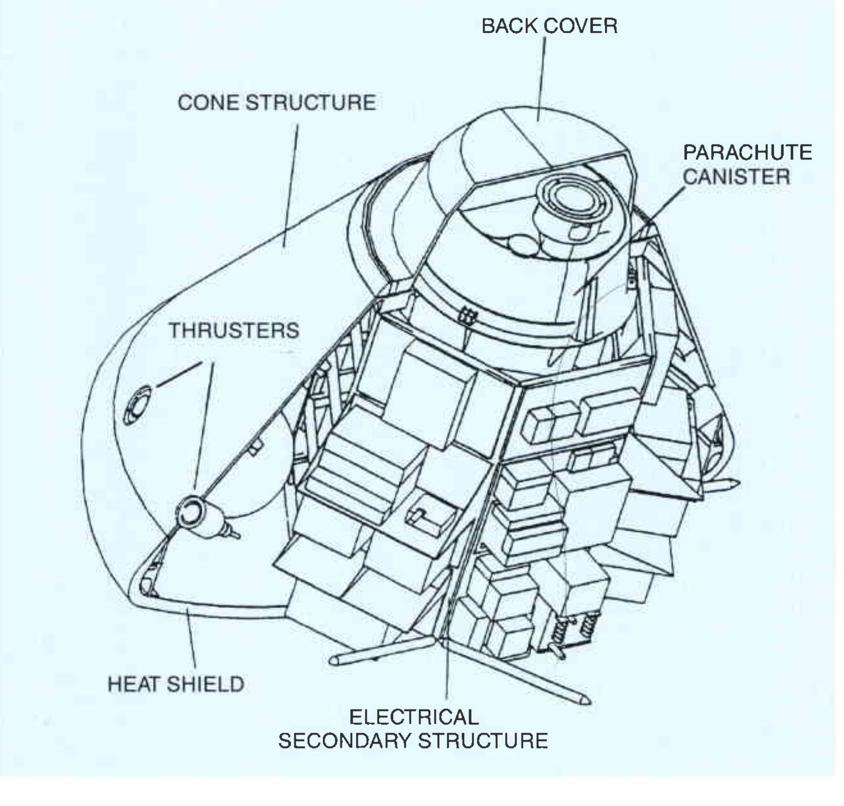
### Thermal protection

The heat shield is composed of 93 tiles made from 'Aleastrasil', a compound containing randomly oriented silica fibres impregnated with phenolic resin. These tiles are arranged with one central tile and six circumferential rows (Fig. 1). The conical part and back cover are covered with 'Norcoat-Liège' tiles.

### Reaction Control System

The Reaction Control System (RCS) will provide attitude control during the ARD's ballistic and guided reentry phases. It is derived from the

**Figure 3. The ARD structural design**



Ariane-5 attitude-control system (SCA: Système de Contrôle d'Attitude), based upon a hydrazine ($N_2H_4$) blow-down concept, and is composed of:

- two $N_2H_4$ tanks and one $N_2$ repressurisation tank
- seven thrusters, with one flow-control valve for each
- an additional set of valves.

### Electronics
The electronics system is also based on the reuse of existing Ariane-5 equipment, i.e.:

- data processing and transmission for flight control and communications provided by one OBC (On-Board Computer) and a 1553 Bus
- sequential orders execution through one ES (Electronique Séquentielle) and one CDC (Centrale De Commutation)
- navigation through one SRI (Système de Référence Inertielle)
- power generation and distribution covered by three NiCd batteries and one BDP (Boîtier de Distribution de Puissance).

### Communications and location
The communications and location system, designed to process, store and transmit data to the ground segment during the ARD's flight, is composed of:

- measurement processing and multiplexing including two UCTMs (Unité de Contrôle et de Télé-Mesure) and one UA (Unité d'Acquisition)
- data transmission by two transmitters
- on-board data recording on two solid-state memory recorders
- location is ensured by one GPS (Global Positioning System) receiver in addition to inertial navigation
- seven antennas (six for telemetry, one for GPS link) located on the heat shield (two) and on the cone (five).

### Descent and recovery
The descent and recovery system is designed to decelerate the vehicle (Fig. 4) before splash-down in order to limit the impact loads and to ensure flotation for up to 36 h.

Its elements include:

- the canister containing the various items listed below
- a mortar and a pilot chute (diam. 0.91 m) for initiating the first stage of deceleration by deploying a drogue chute (diam. 5.80 m)
- a cluster of three slotted poly-conical main chutes (diam. 22.90 m)
- two balloons and associated pressurisation items for flotation
- a SARSAT beacon.

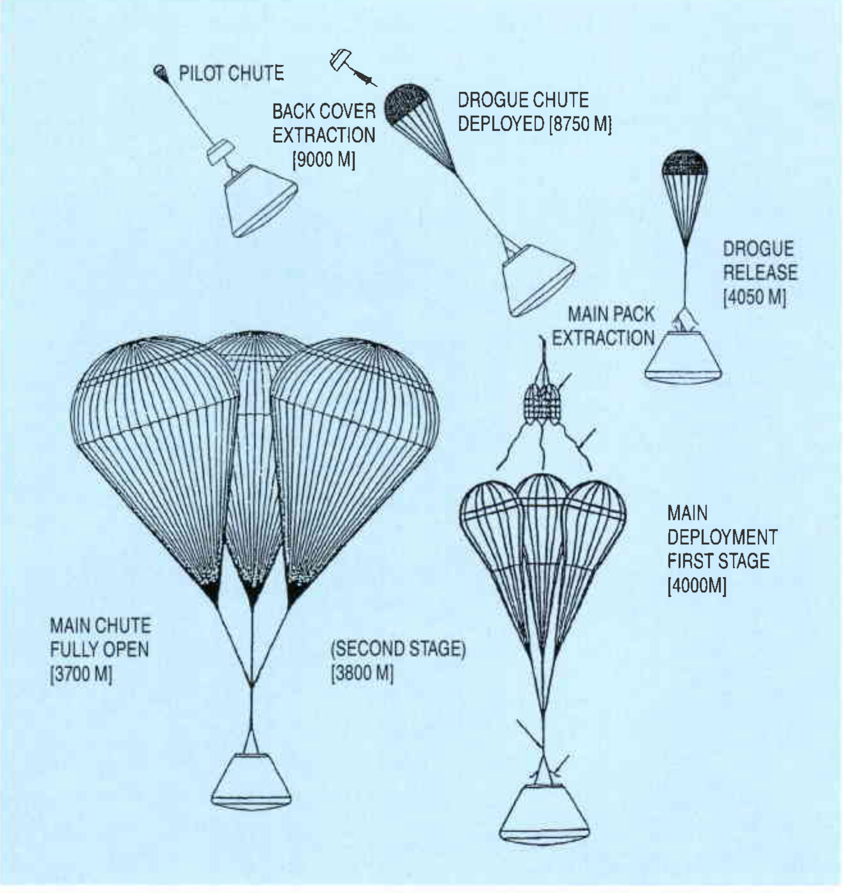



**Figure 4. The parachute deployment sequence**

## Coverage of technology objectives
To cover other technology objectives, the ARD vehicle will be equipped with a significant number of measuring devices. Depending on the nature of the measurement, the data will be: transmitted by telemetry antennas (actual emission rate around 250 kbit/s) during periods of visibility, i.e. mainly just before black-out and less than 45 km after black-out, otherwise stored by UCTM during black-out; or stored (all measurements during the entire mission) by the on-board recorders.

### On-board measurements
The following measurements will be implemented on the ARD (Table 2). In addition, a few functional measurements (equipment temperatures, mission sequences, etc.) have to be taken into account, leading to a total of around 200 measurement channels. The positions of the surface measurements on the vehicle itself have been optimised to meet the technology goals, as discussed below.

### Flight conditions
The flight conditions will be derived from redundant information sources, including:
- reconstruction of the flight trajectory with an inertial measurement unit (the SRI) and GPS

- radar tracking (if available)
- atmosphere characterisation with lidar, balloons and/or rockets (if available)
- pressure measurement on the heat shield
- total angle of attack.

### Aerodynamic coefficients
Information from the SRI and a dedicated tri-axial accelerometer for high altitudes will be used to identify the aerodynamic coefficients. Typical accuracies for the force coefficients will range from 10% at 70 km to 5% at 50 km.

A specific RCS activation plan will be devised to tentatively identify RCS efficiencies as well as derivatives of the aerodynamic coefficient and dynamic stability parameter.

### Aerothermodynamics
Pressure and temperature measurements (Fig. 5) will be used to qualify the pre-flight predictions of heat flux and pressure distributions. The exact locations of these measurements will be finalised based on the actual TPS topology. These temperature-measurement locations will be used firstly for qualification of the thermal-protection material's behaviour, but also to evaluate aerothermodynamic heat fluxes.

Optionally, thermo-indicators could also be used on the cone (temperatures lower than 1500 K) to provide a maximum of temperature mapping and a general overview of the flow-field topology (re-attachment lines, heat flux on protrusions, etc.).

Finally, measurements made on material samples located on the leeward part of the heat shield will be analysed jointly by TPS and gas-surface interaction experts.

### Thermal protection system and TPS material
The temperature history within the basic TPS materials ('Aleastrasil' and 'Norcoat-Liège') will be recorded through four elements instrumented with five thermocouples and ten with two thermocouples (Fig. 5 and Table 2). The six material samples instrumented with four thermocouples will each comprise four Ceramic Matrix Composite (CMC) samples on the heat shield and two Flexible External Insulation (FEI) samples on the cone. The CMC samples will experience heat fluxes as high as 800 kW/m$^2$. The heat fluxes on the FEI samples will range between 45 and 70 kW/m$^2$.

*Table 2. Measurement plan*

| Measurement | Quantity | Remarks |
|---|---|---|
| Thermocouples TPS | 50 | Thermo-drums: – 4 with 5 Tc – 11 with 3 Tc |
| Thermocouples TPS | 12 (6 × 2) | Fluxmeters |
| Thermocouples | 24 (6 × 4) | Material samples |
| Thermocouples | 21 | Internal structure |
| Thermocouples | 14 | RCS nozzles |
| Press. transducers | 15 | Heat shield |
| Press. transducers | 13 | Cone/back cover |
| Press. transducers | 10 | RCS |
| Tri-axial accelero. | 2 (× 3) | Flight mechanics (chute deployment/high altitude aerodynamics) |
| Accelero./gyro. | 6 (2 × 3) | Inertial Measurement Unit (SRI) |
| Accelerometers | 2 | Vibrations |
| Reflectometers | 2 (× 4) | Plasma |
| Strain gauges | 5 | Parachute lines |
| Microphone | 1 | Acoustics |

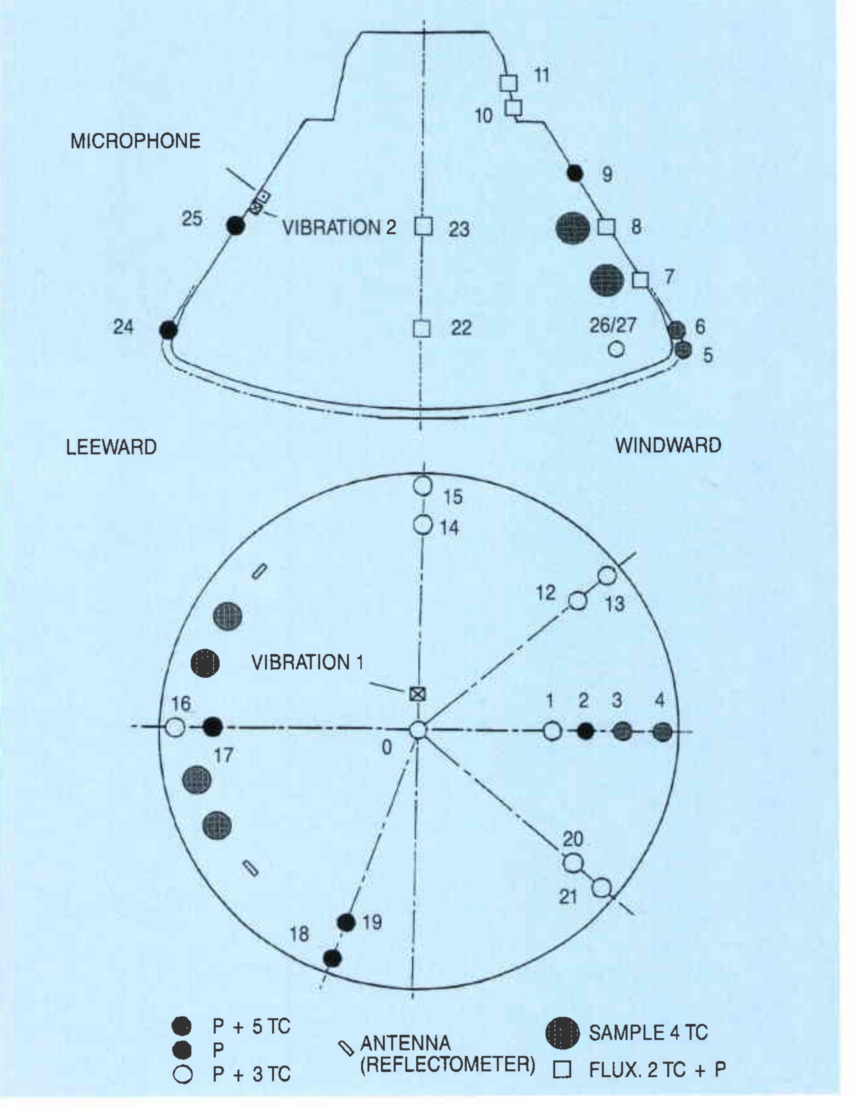



**Figure 5. Measurement-sensor locations on the ARD vehicle**

At all TPS-related measurement locations, thermocouples will be attached to the underlying structure to check the TPS material's efficiency. Analysis of the heat fluxes encountered during reentry and the temperature histories will assist in the post-flight analysis of TPS materials.

### Navigation/guidance/control

An overall assessment of the robustness of the guidance and control algorithms will be made during the flight. The guidance algorithm chosen is an implicit Apollo-Orbiter algorithm based on a reference deceleration profile. This kind of algorithm allows a good final guidance accuracy with limited complexity and storage requirements. However, in order to distinguish dispersions due to the basic navigation system (based on the SRI) from those generated by the guidance function itself, GPS information will be used.

### Deceleration system

Some technology measurements will be made on the parachute system (see Table 2) including the following of all deployment phases with a video camera, a specific tri-axial accelerometer (10 g axial, 2 g transverse), as well as a few strain gauges on main chute lines.

## Conclusions

The ARD should provide a fruitful set of flight data with which to qualify European design, prediction and development tools for reentry scenarios. It represents a major step towards the demonstration of European capabilities to develop, operate and recover such a vehicle.

## Acknowledgement

The ARD Programme has been made possible by a number of contributory factors:

- the considerable industrial experience of Aérospatiale (Prime Contractor) and its direct Sub-Contractors DASA (RCS), Matra-Marconi-Space (communications and location, functional electronics), Alenia-Irvin (descent and recovery), Sabca-Sonaca (structure)
- purchase of and access to a lot of existing soft- and hardware and tools already developed and qualified within the Ariane-5 programme
- the launch opportunity with the second Ariane-5 qualification flight (Apex V502).

# Research Associations for the Development of Industrial Use of Space: The RADIUS Programme

**A.-M. Hieronimus-Leuba & P. Willekens**
Space Commercialisation Office, ESA, Paris, France


**In 1991, ESA launched a programme to promote the industrial utilisation of microgravity: the Research Associations for the Development of Industrial Use of Space (RADIUS) programme. The objective is to create a new user community that will be ready to use future flight opportunities, including the International Space Station, on a commercial basis.**

**Through the programme, leading scientific organisations, experienced in well-defined areas of microgravity research, are identified and given the support required to define and begin undertaking, with non-space industries, several projects that could lead to space experimentation and could bring solutions or improvements to conventional industrial research. ESA provides the seed money to launch the projects and allow the scientific organisations to attract industrial contributions (in cash, kind or manpower).**

**To date, four such research associations or RADIUSes have been formed. They have begun a three-year pilot phase. Within one year of operation, they have succeeded in attracting more than 20 companies to invest in the research projects, and the benefit of the university-industry association is now beginning to emerge.**

## Introduction

In early 1990, an ESA-organised task force, made up of space and non-space industrialists and representatives of national space agencies, recommended that ESA adopt a new approach to expanding the involvement of industrial users in space utilisation. Based on that recommendation and on the experiences of similar NASA initiatives* in the United States and MITI initiatives in Japan, ESA's Director of Manned Space Flight and Microgravity initiated a plan for the promotion of the industrial utilisation of microgravity. The programme, named Research Associations for the Development of Industrial Use of Space or RADIUS, was launched.

The aim of the RADIUS programme is to create a new user community that will be ready to use future space infrastructures on a commercial basis. To fulfil that objective, the RADIUS programme identifies leading scientific organisations, experienced in well-defined areas of microgravity research, and enables them to undertake, with non-space industries, research projects that could benefit from microgravity environmental conditions. The main difference between the RADIUS programme and existing scientific programmes is that, in the case of RADIUS, industrialists propose the subject of experimentation in a field of application where the microgravity parameter could bring additional knowledge and, possibly, new solutions to industrial problems.

## The RADIUS philosopy

Industrial users need an incentive to invest in research projects with potential industrial applications. ESA therefore provides selected leading scientific organisations with 'seed money' to support them in setting up a research association or RADIUS consisting of partners from both university and industry. The RADIUS's Scientific Director, the leading scientist, must attract industrial partners and encourage them to define microgravity-relevant research projects and to invest in kind (with manpower, materials or test facilities) or in cash in those projects. In return, the Scientific Director offers each industrial partner the 'RADIUS service' (see box). In addition to the seed money, ESA provides flight opportunities by giving access to ESA missions or by negotiating with NASA or other space agencies.

As the RADIUS's work progresses and the industrial partners become more and more interested in using microgravity, the RADIUS as a group will participate increasingly in the costs, including the cost of the flight opportunities.

In parallel, ESA has held several discussions with national authorities and representatives of European programmes, such as the EUREKA programme, with the aim of raising additional funding for the RADIUS projects to complement the ESA seed money.

## RADIUS Service

The services offered by the RADIUS Scientific Director to each industrial partner consist of:

- **Scientific data**, collected by the scientific expert from ground-based and microgravity experimentation. In many cases, the scientific expert is associated with another research partner and guarantees the relevance of the microgravity environment to the industrial needs and problems.
- **Technical support** in terms of technical and scientific expertise to define and develop the proper instrumentation and to gain access to microgravity at the lowest cost and in the shortest time.
- **Financial support** by seeking sources of funding at both European and national levels as well as from other industrial partners.
- **Legal support** in order to protect the rights of the companies, through specific contracts between the RADIUS and the industrialists.

## A three-step approach

A step-wise approach to each research project is recommended. The approach involves three phases (Fig. 1):
- Promotional phase
- Pre-commercial phase
- Commercial phase.

During the *promotional phase*, which is already underway, the customers are interested in the RADIUS's research projects but are not yet convinced of the real industrial benefits of microgravity. They participate in the expenses and wait to see whether their requirements can be met. The RADIUS Scientific Director or one of the scientific partners coordinates the microgravity experiment, keeping the industrial objective as a key driver of experimentation. The earlier task force recommended that this period should last about three years, an ideal timeframe for demonstrating the concept on practical grounds and using already planned flight opportunities.

In the *pre-commercial phase*, which would follow if the promotional phase was successful, the customers will have gained confidence and be prepared to pay more. They will contribute to most of the costs, including a share of the cost of the flight opportunities.

By the third phase, the *commercial phase*, the customers will know exactly what they can

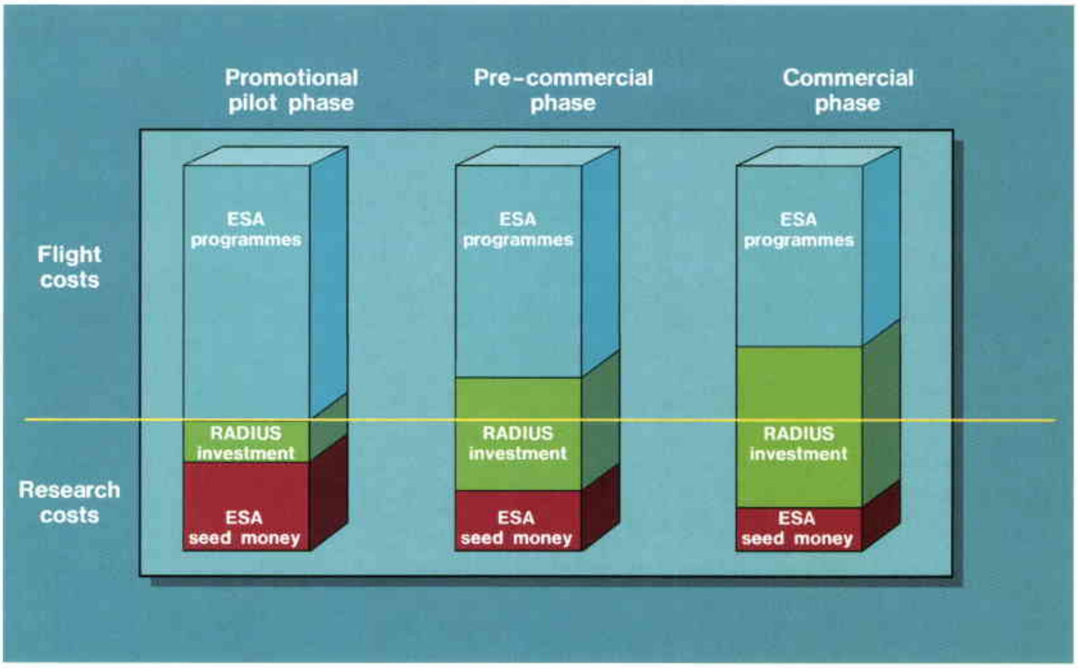



Figure 1. The phases of a RADIUS project and the distribution of the costs

obtain from flight experimentation, and the relevant hardware will be tailored to their requirements and a pricing policy established.

These three phases correspond respectively to the three phases of the Space Station Alpha Utilisation Programme:
— the promotional/pilot phase corresponds to the precursor missions of the Shuttle to Mir (1995 – 1997)
— the pre-commercial phase corresponds to the period of Early Utilisation opportunities and availability of the U.S. Laboratory until the availability of the European Laboratory (1998 – 2002)
— the commercial phase covers the Steady State Utilisation period when the Space Station will be fully operational (after 2002).

This approach requires that the maximum effort is devoted to adapting to the requirements of potential customers and to leading them carefully into the space user community.

**Implementation of the programme**
The RADIUS programme started with the selection of seven leading scientific organisations that are experienced in today's major research areas. Those candidates were given one year to evaluate the feasibility of finding industrial partners and establishing a 'hosting structure' to promote the industrial utilisation of space. The feasibility phase ended in July 1993, and the seven 'RADIUS candidates' proposed their chosen research projects (see box).

At the beginning of 1994, ESA awarded four of the RADIUS candidates contracts for one year to start the pilot phase of the programme. That phase will continue for three years. It will serve to consolidate the university-industry association and to seek complementary funding from European and national sources through concrete research projects.

The RADIUS programme will remain open to the creation of new associations and possibly to topics not yet covered, such as combustion or any other microgravity-relevant themes being investigated under the microgravity programmes of the various space agencies.

**The RADIUSes' progress to date**
The RADIUSes that started their pilot phase activities in 1994 have already shown evidence of significant interest from their industrial partners. All of the RADIUSes have fulfilled the condition of having at least one industrial partner participating in the proposed research project. Moreover, the four RADIUSes have been able to raise an average

**The seven proposed RADIUS research projects**

*Projects now underway:*
— Dispersion and fluid physics (C-CORE of Canada with Belgium, Italy, Norway and UK)
— Protein crystallisation, purification (CEA-IBS of France with Denmark and Italy)
— Zeolites (TU Delft of The Netherlands with Belgium and France)
— Crystal growth (Freiburg University of Germany with France)

*Projects being considered:*
— Human physiology and bone physiology in particular (MEDES of France with The Netherlands and Switzerland)
— Cell and molecular biology (Hubrecht Laboratory of The Netherlands)
— Dispersion and colloids (Fraunhofer ITA of Germany)

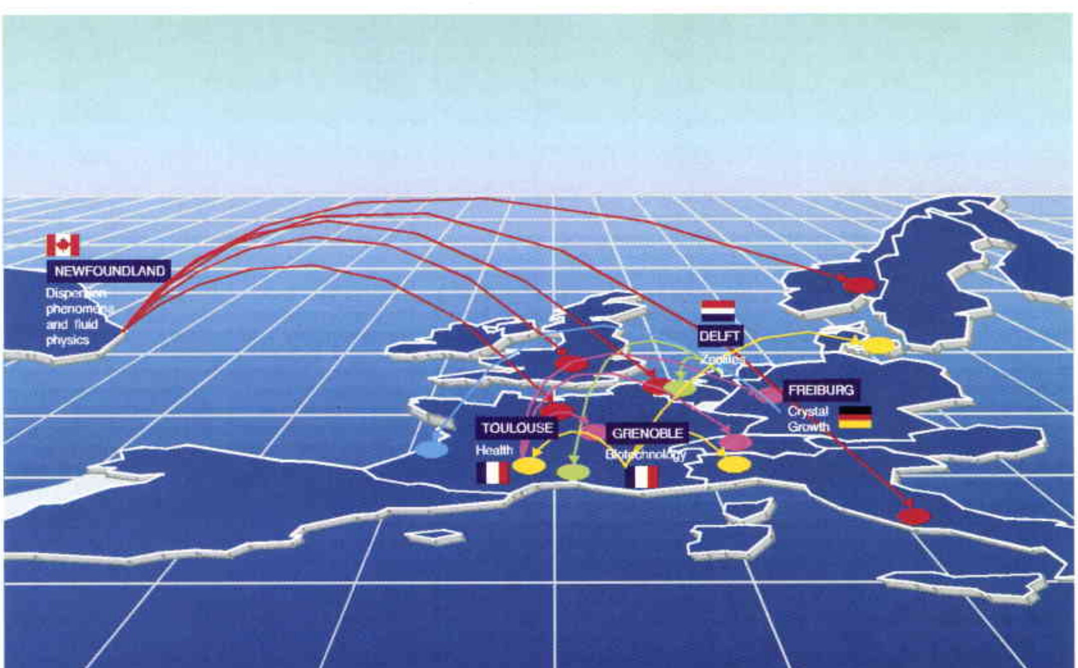



**Figure 2. Distribution of the RADIUSes and the RADIUS partners**

of 3.5 times the amount that ESA provided as seed money. That success in obtaining funding either in cash or in kind from industry and from national funding sources is very encouraging.

Each RADIUS has a multinational dimension (Fig. 2): several European universities and firms with complementary expertise and centres of interest are involved. Each RADIUS started at a different time and they are all therefore at different stages of progress. Some have already experienced microgravity through parabolic flight campaigns; one is starting the development of laboratory equipment in relation with the RADIUS projects; and another is exchanging materials among the industrial partners for ground analysis and characterisation.

**C-CORE (Canada)**

The first RADIUS, called the Consortium for Industrial Research in the Use of Space (CIRUS), is led by the Centre for Cold Ocean Resources Engineering (C-CORE), a Canadian research organisation in Newfoundland. CIRUS started working in February 1994 with universities and institutes in Belgium, Italy and Norway on research projects related to dispersion phenomena in microgravity and their potential applications for the oil industry. The projects identified by C-CORE have been prioritised according to the availability of funding and the maturity of the industry-university association involved in each project.

The first project started by the RADIUS is related to the measurement of a key thermodynamic coefficient, the so-called Soret Coefficient, and its influence on the thermodynamics of fluids in deep oil reservoirs (deeper than 4000 m). The petroleum company involved in this project is primarily interested in optimising its prediction model, which is prone to inaccuracy in measuring the limits and phase interfaces in its reservoirs. Given that an error of 50 metres could delay drilling, and therefore, petroleum production by several weeks, improved knowledge of dispersion phenomena in porous media through microgravity experiments is of great relevance to the global petroleum industry.

A prototype, a Soret Coefficient in Crude Oil (SCCO), was developed and co-funded by Elf Aquitaine (F) and the Microgravity Research Centre in Brussels (B) to demonstrate the technical feasibility of an experiment that could be ready for a flight in microgravity at the end of 1996.

The consortium has also recently submitted a proposal to the Canadian Space Agency (CSA) for a project called Microgravity Industry Related Research for Oil Recovery (MIRROR). The project consists of three experiments that would be integrated in a Get-Away Special (GAS) that the CSA will fly by the end of 1996. The experiments will investigate three phenomena: isothermal diffusion in porous media, surfactant foam stability in the presence of hydrocarbons, and capillary transport through porous media.

C-CORE has started several other projects in the field of enhanced oil recovery and heat pipe applications as well as some studies on waste and contaminants involving environmental firms. More recently, C-CORE and the Microgravity Advanced Research Centre (MARS) in Naples (I), have made significant progress in attracting the interest of restoration companies to work on several research topics related to the protection of historic monuments by analysing the behaviour of liquids in porous media such as stonework or wood from those monuments.

C-CORE has presented the results of two parabolic flight campaigns to several oil companies at workshops organised by the oil industry. The second campaign, organised by ESA and using the CNES Caravelle aircraft, provided 93 parabola with 75 runs recorded with transparent porous media models. The research was aimed at providing oil and environmental industries with pertinent information related to enhanced oil recovery and contaminant migration in soils (Fig. 3).

A third parabolic flight campaign was held in April to allow the technical specifications of the MIRROR programme to be refined.

