european space agency

esa bulletin

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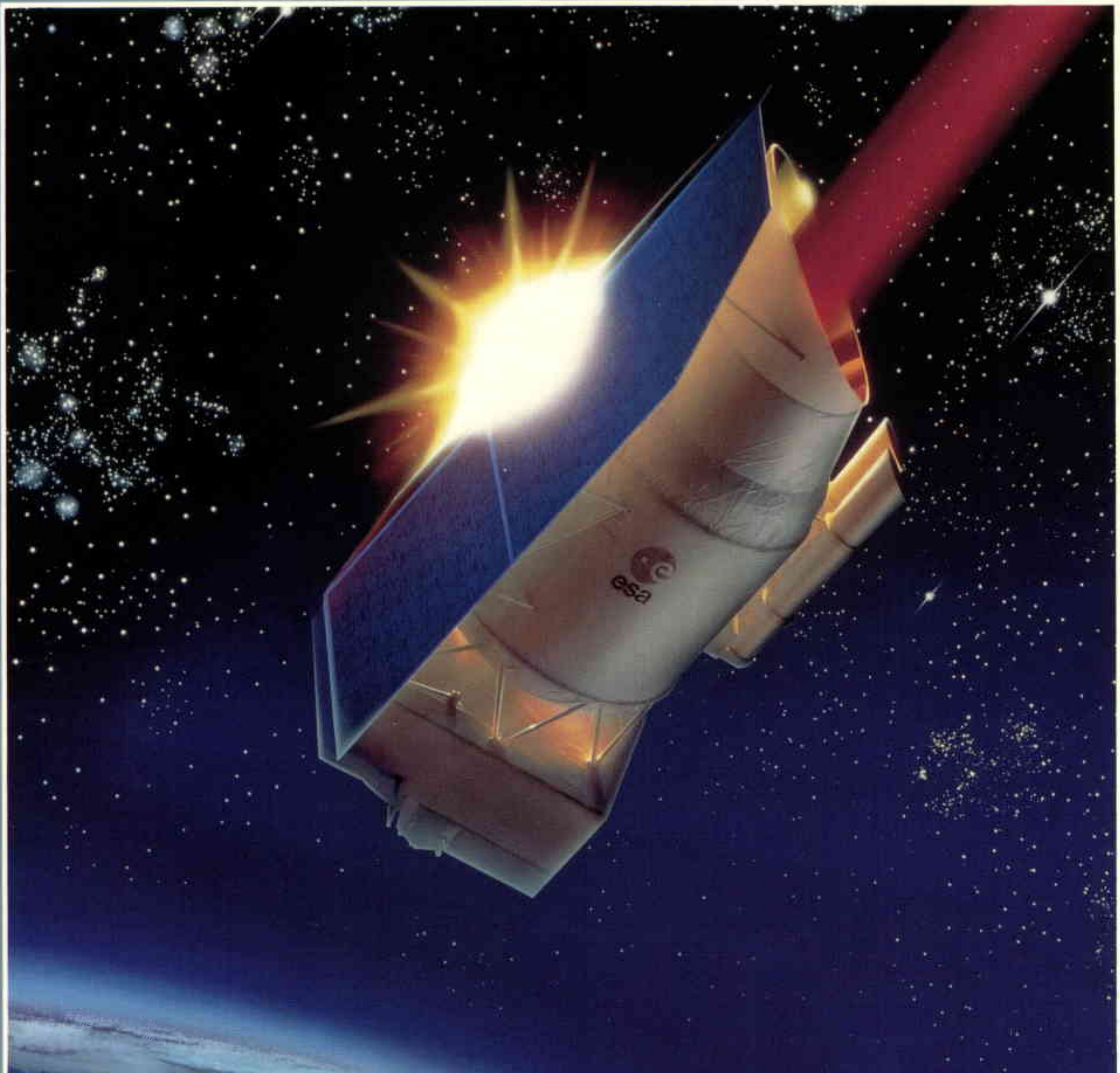

number 67

august 1991

european space agency

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

In the words of the Convention: The purpose of the Agency shall be to provide for and to promote, for exclusively peaceful purposes, co-operation among European States in space research and technology and their space applications, with a view to their being used for scientific purposes and for operational space applications systems.

(a) by elaborating and implementing a long-term European space policy, by recommending space objectives to the Member States, and by concerting the policies of the Member States with respect to other national and international organisations and institutions;
(b) by elaborating and implementing activities and programmes in the space field;
(c) by co-ordinating the European space programme and national programmes, and by integrating the latter progressively and as completely as possible into the European space programme, in particular as regards the development of applications satellites;
(d) by elaborating and implementing the industrial policy appropriate to its programme and by recommending a coherent industrial policy to the Member States.

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The major establishments of ESA are:

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

ESRIN, Frascati, Italy.

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agence spatiale européenne

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

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esa bulletin

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

Publication Manager
Bruce Battrick

Editors
Bruce Battrick, Duc Guyenne

Assistant Editor
Erica Rolfe

Layout
Carel Haakman

Montage
Keith Briddon

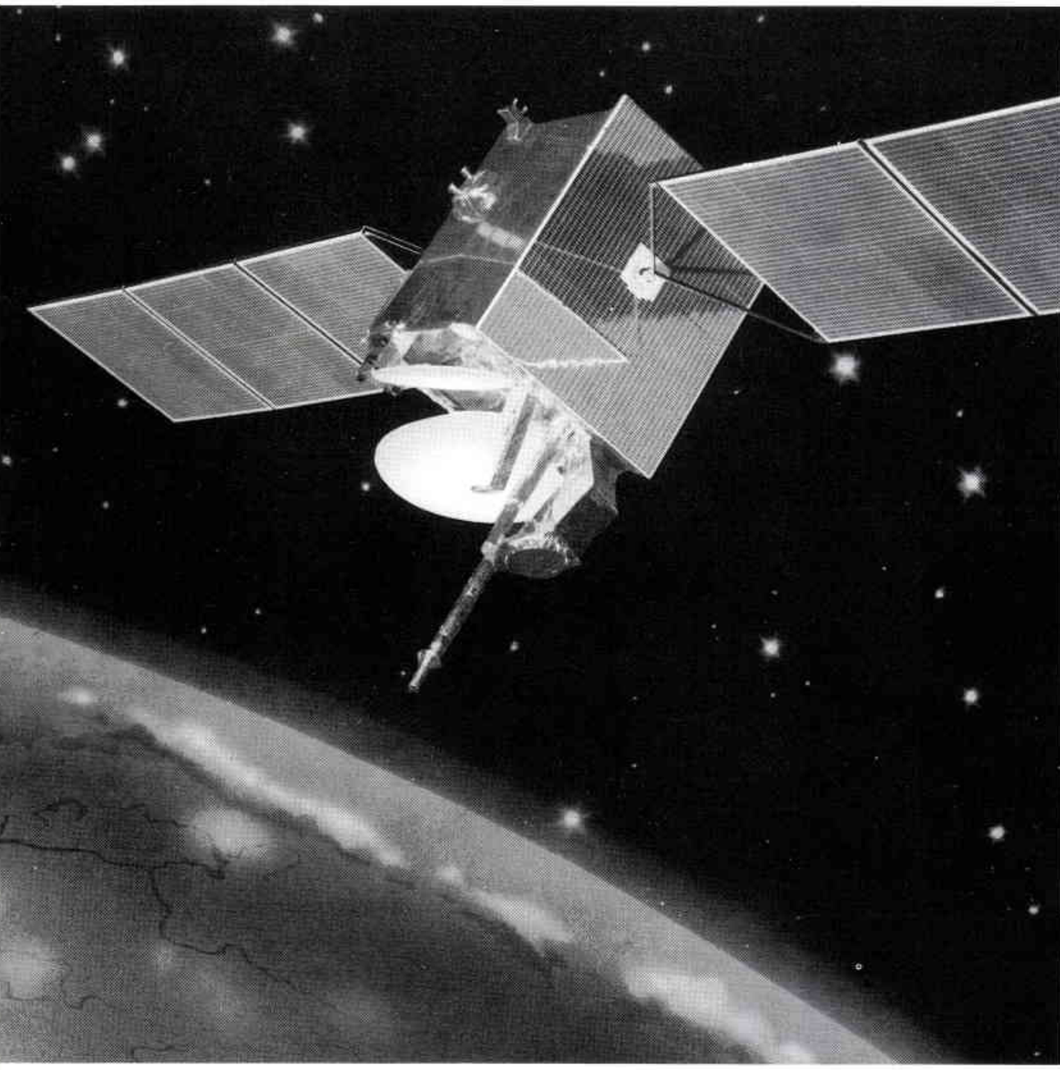
Advertising
Brigitte Kaldeich

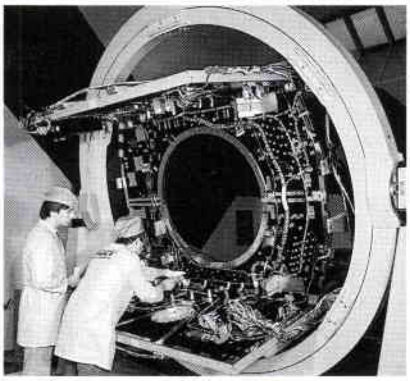
Printed in The Netherlands
ISSN 0376-4265

european space agency
agence spatiale européenne

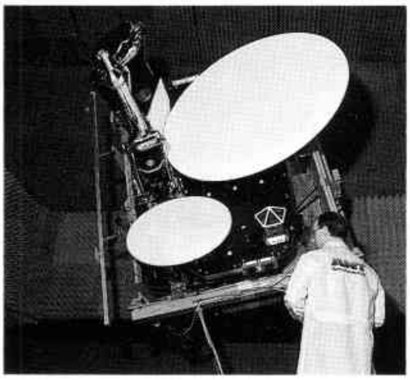
Satellite Technology from ANT:

DFS Kopernikus – The German Telecommunications Satellite





Satellite integration hall at ANT



DFS antenna module measurement

ANT 8927 E Schr.

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

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

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

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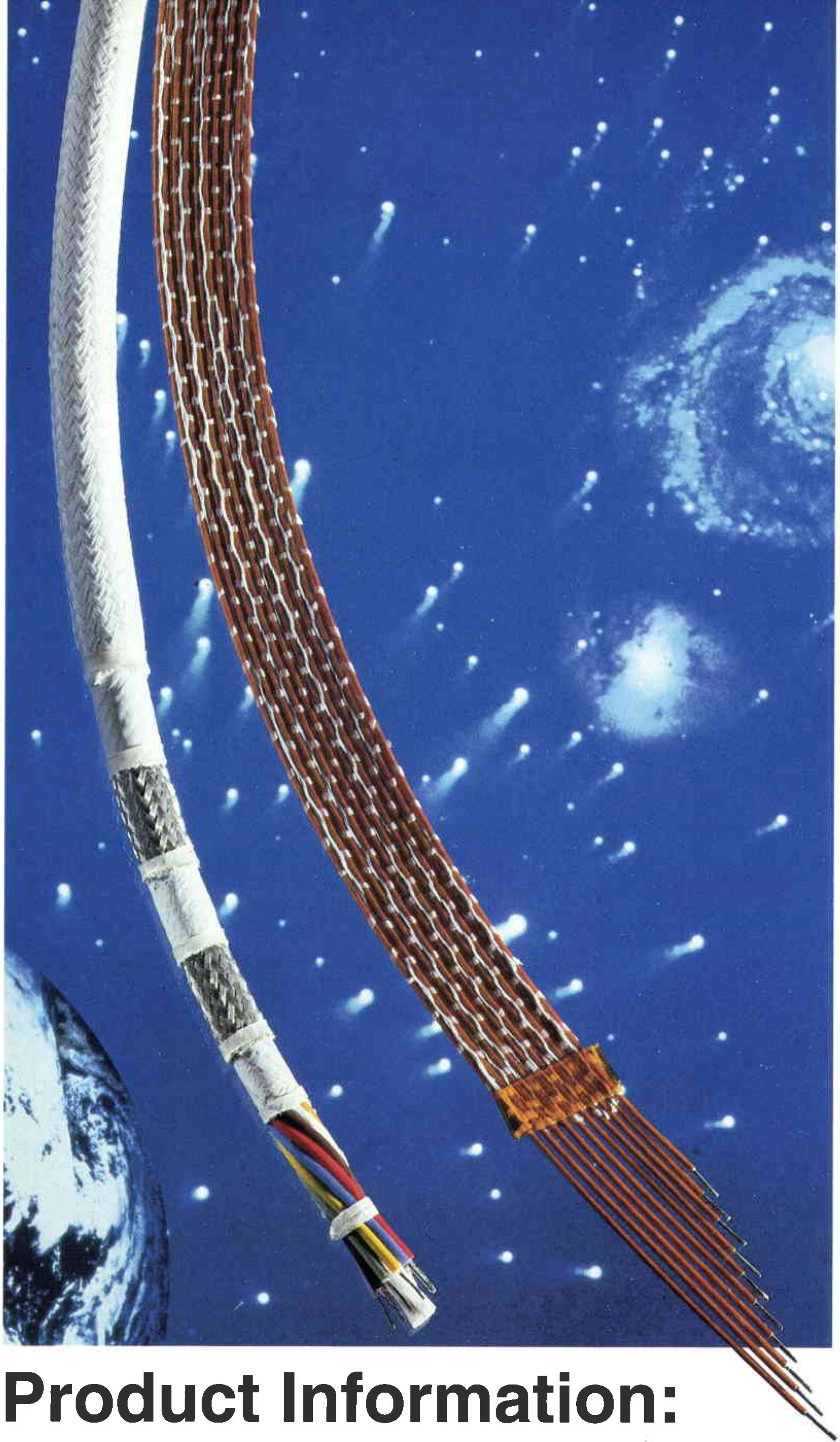

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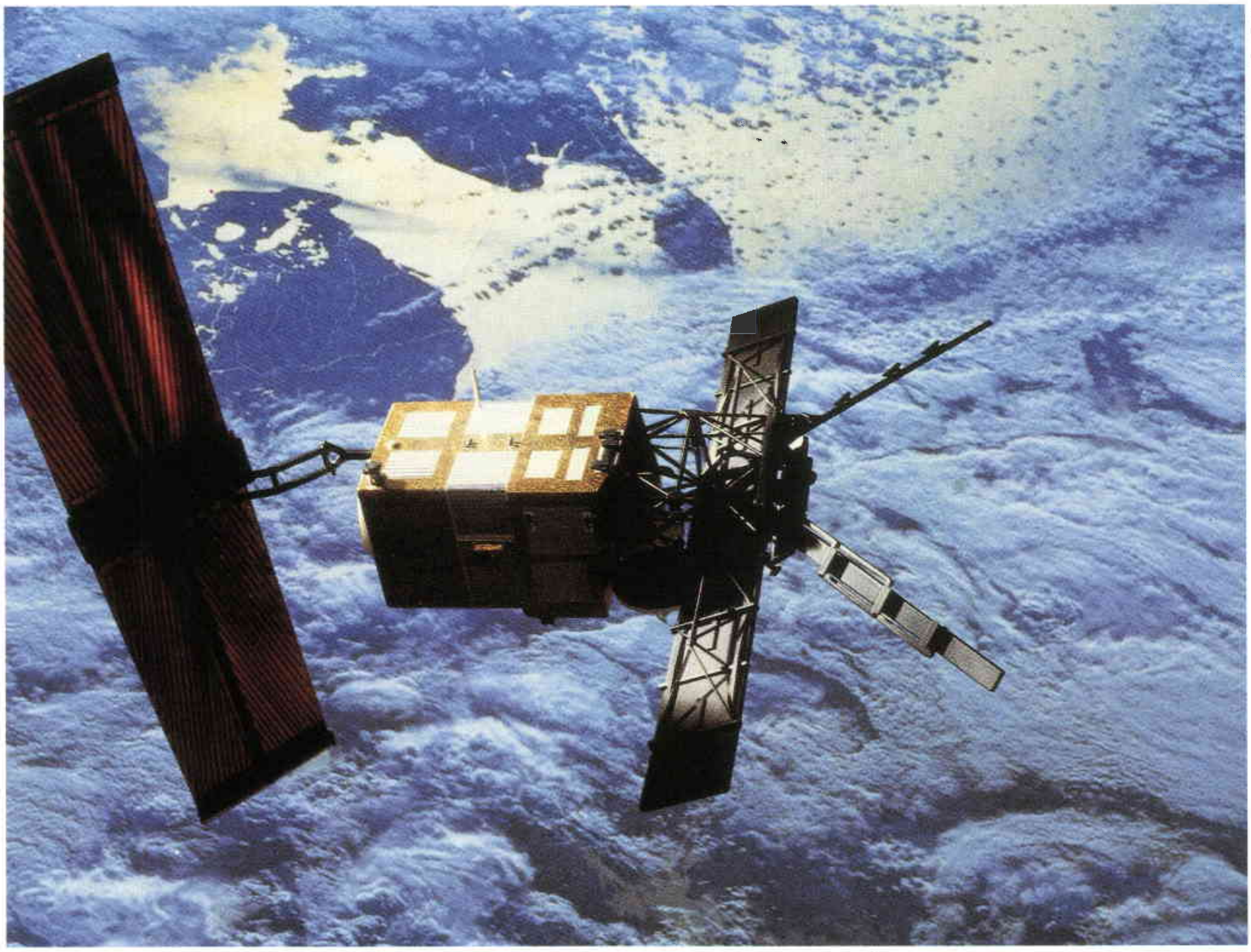
Mission for the Blue Planet.



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More than 20 years ago, the first pictures taken from space showed completely new views of the Earth. Since then, space has turned out to be the right point of view for the global research and monitoring of our planet Earth.

As prime contractor to ESA, Dornier took over the responsibility for the program of the first European Earth observation satellite ERS-1. As system leader in a consortium we have developed this first all-weather satellite system in cooperation with 50 international partners. Microwave and infrared sensors collect geophysical data of the oceans, polar ice caps, offshore regions and selected land areas independent of the cloud coverage and the time of the day. That way, valuable information is made accessible to users, for example in the fields of environmental protection, climatology, weather forecasting, oceanography and land use.

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The ISO Mission – A Scientific Overview

M. F. Kessler, A. Heske, L. Metcalfe & A. Salama
ESA Space Science Department, ESTEC, Noordwijk, The Netherlands

The Infrared Space Observatory (ISO) satellite will be the World's first true astronomical observatory in space, operating at infrared wavelengths. Astronomers will be able to choose specific targets in the sky and point ISO towards them for up to ten hours at a time to make observations with versatile instruments of unprecedented sensitivity. During its lifetime of eighteen months, ISO will be used to observe all classes of astronomical objects ranging from planets and comets in our own solar system, right out to the most distant galaxies.

Why infrared observations?
In the years since observational astronomy finally escaped from confinement to the narrow visible range of the electromagnetic spectrum accessible from the ground, it has become clear that a full understanding of the properties and physics of astronomical sources can only be obtained by studying them across the widest possible frequency range. A good example is a nova. The behaviour, at visible wavelengths, of a star suddenly brightening dramatically over a period of only hours or days and then fading slowly over hundreds of days has been known for centuries. However, it was only with the advent of X-ray, ultraviolet and infrared observations that the true nature of such a nova outburst began to be understood.

The infrared region of the spectrum is of great scientific interest, not only because it is here that cool objects (15–300 K) radiate the bulk of their energy, but also because of its rich variety of diagnostic atomic, ionic, molecular and solid-state spectral features. Measurements at these wavelengths permit determination of many physical parameters of astronomical sources, such as energy balance, temperatures, abundances, densities and velocities.

Infrared astronomy and the study of dust are inextricably linked. Dust particles, ranging in size from a few hundred Angstroms to tens of microns, are a very common phenomenon throughout the Universe. This dust absorbs visible and ultraviolet light and re-radiates it in the infrared. It is estimated that dust in the interstellar medium accounts for approximately one third of the total luminosity of our Galaxy. Detailed photometric and spectroscopic study of this emission by ISO will give astronomers a much clearer understanding of the energy balance of the Galaxy and of the composition (large molecules, carbon grains, silicate grains, etc.) of the dust in different parts of it.

Many astronomical sources are surrounded by clouds of dust and gas. These clouds act as an interstellar 'fog', obscuring the astronomical objects and making it very difficult to observe them with visible light. Owing to its longer wavelength, infrared radiation can pierce these dusty regions and bring astronomers information about the conditions inside. As an example, the centre of our Galaxy is hidden from optical telescopes by thick veils of dust. However, a clear view can be obtained even at a relatively short infrared wavelength of 2 micron and the Galactic Centre can, therefore, be best studied at infrared wavelengths.

Figure 1 shows how the Galactic Centre appeared to the infrared survey satellite IRAS.

Why in space?
The scientific potential of infrared astronomy has been amply demonstrated by observations made from both ground-based telescopes and those on high-flying aircraft and balloons. However, Figure 2 shows the two main limitations to these observations. Firstly the Earth's atmosphere is totally opaque at many wavelengths, absorbing all the incoming radiation and thus preventing the astronomer from viewing the celestial object. Work from ground-based telescopes

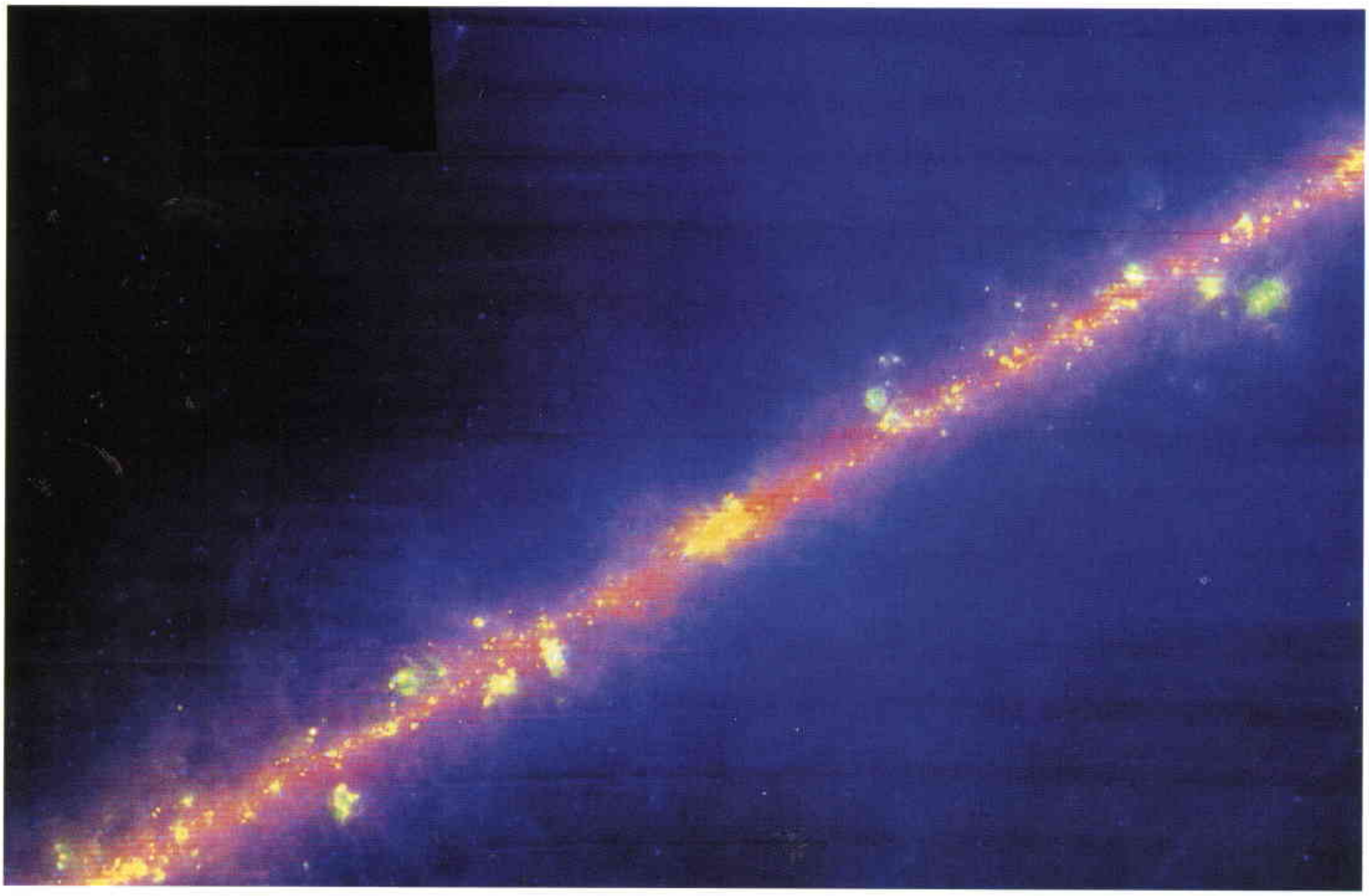


Figure 1. IRAS view of the centre of the Milky Way. This is a composite image made from data taken at three wavelengths and presented in false colour. The yellow and green knots and blobs scattered along the band are giant clouds of interstellar gas and dust (called HII regions) heated by nearby stars. Some are warmed by newly-formed stars in the surrounding cloud, and some are heated by nearby massive, hot, blue stars that are tens of thousands of times brighter than our Sun. Red areas represent regions dominated by cold gas and dust. The large yellow bulge near the middle is the centre of our Galaxy. (Courtesy of NASA/JPL)

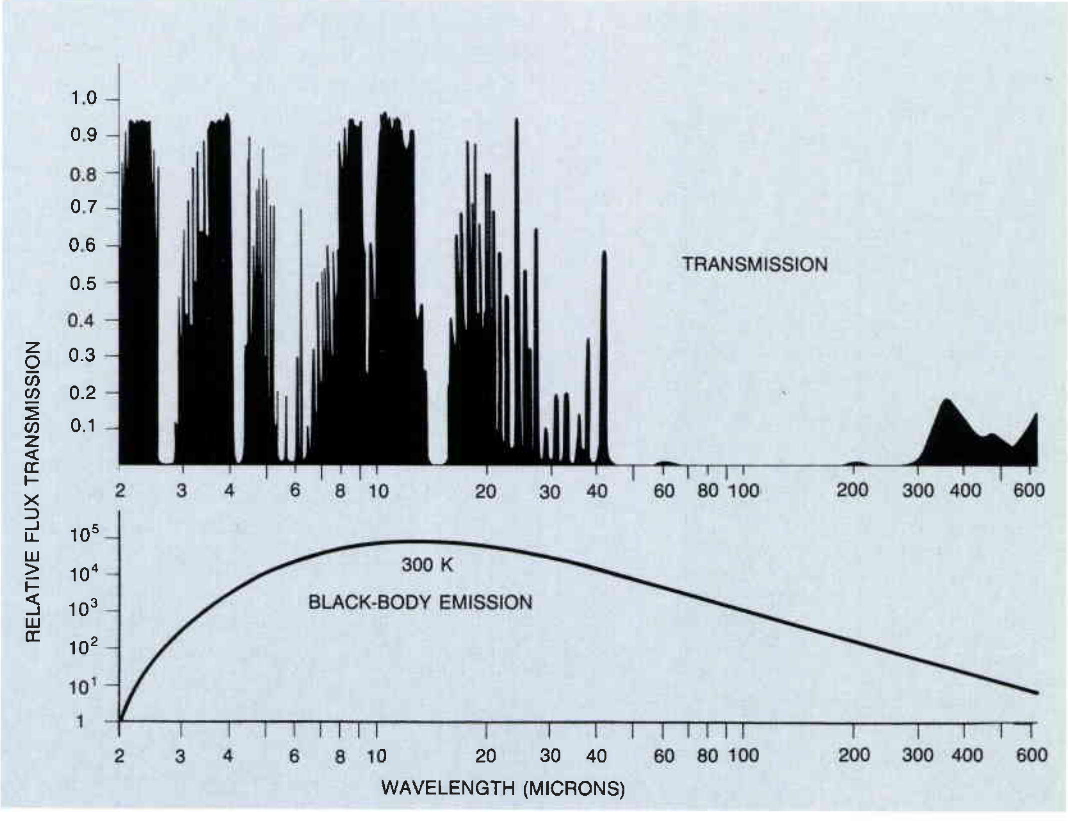


Figure 2.

Upper panel:
Transmission of the terrestrial atmosphere as a function of wavelength. Note that, from the ground, observations are only possible through some 'windows', shown in black.

Lower panel:
Relative flux from a 300 K black body as a function of wavelength, showing that the thermal emission from the warm (approx. 300 K) telescope optics and atmosphere peaks around 10 micron wavelength. This emission hampers observations and is a maximum where the Earth's atmosphere is relatively transparent.

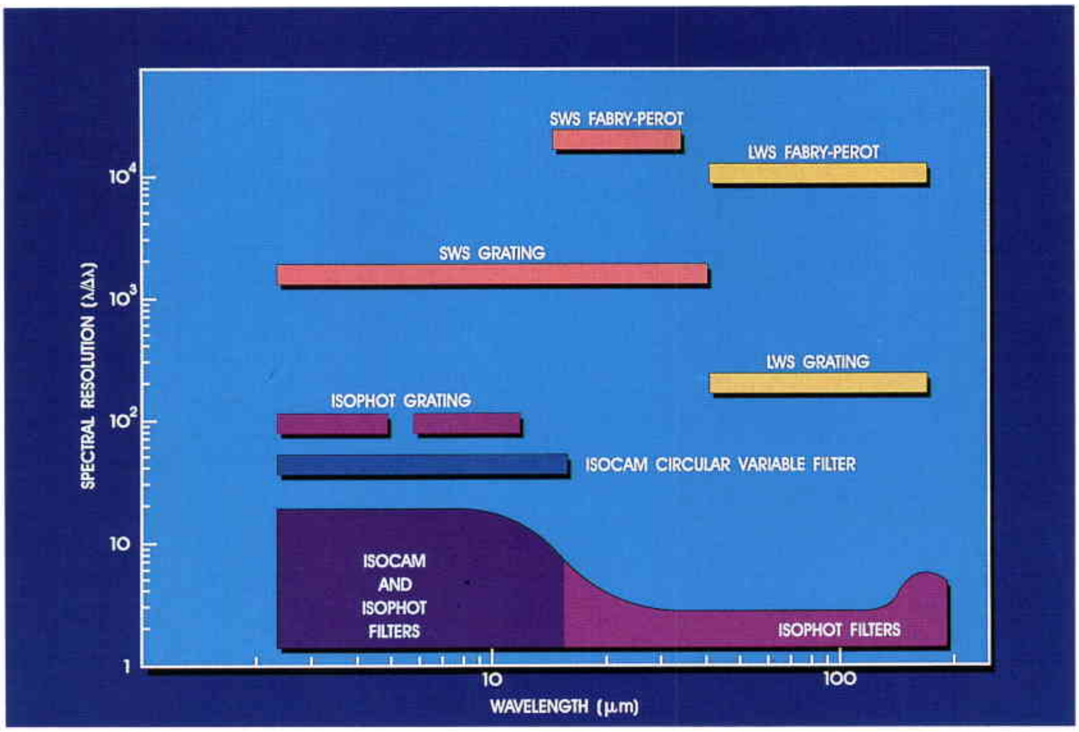


Figure 3. Spectroscopic and photometric capabilities of the ISO scientific instruments.

is only possible through a number of narrow spectral 'windows'. Even at altitudes of 30–40 km, which are typical for balloon-borne telescopes, the atmosphere is not totally transparent.