**Figure 3. S. Goodman (U of Newfoundland) observing a sample cell during a parabolic flight. In reduced gravity, the fluid in the cell moves up the porous media column by capillary action alone. The experiment is part of research into enhanced oil recovery and contaminant migration in soils, aimed at benefiting the oil and environment industries. (Photo: University of Newfoundland)**

**CEN-Grenoble (France)**
The second RADIUS, headed by the Institute of Structural Biology at the Centre d'Etudes Nucléaires in Grenoble (IBS/CEN-G), began its pilot phase in August 1994. It is working on protein crystallisation with application-driven research in biotechnology. The RADIUS is structured around four poles, each composed of research institutes and industrial partners that have proposed several projects concerning crystallisation of animal genes, enzymes and immune proteins in association with pharmaceutical companies from Denmark and France and universities from France and Italy.

The RADIUS has worked closely with one of the U.S.'s most successful Centers for Commercial Development of Space (CCDS), the CCDS at the University of Birmingham in Alabama. That CCDS, which has had NASA accreditation since 1987, has already performed several experiments in the Shuttle middeck or on board the SpaceHab laboratory.

The IBS/CEN-G RADIUS intends to use flight opportunities such as Foton or Spacelab (or SpaceHab), once satisfactory reference crystals have been grown on ground and exchanged among the partners. It is also interested in purification techniques and is considering reusing existing facilities such as RAMSES, which was flown on board Spacelab IML-2 in July 1994.

Some of the RADIUS partners have issued several scientific publications. ESA requires that each RADIUS provides regular information relating to its industrial, technical and scientific performance. It is therefore considered to be very positive that the RADIUS programme is acknowledged in several refereed articles written by co-authors from the university and the industry working together in the frame of a RADIUS project.

**Delft University of Technology (The Netherlands)**
Having secured the interest of several Belgian and Dutch petrochemical companies, the Laboratory for Organic Chemistry & Catalysis at the Delft University of Technology started the first year of its pilot phase in November 1994. The laboratory had already worked with the companies on the development of a ground-based microwave for zeolite crystal growth.

The other partners in the RADIUS, the University of Leuven in Belgium and the University of Montpellier in France, are studying three other concepts for ovens for zeolite crystal growth. The petrochemical companies are interested in working on several types of zeolite and are ready to use their own resources to analyse the crystals in cooperation with the other industrialists. These companies have contributed financially to the RADIUS start-up activities.

The RADIUS aims at developing applications for the industrial use of catalysts for the petroleum industry, and the fine and bulk chemical industry, as well as the use of molecular sieves for gas and liquid separation and the use of ion exchange for the detergent industry.

The first opportunity to fly zeolites with the participation of the RADIUS industrial partners (including the US oil industry) is expected to be on board USML-02, a Spacelab microgravity mission in September 1995. They will be flown in the Zeolite Crystal Growth facility developed by NASA's Office of Space Access and Technology for one of its Centers for Commercial Development of Space, the Batelle CCDS, and the Worcester Polytechnic Institute in Boston.

**Freiburg University (Germany)**
The Crystal Growth RADIUS of the University of Freiburg began its Pilot Phase on 1 November 1994. It is focusing on the growth in space of single crystals of electronic, opto-electronic and electro-optical materials. Based on its long experience in materials processing in space, the Institute for Crystallography at the University of Freiburg is proposing several research projects with German, French and British partners in the expanding field of semi-conductors. The RADIUS has agreed with the firms to use their facilities for analysis and characterisation of their sample materials.

## The other RADIUSes
MEDES in Toulouse, a company created by the French space agency CNES, together with a hospital in Toulouse and several other organisations have proposed to set up a RADIUS on health and space medicine. In association with the Universities of ETH Zurich (CH) and Saint-Etienne (F), the group of scientists is proposing to work with a pharmaceutical company to develop bone strength and risk prediction models in cooperation with several hospitals. The activity plan includes the use of a 3D CT-Scan to develop the mathematical model that would estimate bone strength from bone mineral distribution and bone architecture. The

programme also includes measurements of the effectiveness of drugs in relation with exercise. Those models have a large potential market in hospitals and pharmaceutical companies seeking a better understanding, and hence prediction and treatment, of osteoporosis and other bone diseases.

To complement that field of research, it is proposed to include it in a more global Health RADIUS along with research projects proposed by the Hubrecht Laboratory in Utrecht, The Netherlands, in the area of cell and molecular biology. That Laboratory has identified some interesting applications in the field of wound healing, for instance.

Another RADIUS proposal came from one of the Fraunhofer Institutes in Hanover, Germany. The Institute for Toxicology and Research on Aerosols (Fgh/ITA) proposed to study aerosol dynamics and the application in industry of knowledge on fundamental aspects experienced in microgravity conditions, especially on nucleation, condensation and agglomeration phenomena. Although a large spectrum of industrial applications was identified during the RADIUS feasibility phase, complemented by a study on 'Dispersions and Colloid Systems' funded by the European Commission, the RADIUS had not yet been able to find an industrial partner with which to start the pilot phase. Discussions are being held with the Institute in order to find a way to include it as a potential 'node' in one of the existing RADIUSes.

**The EUREKA programme**

The EUREKA initiative was launched in 1985 by 17 countries from Western Europe and the European Union. Since then, several other countries have joined to support the more than 700 projects undertaken so far, involving about 600 participants from industry and universities.

The objective of the EUREKA programme is very similar to that of the RADIUS programme: the promotion of cooperation between universities and industry on application-driven research that could prepare the development of new markets and products. Some of the EUREKA programme's main priorities, such as the productivity and competitiveness of European industries and economies, are also important targets for the RADIUS programme. Both EUREKA and RADIUS are seeking a 'bottom-up' approach in which industry, in providing part of the funding, manpower and materials, plays the leading role in the definition of requirements and the execution of experimentation.

EUREKA has no dedicated funding but calls upon national public funding organisations to support the projects that their country has endorsed. Once the projects are internationally supported and 'labelled' as EUREKA projects, the international EUREKA network system helps to disseminate information on RADIUS projects and themes, and helps the teams to find new partners.

ESA has organised several meetings with the RADIUSes, the national space agencies and the EUREKA coordinators from Belgium, France, Germany and The Netherlands. Based on those preliminary discussions, it seems that most of the currently proposed RADIUS projects are eligible for the EUREKA programme since most of the RADIUS projects involve multinational cooperation.

ESA and the EUREKA coordinators are also discussing ways and means of facilitating access to the EUREKA programme for all the projects running under the RADIUS programme.

**Flight opportunities**

ESA's main commitment in the RADIUS Programme is to facilitate the start-up of RADIUSes, by providing funding for RADIUS feasibility studies and seed money during the Pilot Phase, and arranging quick and inexpensive access to flight opportunities.

The approach is to offer industrial users of RADIUSes, when they express the need, the right means of access to space at the right time. In principle, little or no hardware development is involved since RADIUSes are encouraged to use existing facilities or instruments in order to reduce the 'flight' costs to a minimum. Although the flight opportunity will be requested by the RADIUS Scientific Director, the objective is to fulfil industrial user requirements by making the space experimentation 'industry-driven'.

To this end, ESA will define a flight opportunity policy and establish a plan for making quick, low-cost access to microgravity available on request by industry. This plan will tie in with the programmes already existing under the ESA Microgravity and Manned Space Programmes as well as similar national and European industrial promotion initiatives.

At the present level of costs of space transportation, it is very difficult to convince firms to contribute both towards hardware development costs and towards flight costs. Generally, if the industrial partner contributes to the RADIUS programme by allocating one person-year from its R&D staff, it has shown its interest and commitment to the project. The contribution to the flight costs would be considered at a later stage, when 'pre-commercial' perspectives emerged from the RADIUS pilot phase. Therefore, during this promotional phase, the flight would be free of charge for RADIUS users while, later on, a charging policy would be developed as the projects move from a pre-competitive to a more 'market-oriented' or 'pre-commercial' stage. This charging policy will be defined in order to stimulate the RADIUSes to contribute to the flight costs as their industrial partners increase their investment in the RADIUS research projects. It will be based on the value of the service offered to the participating firms.

In addition, international cooperative missions should be organised by the various space agencies, providing each industrial user community with a means of access to opportunities in order to prepare for utilisation of the future space station. The establishment of a solid industrial user community, starting now, is essential if the agencies want their members to be ready to use 10% to 30% of the Space Station utilisation capacity.

### Monitoring the RADIUS's performance

At the end of each year of the pilot phase, ESA will evaluate each RADIUS's performance and reconfirm the seed funding based on the results. It is ESA's intention to judge the RADIUSes not only on the cash flow generated by their industrial projects, but also on the quality of the effort (cash and kind) made by industry in the research programme as well as the success in demonstrating the relevance of microgravity to solving an industrial problem. Other performance criteria will be considered (e.g. publication, patents, new business creation, etc.), but the essential requirement in order to meet the RADIUS Programme's objective is the level and quality of the industrial commitment in the RADIUS project. These firms will be the nucleus of a future industrial user community which will be ready to use the future space infrastructure.

#### Metrics system for bimonthly monitoring

A metrics system is used to first assess and then evaluate the performance and the direct and indirect results of each RADIUS, as well as the overall RADIUS programme. These metrics are based on parameters that are already being used to measure the succcess of the first year of activities. Every two months, each RADIUS must submit to ESA a report on the status of a number of performance points.

**Metrics used to monitor a RADIUS's performance**

**1. Industrial performance**
- Non-financial outcome of the industrial involvement: publications, patents, intellectual property rights (IPR)
- Financial participation: manpower, in kind and cash

**2. Research projects' performance**
- Relevance to space research and microgravity
- Programmatic performance
- Potential of the projects: market, new products or spin-off companies

**3. RADIUS management performance**
- Marketing performance: new contacts, new teamings, etc.
- Financial performance: new sources of funding, new programmes, e.g. EUREKA
- Contractual performance: management of the IPR, contractual links with the partners
- Scientific performance: assessment from non-space scientists and industrialists
- Flight preparation: search for flight opportunities using existing equipment and sharing infrastructures
- Education performance: information dissemination, student involvement, etc.

In the long term, each RADIUS must evolve into a self-supporting organisation, able to find the appropriate funding sources for its projects on national and European levels. The metrics system is based on an *a priori* assessment of the performance, where the partners agree upon target objectives, and an *a posteriori* evaluation, where the actual performance in securing industrial contributions, in developing ground and space hardware on target, in remaining within the financial budget, and in meeting the pre-defined management objectives is measured.

### Conclusions

The RADIUS programme was established on the basis of recommendations from representatives of non-space industries, research institutes, European and national space agencies, as a means to promote the use of space by industry. Within one year of operation, the RADIUSes have succeeded in finding more than 20 companies that are working and investing their own resources in research projects elaborated in cooperation with the existing microgravity user community. In addition, each RADIUS has found leverage funding for its first year of activities using the ESA seed money as a key factor in the decision of other space agencies to participate in the programme.

The pilot phase should consolidate these associations, preparing the teams for possible utilisation of flight opportunities, including the future International Space Station.

# Towards Automatic Product Generation from Meteosat Images

**V. Gärtner**
European Space Operations Centre (ESOC), Darmstadt, Germany

**The Meteosat satellite system is a series of European weather satellites in geostationary orbit over Africa at a longitude of 0°. From this position, the Earth and its atmosphere are viewed on a half-hourly basis. The Meteosat images are received, processed and re-disseminated from ESOC in Darmstadt (D). In addition to the imagery mission, for more than a decade the Meteorological Information Extraction Centre (MIEC) at ESOC has been deriving a number of meteorological products from the image data using an operational automatic processing scheme. During this period, improvements in the automatic quality-control processes have made the products less dependent on final manual quality-control checks, which represents an important step towards future, fully automatic product generation and distribution.**

## Introduction

Since 1977, the Meteosat satellites have been providing Europe with images from space for weather monitoring. The Meteosat Programme was initiated by the French space and meteorology authorities and was taken up by ESA as an pre-operational programme, which ended in November 1983. The Meteosat Operational Programme (MOP) was then run by ESA until 1986 when the European Meteorological Satellite Organisation, Eumetsat, was founded. Since then, ESA has continued to conduct the MOP operations on behalf of Eumetsat. At the end of November 1995, the present programme comes to an end and thereafter both the spacecraft-operations and product-generation tasks will be performed by Eumetsat itself.

The fact that they are geostationary and positioned over the equator at 0° longitude allows the spin-stabilised Meteosats to continuously view the same part of the Earth. The images are taken by scanning the Earth from south to north, as the spacecraft rotates, in half-hourly repetition cycles. The radiometer on board is equipped with detectors working in the visible (VIS) (0.5 – 0.9 micron), the infrared (IR) (10.5 – 12.5 micron) and the water-vapour (WV) (5.7 – 7.1 micron) spectral ranges of the electromagnetic spectrum. Meteosat thereby provides 48 images in all three spectral channels during a given 24-hour period.

These images are received at ESOC via the ESA ground station in the Odenwald (Germany), they are geometrically corrected (rectification process), and then redistributed to the user community via the dissemination system onboard the Meteosat spacecraft. A set of operational meteorological products that has been developed at ESOC is generated operationally on a day-to-day basis. They are a contribution to the worldwide meteorological observation system known as the World Weather Watch (WWW), operated by the World Meteorological Organization (WMO). The extraction of the meteorological products is performed in a fully automatic processing scheme. However, before these products are released for distribution to the worldwide user community, they have to undergo a final manual quality check in which a trained meteorologist inspects them for correctness.

## Meteorological product generation

In the Meteorological Information Extraction Centre (MIEC), every hour the Meteosat images are automatically analysed and interpreted to retrieve their information content. For this, the images are divided into subareas of 32 x 32 infrared pixels, so-called 'Meteosat image segments'. They are equivalent to areas of 160 x 160 $km^2$ at the sub-satellite point, as the pixel size of Meteosat images is 5 x 5 $km^2$ in the infrared and water-vapour channels. In the visible channel, the resolution is 2.5 x 2.5 $km^2$.

The most suitable channel for meteorological product extraction is the IR channel because the received radiances are emanating from the Earth's surface or the cloud-top regions and are directly proportional (via Planck's law) to the temperatures of the radiating surfaces. Figure 1 shows a typical Meteosat IR image, taken at 11.00 Z on 10 June last year.

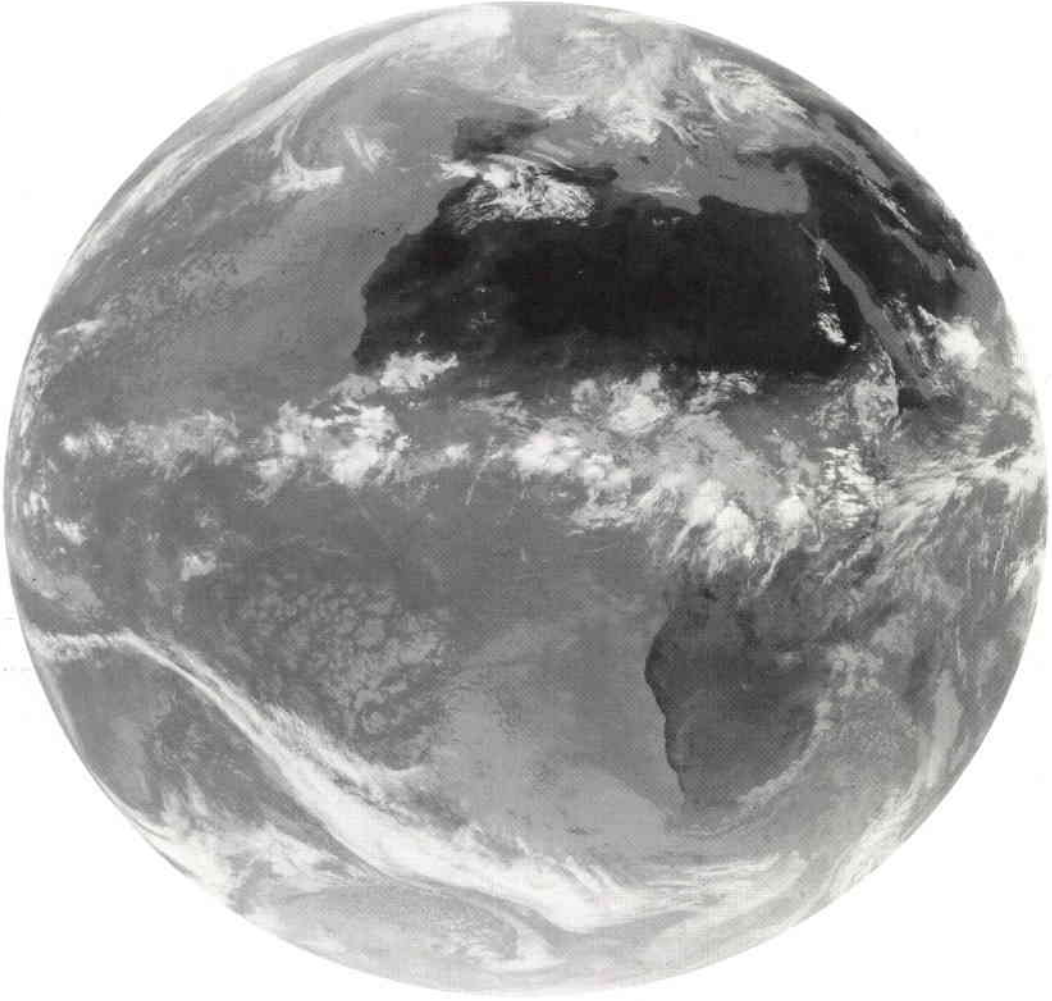


**Figure 1. Meteosat infrared image taken at 11.00 Z on 10 June 1994**

The automatic image-processing scheme is based primarily on a bi-dimensional histogram analysis, which is applied to every image segment. The results of the histogram analysis are so-called 'clusters', which are characterised by their mean values (digital counts) and the standard deviation of the pixel distribution of the cluster. In every image segment, up to five different clusters can be detected automatically. In the next processing step (image interpretation), the extracted clusters are associated with physical scenes (clouds, sea or land surfaces). These identified clusters form the basis for all meteorological products.

The operational product suite consists of:

- Cloud-motion wind vectors from the VIS and IR channel.
- Wind vectors derived from WV channel features.
- Cloud analysis (CLA).
- Cloud Top Height (CTH) maps.
- Sea Surface Temperature (SST).
- Upper Tropospheric Humidity (UTH).
- Climate Data Sets (CDS).

The above products are at present generated twice, four times or eight times per day. The main product-generation times are the main synoptic observation times, at midday (12.00 Z), midnight (0.00 Z), early morning (6.00 Z) and early evening (18.00 Z), at which, for example, the most important MIEC product, the wind vectors, is extracted.

The CLA, CTH, UTH, SST and CDS products are based on single Meteosat images. For the generation of the wind products, a set of three images is required to apply a cross-correlation tracking scheme for displacement-vector generation. At the end of the automatic product generation, the image content of every Meteosat segment is known to the best degree possible.

Figure 2 shows the cloud-analysis product for the image shown in Figure 1. The grid of image segments can easily be identified. The cloud-free segments or parts of segments are shown in colour: blue = sea, other colours = different land surfaces. The amount of cloud is proportional to the grey area covered in the segment and different grey values characterise

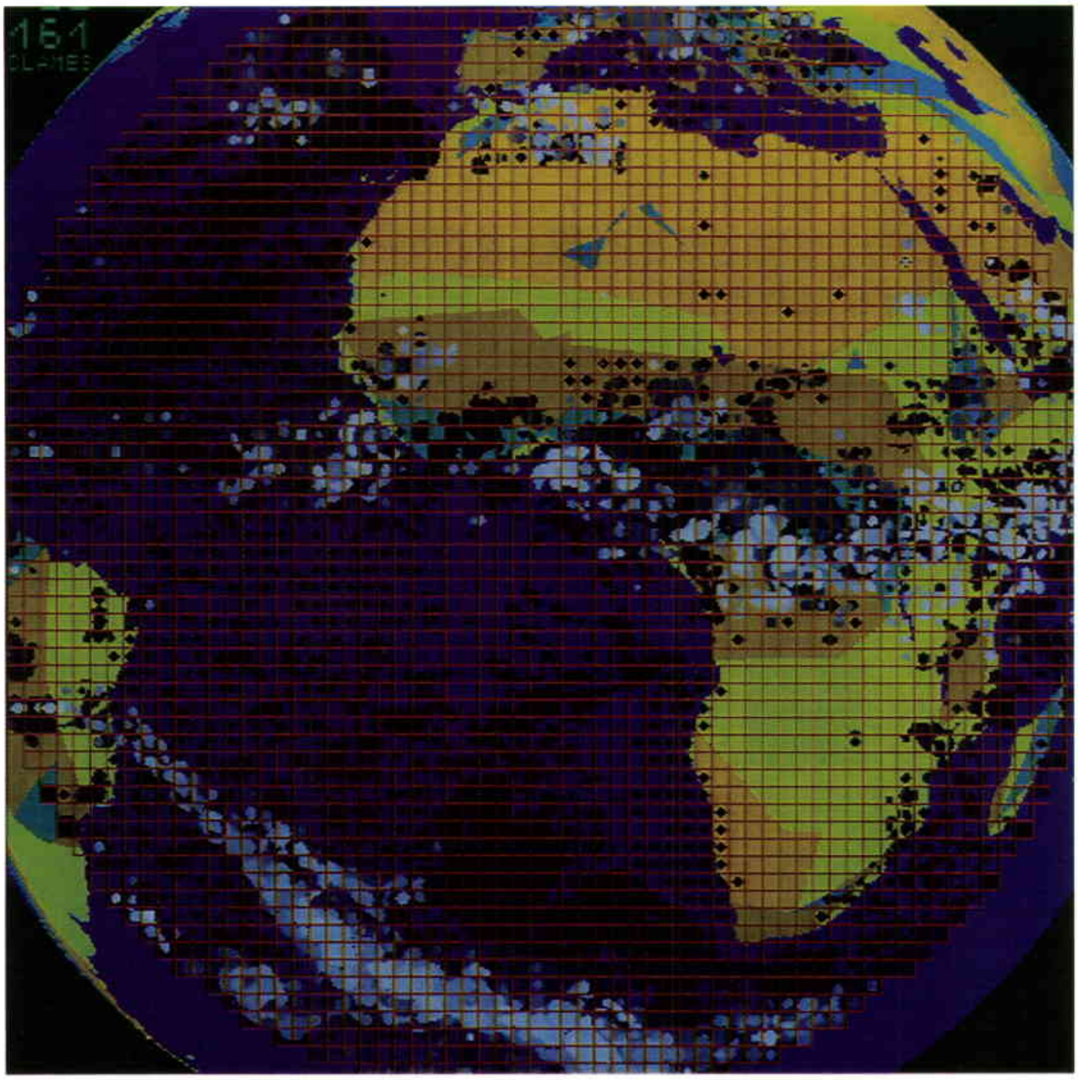



**Figure 2. Meteosat cloud-analysis product for 10 June 1994 at 11.00 Z. (The overlaid grid shows the MIEC segment size; clouds are grey, while cloud-free areas appear in colour)**

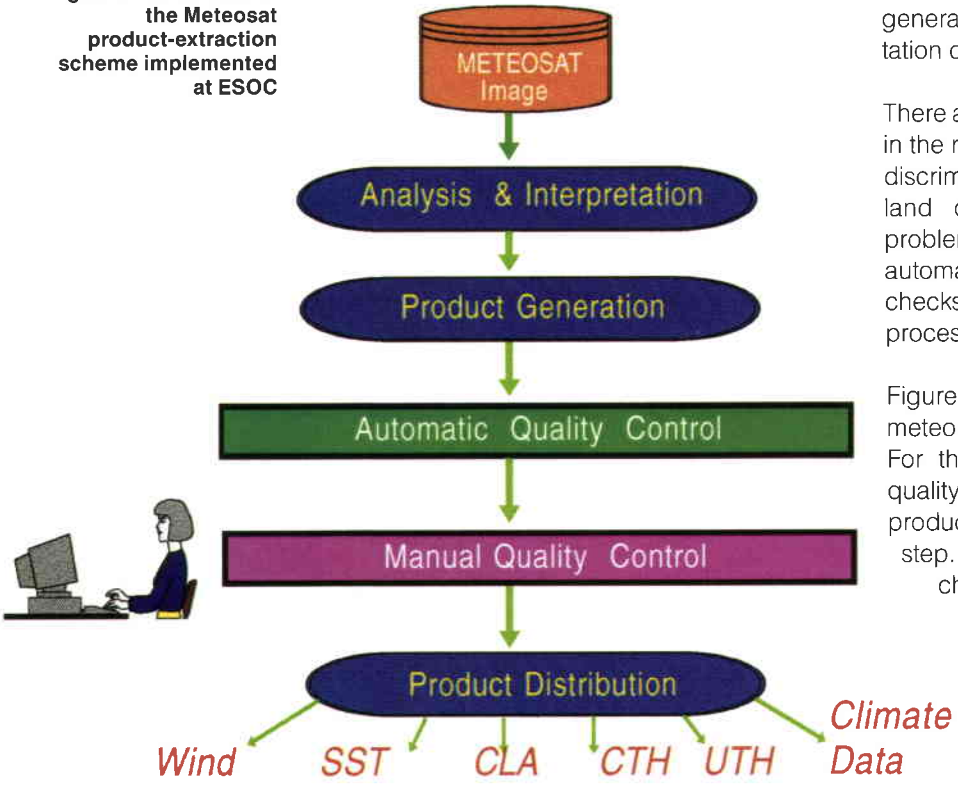



**Figure 3. Schematic of the Meteosat product-extraction scheme implemented at ESOC**

different cloud-top temperatures. Figure 2 was generated by automatic analysis and interpretation during the segment-processing stage.

There are always some ambiguities to be found in the results. For example, it is often difficult to discriminate between low-level clouds and land or sea surfaces. To overcome this problem, as for the other MIEC products, automatic and finally manual quality-control checks have been introduced into the MIEC processing chain.

Figure 3 shows the concept of the overall meteorological product-generation process. For the time being, the integrated manual quality control of the automatically extracted products is still an essential processing step. However, the automatic quality-control checks have been refined to such an extent during the last ten years that the quality-control staff's average workload has not increased despite the fact that the set of products being generated has increased significantly over the same period.

**Quality-control processes**

The quality-control step is divided into the automatic and manual quality-control tasks (Fig. 3). Due to the increasing demand for remote-sensing data for the assimilation processes in numerical weather-prediction models, the automatic quality-control element is taking on even greater importance because the manpower needed to perform intensive manual quality control on still more products will not be affordable.

An essential element of the algorithms applied for product extraction is a consistency check against internally and externally provided data. This is elaborated upon below for three MIEC products:

Winds

The basis for the MIEC wind-vector generation in all three spectral channels on board Meteosat is always a cross-correlation calculation for two adjacent pairs of images to determine the movements of identified cloud tracers. The reason for using pairs of adjacent images is that this enables the system to apply an automatic consistency check between two wind vectors derived for half-hourly time intervals. Only if the two half-hourly vectors agree to a reasonable extent is the resulting hourly wind vector calculated from the two components. This method, the so-called 'symmetry check', which is equivalent to a temporal consistency check, is a fundamental quality criterion to avoid the generation of false information.

Analogous to the temporal consistency check, a spatial (horizontal) consistency check has been proved to be a very useful quality-control tool, especially for the WV and VIS winds, because in those two channels one can often find large homogeneous fields of wind vectors. In the spatial consistency check, the extracted wind vectors are compared with the vectors in neighbouring segments which have been generated in the same height regime. Only if the vectors are consistent with each other are they accepted and forwarded for dissemination to the user community.

Whilst the infrared winds have been derived in the MIEC scheme since the start of the Meteosat programme, the WV wind extraction began in 1991 and finally became operational in 1993. The visible winds represent the most recent MIEC product, made available in 1994.