The second problem is that the telescope and atmosphere are warm and emit infrared radiation themselves. Astronomical sources a million times fainter must be found against this undesired 'background' (really foreground!) emission. This severely limits the sensitivity of ground-based observations.

Table 1 — Main characteristics of ISO instruments

Instrument/ Principal Investigator	Main function	Wavelength (μm)	Spectral resolution	Resolution	Outline description
ISOCAM (C. Cesarsky, CEN-Saclay, F)	Camera and polarimetry	2.5–17	Broad-band narrow-band, and circular variable filters	Pixel FOVs of 1.5, 3, 6 and 12 arsec	Two channels each with a 32 × 32 element detector array
ISOPHOT (D. Lemke, MPI für Astronomie, Heidelberg, D)	Imaging photo-polarimeter	2.5–200	Broad-band and narrow-band filters Near-IR grating spectrometer with R ~ 90	Variable from diffraction-limited to wide beam	Three subsystems: (i) Multi-band, multi-aperture photo-polarimeter (3–110 μm) (ii) Far-infrared camera (30–200 μm) (iii) Spectrophotometer (2.5–12 μm)
SWS (Th. de Graauw, Lab. for Space Research, Groningen, NL)	Short-wavelength spectrometer	2.5–45	1000 across wavelength range and 3×10^4 from 15 to 30 μm	7.5 × 20 and 12 × 30 arcsec	Two gratings and two Fabry-Pérot interferometers
LWS (P. Clegg, Queen Mary & Westfield College, London, UK)	Long-wavelength spectrometer	45–180	200 and 10^4 across wavelength range	1.65 arcmin	Grating and two Fabry-Pérot interferometers

Thus, for maximum sensitivity and wavelength coverage, it is necessary to cool the telescope and its instruments and to operate them in space. The first major step in this direction was taken with the highly successful Infrared Astronomical Satellite (IRAS), which surveyed nearly all the sky in four broad photometric infrared bands. Among the results of the IRAS mission (US/NL/UK) is a catalogue of over 250 000 sources. ISO will build on the results of IRAS by making detailed observations of selected sources. Compared to IRAS, ISO will have a longer operational lifetime, wider wavelength coverage, better angular resolution, more sophisticated instruments and, by a combination of detector improvements and longer integration times, a sensitivity gain of up to several orders of magnitude.

ISO as an observatory

ISO will be a true astronomical observatory. It will have a highly versatile and sensitive set of scientific instruments, capable of undertaking a wide range of scientific tasks. Time on this observing facility will be available to all European and US astronomers. The overall ISO system includes not only the scientific instruments and the spacecraft in orbit, but also its control centre on the ground.

Four instruments make up the ISO scientific payload: an imaging photopolarimeter (ISOPHOT), a camera (ISOCAM) with polarimetric capabilities, a short-wavelength spectrometer (SWS), and a long-wavelength spectrometer (LWS). These instruments are being built by international consortia of scientific institutes for delivery to ESA. The technical aspects of the instruments were discussed in ESA Bulletin No. 61 by Eggel et al.; their main characteristics are summarised in Table 1, while an overview of their scientific capabilities is given in Figures 3 and 4. In summary, the four instruments provide a range of photometric, polarimetric, spectroscopic and imaging capabilities across the entire ISO wavelength range.

In order to prevent the sensitivity of the scientific instruments from being degraded by their own thermal emission and that from the telescope, all parts of ISO 'seen' by the infrared instruments must be cooled to only a few degrees above absolute zero (−273°C). Thus, the ISO satellite is, essentially, a huge Thermos flask designed to provide the extremely low temperatures necessary. ISO consists of a cryostat containing, at launch, over 2000 l of liquid helium, and a cryogenically cooled telescope with an aperture of 60 cm. The telescope can be pointed anywhere on the sky to an accuracy of a few seconds of arc for a period of up to 10 h. The in-orbit lifetime of the satellite is limited by evaporation of the liquid-helium cooling fluid, but will be at least 18 months. The spacecraft is described in more detail in another article in this Bulletin by Ximénez de Ferrán, and the cryogenic system was presented by Davidson et al. in ESA Bulletin No. 57.

An Ariane-4 launcher will place ISO into a highly eccentric orbit with an apogee of 70 000 km, a perigee of 1000 km and a period of 24 h. In this orbit, ISO will spend 16 h per day outside the Earth's radiation belts. The infrared detectors in the scientific instruments are made from small pieces of silicon and germanium. If the energetic particles in the radiation belts (mainly electron and protons) hit these detectors, they release a large number of electrons, which prevents the ISO instruments from operating at full sensitivity.

The operations with ISO will be carried out by a team of scientists and engineers located at the ISO Control Centre in Villafranca in Spain. ISO's in-orbit lifetime is strictly limited by the evaporation of its liquid helium and this makes the efficiency of the operations even more important than usual.

ISO will be used to make observations of specific objects in the sky that have been selected by individual astronomers via a process of proposal submission and approval. The detailed observing schedule will be planned on an orbit-by-orbit basis a few days in advance. During scientific operations, ISO will always be in real-time contact with the ground Control Centre. However, it is planned to minimise real-time modifications to the scientific observing programme in order to maximise overall efficiency.

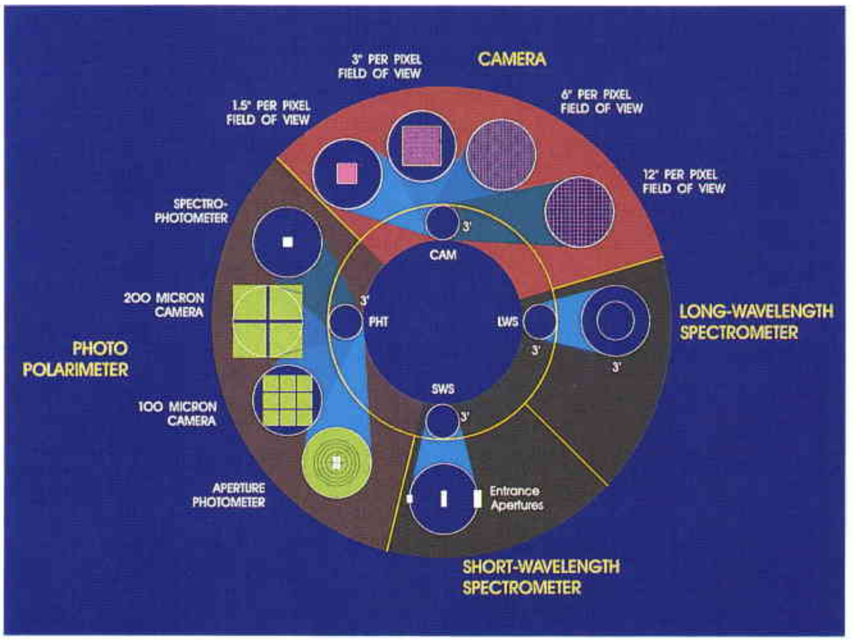


Figure 4. Imaging capabilities of the ISO scientific instruments. Each of the four instruments receives a circular 3 arcmin field of view, drawn to scale in the central part of the figure. The outer annulus shows — in expanded scale — more details of the detector fields of view as projected onto the sky.

It will be possible to view the downlinked data as soon as they are received (the so-called 'quick-look facility'). They will then be subjected to sophisticated pre-processing before being sent on tape to the commissioning astronomer's institute for scientific analysis and interpretation. The results will also be placed in an archive for later use by the astronomical community.

Figure 5 gives a pictorial representation of the ISO operations.

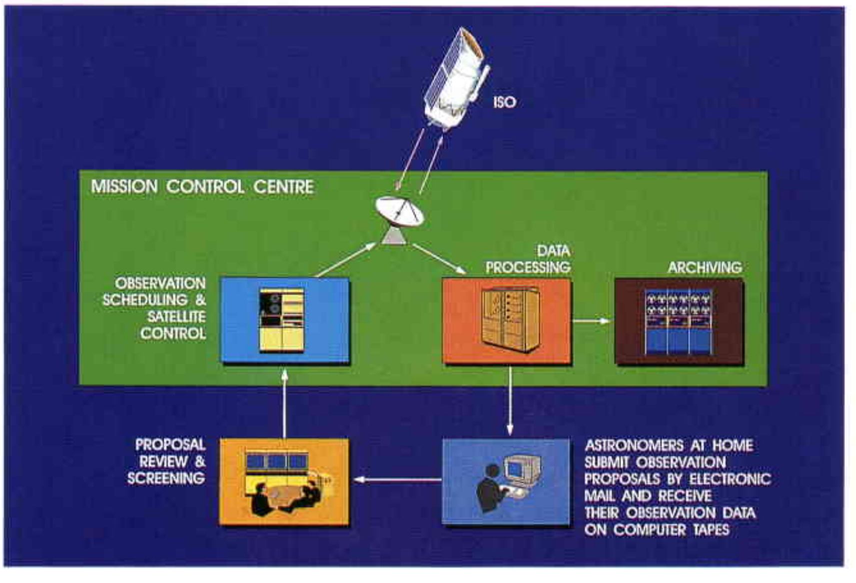


Figure 5. An overview of the activities involved in planning, executing and analysing an ISO observation.

Selected science highlights

ISO will be offering high sensitivity and sophisticated observing facilities for a difficult spectral region, and it is expected that its scientific programme will touch upon virtually every field of astronomy, ranging from solar system studies to cosmology. Some of the possible scientific highlights are summarised below.

Solar system

Planets and their satellites

Like the Earth, most planets have atmospheres, composed mainly of molecules of various gases. ISO will be used to investigate the chemical composition and the physical nature of the atmospheres of the giant planets, together with Titan and Mars. A detailed inventory of the species present will be established, allowing for a better understanding of the planets' chemistry. Titan, too faint to be observable from the ground in the infrared, is the only satellite in the solar system to possess a thick atmosphere. This is thought to be similar to the atmosphere originally possessed by the Earth. Studies of Titan's atmosphere are expected to lead to a better understanding

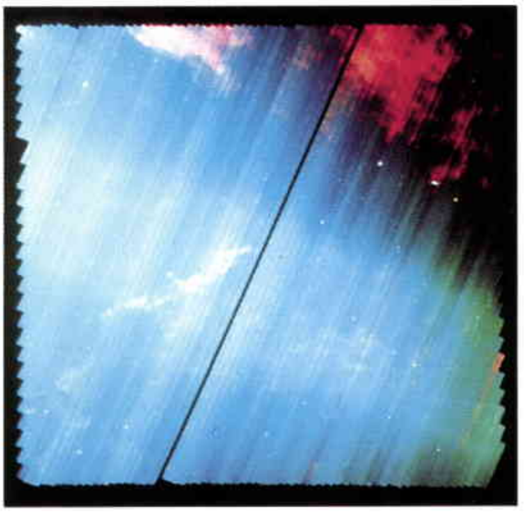


Figure 6. An IRAS image (wavelength 60 microns) of the ecliptic plane, showing the central asteroid dust band, consisting of asteroid collision debris (wide band cutting across centre of picture) (Courtesy of M. Sykes, Univ. of Arizona)

of how the Earth's atmosphere evolved. Detailed studies of Mars's surface temperature and emissivity properties, their temporal variations and their relation with atmospheric dynamics (e.g. dust storms) will also be possible with ISO.

Comets

Comets are believed to retain, in the form of ice and trapped dust, the original content of the primordial solar nebula, from which our solar system condensed. Therefore, their study provides a unique probe of the history of our solar system and its relation to the interstellar medium. With ISO it will be possible to detect comets at large heliocentric distances (5 AU), to study the onset of activity (emission of gas and dust) when a comet approaches the Sun, in particular to study the activity, evolution and composition of the coma. Cometary dust and nucleus have a low temperature and albedo and are, thus, best detectable in the infrared. The spectral, spatial and sensitivity capabilities of ISO will allow a thorough comparison of the general interplanetary dust with the properties of dust close to its probable sources, comets (cometary trails) and asteroids (asteroidal bands) (Fig. 6).

Interstellar medium

The space between the stars is not empty. It is a very active and violent space, containing objects such as gaseous nebulae, supernova remnants, dark molecular clouds, dust, and high-velocity winds from young stars. The material of the interstellar medium has an extremely wide variety of temperatures and densities.

Cirrus

IRAS revealed a new component of the interstellar medium – extended, fuzzy clouds which often have filamentary structures. These clouds range in angular size from tens of degrees down to a few arc minutes (the limiting spatial resolution of IRAS) and, because of their appearance, they have been named 'infrared cirrus' (Fig. 7). The nature and composition of these puzzling clouds will be explored by ISO.

Star-forming regions

The processes by which stars form are not yet well understood. Much of the action is hidden by dust and more infrared observations are needed. Under the right conditions, some dense parts of molecular clouds can start to collapse upon themselves. Initially, these so-called 'protostars' radiate by virtue of the gravitational energy

Figure 7. A false colour IRAS field of a 16 x 16 degree region of the sky rear the galactic plane in the direction of Canis Major, revealing typical filamentary structure of the interstellar cirrus (here shown in green) at a wavelength of 100 microns. (Courtesy Space Research Laboratory, Univ. of Groningen)

of the infalling material and remain cold as compared to the Sun. Eventually, their temperature rises sufficiently for nuclear reactions to start. When 'burning' of hydrogen to form helium is underway, the protostar has become a star.

Stars are formed with a wide range of initial masses; a well-known example of a region of massive star formation is in the constellation Orion (Fig. 8). Among the many open questions on star formation to be addressed by ISO observations are: What triggers the collapse process? Does the accretion always involve a disk? What determines the relative numbers of large and small stars in the resulting cluster? What is the role of the high-velocity (several hundred km/s) mass outflows that are seen from young stars? and What are the properties of the embedded young stellar objects?

Chemical factory
The interstellar medium, containing atoms like hydrogen, oxygen and carbon and molecules like carbon monoxide or water vapour, acts as a chemical factory. Atoms and molecules can collide and they can absorb radiation from nearby stars. By these two processes, other larger molecules may be formed. The physical conditions in interstellar space under which the formation of molecules takes place are extremely difficult to simulate in the laboratory. The ISO spectrometers will reveal the chemical processes in molecular clouds or thick envelopes around young stars.

Stars and stellar physics
Stars are dense gaseous spheres which – for most of their lives – burn, or strictly speaking fuse, hydrogen to form helium in their interior, like the Sun. As stars get older, other nuclear reactions start and, eventually, the star ends its life in a way which depends on its mass. Stars have been extensively observed at many wavelengths, but much important information on their structure and their evolution can only be extracted from infrared observations.

Vega-type stars
The nearby star Vega, or Alpha Lyrae, is the fifth-brightest star at visible wavelengths and is still in its hydrogen-burning phase. It had been extensively observed at many wavelengths and its properties were thought to be well understood. It was, thus, a great surprise when infrared observations by IRAS showed brighter-than-expected emission at wavelengths longer than 25 micron. These data indicate the presence of a disk of cool (around 85 K) material in orbit around the star. This disk may well represent an early stage in the condensation of a planetary system.

Figure 8. IRAS false-colour map of the sky around the constellation Orion. Well-known regions of star formation are apparent, such as the Orion Molecular Cloud (large feature dominating lower right of picture), located in and surrounding the sword of Orion. The large ring in the upper right of the image is a shell of gas swept up by the expanding gases around a young star. The bright region left of centre is the Rossette Nebula in Monoceros. (Courtesy of NASA/JPL)

A number of other stars also have similar 'infrared excesses'. In one of these cases, Beta Pictoris, observations in the visible have actually revealed a thin disk of gas and dust around the star (Fig. 9).

Imaging, photometry and spectroscopy between 3 and 200 micron of these stars will also give us a deeper insight into the formation processes of our solar system. ISO will also be used to investigate how widespread the phenomenon of matter in orbit around these types of stars is.

Stellar evolution
Stars contain enough hydrogen for the fusion to last for a long time, but not forever. The rate at which a star consumes its fuel depends on its mass; the more massive a star, the quicker it evolves. After around five to ten billion years, stars like our Sun evolve to become so-called 'red giants', i.e. very large cool stars. More massive stars, such as

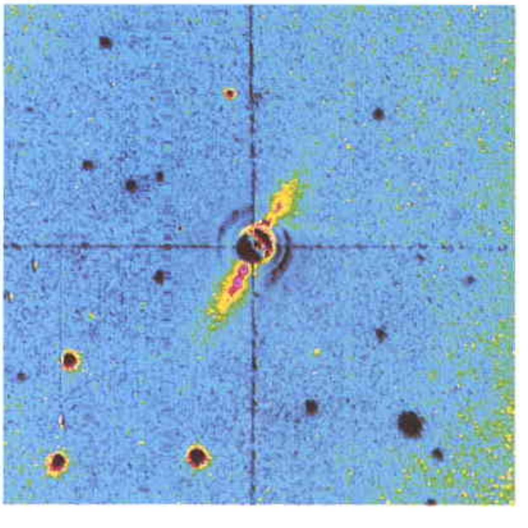


Figure 9. An optical image of the star Beta Pictoris, showing the presence of a disk (seen edge-on) of material around the star. The image has been taken using a technique that blocks out the light from the star itself so as to be able to see the faint structure around it. (Courtesy of NASA/JPL)

those with around 40 times the mass of the Sun, race towards the red-giant phase in only a few million years. During this giant phase, the stars lose a significant amount of their mass via outflows and winds from their atmospheres. A circumstellar envelope is thus built up and sometimes these envelopes are so massive that the stars can no longer be seen in the optical. At the end of this phase, stars can evolve into planetary nebulae (Fig. 10), small hot stars – white dwarfs – surrounded by their expelled material, which is ionised by the ultraviolet radiation from the stars themselves.

Figure 10. The Helix Nebula. An optical picture of a Planetary Nebula about 1 degree in diameter. (Courtesy of Hale Observatories)

With ISO it will be possible to study those stars that are deeply embedded in their circumstellar envelopes. These are at the very end of the phase as a giant, and one open question is how the star evolves during the very short transition phase from a red giant to a planetary nebula and a white dwarf. During the phase of mass loss, the star returns its matter – now processed to include heavy elements – to the interstellar medium. This enriched interstellar medium is the source material for the next generation of stars, and its chemical composition is therefore of great interest. This will be deduced from measurements by the ISO spectrometers of the atomic and molecular spectra of planetary nebulae.

A massive star that fails to lose enough mass during its evolution is, then, doomed to end its life in a huge explosion, a supernova, such as that seen in our companion Galaxy, the Large Magellanic Cloud in 1987 (Fig. 11). This explosive event also returns the material from a dying star to the reservoir from which new stars may form. ISO will study the 'leftovers' (called 'supernova remnants') of such events, which are the source of very heavy elements, like iron.

Extragalactic

Other galaxies, far distant from our own Milky Way Galaxy, have always attracted much observational attention. They have a variety of morphologies, many having spiral arms, interstellar matter and a core region or nucleus, thus reflecting the structure of the Milky Way. Study of these galaxies gives a 'bird's eye view' of processes occurring in the Galaxy, but difficult for us to see. Many galaxies are so far away from the Earth, and their light takes so long to reach us, that observing them is like looking back in time, thereby allowing an examination of the evolution of the Universe. The infrared properties of galaxies are extremely diverse; for example, far-infrared luminosities have been found that span a range of seven orders of magnitude.

There are many questions in extragalactic astronomy needing answers: What are the mechanisms that trigger and maintain the

Figure 11. Two colour photos showing the sudden appearance of the bright supernova 1987A (left of centre and above the main body of the galaxy). The left-hand picture was taken before the supernova exploded and the right-hand one afterwards. (Courtesy of ESO)

formation of stars in galaxies? Why are some galaxies producing large numbers of new stars in hugely energetic bursts? What is the energy source at the centres of the most luminous galaxies making them orders of magnitude more energetic than their quieter neighbours? These questions are central to understanding the processes by which galaxies evolved from their original formation to give us the Universe we see today.
In order to answer these questions, it is necessary to discover the physical conditions prevailing in the diverse and often exotic sources that populate the Universe.

Using ISO, astronomers will seek to understand the properties of star-forming regions in nearby, normal galaxies (Fig. 12), by studying, spectroscopically and photometrically, the properties and spatial distribution of the dust produced there, the kinds of organic compounds that form in the interstellar medium, the energetics of the gas, and the mass distribution of stars produced there.

The results of these studies will be compared with observations of the same entities in radically different environments such as the nuclei of active galaxies, completely obscured by dust absorption at visible wavelengths, or at the heart of colliding galaxy systems (Fig. 13), powerfully luminous at far-infrared wavelengths. With these observations it may be determined whether some galaxies with extremely luminous nuclei ('active' galaxies) are, in fact, the final stage in the development of galaxy mergers. In this scenario, two galaxies collide, precipitating a huge burst of star formation throughout their interstellar material. This would give rise to a far-infrared, ultra-luminous galaxy which finally decays to become an active galaxy with a massive black hole at its nucleus: a Seyfert galaxy or a quasar.

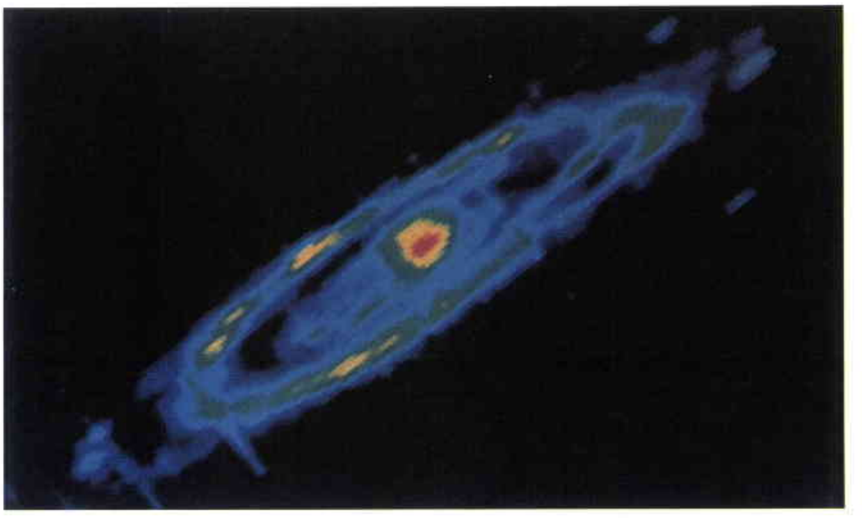


Figure 12. An infrared (IRAS) false-colour image of the nearby spiral galaxy M31, the great nebula in Andromeda. Most of the infrared radiation comes either from the core of the galaxy or from the ring structure, which is probably an active site of star formation. (Courtesy of NASA/JPL)

Since ISO's instruments can see emission from cold (a few Kelvin to a few hundred Kelvin) dark matter (i.e. material not luminous in the visible), it may detect the elusive population of low-mass stars thought to condense out of the streams of gas that flow from intergalactic space onto many of the large elliptical galaxies at the centres of galaxy clusters. These 'cooling flows' of gas, inferred from X-ray observations, produce no corresponding population of stars detectable at visible wavelengths.

Cosmology

ISO can address a number of questions of great cosmological significance. A particularly vital question concerns the total mass in the Universe. If this is greater than a certain amount, then gravitational force will eventually stop the expansion of the Universe and make it collapse into itself again. If the Universe is less massive than this 'closure' mass, it will go on expanding forever. The density of directly detected matter (self-luminous, light-reflecting, or light-obstructing) currently accounted for in the Universe is at most about 20% of the closure density. However, mass could be hidden in dark

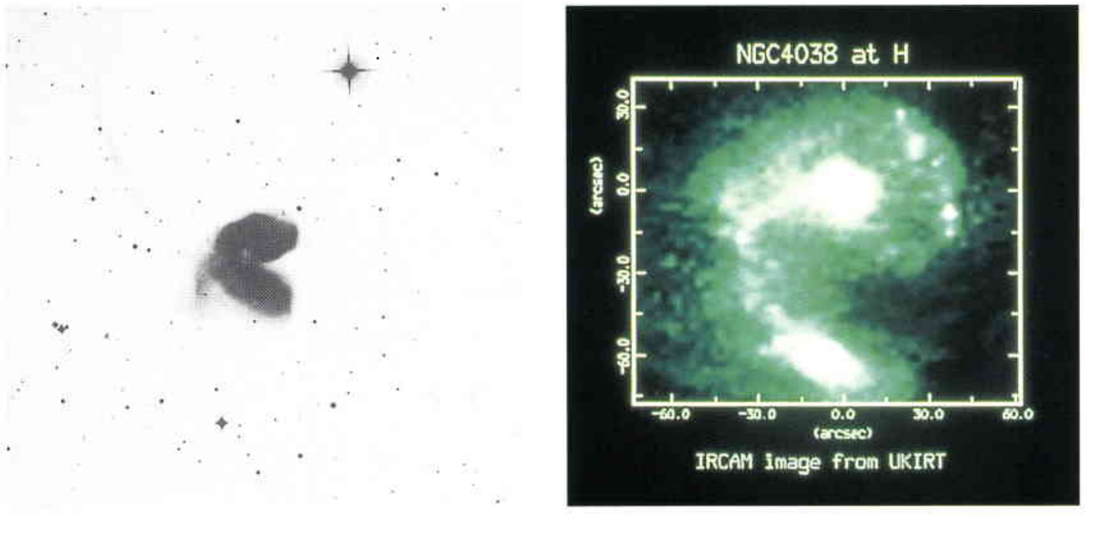


Figure 13. Optical (left) and infrared (1.6 micron) images of the interacting galaxies known as the Antennae. (Courtesy of Palomar and UKIRT, respectively)

forms, invisible at optical wavelengths, but radiating in the infrared region.

One possibility is that some of this missing mass is hidden in the form of objects called Brown Dwarfs (Fig. 14). These are 'failed' stars, i.e. bodies formed out of the interstellar material, but which were not massive enough to support nuclear burning in their cores. It has been suggested that such objects might constitute the unseen haloes of galaxies, postulated in order to account for the detailed orbits of material around galaxy nuclei. It is hoped that the camera (ISOCAM) and the photopolarimeter (ISOPHOT) will be able to unambiguously detect, and confirm the existence of, such objects for the first time.

Figure 14. Artist's impression of a Brown Dwarf, silhouetted against the backdrop of the immensely rich star fields of the Milky Way. A Brown Dwarf is an object that started to collapse to become a star but was not massive enough to be able to initiate nuclear reactions. (Courtesy of NASA)

Chronology of the ISO Mission

March 1979	Proposal to ESA for ISO
1979	Assessment Study
1980	Pre-Phase-A Study
1981–1982	Phase-A Study
March 1983	Selection of ISO for inclusion in ESA's Scientific Programme
June 1985	Selection of scientific instruments
Dec. 1986	Start of Phase-B (Definition)
March 1988	Start of Phase-C/D (Main Development)
May 1993	Launch

ISOCAM and ISOPHOT both plan to perform very long observations intended to detect sources out to high (z = 2) red shifts. The relative proportions of blue galaxies, merging galaxies, active galaxies and more typical galaxies found in such deep source counts is an indicator of the mechanisms through which galaxies originally formed. Did they form at about the same time in a single great burst, or have they formed by a process of hierarchical merging of galaxies, so that they grow, and mergers become less common, as time goes on?

Conclusion

During its lifetime, ISO will offer astronomers a unique opportunity to study the Universe at the relatively unexplored infrared wavelengths. ISO's legacy to the future will be the database of its observational results, which will be used by astronomers long after its in-orbit mission has been completed. The science of ISO will build not just upon the results of the IRAS mission, but also on those from ground-based optical, infrared, submillimetre and radio telescopes. Observations with ISO will have a significant impact on all areas of astronomy. However, the most exciting aspect of the mission is that it is a voyage into largely uncharted waters, and no-one knows what will really be discovered. Hopefully, nature has a few surprises in store for us once again!

Acknowledgements

The scientific highlights described in this article are based, in large part, on the work of the Principal Investigators of the ISO instruments (Catherine Cesarsky for ISOCAM; Peter Clegg for LWS; Thijs de Graauw for SWS; and Dietrich Lemke for ISOPHOT) and their teams of astronomers in defining their observational programmes for the mission.

The ISO Spacecraft

S. Ximénez de Ferrán
ISO Project, ESA Directorate for Scientific Programmes,
ESTEC, Noordwijk, The Netherlands

The ESA Infrared Space Observatory (ISO) will provide astronomers with a unique facility for detailed exploration of the Universe at infrared wavelengths, covering targets ranging from Solar System objects to distant extragalactic sources. The Observatory has two primary elements, a space segment, namely the ISO satellite, and a ground segment. The latter will provide all the facilities needed for satellite control, for the planning of observations, and for data processing, including real-time assessment, quick-look analysis and non-real-time offline data analysis.

Introduction

The ISO spacecraft, shown in Figure 1, has been conceived as two largely independent modules: the Payload Module (PLM) and the Service Module (SVM).
The PLM is essentially a large liquid-helium cryostat, which contains the telescope, with four scientific instruments mounted behind the primary mirror and cooled to a temperature near absolute zero. The characteristics of the various scientific instruments are summarised in Table 1 (technical descriptions of these instruments appeared in ESA Bulletin No. 61). The SVM houses the warm electronics of the scientific instruments, the hydrazine propellant tank, and all the other classical spacecraft subsystems. The Sun shield, with its covering of solar cells, always faces the Sun to provide electrical power whilst at the same time protecting the PLM from direct solar insolation.

The ISO spacecraft will be placed in a 1000 km x 70 000 km elliptical orbit (24 h period) by an Ariane-4 launcher in 1993. This particular orbit will ensure that most observations can be made during the 14 h per orbit when the satellite is travelling outside the Earth's radiation belts. The spacecraft will be tracked from a single ground station, at which the ISO ground segment will be housed.

Mission requirements and system description

Observations of infrared celestial sources

The primary objective of ISO is to make observations of celestial objects at infrared wavelengths between 2.5 and 200 microns. It is therefore essential that all radiation-gathering equipment, the telescope and scientific detectors, be protected from the disturbing effects of infrared emissions from various elements of the system itself.

All objects emit radiation as a function of their absolute temperature T. The total energy emitted is proportional to T^4, and the wavelength at which the radiation's spectral density is at a maximum is inversely proportional to T. The first requisite for ISO, therefore, is to provide a telescope, including baffles, that is kept very cold. The focal-plane units (FPUs) of the scientific instruments and the infrared detectors inside those units must also be maintained at temperatures close to absolute zero. The detailed requirements are summarised in Table 1.