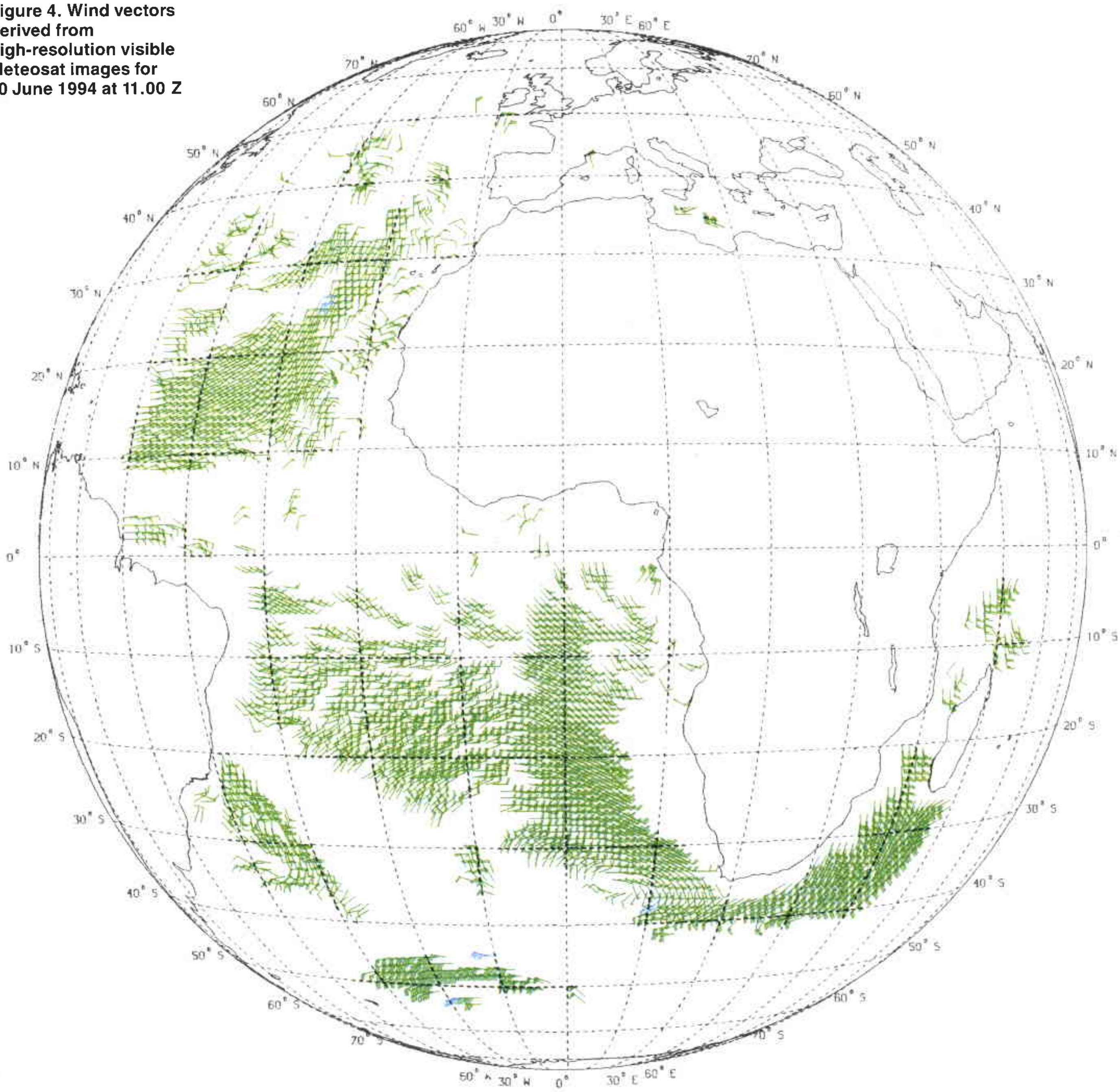
Figure 4 is an example of VIS wind vectors derived for the scenes of the image shown in Figure 1. They are extracted from Meteosat's visible-channel images, the spatial resolution of which is twice as good as for the WV and IR images. At the moment, this wind product is in the process of final validation. The higher resolution of the visible channel explains the high density of observations seen in Figure 4. These wind vectors are of good quality, especially over the sea surface in the lower part of the troposphere (between 950 and 700 hPa). For this reason, all other visible wind vectors are excluded from the final product, shown in Figure 4. For example, no vectors are included in the jet-stream area of the South Atlantic (see Fig. 1).

In the MIEC system, the manual quality control of the IR winds is performed by a trained meteorologist inspecting the automatically generated wind vectors of all segments on a video display. This is necessary because, especially in the IR channel, the height assignment is occasionally dubious because of the presence of semi-transparent clouds. The operator can decide on a case-by-case basis whether to retain or reject the generated wind vector, but does not have the authority to modify the automatically generated information in any way. To assist the operator in the decision-making process, there is the opportunity to compare the IR wind vectors with the numerical forecast received from the European Centre for Medium-range Weather Forecasts (ECMWF) on a video display. If the set of winds is of insufficient quality (e.g. problems with image rectification), the whole product can be rejected and the production of a backup product, which is produced for an image triplet one hour later, can be enabled.

For the VIS and WV winds, however, the manual quality-control task is greatly reduced because the operator is only given the choice of either accepting or rejecting the complete product. This approach has been proven to be acceptable for the VIS and WV winds, as the dense coverage of vectors allows successful application of the spatial consistency check for automatic quality control.

Besides the developments in wind-vector quality control, improvements in the basic extraction scheme (image filtering technique, modifications to the calibration scheme, etc.) have contributed significantly to the improvement of the quality of the wind product. For illustrative purposes, the speed RMS error of the MIEC infrared winds is compared to co-located radiosonde observations for high-level winds (above 400 hPa) in Figure 5. It can be seen that the RMS error of about 9 m/s in 1987 was reduced to less than 7 m/s in 1994, due

**Figure 4. Wind vectors derived from high-resolution visible Meteosat images for 10 June 1994 at 11.00 Z**



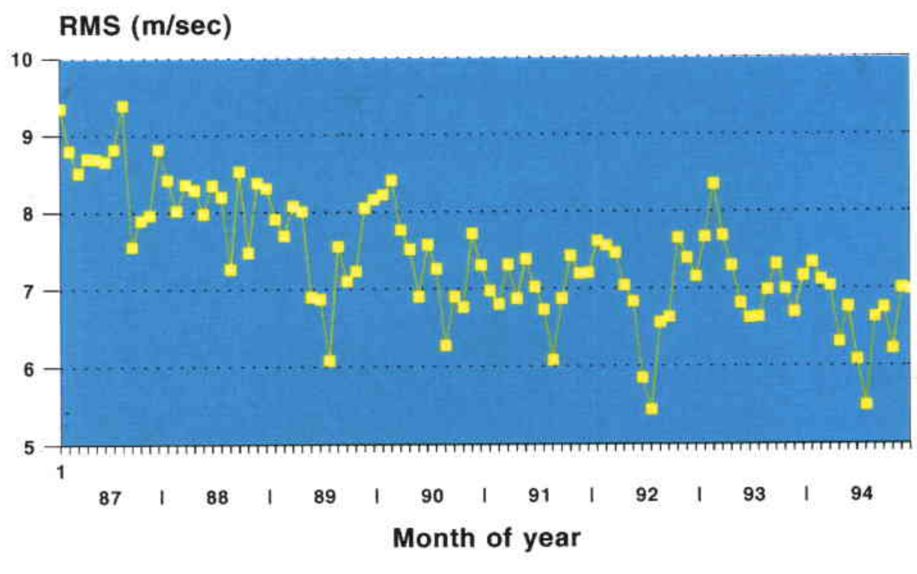



**Figure 5. Root mean square (RMS) error of the speed difference between Meteosat infrared winds and co-located radiosonde observations for height levels above 400 hPa**

mainly to improvements in the automatic extraction and quality-control schemes. The manual quality-control methods remained unchanged during this period.

Figure 6 shows the total number of wind vectors derived in December during the last 9 years. It can be seen that in recent years the number of wind vectors generated has increased significantly due to the addition of WV and VIS winds, despite the fact that the size of the meteorological quality-control team has remained unchanged.

A further successful prototyping study conducted within the framework of the MIEC development activities demonstrated that it is possible to generate WV winds on a dedicated workstation system in a fully automatic manner (without operator involvement) on an hourly basis. During a two-week period in September 1994, about 1.3 millon WV wind vectors were extracted and distributed to the ECMWF. In this new scheme, more advanced consistency checks have been successfully tested. However, to enable the user community to make the best use of these new datasets, a set of associated quality indices for all wind vectors is also under development. This approach is the most promising for the fully automatic product-generation process for the future, because these quality indices will allow the users to assign appropriate weights to the automatically generated products when assimilating the data into numerical forecasting models. The quality indices therefore have to be developed and defined in cooperation with the numerical centres (e.g. ECMWF).

### Clouds

For the cloud-analysis product shown in Figure 2, the two most important automatic quality-control checks are the following:

a. A check on the temperature of the lowest cloud level found in a segment against a threshold temperature depending on the surface temperature given by the ECMWF surface-temperature forecast. This feature is necessary because, especially at night when no information is available from the visible channel, discrimination between surface and low-level clouds is sometimes very difficult.

b. Another very useful quality-control feature for the cloud-analysis product, introduced in June 1994, is based on the so-called 'clear-sky tracking technique'. This means that for all image segments where the automatic processing scheme has not identified any clouds (clear sky), the cloud motion cross-correlation tracking scheme is applied. If a displacement vector of any kind, resulting from the movement of so-far unidentified cloud features, is found, the cloud-analysis result for that segment is marked as being suspect. In Figure 2, these segments are marked by the purple diamond-shaped symbols. This quality check has also reduced the shift staff's workload. Previously, they had to search visually for any of these unidentified cloud scenes by checking animated sequences of Meteosat images on the video displays.

Figure 7 shows the average number of operator actions per manual quality-control session. It can be seen that the introduction of the clear-sky tracking control scheme has reduced the number of manual actions for the CLA product by about 50% since June 1994.

### Sea-surface temperatures

An automatic quality-control check for the sea-surface-temperature product was introduced in

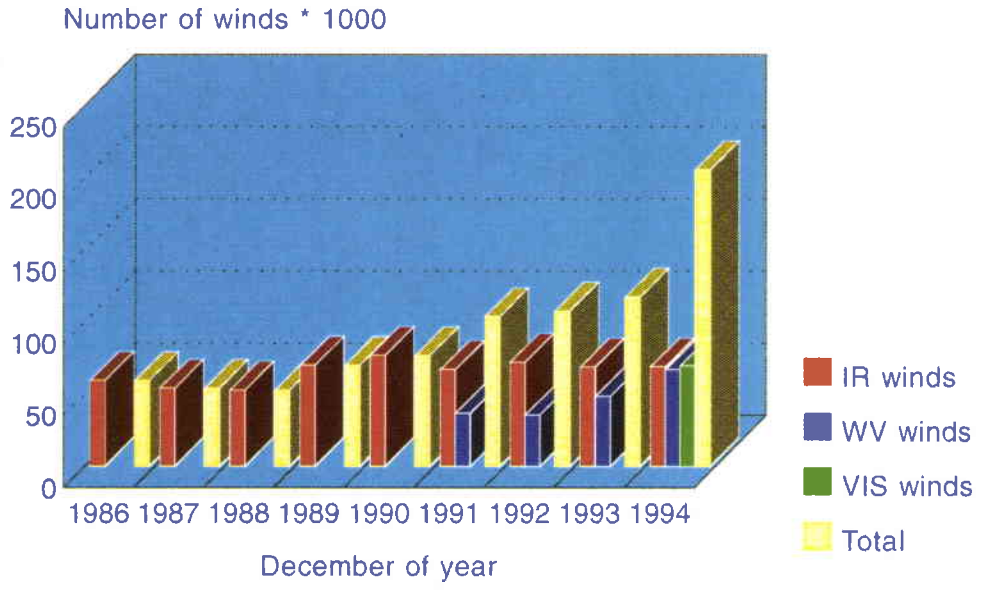



**Figure 6. Number of extracted wind vectors for the month of December in the years 1986 to 1994**

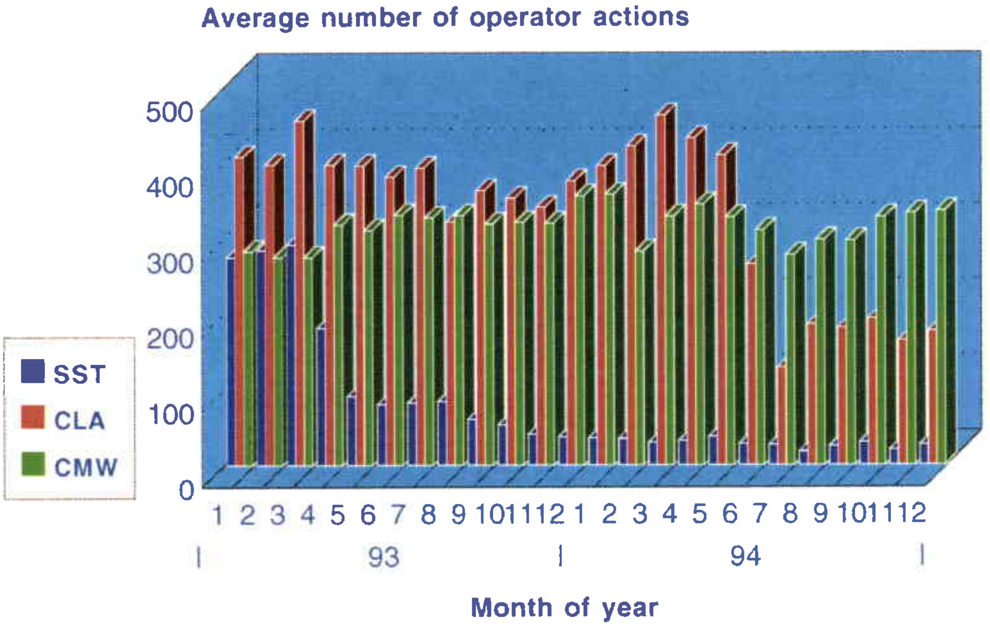



**Figure 7. Average number of operator actions per manual quality-control session in 1993 and 1994 for the SST, CLA and wind products**

April 1993, which also resulted in a significant reduction in manual operator actions (Fig. 7). The SST product is objectively compared with the sea-surface-temperature fields received from the National Meteorological Centre (NMC) in Washington. All Meteosat temperatures that deviate by more than 1.5° from the NMC field are marked as being suspect. This check is introduced because the Meteosat SSTs are mainly based on the IR channel information and the coarse resolution from geostationary orbit means that the individual pixel values often suffer from cloud contamination (sub-scale clouds) which would cause the SST predictions to be too low. Furthermore, the SST is a relatively conservative quantity that does not exhibit rapid changes. Hence, sudden deviations in Meteosat and NMC data of more than 1.5° would be unrealistic observations.

## Future developments

For the IR cloud-motion winds, the average number of operator actions (Fig. 7) is still relatively high compared to the other MIEC products, but the product quality has been improved in recent years (Fig. 5). Furthermore, the developments in the area of VIS and WV wind extraction are promising for the application to IR wind-vector generation also. The use of more intensive consistency checks (temporal as well as spatial), together with cross-checking of the three wind products from the different channels, is expected to lead relatively soon to the generation of a single set of wind vectors. This set will be a homogeneous combination of the vectors from all three spectral channels. For this future combined product, the number of manual actions will then also be much lower than for the present infrared winds.

Based on experience so far, continuation of the development of these automatic quality-control checks for the meteorological products will ultimately allow a fully automated extraction scheme to be established within the next couple of years.

## Conclusion

The development of Meteosat image data-product extraction during the last decade has allowed a fully automated processing scheme to be successfully set up which is able to generate the maximum number of meaningful meteorological products for a given set of image data. This is especially important when considering the need for more good-quality observations for incorporation into increasingly more sophisticated numerical weather-prediction models. Moreover, in a time of limited financial resources, only a fully automated system can cope with the product-generation requirements of future satellite systems like the second generation of Meteosats, which will have 11 spectral channels and a 15 min image repetition cycle. Only the development of adequate automatic processing tools will ensure the optimal operational exploitation of the data provided by these and future Earth-observation satellite systems.

## Acknowledgement

The results that have been described were achieved through the dedicated long-term support of both current and former staff of the Meteosat Exploitation Project. Several of the improvements discussed resulted from cooperation and discussions with scientists working with the national weather services and other national or international organisations.

# Agency Law and Practice in the Protection of Inventions

**P.A. Kallenbach**
Legal Affairs, ESA, Paris

**The resolution of a technical problem in space research and development activities can often lead to the making of an invention. Article III of the ESA Convention relates in particular to in-house inventions and 'extra-muros' inventions, and to the protection of such inventions, and their use by ESA Member States and companies in these States free-of-charge in the field of space research. A comprehensive set of rules based on this Article was developed in 1989 as guiding principles between the Convention and the general clauses and conditions of contract.**

**Need for protection of inventions**

Although it is generally agreed that intellectual property such as inventions should be protected, it may not be clear why an international intergovernmental organisation such as ESA should take out such protection, nor how this protection should be realised in practice.

Article III of the ESA Convention makes the Agency responsible for securing rights in inventions resulting from contracts it has placed, as well as for disclosing its own inventions to Member States (or Participating States in the case of the optional programmes). These obligations can only be fulfilled if the inventions are sufficiently protected – preferably by patents – against unauthorised use by non-European industry, and by granting royalty-free licences on these patents in the context of ESA or its Member States' space programmes.

Patent protection has the advantage that exclusive rights in an invention can be obtained in the country where patent applications have been filed during a limited, but reasonable period of time (up to 20 years), while allowing public disclosure of the invention without losing these rights after filing has taken place. Therefore, filing has the advantage that an invention can immediately be disclosed, while preventing others from obtaining patent rights on the same invention when applying for a patent after the filing date.

Another reason why ESA should secure patent protection for inventions made is the possibility of using such patents in an exchange of intellectual property rights, in particular with non-European space industries or organisations.

The potential value of patents for gainful use by industry could be seen as another possible argument for ESA to protect inventions, more in the context of the previously mentioned exchange than with a view to exploitation and generation of income.

Yet another consideration in the context of a rationale for the protection of intellectual property is similar to one of the objectives of other scientific and technical institutions, namely to gain prestige from the quality and quantity of patented inventions.

Last but not least, the main reason for protecting the intellectual property of intergovernmental organisations stems from the fact that their activities are funded by public money. It is therefore considered in the interests of the tax payers to control the use of innovative technologies developed during the execution of these organisations' technical programmes. Measures should thus be taken to avoid the results of the investments made by the Governments of Member States being given away freely to industry outside these States.

**Protection of ESA and Contractor inventions in practice**

(a) ESA in-house inventions

The rights in inventions made by ESA staff members belong to the Agency as a result of their employment contract (Staff Rules and Regulations, rule 4.2). Staff inventions are examined by an internal Patents Group to determine, inter alia, their potential patentability and the industrial applicability thereof, and their interest for the Agency's activities.

# Utilisation of ESA Inventions

**(a) Space applications**
Most inventions made by ESA engineers are related to the exploration or exploitation of space, and several have found widespread application:

- The sequential switching shunt regulator (S3R), invented by D. O'Sullivan and A. Weinberg, is a device for regulating the current drawn by a load from a solar array. It has been or will be used on several European spacecraft projects, such as ECS, Marecs, Iras, Giotto, Olympus, Italsat, TV-SAT, Skynet, and Unisat. In addition, it will also be used on the Spacebus series of satellites, and there has also been interest in using it on future American spacecraft.
  **(ESA Patent 48)**

- Several spacecraft projects have made use of a gas-leak detection apparatus invented by G. Sänger and A.K. Franz, for determining attitude-control-system leak rates. These projects include ISEE-B, Sirio-2, ISPM (Ulysses), Exosat, Hipparcos and ERS.
  **(ESA Patent 58)**

- The 'solar sailing' method of attitude control for three-axis-stabilised spacecraft, invented by U. Renner, prescribes using rotation of the solar panels instead of thrusters for attitude control. The invention has been adopted as a nominal means of attitude control for spacecraft using the Eurostar bus developed by Matra and British Aerospace (Inmarsat 2, Telecom 2, Locstar, Hispasat, Italsat and Orionsat). A great deal of interest in this invention has come from the United States, where it has now been implemented on a series of US Navy satellites.
  **(ESA Patent 69)**

- A battery charge detector for Ni-Cd batteries on low-Earth-orbit (LEO) missions, invented by H. Spruijt, will be used on several LEO spacecraft, such as the STRV-1a (UK) and Freja (Sweden) satellites.
  **(ESA Patent 124)**

- A method for augmenting the power delivered by the external solar-array panel of a spinning satellite in transfer orbit with the array in stowed configuration, invented by H. Lechte, has been used for satellites of the Inmarsat-2 programme.
  **(ESA Patent 133)**

- G. Crone and A. Roederer have invented an antenna consisting of two identical superposed wire-grid reflectors, for transmitting/receiving two orthogonally polarised beams in/from different directions. This invention has been implemented on Eutelsat-2 spacecraft, and on the Chinese satellite DFH-3. Orionsat and several other communications satellites are also prospective users.
  **(ESA Patent 136)**

- Associated with the above Crone and Roederer antenna is a laser-based method of manufacturing a parabolic reflector with a polarisation- or frequency-selective surface on an insulating support material, invented by R. Halm, and used in conjunction with some of the projects that the antenna will be used on.
  **(ESA Patent 154)**

- A multibeam antenna feed device, invented by A. Roederer, allows reduction of the mass and insertion loss of antenna feeds, efficient operation of the power amplifiers, beam overlap, and control of beam direction and coverage. The invention will be used in the communications payload of Inmarsat 3.
  **(ESA Patent 217)**

- A method of rectifying spin-scan radiometer image data in real time, invented by J. de Waard, J. Adamson and A.M. Bos, is used in particular in the context of Meteosat data processing and distribution. The method allows application of the rectified images for 'nowcasting'.
  **(ESA Patent 219)**

- A device for providing protection against debris produced by pyro bolt cutters has been invented by R. Halm and P.G. Edwards, for use in hold-down and release mechanisms for the ERS-1 and ERS-2 antennas.
  **(ESA Patent 240)**

**(b) Non-space applications**
A small number of inventions made primarily in the context of space programmes have already found, or could find, terrestrial applications. Some examples of this 'spin-off' are as follows:

- A flexible mount for supporting elements of optical instruments capable of eliminating the effects on instrument pointing of a difference in the thermal expansions of the ground support and the optical elements, while maintaining a high load-supporting capability. This invention, by T. van der Laan, can be applied in the supports of (large) astronomical telescope mirrors.
  **(ESA Patent 118)**

- A method for creating microgravity conditions on Earth has been invented by D. Mesland. The principle of the method is based on the brief period of free fall occurring in a sample when launching it in a free-fall trajectory under Earth gravity conditions. Typical applications are the realisation of semi-continuous microgravity conditions in biological cell cultures in the laboratory, thus avoiding the costs of sending experiments into space.
  **(ESA Patent 170)**

- A method for recognition and location of the centre of photon events detected by a charge-coupled device was invented by G. Cox and M. Perryman. Although originally intended for use in photon-counting systems for optical astronomy, such photon counting can also be used in biomedical applications.
  **(ESA Patent 185)**

- A current sensor consisting of a transformer with a galvanomagnetic (Hall-effect) device inserted in its air gap was invented by L. Ghislanzoni. The sensor features a sum circuit to which the voltage of a short-circuited secondary winding is provided as one input and the voltage across the galvanomagnetic device as the other. The sum signal is proportional to the current to be measured. The current sensor has very low impedance. Its applications are to current sensing in power-system electronic switches, e.g. for Columbus, but non-space applications requiring an insulated AC + DC current measurement with an accuracy of better than 0.2% are also envisaged.
  **(ESA Patent 186)**

- A method for ensuring synchronisation between a user terminal and a master station in a CDMA multiple-access communications system using a voice-activated carrier signal has been invented by R. de Gaudenzi and R. Viola. The invention allows a mobile CDMA communication system to be operated in a non-continuous manner, in such a way as to keep spread-spectrum acquisition time compatible with real-time telephone communications needs.
  **(ESA Patent 210)**

- A circularly polarised turnstile antenna, originally conceived by A. Roederer, P. Garcia-Müller and A. Jongejans for communication between satellites and trucks, has other applications due to its uplifted toroidal radiation pattern, in particular for mobile communications within city centres.
  **(ESA Patent 253)**

- A new type of plasma spray gun, invented by M. Lang, has the feature that it can coat a surface uniformly and rapidly via its long slit-shaped nozzle.
  **(ESA Patent 257)**

- A system for synthesising microwave filters which comprise a rectangular waveguide with several resonators without tuning elements, and coupled by coupling elements having finite thickness, has been invented by M. Guglielmi. The system is interactive and allows filter synthesising by 'soft tuning' in a rapid way. Software based on the invention has been licensed to many users.
  **(ESA Patent 271)**

- An adjustable satellite ground antenna mount for the automatic tracking of satellites, invented by C. Hughes, has a simple triangular construction which makes it collapsible for transportation.
  **(ESA Patent 299)**

**Enquiries concerning the above inventions should be addressed to:**

Legal Affairs
ESA Headquarters
8 – 10 rue Mario Nikis
75738 Paris 15
France

# General Conditions for Licensing of Patented ESA Inventions

Conditions apply to the making, using or selling of products which incorporate a patented ESA invention (licensed products), as follows:

**Space applications**

- Free non-exclusive licence for applications in ESA or its Member States' space programmes.

- Royalty-bearing non-exclusive licence for applications in space programmes outside ESA or Member States' space programmes.

- Royalty-bearing exclusive licences may be granted subject to a number of special conditions.

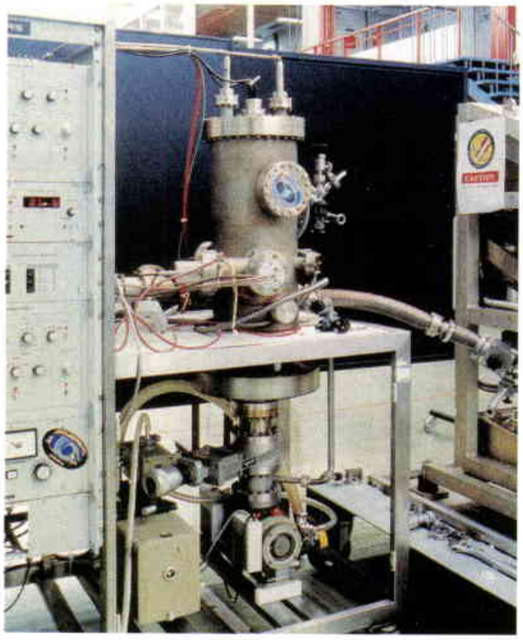
**Non-space applications**

- Royalty-bearing non-exclusive licence for applications outside ESA or Member States' programmes.

The royalty rate bracket applicable is between 0.5 and 5%, being a function of the type of licence, and the relation between the patented invention and the licensed product.

Licence agreements entail the initial payment of a licence fee to be deducted from future royalties.

The transfer of ESA-patented technology to countries outside Member States is subject to formal approval from these States, similar to the procedure applicable to contractor-developed technology.



Gas-leak detection apparatus (PAT 58)

A patent application may then be filed in a first country, usually France, to establish a priority date and also to determine actual patentability using the results of the novelty search report drawn up in connection with this filing action. France is usually the country of initial filing because ESA's Head Office is located in Paris. A secondary advantage of protection in France is that it covers a large industrialised territory, which includes the Ariane launch base in French Guiana.

Within the year following first filing, the Agency has the possibility, provided by the Union of Paris Convention, to file patent applications in member countries of this Convention based on the same invention as originally filed in France, and claiming the French filing date as the priority date.

The Patents Group decides on the extensions of protection of the first patent application to other countries based firstly on whether the novelty search report includes documents that affect the patentability (novelty, unobviousness) of the invention, and secondly on whether or not the invention's technical applications are space-oriented.

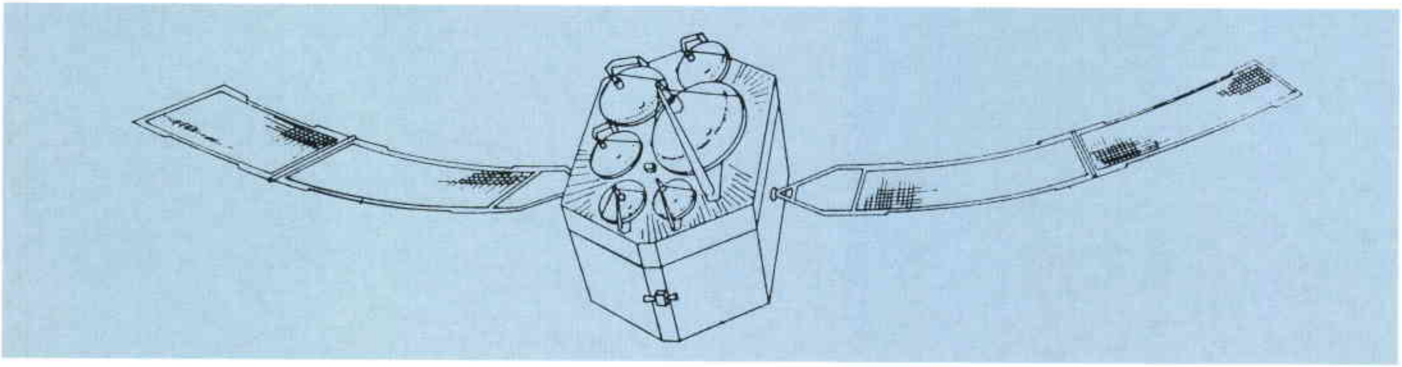
If the invention is limited to space applications, the principle of royalty-free licensing to ESA Member States outlined above applies, and further protection in these States is usually considered to be unnecessary, since industry is entitled to obtain a non-exclusive royalty-free licence for use of the invention in the context of ESA or its Member States' space programmes.

Space-related inventions are usually further protected by filing patent applications corresponding to the initial application in non-European countries having a space industry, such as the United States, Canada and Japan. Although this is at present considered to provide sufficient protection of European space industry's interests, other countries such as Russia and China could also be considered in the near future. These two countries have only recently adopted patent laws in line with the Union of Paris Convention, but they have not yet become members.

An example of an invention that is typically space-related, and therefore mainly protected outside Europe, is the 'solar sailing' method of attitude control for three-axis-stabilised spacecraft invented by U. Renner (ESA Patent No. 69). This method resolves the problem of using thrusters for attitude control by instead rotating the solar panels, thereby saving fuel and extending the working life of the spacecraft. It was first tried successfully with ESA's OTS satellite and was later applied to the ECS series of satellites, and to spacecraft based on the Eurostar bus. It has also been implemented on a series of US Navy satellites. A licence based on the American patent for the invention is being discussed with the US Government.

As mentioned above, ESA can grant royalty-free non-exclusive licences on its patented inventions for use thereof in the context of ESA and its Member States' space programmes. In the case of non-European space programmes, licensing fees and

Sketch of ESA's Orbital Test Satellite (OTS), used to demonstrate the validity of the solar-sailing technique (PAT 69)



**Flexible mount using membrane torsion (PAT118)**

royalties can be charged which are subject to negotiation.

Another example of a typically space-oriented technology is a multibeam antenna feed device invented by A. Roederer (ESA Patent No. 217). The invention was made to resolve problems associated with the high masses and insertion losses of such antenna feeds, while at the same time aiming at efficient power-amplifier operation and beam control. Since this feed device is intended to be used in communications-satellite payloads and would not have any application in terrestrial communications, this invention was held to be limited to space application, not requiring protection in Europe, in view of the granting of free licences.