The solution adopted for ISO is to enclose the telescope in a cryostat. The main element is a toroidal tank containing 2140 l of superfluid helium (HeII) at a temperature of 1.8 K. The tank is insulated from external heat inputs by three vapour-cooled radiation shields (VCS) equipped with multi-layer insulation (MLI). The tank, radiation shields and telescope are suspended from the cryo vacuum vessel (CVV) by low-conductivity straps. Boiling helium from the tank provides cooling to the optical support structure (OSS), the focal-plane units and telescope mirrors mounted on the OSS, the optical baffles and, when flowing through the radiation shields to the exhaust nozzles, intercepts incoming heat from the outside environment. Some of the scientific detectors are directly cooled by copper straps connected to the helium tank. A heat shield

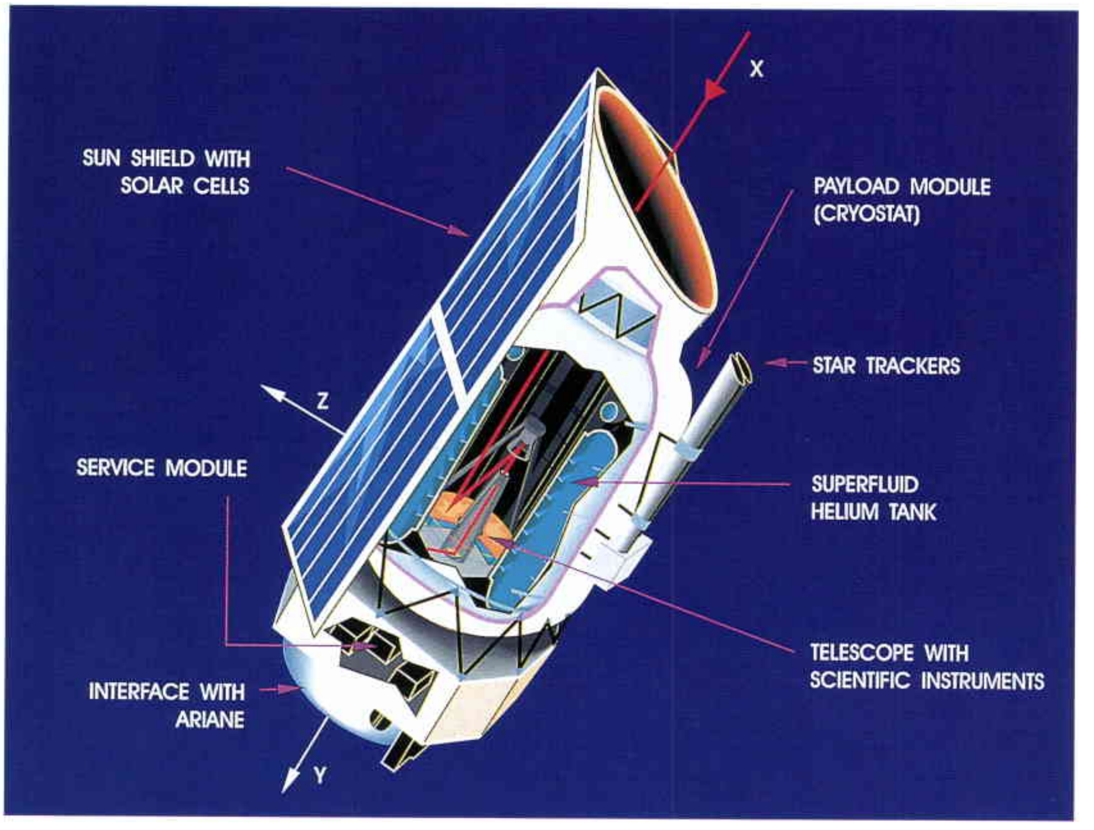


Figure 1. Overall configuration of the Infrared Space Observatory (ISO).

Table 1 — Temperature requirements

Component	Temperature, K	Temperature stability, deg
Detectors interface	$1.7<T<1.9$	± 0.05 in 1000 sec
Optical Support Structure/ Focal-Plane Unit interface	$2.4<T<3.4$	± 0.10 in 1000 sec
Primary mirror	<3.2	± 0.10 in 1000 sec
Secondary mirror	<4	
Lower baffle	<5	
Upper baffle	<7.5	

connected to the tank encloses all four focal-plane units.

The pressure inside the HeII tank is 17 mbar, the equilibrium boiling point at a temperature of 1.8 K. This pressure is maintained in orbit by the impedance of the vent line, and on the ground prior to launch by continuous pumping of the tank exhaust. The gaseous-helium exit is located at the highest point of the tank, allowing separation by gravity of the liquid and gas phases during ground operations. Once in orbit, one of the remarkable properties of superfluid helium is exploited, the so-called 'thermodynamic fountain effect', by which a simple porous plug functions as a phase separator, keeping the liquid phase in the tank while allowing the gaseous helium to flow through the vent line.

A flow diagram for the ISO cryostat is shown in Figure 2.

To protect the cryostat from external heat inputs and in particular from direct solar illumination, a Sun shield shades the cryo vacuum vessel. This shield is composed of two flat plates (Fig. 1), the outer faces of which carry the solar cells that provide the electrical power needed for the mission.

During ground operations, the vacuum in the cryo vacuum vessel is maintained by a cryo cover, which is also insulated with radiation shields and multi-layer insulation. It is held in place by a clamp band, which will be released in orbit to jettison the cover after satellite outgassing, approximately 15 days after lift-off, at which point the scientific observation programme will commence.

The cryostat is designed for a minimum operational lifetime of 18 months (it was described in detail in ESA Bulletin No. 57).

Optical requirements

Two main sets of optical requirements are imposed on the ISO spacecraft. Firstly, there are the light-gathering requirements, which can be summarised as follows:

Entrance-pupil diameter:	600 mm
Focal length:	9000 mm
Unvignetted field of view:	20 arcmin
Instrument unvignetted field of view:	3 arcmin
Wavelength range:	2.5–200 micron
Image quality:	diffraction limit at 5 micron

These requirements are met with a Ritchey-Chrétien Cassegrain telescope configuration, as this is the best solution for an astronomical telescope that must cover a wide spectral range in combination with a limited field of view. This configuration is free from either coma or spherical aberration.

The ISO telescope (Fig. 3) has a primary mirror with an overall diameter of 640 mm, a secondary mirror with a diameter of 87.6 mm, and a four-faced pyramidal mirror that distributes the light collected to the four focal-plane units. The pyramidal mirror has a central hole that allows some of the light to impinge on a quadrant star sensor (QSS). This will allow measurement of the alignment offset between the telescope and the spacecraft's attitude-control sensors.

The lightweight mirrors are made of fused silica and are gold-coated to give them good reflection characteristics in the infrared. The primary mirror is circumferentially mounted onto the optical support structure via three fixation devices, each consisting of an invar pad fixed to the mirror and crossing blades that provide the required degrees of freedom. The secondary mirror is mounted on a tripod. Both mirrors are cooled by copper straps connecting their rear faces to the helium-cooled optical support structure.

The second set of requirements relates to the stringent control of stray light emanating from bright infrared sources outside the telescope's field of view, for which the following viewing constraints have been defined:

- The direction to the Sun must be kept in the plane of symmetry (X,+Z-plane) of the Sun shield, and the solar aspect angle must be between 60° and 120°.
- The directions of the Earth, Moon and Jupiter must be outside cones of 77°, 24° and 5° half angle from the telescope axis, respectively.

With these viewing constraints, the total stray light falling on the instruments must be less than 10% of the diffuse zodiacal background. This requirement is fulfilled by means of the main baffle with sharp-edged vanes surrounding the telescope, Cassegrain baffles around the secondary mirror and the central hole of the primary, and a gold-coated truncated-cone Sun shade that reflects direct illumination from the Earth back to space (Fig. 4).

Moreover, with the temperature distribution described in the previous section, the infra-

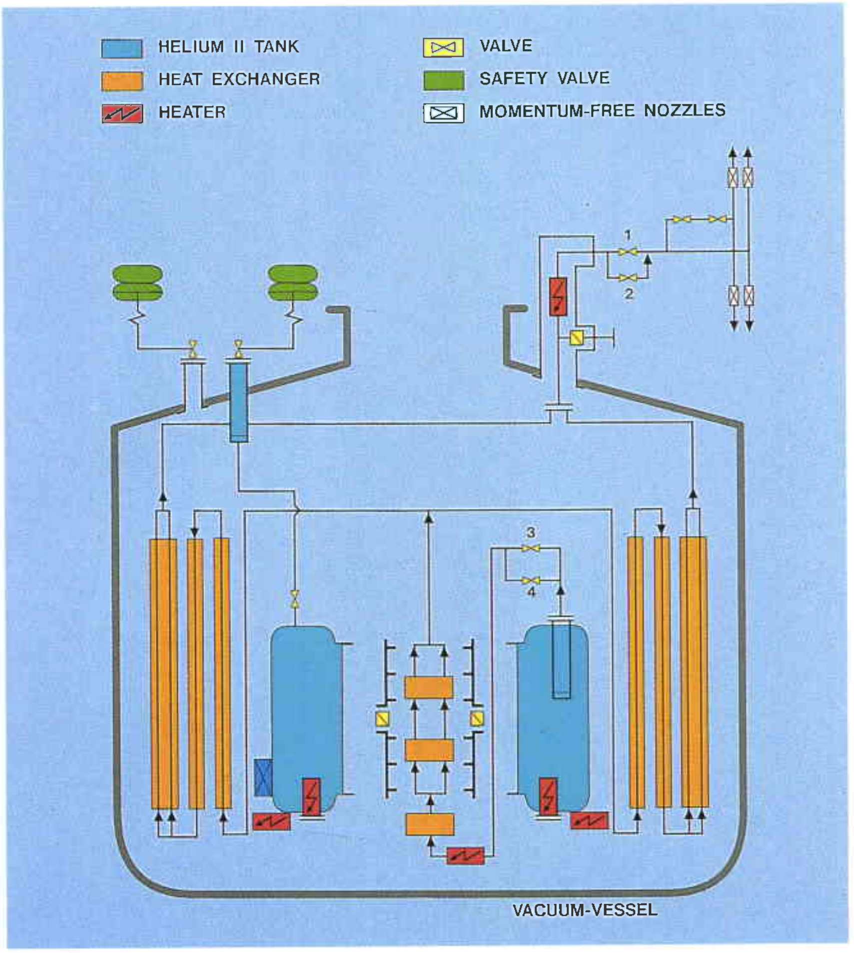


Figure 2. Helium flow diagram for ISO when in orbit.

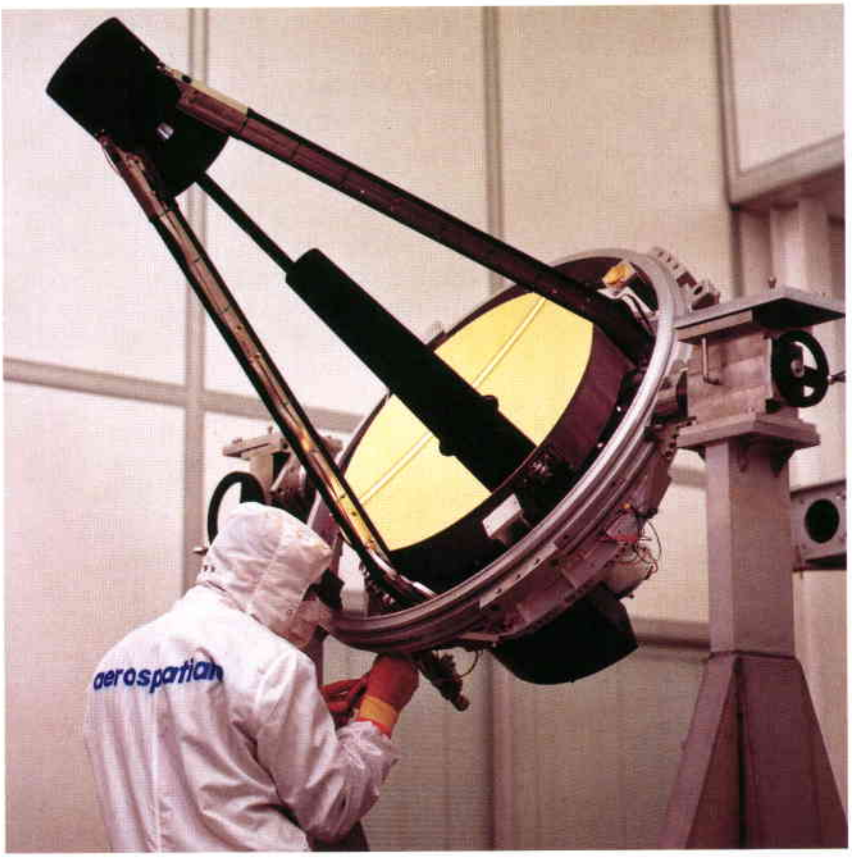


Figure 3. The primary mirror of the ISO telescope.

Figure 4. The ISO Sun shade.

red self-emission of all optical elements gives a noise background that is also less than 10% of the zodiacal background, at wavelengths from 5 to 200 micron.

Pointing requirements

ISO will be operated in a similar manner to a ground-based observatory, and therefore the spacecraft has to be able to manoeuvre smoothly from one celestial source to the next, and then maintain accurate pointing on that target. The spacecraft must also be capable of pointing at any region of the sky that satisfies the straylight constraints described above. The slew speed between sights is set at 7°/min in order to optimise observation time, and the duration of each observation can range from a few seconds to up to 10 h, depending on the type of source.

During a scientific measurement, the following telescope optical-axis pointing accuracy is required:

Absolute pointing error:	11.7 arcsec
Absolute pointing drift:	2.8 arcsec/h
Relative pointing error:	2.8 arcsec

These pointing requirements must be satisfied by the spacecraft's Attitude and Orbit Control Subsystem (AOCS), in combination with careful spacecraft structural design to avoid thermo-elastic deformation between the telescope's optical axis and the attitude sensors. Three operational pointing modes have been defined:

- fine-pointing mode on a single point source

- raster pointing, where the telescope axis is slewed through a rectangular pattern of pointings (up to 32x32 pointings)

- calibration mode, in which any misalignment between the telescope and the spacecraft's attitude sensors is measured.

For the high-accuracy pointing modes, the attitude errors are measured with gyroscopes, star tracker and fine Sun sensors. In the calibration mode (activated once per orbit), the quadrant star sensor replaces the star tracker. The performances of the various sensors are summarised in Table 2.

A state-reconstructor in the AOCS computer produces minimum-variance estimates for the attitude, angular velocity and disturbance acceleration. This state-reconstructor also serves as a sensor-data smoothing filter.

The control torques for high-performance slews and pointing modes are provided by a reaction-control wheel system, giving a maximum torque of 0.2 Nm, with a total of 126 torque levels, and a maximum angular-momentum storage capability of some 18 Nms. A so-called 'dual control law' is used together with a velocity controller that limits angular velocities to 8 deg/min. The 'dual control law' consists of a nonlinear time-optimal subcontroller and a linear state feedback subcontroller. For large errors during slewing the time-optimal control prevails, whereas for fine pointing the linear law predominates.

A schematic of the AOCS is shown in Figure 5. The modes of operation include, besides the pointing modes, other functions related to safety, satellite autonomy, and health checking of the subsystem elements, some of which are addressed below.

An important factor in achieving the requisite pointing accuracy for the ISO spacecraft is the limiting of the drift between the optical axis of the telescope and that of the star tracker. Such drift can be induced by transient thermo-elastic deformation of structural elements linking the two optical axes. Consequently, the star-tracker support structure has been mounted on the cryostat's outer wall, rather than on the Service Module. This alone does not prevent local deformation due to temperature gradients in the cryo vacuum vessel from degrading pointing performance. It is also necessary to maintain a stable and uniform temperature distribution in these two structures.

This temperature stability is achieved by covering the cryo vacuum vessel with multi-layer insulation, even at the expense of a penalty in the lifetime of the satellite. In addition, the star-tracker sensors (two for redundancy) are enclosed within a thermal housing, with heaters, which should provide a constsant sensor temperature and, even more importantly, maintain a constant temperature gradient between the mounting feet of the operational star tracker (better than 0.1°C over one orbit, except for 2 h around perigee). The specially stiffened fixing of the housing to the cryo vacuum vessel ensures that the thermal conductance between the two is less than 3 mW/°C.

Table 2. Performance figures for the various ISO sensors

Star tracker	
Field of view:	4 x 3°
Sensitivity:	Visual magnitude from +2 to +8
Bias error:	2 arcsec (0.5 arcsec in centre of field of view)
Tracking speed:	5 arcsec/s
Gyroscope	
Random drift:	3.6 arcsec/h
Gyro noise:	0.2 arcsec at 2 Hz
Maximum rate:	1 deg/s
Fine Sun sensor	
Field of view per slit:	62 x 1°
Accuracy:	3 arcmin (1 arcmin in centre of field of view)
Noise equivalent angle:	2 arcsec

Single-ground-station safeguards

A further top-level requirement stems from the type of orbit that the ISO spacecraft will be in and the single-ground-station coverage. (In order to retrieve additional good-quality scientific data, ESA is currently seeking international collaboration to provide a

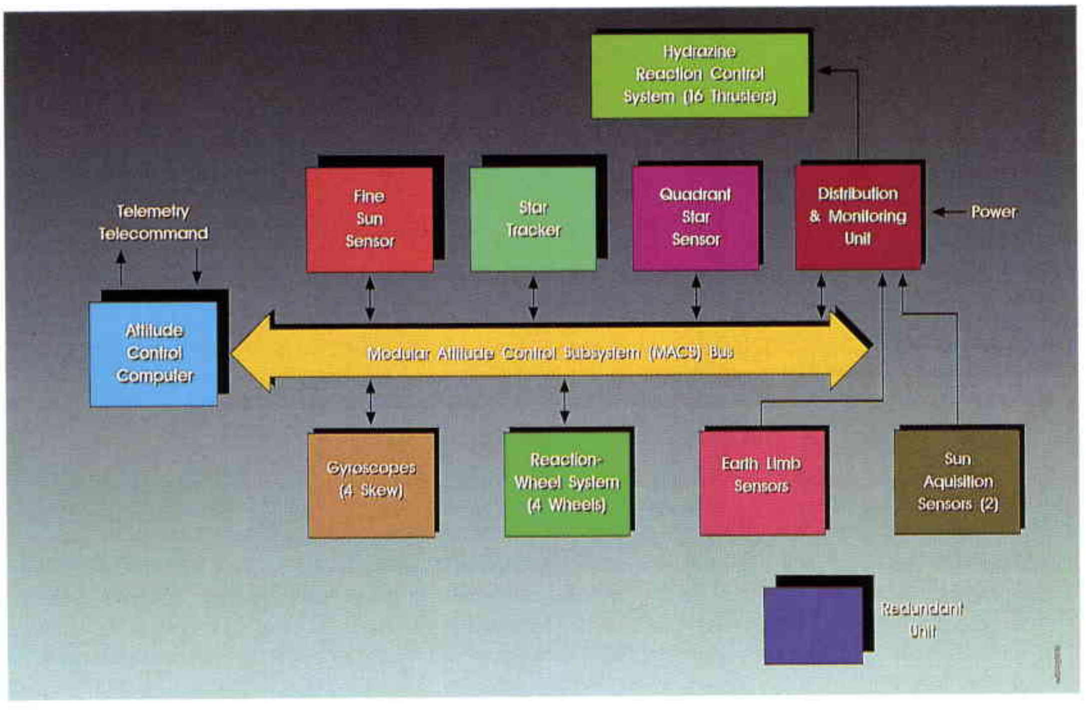


Figure 5. Schematic of ISO's Attitude and Orbit Control Subsystem (AOCS).

second ground station). The highly elliptical 1000 km x 70 000 km orbit makes spacecraft tracking and control impossible during perigee passage.

It is also imperative that the ISO spacecraft should be able to survive a possible failure of the single ground station. The system must therefore ensure that the satellite is safe and that its cryogenic helium is not wasted during any such event. Moreover, even small heat inputs to the optical elements during perigee passages could disturb the telescope's thermal equilibrium.

To meet these mission safety requirements, the launch window selected ensures that there is always a region of the sky to which the spacecraft can point without violating the stray-light constraints (the Sun and the Earth; the Moon and Jupiter do not affect the thermal equilibrium). Autonomous functions onboard the satellite would prevent violation of the constraints for at least three orbits in the event that ground control is lost.

Several souces could trigger these autonomous functions:

- ground command, if the control centre is aware of an imminent station shutdown
- detection by the AOCS of a violation of any of the pointing constraints
- detection by the onboard data-handling system of a longer than normal break in ground transmission to the satellite (period programmable by the Control Centre).

Two main functions are active during the period of autonomy:

- Firstly, the cryostat must be protected against catastrophic heat inputs. The OBDH system will therefore switch-off all electrical units that could dissipate power inside the cryostat, i.e. the four scientific instruments and the cryo electronics unit (used to measure temperatures, pressures and amount of helium in the tank). The AOCS will initiate the first level of attitude safeguard, called the Programmable Pointing Mode (PPM), in which the spacecraft will follow a pre-programmed path on the sky that avoids violation of Sun and Earth constraints. The PPM ensures that the spacecraft's attitude is maintained with sufficient accuracy for observations to be resumed without need for further calibration.
- The second function safeguards the thermal environment of units outside the cryostat. The OBDH will scan the temperatures on the spacecraft and switch on and off the relevant heaters, located on or near critical elements such as the hydrazine tank and pipework, the reaction wheels and the fine Sun sensor.

Electromagnetic compatibility
The very weak output signals from the scientific detectors have to be protected from electronic noise, whether conducted or radiated, originating from other elements of the satellite. A stringent spacecraft design requirement, verified by testing at unit, subsystem and satellite level, ensures full electromagnetic compatibility (EMC) between the onboard instruments and other subsystems.

An important element in this clean EMC design is the spacecraft's power subsystem. It is based on a sequential switching shunt regulator, which provides very good efficiency and reliability as well as a low output impedance and constant bus ripple under all load conditions.

A further requirement is that the spacecraft's external surfaces must not become electrically charged and no electrostatic discharges should take place. Special care has therefore been taken in the design of the thermal-control hardware, which could be susceptible to charging, by making the outside surfaces conductive and grounding all elements to the structure.

Another developmental challenge lay in designing the optical coatings for the baffling system, which have to preclude any electrostatic charging close to the focal-plane units and provide a high absorptivity in the far-infrared. A special conductive black paint has been produced for this purpose.

Data collection and transmission
ISO is a real-time mission. The operating principle involves having a single scientific instrument, selected as a function of the type of observation in hand, active at any given moment. An exception to this philosophy is the ISOCAM instrument, which could be active in parallel at low bit rate to provide images of the celestial source under study.

For this reason, four different data formats – one per instrument – can be selected. Each of these formats also includes all of the satellite housekeeping information, the largest part of which is devoted to the AOCS parameters needed for accurate spacecraft attitude reconstitution.

The nominal data rate is 32 768 bit/s, 23 424 bit of which are allocated to the prime instrument. Communications with the ground are via a transponder working at S-band.

Other special features of ISO

Heat balance of the Payload Module

As noted above, heat inputs to the helium tank have been minimised by enclosing it with vapour-cooled shields that intercept ambient heat before it can reach the cryogenics. Another important source of heat is the Service Module, the average temperature of which will be 20°C when the Payload Module's outer wall is at −150°C.

To avoid such a temperature gradient causing a net conductive heat transfer to the vessel, the interface between the two Modules consists of 16 tubular glass-fibre struts with very low thermal conductivity. They are filled with Ecofoam resin to prevent radiative heat transfer from taking place inside the tubes. The development programme for these struts has included extensive mechanical and thermal validation testing.

Direct liquid-content measurement

An important factor for the planning of ISO's scientific operations is accurate knowledge of the amount of superfluid helium (HeII) remaining in the tank. The ability to make this measurement under microgravity conditions is a novel development for ISO, which relies on the near-infinite thermal conductivity of the superfluid helium. A calibrated heat pulse is introduced into the tank, which increases the temperature of the helium by an amount directly proportional to the mass remaining.

Launch operations

An important aspect of the Payload Module is the cryogenic operations required prior to launch. The superfluid-helium tank will be topped off when the satellite is already mounted on the launcher, by removing the Ariane fairing (a nonstandard operation). The tank will then be closed to minimise helium loss and to avoid having to pump. To maintain the insulation performance after this operation, a second reservoir containing 60 l of normal liquid helium (HeI) will be used to cool the radiation shields. This HeI tank, which can be accessed through windows in the Ariane fairing, will be completely depleted prior to lift-off.

During the launcher's third-stage flight, commands issued by Ariane's electronics will operate a set of cryogenic valves that will open the helium vent line to space, and also the main helium tank and its porous-plug phase separator. Initially, the vented helium mass flow rate will be about 20 mg/s, rising to a peak of about 27 mg/s and then falling until, after about 20 d in orbit, it will be about 5 mg/s, the in-orbit equilibrium point.

To cope with this range of flow rates, the system is equipped with two sets of nozzles. Initially, both will be open to accommodate the high mass flow rate: as the rate falls and the temperatures decrease, the larger nozzles will be valved off, leaving only the smaller set open.

Figure 6. ISO Payload Module under test at MBB, Munich.

Current development status

The ISO spacecraft's main development phase (Phase-C/D) is already well advanced. The qualification tests performed on the Payload and Service Modules (Fig. 6), and the results obtained, are summarised in Figure 7.

The qualification of the Payload Module has been a challenging task, involving more laboratory experimental effort than a classical qualification procedure, and requiring inventive solutions to overcome unforeseen problems. Operation of the cryostat was

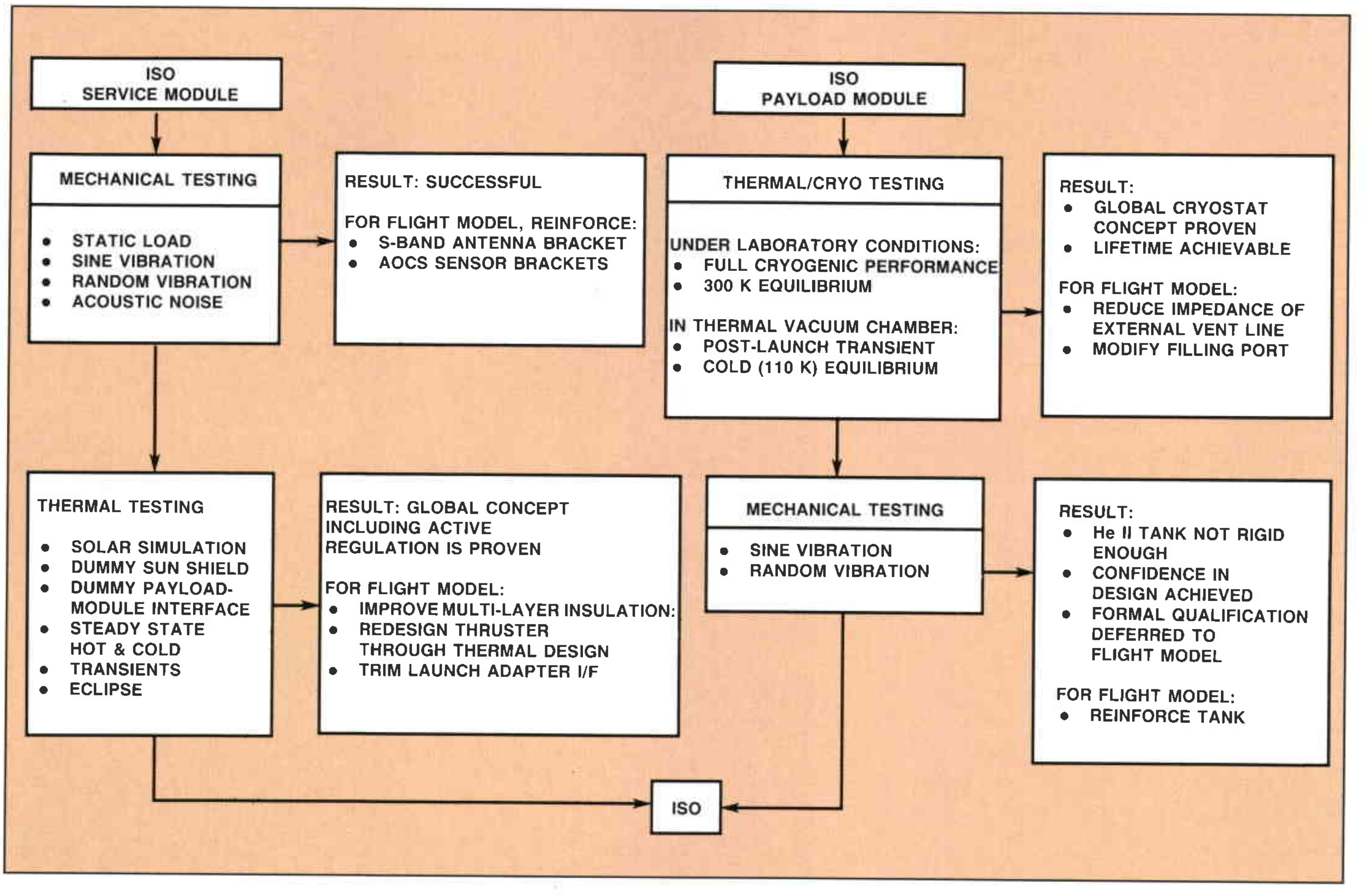


Figure 7. ISO Payload and Service Module qualification-test objectives and results.

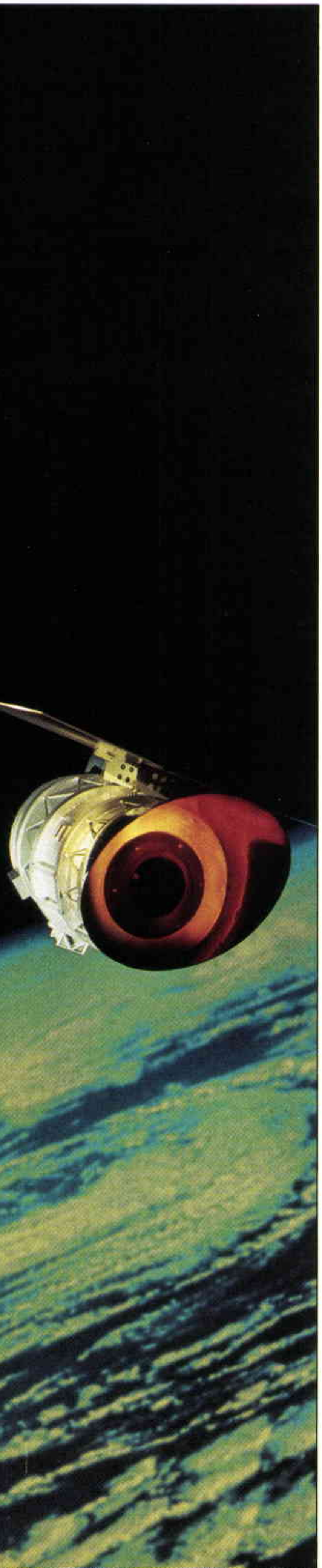
demonstrated first at room temperature and later in a vacuum chamber that simulated the in-orbit environment. The cryo tests showed that some elements of the external vent line, which showed too high a pressure drop, needed modification, as did the helium filling port, to preclude unwanted heat transport.

The telescope has followed its own qualification programme, and a special facility was developed to test it optically at cryogenic temperatures. These tests have demonstrated the correct behaviour of the optics, in terms of both image quality and alignment of the mirrors and scientific-instrument focal-plane units. The telescope has now been mounted on the Payload Module structural model, and will be mechanically qualified at cryogenic temperatures (a warm qualification has already been performed).

In parallel with the thermal/structural qualification of the Service Module, the spacecraft's electrical subsystem has been in development. All breadboarding has been completed and production of the qualification units is close to completion. Integration of the flight Service Module structure is under way, and the first electronics units will be mounted on the structure this summer. This process, including initial checkout of the units, will continue until the end of the year, when the integrated module test will start.