Subsequently, a European company was granted a non-exclusive licence on the rights in the patent applications filed and patents resulting, for use in the context of a non-European space programme. Therefore this licence, although relating to space technology, was granted as royalty-bearing.

If the invention also has potential applications outside space, the Agency should file patent applications in countries in addition to the ones covered for space-related inventions, for instance in Europe, in order to protect the interests of its Member States. The licensing situation with regard to these inventions is, however, different from that for the pure space inventions. Whereas space applications of an invention are subject to the same licence conditions as space inventions, non-space licences cannot be granted on a royalty-free basis, even to industry in Member States. One of the reasons for making these licences royalty-bearing is to possibly obtain some return on the costs of filing in countries not usually covered by ESA in respect of space patents. Non-space licences can, however, be exclusive subject to certain conditions (general ESA licensing conditions are summarised in a separate panel).

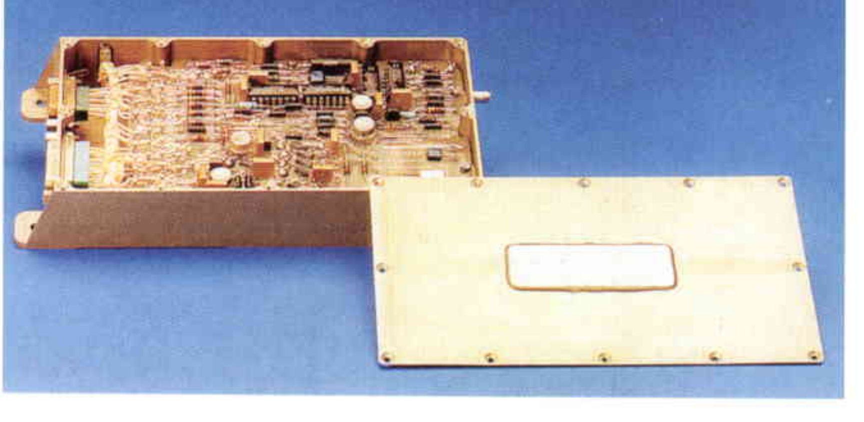
An example of a technology which, although initially intended for applications in optical astronomy, also found an application outside space is a method for the recognition and location of the centre of photon events detected by a charge-coupled device invented by G. Cox and M. Perryman. Initially, the invented technology was held to be limited to space, and therefore only protected outside Europe. At a later stage, however, as a result of a technology-transfer exercise undertaken by Spacelink Europe, it was discovered that the technology could be applied in the biomedical field. A European company intending to sell products based on the ESA invention in the United States was granted a licence on the American patent, which is royalty-bearing.

### (b) Contractor inventions

In the case of inventions made by ESA contractors ('extra-muros' inventions) in the course of executing work under contract, ESA has adopted a 'licence policy' in line with Article III of the ESA Convention, according to which the contractor keeps the rights in such inventions, but grants royalty-free irrevocable licences to ESA and to its Member States. This policy is intended to stimulate the exploitation of such inventions both within and outside ESA programmes.

According to the 'General Clauses and Conditions for ESA Contracts', inventions made under contract to the Agency should be protected by the contractor by filing patent applications and keeping ESA informed of such actions and their outcome. Experience has shown, however, that only a relatively small number of patents are actually declared to the Agency.

**The battery charge detector applied to the Battery Re-charge Experiment (BRE) flown on the STRV-1a mission. The technique developed in connection with Patent 124 significantly reduces solar array sizing and extends battery lifetime (PAT124)**



If the contractor does not intend to protect an invention made in the course of the contract work, he should transfer his rights to ESA, which may take action in his stead.

Under the licence policy, ESA and its Member States, however, have certain rights in the patented inventions of contractors, in view of the funding of the related contract work. The most important is the right to free licences, which should be granted by a (former) ESA contractor for use of their patented inventions in the context of ESA and Member States' space programmes.

**Polarisation-sensitive reflector for the Chinese satellite DFH-3 (PAT 136)**

ESA may also receive royalty payments on licence agreements based on patented inventions which were originally made under ESA contract, but for which a licence has been granted by the contractor to a third party for use in non-space applications.

The latest revision of the 'General Clauses and Conditions for ESA Contracts' foresees further protection of industrial intellectual property, in so far as the contractor should inform the Agency of the existence of any background inventions, i.e. those inventions and patents not resulting from an Agency contract, and which he intends to use for the purpose of the new contract. The contractor may request the Agency to restrict the dissemination of this information. The proper identification of background inventions allows determination of which of the contractor's intellectual property generated in the course of the contract actually falls under the free-licence policy.

The revision also relates to transfer of inventions made in the course of an ESA contract to a territory outside Member States. Such transfers shall be subject to prior review by ESA and its Member States under conditions of strict confidentiality. The review is initially intended to determine whether exports are for peaceful uses, and should not jeopardise the competitive position of European space industry.

## Some problems in present protection practices

### (a) ESA inventions

Where an ESA invention is limited to space applications, the Agency will basically not protect it in the ESA Member States, in view of the free-licence policy with respect to European industry. Non-European firms, however, which have a subsidiary within the Member States, can therefore use the invention without being prosecuted since they do not infringe patent rights in these States. Up to now, this has not been a problem because foreign companies are not usually involved in space activities in Europe, but the situation may have to be reviewed should this happen.

In some cases, in particular when a licence is granted at an early stage in the patenting proceedings, the ESA Patents Group decides to extend protection of space inventions also to some European countries in addition to non-European countries, in order to better safeguard the interests of the Agency. This has, for instance, been the case with the Roederer invention (ESA Patent 217) described above, where strong non-European interest had been manifested.

A definition is required with respect to the term 'space applications', in view of the granting of free licences. It is clear that inventions made in respect of any typical spacecraft technology related to the system or subsystem have a space application, including such things as: spacecraft configuration, attitude control, solar generators, environmental control, life support, propulsion, and remote sensing.

Typical spacecraft technologies may, however, also be used for defence purposes. Such applications of ESA inventions cannot, in principle, be the subject of a licence in view of the exclusively peaceful purposes aspect of the European space programme.

Since even within the spacecraft technologies mentioned there are terrestrial applications, e.g. solar cells, each invention should be assessed with regard to its 'spin-off' potential, to decide on space or non-space applications.

Other spacecraft technologies that more clearly could have non-space applications include: antennas, communications equipment, communications systems, data processing, ground-support facilities, measurement and control, mechanical engineering, materials, optics, power supplies, and test facilities.

A typical example to demonstrate the dilemma when deciding on the 'space' or 'non-space' application is an antenna, which can be used both for communications relating to spacecraft control and for ground reception of commercial satellite channels.

A better method for differentiating between 'space' and 'non-space' applications would therefore be whether the technology invented, basically for space purposes, could be the subject of large-scale commercial exploitation, as opposed to the 'one-off' nature of typical space technologies.

A major problem in the use of ESA inventions is how to make potential space users aware of their existence. Some ESA inventors, faced with resolving a problem in a project leading to the making of an invention patented by ESA, will propose the use thereof by the project in preference to other solutions.

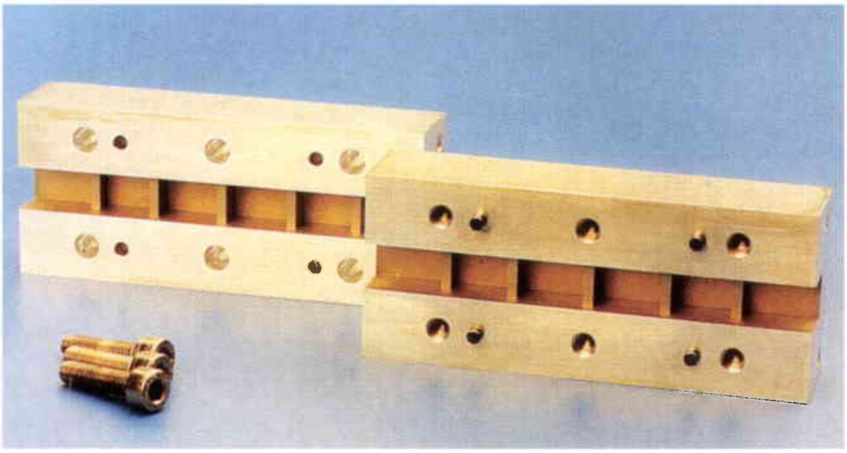
A further tool in promoting the use of ESA inventions is the 'Catalogue of ESA Patents', together with announcements of new inventions published in the ESA Technology Programme's quarterly newsletter *Preparing for the Future*.

An agreement has been signed with the European technology-transfer group 'Spacelink Europe' for the promotion of non-space applications of ESA inventions. This group has published catalogues of 'Transferable European Space Technologies' (TEST), which include references to selected ESA inventions having particular non-space potential.

Finally, published ESA patent applications are recorded in the 'European Aerospace Database', a file managed by the Information Retrieval Service at ESRIN (Frascati, Italy). In this way, ESA inventions are made accessible to searchers identifying novel space technologies.

(b) Contractor inventions

Whereas the 'licence policy' has been introduced in order to stimulate the contractor to exploit inventions he makes, the obligation to grant free licences on patents, even though limited to ESA and Member States' programmes, is regarded as a drawback in a competitive market situation. The policy can therefore give rise to a clash of interests, with the Agency on the one hand acting in the interests of Member States by imposing free licences, and the contractor on the other wishing to exploit an invention and having to assign free rights to his competitors.



**System for synthesising microwave filters (PAT 271)**

The situation is even worse when a company is required to grant free licences to a competitor for work relating to an ESA programme for which this company was not awarded a contract. This situation is, however, covered by the Agency's right of reproduction, which allows ESA to indemnify the originator of the technology.

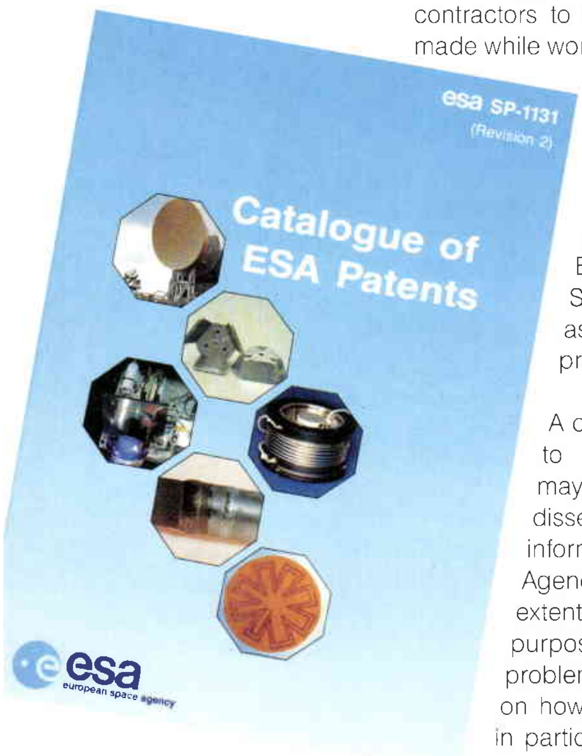
The small number of inventions patented by contractors, declared to ESA before final payment for contract work, can be explained as resulting from the type of work, but also from the contract conditions. ESA contract work is usually aimed at finding a solution for a unique technical problem, or at manufacturing a 'one-off' product. In neither case is the market large enough to justify patent protection against competition.

**Tracking mount for use with Earth station antennas (PAT 299)**

The obligation to grant free licences for use of a patented invention by ESA and its Member States could equally discourage contractors from filing patent applications. It should, however, be realised that ESA mostly bears the development costs related to inventions made under contract.

Finally, the stipulation that royalties should be paid to ESA in the case of a licence agreement does not encourage contractors to protect their inventions.

In order to safeguard any ESA rights in contractor inventions, two practical methods have been applied:
- patent audits at the contractor's site to determine whether or not an invention was made in the course of work funded by the Agency, and
- as a byproduct of a technology watch, monitoring patent applications filed by ESA contractors to identify inventions possibly made while working under contract to ESA.




These methods are not aimed at sanctioning the non-declaration of inventions, but simply at making an inventory of contractor's patented inventions in which ESA, and thus its Member States, have certain rights, so as to avoid any unjustified property claims at a later date.

A company involved in replying to an ESA Call for Tender may request the restricted dissemination of its background information, in which case the Agency should limit this to the extent required to achieve the purpose of the contracts. A problem can then be a lack of detail on how the purpose was achieved in particular for further work on the contract. Although such a problem may occur, it should be made clear by the bidder from the outset that he wishes to restrict dissemination in order not to prejudice his justified interests, so as to not compromise the validity of his offer by being marked down on this point during tender evaluation.

It is of course clear that a company responding to a Call for Tender and having in its possession patents that could be based on an invention made during a previous ESA contract in the same field, is in a stronger position than other bidders. Nonetheless, this company's offer should be evaluated strictly for compliance with the contract specifications, and not be compared with the other tenders.

A European company replying to an international competitive call for tender, and wishing to make use therein of a patented ESA technology, faces the problem that it should pay licensing fees and royalties to ESA, and would have to add the costs to their overall financial proposal. This company should, however, contact ESA prior to submitting its offer, to negotiate the conditions of a licence. In view of the international competitive situation, and ESA's role in improving the worldwide competitiveness of European industry, the company should then be able to obtain favourable conditions.

More recently, ESA has proposed technology-development contracts in which potential contractors would partly contribute their own funds ('mixed funding'). As a result, the rights of ESA in the intellectual property generated in the course of a contract relate to a pro-rata fraction thereof.

Such 'mixed funding' could have an effect on the obligation with respect to free licensing of inventions patented by the contractor, for example in as far as the contractor could select, in agreement with ESA, the companies entitled to free licences in the context of ESA or Member State space programmes. Royalties due to ESA in the case of sales of non-space items embodying patents would be reduced on a pro-rata basis.

The obligation of contractors to notify transfer of inventions outside Member States to ESA may be seen as contrary to good commercial practice. It should, however, be clear that the Agency will treat the information as confidential, and that if there should be an objection, this is not legally binding on the foreseen transfer, the main object of this exercise being to allow track to be kept of intellectual property in which ESA and the Member States have certain rights.

**Conclusion**

It has been shown that the Agency's policy in the protection of inventions made by its staff and contractors is one requiring adaptation to developments both in ESA's programmes and in the contractors' needs. Some problems arising from this changing situation have been briefly discussed, and some solutions outlined. Protective measures introduced by the Agency have been instituted in the interests of contractors and are aimed primarily at improving their competitive position.

# ERS Product Assurance and Quality Control

**P. Lecomte, V. Amans, O. Colin, R. Gomez & J. Sanchez**
ERS Mission Coordination and Product Assurance Section, ESRIN, Frascati, Italy

**Since the ERS-1 satellite was placed into orbit in July 1991, it has been providing the user community with very high quality data sets. In order to be able to guarantee that quality to the scientific community, the ERS Mission Coordination and Product Assurance Section at ESRIN has been performing a permanent background task: from mission planning and data acquisition to the processing and dissemination from the point of view of Quality Control. This paper explains the concept of Product Assurance and Quality Control, and describes all areas of the ERS ground segment in which the Section is involved.**

**In preparation for the launch of ERS-2 in April, a complete review of the Section's role was carried out and the experience gained through ERS-1 has been used to improve the products and services offered. In the longer term, this exercise will take on a greater significance as ESA prepares for a much more ambitious mission, the Envisat mission.**

## Product assurance

To ensure Product Quality Assurance requires 'a planned and systematic pattern of all actions necessary to provide adequate confidence that the item or product conforms to established technical requirements' (ANSI/IEEE Standard 730.1-1989). The Quality Assurance activity is the process of verifying that these standards are being applied.

The principles of Product Quality Assurance activities are described in the ESA software engineering standards (PSS-05-0 Issue 2).

In small projects, the operators themselves can perform the quality assurance, but in large projects, specific staff should be allocated to the role. A Product Quality Assurance Plan (PQAP) defines how adherence to the standards will be monitored. The Plan's table of contents can function as a checklist of the activities that must be carried out to ensure the quality of the products. Those responsible for Product Quality Assurance should define how each activity is to be monitored.

A Quality Assurance Plan has been developed for the routine operations of the ERS ground segment. It covers the following activities:
- Background mission planning
- Satellite monitoring
- Ground station monitoring:
  - Data acquisition
  - Processing
  - Dissemination
- Quality control of ESA products produced by:
  - ESA stations
  - Processing and archiving facilities
  - Other stations
- Monitoring of ESA ground segment software status
- Triggering the evolution of algorithms:
  - Debugging
  - Upgrade
- ESA systems configuration control
- Managing studies to evaluate:
  - Algorithm evolution impact
  - Calibration methods.

The Plan defines, for each activity, the specifications for each type of element, such as hardware, software, algorithm, product and method, as well as verification procedures, the software tools to be used, the analyses to be performed and the reporting mechanisms.

## ESRIN Product Control Service

For the ERS ground segment, the ERS Mission Coordination and Product Assurance Section in ESRIN (Frascati, Italy) manages all of those activities, with the support of a system called the Product Control Service (PCS). The PCS is the environment in which all the ERS data is collected, analysed, controlled and archived. It is also where the Product Quality Control is performed.

The PCS has recently been upgraded to cope with two satellite data flows, as shown in Figure 1. Its operational environment is now based on the following principles:

- It is composed of a mixed VAX/DEC Alpha cluster, which means that all PCS applications are running on top of a unique, homogeneous and common file system, therefore data storage resources (disks, peripherals) can be shared.

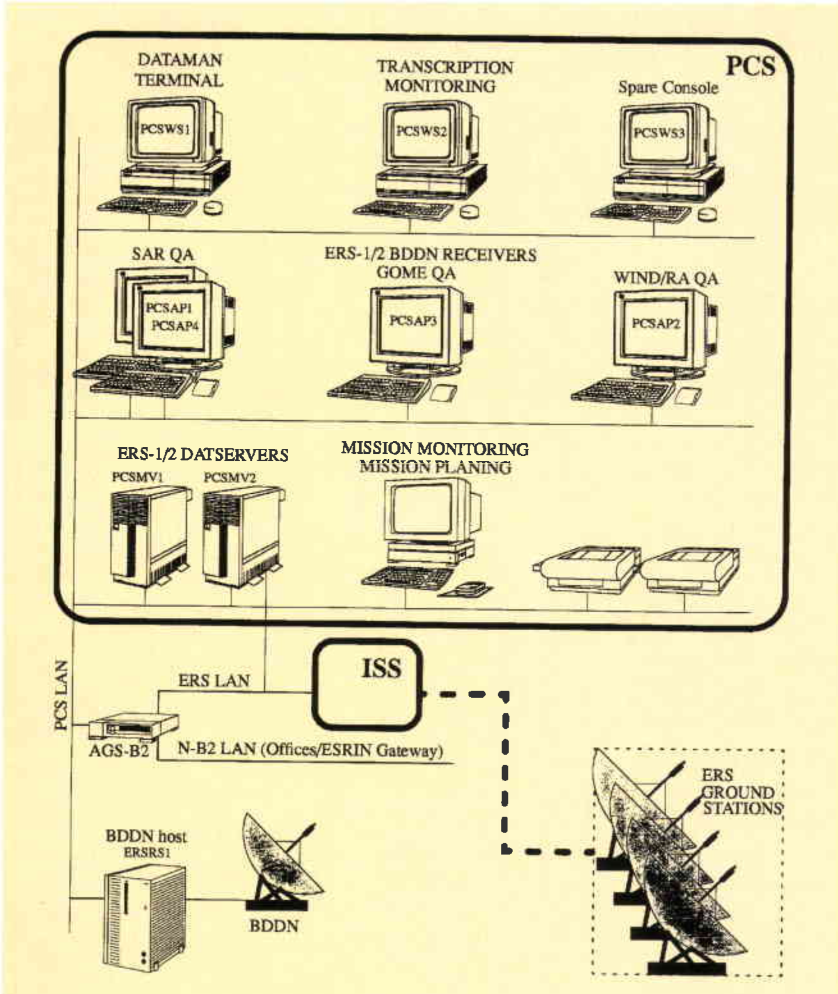



**Figure 1. Layout and configuration of the Product Control Service (PCS)**

— Most of the products and report files as well as the relevant parameters for the sensor monitoring generated within the ERS ground segment (the stations, mission management and the control centre at ESOC in Darmstadt, Germany) are handled through the Interface Sub-System (ISS) located at ESRIN. Other files such as SAR images and, after ERS-2 has been launched, GOME (Global Ozone Monitoring Experiment) and Micro-Wave Sounder raw data products are received from the Broadband Data Dissemination Network (BDDN).

— ERS-1 and ERS-2 data flows are logically split on the file system for clarity. However, both ERS-1 and ERS-2 data will be available from all machines.

— The logical organisation of ERS data on the system optimises the network traffic on the PCS LAN Ethernet segment.

The PCS functions are organised according to three types of activity: file management, global instrument monitoring and product quality control. Three main sets of software tools are running on the cluster and are dedicated respectively to the handling and routing of the incoming files (Dataserver), and to the analysis and control of the SAR (Sarcalq) and the Low-Bit-Rate products (Rascals).

## Mission preparation

Based on the ANSI/IEEE definition, Quality Assurance must cover all the actions necessary to ensure the good quality of the data.

Quality Assurance starts at the very beginning of the lifetime of the data: at its acquisition. In fact, good data can be useless if it is not acquired properly. In this context, 'properly' means at the right geographical location as well as with the proper continuity. For example, the altimeter scientific community is interested in a data set that covers the whole planet for a certain period of time.

For the ERS missions, the difficulty in the planning activity lies in the multiplicity of the instruments onboard and the need for a coordination of the SAR mission on the one hand and of the other instruments on the other hand. The planning cannot be done in the same way for the two parts as different and conflicting requirements have to be handled.

For the SAR mission, the planning is based on a direct and permanent contact with the user in order to schedule image acquisition for the right time and for over the appropriate area of the Earth. This activity is the responsibility of the ERS Central User Service. At the same time, the users of the data collected by the other instruments are also interested in global coverage and are ready to handle all the available production. The mission planning for the other instruments therefore consists of the scheduling of the instruments and the on-board recorder to take full advantage of the recorder's capacity and to protect certain geographic areas used for instrument monitoring against systematic gaps (due to the acquisition of SAR images or to gaps in the data recording), in view of instrument calibration and verification. This activity — the scheduling of the other instruments and the on-board recorder — is called background mission planning.

## Background mission planning

The quality control during background mission planning is the activity that ensures the quality of the mission itself. Even if the instruments are working perfectly, the overall data quality will be affected by satellite manoeuvres, the scheduling of the on-board recorders, i.e. when the data is stored or when it is dumped to the ground stations, as well as by the planning of the ground-station acquisitions.

The objective of the background mission planning is to define a background mission operation plan that best fits the ERS users' requirements. The major determining factors are the design of the spacecraft, the type of orbit (a repeat cycle of 3, 35 or 168 days) and the priorities given to that phase, such as interferometry, geodesy and/or cryosphere. For example, on ERS, the design of the on-board recorder — the physical length of the tape — limits the storage capacity to 100 minutes of Low-Bit-Rate (LBR) data, whereas in some cases the relative position of the ground stations leads to 120 minutes of data being acquired. On the other hand, for some orbits, the dump capacity is limited by station visibility.

Based on those factors, a data-recording strategy has been defined for the on-board data recorder, taking into account the following elements:
- Requests specific to the mission
- User requests for calibration and validation
- Descoping strategy
- Protected zone for calibration and validation activities
- Station planning and visibility
- Mission analysis (LBR, and Instrument Data Handling and Transmission (IDHT) system)
- Quality Assurance monitoring
- LBR acquisition and recording analysis, i.e. a comparison of real acquisition and dissemination with the background mission operation plan.

The objective is not only to provide a full background mission operation plan that includes a scheduling of the payload operations compliant with the mission planning rules and the on-board constraints, but also to prototype and validate new mission strategies and to fine-tune the planning parameters in order to maximise the mission benefits. The final result — the best compromise between constraints and requirements, validated through simulations — is sent to the Mission Monitoring and Control Centre at ESOC for translation into satellite commands. Its validity will be monitored against the background mission operation plan during the actual operations.

### Fast Delivery Product generation

Once the data has been acquired, recorded on-board for the LBR instruments and dumped to the ground stations, two types of activity are carried out at the ESA ground stations: the processing and the distribution of the raw data to the user community and the archive centres.

The so-called Fast Delivery Products (Fig. 2) are generated at the ground station immediately after a full orbit of raw data has been received, and they are distributed to the users within three hours. In parallel, they are disseminated to the PCS where an indirect control of acquisition and processing can be carried out by analysing each product. The direct control of the station activities is ensured by ESOC for the Kiruna station and by the Ground Station Facilities at ESRIN for the other ESA stations. The Section maintains permanent contact with those two entities in order to identify any anomalies that may occur at the level of acquisition, processing or dissemination.

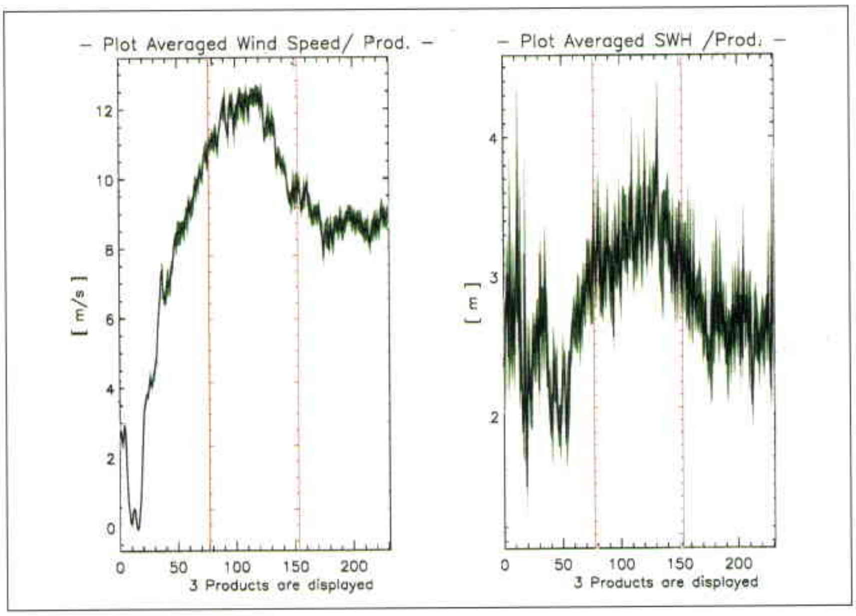



**Figure 2. An example of a radar altimeter Fast Delivery Product: wind speed and sea wave height (SWH) generated by Hurricane Emily, as seen by ERS-1 on 30 August 1993**

### Off-line products

A second set of products, off-line products (Fig. 3), has been defined to satisfy the need for higher quality data, but those products require updated parameters and more computer time. They are generated by the Processing and Archiving Facilities (PAF), which are managed and monitored by ESRIN.

For those products, the PCS is responsible for the coordination of the routine Quality Assurance activities performed at the PAF, as well as for the computation of the calibration constants and corrections required to calibrate the ERS products. The product validation activities are another of the Section's tasks.

For the SAR, 21 SAR products from six different processors have been validated, with six different levels of processing ranging from the raw data to the geo-terrain corrected products.

### Routine monitoring

All Fast Delivery Products generated at the ESA ground stations are received and stored for a maximum of 15 days in the PCS rolling archive, which is accessible on-line, and then archived on magnetic support. The existence of the rolling archive for a certain period of time allows not only a routine monitoring of pre-determined parameters, but also a detailed inspection of suspected anomalies.

A set of routine activities has been set up within the PCS in order to have an overview of the mission and the availability of the data and their quality at any time. Most of the anomalies at acquisition, processing or dissemination level can be detected by analysing the so-called Daily Report, a summary of one day's activity based on the results of the checking of every single low-bit-rate Fast Delivery Product from the Wind Scatterometer, the Radar Altimeter and the SAR in wave mode (respectively called UWI, URA and UWA products), the headers of the SAR Fast Delivery Products (called UI16) and the extracted raw data from the Scatterometer and the Radar Altimeter (respectively EWIC and ERAC). In the Daily Report, the main fields of the Main and Specific Product Headers, the Product Confidence Data (PCD) and most of the geophysical parameters extracted from each product, are plotted as a set of time series, to allow evolutions and trends to be followed.

**Figure 3. An example of a SAR off-line precision image: Frankfurt airport on 3 May 1992. Produced by the Italian Processing and Archiving Facility.**

Any observed anomaly, absence of scheduled products or suspected poor quality is recorded, analysed in more detail using dedicated tools, and cross-correlated with station reports. Among those reports are the unavailability reports generated by ESOC detailing the instrument anomalies; the acquisition, production and dissemination reports generated automatically at the stations by the Fast Delivery Processing Chain and which provide information on the respective activities; and the event report on the detection of an anomaly, which is generated by the station staff and documented with the processor logs.

Two sets of statistics are derived from that level of monitoring:
- The raw data availability statistics, which take into account the unavailability of all the instruments and stations
- The low-bit-rate processing success based on the received against expected data in the PCS, with the unavailability excluded (processing success measures the amount of processing/distribution failure per station).

The routine monitoring is completed by monthly Wind Scatterometer and Radar Altimeter reports showing time series analysis of the most important parameters and allowing long-term monitoring of instrument performance.