The ISO flight model, after mating of the Payload Module, Service Module and Sun shield, will undergo a series of electrical integrated system tests, including validation of the interfaces with the ground segment. It will be mechanically accepted after vibration and acoustic tests, and finally it will be subjected to thermal-vacuum and solar-simulation testing in the Large Space Simulator facility at ESTEC, in Noordwijk (NL).

The ISO spacecraft will leave ESTEC in 1993 en route to its Ariane launch.



Reading ISO's Scientific Instruments

H. Eggel & H.P. Schaap
ISO Project Team, ESA Directorate for Scientific Programmes,
ESTEC, Noordwijk, The Netherlands

In order to work satisfactorily, an infrared detection system must be physically colder than the objects it needs to observe. Some of the objects to be observed by the Agency's Infrared Space Observatory (ISO) might be as cold as a few tens of degrees Kelvin. It is therefore essential that ISO's detectors should themselves operate at temperatures close to absolute zero. To avoid problems with electromagnetic interference, it is also necessary that detector read-out (i.e. first-stage signal amplification) take place as close as possible to the detectors. As conventional amplifiers cannot work at temperatures close to absolute zero, special techniques have had to be used for ISO's detectors.

Introduction

Four scientific instruments make up the payload of the ISO satellite*. The techniques used for their read-out can basically be divided into two groups. One group uses single-element detectors, each connected to an integrating amplifier. For the group of linear or two-dimensional detector arrays, multiplexers are included in the design, thereby reducing the numbers of amplifiers and wires needed, but requiring more sophisticated read-out electronics.

The read-out electronics have to match the very high infrared-detector resistances of up to 1016 Ohms, to harness resistances of some 500 Ohms and the data-processing unit's input circuit. Figure 1 shows, in a simplified way, how this has been achieved.

Through various optics, both internal and external to the instrument, the detector receives infrared light, which it converts into a current. A so-called 'integrating amplifier' converts this current into a charge in a capacitor. After a certain time, this capacitor becomes fully charged and if no action were taken the circuit would be inoperable. The charge is therefore removed at regular intervals by temporary closure of a switch (Reset). The time between two resets is the so-called 'integration time'. Depending on the amount of current, which is a function of the amount of infrared radiation, the rate of charge varies. By measuring this charge rate, one can determine the level of radiation.

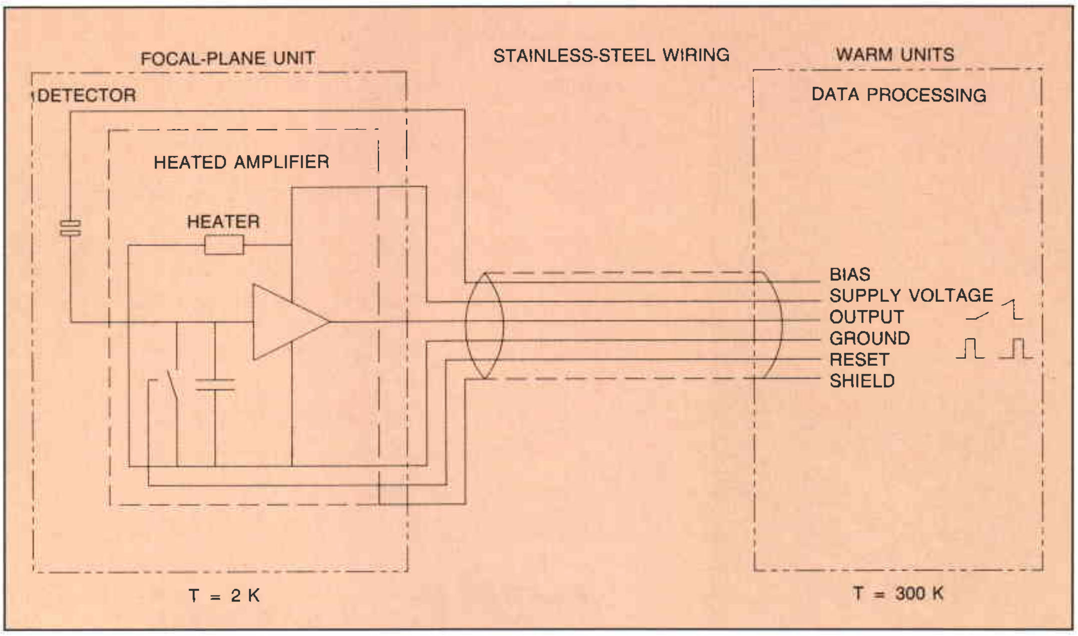


Figure 1. Single-element read-out

* See ESA Bulletin No. 61, pp. 20–27.

Single-element read-out

Because the read-out electronics' junction field effect transistor (JFET) cannot operate at temperatures of 2 K, it is 'heated' to approximately 60 K by dissipating electrical power (150 microwatts) in a resistor that is thermally coupled to the amplifier. The amplifier and its heater are thermally isolated from the housing to avoid heating the infrared detectors.

There are two versions of the amplifier: a single amplifier in a metal case with wires attached for its connection (Fig. 2), and a version in which 12 of these amplifiers have been integrated onto one substrate, with a single heater to maintain them at the required temperature.

Figure 2. Heated integrating amplifier

Multiplexed-detector read-out

The use of heated amplifiers becomes impractical for the read-out of large numbers of detector elements such as a linear array of 64 pixels for spectroscopy, and even more so for a two-dimensional array of 32x32 pixels for imaging. Amplifiers and analogue multiplexers using MOS (Metal-Oxide Semiconductor) technology have been developed for this purpose. These devices can operate at the same low temperature as the infrared detectors (2–4 K).

The readout for a 32x32 element indium-antimonide detector array is shown in Figure 3. Each detector pixel is connected to the input of a voltage follower in rows of 32 pixels, which are scanned column by column. Reset switches start and stop the integration in the same way as for the single-element detector. A pre-amplifier for the 32 row outputs is located at the outer wall of the cryostat vacuum vessel. A total of 50 wires are needed to read-out the 1024 pixels (32 outputs, plus clocks and bias and supply lines).

Figure 4 shows the implementation of the read-out electronics. The detector array is shown in the centre of the substrate (marked SC3I). Above and below it are row hybrids for 16 channels each, and to the left of it the column scanner hybrid where the harness to the pre-amplifier is also connected.

A further reduction in size has been achieved for the 32x32 silicon detector array (Fig. 5), which is located directly on top of the complete read-out chip (6 mmx6 mm). Each of the detector pixels is joined to the read-out circuit by tiny indium spheres.

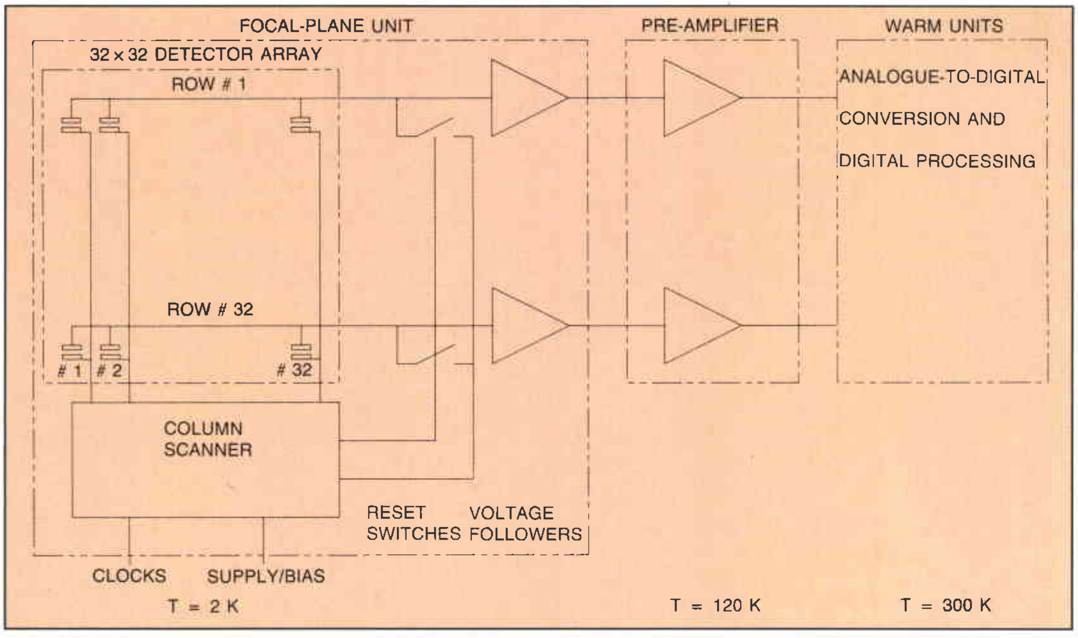


Figure 3. Multiplexed detector read-out

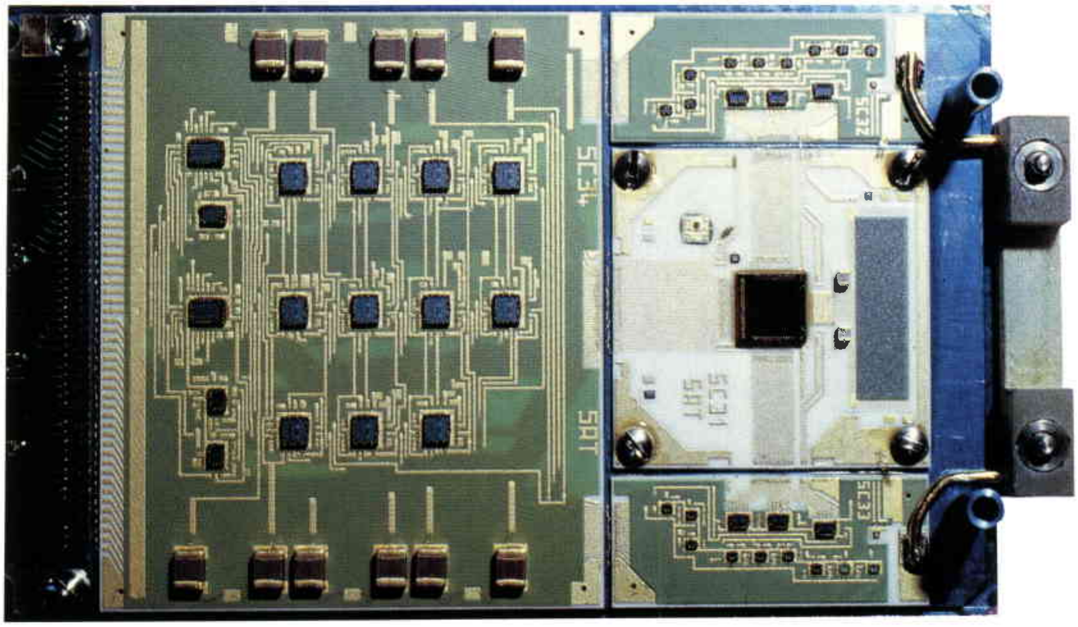


Figure 4. Read-out electronics for a two-dimensional array

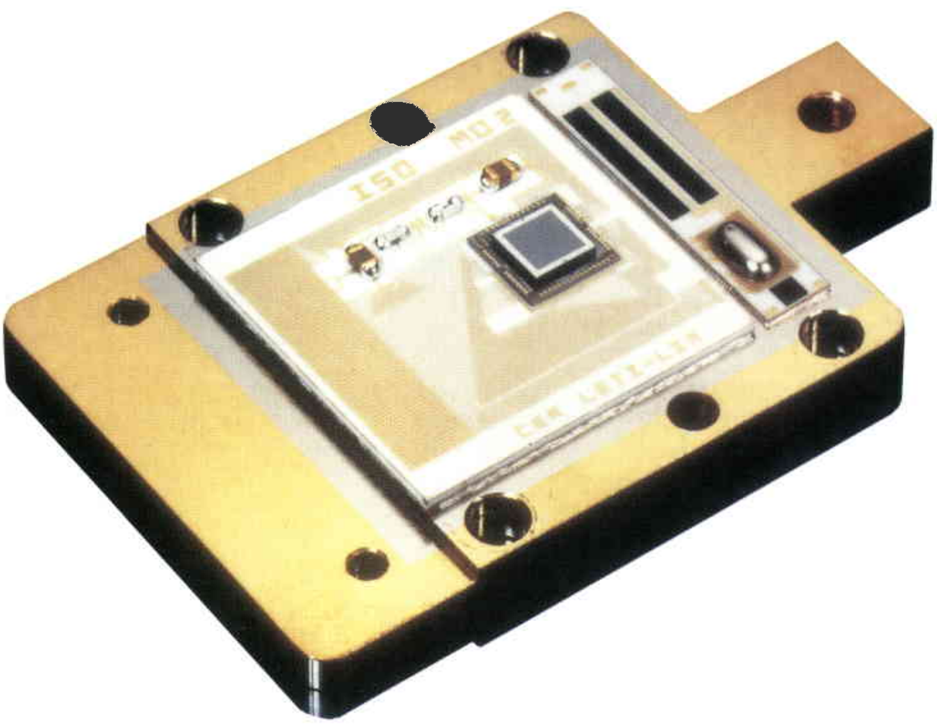


Figure 5. Monolithic read-out chip for a two-dimensional array

The power dissipation for the array's read-out is kept below 10 mW, including the detector.

Conclusion

Despite the harsh constraints imposed by the need for a low power dissipation and the stringent environmental factors of extremely low operating temperature, launch survival, and freedom from electromagnetic interference, the infrared detectors carried by the ISO scientific satellite should be able to perform at the very limits of their sensitivity, thanks to the development effort that has been invested in the supporting read-out technologies.

Acknowledgements

The electronic devices that have been described are produced by the following companies:

- Heated Integrating Amplifiers: Infrared Laboratories, Tucson, Arizona.
- 32x32 Array Read-out: Societe Anonyme des Telecommunications (SAT), Paris, and Laboratoire d'Electronique et des Techniques de l'Informatique (LETI–LIR), Grenoble, France.
- Linear-Array Readout: Inter-Universitair Micro-Electronica Centrum (IMEC), Leuven, Belgium.

Coordinated Parts Procurement for ISO — A Contribution to Cost-Effectiveness

M. von Hoegen
ISO Project Division, ESA Directorate for Scientific Programmes, ESTEC, Noordwijk, The Netherlands

J. Minnee
Product Assurance and Safety Department, ESTEC, Noordwijk, The Netherlands

F.J. Ziegler
ISO Parts Procurement Manager, Product Assurance Department, MBB/Deutsche Aerospace, Munich, Germany

The procurement of high-reliability electronic components for the Agency's ISO scientific satellite has been centrally coordinated for all users. The many benefits that have been derived from this approach have included previously unidentified opportunities for the rationalisation of parts types, a greater degree of flexibility, and improved management control. The end result has been a measurable step forward in overall cost-effectiveness.

Introduction

The procurement of high-reliability electronic parts is an important activity in any satellite development project, which usually involves a large number of electrical subsystem contractors, all of whom must acquire these so-called 'hi-rel' parts. The lead times for these components are often as long as 12 to 18 months, which means that they can drive the project schedule because components cannot be ordered until the design is complete but are needed soon thereafter, before assembly of the electronic units.

A satellite typically contains several hundred thousand individual components of several hundred different types, all of which are subject to strict quality control. The combination of these very large numbers of parts, long lead times and strict requirements call for an effective organisation, special precautions, and tight controls to ensure that the overall project schedule is not jeopardised.

The ISO satellite is an observatory-type mission that will be accessible to the astronomical community at large. The scientific instruments provided by the ISO Principal Investigators (PIs) with national funding are therefore also general-purpose astronomical facilities, which are also required to use hi-rel parts. These PIs have also chosen to procure their parts via the centralised procurement organisation established by the Agency for the spacecraft.

All ISO electronic units are to be delivered in two models, known as the 'flight' and 'flight-spare' models, the latter being the qualification model refurbished as necessary. The qualification model therefore also has to be built with hi-rel electronic components, which must be delivered early in the project.

The ISO project has 20 users of hi-rel electronic components, who together need more than 220 000 parts of more than 300 types originating from some 70 different suppliers. Many of these parts are subject to special requirements, such as a high resistance to electron and proton radiation because ISO will pass through the Earth's radiation belts once per day during its 18 month mission lifetime.

In order to maintain the ISO project schedule, it was necessary to establish the parts-procurement scheme and to select the parts-procurement agent during the satellite definition phase (Phase-B). Most parts also had to be ordered before the detailed designs for the electronic units were totally complete. A further complication was introduced by the fact that some electrical-subsystem contractors could only be selected much later, at the start of the project's main development phase (Phase-C/D). This meant that precautionary measures had to be taken that would permit components to be changed with minimum or no cancellation charge when the detailed design was complete.

Chosen procurement approach

A centrally coordinated parts-procurement scheme was chosen for ISO as it held the most promise of being flexible and cost-effective, whilst at the same time permitting good coordination and control for all parties concerned, i.e. the parts users, the parts procurement agents and their suppliers, the satellite prime contractor and ESA. A competitive tender action led to the selection of MBB (Munich) as the Parts Procurement Agent, with Tecnologica (Madrid) as its subcontractor.

The main features of the procurement approach selected are:

- All technical and programmatic aspects are centrally coordinated by the Prime Contractor.
- An ISO Parts Coordination Board (IPCB) is established in the pre-procurement phase as an advisory board to the Prime Contractor, to familiarise parts users with all aspects of parts procurement, including selection of parts types, preferred manufacturers, etc., and to alert users to more general parts problems, including export licenses and delivery problems.
- The Prime Contractor, Procurement Agent and ESA are responsible for all common tasks, e.g. management, parts qualification and negotiation with parts users and suppliers.
- Users order parts directly from the Procurement Agent and are invoiced for recurring costs, thereby ensuring that care is taken in defining orders.
- Non-recurring parts costs and Procurement-Agent surcharge costs are paid by ESA, which recharges the Principal Investigators with their share.

Procurement organisation

The ISO Parts Procurement Organisation is summarised in Figures 1 and 2. It has two features that are not typical of such structures:

- The Principal Investigators (PIs) were represented on the IPCB Advisory Board and a formal agreement was made between the PIs and ESA which permitted them to buy parts through the Procurement Agent.
- The IPCB consisted of members of each major parts user and representatives from the Prime Contractor, the Procurement Agent and ESA. One PI representative coordinated the requirements for all scientific instruments.

The IPCB served as an advisory board to Aerospatiale, the Prime Contractor, in order to unify parts selection, perform type reduction, standardise on component package configurations, advise on manufacturers known for high quality and reliable delivery, address all problematic issues, and propose alternatives for consideration by all ISO users. This board was set up only for the pre-

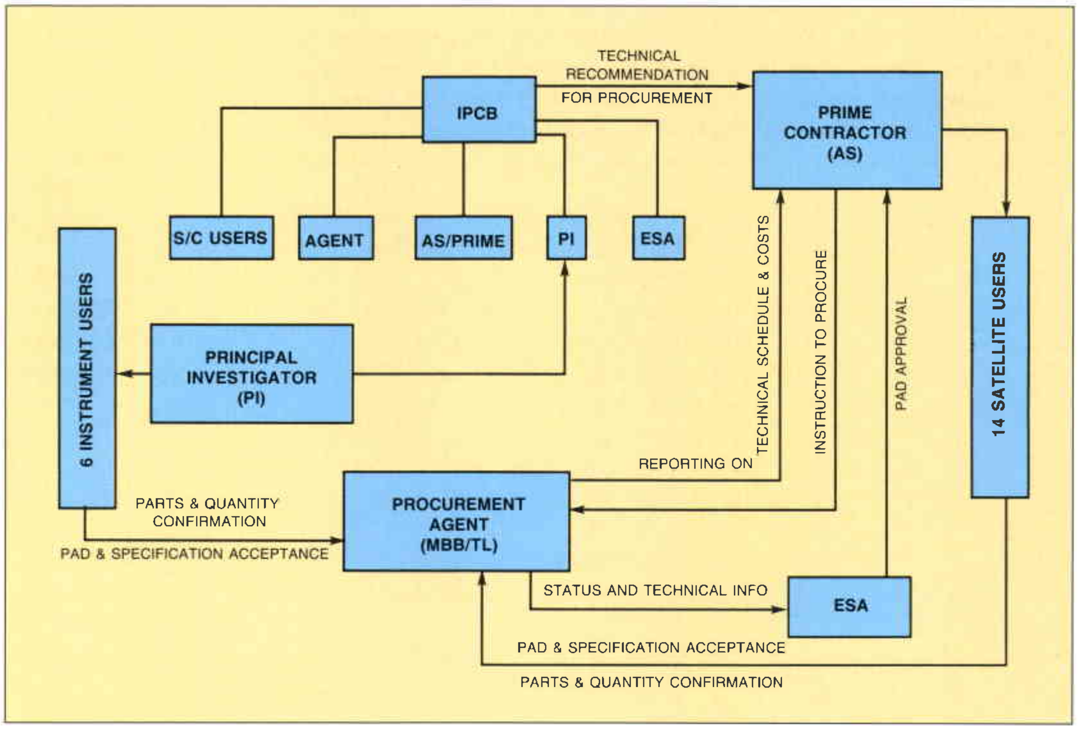


Figure 1. ISO parts procurement organisation: Pre-procurement phase

procurement phase, during which a number of meetings were held with all of the users. During the actual procurement phase, all issues were dealt with by the Prime Contractor, the Procurement Agent, and ESA (Fig. 2). This approach proved to have sufficient flexibility to cope with newly occurring parts/manufacturer or user difficulties.

One of the IPCB's major tasks was to reduce the number of parts types requested by the many users. Two successive coordination exercises reduced that number from an initial 500 to 350, representing a significant saving in overall procurement effort (Table 1).

Table 1. — ISO procurement statistics

Parts users, including Principal Investigators	20
Parts manufacturers (Europe, USA + Japan)	72
Quantities (two satellite models)	222 080
Line items	2249
Parts types	352
SCC specifications used	225
Newly written specifications	69
Parts evaluation	16
Radiation (characterisation, latch-up + lot acceptance tests)	180
Precap inspections	467
Destructive physical analyses	294
Lot acceptance tests	128
Manufacturing lots	2290
Purchase orders	491
Lot rejections (at manufacturer)	39
Changes (types, quantities, values, etc.)	7703

Schedule
The major ISO schedule milestones at the beginning of the project (Fig. 3) were as follows:

- Phase-B (design phase) kick-off — End 1986
- Phase-C/D (main development phase) kick-off — March 1988
- Start of subsystem manufacture (QM) — Feb.-July 1989
- Start of procurement (pre-procurement) — Nov. 1987

Given this schedule, and more specifically the dates quoted by the subsystem contractors as 'parts need dates', it was clear that it would be difficult or almost impossible to reconcile manufacturer lead times and delivery dates based on that initial schedule. Consequently, several corrective actions had to be implemented:

— During the type-reduction exercise, specifically those part types with very long lead times were proposed to be eliminated and replaced by similar units that would be available more quickly.
— Advance orders were placed although the design was not yet frozen.
— Radiation characterisation tests for microprocessors were performed by ESTEC during the Phase-B, before the procurement agent was selected.
— User parts need dates were reviewed and negotiated, and the planned integration sequences for different spacecraft units were optimised taking the parts delivery and subsequent spacecraft unit delivery constraints into account. The result was a final list of parts need dates that was acceptable to all users (Fig. 3).

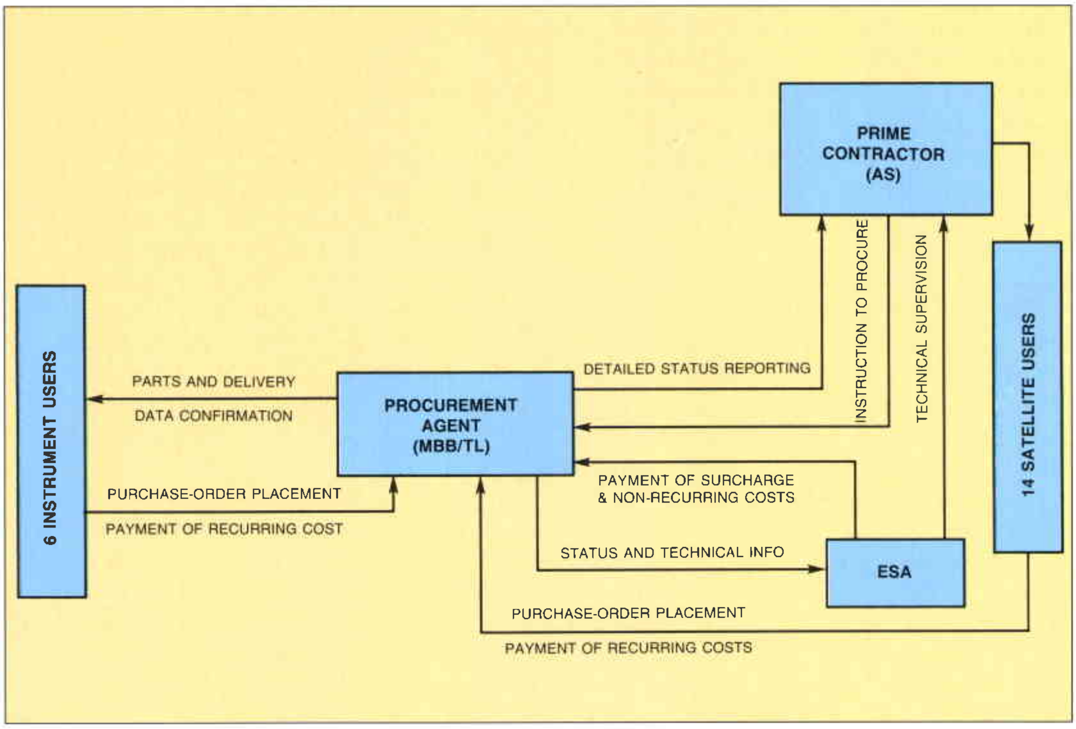


Figure 2. ISO parts procurement organisation: Procurement phase

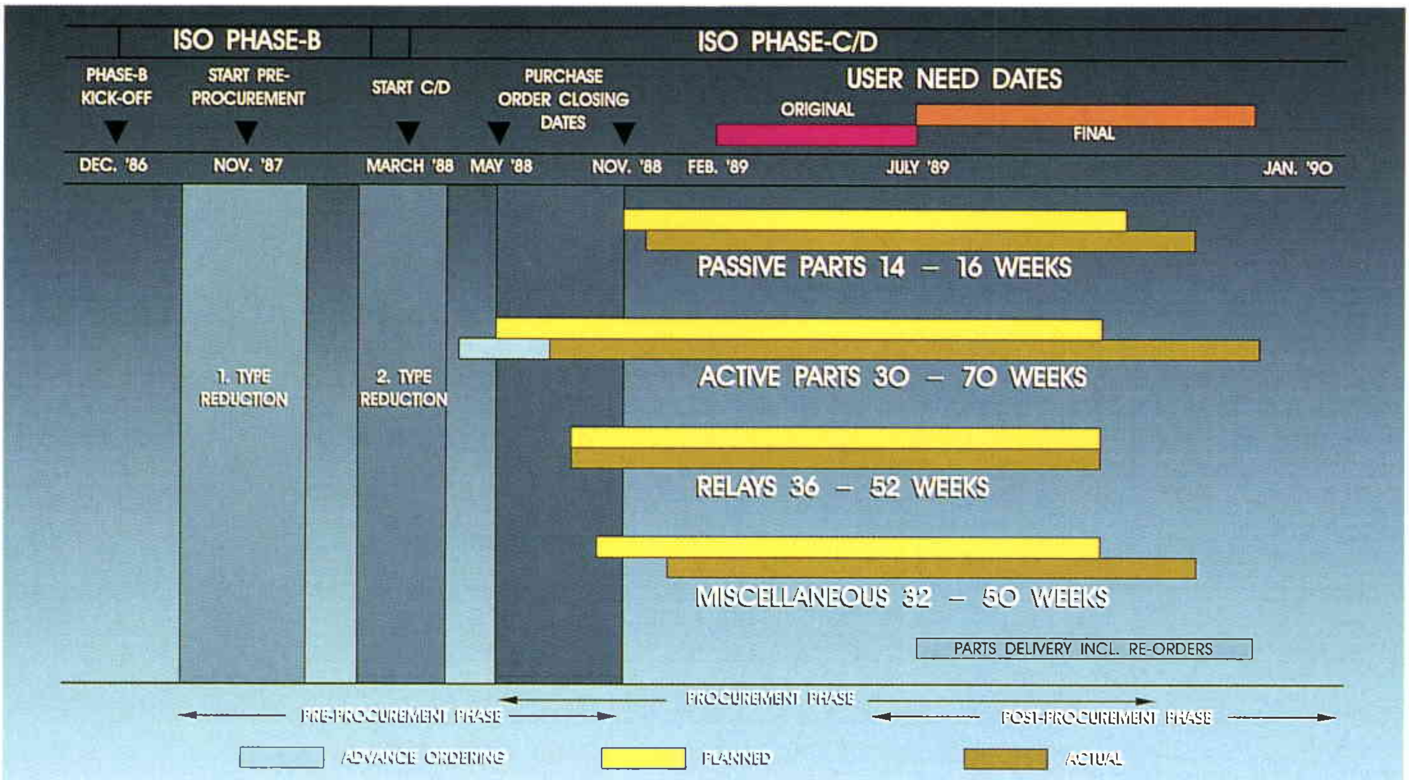


Figure 3. ISO procurement milestones

As already mentioned, procurement had to start while the final users were still being selected, and in some cases users had to give their 'best estimates' of what components types and quantities would be needed. This resulted in a relative large number of changes (some 4600 in total) in terms of part types, part characteristics and quantities in the period between April and December 1988.

At the time when the parts users were finalising their designs for the ISO systems/subsystems, additional changes (approx. 2200) were required to be introduced into the procurement programme, which by then was running at full speed. As a result, some parts that had already been ordered with the manufacturer were no longer needed, and some additional parts had to be newly ordered.

It was possible, however, to cope with many of these late changes in the ISO Programme by re-using the then surplus components originally ordered, thereby allowing many cost and programmatic impacts of these late changes to be reduced or even eliminated. Each of the changes was scrutinised using a special configuration-control feature in the Procurement Agent's computerised procurement program, which included changes in quantity, types, characteristics, costs and schedule.

Some 21 issues of these computerised lists were distributed to the Prime Contractor and ESA, and special issues relating to each user were distributed to the user concerned for review and information.

Component engineering aspects

All components were selected to comply with ESA PSS-01-60, 'Component Selection, Procurement and Control Requirements' and existing ESA standard parts (SCC) specifications, and to make maximum use of European suppliers. Some 70 new parts specifications had to be written in the standard SCC format and were approved specifically for ISO.

One of the most important activities of a parts-procurement programme is the part-type-reduction exercise. This activity requires not only detailed knowledge of the qualified components, their similarity and related components manufacturer performance, but also knowledge about the typical usage of a component in the design. As already mentioned, the Procurement Agent's final reduction of the number of types to be used in the ISO Programme from some 500 to 350 resulted in a major economic benefit.

An additional reason for pursuing part type reduction was the need for radiation-resistant components to cope with ISO's intended orbit. A number of component types were eliminated either because a radiation-resistant version was not available, or because difficulties were expected in obtaining export licences from the USA.

The radiation requirements for ISO's components were derived assuming an omnidirectional shielding of 4 mm of aluminium or its equivalent, multiplied by a safety factor of 2. The radiation hardness of components had to be better than 50 krad. In addition, heavy-ion-induced single-event-upset and latch-up testing had to be introduced into the parts selection and testing programme. In cases where no radiation data were available, special radiation characterisation tests had to be performed prior to procurement to assess the suitability of the component's design and technology for the ISO mission. A total of 27 characterisation tests and 147 radiation lot acceptance tests were performed in this context.

In order to define all the procurement requirements for each individual part type, so-called 'Parts Approval Documents' (PADs) were issued, identifying:
— specification to be used
— manufacturer, including a backup, to be used
— lot acceptance programme/level required
— radiation characterisation testing
— radiation lot acceptance testing
— quality level for procurement

and many other specific details. A total of about 600 of these PADs were approved by the Prime Contractor and ESA.

Parts for the scientific instruments
Because of the observatory nature of ISO, the scientific instruments were required to be built with hi-rel electronic components just like all the other satellite subsystems. The Principal Investigators were therefore encouraged to order their hi-rel parts through the ISO Procurement Agent also, thereby benefitting from the cost savings and improved control offered by the centrally coordinated system.

The choice of microprocessor type was one area where problems were encountered. While the space electronics industry follows the ESA guideline in using MIL-STD-1750 type microprocessors, the scientific community has more experience with the microprocessors used in personal computers. Although it was concluded that the 80c86-type microprocessor was the most suitable for the scientific instruments, there was no guarantee that the radiation-hardened version could be exported from the United States.

A subsequent extensive radiation test programme at ESTEC concluded that the standard 80c86 family of components could be used for ISO provided:
— no electrical bias is applied to these components
— the electrical design has so-called 'cold redundancy', i.e. redundant circuits are switched off when the main circuit is operating
— these components have an extra 7 micron-thick epitaxial layer to greatly reduce the risk of latch-up due to heavy-ion impacts (the manufacturer agreed to produce the components with the required epitaxial layer).

Costs
The ISO coordinated parts procurement, involving 20 users, resulted in:
— Many users of common parts types.
— Large quantities of individual part types being employed, which:
  — reduced part unit (recurring) costs
  — increased sharing of lot-related (non-recurring) costs
  — reduction of 'minimum-buy' costs.

While initially non-recurring costs for low-quantity active parts could amount to more than 150% of the recurring costs, the standardisation effort and the grouping of many users of the same part type have resulted in the non-recurring costs being reduced to less than 45% of the recurring costs. Many users, specifically the Principal Investigators, were able to reduce their recurring costs to less than 30%, because they adapted their designs to use the maximum number of qualified parts that were also needed by other users.

Procurement-Agent engineering and management costs
The main activities of the Procurement Agent are listed in Table 2.

Table 2. Main responsibilities of the Procurement Agent

— Management of all procurement activities
— Performing cost and schedule control
— Reporting on progress, problems, costs and schedule
— Consolidating user parts lists into a common computerised procurement list and proposing alternative/standardised parts
— Performing configuration control of all changes to user parts list and associated purchase orders
— Establishing procurement specifications in SCC format
— Negotiating specifications and providing quotations
— Proposing type-reduction/standardisation and replacement of parts
— Performing radiation-characterisation tests
— Establishing parts-evaluation plans and performing evaluation
— Preparing parts-approval documents
— Consolidating user purchase orders and placing orders with manufacturers
— Performing inspection of component pre-encapsulation
— Performing source inspection/acceptance tests
— Performing receiving inspection and destructive physical analysis
— Dispatching parts to users.

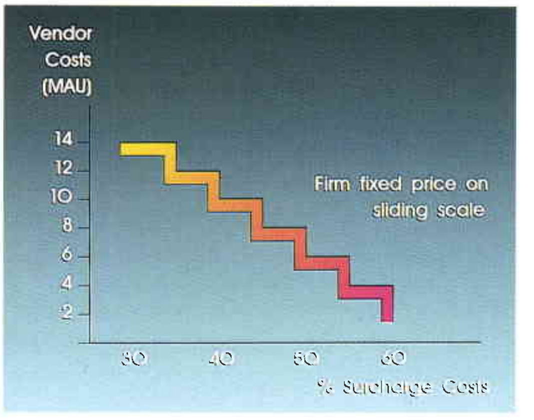


Figure 4. Procurement Agent's formula for surcharge as a function of parts manufacturer (vendor) cost

All of these activities, which are covered by surcharge costs, generally depend on the number of types of components to be procured and vary according to the quantity of parts involved and whether those parts are 'active' or 'passive' components. To cover these costs, the Procurement Agent is requested to propose a formula expressing his surcharge as a function of the parts manufacturer (vendor) cost. This formula is fixed for the total procurement activity for the project (Fig. 4).

The advantage of this arrangement is that the total procurement cost is a simple pre-defined function of vendor costs. The Procurement Agent, satellite Prime Contractor and ESA have to cooperate closely and exercise tight control to ensure minimum vendor prices during negotiations with parts manufacturers.

Cost considerations and programmatic aspects

Although one might believe at the beginning of a project that one has selected the most cost-effective procurement system, one does not know whether this is true until the chosen approach has been implemented and compared with other systems using the same database. For ISO, we have compared the following two cases:

1. Spacecraft users and PI users are all coordinated, as for the ISO project procurement.

2. All users procure individually, with no procurement coordination.

Figure 5 shows the ISO parts vendor costs compared with the same parts types and quantities if procured by each of the 20 users acting individually (recurring & non-recurring costs). Figure 6 shows the total cost when adding the surcharge to the parts costs of Figure 5. Clearly, full procurement coordination for all users leads to a much lower overall cost. The total parts cost would be some 80% higher if all users were to procure their parts individually. The 80% is an average, in that in the case of ISO the 20 individual users would have incurred between 50% and 100% higher costs if they had not joined the central coordinated procurement scheme.

Type reduction and cost benefits

There are many reasons why a drastic reduction in parts types is necessary, including:

— reliability aspects
— vendor-related cost aspects
— procurement-effort-related cost aspects
— risk aspects.

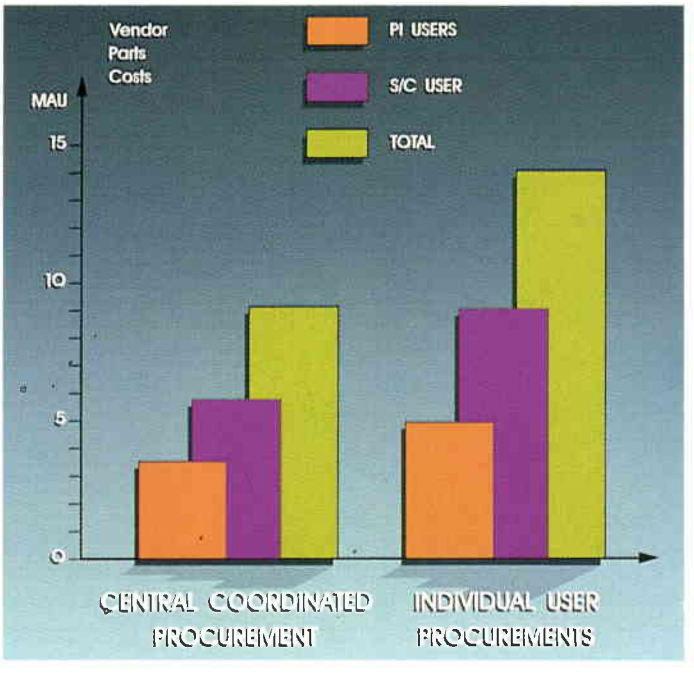


Figure 5. Comparison of centrally coordinated and individually organised parts procurement: Parts costs only

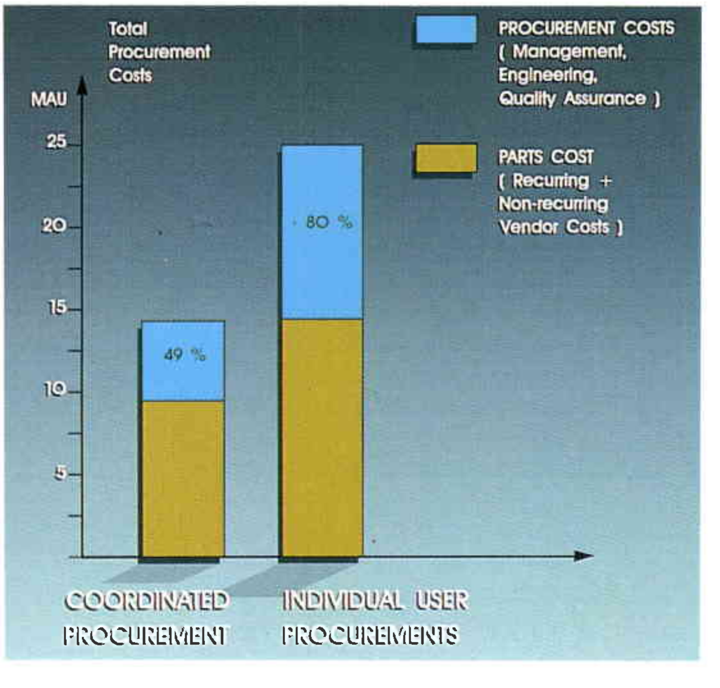
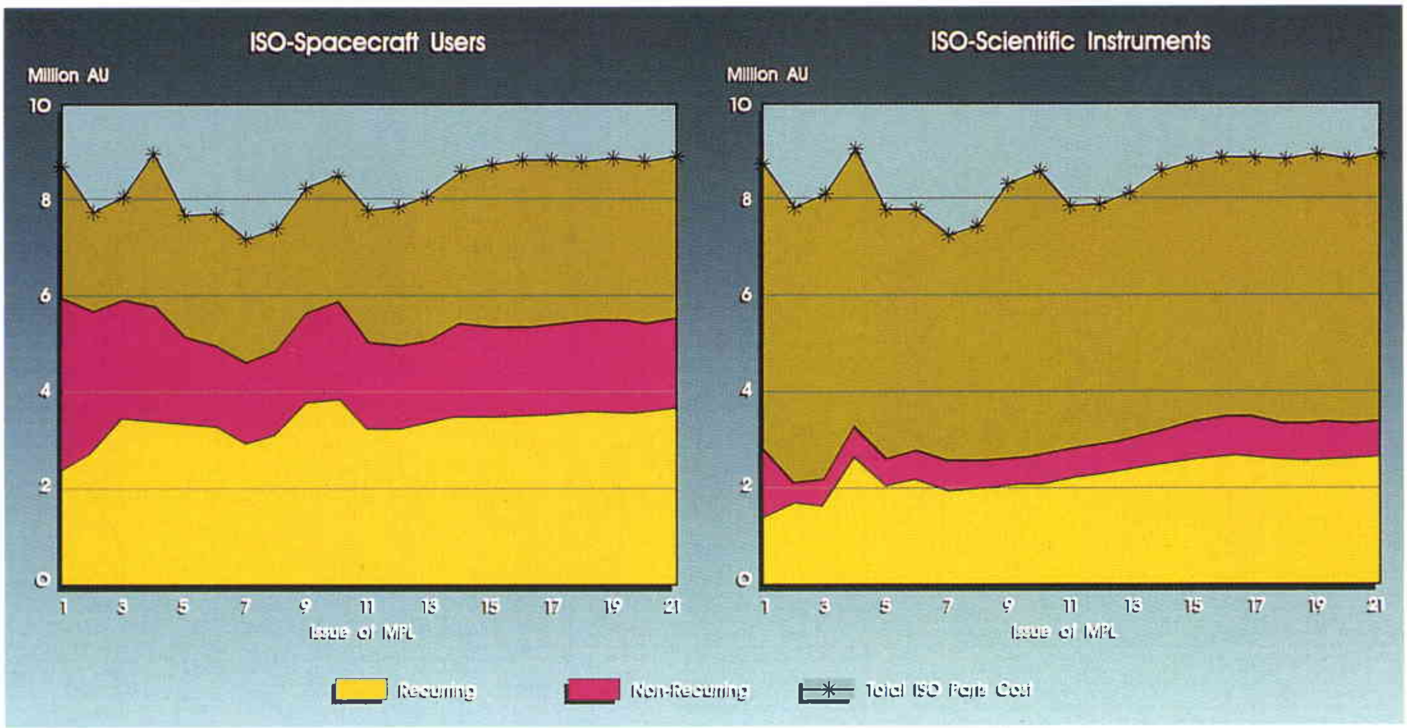


Figure 6. Comparison of centrally coordinated and individually individually organised parts procurement: Total procurement costs



Figures 7–9. ISO vendor costs for various users

In Figures 7a,b the relationship between vendor cost-related aspects and a reduced number of types is shown for the recurring versus non-recurring costs. A coordinated procurement implies that it is preferable to have as many users as possible for one part type. This in turn means that the quantity needed of this particular part type is automatically increased. The so-called 'minimum buy' costs are thereby reduced or eliminated, and the part's unit cost (recurring) is reduced depending on the quantities being ordered.

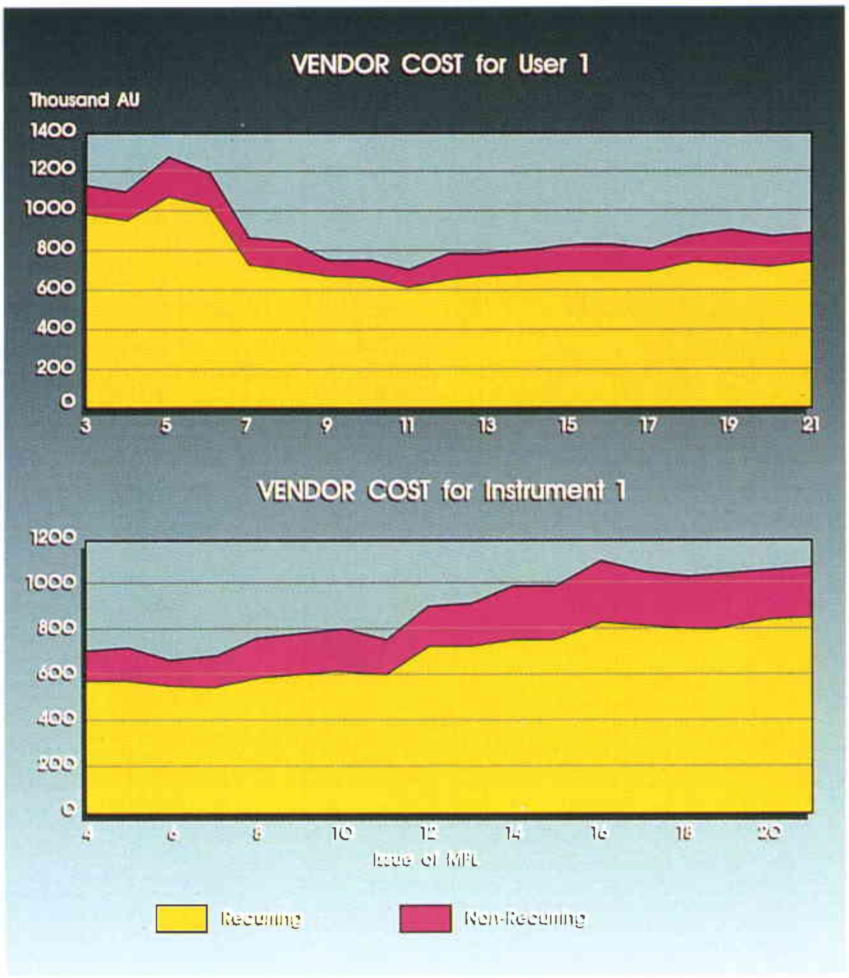
In addition, the lot-related costs (non-recurring) are shared among the number of users requiring a particular part type. After having performed a good part-type reduction exercise therefore, the ratio of non-recurring to recurring costs per user should be in the order of 15 to 30%, which is demonstrated in Figures 8a,b.

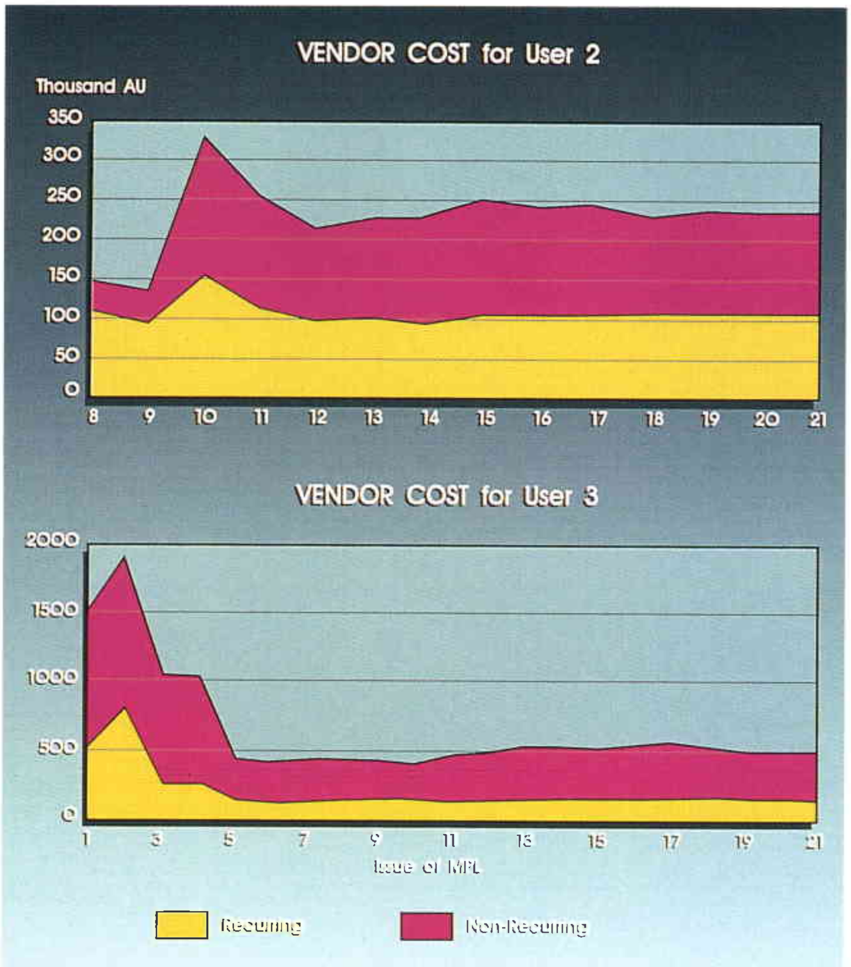
This means that if a user only selects part types that are already qualified, on which lot acceptance level-1 or 2 tests need not to be performed, the related vendor costs are drastically reduced. If, however, a user selects part types that are not so common, the non-recurring costs are between 50 and 200% of the recurring costs, as shown in Figures 9a,b.

Conclusion

Based on the experiences described above for ISO, it is advisable to start at the very beginning of a satellite project (Phase-B) with an extensive part-type reduction and standardisation exercise, not only to reduce the overall procurement costs, but also to increase system reliability and reduce the overall project risks incurred through using multiple part types, and the associated risk of lot failures occurring.

8 a,b





With fewer part types, the procurement effort can then be concentrated on those particular manufacturers, which in turn leads to better quality/reliability and reduces risk and management costs.

One should therefore not ask a Procurement Agent to bid a (firm) fixed price for the parts costs plus the associated procurement effort against a preliminary spacecraft parts list, but rather request bidders to propose the procurement effort as a firm fixed surcharge on the total parts costs, which are deemed to be proposed on a cost-reimbursement basis. This surcharge must be proposed as a firm fixed percentage of the total parts costs, i.e. a sliding scale of surcharge percentage against total volume of parts costs. This also has the advantages of simpler administration with respect to change notices and easy verification of total parts costs by audit.

The approach adopted for ISO has proved to be cost-effective, given the particular constraints of the Programme. Although perhaps still not the optimum solution, it nevertheless represents a considerable step forward.

9 a,b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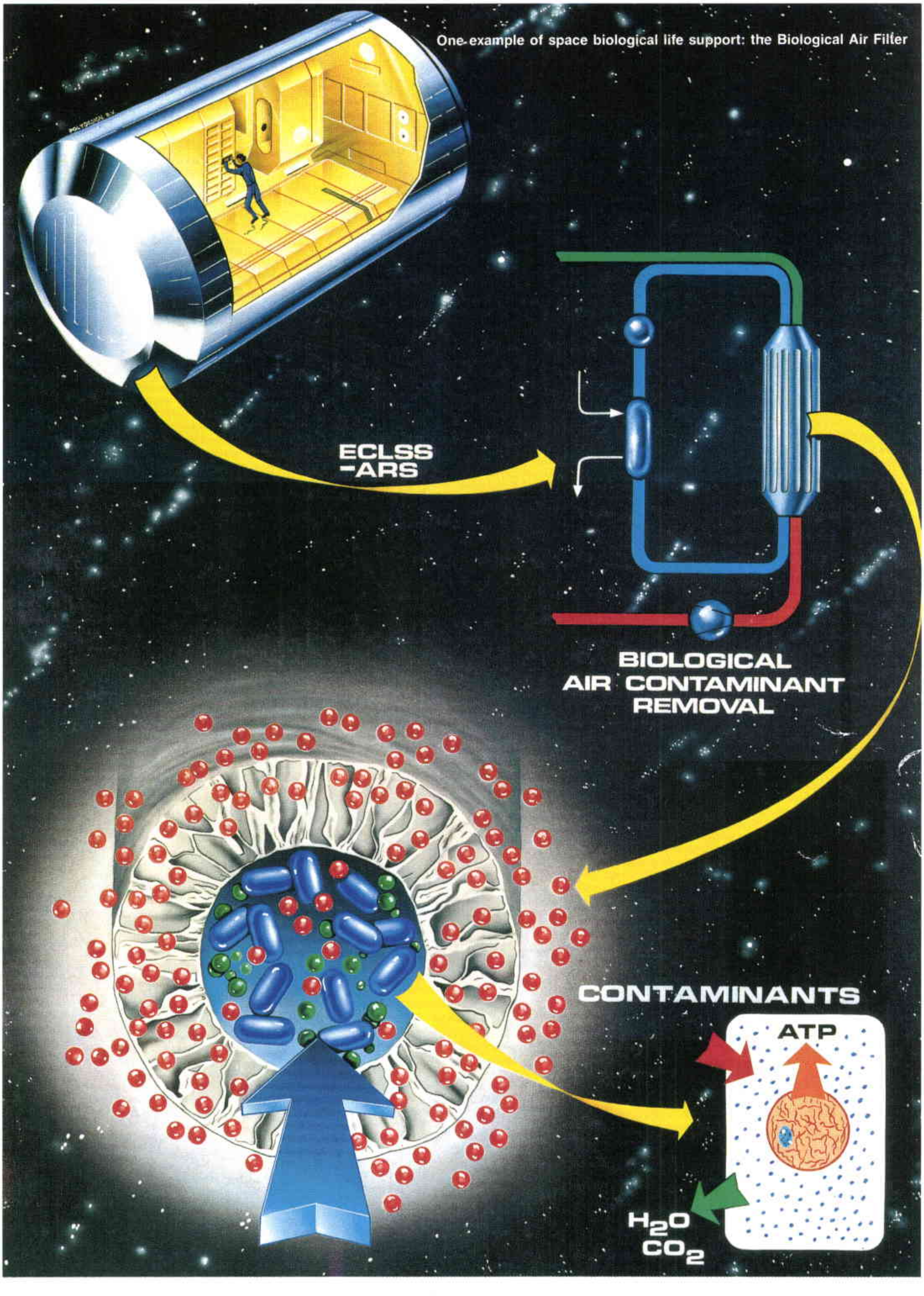
Tél. 071/36.65.25 - Telex 51227 ACECBU-B


One example of space biological life support: the Biological Air Filter
ECLSS
-ARS
BIOLOGICAL
AIR CONTAMINANT
REMOVAL
CONTAMINANTS
ATP
H_2O
CO_2

Man in Space – A European Challenge in Biological Life Support

C. Tamponnet, R. Binot, C. Lasseur & C. Savage
Thermal Control and Life Support Division, ESTEC, Noordwijk, The Netherlands

The decision to acquire the ability to support man whilst living and working in space has stimulated the development of a number of life-support technologies within the Agency. Among these, biological processes are very promising because only they can ultimately support man in isolation from Earth. These and similar future technologies will be critical to the success of Europe's future space endeavours.

Introduction

On 12 April, it was thirty years since Yuri Gagarin became the first man in space, twenty years since the first space station 'Salyut-1' was put into orbit, and ten years since the first flight of the American Space Shuttle. Whilst the driving force during the first years of the space odyssey was a political struggle between the two superpowers, once the race to the Moon had been won by the United States scientific and economic factors came to the fore in the promotion of space programmes.

In parallel, other countries entered the race. The first European astronaut in space was J.-L. Chretien, on a Franco-Soviet mission to Salyut-7 in July 1982. ESA's first astronaut, U. Merbold went into space on the ninth US Shuttle Mission in November 1983, with Spacelab-1. At this point, we in Europe were still relying on the two major space powers – the USA and the USSR – for sending men into space and providing them with the support systems needed to live and work there.

The decision by the ESA Council meeting at Ministerial Level in Rome in 1985, and subsequently confirmed at the Ministerial Meeting in The Hague in 1987, to acquire the capability needed to support man living and working in space via the Hermes, Ariane-5 and Columbus Programmes, was the trigger for initiating the development of space life-support technologies in Europe. Early in 1987, a group was set up at ESTEC to address these specific tasks, called the Life Support and Habitability Section.

Autonomy for man in space is a long-term objective that no country has yet achieved. In the specific case of the life-support system, this autonomy will certainly not be demonstrated by the current ESA projects: the life-support function is assured by NASA for the Columbus Laboratory attached to the International Space Station 'Freedom', and by Hermes for the Columbus Free-Flying Laboratory (only manned when attached to Hermes), whilst for Hermes itself the short mission durations foreseen will require only first-generation 'open-loop' systems. The goal of European autonomy therefore involves studying and developing the techniques that will be required for the post-Columbus era, specifically for the European Manned Space Infrastructure (EMSI), and ultimately for lunar bases and planetary missions. It is here that the need will arise for true biological, rather than the current physical/chemical, life-support techniques.

Life support

The discipline of life support covers basically all the techniques that enable the crew of a spacecraft or planetary base to survive in a hostile environment. The goal is therefore to develop those techniques necessary to ensure the biological autonomy of man when isolated from his original biosphere. Indeed, although man may now have broken the chains of terrestrial gravitation, he has yet to cut the umbilical cord connecting him to mother nature.

Thermodynamically speaking, man as a living creature is an open system (i.e. he exchanges matter and energy with his environment) that maintains its own structure in the face of pervading disorder (called 'entropy' by scientists) by transferring its own element of disorder to its environment supporting planet, called the 'lithosphere'), but an open one in terms of energy. It maintains its own level of entropy vis-a-vis our supporting star the Sun, and the lithosphere.

Human life-support requirements

Life-support systems can be divided into five main areas (Fig. 3) based on their degree of criticality for the crew:

1. Atmosphere management: ventilation, proper temperature and pressure, oxygen regeneration, carbon-dioxide removal, contamination control and monitoring, etc.

2. Water management: potable and hygiene water must be provided.

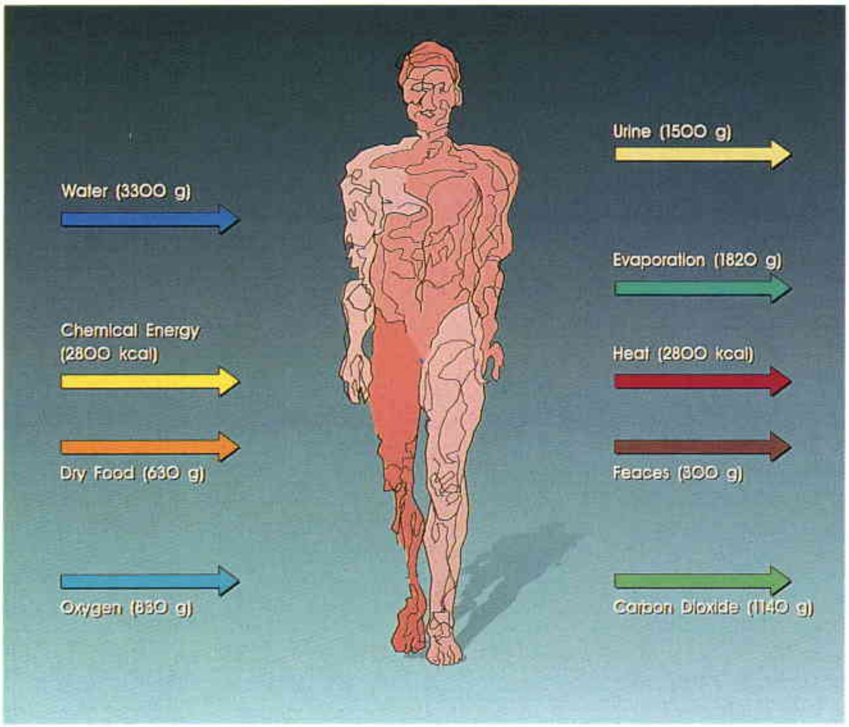


Figure 1. Man as an open system in terms of energy and mass transfer. Schematic representation of main daily data.

3. Food production and storage: food for use by the crew must be of high quality, nourishing, uncontaminated, and constitute a balanced diet. Moreover, if supplied from Earth, it must be suitably pre-treated for long-term storage before use.

4. Waste management: both human waste and trash must be collected, pre-treated, and stored or further processed.

5. Protection and safety of the crew: next to collision with a meteorite or other space debris, fire is arguably the greatest hazard faced by the crew. Temperature and smoke detectors and fire-suppression equipment are therefore obligatory. In addition, both active and passive methods and techniques must be employed to maintain the crew's health and protect it from potentially harmful extraterrestrial factors, such as cosmic rays and particles, the effects of microgravity, and chemical or biological xenobiotics.

Regeneration of life-support materials

There are essentially only three practical techniques available for contributing to the support of human life in space (Fig. 4):

1. The launching of all required consumables at the start of the mission, or resupplying them.

2. The re-use of life-support materials during the flight.

3. The utilisation of in-situ resources (in the case of planetary bases or missions to planets).

Historically, air, water and food have been carried on board and the waste stored and returned to Earth. This open-loop life-support system has been used very successfully for short-duration space missions (Figs. 2b & 5a). As space missions get longer, however, the supply loads get heavier and soon become prohibitive, ultimately cutting short the missions regardless of how exciting or potentially important they may be. It is therefore essential that we try to 'close' some of the more vital loops in order to permit longer missions.

First, one has to discriminate between regenerative and non-regenerative life-support materials. In Figure 3, the regenerative functions are shown in white boxes and the non-regenerative ones are in shaded boxes.

Presently, physical/chemical processes are available to regenerate air and water by appropriate treatments of substances released by the crew (Figs. 2c & 5b). The air loop can be closed by regenerating oxygen from carbon dioxide via the use of a molecular sieve, carbon-dioxide reduction by Bosch reactor, and water electrolysis. The water loop can be partially closed by employing evaporation systems or membrane filtration techniques.

Biological life-support systems

The above physical/chemical regenerative techniques consume a lot of energy that is expensive to produce and cannot replenish food stocks, which must still must be resupplied from Earth. Consequently, solid wastes have to be collected, pre-treated, and stored.