The Section is developing a new tool, the Mission Monitoring System, which will allow the quality of the whole ERS ground segment to be monitored. It will provide easy access to all the relevant parameters, by means of daily reporting, as well as interactive access to the parameter database. The major tasks of the Mission Monitoring System will be:
- To improve the daily reporting of information by creating an event database, covering the on-board (instrument availability and sensor modes) as well as the on-ground (acquisition, processing and dissemination) aspects of the ERS system.
- To create a history of the ERS missions covering data availability, anomalies and system configuration.
- To enhance the on-line monitoring and reporting by maintaining statistics on performance, by monitoring the mission planning rules and their impacts and by monitoring the on-board and on-ground resource utilisation in order to validate the mission strategies.

### Detailed product analysis

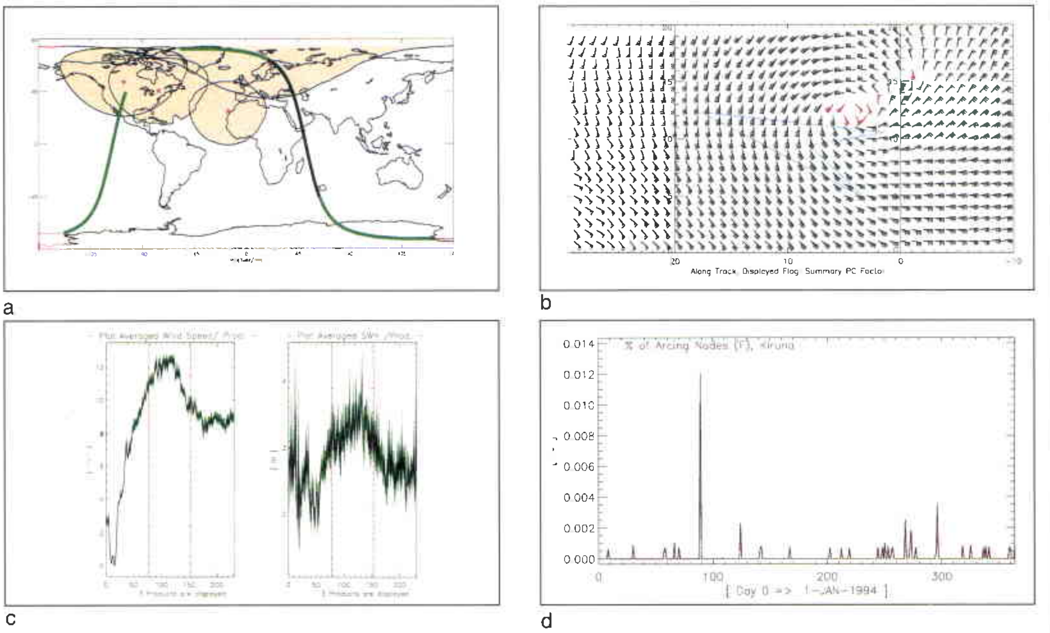
Two important software tools, Rascals and Sarcalq, have been developed under PCS responsibility to perform detailed analyses of each Wind Scatterometer, Radar Altimeter and SAR product (see insets). Both systems provide visual access to all information included in the products and also allow the automatic extraction of a set of relevant parameters, which are kept in an on-line database for long-term monitoring of sensor performance and Product Quality Assurance.

**Anomaly reporting**

The detection of an anomaly in the processing triggers the generation of an Anomaly Report. Investigations are first carried out at ESRIN, with the tools available in the PCS, the inspection of the station logs or the reprocessing of the raw data in the reference chain when necessary. Whenever a corrective action is requested, a non-conformance report is issued to the person responsible for the maintenance of that chain, if the problem is related to a software anomaly. The Mission Coordination and Product Assurance section controls each step in the process, under the supervision of the ERS Ground Segment Configuration Control Board.

**Reporting activities**

Reporting is probably the most important of the Product Assurance activities. In fact, Product Assurance is of no use if the information is not




## Analyses using the Rascals software

Rascals is a software system dedicated to the monitoring and analysis of sensor performance and data product quality for the ERS-1 and ERS-2 Wind Scatterometers, Radar Altimeters and SAR in wave mode. The system can access raw data and fast delivery products as well as housekeeping data generated by the different ERS instruments. The functionality covered by the Rascals system ranges from the graphical visualisation of all parameters provided in the data products to specialised analysis functions supporting the geophysical validation of the measurements.

In the interactive mode, Rascals allows the relevant data to be displayed, investigated and processed. In the routine mode, it samples the data products to build a historical database.

(a) The ERS-1 orbit acquired at Kiruna on 12 February 1995 and containing the data acquired between 18:00 and 19:27. The line represents the Radar Altimeter track, and the small square in the Indian Ocean shows the position of the Scatterometer product at 18:51.

(b) The sea-surface wind of this particular product, together with half of the previous product and half of the next product.

(c) The Radar Altimeter wind speed and significant wave height at the same acquisition time.

(d) Rascals maintains automatically a database of engineering and geophysical parameters, extracted daily. This figure, showing the occurrence of arcing events in 1994, is an example of the content of this database.

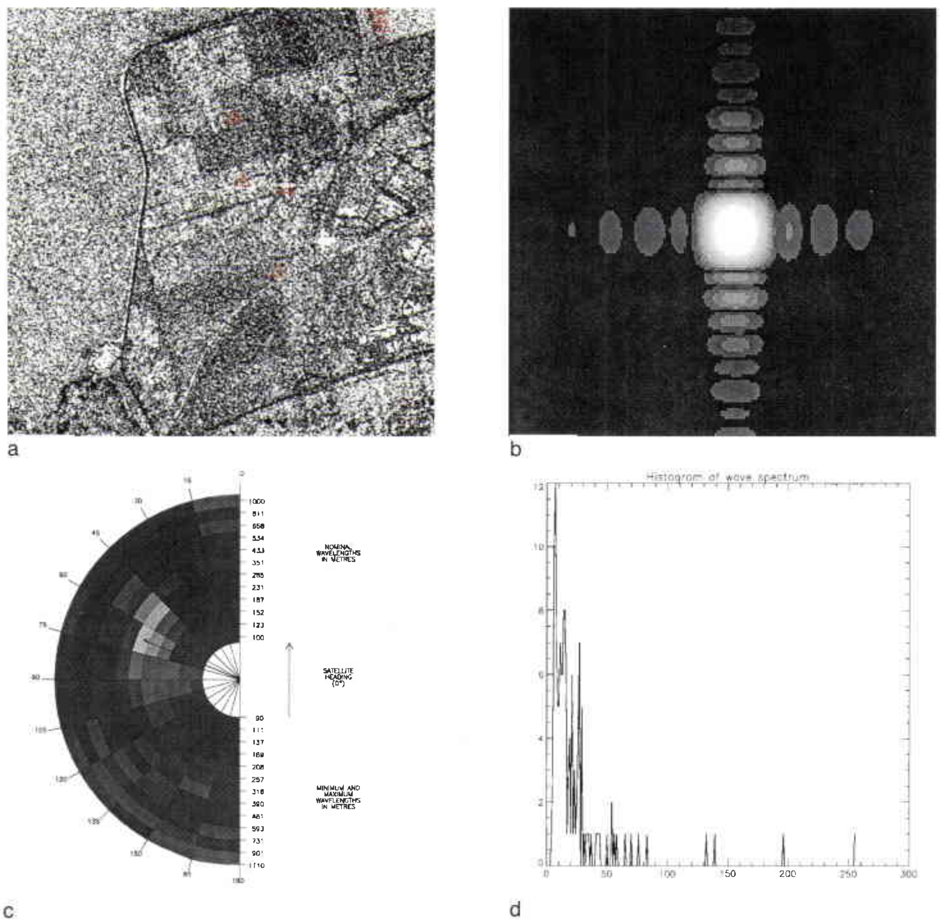
passed to the users, and if it has no impact on the global product quality evolution.

Three types of reports are required:
- Unavailability statistics to inform the user of missing data
- Operation reports to enable the user to keep up-to-date with the mission evolution and the product quality
- Information to users on the plans and possible product evolution.

**Ground Segment Configuration Control Board**

The role of the Configuration Control Board is formally defined in ANSI/IEEE Standard 729-1983. It is to:

- Identify and define the configuration items in a system
- Control the release and change of the configuration items throughout the system lifecycle




## Analyses using the Sarcalq software

Sarcalq has been developed to analyse the SAR images acquired over calibration sites in order to calculate the SAR calibration constant, and to monitor the instrument stability, compute the in-flight antenna pattern and control the performance of the different SAR processors. This tool is also used to visualise the SAR images and wave products, and to monitor the production at the ESA stations.

(a) Flevoland (The Netherlands) showing the location of one of the transponders deployed in that area to be used to calibrate and monitor the stability of the ERS SAR system in image mode.

(b) The Impulse Response Function corresponding to that transponder.

(c) The ERS SAR also has a wave mode capability which is interleaved with the Scatterometer. In this mode, the SAR makes small imagettes (5 × 6 km), from which the imagette spectra can be extracted. This spectra shows the direction and the strength of the waves in the ocean.

(d) The histogram of the same product.

— Record and report the status of configuration items and change requests
— Verify the completeness and correctness of configuration items.

It is clear that good configuration management is essential for efficient development and maintenance, and to ensure that the integrity of the system is never compromised. With respect to the ERS ground segment, system configuration management ensures that all major tasks such as the scheduling of the instruments and the station acquisitions, or the data production and dissemination are performed properly. The configuration management of the ERS ground segment is a key element of the mission Quality Assurance as defined earlier. It covers all elements of the overall system, from the space segment (e.g. on-board software or parameters) to the ground segment (e.g. hardware, software, look-up-tables, products, formats, documentation).

The main source of information for the control of the ERS ground segment configuration is the Configuration Control Database. This Database contains all the elements necessary to trace the evolution of any item of the ERS ground segment, such as station anomalies, Non-Conformance Reports (NCR), the status of the NCRs from issue to closure, or the latest version of every item (software, hardware). The aim of this activity is to detect, for example, a wrong parameter up-loaded into the satellite computer, or the presence of a corrupted Look-Up Table in a processor after maintenance of the hardware.

Although the Configuration Control Board is often underestimated and seen to be one more board slowing down the process of improving the service to the users, it is nevertheless the only way to ensure the regular and proper dissemination of validated products to the user community.

**Algorithm monitoring and evolution**

In a long-term project like ERS which spans more than a decade, it is impossible to define steadfast algorithms to be used for deriving the products to be provided to the users from the instruments' raw data. The algorithms used may evolve because of the development of new algorithm techniques or because of the evolution of the mission itself. In particular, assumptions about the mission profile defined a long time before the actual launch of the satellite, may be found to be obsolete when the satellite is flown and the data distributed to the user community. The mission itself triggers new concepts and new ideas, which cause new and different mission requirements and new product definitions to be issued.

A good example of such an evolution for the ERS mission is the SAR interferometry. That technique was initially proposed as a possible use of the SAR images when ERS-1 was launched. The results of the first studies, however, were so successful that that application became a major issue with respect to the SAR product specifications and the ERS-2 mission profile (Fig. 4).

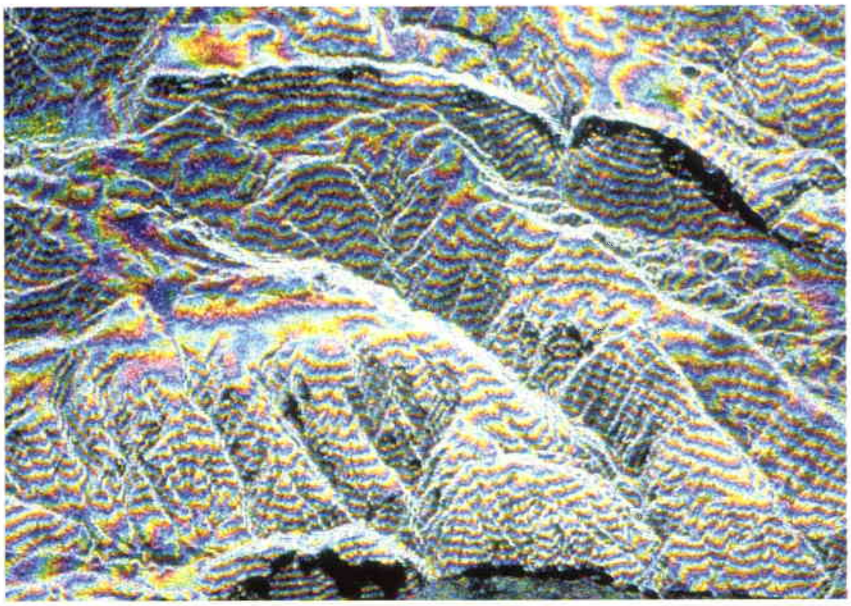


**Figure 4. ERS-1 Fringe Working Group Reference Data Set: Gennargentu (east coast of Sardinia). Interferogram projected onto SAR Intensity image. The area consists of slopes covered in vegetation, rising steeply to peaks of approximately 1200 m. (Produced by Polimi, Italy)**

It is a major task to understand the details of product computation in order to have a complete overview of the algorithm limitation and its possible improvements, to take into account at the same time the evolution of the hardware and of the algorithm techniques applicable to this particular product, and to satisfy user needs, while still ensuring that the constraints imposed by the ground segment design and the mission constraints are always taken into account. This activity requires skilled personnel, able at the same time to cover all the aspects of the Product Assurance concept, and to understand in depth the details of each element of the ground segment (systems, hardware, algorithms, software, user needs) in order to be able to respond to a new requirement.

**Reference system**

One of the quality control activities is to ensure that any software evolution required to correct a software anomaly or to introduce a new algorithm does not affect the integrity of the ERS ground segment.

In order to check the impact of any modification, any new software is installed on a replica of a ground station system at ESRIN and tested, first locally and then in short loop, i.e. processed and disseminated to the PCS. In the PCS, the data is analysed in detail using all the tools available. Once it has been confirmed that there are no side effects, the test results are submitted to the Configuration Control Board for approval. The new software is then installed at the real ground station under the Section's supervision and the detailed tests performed during the short loop are repeated as soon as the software is used operationally.

That reference system is one of the key elements available to the CCB to ensure the stability of the ground segment.

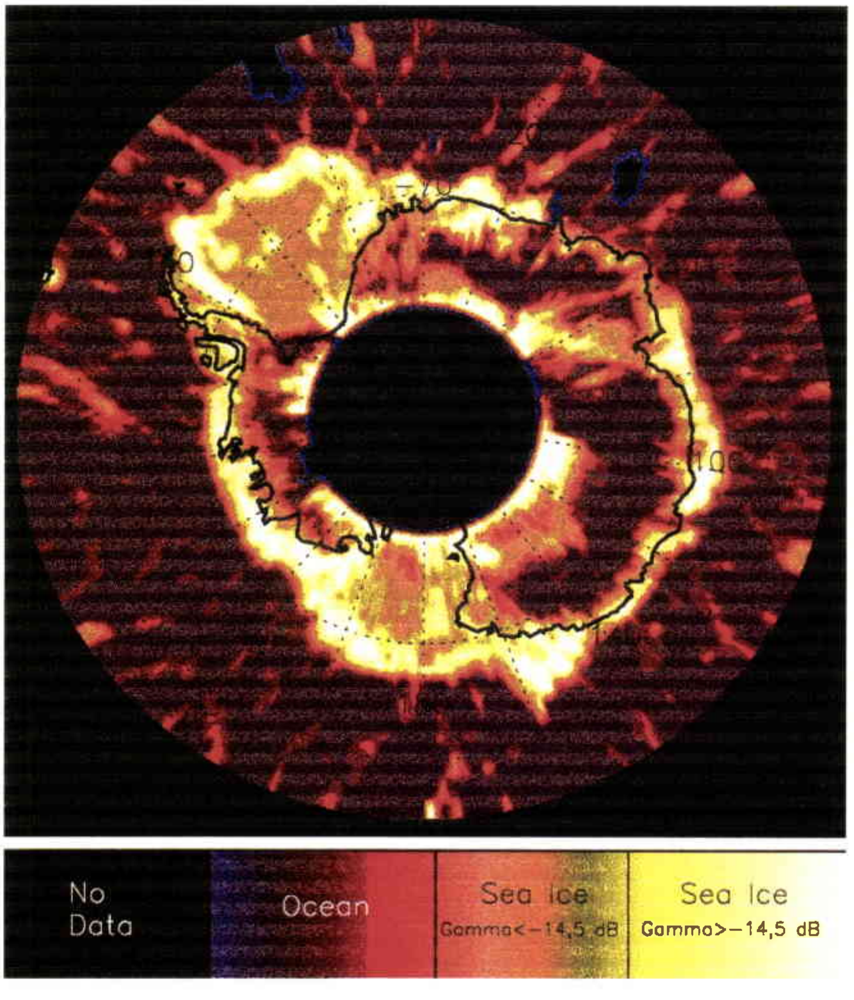



**Figure 5. Analysis of sea ice over Antarctica in April 1994, using scatterometer data. This study was conducted by the PCS in order to better understand the scatterometer data.**

## New studies

Quality Assurance is based on an up-to-date knowledge of all the engineering and scientific aspects of the overall project. Close contact with the scientists is mandatory in order to be able to understand the instruments, and to improve the quality of their engineering calibration or geophysical validation.

As an example, the rain forests are used as a uniform target for the calibration of the ERS SAR and scatterometer. It is therefore important to promote and to closely follow studies on the interactions between microwaves and such a target. Although those studies are often not directly conducted by the team responsible for Product Quality Assurance, it should be a constant concern that the team is involved in the Scientific Advisory Groups, in the different studies proposed by ESA and more generally in close contact with the scientific community.

This type of activity is also required in order to be aware of the users' concerns and to be able to respond to their needs by developing new applications (Fig. 5), which can require new product specifications and new Quality Assurance techniques.

## PCS evolution for ERS-2

To serve the ERS-2 satellite, the PCS had to be updated to handle a new instrument, GOME, and new functions implemented in the ground segment such as the real-time transcription of raw data at each station.

The introduction of GOME required an evolution of the basic concepts that were defined for ERS-1. In fact, the Product Quality Assurance Plan was based on the analysis of the Fast Delivery Products for the routine surveillance of the data. The PCS receives those products in less than three hours. It was only if an anomaly was detected at that level that an analysis of the raw data was performed. However, there is no real-time processing for GOME. Therefore, the PCS has to cope with raw data assimilation and analysis using the transcription tapes generated at the station and received by the PCS with a few days' delay. In order to perform instrument surveillance in real time, the housekeeping data summarising the overall spacecraft status will have to be analysed. Previously, this data was only used in a subsequent step for deeper analysis of an anomaly.

Two new concepts were introduced in the Quality Assurance Plan:
— Separation of the instrument status analysis from the data quality control
— Analysis of the actual data with a few days' delay.

In response to those new concepts, the Rascals tool was updated and now has the capacity to fulfil the new requirements introduced by the GOME instrument.

## Conclusion

Product Assurance and Quality Control activities are of paramount importance in the exploitation of any productive system. The ERS satellites are no exception.

In accordance with international standards, the ERS Mission Coordination and Product Assurance Section at ESRIN is undertaking all necessary actions to ensure that the different ERS products adhere to the established technical requirements. That effort is important because most of the analyses need to be carried out in near-real-time.

With the impending launch of ERS-2, all of the Section's different activities were reviewed to ensure that the Section would be able to handle both the ERS-1 and the ERS-2 missions at the same time. The experience gained during almost four years of ERS-1 data analysis was also used to improve some of the existing activities and to define others required to take full advantage of the new ERS products such as the interferometric products.

Today, the ERS Mission Coordination and Product Assurance Section is able to guarantee the adequate exploitation of both the ERS-1 and ERS-2 satellites and is looking forward to meeting that challenge.

## ESA 1996 PRODUCT ASSURANCE SYMPOSIUM
## and
## SOFTWARE PRODUCT ASSURANCE WORKSHOP
## ESTEC, Noordwijk, The Netherlands, 19-22 March 1996

**Abstract deadline: 15 September 1995**

Since the previous conferences held in 1991 and 1992, the environment of space projects has undergone major changes worldwide, with consequent effects on product assurance (PA). The 1996 meetings will address these changes and trends under the general theme of

*Space Product Assurance and Industrial Competitiveness.*

The Symposium and the Workshop will provide a forum in which developers, operators and users of space systems can discuss the lessons learned by policy makers, procurement agencies and suppliers.

*PA* concerns everybody in the customer's and supplier's organisations, and it must be fully integrated into programmes from the very beginning if managers and and specialists are to have appropriate tools for decision making. The Symposium is aimed at executives and managers who regulate, procure, operate or use space systems and who wish to discuss the challenges of the future, as well as the PA professional.

*Software* can account for a large part of the cost and risk in a project and therefore the Symposium includes a concurrent Software PA (SPA) Workshop.

*An exhibition of PA software tools is planned.*

***Address for enquiries and mailing of abstracts:***

ESTEC Conference Centre
Postbox 299
2200 AG Noordwijk, The Netherlands
Tel. +31 1719-85005
Fax +31 1719-85658

## AUSTRALIAN INTERNATIONAL SPACE SCHOOL (AISS)
## Sydney, Australia, 15 - 21 July 1995
## INTERNATIONAL APPLICATION

Educators and students from around the world are invited to attend the 4th International Space School (AISS) to be held in Australia. AISS is an annual event, which hosts 100 delegates, who are selected from throughout Australia, and by application from other countries.

- AISS is an educational programme which highlights Australia's role in Space and Astronomy.
- AISS is sponsored by the Australian government through the Australian Space Office, and by a private company, *Fundraising Options*. AISS is *free of charge* to selected delegates.
- The AISS programme is based within the University of NSW, at Kensington in Sydney.

International applicants are welcome. To be accepted, all applicants:

- must complete an application form (available from AISS)
- must be approved by an education authority
- must organise their own travel to Australia
- should be able to speak, or understand English
- must be older than 15 years

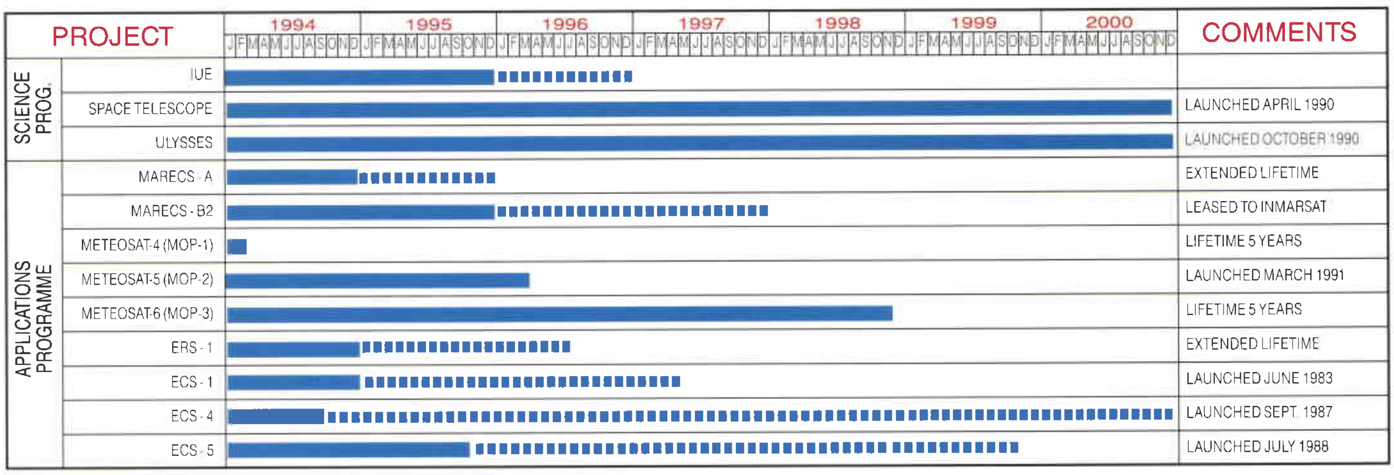
***All expenses at AISS are met by the Sponsors.***

***Application deadline is 2nd June 1995.***

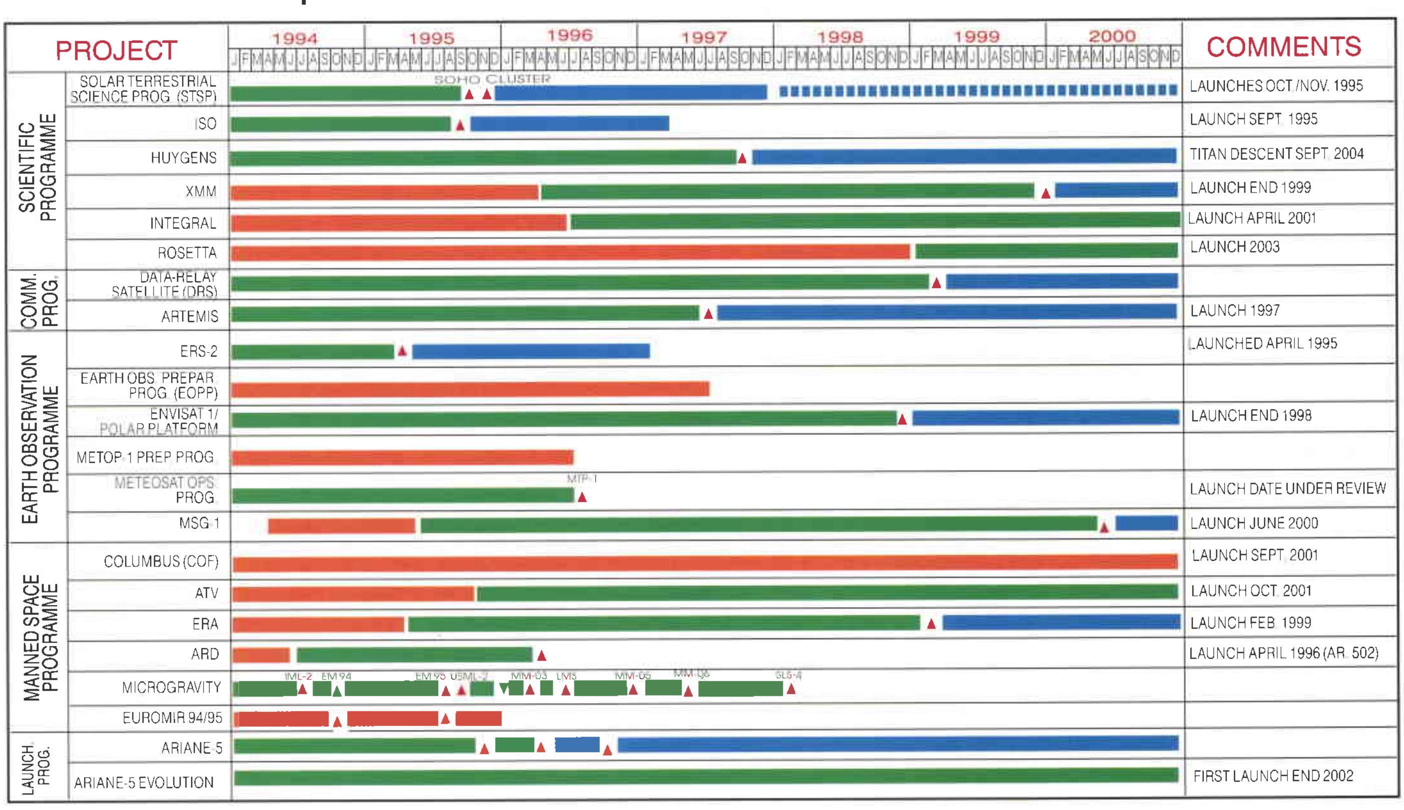
Fax applications (or enquiries) to: 61 2 3497606
Postal address for AISS:
81 Haig St: MAROUBRA, NSW 2035
AUSTRALIA
(This number is a phone / fax / message machine, open 24 hours)

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

## In Orbit / En orbite




## Under Development / En cours de réalisation




■ DEFINITION PHASE ■ MAIN DEVELOPMENT PHASE ▲ LAUNCH/READY FOR LAUNCH

■ OPERATIONS ■■■ ADDITIONAL LIFE POSSIBLE ▼ RETRIEVAL

## Ulysse

*La sonde, qui est largement entrée dans sa quatrième année d'exploitation, est en excellent état, tous les instruments et sous-systèmes fonctionnant de façon nominale. Depuis le dernier rapport, les opérations ont été quelque peu compliquées par le retour début octobre du même phénomène de nutation qui s'était produit brièvement peu après le lancement. Provoquée par un réchauffement solaire non uniforme du bras axial lorsque le satellite tourne sur lui-même, cette perturbation a vu son intensité augmenter comme prévu, pour atteindre une crête les derniers jours de décembre. Début février, la nutation s'est estompée comme on s'y attendait lorsque les positions relatives de la sonde, du Soleil et de la Terre se sont modifiées. A mesure que la sonde se dirige vers les hautes latitudes septentrionales du Soleil, sa géométrie orbitale prend un aspect tel que cette perturbation devrait atteindre une nouvelle crête en avril mai et durer jusqu'à août ou septembre.*

*Pendant la période récente de nutation, les procédures opérationnelles préétablies (mettant en oeuvre le système Conscan embarqué pour obtenir un amortissement actif) ont très bien réussi à maintenir le pointage de l'antenne à grand gain à l'intérieur d'une marge de 0,2°, ce qui a pratiquement exclu toute incidence sur l'exploitation scientifique. Des manoeuvres 'transparentes' de cette nature, exigeant une liaison montante (pratiquement) continue en direction d'Ulysse, n'ont pu être réalisées que grâce au dévouement et au professionnalisme de l'équipe commune ESA NASA d'exploitation du satellite au JPL et à la coopération du réseau de l'espace lointain de la NASA et de la station sol de l'ESA à Kourou.*

## Soho

### Industrie

*Début décembre 1994 a démarré l'essai de simulation solaire sous vide thermique du modèle de vol de Soho. Il s'est déroulé sans problème, permettant de mettre à l'épreuve dans un environnement représentatif la quasi-totalité des éléments de la sonde, et ce pour la première et seule fois du programme. Certaines divergences entre températures prévues et mesurées, en particulier du côté de la sonde exposé au Soleil, ont provoqué l'exécution d'essais supplémentaires hors programme en février dans la chambre sous vide thermique Simles, afin d'expliquer certaines interactions entre la sonde et la chambre elle-même et d'apporter des données à l'appui des activités de corrélation en cours sur le modèle mathématique thermique.*

*A la mi-janvier, l'expérience UVCS a été démontée pour procéder aux mises à niveau critiques nécessaires, tandis que le reste de la sonde subissait un deuxième essai de compatibilité avec le secteur sol et, immédiatement après, des essais destinés à vérifier les prévisions de microvibrations à bord de l'engin.*

*Ces essais de microvibration ayant été menés à bonne fin, les modules de charge utile et de servitude ont été dissociés pour des activités à conduire en parallèle. Des accéléromètres ont été installés sur le module de servitude et des études ont été menées afin d'élucider les non conformités observées au cours des précédentes phases d'essai. Le modèle de vol de l'enregistreur état solide a été livré et installé fin février, après que les responsables de l'Agence et de la NASA se furent mis d'accord sur une configuration mixte comprenant un enregistreur à bande et un enregistreur état solide pour la mission Soho.*

*Après une série d'activités qui avaient pour objet de mettre plusieurs expériences à niveau, sous leur forme définitive (voir ci-dessous), le module de charge utile a été équipé des instruments nécessaires aux essais en vibration, et fait l'objet de mesures des propriétés physiques.*

### NASA (lancement et opérations)

*De nouvelles discussions ont eu lieu entre la NASA et Martin Marietta Space System (MMSS), responsable du lancement, au sujet de la date de celui-ci. On est parvenu fin janvier à un accord en bonne et due forme sur une date de lancement nominale fixée au 30 octobre, date qui a été acceptée par l'ESA.*

*Une revue de conception critique du véhicule lanceur de Soho a eu lieu le 19 janvier dans les locaux de MMSS à Denver.*

*Le deuxième essai de compatibilité avec le secteur sol a eu lieu à la mi-janvier, pendant environ une semaine, avec des séances quotidiennes interactives entre le centre de télécommande du Goddard Space Flight Center et le véhicule spatial, en place dans l'installation d'essais d'Intespace à Toulouse. La préparation du simulateur logiciel de la NASA s'est achevée en février et des essais indépendants ont été exécutés afin de valider ce simulateur en regard des résultats des essais réels.*

### Expériences

*Pour la mise à la norme de vol de l'UCVS, les masses inertes internes ont été remplacées par le spectromètre de vol (avec les détecteurs à lignes à retard croisées) et le mécanisme d'occultation des miroirs. Ces activités ont été menées dans l'une des salles blanches de MMS à Toulouse.*

*Le modèle de vol de l'instrument SUMER a été installé sur la sonde et entièrement vérifié, en remplacement du modèle de qualification qui avait été utilisé pour les essais de bilan thermique/thermiques sous vide.*

*Les PROM de l'unité électronique du LASCO ont été mises aux normes de vol.*

*L'expérience EIT a été fortement améliorée (porte avant de conception nouvelle, caméra, filtres) également dans l'une des salles blanches de MMS-F, et certains problèmes thermiques apparus au cours de l'essai système ont été résolus.*

*Le remplacement prévu des expériences CELIAS et VIRGO par des unités de vol complètes n'a pu se faire dans les délais impartis et sera reprogrammé à un stade ultérieur du programme.*

## ISO

*Les choses ont très bien progressé dans tous les secteurs du projet. Tous les essais d'ambiance du satellite au niveau système ont été menés à bien et dans les délais. Les quelques anomalies qui se sont fait jour au cours des essais les plus récents sont à l'examen. Les deux suiveurs stellaires ont été renvoyés au fournisseur pour être équipés de*

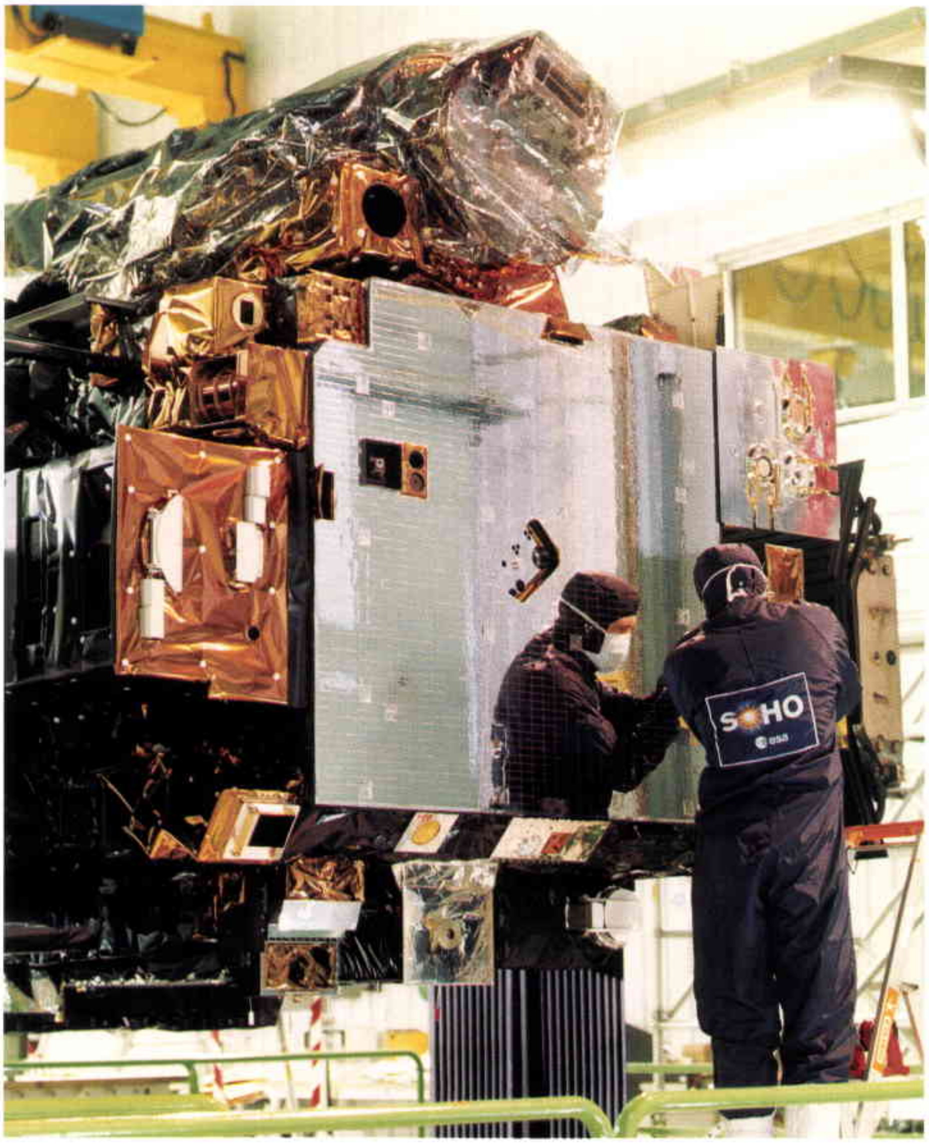
## Ulysses

The mission, well into its fourth year of operations, is in excellent shape, with all instruments and spacecraft subsystems functioning nominally. Since the last report, mission operations have been complicated somewhat by the return in early October of the same nutation-like disturbance that was present for a short period just after launch. Driven by non-uniform solar heating of the axial boom as the spacecraft spins, the disturbance increased in intensity as predicted, reaching a peak during the last few days of December. By early February, the nutation had died away as expected as the relative positions of the spacecraft, Sun and Earth changed. The orbital geometry as the spacecraft climbs to high northern solar latitudes is such that the disturbance is likely to peak again in April/May and be present until August or September.

Throughout the recent period of nutation, the predefined operational procedures (involving the use of the on-board Conscan system to achieve active damping) have been highly successful in maintaining the high-gain antenna Earth-pointing within about 0.2°, resulting in practically no impact on scientific operations. Such 'transparent' operations, requiring a (nearly) continuous uplink signal to Ulysses, could not have been achieved without the dedication and professionalism of the joint ESA-NASA Spacecraft Operations Team at JPL and the cooperation of NASA's Deep-Space Network and ESA's Kourou ground station.

*Préparation du modèle de vol de Soho aux essais d'équilibrage thermique/vide chez Intespace (F)*

Soho flight model before thermal-balance/vacuum testing at Intespace (F)




## Soho

### Industry

The beginning of December '94 saw the start of solar-simulation/thermal-vacuum testing of the Soho flight model. The test progressed safely and allowed most elements of the spacecraft to be exercised in a representative environment for the first and only time in the programme. Certain discrepancies between predicted and measured temperatures, particularly on the Sun-facing side of the spacecraft, led to an additional offline test in February in the Simles thermal-vacuum chamber aimed at explaining some interactions between the spacecraft and the chamber itself and supporting the ongoing thermal mathematical model correlation activities.

In mid-January, the UVCS experiment was demounted for its necessary critical upgrading, while the rest of the spacecraft has undergone a second ground-segment compability test and, in close succession, tests aimed at verifying predictions of the microvibration environment aboard the spacecraft.

After the successful completion of these microvibration tests, the payload and service modules have been demated and parallel activities have been run. On the service module, accelerometers have been fitted and some investigations have been performed to close out non-conformances found during earlier test phases. The flight model of the solid-state recorder was delivered and installed at the end of February, after ESA and NASA management had agreed a mixed configuration of one tape recorder and one solid-state recorder for the Soho mission.

The payload module underwent a series of activities aimed at upgrading several experiments to final status (see below). It was then instrumented for the vibration tests and underwent physical-properties measurements.

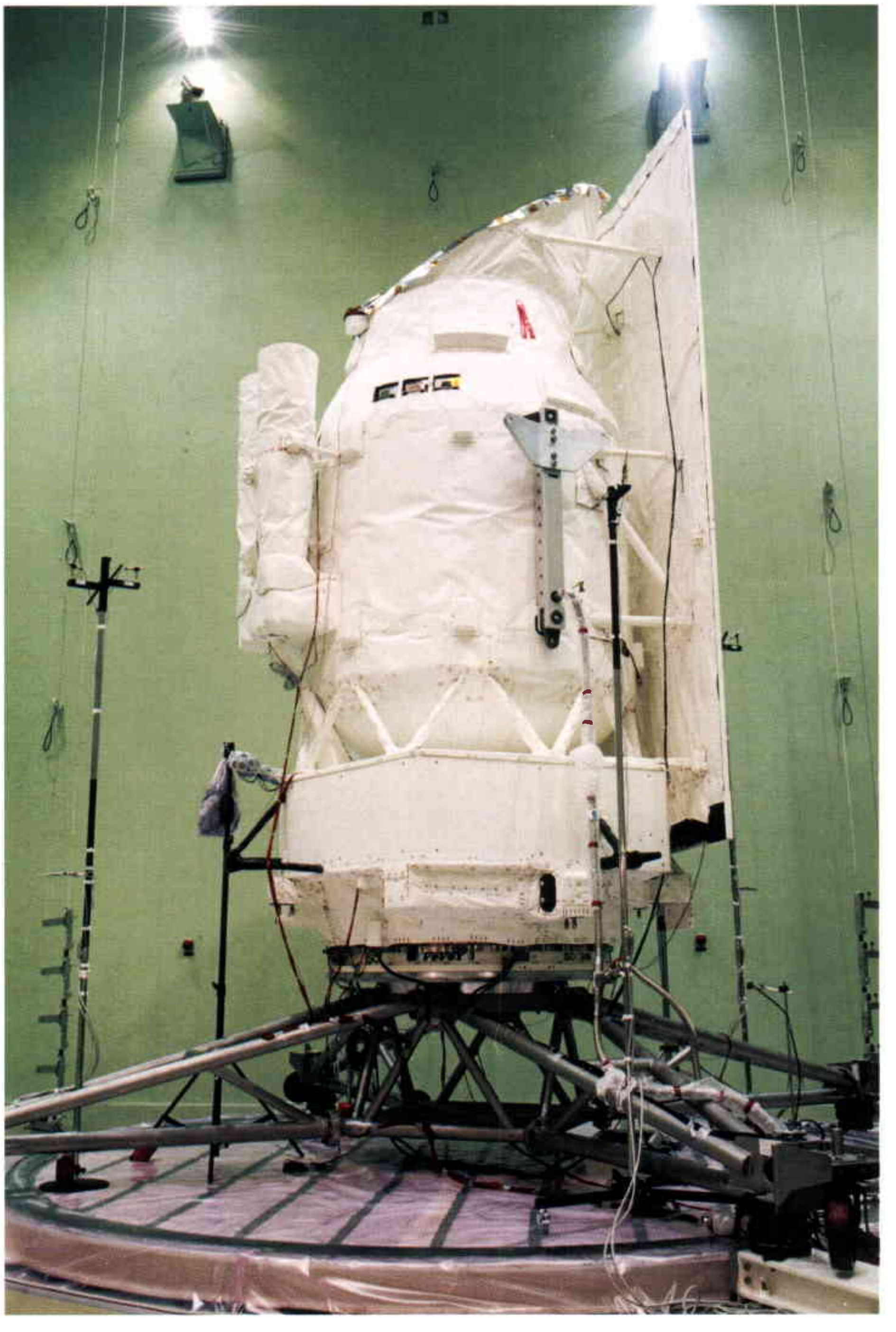
### NASA (launcher and operations)

Further discussions took place between NASA and the launch contractor Martin Marietta Space System (MMSS) regarding the Soho launch date. At the end of January, a formal agreement was reached on a nominal launch date of 30 October, which was accepted by ESA.

*nouveaux détecteurs améliorés afin de parvenir à la qualité de pointage requise. L'essai final au niveau système du satellite intégré s'achèvera lorsque les deux suiveurs stellaires améliorés auront été installés sur le satellite en avril.*

*Les travaux ont également très bien progressé en ce qui concerne la réalisation et les essais du secteur sol. Les essais d'interfaces opérationnelle s entre le satellite (à l'ESTEC) et le secteur sol (à l'ESOC, Darmstadt et Villafranca près de Madrid) ont démontré que le système fonctionne correctement. Les essais de compatibilité radiofréquence ont été menés à bien dans les deux stations sol ISO de Goldstone, en Californie. Les derniers essais satellite-stations sol, y compris le logiciel scientifique et des opérations en vol, sont programmés en avril.*

*Le projet continue de respecter le calendrier et tous les travaux sont axés sur un lancement prévu en septembre 1995. La revue de recette du satellite, lancée fin février, devrait s'achever en avril.*



ISO flight-model satellite during acoustic testing at ESTEC (NL)

*Modèle de vol du satellite ISO aux essais acoustiques à l'ESTEC (NL)*

## Huygens

*Les essais de qualification mécanique au niveau système menés sur le modèle structure/thermique/pyrotechnique de la sonde sont en voie d'achèvement. Les essais acoustiques et en vibration ont été menés à bien et, à la date où nous écrivons, la sonde a déjà subi quinze jours de ses essais de bilan thermique/thermiques sous vide qui doivent en prendre vingt deux.*

*En première évaluation, les résultats des essais thermiques exécutés à ce jour montrent que les caractéristiques thermiques correspondent à peu près aux prévisions. Huygens est appelé à subir des conditions thermiques extrêmes, la distance entre la sonde et le Soleil variant de 0,6 à 6 UA. La sonde pénètrera ensuite dans l'atmosphère dense de Titan, où la température est de l'ordre de -200°C. Les essais de rotation et radiofréquence du modèle spécial n° 2 (SM2) de la sonde ont été menés à bien à l'ESTEC. L'essai fonctionnel final du SM2, pour lequel le modèle sera largué de la nacelle d'un ballon, est en préparation chez Fokker et sera terminé en mars. La revue de recette pour le vol aura lieu les 4 et 5 avril avant expédition à Kiruna pour un lancement en mai.*

*L'intégration du modèle d'identification de la sonde est terminée et la séquence d'essais des sous-systèmes intégrés est en cours. A ce jour, les sous-systèmes de la sonde ont fonctionné de façon satisfaisante, mais des difficultés ont été rencontrées pour l'équipement de vérification, ce qui a occasionné un supplément de travail et de légers retards dans le programme du modèle d'identification. Ces problèmes sont aujourd'hui résolus et les essais des sous-systèmes intégrés se poursuivent.*

## Integral

*Les propositions de charges utiles font l'objet d'une revue conduite par des pairs constituant le Comité d'évaluation scientifique d'Integral. Des problèmes nationaux de financement ont nécessité le réaménagement des collaborations scientifiques pour deux instruments. Toutefois, le processus de sélection qui*

A Critical Design Review of the Soho launch vehicle took place on 19 January at MMSS' premises in Denver.

The second ground-segment compatibility test took place in mid-January, lasting about a week, with daily interactive sessions between the Command Centre at Goddard Space Flight Center and the spacecraft in the Intespace test facility in Toulouse. Preparation of the NASA spacecraft software simulator was completed in February and independent testing has been performed to validate it against real test results.

**Experiments**
UVCS has been upgraded to flight standard by replacing its internal mass dummies with a flight spectrometer assembly (with cross delay line detectors) and mirror occulter mechanism. These activities were performed in one of the MMS clean rooms in Toulouse.

The SUMER flight model has been installed on the spacecraft and fully debugged, replacing the qualification model that had been used in thermal-balance/thermal-vacuum testing.

The LASCO electronic unit's PROMs have been upgraded to flight standard.

EIT has been extensively upgraded (front door with new design, camera, filters) also in one of MMS-F clean rooms, and some thermal problems that emerged in the system thermal test have been tackled.

The planned replacements of CELIAS and VIRGO with full flight units was not possible in the time allocated and will be replanned later in the programme.

# ISO

Very good progress has been made on all elements of the project. All satellite system-level environmental tests have been completed successfully and on schedule. A few anomalies that emerged during the most recent tests are being investigated. Both star trackers have been returned to the supplier to be fitted with new, improved image sensors to achieve the required pointing performance. The final satellite integrated system test will be completed after the two upgraded star trackers have been installed on the satellite in April.

Progress on ground-segment development and testing has also been very good. Operational interface tests between the satellite (at ESTEC) and the ground segment (at ESOC, Darmstadt and Villafranca, Madrid) have demonstrated that the system works well. Radio-frequency compatibility tests were successfully completed at the two ISO ground stations at Goldstone in California. The final satellite/ground-station tests including the science and spacecraft flight operations software are planned for April.

The project remains on schedule and all work is geared towards the planned September 1995 launch. The satellite acceptance review, started in late February, is expected to be completed in April.

# Huygens

Mechanical qualification testing at system level on the structural/thermal/pyro model Probe is nearing completion. Vibration and acoustic testing have been successfully completed and the Probe is currently fifteen days into the twenty-day thermal-vacuum/thermal-balance test.

Early assessment of the results of the thermal cases performed so far points to thermal performance more or less as predicted. The thermal environment to be experienced by Huygens is extreme, with the Probe's distance from the Sun varying between 0.6 AU and 6 AU. The Probe then enters the dense atmosphere of Titan, where the temperature is approximately −200°C.

Probe Special Model 2 (SM2) radio-frequency and spin testing has been successfully accomplished at ESTEC. SM2 final functional testing with the balloon gondola is under way at Fokker and will be completed in March. The Flight Acceptance Review will take place on 4-5 April prior to shipment to Kiruna for launch in May.

Integration of the engineering-model Probe has been completed and the integrated subsystem testing sequence is in progress. So far the Probe subsystems have been working satisfactorily, but problems were experienced with the checkout equipment, creating extra work and slight delays to the engineering-model programme. These problems have now been resolved and integrated subsystems testing is proceeding.

# Integral

The Integral payload proposals are undergoing a peer review by the Integral Science Evaluation Committee. National funding problems have required the rearrangement of the science collaborations on two instruments. However, the selection process, which is planned to be completed in May, is proceeding according to schedule.

The Integral Phase-B proposal which was received from Alenia Spazio (I) on 5 January in response to the Agency's Request for Quotation is under evaluation at ESA for presentation to the Agency's Industrial Policy Committee in May.

The cooperation with Russia providing the Proton launcher for Integral in return for scientific observation time is proceeding.

The draft of the ESA/RSA Arrangement concerning the Integral mission has been agreed between ESA and RSA representatives. On ESA's side, the arrangement has been approved by the Science Programme Committee and will now be forwarded to Council for approval. On the Russian side, an Integral management team has been nominated.

# ERS

**ERS-1**
The orbit of ERS-1 will be changed in March 1995 from its present 168-day repeat cycle to a 35-day repeat cycle to allow proper phasing with ERS-2. ERS-1 will remain in full operation until ERS-2 is commissioned.

**ERS-2**
Following the failure of the Ariane V70 launch at the end of 1994, the ERS-2 launch campaign, which had already been underway at CSG, had to be

devrait être achevé en mai se poursuit conformément au calendrier.

La proposition de phase B, qui a été reçue d'Alenia Spazio (I) le 5 janvier en réponse à la demande de prix envoyée par l'Agence, est en cours d'évaluation à l'ESA en vue de sa présentation au Comité de la politique industrielle en mai. La coopération avec la Russie, qui prévoit un lanceur Proton pour Integral en échange de temps d'observation scientifique, se déroule normalement.

Le projet d'arrangement ESA/RKA relatif à la mission Integral a été approuvé par les représentants des deux agences. Côté ESA, il a été approuvé par le Comité du programme scientifique et va être transmis au Conseil pour approbation. Côté russe, une équipe de gestion d'Integral a été désignée.

# ERS

### ERS-1

L'orbite d'ERS-1 sera modifiée en mars 1995 pour passer du cycle de répétition actuel de 168 jours à un cycle de 35 jours et assurer une bonne synchronisation avec ERS-2. L'exploitation d'ERS-1 se poursuivra sans restriction jusqu'à la mise en service officielle d'ERS-2.

### ERS-2

L'échec du lancement Ariane V70 fin 1994 avait obligé à interrompre la campagne de lancement d'ERS-2, qui avait déjà commencé au CSG, et à réentreposer le satellite. Les activités ont été remises en route fin février.

Tous les préparatifs ont bien avancé, y compris pour le secteur sol, et sont dans les temps pour un lancement actuellement prévu en avril. Les préparatifs de la phase de mise en service d'ERS-2 sont également achevés.

# EOPP

### Programmes futurs

Les activités relatives au programme Météosat de deuxième génération (MSG) étant passées de l'EOPP aux phases B et C/D tandis que s'engageait pour Metop le programme préparatoire correspondant, les travaux de l'EOPP se concentrent désormais sur la définition des missions et programmes postérieurs à Envisat.

La série des trois missions prioritaires d'exploration de la Terre dont il a été convenu lors de la réunion de consultation des utilisateurs tenue à l'ESTEC les 25, 26 et 27 septembre fait l'objet de propositions d'études système de phase A soumises au Conseil directeur du programme d'observation de la Terre. En parallèle, des groupes consultatifs scientifiques sont mis en place pour chacune de ces missions possibles.

Une large consultation a été lancée auprès des groupes utilisateurs susceptibles de s'intéresser à la mission prioritaire de surveillance de la Terre, qui aura pour objet les zones côtières.

### Campagnes

Les données de la campagne de vols EMAC 1994 ont été en majeure partie traitées et un nouveau mode de diffusion des données, sur 'autoroute électronique', utilisant un serveur WWW à l'ESTEC a été mis en oeuvre avec succès.

Le programme de vols EMAC 1995 est actuellement mis en route.

L'équipement d'étalonnage JERS-1 financé au titre de l'EOPP a été mis en place en octobre en appui du vol NASA/DASA-ASI des instruments SIR C et XSAR.

### Météosat de deuxième génération (MSG)

La phase B du programme Météosat de deuxième génération se poursuit conformément aux plans. L'évaluation de la proposition de phase C/D, en cours d'élaboration, devrait démarrer en avril 1995. En novembre 1994, le Conseil d'Eumetsat a donné son accord de principe pour que l'ESA assure l'approvisionnement de deux autres satellites, sous réserve de la conclusion d'un accord de coopération satisfaisant.

### Programme Météosat de transition (MTP)

L'exploitation des satellites Météosat se poursuit, avec Météosat-5 à poste à 0° et Météosat-3 à 75° ouest.

Après une longue période d'attente, les essais ont repris sur Météosat 6 en février. Cette série d'essais qui doit se dérouler jusqu'au début de juin comprendra un essai système de bout-en-bout qui conclura la deuxième partie des essais de recette.

La mise au point du prochain modèle de satellite se déroule parallèlement aux activités visant à assurer le bon fonctionnement du radiomètre.

# Metop

Le Conseil d'Eumetsat siégeant en novembre dernier n'a pas entériné le programme EPS qui avait été proposé par le secrétariat de cette organisation. La configuration Metop qu'avait définie le groupe de travail du Conseil d'Eumetsat lors de l'atelier de définition de la charge utile tenu à Zurich en août 1994 n'a pu en conséquence être confirmée. Souhaitant obtenir une réduction du coût de programme EPS de l'ordre de 15% tout en maintenant autant que possible la définition de la charge utile, le Conseil d'Eumetsat a réinstauré le groupe de travail pour qu'il revoie les hypothèses de programme à la lumière de ces objectifs.

Lors de sa session principale tenue à Venise en février, le Groupe de travail est convenu d'un concept de programme présentant la réduction souhaitée, obtenue par les moyens suivants: hypothèses révisées quant aux coûts de lancement, possibilités de lancement double, économies sur les coûts de l'architecture du secteur sol et de l'exploitation et formule révisée pour la charge utile Metop-3.

La configuration de base des satellites Metop-1 et 2 a été confirmée, malgré quelques incertitudes subsistant au sujet de l'emport d'instruments mineurs. Pour lancer la phase B dans sa totalité, l'Agence a préféré attendre que le Conseil d'Eumetsat ait approuvé la nouvelle approche, partant de l'hypothèse que cela se ferait lors de sa prochaine réunion, en juin 1995. Dans l'intervalle, une autorisation partielle d'engagement des activités de phase B portant sur des points critiques est envisagée sous réserve que l'évaluation de l'offre de phase B actuellement en cours donne satisfaction.

L'ESA prépare en parallèle le programme de mise en oeuvre de Metop 1 (Phase C/D) en vue de soumettre celui-ci pour approbation avant la fin de l'année.

interrupted and the satellite put into storage. Activities were restarted at the end of February.

All preparations, including those of the ground segment, are well advanced and consistent with a launch currently planned for April. Preparations for the ERS-2 commissioning phase are also complete. (see 'In Brief' for latest information).

# EOPP

### Future programmes
Following the Meteosat Second Generation (MSG) transition from EOPP into the Phase-B and C/D activities and Metop into the Metop Preparatory Programme, EOPP activities are now concentrating on the definition of post-Envisat missions and programmes.

A set of three priority Earth Explorer Missions, agreed at the User Consultation Meeting held at ESTEC on 25-27 September are being proposed for system Phase-A studies to the Earth Observation Programme Board. In parallel, Science Advisory Groups are being established for each of these possible missions.

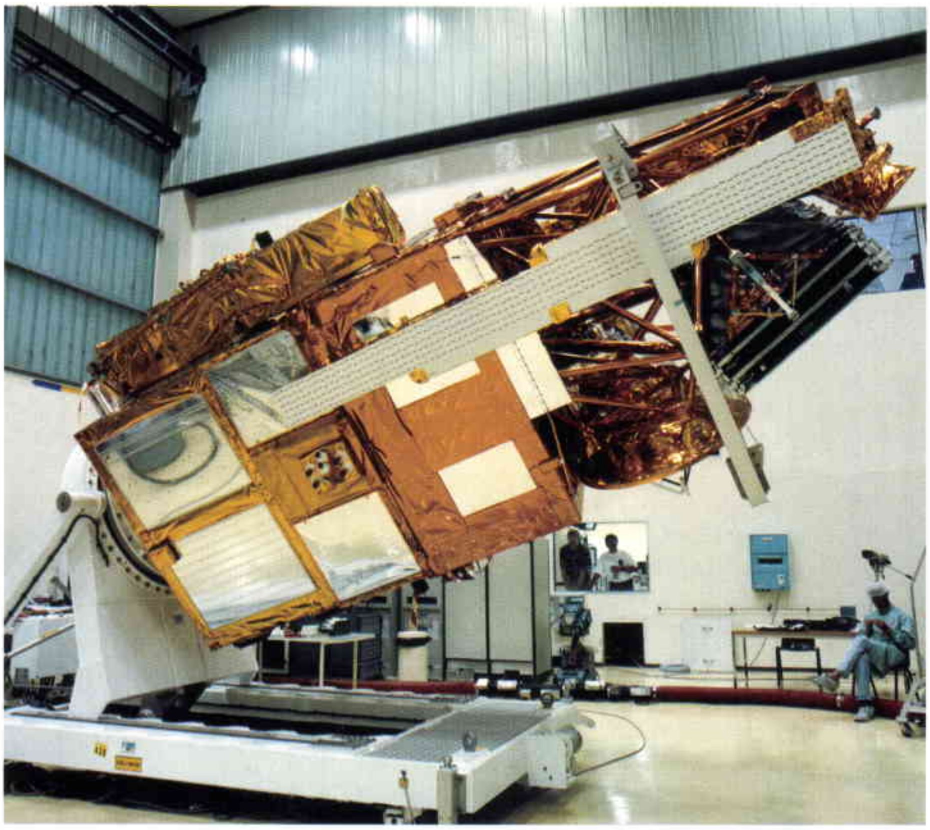
Wide consultation with potential and interested User Groups has been initiated for the priority Earth Watch Mission, which will address coastal zones.