Food production can only be achieved by biological means. In fact, 'food' consists of an enormous diversity of molecules which cannot be chemically synthesised one by one, and which so far can hardly be precisely enumerated.

In terms of energy expenditure and material transfers, the food produced is likely to be, at least in the foreseeable future, vegetarian in nature, with possible exceptions being biomass, such as Single-Cell Proteins (SCPs) coming from lower forms of life (yeasts, unicellular algae, photo-autotrophic and photo-heterotrophic bacteria, etc.). According to data from studies of terrestrial food chains, 1% of captured energy is stored and available in plants, while only 0.01% is stored in vegetarian animals.

However, commitment to the production of foods means that a certain volume of the spacecraft, space station or planetary base must be dedicated to this function. Food production in such a restricted area is a complex operation, involving careful control of many parameters, including light intensity and spectral distribution, light/dark cycle times, temperature, nutrient supply, air and water composition and quality, etc. It will also be necessary, if propagation from generation to generation is to be permitted, to monitor continually the quality of the end-products to ensure that any harmful mutations are detected and eliminated. Food production also involves the process of 'harvesting' and the further processing of the raw material to provide acceptable food products.

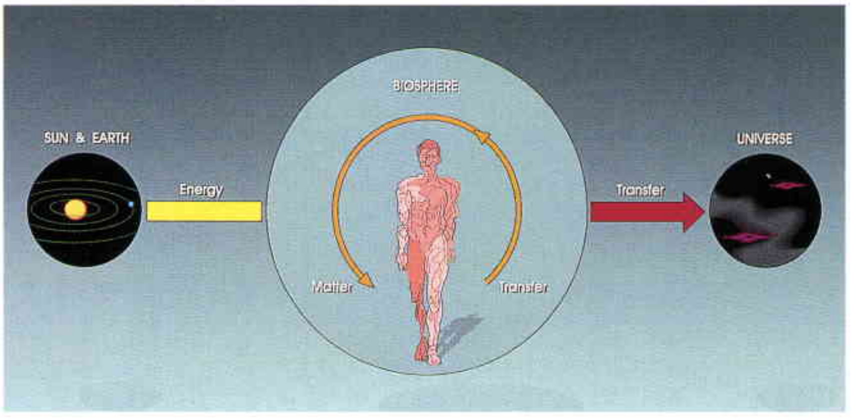
If the obligatory introduction of biological techniques for food production into life-support systems produces a certain number of problems to be solved, it also opens up a new area of solutions for other life-support requirements:

Atmosphere management

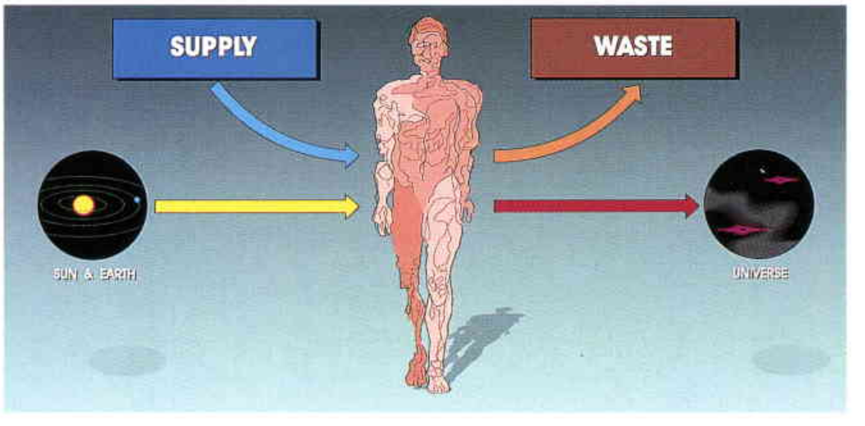
The oxygenic photo-autotrophic organisms (e.g. the higher plants) produce food from carbon dioxide and water according to the general equation:

$$CO_2 + H_2O + Light = O_2 + Biomass + Heat$$

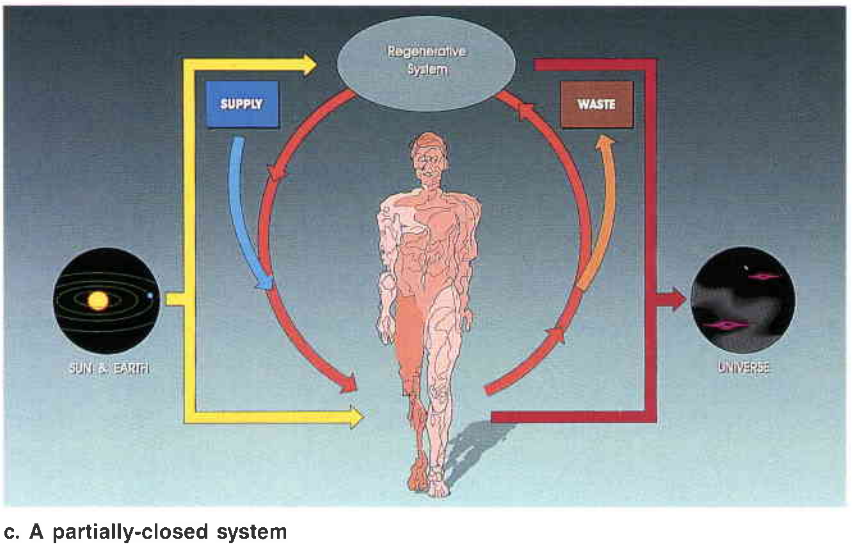
Many low-weight, volatile organic compounds which are found as air contaminants in small, closed, inhabited volumes such as a spacecraft cabin and arise mainly from human metabolic processes, equipment off-gassing, leakage from coolant loops, fire control equipment, etc., can also be substrates (nutrients) for a variety of micro-organisms.



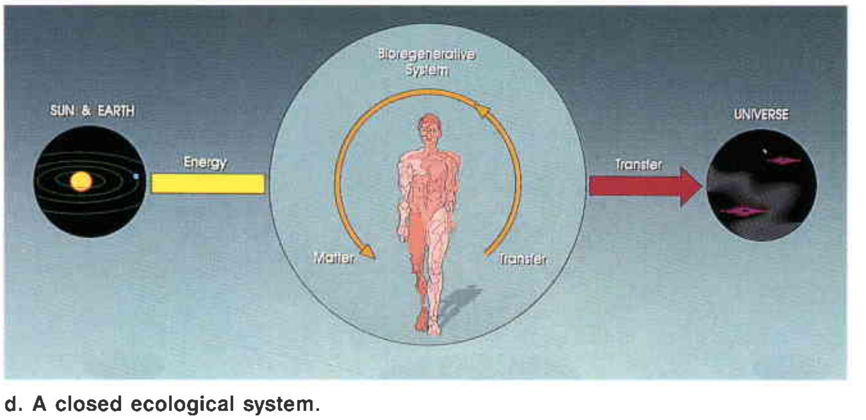
a. The biosphere



b. An open-loop system



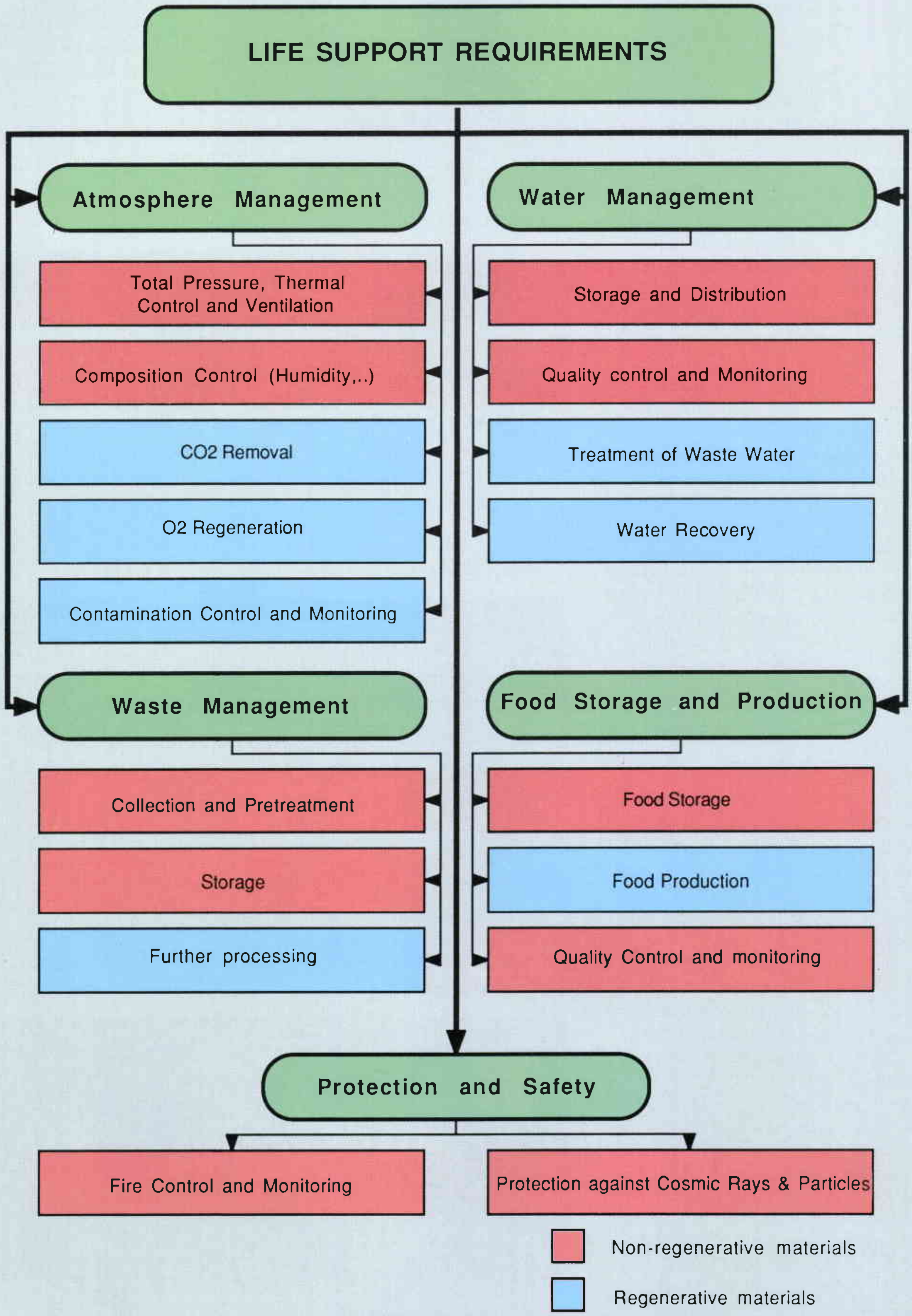
c. A partially-closed system



d. A closed ecological system.

Figure 2. Place of man in various life-support systems

Figure 3. Classification of life-support requirements in terms of life-support systems.



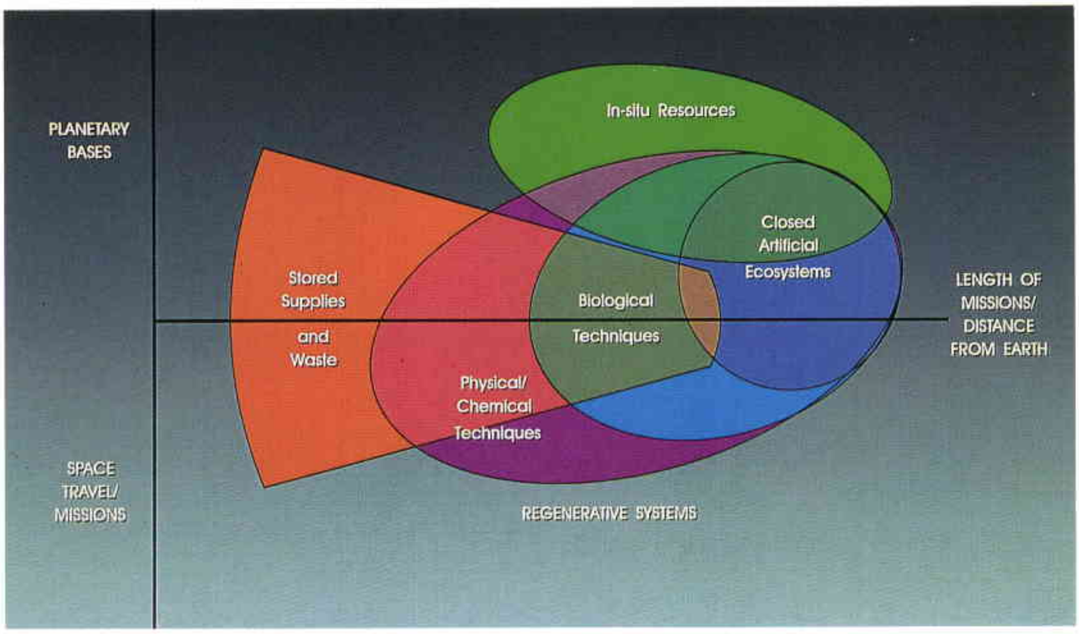


Figure 4. Type of life-support system for planetary bases and space travel/missions as a function of length of mission/distance from Earth.

The concept of a Biological Air Filter then appears as a possible solution for contamination control .

Water management
The main problem in regenerating water is to eliminate compounds that make it non-potable and/or non-hygienic, which are mainly micro-organisms (bacteria, viruses, protozoans, yeasts) and organic and mineral compounds. A potable water can be used safely for human consumption without any time limit. So-called 'hygiene water' can be safely used for human and environmental hygiene purposes, and occasionally in certain circumstances as potable water.
The solutions that have been developed are either purely physical (successive membrane filtrations, evaporation and cooling) or chemical (super-critical water oxidation), but are very energy-consuming.

A biological solution can also be envisaged from the general equation described above. This equation has both a water-consumption and a heat-production element. This heat has to be eliminated because of the harmful consequences it could have on plants. The solution nature chooses is plant transpiration (water evaporation from the leaves). This plant water transpiration can easily be recuperated (condensation) and considered as potable (occasionally an excessive organic carbon content may have to be corrected).

Another solution would be to adapt to the specific spacecraft and/or planetary-base conditions, the conventional biological treatment processes used on Earth to regenerate used waters from urban communities.

Waste management
As missions get longer, the volume of waste produced by the crew will increase. A good waste-management system will be needed to minimise both the volume and mass of the stored waste, probably relying on a combination of compaction and dehydration.

Biological processes can be foreseen for further decreasing the mass and volume of stored waste, but only for the biodegradable (i.e. mainly organic) elements. In that case, biodegradation can lead to end-products such as carbon dioxide and nitrogen, which are easily managed, but also to some less desirable ones such as hydrogen and hydrogen sulphide, the production of which can better be avoided. The interest then really resides in converting these waste materials which, by definition, are not usable as human consumables, into reactants that can be regenerated into consumables.
Although biological processes, once incorporated into life-support systems, generate waste that adds to that already described – e.g. spent plant and micro-organism nutrient solutions, inedible biomass after harvesting and food processes, volatiles produced by plants and micro-organisms – at least these wastes are of biological origin and thus biodegradable.

Closed ecological systems
The introduction of biological processes for food production has positive side-effects on other life-support requirements and allows the notion of loop-closure to be addressed. Regenerative life-support materials can be roughly divided into three categories, according to their physical forms:
– gas in atmosphere (air)

– water-soluble products (water), and
– solid materials (food, waste).

Nearly complete (air, water or food and waste) loop closure can be foreseen independently for each category using physical/chemical and/or biological techniques, or in a closed ecological system based mainly on biological techniques. The first approach is actually being developed for air and water loops using only physical/chemical techniques (Fig. 5b). The second involves the closure of all three loops through a common set of bio-regenerative processes (Fig. 5c). Such a system almost completely removes the need for resupplying consumables from Earth, thereby achieving autonomy, but it embodies a lot of concepts that are at the boundaries of today's knowledge and technical capabilities.

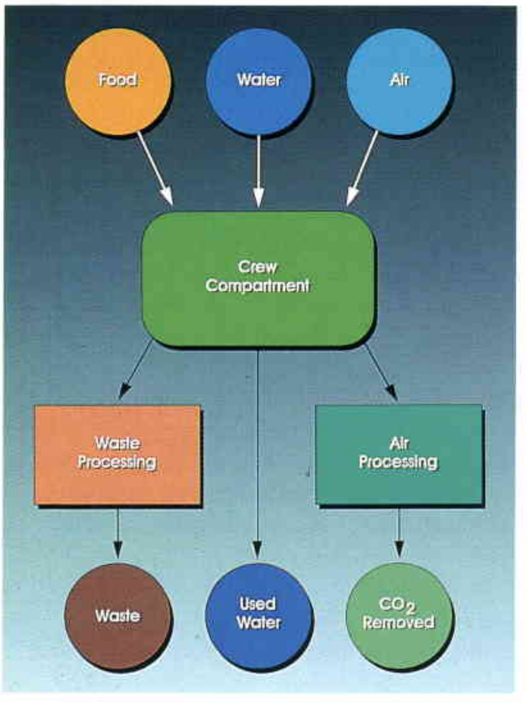
To support life in space with the help of a closed ecological system, it will be mandatory to:

1. Know more about the behaviour, performance and ageing characteristics of the constituent biological elements.

2. Develop and validate the separate biological waste-processing, water-recovery, food-production and air-revitalisation systems.

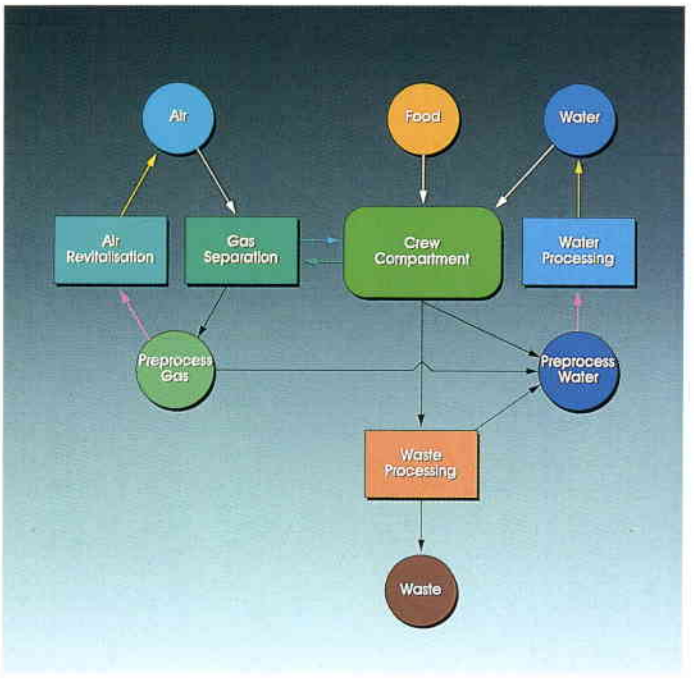
3. Develop and validate the physical closure of the loop and study its long-term behaviour and control system.

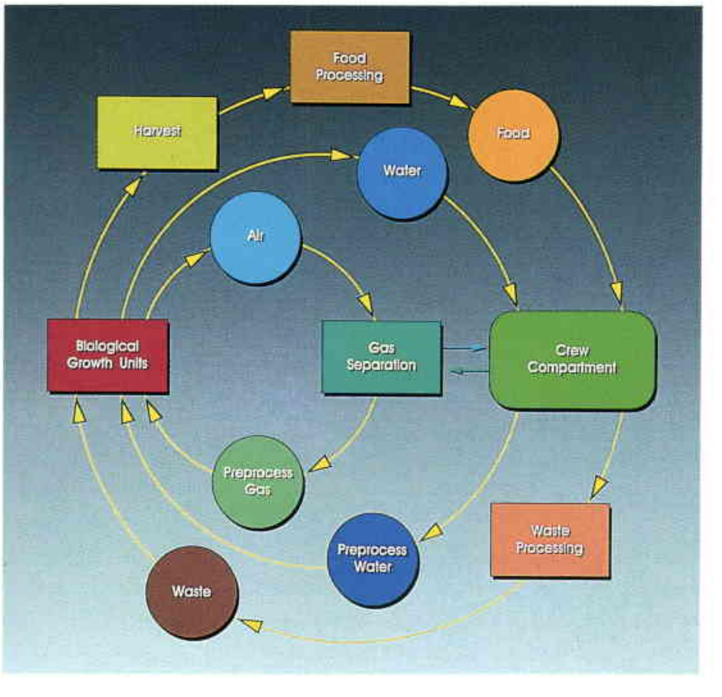
Figure 5. Structure of life-support systems:
a. Open-loop system (Vostok, Mercury)
b. Partially closed physical/chemical systems (Shuttle, Hermes, Space Station)
c. Closed ecological system.



Recent European progress in biological life-support

ESA is currently developing biological life-support techniques for future programmes, essentially in the time-frame beyond 2000. Indeed, the planning for Europe's involvement in manned space activities in the early twenty-first century is only now being assessed within the framework of the EMSI (European Manned Space Infrastructure) Programme. Nevertheless, it is clear that for the early phases of these activities, essentially covering the short to medium term, only biological processes that represent solutions for one specific life-support requirement can be studied, developed and validated.





In parallel with these developments, the technologies applicable to autonomous closed ecological life-support systems are also being studied according to the rationale described above. Such systems can only be foreseen at the earliest circa 2010 in a form suitable for a permanent lunar base, and circa 2020 for missions to other planets (Mars).

Biological Air Filter (BAF)

For inhabited space vehicle/stations, atmospheric contamination is an important life-support concern, with potential impacts on toxicologic, safety and habitability aspects. Most of the contaminants, both chemical and microbial, originate directly from the crew itself. However, important additional sources are secondary contaminants from the various life-support systems, from materials off-gassing, and gas leakage. In Europe, the currently-proposed leading concepts to control the degree of contamination are based on a combination of particle filters, oxidation catalysts promoting the oxidation of reduced compounds by the oxygen present in the air, and adsorption and chemisorption filters.

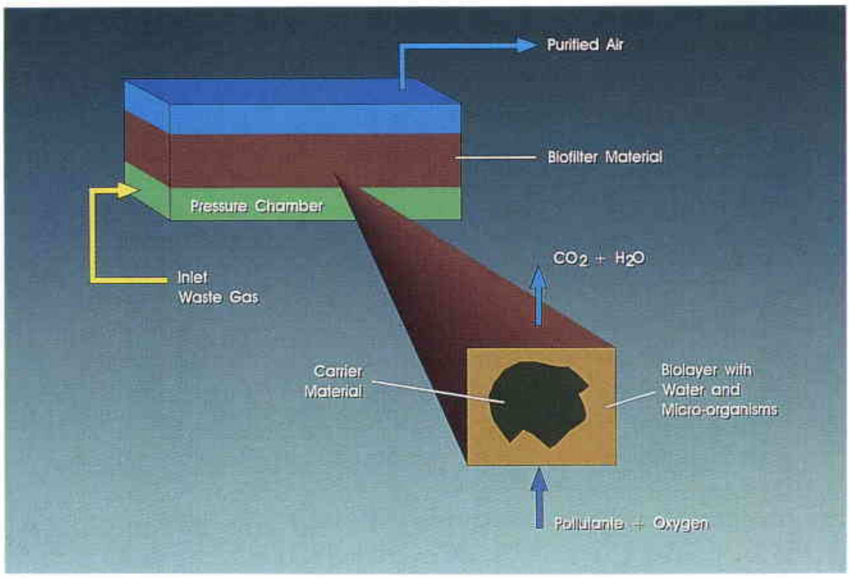
However, high-efficiency decontamination requires high-temperature catalysts, which are rather sensitive to poisoning, with efficient adsorption and chemisorption filters to protect the catalytic beds and to prevent the formation and release of harmful byproducts such as fluoric and bromic acids. A broad range of lower-molecular-weight compounds produced by catalytic oxidisers are more difficult to remove for the adsorption filters, and may eventually prove more toxic than the primary contaminants.

Unfortunately, many compounds that are poisonous for the oxidation catalysts are of biological origin (e.g. reduced sulphur compounds). Others are imposed by other requirements such as fire resistance of synthetic materials and the use of freons and bromo-fluorated compounds as coolants or fire suppressants. Pre- and post-filters that protect the catalytic beds and the crew have then to be replaced periodically, and the system needs resupplying.

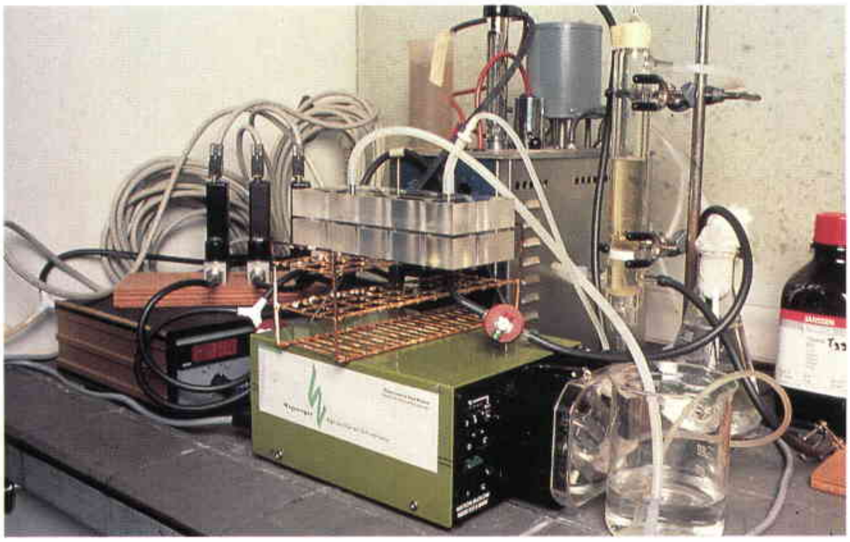
Hence, activity intended to develop a self-regenerating biological air filter for gaseous- and aerosol-contaminant removal, and both microbial and viral pathogen control, has been initiated at ESA. The principle of the system is based on a support/sorbant material colonised by selected innocuous micro-organisms in a near-resting state, converting the various contaminants to inert chemicals, mainly carbon dioxide, water and salts (Fig. 6).

The ability of microbes to mineralise waste organic compounds has been recognised and used for purification purposes for a very long time in 'activated sludge' water-treatment processes, making biological purification the first and more widely used purification process for a very broad range of waste waters ranging from municipal to industrial in origin. If we imagine such an activated-sludge system in which we maintain just enough water to keep the microbes alive and replace the continuous phase by the polluted air stream, we have a good representation of the principle of a Biological Air Filter (BAF).

For most of the several hundred chemical contaminants addressed, one or more bacterial strains have been selected that



a



b

Figure 6. The Biological Air Filter (BAF):
a. Basic design
b. BAF experiment with a flat-sheet membrane reactor.

have the ability to effect complete aerobic mineralisation to carbon dioxide, water and salts. Overall, more than 85% of the expected contaminants have been found to be biodegradable. Some of these, particularly the aromatic hydrocarbons, the aliphatic and aromatic halocarbons, the sulphides and ammonia are general noble catalyst poisons. For typical xenobiotics like the aliphatic chloro-fluorocarbons and bromo-fluoro-carbons, and the silanes and siloxilanes, biodegradability is still not satisfactorily demonstrated, due mainly to a lack of fundamental or applied research. However, in anaerobiosis, the bacterial degradation of

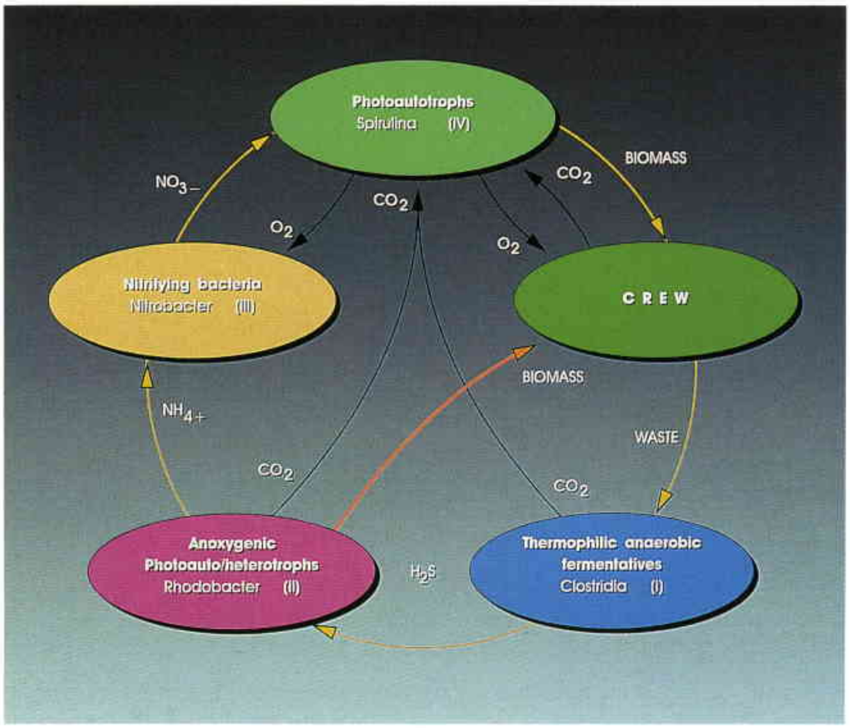


Figure 7. Schematic of MELISSA, showing the five-compartment loop.

bromocarbons was recently demonstrated, and the acceptability of the silanes and siloxilanes for a BAF will now have to be demonstrated.

A large number of microbial strains have already been identified with variable biodegradation capabilities. These strains belong to about 50 bacterial, yeast or fungal genera. Of these genera, 16 have been found to be able to convert one or more xenobiotic contaminants. Experimental results achieved so far are very promising, in that:

- the ability of the strains tested to efficiently degrade contaminants in an extremely low range of concentrations has been demonstrated
- testing of the biodegradability of a mixture of contaminants by co-cultures has shown an increase in performance over the results obtained with pure contaminants
- the stability and performance of some 'delicate' microbial strains have been considerably improved by culturing in 'BAF conditions', i.e. complex microbial populations degrading complex mixtures of contaminants.

The Micro-Ecological Life-Support System Alternative (MELISSA)

MELISSA has been conceived as a micro-organism-based ecosystem intended as a tool for developing the technology for a future biological life-support system for manned space missions. It is a joint venture involving five independent organisations (SCK/CEN Mol as prime contractor, University of Ghent, CNRS at Gif-sur-Yvette, University of Clermont-Ferrand, and Matra Espace) and ESA.

The driving element of MELISSA is the reprocessing of edible biomass from waste, carbon dioxide and minerals, with the use of sunlight as a source of energy for biological photosynthesis. Light-dependence is minimised by the incorporation of anaerobic steps in the waste recycling loop, allowing the usual carbon-oxidation reduction loop to be partially short-circuited.

MELISSA has four successive microbiological compartments (Fig. 7), colonised respectively by thermophilic Clostridia for waste liquifaction–fermentation, anaerobic Photo-rhodochromogens for the removal of soluble organics, nitrobacteria for the nitrification of ammonium ions, and the blue-green algae Spirulina (Fig. 8) for food production and carbon-dioxide/oxygen recycling.