### Campaigns
A major portion of the EMAC 1994 flight-campaign data has been processed and a new method of data distribution has been successfully implemented via an 'electronic highway' using a WWW server at ESTEC.

The EMAC 1995 flight programme is now being initiated.

The EOPP-funded JERS-1 calibration equipment was deployed in October to support the NASA/DASA-ASI-X-SIR-C SAR flight.

### Meteosat Second Generation (MSG)
The Meteosat Second Generation Phase-B programme is continuing according to plan. The Phase-C/D proposal is now in preparation and its evaluation is expected to start in April 1995. In November 1994, the Eumetsat Council accepted, in principle, that ESA should be their procurement agent for two further satellites, subject to the conclusion of a satisfactory cooperation agreement.



*Intégration du satellite ERS-2 au Centre spatial guyanais (CSG) en mars 1995*

Integration of ERS-2 at the Guiana Space Centre (CSG) in March 1995

### Meteosat Transition Programme (MTP)
Operations at 0° and 75° W are continuing with Meteosat-5 and Meteosat-3, respectively.

After a long stand-by period, tests on Meteosat-6 started again in February. This test series, which will run until early June, will include a system end-to-end test, which will conclude the second part of the commissioning test.

Development of the next model is progressing in line with the activities to secure proper operation of the radiometer.

# Metop

The Eumetsat Council, meeting last November, did not endorse the EPS programme as proposed by the Eumetsat Secretariat. Consequently, the Metop configuration defined by the Eumetsat Council Task Force at the Zurich Payload Definition Workshop in August 1994 could not be confirmed. Eumetsat's Council sought to reduce the cost of the EPS Programme by the order of 15%, while preserving the payload definition to the maximum extent possible. The Council re-established the Task Force to re-examine the programme assumptions with these objectives in mind.

At its main session in Venice in February, the Task Force agreed a programme concept with the desired cost reduction. This was achieved by the following measures: revised assumptions on the launch costs, dual launch possibilities, ground-segment architecture and operations cost savings, and a revised approach to the Metop-3 payload.

The basic satellite configuration for Metop-1 and 2 was confirmed, but with some uncertainties remaining regarding the embarkation of minor instruments.

The Agency has opted to delay the full go-ahead of Phase-B until after

## Envisat-1/Plate-forme polaire

*Les dernières négociations avec le maître d'oeuvre (MMS-B) devraient aboutir prochainement.*

*La fabrication et les essais des unités du modèle d'identification du module de charge utile avancent. Les problèmes que posaient les mécanismes d'entraînement du réseau solaire et de l'antenne en bande Ka ont été traités et des modifications ont été apportées à leur conception.*

*Les unités du modèle de vol du module de servitude sont en cours de fabrication. Les seules difficultés qui subsistent ont trait au répéteur mode double.*

### Charge utile

*La négociation des contrats de sous-traitance avance bien au sein du consortium Envisat; elle approche du stade final pour les instruments GOMOS et RA-2.*

*Sur le plan technique, des progrès significatifs ont été réalisés pour tous les instruments; plusieurs questions qui restaient en suspens à la suite de la revue de la mission et de la conception préliminaire au niveau système d'Envisat faite en juillet 1994 ont été réglées ou sont près de l'être. La conception mécanique de l'antenne ASAR a notamment été gelée et des améliorations ont été apportées en vue de résoudre le problème de lumière parasite de l'instrument MERIS.*

*La masse prévisionnelle totale de la charge utile, qui se rapproche des limites de la capacité d'emport de la plate-forme polaire, constitue désormais un nouveau sujet de préoccupation. Une action vigoureuse a été engagée en vue de réduire la masse actuelle de la charge utile et examiner de plus près les limites de la plate-forme.*

### Secteur sol

*Le Comité de la politique industrielle de l'Agence (IPC) a approuvé, lors de sa réunion de janvier 1995, la proposition d'approvisionnement relative à la phase principale de réalisation (phase C/D) du secteur sol (GS) d'Envisat et du système de gestion des données de charge utile (PDS). L'appel d'offres ayant trait au contrat final de phase C/D du GS/PDS a été adressé à l'industrie fin février, après approbation de l'IPC. Les propositions de l'industrie devraient normalement être remises d'ici fin mai.*

*Les deux groupes industriels en concurrence, pilotés respectivement par Matra et par Thomson-CSF, ont mené à bien leurs études de phase de consolidation sur le GS/PDS. Les résultats de ces études ont été présentés a l'ESTEC (NL) début mars.*

## Programmes spatiaux habités

### Contribution de l'Europe à la Station spatiale internationale Alpha

*A l'automne 1994, M. D. Goldin, Administrateur de la NASA, a demandé aux partenaires de la Station spatiale internationale Alpha (ISSA) pour mars 1995 au plus tard une confirmation définitive du contenu technique de leur participation. L'Agence avait initialement prévu d'être en mesure de donner cette confirmation après le Conseil au niveau ministériel programmé pour octobre 1995.*

*Devant cette demande de la NASA, le Conseil a donné son accord pour que le processus de décision relatif aux programmes spatiaux habités soit accéléré, avec pour objectif la mise au point définitive de la proposition en temps voulu pour une décision en mars 1995.*

*Lors de sa réunion de janvier, le Conseil directeur des programmes spatiaux habités s'est vu présenter un premier projet de proposition de programme sur la participation de l'Europe à la Station spatiale internationa le Alpha, qui comprenait l'élément orbital Columbus (COF), le véhicule de transfert automatique (ATV), un véhicule de sauvetage des équipages (CRV) et la préparation de l'utilisation, pour un coût de 3,3 milliards d'unités de compte (Md UC) jusqu'à l'an 2000, et pour une enveloppe totale de 3,9 Md UC.*

*Jugeant cette proposition trop onéreuse, le Conseil directeur a fixé un objectif limité à 2 Md UC pour la période 1996-2000. Un scénario réduit d'où était retiré le véhicule de sauvetage des équipages et comportant un certain étalement du calendrier de réalisation a en conséquence été élaboré en vue d'une réunion spéciale du Conseil directeur qui s'est tenue en février. La proposition allégée, y compris les installations de recherche en microgravité pour Columbus, respectait la limite des 2 Md*


The ATV carrying cargo to International Space Station 'Alpha'

*Le véhicule de transfert automatique (ATV) transportant son cargo vers la Station spatiale internationale Alpha*

Eumetsat's Council approves the approach, on the assumption that this will take place at its next meeting in June 1995. In the interim, a partial release of Phase-B activities related to critical issues is envisaged, subject to the successful outcome of the Phase-B tender evaluation which is now under way.

In parallel, ESA is preparing the implementation programme for Metop-1 (Phase-C/D) with the aim of submitting this for approval before the end of the year.

## Envisat-1/Polar Platform

Final negotiations with the Prime Contractor (MMS-B) are expected to be finalised soon.

Manufacture and testing of the Payload Module engineering-model units is progressing. Problems with the solar-array and Ka-band antenna mechanisms have been addressed and design modifications have been introduced.

The Service Module flight-model units are being manufactured. The only remaining difficulties are with the dual-mode transponder.

### Payload

Subcontract negotiations are progressing well within the Envisat consortium. Those for the GOMOS and the RA-2 instruments are approaching their final stages.

Significant technical progress has been achieved on all instruments and several open issues identified during the Envisat Mission and System Preliminary Design Review in July 1994 have now either been settled or are close to resolution. In particular, the mechanical design of the ASAR antenna has now been frozen, and improvements have been made to resolve the MERIS instrument's stray-light problem.

The predicted overall payload mass has become a new area of concern as it has grown close to the limits of the Polar Platform's load-carrying capability. Vigorous efforts have been initiated both to reduce the current payload mass and to further explore the Platform's limits.

### Ground segment

The Agency's Industrial Policy Committee (IPC), at its meeting in January 1995, approved the Procurement Proposal for the main development phase (Phase-C/D) for the Envisat Ground Segment (GS) and Payload Data Segment (PDS). The Invitation to Tender for the final GS/PDS Phase-C/D contract was released to Industry at the end of February, following the IPC approval. Industrial proposals are expected to be delivered by the end of May.

The two competitive industrial consortia, led by Matra and Thomson-CSF, have successfully finalised their consolidation-phase studies for the GS/PDS segments. The study results were presented at ESTEC in Noordwijk (NL) at the beginning of March.

## Manned Space Programme

### The European contribution to International Space Station Alpha

In the Autumn of 1994, the NASA Administrator, Mr D. Goldin, requested the Partners in the International Space Station Alpha (ISSA) to definitively confirm the technical content of their participation at the latest by March of 1995. The Agency had originally aimed to be in a position to provide this confirmation after the Ministerial Council, planned for October 1995.

In view of this request from NASA, the Council endorsed an accelerated decision process for the Manned Space Programme, aimed at finalising the Proposal in time for a March 1995 decision.

The Manned Space Programme Board was presented at its January meeting with a first draft of the Programme Proposal for the European participation in the International Space Station Alpha, composed of the Columbus Orbital Facility (COF), the Automated Transfer Vehicle (ATV), a Crew Rescue Vehicle (CRV), and Utilisation Preparation, at a cost of 3.3 billion accounting units (BAU) up to the year 2000, and a total envelope of 3.9 BAU.

The Programme Board concluded that this proposal was too expensive, and set a target of 2 BAU for the period 1996-2000. Consequently, a reduced scenario, with the elimination of the Crew Rescue Vehicle and some stretching of the development schedule, was prepared for a special meeting of the Programme Board in February. The descoped proposal, including the microgravity facilities for Columbus complied with the 2 BAU constraint, and the Programme Board decided that this represented the minimum viable programme from a technical viewpoint. Consequently, this scenario formed the basis for the preparation of the special Act in Council which should confirm Europe's commitment to International Space Station Alpha.

### Columbus Orbital Facility (COF)

In the meantime, industry confirmed that the cost target set for the COF space-segment development should be technically achievable assuming maximisation of cost benefits from use of common elements. The proposed configuration was based on the use of the Italian Mini Pressurised Logistics Module (MPLM) design as the basic structure of the COF. Cost savings were also identified through utilisation of the Data Management System to be developed by the Agency for the Service Module of the Russian segment of the Space Station, and re-use of the Environmental Control and Life Support System (ECLS) to be developed by the Ageny for the MPLM.

A completely revised statement of work for the COF development phase, updated to reflect the COF design-to-cost approach, was released to industry in December. In response a committing Phase-C/D industrial offer was delivered in February.

COF baseline industrial activities continued under contractual coverage which expires at the end of March 1995. Activities after that time depend upon the unblocking of the budget associated with the updated Columbus declaration.

### Complementary Columbus Orbital Facilities (CCOF)

The DMS(R) and ECLS for the Mini Pressurised Logistics Module (MPLM) programme proposals were submitted to Council for approval in October. For various reasons, final approval of both programmes was delayed and so, due to

*UC, et le Conseil directeur du programme a décidé qu'elle représentait le programme viable minimal sur le plan technique. Ce scénario a donc été pris pour base pour préparer l'Acte en Conseil spécial qui devrait confirmer l'engagement de l'Europe dans le projet de Station spatiale internationale Alpha.*

**Elément orbital Columbus (COF)**
*Pendant ce temps, l'industrie a confirmé qu'il devrait être techniquement possible de tenir l'objectif de coût fixé pour la réalisation du secteur spatial du COF, dans l'hypothèse d'une optimisation des coûts grâce à l'utilisation d'éléments communs. La configuration proposée reprenait la conception du mini-module logistique pressurisé (MPLM) de l'Italie pour la structure de base du COF. En utilisant le système de gestion de données à mettre au point par l'Agence pour le module de servitude de la composante russe de la Station spatiale et en reprenant le système de régulation d'ambiance et de soutien-vie (ECLS) à mettre au point par l'Agence pour le MPLM, d'autres réductions de coût devaient également être possibles. Un descriptif des travaux entièrement remanié, mis à jour en fonction de la formule de conception à objectif de coût adoptée pour le COF, a été communiqué à l'industrie en décembre pour la phase de réalisation. En février, l'industrie présentait une offre ferme de phase C/D.*

*Les activités industrielles de référence relatives au COF se sont poursuivies dans le cadre contractuel valable jusqu'à fin mars 1995. Après cette date, les activités seront subordonnées au déblocage du budget associé à la Déclaration Columbus mise à jour.*

**Installations orbitales complémentaires Columbus (CCOF)**
*Les propositions de programme relatives au DMS(R) et à l'ECLS du mini module logistique pressurisé (MPLM) ont été soumises à l'agrément du Conseil en octobre. Pour des raisons diverses, l'approbation des deux programmes a été ajournée et, vu l'urgence, des activités industrielles préliminaires ont été engagées dans les limites des possibilités juridiques et financières dont disposait l'Exécutif.*

*Les activités relatives au DMS(R) ont commencé dans l'industrie en novembre; une revue des impératifs système a été menée à bien en décembre, avec la participation de l'Agence spatiale russe (RKA), de la NASA et de l'industrie russe. Par la suite, les premières livraisons des moyens logiciels au sol du DMS(R) ont été faites à l'industrie russe.*

*Après l'accord de principe intervenu entre l'ESA et l'Agence spatiale italienne sur l'utilisation de l'ECLS pour le COF et pour le MPLM, des tâches spécifiques liées à l'harmonisation des impératifs techniques et des spécifications de l'ECLS commun au MPLM et au COF ont également été mises en route dans l'industrie.*

*La fusion des activités industrielles relatives à la base de données mission, à livrer à court terme, et au banc de référence de développement au sol de logiciels, faisant partie des éléments complémentaires, avec les activités de référence en cours sur le COF a été menée à terme; les travaux ont progressé de façon satisfaisante dans l'industrie.*

**Véhicule de transfert automatique (ATV)**
*La phase B de l'ATV s'est déroulée conformément au calendrier. Lors de la revue de concept et programmatique au niveau système, les avis se sont rejoints sur une architecture unique pour l'ATV, reposant sur un concept modulaire (modules de propulsion et de ressources), une interface standard avec la cargaison et deux éléments porteurs (l'un non pressurisé, l'autre mixte pour cargaison pressurisée/ravitaillement en ergols/ rehaussement d'orbite).*

*La NASA et l'ESA ont poursuivi leurs échanges de vue techniques afin de consolider les interfaces de l'ATV et la mission de réapprovisionnement logistique de la station en mode non pressurisé.*

*La définition de la mission de transport de cargaison pressurisée/ravitaillemen t en ergols/rehaussement d'orbite par l'ATV au bénéfice de la partie russe de la station s'est poursuivie dans le cadre de l'étude de flotte mixte en cours qui englobe les missions de la navette américaine et des véhicules Progress, Soyouz et ATV.*

*Le programme relatif au prédéveloppement et à la vérification du rendez vous ATV (ARP) a été lancé dans l'industrie. Des contrats ont été passés pour les activités relatives au noyau système et pour la mise au point d'un récepteur GPS et de détecteurs optiques de rendez-vous.*

**Développements technologiques**
*Les activités ont progressé conformément aux plans, couvrant une large gamme de technologies de transport spatial et comprenant des études confiées à des sociétés russes. La passation de contrats industriels relatifs à un parachute-voile et à un système d'atterrissage en douceur (rétrofusées) a été autorisée en janvier.*

**Bras télémanipulateur européen (ERA)**
*L'Exécutif a reçu en janvier 1995 une proposition de l'industrie portant sur le bras télémanipulateur européen révisé. Le démarrage du contrat industriel est prévu pour le second trimestre 1995.*

*Les discussions qui se sont poursuivies avec l'industrie russe sur les interfaces avec les éléments russes de l'ISSA devraient parvenir à leur aboutissement avant le démarrage du contrat industriel de développement.*

**Démonstrateur de rentrée atmosphérique (ARD)**
*La conception de l'ARD et les analyses connexes ont progressé de façon substantielle; les revues qui ont été faites du secteur spatial et du secteur sol ont confirmé les choix conceptuels et permis de consolider le concept opérationnel. La définition des interfaces avec Ariane-5 a avancé et l'on ne prévoit aucun problème majeur.*

*Des échantillons de protection thermique ont été soumis à des essais qui ont donné de bons résultats.*

**Véhicule de sauvetage des équipages/Véhicule de transport d'équipages (CRV/CTV)**
*Bien que le CTV n'ait pas finalement été retenu pour faire partie de la contribution européenne à la Station spatiale internationale, ce projet a considérablement avancé, passant d'un concept qui reposait sur une définition unique de véhicule devant servir à la fois au sauvetage et au transport des équipages de la station à un nouveau concept selon lequel chacune de ces deux missions donne lieu à une définition. Cette réorientation a été décidée devant le regain d'intérêt de la NASA pour un véhicule strictement réservé au sauvetage de l'équipage de la station, séjournant*

the urgency, preliminary industrial activities were initiated within the legal boundaries and approved financial capabilities available to the Executive.

The DMS(R) activities in industry were initiated in November, and a System Requirements Review was successfully completed in December, with the participation of the Russian Space Agency (RKA), NASA and Russian industry. Subsequently, the first deliveries to Russian industry of the DMS(R) ground software environment were completed.

Following the agreement in principle between ESA and the Italian Space Agency to use the ECLS for both the COF and MPLM, specific tasks related to the harmonisation of MPLM/COF ECLS technical requirements and specifications were also initiated in industry.

The merging into the ongoing COF baseline activities of the industrial tasks for the Mission Data Base early delivery item and the Ground Software Reference Facility enhancement item has been completed and industrial work is progressing satisfactorily.

### Automated Transfer Vehicle (ATV)
The ATV Phase-B has proceeded on schedule. A convergence to one ATV architecture based on a modular concept (propulsion and resource modules), standard interface with cargo, and two Carriers (unpressurised and mixed pressurised/refuel/reboost cargoes) was reached at the System Concept and Programmatic Review.

NASA and ESA continued the technical interchanges to consolidate the ATV interfaces and mission for the unpressurised logistics re-supply of the station.

The definition of the ATV reboost/refuel/ pressurised cargo mission to the Russian side of the station continued as part of the on-going Mixed Fleet Study, which includes the missions of the Shuttle-Orbiter, Progress, Soyuz and ATV vehicles.

The programme for ATV Rendezvous Pre-development and Verification (ARP) has started in industry. Contracts were placed for the System Kernel activities, and for the development of a GPS receiver and rendezvous optical sensors.

### Technology developments
Progress has been as planned, covering a wide spectrum of space-transportation technologies, including investigations assigned to Russian companies. Industrial contracts for a parafoil and a soft landing system (retro rockets) were authorised in January.

### European Robotic Arm (ERA)
An industrial proposal on the revised European Robotic Arm was received in January 1995, and the start of the industrial contract is planned for the second quarter of 1995.

Discussions with Russian industry on the interfaces with the Russian ISSA elements have continued and are expected to be finalised before the start of the industrial development contract.

### Atmospheric Reentry Demonstrator (ARD)
The design of the ARD and related analyses have made substantial progress, and reviews of the space and ground segments have confirmed design choices made and allowed the operations concept to be consolidated. The definition of interfaces to Ariane-5 progressed, and no major problems are expected.

Thermal-protection samples have been tested and the results were satisfactory.

### Crew Rescue Vehicle/Crew Transportation Vehicle (CRV/CTV)
Although not finally retained as part of the European contribution to the International Space Station, considerable progress was achieved on the CTV project, which evolved from a concept based on a single definition of a vehicle for both station crew rescue and transportation, to a concept with one definition for each of these two missions. The reorientation was decided because of the revived interest from NASA in a Crew Vehicle strictly dedicated to Station Crew Rescue, with a five-year stay time in orbit, launched and operated by NASA.

The new development approach was bsed on the development of a Crew Rescue Vehicle to be launched by the Space Shuttle in 2002, followed by the evolution of thic CRV towards a Crew Transport Vehicle (to and from orbit) to be launched by Ariane-5 in late 2004. Discussion were undertaken with both NASA and RKA on possible co-operative developments in this area.

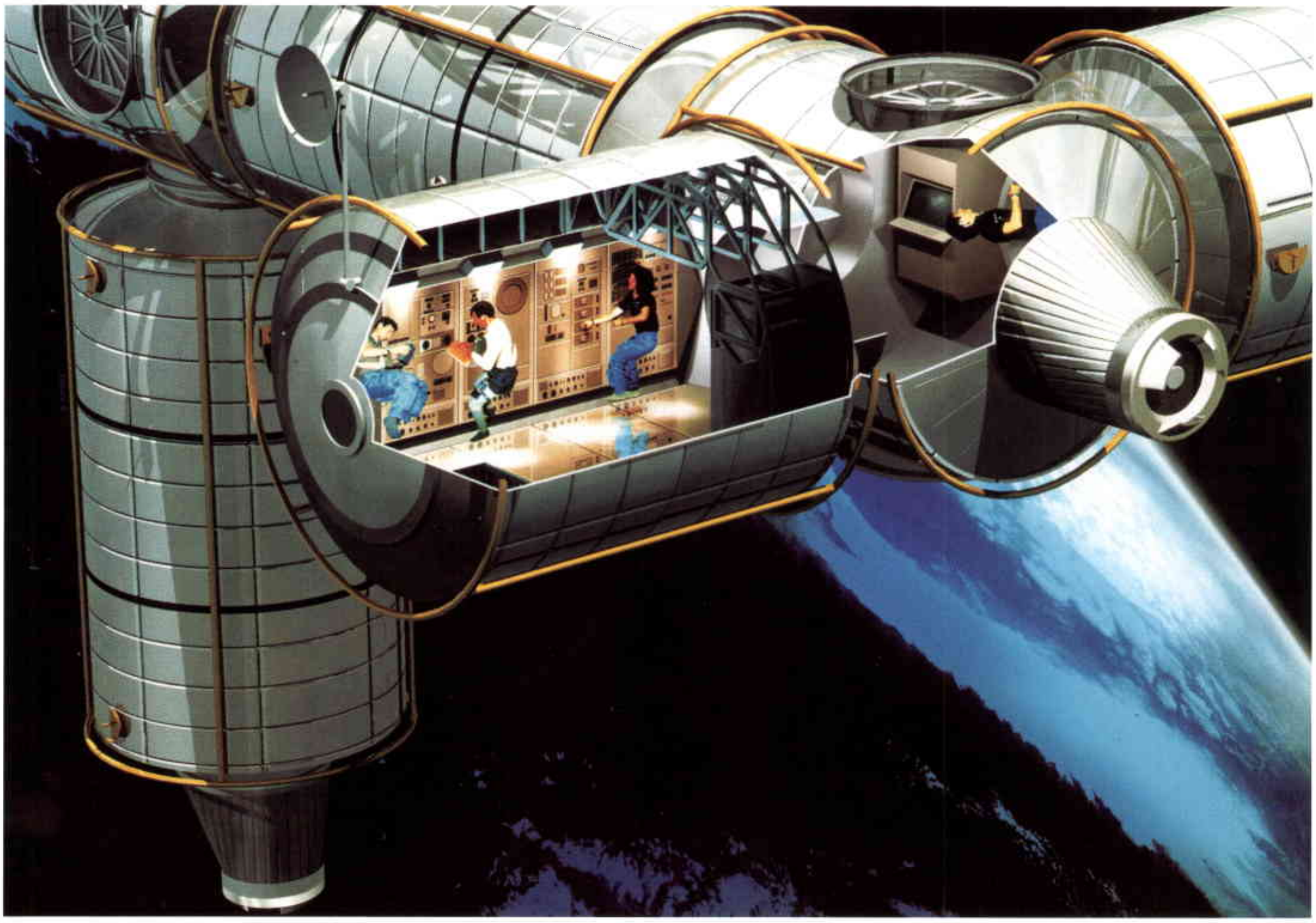
### International cooperation
The formal steps needed to finalise the Memorandum of Understanding (MOU) negotiations in the framework of the Space Station Multilateral Consultative Working Group continued, resulting in the release to the Russian Space Agency, RKA, of an agreed text related to programme management and documentation. The partners also agreed on the approach for Utilisation Distribution and Common Systems Operations Cost Obligations. The concept was presented by NASA to Russia in December and was the main subject of NASA/RKA negotiations in January 1995. Finally, concerning transportation and communication, agreement was reached and will now be presented to Russia.

Concerning the ESA/NASA bilateral MOU negotiations, an update of the first draft of the ESA/NASA MOU is in preparation to take into account the multilateral agreements related to programme management, documentation and the above-mentioned approach for the operations and utilisation sharing.

The Agreement on co-operation between ESA and RKA on the manned space infrastructure and space transport systems during the period 1993-1995, was signed in Moscow on 5 October 1994 by the Directors General of the two Agencies. Also in October, ESA and RKA agreed on the principles for the cooperation on the European Robotic Arm and the Data Management Systems.

## Microgravity

The 'first slice' of the current European Microgravity Research Programme – EMIR-1 – will end in 1997. The programme proposal for the continuation, EMIR-2, covering the period up to the year 2001 has been further refined and was well received by the Microgravity Programme Board. In parallel, a programme proposal for Microgravity Multi-User Facilities on the Space Station, known as the MFC programme and covering the period 1997 to 2002, was revised after consultations with those



*cinq ans en orbite et lancé et exploité par la NASA.*

*La nouvelle voie ainsi tracée pour le développement du véhicule comprend la réalisation d'un véhicule de sauvetage des équipages à lancer par la navette spatiale en 2002, suivie de la transformation de ce CRV en un véhicule de transport d'équipages (à destination et en provenance de l'orbite) à lancer par Ariane-5 fin 2004. Des échanges de vues ont été engagés avec la NASA aussi bien qu'avec la RKA sur la conduite éventuelle d'activités de développemen t en coopération dans ce domaine.*

### Coopération internationale

*Les étapes de la procédure officielle à suivre pour l'aboutissement définitif des négociations du Mémorandum d'accord (MOU) dans le cadre du Groupe de travail consultatif multilatéral sur la Station spatiale se sont poursuivies, débouchant sur la communication à l'Agence spatiale russe (RKA) d'un texte arrêté en commun sur la gestion du programme et la documentation. Les partenaires sont également convenus de la ligne de conduite à suivre en ce qui concerne les obligations relatives à la répartition de l'utilisation et aux coûts d'exploitation des systèmes communs. Ce concept, présenté par la NASA à la Russie en décembre, a été le principal objet des négociations NASA/RKA de janvier 1995. Pour finir, un accord s'est dégagé dans le domaine des transports et des télécommunic ations, et va maintenant être présenté à la Russie. En ce qui concerne les négociations bilatérales du MOU entre l'ESA et la NASA, une mise à jour du premier projet du MOU ESA/NASA est en cours de préparation en vue de prendre en compte les accords multilatéraux relatifs à la gestion du programme, à la documentation et à l'approche susmentionnée quant au partage de la gestion et de l'utilisation de la station.*

*L'accord de coopération entre l'ESA et la RKA en matière d'infrastructure spatiale habitée et de systèmes de transport spatial au cours de la période 1993-1995 a été signé à Moscou le 5 octobre 1994 par le Directeur général de chacune des deux agences. En octobre également, l'ESA et la RKA sont convenues des principes de coopération pour le bras télémanipulateur européen et le système de gestion des données.*

The International Space Station 'Alpha'

*La Station spatiale internationale Alpha*

## Microgravité

*Le programme européen de recherche en microgravité en cours — EMIR 1 — (première tranche) arrivera à son terme en 1997. La proposition de programme ayant pour objet de lui faire suite (EMIR-2), qui couvre la période allant jusqu'à 2001, a été affinée plus avant et bien accueillie par le Conseil directeur du programme de recherche en microgravité. Dans le même temps, une proposition de programme se rapportant aux installations à utilisateurs multiples destinées à la Station spatiale, le programme MFC, et couvrant la période de 1997 à 2002 a été révisée après*

Member States interested and discussed at a third meeting of Potential Participants in February 1995.

Biobox, a multi-user facility for biological experiments, was launched aboard the Russian unmanned retrievable satellite Foton-10 on 16 February. This flight was nominal and all systems worked well, with a successful landing on Russian territory on 3 March. However, the satellite was subsequently badly damaged in an accident during helicopter transport. A failure investigation is in progress.

On 30 November 1994, the Texus 33 sounding rocket carrying three ESA experiments was successfully launched from Kiruna in Sweden.

The 21st ESA parabolic-flight campaign with the Caravelle airplane took place in March. Nine experiments were conducted, most of them in preparation for the Euromir-95 mission.

The next major opportunity for ESA microgravity experimentation will be the Euromir-95 mission, to be launched in August. Two multi-user facilities are being developed for, and twenty-four ESA microgravity experiments will be flown on this mission. Preparations for this time-critical mission are proceeding according to plan.

In September 1995, the Advanced Protein Crystallisation Facility (third flight), and the Glove Box (second flight), will be flown on the USML-2 Spacelab mission.

For 1996, the fourth flight of Biorack is planned for the MM-03 Shuttle mission to Mir and the flight of four multi-user facilities is foreseen on the LMS Spacelab mission. The multi-user facilities are the Bubble, Drop and Particle Unit, the Advanced Gradient Heating Facility, two units of the Advanced Protein Crystallisation Facility and the Torque Velocity Dynamometer.

## Euromir

Following the successful completion of the Euromir-94 flight, and ESA astronaut Ulf Merbold's work on board the Russian Space Station Mir, the work of the Euromir Project Team has concentrated fully on the preparation of the next flight, Euromir-95, planned for launch on 22 August 1995.

DLR's Space Operations Centre (GSOC) was selected as operations centre for the Euromir-95 mission, and efforts are under way to link GSOC with the various user sites in Western Europe.

Major efforts in January in industry and at various institutes were concentrated on completing the experimental facilities needed for training the astronauts and cosmonauts.