In the first phase of the MELISSA contract, an important bibliographic review has been completed to check the validity of the underlying concept. Theoretical efficiency, safety, biomass quality and the inter-connected-compartment toxicity have been studied. This was followed by the study of pure cultures of Clostridia, Rhodobacter, and Spirulina. Compatibility between Clostridia and Rhodobacter compartments has been tested and encouraging results have been obtained. The next phase, now in process, is the optimisation of each micro-organism culture in order to prepare for continuous culturing.

At the same time, two theoretical topics are also being studied:
- modelling of the mass balance of the loop
- identification of the main technological difficulties to be expected from the physical closure of the loop.

In parallel with these activities, the difficult problem of the control system, both at compartment level and globally, is under study. Due to its compartmentalised structure (the loop can be considered as inter-connected subsystems each representing a physical entity, and the global stability can be considered as the stabilisation of the smaller subsystems), MELISSA control can be studied in a first approach deterministically. The results to date have confirmed that the necessary control system will be highly complex, featuring:

- a high number of measurements and/or controlled parameters
- non-linearity
- linked parameters
- both very long and very short process time constants
- complex analysers
- a high level of reliability.

Satisfying the control requirements will involve use of the most up-to-date technologies in continuous process control (smart sensors, predictive modelling, expert technologies, fault-tolerant systems, etc.). With the goal of evaluating a preliminary design for a suitable control system, a continuous culture linking two compartments of MELISSA is now being attempted at ESTEC (Fig. 9).

European perspectives in biological life support

The European perspectives in biological life support are intimately linked to the more general development of life-support activities. They are now a modest, but destined to increase, part of the overall ESA effort in this domain.

As explained above, the actual use of a biological life-support technique must be preceded by three important milestones:

(i) acquisition of complete scientific knowledge about the particular biological process

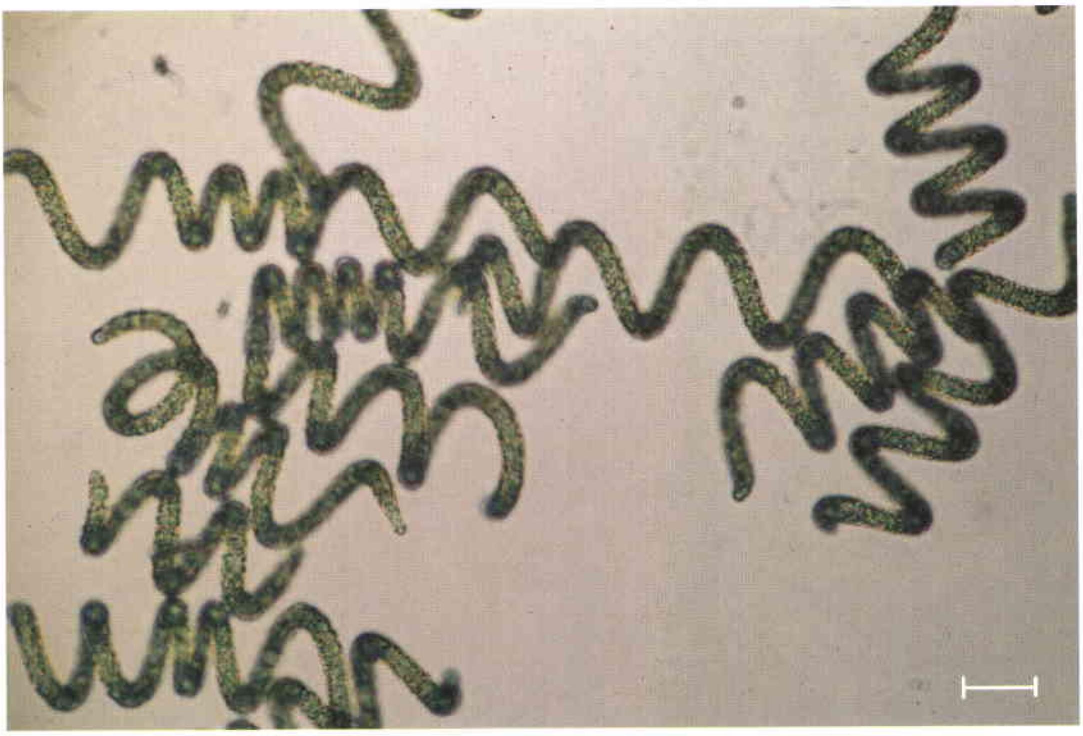


Figure 8. The microalgae Spirulina (scale bar indicates 0.1 mm).

(ii) development and validation of the biological technique based on that prior scientific knowledge

(iii) integration of this biological technique into a functioning space life-support system, which may be only partly biological in nature (first on the ground, and then under real space conditions).

Following this rationale, we will continue the BAF and MELISSA programmes already started, initiate new programmes to develop and validate new biological techniques, and monitor those biological research fields where important breakthroughs can be expected in the future for space-oriented applications in life support.

Continuation of existing programmes

The Biological Air Filter (BAF)

Following up the very promising results summarised above, it is planned to continue the development of the BAF both at the basic scientific level (identification of strains of micro-organisms, contaminant conversion efficiency, mutual compatibility of strains, etc.) and at the technological level (implementing the science in engineering hardware). Extensive testing is planned at ESTEC and, in view of the possibility that performance may be influenced by gravity effects, an orbital test flight has been proposed.

The Micro Ecological Life-Support System Alternative (MELISSA)
MELISSA has been designed to be a simplified model for more complex (and more efficient) ecosystems to be used as life-support systems. With this goal in mind, it is foreseen to carry on the scientific and technological investigations of each compartment in order to increase our knowledge and to prepare continuous cultures. Once this has been mastered, it is planned to implement the physical closure of the loop as soon as possible. MELISSA will then be used as a research tool to help us to understand the global behaviour (modelling, simulation of sudden perturbations, stability) of the ecosystem and to optimise the design in terms of efficiency and safety.

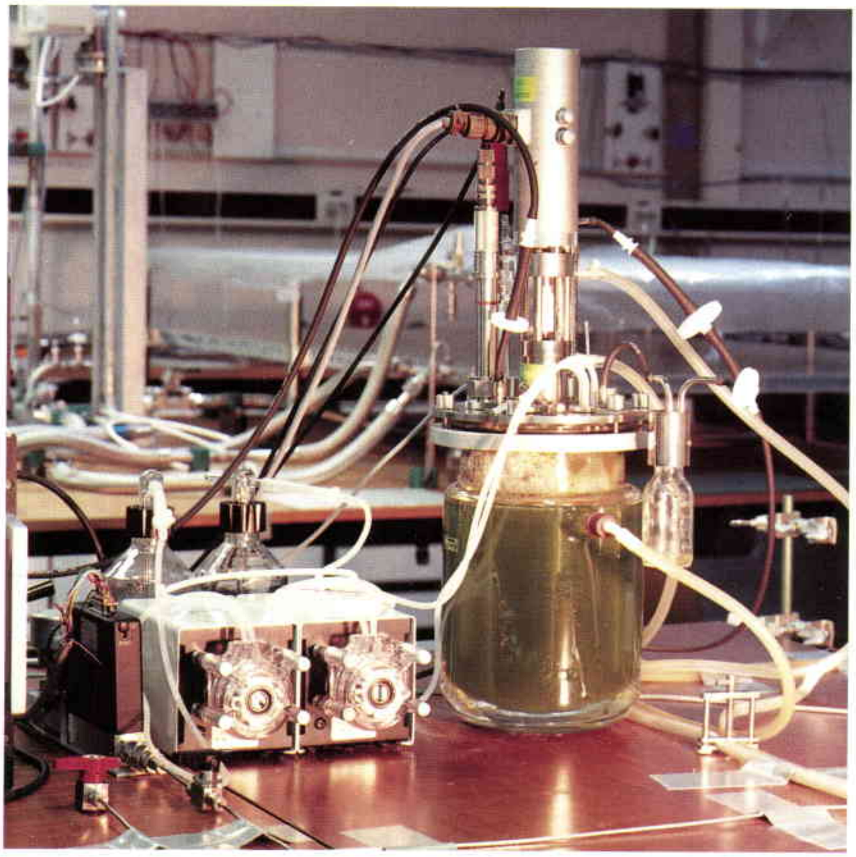


Figure 9. The Spirulina compartment in the ESTEC laboratory facility.

Initiation of new programmes

Optimisation of higher-plant cultivation under near-space conditions
One of the most important aspects in biological life support is to develop and validate techniques fulfilling one important life-support requirement, namely food production. The cultivation of Spirulina in the MELISSA programme can be seen as a first attempt to tackle that question, but sound and acceptable food for crew consumption can only be anticipated from higher-plant biomass.

Indeed, although the daily protein intake can easily be fulfilled with single-cell proteins, only plants can provide the daily carbohydrate and lipid intakes needed. A human can live without difficulty on a lipid-free diet for more than a year (assuming that the quantity of essential stored fatty acids is sufficient), but the carbohydrate and protein intakes are absolutely vital.

This programme should therefore have multiple goals:

- Definition of the nutritional needs to be provided by regenerative means as a function of the length and type of space mission.
- Selection of plants according to: their ability to provide the crew with sufficient edible biomass; their growth-condition compatibility with the 'space conditions'; and their ability to grow on media regenerated from waste.
- Studies on plant models of the intrinsic problems of growth in closed and limited conditions, for example: plant contamination control and monitoring; water and carbon-dioxide supply; oxygen removal; nitrogen sourcing; light intensity and spectral quality; and biological rhythms.
- Safety problems related to the genetic variability of the chosen strains due to mutations induced by cosmic rays and particles.
- Effects of microgravity on plant life-cycles (from seedling to fructification).
- Optimisation of the control system for managing the different subsystems of the higher-plant compartments and the connections with preceding, surrounding and following compartments.

This is a typical biological programme destined to fulfil one specific life-support requirement, but one that can also be integrated easily into an autonomous artificial ecological system. Recent and foreseen progress in plant genetic engineering and in the understanding of the DNA reparation mechanisms, provides some hope that they will provide us with specific tools and strains.

Biological waste-material recycling
Whether incorporated into a more general waste-management programme as the ultimate milestone or standing alone, such a programme's goals will be to recycle waste materials into reagents capable of being regenerated into edible biomass. One might expect such a programme to be an extension of the development of the microbial compartments for the MELISSA programme. Such a programme should benefit considerably from the expanding field of anaerobic microbiology. In fact, knowledge of the physiology and biochemistry of anaerobic micro-organisms has been rather scarce, but is now growing rapidly with the development of industrial biotechnology.

Biological water treatment
Initially, water treatment will be essentially a physical/chemical process, with biological processes foreseen as secondary processes (plant-transpiration water). However, an activity aimed at developing a self-regenerating biological water-treatment system for water-soluble contaminant removal could be foreseen, based on principles similar to those used for the Biological Air Filter.

Definition of a closed ecological system (a follow-up programme to MELISSA)
In this programme, an attempt will be made to define an optimal closed ecological system, taking into account a large number of factors such as length of missions, distance from Earth, type of mission (to space station, planetary base, etc.), number of crew, launch capacity at the time of the mission (Ariane-5 or more powerful launch vehicle). Depending on these factors, the best compromise between regenerative systems and resupply, and between physical/chemical and biological processes, will have to be found. Such a programme would only deal with the third phase in the rationale described above, i.e. the development and validation of the physical closure of the loop and its control system.

Conclusion
Most of the potential biological life-support technologies of interest for space use have a development time of ten to twenty years. It is therefore essential to start now if they are to be available in time, and this will be a far more cost-effective approach in the long run than highly expensive 'crash-actions' at a later date. The interactions between the different biological elements enclosed in a spacecraft or space station – typified for example by the BAF for removal of atmospheric contaminants, the food-production facility based on higher-plant cultivation, the waste-processing system, the water-treatment processes, and the commensal microflora of the crew – are both inevitable and complex.

Due to this complexity, the development of a closed ecological life-support system technology will be a long-lead-time activity that will involve considerable experimental investigation, both on the ground and in space. Current activities (MELISSA) are preliminary and limited to the understanding and control of simple micro-organism-based elements. Follow-up work will require a dedicated test bed for the system-level investigation of progressively more complex systems. Since the crew is itself an important biological element of the system, both influenced by and impacting upon the stability of the ecosystem, suitable testing will a require facility capable of evolving to accommodate man in the system.

Moreover, in the same way as the USA's lunar programme provided terrestrial byproducts from space-related breakthroughs in the seventies (micro-computers, etc.), one can expect similar positive 'spin-offs' from the studies of space biological life-support systems. Indeed, they will give us the basic knowledge and tools needed to cope with – and perhaps even solve – some of the environment-related problems that are of growing concern here on Earth.

Figure 1. The EMSInaut and CIC team From left to right:
G.I. Elgjo, F. Capella, J. Schiemann, C. Viberti, R. Reiding, J. Persson, P. Nespoli, A. Maillet and P. Nyborg

The ISEMSI Experiment: Europe's First Simulation Campaign for Long-Duration Manned Spaceflight

M. Novara
Mechanical Systems Department, ESTEC, Noordwijk, The Netherlands

J. Collet
Head of Long-Term Programme Office, Directorate for Space Station and Microgravity, ESA, Paris, France

R.J. Vaernes
Head of Diving Division, Norwegian Underwater Technology Centre, Bergen, Norway

The goal of achieving European autonomy for the long-duration manned space missions planned for the beginning of the next century has given rise to several studies being undertaken in 'space-analogous' environments during the last two years. The first wholly space-oriented long-duration manned simulation campaign undertaken in Europe took place during 1990, involving a crew of six isolated for four weeks in a hyperbaric chamber complex. The resources available for the study were entirely devoted to obtaining scientific data on the psychological and physiological effects of long-duration isolation and confinement on crew performance. Fundamental lessons were learnt on the operational side also, and these will be fully exploited in setting up future simulation campaigns.

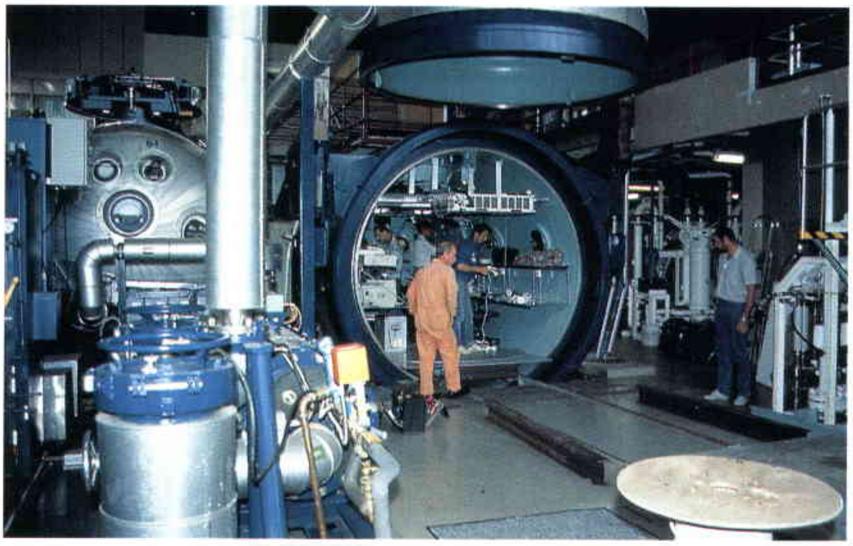
Introduction

During the last two years, the Long-Term Programme Office (LTPO) of the Agency's Directorate for Space Station and Microgravity has sponsored scientific studies conducted in 'space-analogous' environments such as Antarctica and by deep-sea diving. In 1989, a group of six men, of different nationalities, was monitored during a seven-month crossing of the Antarctic on skis and sledges (see ESA Bulletin No. 64, pp. 44–49). Also during 1989, an experimental deep-sea saturation dive, simulated in a hyperbaric chamber complex in Marseille, was closely monitored by the LTPO (the HYDREMSI experiments, reported in ESA Document LTPO-SR-90-01). In both cases, ESA added to the original protocols some pilot experiments in the fields of psychology, physiology, contamination, and teleoperations.

The interest shown by the LTPO in these activities stems from the need to develop an independent European knowledge of human factors in support of the long-duration manned space missions expected to take place at the beginning of the next century, in the cadre of the planned European Manned Space Infrastructure (EMSI). Such knowledge cannot be gathered by theoretical means, but must come from field experience; simulation in analogous environments is regarded as the best means of acquiring that experience without taking unnecessary risks.

Simulated ('dry') dives in hyperbaric chambers yield very many interesting scientific results concerning the performance of a crew isolated and confined for long periods (more than two months) whilst carrying out a variety of operational tasks. The application of these results to manned spaceflight is somewhat controversial, however, due to heavily biasing collateral effects such as the neuro-physiological consequences of high barometric pressure in a deep-dive simulation (known as HPNS, or High-Pressure Nervous Syndrome).

Consequently, the scientist members of the Agency's Space Psychology Advisory Group (SPAG) recommended to the LTPO, during 1989, that experimental research be undertaken specifically on the problems of a psychological nature that could be encountered by space crews due to the abnormal living conditions of long-term isolation and confinement, avoiding all biasing effects wherever possible. Based on



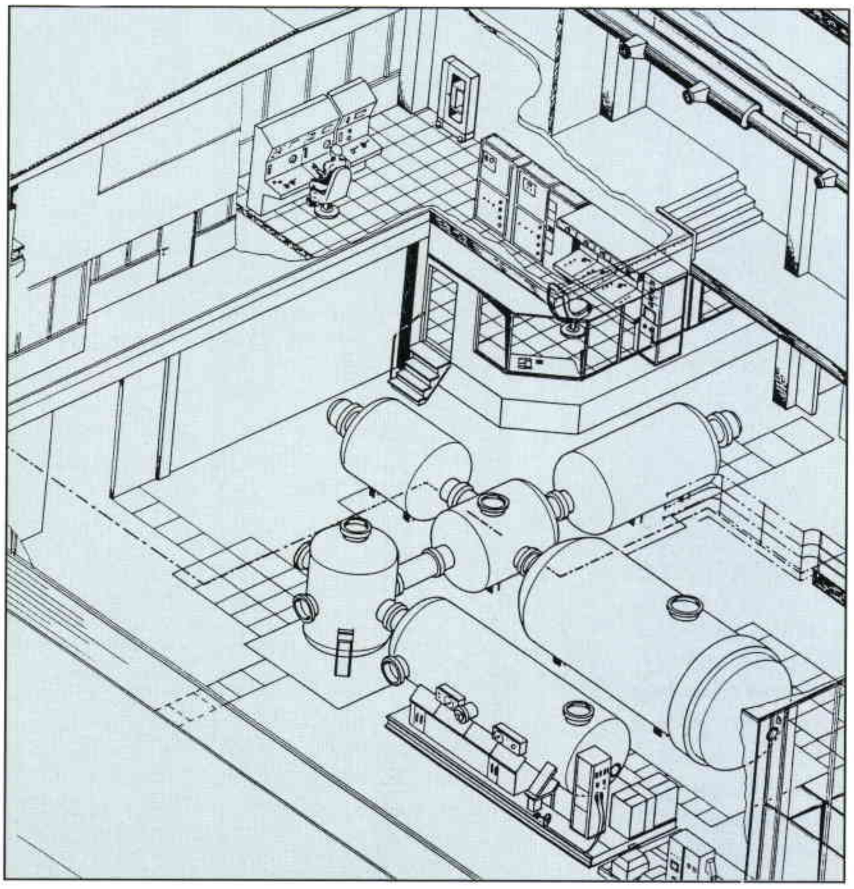


Figure 2. The Hyperbaric Chamber Complex at NUTEC, in Bergen, Norway. The Chamber Control Room is also visible

the experience acquired with the HYDREMSI pilot campaign, an experiment in the hyperbaric chambers of the Norwegian Underwater Technology Centre (NUTEC), in Bergen, was planned.

The study was based on an isolation period of four weeks for a crew of six males (plus two reserves), ideally with a professional background similar to that of astronauts (scientists/engineers), who would carry out meaningful operational and research tasks during their stay. The experiment was christened 'ISEMSI' (Isolation Study for EMSI).

ESA's involvement in what has been Europe's first manned simulation experiment specifically conceived for long-duration spaceflight was multi-facetted, with the LTPO as sponsoring authority, ESTEC's Life-Support and Habitability Section providing technical management, various ESTEC Sections serving as participating experimenters, and the Agency's European Astronaut Centre providing ground-control personnel as well as an experiment of its own. The co-sponsorship of Norsk Romsenter (Norwegian Space Centre) was also an important asset.

The objectives

ISEMSI was basically a science-oriented simulation, in which the available resources were economically managed with the aim of achieving the following limited set of scientific research objectives:

- to collect valuable knowhow on the neuro-psycho-physiological aspects of long-duration isolation and confinement
- to gather and organise a community of researchers oriented towards specific space-related psychological issues.

ISEMSI was therefore not meant to mimic closely an actual manned space mission in such aspects as crew selection or timeline management, but was rather expected to rely largely on the operational infrastructure provided by the analogous environment in which it was to be carried out (hyperbaric chambers).

The technical scenario

Residual practical constraints were imposed by the fact that the mission was technically a low-depth dive (5 msw) in hyperbaric chambers, which influenced crew selection, operations, communications, habitability, and atmospheric parameters, to mention only the most striking aspects. The living and working environment afforded by the chambers was limited to a total of about 100 m^3, subdivided into one large working and living module (50 m^3), two sleeping modules, one interconnecting module (doubling up as shower and toilet), and a storage module.

The period of isolation started on 17 September and ended on 15 October 1990. It was preceded by a three-week training period for the crew in Bergen, during which preliminary testing was also conducted to establish baseline references for most experiments. A five-day post-isolation period, during which assessment tests were conducted, followed at the end of the experiment.

The simulated scenario was one of practically total physical isolation for the crew, whilst communication (voice and video) was not significantly limited. Immediate extraction of the crew from the pressurised chamber was not allowed, the shallow depth requiring a formal decompression protocol of 7 h to prevent any occurrence of 'the bends'. No direct viewing through portholes was allowed and no resources were allowed in from outside except water and electricity. Food, clothes and other consumables (including those needed for the experiments) were stored inside the chambers. All scientific samples collected were retained onboard for delivery at the end of mission (e.g. frozen biosamples), while only waste was dumped through an airlock. Voice and two-way video communications were available, as well as fax and electronic mail.

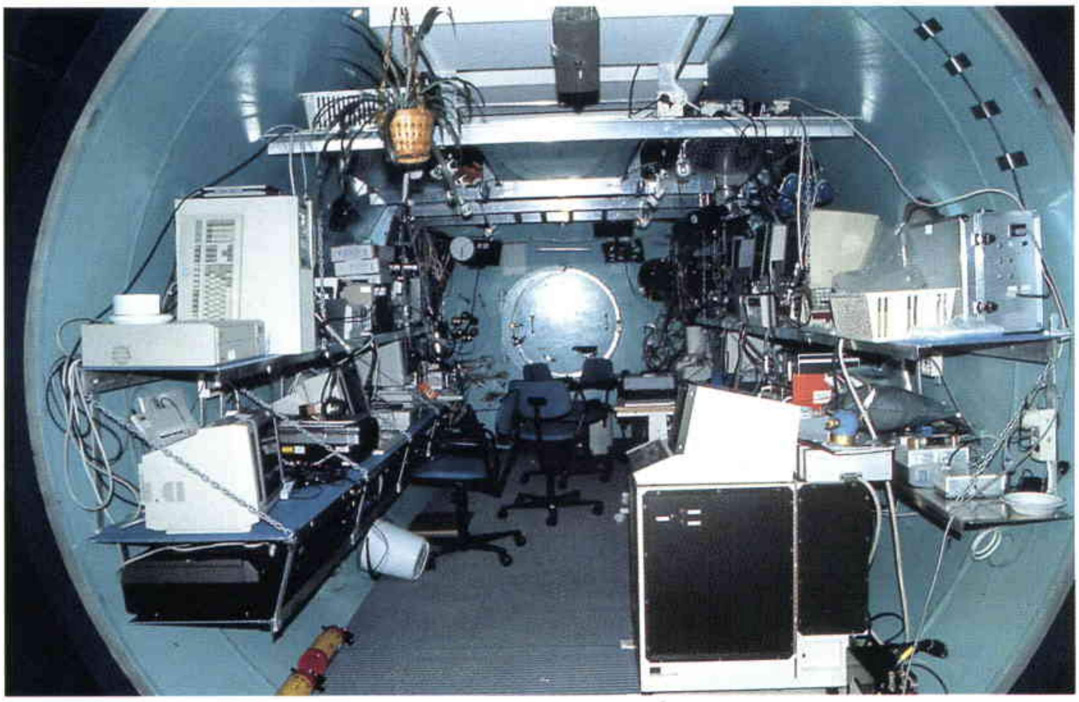


Figure 3. Interior of the main living and working chamber, with the ISEMSI experiment equipment installed

The crew

The crew members – the 'EMSInauts' – were selected by NUTEC from among more than 40 volunteers from universities and space-related European industries and institutes (including ESTEC). The six eventually chosen (aged between 25 and 33) were each from a different ESA Member State: France, Germany, Italy, The Netherlands, Norway, and Sweden. Their backgrounds were quite varied, ranging from a physiologist to several aerospace engineers.

NUTEC's selection procedure was based on a simple set of medical and psychological 'select-out' criteria, aimed at excluding participants exhibiting potentially problematic symptoms. As agreed with the SPAG group, no definitive set of 'select-in' criteria was included in the study hypotheses.

Aside from their payload-operations tasks (each EMSInaut was responsible for a share of the experiments being conducted), the crew members were given individual system-operations tasks: Commander, Logistics Manager, Computer Specialist, Systems Specialist, Hygiene Specialist, and Data Manager.

The operational scenario

Operations were directed by a 'ground' control team (the ISEMSI Operations Support Team, or IOST), which was centred around the Chamber Control Room at NUTEC. In the original planning, the IOST was to consist of the control personnel normally provided by NUTEC (chamber superintendent, supervisors and operators). During the preparation phase, some space-mission-related functions were added, these including Crew Interface Coordinators (CICs), Planner/Replanners (P/Rs), and a Science Coordinator (SC).

The CICs were the persons in charge of communications between the crew and the outside World. They were the only persons with whom the EMSInauts would talk for most of the 28 days, except for brief contacts with friends and family (twice a week) and the communications with the experimenters. The CIC role turned out (as expected) to be a key one, being not only concerned with the management of communications (i.e. operating the switchboard), but also requiring a lot of technical and scientific knowledge of both the experiments and the system, in order to cope with all sorts of unexpected problems, as well as a good deal of 'diplomatic' skill in dealing with the crew's problems and requests. Two of the CICs were in fact the reserve EMSInauts, which proved a very practical solution given their familiarity with the crew members and their knowledge of both the system and the payloads.

The CICs operated on a complex shift plan, consisting of 25 h watches at the communications console, followed by 23 h off, 8 h covering the role of P/R, and another 16 h off. The P/R function was also fundamental, and involved constant maintenance and updating of the day-to-day schedule for the payload-related activities for the onboard crew (with a 'granularity' of 30 min). Schedule management required considerable effort during the 28 days (as well as during the training and post-isolation periods), due to the challenge of integrating the needs of more than 30 experimenters with the system-operations tasks, and still leaving some time for leisure (movies, video games and physical exercise being the preferred activities).

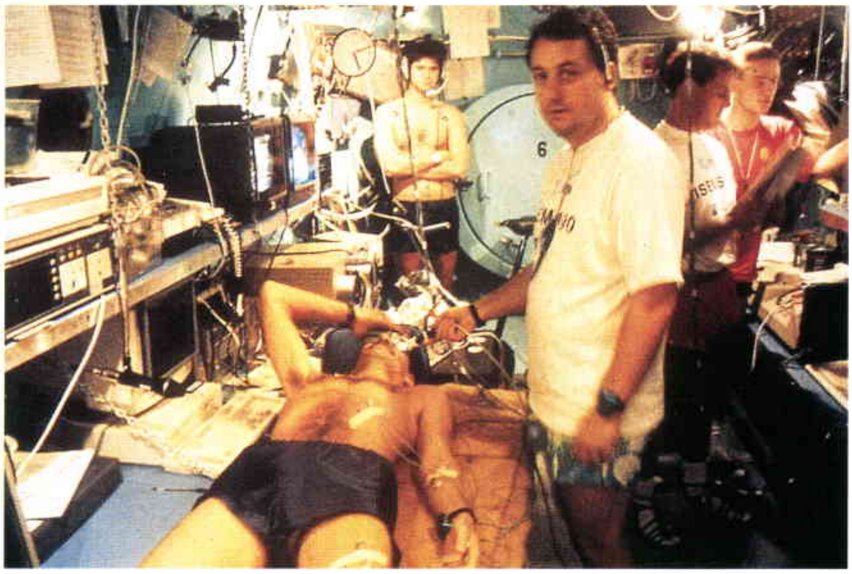


Figure 4. Measurement of skin evaporation rate (part of the Autonomic Nervous System Experiment), carried out regularly by the EMSInauts. In the background, an EMSInaut is preparing for a tele-science session

The SC position was intended as an interface between the User Teams (the experimenters) and the operational structure of ISEMSI, being charged at the same time with ensuring the maximum scientific return from the study. During the experiment, the SC function never worked as intended, due to constraints ranging from lack of availability to insufficient seniority. It was therefore shared between the P/Rs and CICs (permanently on site) and the Study Management (for matters requiring authoritative intervention).

The experiments

The psychological tests to which the crew were subjected were rather extensive, ranging from the subjective status and performance of individuals (assessed via computer-based tests and questionnaires), to the crew's social interaction and group dynamics (investigated by examining videotapes of discussions, meals, etc.). The physiological research supported the psychological investigations, concentrating on the performance of the autonomic nervous system; such parameters as hormone levels in the blood, immunology, heart-rate variability, and perspiration rate were regularly measured during the 28 days.

The EMSInauts themselves showed some variance with time, and between individuals, in their response to their isolation. The results yielded by the psychological and physiological studies are reported in the companion article in this same ESA Bulletin.

Considerable interest was shown in the ISEMSI Experiment by tele-operations and contamination experimenters, due to the unique opportunity that it offered of operating with a crew enclosed and isolated for such a long period of time. These technology-oriented experiments were largely sponsored by ESTEC, and included (Table 1):
- monitoring of chemical and microbiological contamination (of particular importance in an enclosed habitat, where the air was continuously recycled for 28 days)
- tele-medicine (with simulated illnesses, treated on board by a summarily trained medical assistant, with the support of a physician sitting at a remote location)
- tele-training (onboard maintenance of equipment, following the instructions of a technician given via a multimedia interface)
- tele-science (with a scientist instructing the crew from the ground on how to carry out physiology experiments).