Crew training on the experiments involving the ESA astronauts and their Russian cosmonaut colleagues started in January/February at the astronaut training centre in Porz-Wahn.

The ESEF support structure for Euromir-95 experiments to be mounted outside of the Spectr module has been shipped to RCS-Energia for launch by mid-May.

*consultation des Etats membres intéressés et a été examinée par les participants potentiels lors de leur troisième réunion , en février 1995.*

*L'installation à utilisateurs multiples Biobox destinée à des expériences biologiques a été lancée dans l'espace à bord du satellite automatique récupérable russe Photon 10 le 16 février 1995. Le vol s'est déroulé dans des conditions nominales et tous les systèmes ont bien fonctionné. Le satellite Photon 10, revenu sur Terre le 3 mars 1995 en territoire russe, a malheureusement été très endommagé à la suite d'un accident survenu pendant son transport en hélicoptère. Une enquête est en cours.*

*Le 30 novembre 1994, la fusée-sonde Texus 33 emportant à son bord trois expériences de l'ESA a été lancée avec succès de Kiruna (Suède).*

*La vingt-et-unième campagne de vols paraboliques de l'ESA en Caravelle s'est déroulée en mars 1995. Neuf expériences ont été conduites, dont la plupart préparait Euromir-95. Euromir-95 sera la prochaine grande mission d'expérimentation en microgravité de l'ESA . Deux installations à utilisateurs multiples sont actuellement mises au point pour cette mission sur laquelle seront embarquées vingt-quatre expériences de recherche en microgravité de l'ESA. Les préparatifs dont le calendrier est très serré se déroulent conformément aux plans.*

*En septembre 1995, l'installation de cristallisation de protéines de pointe, dont ce sera le troisième vol, et la boîte à gants, dont ce sera le second, seront embarquées dans le cadre de la mission Spacelab USML-2.*

*Pour 1996, on prévoit un quatrième emport du Biorack sur la mission de la Navette S/MM-03 à destination de Mir ainsi que l'emport de quatre installations à utilisateurs multiples sur la mission Spacelab LMS. Les quatre installations à utilisateurs multiples sont l'ensemble d'étude des bulles, gouttes et particules, le four à gradient de haute technologie, l'installation de cristallisation de protéines de pointe en deux exemplaires et le dynamomètre d'étude du couple force-vitesse. 5*

## Euromir

*Après le déroulement satisfaisant du vol Euromir-94 et le travail de l'astronaute Ulf Merbold à bord de la station spatiale russe Mir, les activités de l'équipe projet Euromir se sont entièrement tournées vers la préparation de la prochaine mission, Euromir-95, dont le lancement est prévu pour le 22 août prochain.*

*Le Centre allemand d'opérations spatiales (GSOC) du DLR a été sélectionné pour diriger les opérations de la mission Euromir-95; on s'emploie actuellement à relier le GSOC aux différents sites utilisateurs d'Europe occidentale.*

*D'importants efforts ont été consacrés en janvier, dans l'industrie et différents instituts, à l'achèvement des installations expérimentales nécessaires à l'entraînement des astronautes et des cosmonautes. Les astronautes de l'ESA et leurs collègues russes ont commencé en janvierfévrier, au Centre de formation des astronautes de Porz-Wahn, à s'entraîner au fonctionnement des expériences dont ils auront la charge.*

*La structure de soutien de l'ESEF destinée aux expériences de la mission Euromir-95 à monter à l'extérieur du module Spectre a été expédiée à RCS-Energia pour être lancée à la mi-mai.*

First step on the moon

irs information retrieval service — esa european space agency / agence spatiale européenne

NEW ONLINE DATABASES FROM ESA-IRS

# Stay ahead in the European aerospace industry in the 1990's

**Are you a manager, scientist, engineer or researcher in the aerospace industry ?**

Equipped with a PC and a modem connected to a telephone line, you can access directly online many of the NEW and unique aerospace databases from the European Space Agency Information Retrieval Service, ESA-IRS.

No library, CD-ROM or other similar information source is more complete, up-to-date and international in coverage!

- ESA and NASA Reports
- Scientific and Technical Reports
- International Space Journals
- Daily News
- Contract Opportunities
- Conference Proceedings
- Earth Images Catalogues
- Spaceflight Data
- Market Research Reports
- Company Directories

**NEW !**

**All ESA-Profs users can now access the ESA-IRS online databases**

**Profs: the e-mail system of ESA available at all establishments*

**ESA-IRS, Esrin, Via Galileo Galilei, 00044 Frascati, Italy**
**Fax:** (+39 6) 94180361, **Tel:** (+39 6) 94180300, **E-mail address:** IRSHELP@ESRIN. BITNET
E-mail address for ESA-Profs users (ESA-IRS HELP-DESK): IRSHELP

# In Brief

## ERS-2 Opens New Era in Earth Observation

Early in the morning of 21 April, ESA launched its most complex Earth-observation satellite to date, the second European Remote Sensing (ERS-2) satellite, marking the beginning of a new era in Earth observation by radar.

ERS-2's task originally was to take over the work begun by its sister craft, ERS-1: to provide scientists and application-oriented users with Earth-observation data. The four-year-old ERS-1, however, has remained technically operational well beyond its 30-month design life and it was thus decided to allow the two satellites to operate in tandem for a period of nine months. ERS-1 will now be kept in service until the end of 1995.

In keeping with the thought that 'two eyes are better than one', for the next nine months, the two satellites will pass over the same regions of the Earth in quick succession, doubling the number of radar-altimeter measurement points and gathering digital data for a highly precise, three-dimensional map of the Earth's continental surface. Producing such a digital map using conventional methods would be very difficult and for some of the regions of the Earth for which topographical maps do not exist, it would be impossible.

*Integration of ERS-2 in preparation for launch*

Although the first ERS satellite revolutionised many areas of the Earth sciences, the second satellite will offer even more features. Most notably, it is carrying a new instrument, called the Global Ozone Monitoring Experiment or GOME, that will monitor changes in the ozone content of the atmosphere. The measurements made will allow a complete ozone map of the world to be generated every three days. Because the measurements are made independently of variations in solar intensity and of the sensitivity of GOME's sensors, they are expected to be three to five times more accurate than results obtained with existing monitoring systems.

Other instruments on board include a radar altimeter to measure the distance between the satellite and sea or ice surfaces as well as wave height; a radiometer to measure sea surface temperatures and vegetation on land surfaces, for example, for crop forecasting or to monitor deforestation; and a wind scatterometer to measure wind speed and wave height to enable ships to steer clear of headwinds and heavy seas.

Similar data collected by ERS-1 has been used to keep a watch on oil slicks following tanker disasters or to detect illegal dumping of oil into the ocean, to monitor the world's many active volcanoes, and to predict the extent of flooding during the recent catastrophe in The Netherlands as well as along the Mississippi in 1994.

ERS-1 has also contributed toward new research findings such as those on the El Niño and its impact on the climate, and the first-ever topographical description of the ocean floor beneath the Arctic icecap.

*The next issue of the ESA Bulletin (August 1995) will focus on the ERS-2 mission.*

## First Combined ERS-1/ERS-2 Image Produced

ERS-2 acquired its first experimental image with its Synthetic Aperture Radar (SAR) about 10 days after the satellite was launched. The image covers the Campania region in central Italy, and shows the rough seas of the Gulf of Gaeta and the mountains alongside it.

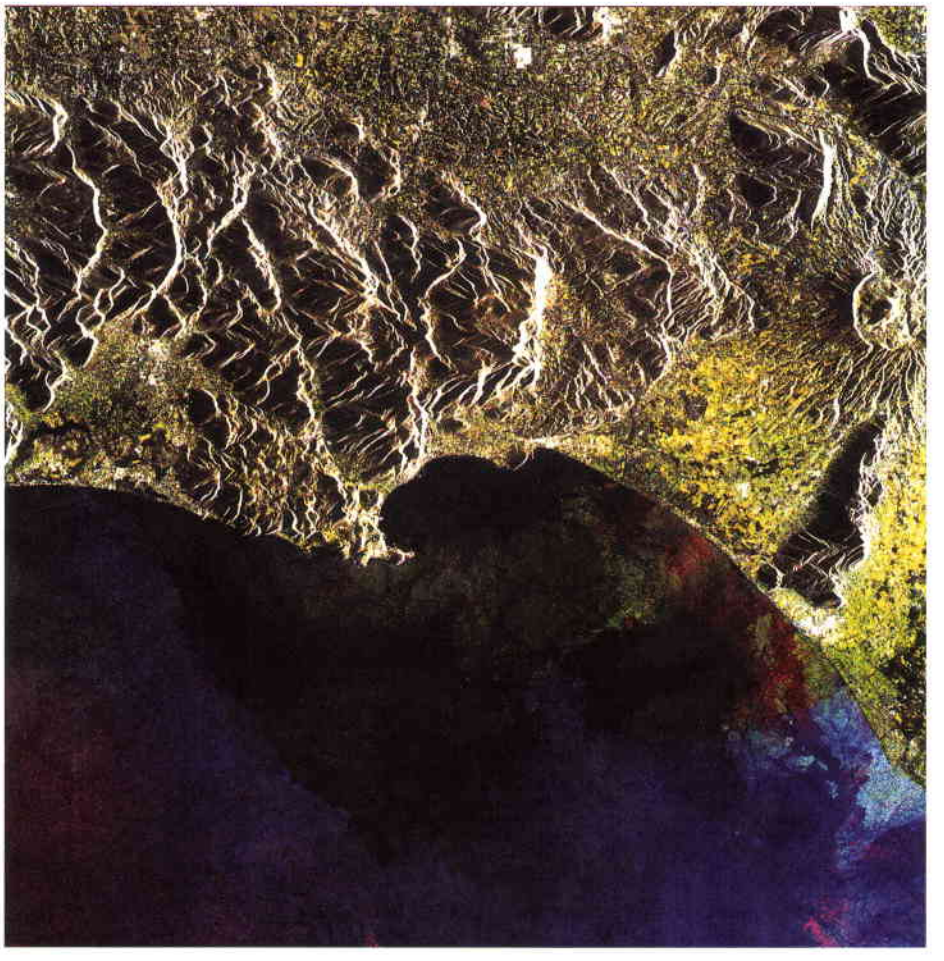
It was combined with two images acquired by ERS-1 as it passed over the same region, to produce the first multitemporal SAR image of the region.

The town of Gaeta is in the centre of the image (in white), at the foot of the mountains, and extends to the promontory of Gaeta. On the left side of the image, near the coastline, the long and narrow lake of Fondi (black) is surrounded by the Aurunci limestone mountains. On the right side of the image, a volcanic structure, the Roccamonfina, rises.

The Rome-Naples highway crosses the upper part of the picture, following the Liri valley. The Abbey of Cassino (white box) is located along the highway, in the upper central part of the image.

Although they were acquired at the same hour, the ERS-1 image of 1 May and the ERS-2 image of 2 May reveal a difference in soil moisture — shown by the greenish colour of the land — due to changed weather conditions.

The colours of the sea correspond to different wind and current conditions at the time of the three acquisitions; black indicates where the sea was calm at all acquisition times.



*A multitemporal image of the Gulf of Gaeta in the Campania region in central Italy, produced by combining an ERS-2 image with two taken by ERS-1*

*Blue: ERS-1 data, 27 March 1995*
*Green: ERS-1 data, 1 May 1995*
*Red: ERS-2 data, 2 May 1995*

## ESA Opens Permanent Mission in Russia

ESA has opened its permanent mission in Moscow after signing an agreement with the Russian Government on 10 April formalising ESA's status in Russia.

The office will be headed by ESA's Alain Fournier-Sicre. It will facilitate cooperation with Russia and with the Russian Space Agency in particular in a wide range of science and technology projects, including flights by ESA astronauts on the Russian space station Mir.

The agreement marks 'a further step in the convergence of Russia's and ESA's space activities', stated ESA's Director General, Jean-Marie Luton after the signing ceremony, 'and will be of decisive importance in developing international space cooperation in the years ahead'.

The agreement includes provisions recognising ESA as a public-law intergovernmental organisation with the legal characteristics required to conduct cooperative space activities with Russian institutions and industrial concerns.

*G.E. Mamedov, the Russian Deputy Minister for Foreign Affairs (seated, left), and J.-M. Luton, ESA's Director General (seated, right), sign the agreement establishing a permanent ESA mission in Russia, at the Ministry of Foreign Affairs in Moscow*

# ESA Names Astronaut for EuroMir 95

Thomas Reiter has been selected as the ESA astronaut to fly on the EuroMir 95 mission this August. He will become the non-Russian astronaut to have spent the longest time in orbit — 135 days — and the first ESA astronaut to 'spacewalk'.

EuroMir 95 is the second ESA mission to the Russian space station Mir with an ESA astronaut on board and is part of ESA's preparations for the International Space Station. It follows EuroMir 94, the month-long mission last October with ESA astronaut Ulf Merbold and 28 European experiments on board.

EuroMir 95 is currently scheduled to be launched on 22 August from the Baikonur Cosmodrome in Kazakhstan, and Reiter is scheduled to return to Earth more than four months later, on 4 January 1996. The mission will be the longest in European space history.

Reiter, from Germany, and another ESA astronaut, Christer Fuglesang, from Sweden, have been training for the mission since August 1993 at the Yuri Gagarin Cosmonauts Training Centre at Star City, near Moscow, and at the European Astronauts Centre in Cologne, Germany. Christer Fuglesang has been named to the back-up crew and must be ready to fly in case a member of the prime crew cannot. Their training has been intensive because, for the first time, the ESA astronaut will serve as the flight engineer on the mission and will be responsible for some Mir and Soyuz systems. Both the prime and the back-up crew will continue to follow the same training until the launch day.

One of the high points of the mission will be Reiter's five-hour Extra Vehicular Activity (EVA) when he ventures outside Mir on a 'spacewalk'. During the excursion, he will install material samples in a European experiment mounted on the exterior of the Spektr module, which is scheduled to be launched in late May. The samples will be exposed to the harsh space environment as part of an experiment to test the hardiness of materials used in the construction of spacecraft.


*Thomas Reiter, the ESA astronaut to fly on EuroMir 95*

Reiter, 36, holds a Master's Degree in aerospace engineering and was a test pilot in the German air force before being selected as an astronaut. Fuglesang, 37, has a science background and holds a Doctorate in experimental particle physics.

EuroMir 95 will carry 41 European experiments. It will also use more European equipment than the first mission, which mainly relied on hardware already onboard Mir. An unmanned Progress cargo craft will deliver about 350 kg of equipment to the station this July. More equipment and samples will be sent aboard a Progress craft in September. Reiter will take only a small amount of equipment with him to Mir. The specialised equipment will include a device for measuring bone density since a reduction in bone thickness is one of the major physiological problems faced by astronauts during long-duration flights. The research may also be helpful in understanding other bone disorders such as osteoporosis.

# Ariane Launches Resumed

Ariane flight 71 took place successfully during the night of 28 to 29 March, marking the resumption of flights following the failure of flight 70 last December. Two other flights have since been launched successfully.

***Flight 71***

Flight 71 used the 44LP launcher version. The two telecommunication satellites Brasilsat B2 and Hot Bird 1 were placed in geostationary transfer orbit with good accuracy.

Following the failure last December, an extensive plan of action was implemented. An inquiry board concluded that the most probable cause of the third-stage engine failure was a partial obstruction by pollution of the gas generator LOX feeding line. The board, however, did not reject the possibility of a leak in the line. In compliance with the board's recommendations, numerous measures were taken to improve the cleanliness and leak-tightness processes and controls of the third stage at all steps in the production line in both Europe and Kourou. In addition and as a precaution, a filter was introduced at the inlet of the more critical component of the LOX circuit, the injection block. Such a measure was not considered to be necessary on the LH2 side because the elements concerned are much wider in section than those of the LOX circuit.

All of those process and hardware changes were qualified in strict compliance with the formal procedures of the Ariane management specification. The hardware for flight 71 was retrofitted in Europe according to the improved flight standard.

***The subsequent flights***

Two other launches have since been successfully achieved. Flight 72, carrying ESA's ERS-2 satellite, lifted off on the night of 20 to 21 April, and flight 73, carrying the Intelsat 706 telecommunications satellite, was launched during the night of 16 to 17 May.

# 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 at the back of this issue.

## ESA Special Publications

ESA SP-367 // 100 DFL
PROCEEDINGS OF THE SECOND EUROPEAN SYMPOSIUM ON AEROTHERMO-DYNAMICS FOR SPACE VEHICLES
21 – 25 November 1994, Noordwijk, The Netherlands
*(ED. J.J. HUNT)*

ESA SP-378 // 70 DFL
PROCEEDINGS OF THE WORKSHOP ON INTELLECTUAL PROPERTY RIGHTS AND SPACE ACTIVITIES — A WORLD-WIDE PERSPECTIVE
5 – 6 December 1994, Paris, France
*(ED. T.D. GUYENNE)*

ESA SP-1116 Rev. 2 // 50 DFL
FACILITIES FOR MICROGRAVITY INVESTIGATIONS IN PHYSICAL SCIENCES SUPPORTED BY ESA
*(ED. B. KALDEICH)*

ESA SP-1162 // 80 DFL
BIORACK ON SPACELAB IML-1
*(ED. C. MATTOK)*

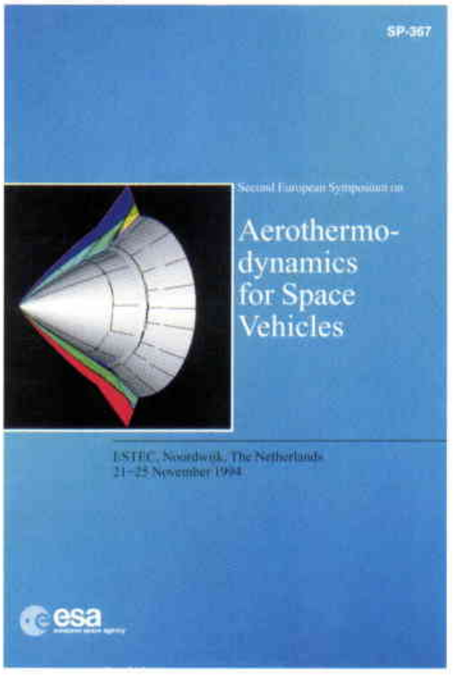
ESA SP-1175 // 35 DFL
INVESTING IN TECHNOLOGY: A REPORT ON THE CACH PROGRAMME
*(ED. M. PERRY)*

ESA SP-1176/1 // 70 DFL
NEW VIEWS OF THE EARTH: SCIENTIFIC ACHIEVEMENTS OF ERS-1
*(ED. T.D. GUYENNE)*

## ESA Brochures

ESA BR-102 // 35 DFL
SPASOLAB
*(ED. B. KALDEICH)*

ESA BR-109 // NO CHARGE
LAND AND SEA — ERS-1 APPLICATIONS
*(ED. F. BEDNARZ)*



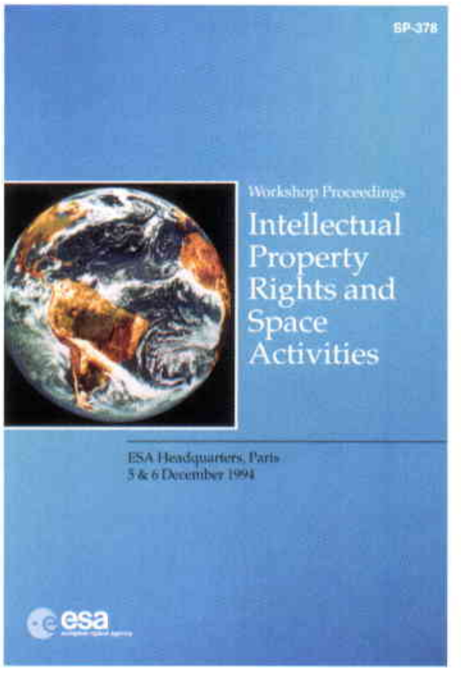

## ESA Newsletters

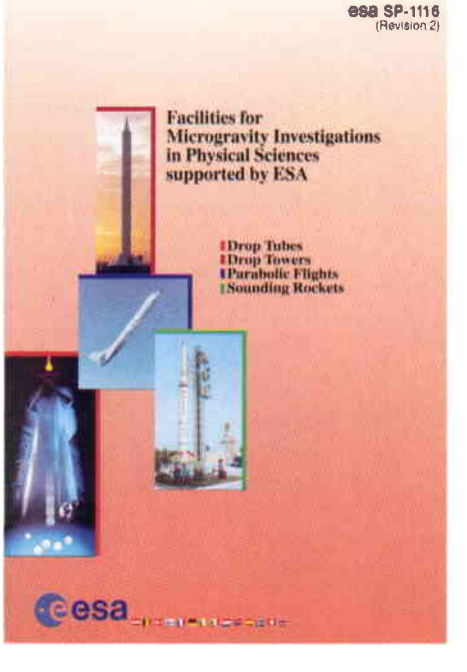
EARTH OBSERVATION QUARTERLY — No. 47 (ENGLISH), MARCH 1995
(NO CHARGE)
*(ED. T.D. GUYENNE)*

MICROGRAVITY NEWS FROM ESA — VOL. 8, No. 1, APRIL 1995
(NO CHARGE)
*(ED. B. KALDEICH)*

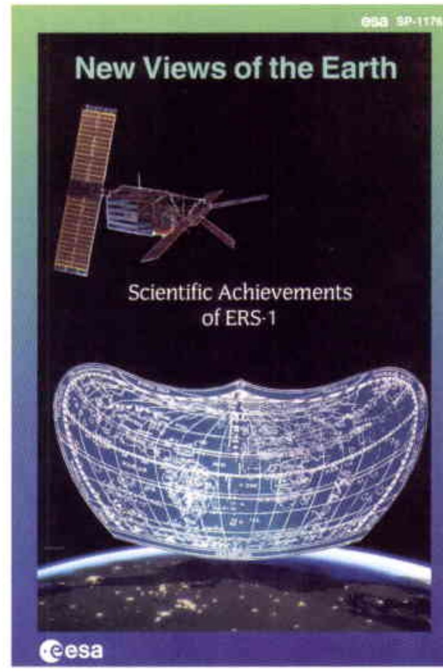
PREPARING FOR THE FUTURE
(Technology Programme Quarterly) — VOL. 5, No. 1, MARCH 1995
(NO CHARGE)
*(ED. M. PERRY)*

REACHING FOR THE SKIES
(Quarterly Newsletter on ESA's Launchers) — No. 14, MAY 1995 (NO CHARGE)
*(ED. T.D. GUYENNE)*








### ESA Procedures, Standards and Specifications

ESA PSS-01-401 Issue 2 // 35 DFL
ESA FRACTURE CONTROL REQUIREMENTS
*ESA PRODUCT ASSURANCE & SAFETY DEPARTMENT AND ESA FRACTURE CONTROL BOARD*

ESA PSS-01-702 Issue 2 // 35 DFL
A THERMAL VACUUM TEST FOR THE SCREENING OF SPACE MATERIALS
*ESA PRODUCT ASSURANCE & SAFETY DEPARTMENT*

ESA PSS-03-209 Issue 2 // 100 DFL
ESACRACK USER'S MANUAL
*ESTEC STRUCTURES AND MECHANISMS DIVISION*

ESA PSS-07-101 // 80 DFL
PACKET UTILISATION STANDARD
*ESA COMMITTEE FOR OPERATIONS AND EGSE STANDARDS*

### ESA Scientific and Technical Memoranda/Reports

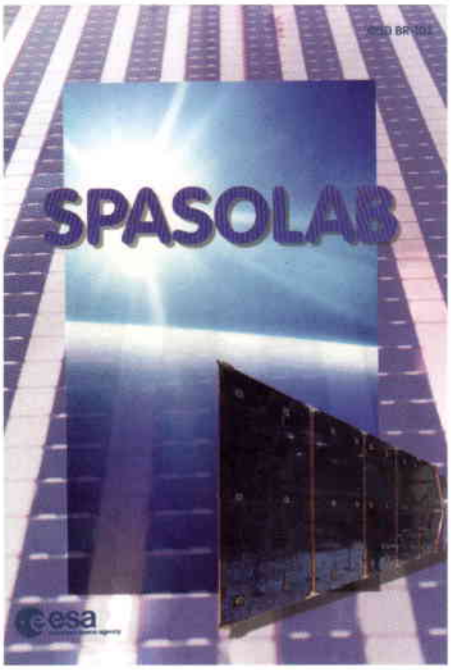
ESA STM-253 // 50 DFL
PRELIMINARY ANALYSIS OF A HEXAPOD POINTING SYSTEM FOR SPACE APPLICATIONS
*G. ISELLA*
*(ED. W.R. BURKE)*

ESA STR-236 // 50 DFL
SURVEY OF METHODS OF CALCULATING HIGH-TEMPERATURE THERMODYNAMIC PROPERTIES OF AIR SPECIES
*M. CAPITELLI ET AL.*
*(ED. W.R. BURKE)*

### ESA History Series

ESA HSR-15 // 35 DFL
UNITED STATES – EUROPEAN SPACE COOPERATION IN THE POST-APOLLO PROGRAMME
*L. SEBESTA*

ESA HSR-16 // 35 DFL
THE SCIENTIFIC PROGRAMME BETWEEN ESRO AND ESA: CHOOSING NEW PROJECTS (1973 – 1977)
*A. RUSSO*




## ESA Publications via Internet

Selected ESA Publications are now accessible via an ESA Publications Division 'home page', on a server run by the Agency's Information Retrieval Services Division – Exploitation Department, at ESRIN in Frascati, Italy.

The address of the host is:

http://esapub.esrin.esa.it/esapub.html

Further information can be obtained from the IRS Help Desk at ESRIN:

Telephone: +39.6.94180300
E-mail: irshelp@mail.esrin.esa.it (Internet)
or irshelp@esrin.bitnet

# Publications Available from ESA Publications Division

| Publication | Number of issues per year | Scope/Contents | Availability | Source |
|---|---|---|---|---|
| **Periodicals** | | | | |
| ESA Bulletin | 4 | ESA's primary magazine | Free of charge | ESA Publications Division, c/o ESTEC, 2200 AG Noordwijk, The Netherlands |
| Earth Observation Quarterly | 4 | Remote-sensing newspaper | ,, | ,, |
| ECSL News | 4 | Newspaper of the European Centre for Space Law (under the auspices of ESA) | ,, | ,, |
| Reaching for the Skies | 4 | ESA's Space Transportation Systems news | ,, | ,, |
| Microgravity News | 3 | Microgravity Programme newspaper | ,, | ,, |
| Preparing for the Future | 4 | Technology Programme newspaper | ,, | ,, |

| **Monographs** | **Code** | | | |
|---|---|---|---|---|
| Conference Proceedings | (SP-xxx) | Volumes on specific Conference Papers | Prices below | ESA Publications Division, c/o ESTEC, 2200 AG Noordwijk, The Netherlands |
| Special Publications | (SP-xxxx) | Detailed monographs on post-graduate level subjects | ,, | ,, |
| Brochures | (BR-xxx) | Concise summaries on on specific subjects | ,, | ,, |
| Scientific & Technical Reports | (STR-xxx) | Graduate level — reflecting ESA's position on a given subject | ,, | ,, |
| Scientific & Technical Memoranda | (STM-xxx) | Graduate level — latest but not finalised thinking on a given subject | ,, | ,, |
| Procedures, Standards & Specifications | (PSS-xxx) | Definitive requirements in support of contracts | ,, | ,, |
| Training Manuals | (TM-xxx) | Series for education of users or potential users of ESA programmes, services or facilities | ,, | ,, |

| | | | | |
|---|---|---|---|---|
| **Public-relations material** | | General literature, posters photographs, films, etc. | | ESA Public Relations Service 8-10 rue Mario-Nikis 75738 Paris 15, France |

**Charges for printed documents**

| Number of pages in document: | 1—50 | 51—100 | 101—200 | 201—400 | 401—600 |
|---|---|---|---|---|---|
| Price (Dutch Guilders) | 35 | 50 | 70 | 80 | 100 |

**Note**

1. *On all European orders over Dfl. 110 — discount of 10%.*
2. *On all orders from outside Europe over Dfl. 110 — no extra charge for airmail.*

# Order Form for ESA Publications

**IMPORTANT**

1. Orders must be accompanied by a Cheque or International Banker's Draft, in Dutch Guilders, made payable to 'ESA Publications Division'. No publications will be sent before receipt of payment.
2. Within Europe mailing is free-of-charge. Outside Europe airmail is free-of-charge for orders over Dfl. 110; smaller orders are sent sea mail.

**RETURN TO: FINANCE DIVISION (EFA/P)**
**ESTEC, POSTBUS 299**
**2200 AG NOORDWIJK**
**THE NETHERLANDS**

| No. of copies | ESA reference | Title | Price per copy, Dfl. | Total Dfl. |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

Total:

Discount for orders over Dfl. 110: 10% of total: .........

Total amount enclosed: Dfl. .........

**MAILING ADDRESS (Print carefully)**

Name ..............................................................................

Function ..............................................................................

Organisation ..............................................................................

Mailing Address ..............................................................................

..............................................................................

Town & Postal Code ..............................................................................

Country ..............................................................................

Date .................................. Signature ..................................

**METHOD OF PAYMENT (Please tick box)**

☐ Cheque
☐ International Banker's Draft

enclosed, made payable to ESA Publications Division'.

esa
european space agency
agence spatiale européenne

**Member States**

Austria
Belgium
Denmark
France
Germany
Ireland
Italy
Netherlands
Norway
Spain
Sweden
Switzerland
United Kingdom

**Etats membres**

Allemagne
Autriche
Belgique
Danemark
Espagne
France
Irlande
Italie
Norvège
Pays-Bas
Royaume-Uni
Suède
Suisse