The microbiological contamination experiments confirmed known hypotheses, such as:
- the trend towards uniformity of skin microbial flora across a group of individuals enclosed together
- the rather fast 'colonisation' of the environment by microorganisms shed by human inhabitants

Table 1 — The ISEMSI Add-On Experiments

Add-On Research Theme	Principal Investigator	Add-On Experiments
Tele-operations	M. Pujos et al. CCMM, Toulouse, France	Tele-medicine
	H.C.D. de Bruyne et al. CAT Benelux, Schellinkhout, The Netherlands	Multimedia/Tele-training
	N. Wootton et al. ESTEC, Noordwijk, The Netherlands	Tele-science
Micro-biological Contamination	C. Ahlén SINTEF/UNIMED, Trøndheim, Norway	Bacterial Composition of Human Skin
	M. Stranger-Johannessen et al. SI, Oslo, Norway	Microbial Composition of Material Surfaces
		Monitoring of Airborne Micro-organisms
Chemical Contamination	S. Klingele et al. Dornier GmbH, Friedrichshafen, Germany	Volatile Organic Compounds Measurement
	R. Müller et al. MPSensorSystems GmbH, Munich, Germany	Experimental Gas-Measuring Unit Test
	K.C. Persaud University of Manchester, United Kingdom	Multi-element Conduction Polymer Gas-Sensor Test
	J.A. Quéméner ESTEC, Noordwijk, The Netherlands	Long-Term Evolution of Atmosphere Composition
	G. Bolstad SINTEF/UNIMED, Trøndheim, Norway	Carbon-Monoxide Monitoring

- the heavy growth of microorganisms in poorly accessible and wet areas (toilets, air conditioning).

In addition, possible disturbances of skin defence mechanisms against colonisation by potentially pathogenic microbes were noted, as well as a difficulty in monitoring the microbial contents of the atmosphere itself (there are significant random variations between samples taken at different times and locations).

Several different prototypes of 'array sensors' for the monitoring of trace-gas contaminants in the atmosphere were tested during ISEMSI. Their performance was promising when compared with results achieved with a more conventional (and more complex) gas-chromatograph/mass-spectrometer device that was also used.

An overall picture of the most important chemical contaminants to be found in enclosed manned habitats (including contaminants produced by man himself) was obtained via the use of Tenax gas-adsorption traps. The method used permitted the fluctuation in contaminants to be monitored on a daily basis, as well as during the complete four-week ISEMSI period. The results will provide valuable input for designing contamination monitoring and control systems for future spacecraft.

Particular attention was devoted to the monitoring of carbon monoxide in the chamber. Results showing the correlation between this contaminant's concentration in the atmosphere and the percentage of carboxi-haemoglobin in the EMSInauts' blood will allow the correctness of the presently specified maximum allowable concentration for manned spacecraft to be evaluated.

The tele-medicine experiment confirmed the feasibility and interest of applying to a space-station scenario many aspects of remote health care already widely used in the maritime environment. ISEMSI allowed us to evaluate positively the tele-medical consultation procedures, as well as the

Figure 5. As no biosamples were 'sent to ground' during the four weeks of isolation, blood samples were either frozen or analysed onboard by the EMSInauts themselves

training protocols for the crew. EMSInauts trained as 'sanitary assistants' had to interview a 'patient' (another EMSInaut, trained to feign illness symptoms), prepare an anamnesis, carry out a medical examination, assess the severity of the case, and administer effective medical care under remote medical advice. An expert system was used throughout the experiment, to provide step-by-step guidance to the sanitary assistant.

ISEMSI demonstrated the great importance of practising and rehearsing emergency procedures. It confirmed that simulation of the medical emergencies that could occur during a long-duration space mission will be required to provide 'refresher training' to astronauts trained as sanitary assistants. It also demonstrated the suitability of the medical equipment selected, including multifunction monitoring devices (e.g. cardiac parameters), biological analysis kits (e.g. blood analysers), and the system of data transmission to ground.

The multimedia/tele-training experiment showed the feasibility and benefits of using a graphic-overlay system in a Columbus or EMSI maintenance, operations and training scenario. This advanced communications medium allows graphics and commands to be superimposed on a video image. The EMSInauts had to carry out a series of maintenance and repair tasks on a piece of faulty equipment, with the guidance of an expert at home base. The use of the graphic-overlay system allowed many of the short-comings of voice communication alone to be overcome.

It was evident that some critical events could not have been solved by oral communication, and that some real-time 'sketching' was necessary to exchange information (e.g. location of a component on a circuit board) satisfactorily. Also, the feasibility of ground-guided tele-training concepts was proven by the same experiment, which turned out to be a very realistic simulation of ground–space interaction during a real manned space mission.

In addition to the 'planned' tele-maintenance operations, the EMSInauts carried out repairs to really malfunctioning equipment inside the chambers (such as an echo-cardiograph), using the most rudimentary tools and with on-line assistance from a specialist at a remote location.

The Telescience Test Bed, already integrated into the Columbus mock-up at ESTEC, was used during ISEMSI to simulate the end-to-end communication between a scientist sitting at his work station and an experiment onboard a space station. Two life-science experiments were chosen for this simulation:
- one in human physiology, monitoring ECG and the heart rate of an EMSInaut exercising on an ergometer, and
- one in echo-cardiography.

Link problems (e.g. unannounced blackouts, transmission delays) and resource constraints (e.g. limited time duration of each session) were artificially introduced to test the system under realistic operational conditions. Both experiments clearly showed how a scientific investigator adapts to unforeseen behaviour of an experiment, and what mechanisms of interaction between scientist and crew are established by the need to maximise scientific return under non-optimum experimental conditions.

The operational lessons learnt

Not unusually during this kind of simulation, the unexpected problems and the questions left open considerably outnumbered the answers actually obtained, making an important result the list of 'lessons learnt', particularly those regarding operational aspects.

The problems experienced within the IOST have already been mentioned. The lack of effective scientific coordination made management of the interfaces to the experimenters difficult, and resulted in the loss of some experimentally relevant data. This is regarded as the single most important lesson learnt. A large, complex simulation campaign requires an adequate organisational structure for the management of participating scientists, similar to those currently in place for actual space missions. No waiver is granted by the 'ground simulation' nature of the event.

The IOST itself turned out to be a very interesting subject for analysis, for the psychologist team also. Performance, work load, stress and group dynamics were all important for the chamber control personnel as well as the onboard crew. Not enough attention was devoted to this aspect ('observing the observers') during ISEMSI, and not enough effort was spent on solving the problems encountered by the IOST. In particular, the central figures of the CIC and P/R will receive much greater attention in future in terms of role definition, specific training, and technical facilities.

The training period generally proved to have been insufficient, particularly as far as the choice of running the tests for setting experimental baselines in parallel with the actual training activities was concerned. The establishment of baselines needs to be separated from the training proper. Also, equipment integration activities need to be completed significantly in advance, so that in-situ training can take place without the disturbance from continuing installation activities.

A 24 h 'dry-run' took place during the last week of training. The EMSInauts were pressurised to 5 msw and carried out some of the activities planned for the isolation period. As it turned out, the dry-run took place too late, and was too short to detect a large number of potential problems and allow them to be corrected effectively before the start of isolation.

Meticulous training, planning and rehearsal is recognised as a powerful anti-stress factor for the crew. For this reason also, aside from other more practical considerations, its importance cannot be over-emphasised.

The crew's role and organisation were also not sufficiently well defined prior to the mission. The EMSInauts showed a clear trend towards actively participating in the experiments, rather than just acting as operators, although most experimenters had based their studies on the assumption of more passive operators. The internal dynamics of the crew also suffered from a lack of specification of individual duties.

Conclusion

Analysis of the ISEMSI scientific results by the experiment teams will continue throughout most of 1991, thanks to the very large amount of data gathered during the 28 days. The primary ISEMSI objective of collecting valuable knowhow on the effects of long-duration isolation and confinement was achieved to a significant degree. The need for continuing and further expanding the research is now quite clear, and planning has started for further future simulation campaigns.

Figure 6. The Multimedia/Tele-training Experiment involved repair work on faulty equipment, carried out by a summarily trained EMSInaut with on-line support from a specialist at a remote location

The ISEMSI experiment has also promoted the formation of a community of European researchers with a specific interest in space-related psychological issues. In addition, considerable momentum has been built up among European scientists through these simulation activities, which are widely recognised as the best means available of acquiring much-needed knowledge in this domain.

All in all, the ISEMSI Experiment has turned out to be an unusually fruitful learning ground for all of the technical and scientific parties involved.

Scientific Results from the ISEMSI Experiment

J. Collet
Head of Long-Term Programme Office, Directorate for Space Station and Microgravity, ESA, Paris, France

Cl. Gharib
Laboratoire de Physiologie, Université Claude Bernard, Lyon, France

K. Kirsch
Institute of Physiology, Free University of Berlin, Germany

R.J. Vaernes
Head of Diving Division, Norwegian Underwater Technology Centre, Bergen, Norway

Mastery of the various factors associated with the prolonged presence of humans in space is a long-term task, involving many disciplines that have so far not been associated with space endeavours in Europe. Although physiologists have been working on space-related problems for some years now, particularly in the USSR, several aspects are still not yet understood. The situation is even worse in other branches of the human sciences, the psychological problems in particular not being well appreciated in the western space world.

Introduction

Europe entered the manned-spaceflight arena with Spacelab, which proved a major success. Confirming their intention to see Europe play a major role in this area, Europe's Ministers then set the achievement of European autonomy in manned space-flight as the next objective for the longer term.

The interim steps – Columbus and Hermes – will progress European technology in many essential domains to the level needed to work towards that eventual autonomy. However, when discussing autonomy, there is one critical area that is not covered by the present manned programme activities, namely those aspects related to the day-to-day life of astronauts in space. For the Columbus Programme, these are a NASA responsibility (hygiene, health care and maintenance, nutrition, rest, etc.), while for the short trips being planned for Hermes (missions of a few days are presently foreseen) the problems are considerably alleviated.

Some 30 years ago, Michael Collins, the Gemini-10 Astronaut, wrote:
'I would have flown by myself or with a kangaroo .... Almost anyone can put up with almost anyone else for a clearly defined period of time in pursuit of a mutual objective that it is important to reach'. This view is still shared, although perhaps not so openly, by some of those involved in manned spaceflight.

However, sending a man or woman into space for a week and putting them on board a Space Station for a few months are two very different things. Moreover, those early astronauts were members of an elite group striving to achieve major milestones in the history of manned spaceflight: there will be no such rewards for the crew of the Space Station.

The problems of psychological adjustment to space conditions – essentially microgravity – are quite specific to that environment. This is often the case with problems of psycho-logical, social and occupational adaptation, which occur elsewhere in exceptional situations that involve:
- a hostile environment;
- isolation from the outside world;
- limited social intercourse; and
- confinement in a limited volume.

Opportunities do exist to study human behaviour in confined and isolated envir-onments on Earth, Antarctic bases and submarine diving stations being two such places in which the inhabitants are exposed to Space-Station-like conditions. By making observations in such environments, we can substantially enhance our knowledge of individual and group responses to stressful environments.

The preceding article in this Bulletin describes how the Long-Term Programme Office (LTPO) of ESA's Directorate for Space Station and Microgravity conducted the ISEMSI simulation study, with the specific aim of understanding human requirements for extended spaceflight.

The psychological aspects of isolation and confinement formed the major theme of the ISEMSI study. Taking advantage of the good cooperation established between the two LTPO advisory groups – the Space Medicine Advisory Group and the Space Psychology Advisory Group – a coordinated scientific programme was established around which the ISEMSI mission was built.

The ISEMSI scientific programme

The main objective of ISEMSI involved psychological studies of individual and group behaviour under conditions of isolation and confinement over long periods of time. A period of four weeks was selected as being representative, from the psychological standpoint, of long-duration spaceflight. A total of six 'crew members' were selected, as this number constitutes a 'group' in group-dynamics terms.

The psychological investigations carried out within the ISEMSI study addressed the themes listed in Table 1.

It has already been concluded from previous space missions that the primary limiting factor on long-duration space flights is the problem of *interpersonal relationships* between the crew members. The primary group of interest consists of the onboard crew, but the critical network is larger and

Table 1 — The ISEMSI Psychology Experiment

Psychological Research Theme	Principal Investigator	Experiments
Social Interaction & Communication	T. Bergan et al. NUTEC & University of Bergen, Norway	SYMLOG Observation System and Questionnaire Communications Classification System EMSInauts' Daily Survey
	C. Tafforin P. Sabatier University, Toulouse, France	Ethological Analysis
Autonomic Nervous System (ANS)	K.A. Kirsch et al. Free University of Berlin, Germany	Heart Rate Heart-Rate Variability
	R.J. Vaernes et al. NUTEC & University of Bergen, Norway	Psycho-biological Tests
Crew Performance	R.J. Vaernes et al. NUTEC & University of Bergen, Norway	Workload Assessment
Cognitive Demand	G.R.J. Hockey et al. University of Sheffield, United Kingdom	Working Memory
	G. Rizzolatti et al. University of Parma, Italy	Visual Search Orienting of Attention
	R.J. Vaernes et al. NUTEC, Bergen, Norway	Mental Performance Measurement Cognitive Evoked Potentials
	G.C. Modugno University of Rome, Italy	Fusion-Critical Frequency
Subjective State	R.J. Vaernes et al. NUTEC & University of Bergen, Norway	Psychosomatic Reactions
Sleep and Rhythmicity	I. Tobler et al. University of Zürich, Switzerland	Motor-Activity Monitoring Morning Evaluation of Sleep Two-hourly Subjective State Evaluation

more complex. When thinking about social interaction, it is essential to include not only the ground staff in voice communication with the crew, but also the Crew Interface Coordinators (charged with managing the crew's communications with the outside world), and scientific personnel and family and friends with whom there is also intermittent contact.

The Crew Interface Coordinator was a central figure in the social network for ISEMSI and his role in the operation was structured as part of the experiment. All communication from the chambers went via the control deck. Direct conversation with relatives and spouses was treated as an experiment variable, and the frequency and amount of time allocated for private conversation was measured.

Table 2 — The ISEMSI Physiology Experiment

Psychological Research Theme	Principal Investigator
Psycho-endocrinology	K.A. Kirsch et al. Free University of Berlin, Germany
Immunology	L. Schaffar et al. Ranguell Faculty of Medicine, Toulouse, France
Blood Volume Regulation	C. Gharib et al. Environmental Physiology Laboratory, Lyon, France
Lower-Body Negative Pressure (LBNP)	A. Güell et al. MEDES, Toulouse, France

During the study, common activities inside the working chambers were recorded on video. A 'task discussion' took place every day according to a pre-determined schedule. These sessions were more thoroughly analysed by scientific groups in France and Norway.

Tests were performed on a regular basis to investigate *workload and individual performances* (e.g. morning and evening status).

The *cognitive demand* research theme included experiments on memory, vigilance, attention and mental fatigue.

Fatigue tests were conducted; the so-called 'Fusion Critical Frequency' (FCF) experiment, which provides information on the central micro blood flow, is based on the frequency of light-intensity oscillation to which the human eye perceives light as continuous (typically 35 to 40 Hz). The FCF is routinely used as a psychological fatigue test for truck drivers, jet-aircraft pilots, etc.

Vigilance tests were performed using stimuli consisting of the digits 0 to 9 presented singly in the centre of a computer screen at a rate of 1 per second for a period of 50 min. The aim was to detect, over the course of the four weeks of isolation, the different influences exerted by working or leisure days on progressive changes in vigilance.

Attention orienting, visual search and distribution of attention tests were conducted with the aim of finding out whether isolation conditions produced a decrease in attentional resources or a redistribution of resources between the various tasks.

Sleep and circadian-rhythm studies were also performed. Subjects living for a prolonged period in dim illumination could become 'desynchronised' with respect to clock time. This could give rise to disturbances of the sleep/waking rhythm, to increased sleepiness during the day, and to impaired performance. Ambulatory monitoring of motor activity was performed by a solid-state actometer worn on the wrist.

A set of *physiological experiments* (listed in Table 2) was also carried out in support of the Autonomic Nervous System theme of the psychological investigations (e.g. psycho-endocrinology and immunology). The interest in these physiology experiments stems from the fact that, whilst such investigations have been carried out during an actual space-flight, very seldom has it been possible to investigate the physiological response to long-duration confinement, sensory deprivation and isolation from social contact, decoupling these factors from microgravity. The study of the hormonal and immunological modifications occurring during ISEMSI, as well as of the balance of fluids and electrolyte, has provided results which it will be very interesting to compare with those obtained during simulated weightlessness (e.g. bed-rest studies of comparable duration).

The psychology-experiment results

Just a brief overview of the results yielded by the most significant psychological and physiological studies will be given here*.

The EMSInauts performed well as a group, as did the individual crew members,

* More comprehensive, though still preliminary, results are available in a collection of Experimenters' Reports, attached to the ISEMSI Final Report compiled by NUTEC (to be published shortly). An even more detailed presentation of the study's scientific output will be given by the Experimenters themselves at an ISEMSI Symposium, which is planned to take place in Paris on 25–26 November 1991.

accomplishing a very high percentage of the tasks that had been assigned to them, and even carrying out unplanned repairs to malfunctioning equipment (e.g. an echo-cardiograph) inside the chambers using the most rudimentary tools, and on-line assistance from a specialist at a remote location. The effective workload on the crew turned out to be rather high, peaking at 12 h per day, with some problems being generated by the length and cumbersome nature of certain procedures (e.g. waste water draining, urine collection).

In fact, there were no severe emotional or social conflicts, and no signs of physical or psychological strain, among the EMSInauts during the experiment. The studies on subjective state and Autonomic Nervous System (ANS) showed that the perceived load imposed by the working conditions and prolonged isolation and confinement, was mostly in the middle range. This was also apparent from the very few psychosomatic and anxiety/stress-related symptoms reported, and was also confirmed by psycho-endocrinological analyses (stress hormones in blood, urine and saliva) and psycho-physiology indicators (heart rate, heart-rate variability).

The study of sleep rhythms conducted using the wrist-worn activity monitors (a promising non-invasive technique which was also able to detect increasing tiredness during the course of the isolation) did not reveal major sleep disturbances. However, the monitors did provide a clear picture of the strong adherence of the EMSInauts to their imposed daily and weekly schedule. Figure 1 shows a typical recording pattern for one EMSInaut, covering the complete period of isolation.

The studies of crew performance and cognitive demand showed no changes in performance for simple tasks, but some impairment was detected with an increased level of complication of the task to be performed. This is evident from the Evoked Potential recordings, shown in Figure 2, where the N100 wave (linked to the state of the central nervous system) is unchanged throughout the isolation, while the P300 wave, which represents the response to a cognitive event, shows altered patterns during the second and fourth weeks.

Recorded data suggest that subjects tend to modify their strategy for accomplishing a cognitive task, as has recently been found for other stress conditions also. There are also suggestions that the subject's behaviour becomes more variable and unpredictable as time passes, rather than steadily more impaired. This is evident from Figure 3, which shows one EMSInaut's response times to a memory-exercising task.

The studies of social interaction and communication showed a strong tendency towards increased centralisation within the team over the four-week period. The Commander's importance increased with

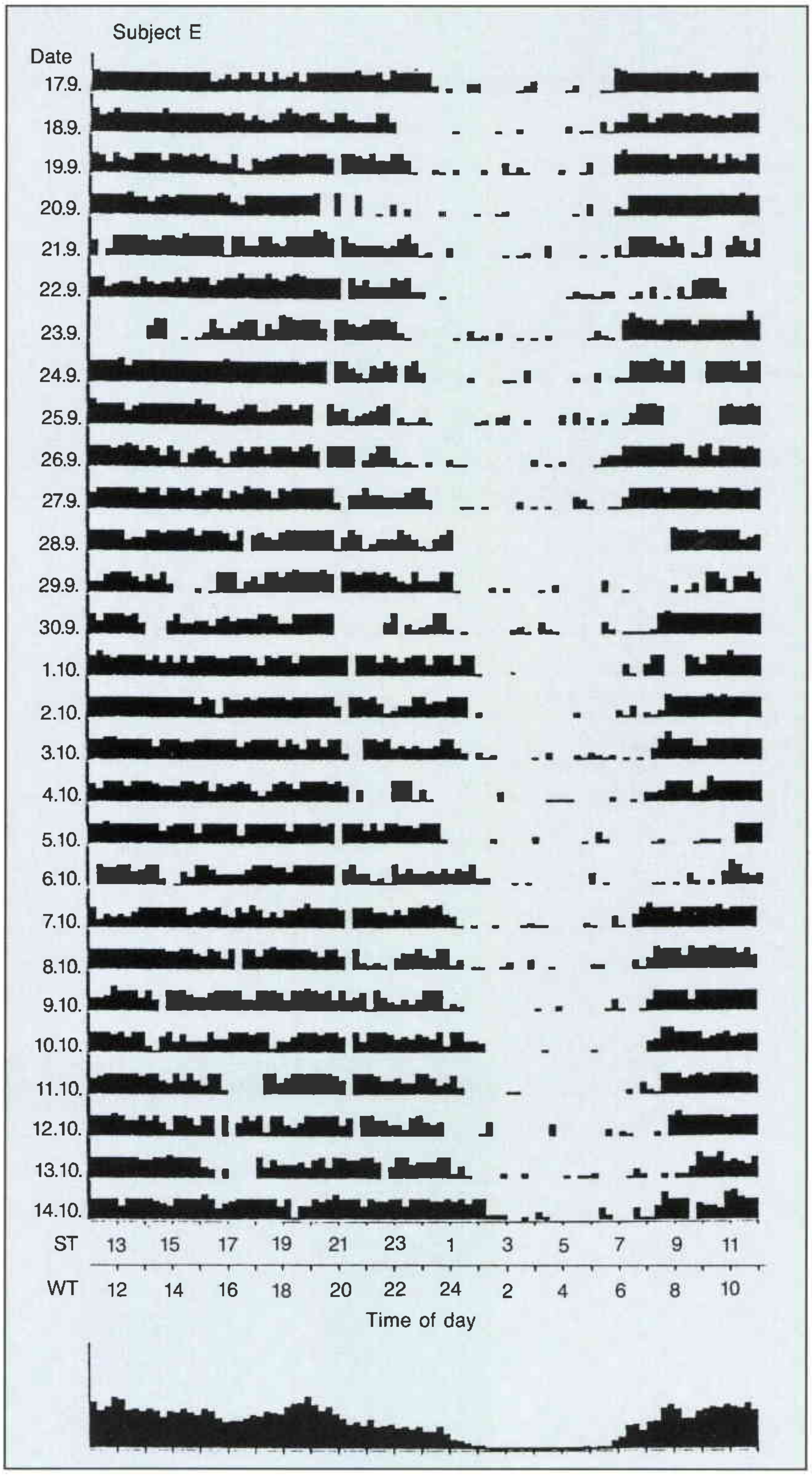


Figure 1. Recording pattern from an activity monitor worn on the wrist by an EMSInaut during his 28 days of isolation. Both summer (ST) and winter (WT) time is given as the switch-over occurred during the experiment. The sum total of all recorded activity is plotted at the bottom of the figure.

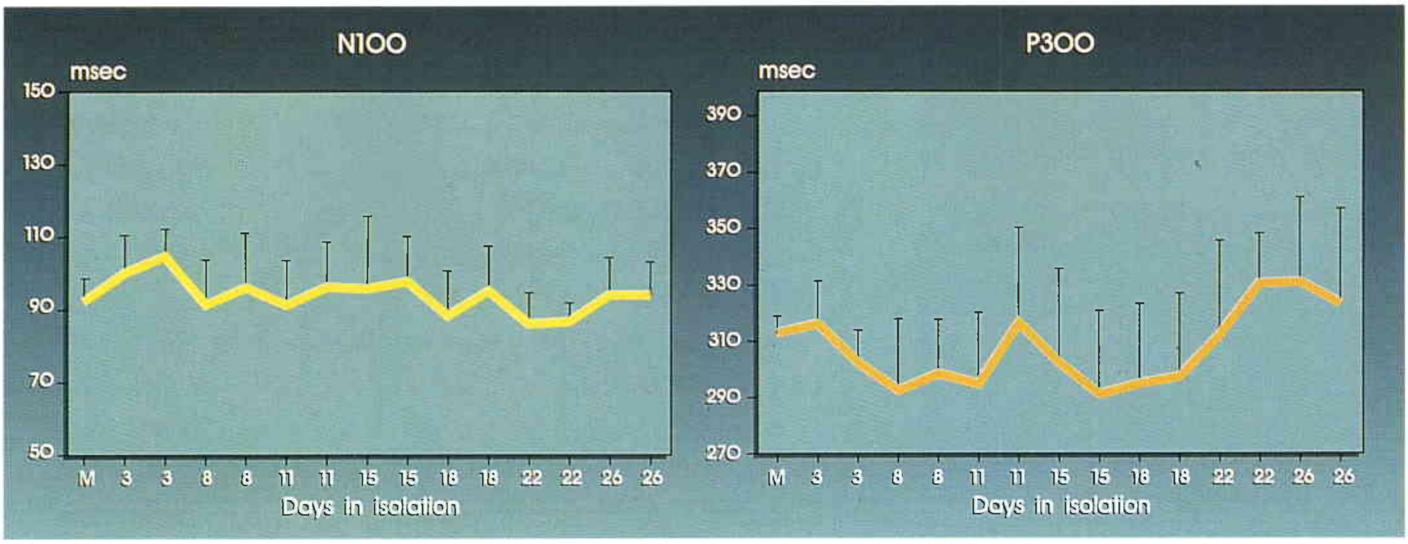


Figure 2. State of the central nervous system (N100 wave) and the response to cognitive events (P300 wave) recorded over the isolation period, averaged over the six-man crew. Note the change in the P300 pattern during the second and fourth weeks.

time, as well as the communication flow to and from him. At the same time, he got gradually less positive evaluations from other team members in terms of how 'well' he was performing as a leader. His popularity increased again after the end of the isolation period, as did that of the other EMSInauts. There was therefore a clear increase in mutual acceptance within the group after completion of the mission.

Figure 4 shows the network of communications established among the crew during 3 days of the isolation period; the thickness of the arrows highlights the process of centralisation.

Generally speaking, the EMSInauts seemed to be closer to each other in interests, background, social habits and skills, and even culture, than a random sample of young men of a particular nationality would normally be.

A significant increase in emotional expression, particularly negative emotions, was evident among the EMSInauts towards the end of the experiment. The crew as a whole felt less goal-oriented and satisfied during the last week of their ordeal. The present hypothesis is that such variations in emotional content are not linked to any particular length of time spent under unusual living conditions, but rather to the dynamics

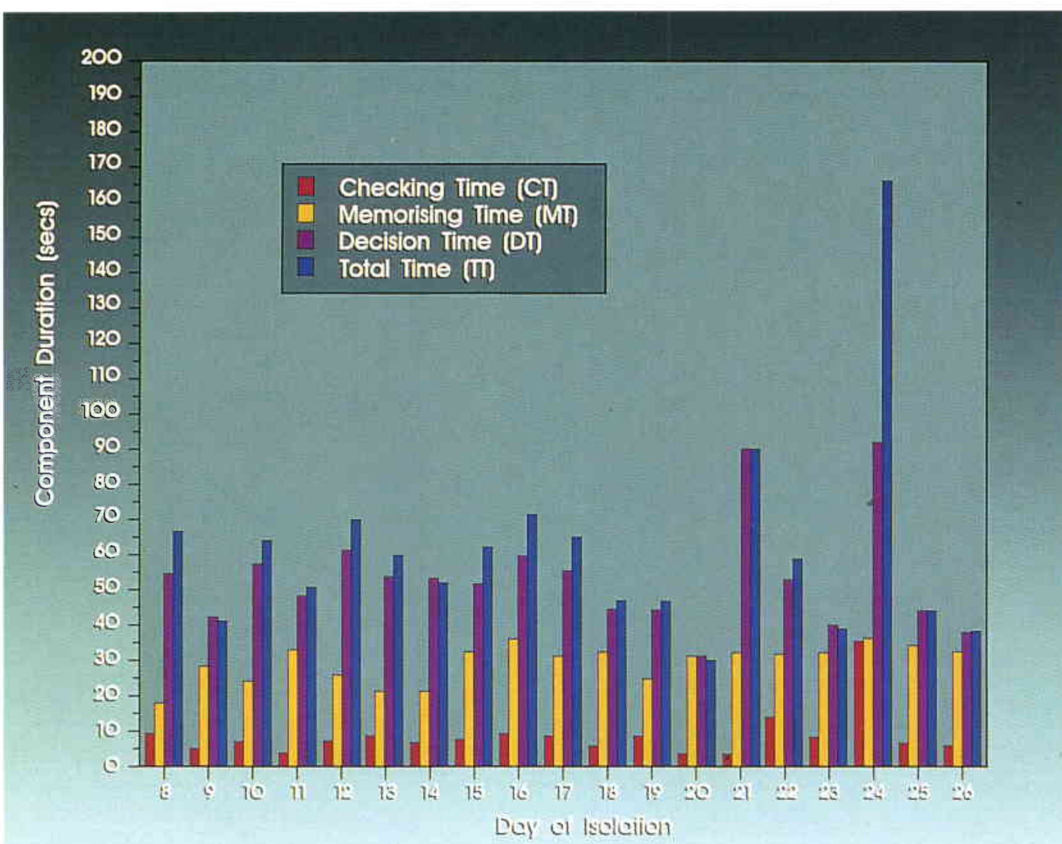


Figure 3. Response times to a memory-exercising task for one EMSInaut over the isolation period. Note the more variable/unpredictable pattern during the fourth week.

of the mission. Thus, they would occur only towards the end of even a significantly longer period of isolation ('light at the end of the tunnel'). This finding may well be the most important single result of the study, and is supported by observations of other groups confined in analogous environments. As a 'hypothesis' it remains to be verified in future studies.

Language was not found to be a problem within the group, which had little or no difficulty in communicating with the outside world. English was used by EMSInauts throughout the experiment, although there were no native English speakers, so that everyone had a comparable 'handicap'. An interesting observation was the clear preference for using the mother tongue in communications with the Experimenters.

The EMSInauts showed high motivation for individual and group success, with an 'esprit de corps' developing among them, and even an 'us-and-them' syndrome ('us' being the crew on board, and 'them' the ground control staff, the two parties frequently having contrasting views and interests). While the crew gradually reported fewer difficulties with ground control as time passed, problems of the 'them' variety were evident again at the very end of the isolation period.

Indeed, some difficulties experienced within the ISEMSI Operations Support Team (IOST) with the management of Experimenter interfaces and with the day-to-day schedule maintenance did create stressful situations for the crew members, who were obliged to act independently from the IOST. This meant, for instance, that the EMSInauts had to contact Experimenters directly in the event of difficulties with their instruments, or had to rearrange their own time allocations. How much such occurrences deviated from a comparable space mission scenario is a matter for further verification.

The physiology-experiment results

The study of endrocrine parameters showed that peak levels of stress hormones occurred during the second week of isolation. This result could be well correlated with other parameters such as the cardiovascular data (heart rate and its variability), as well as with the results of skin-evaporation-rate and skin-lipids measurements. One promising aspect is that the non-invasive measurement techniques (such as evaporation rate) proved their merit in reproducing the same reaction patterns recorded by invasive techniques, and are therefore excellent candidates for space-applied monitoring devices. Further studies to confirm this approach are needed.

Another interesting result, although one that also needs further confirmation, concerns the blood-volume-regulating hormone levels observed during ISEMSI, which may be related to the forced prolonged inactivity to which the crew members were subjected for 28 days. Similar modifications are induced in space by the microgravity environment, which causes a shift in fluids towards the upper part of the body. Consequently, the experimenters believe that long-duration confinement may become a valuable analogue for the simulation of some physiological aspects of spaceflight.

The special environmental features of the ISEMSI study allowed measurement of the total water turnover of the crew, since both the water intake (log book) and water output (urine, evaporation) could be monitored. Under these conditions, the water intake

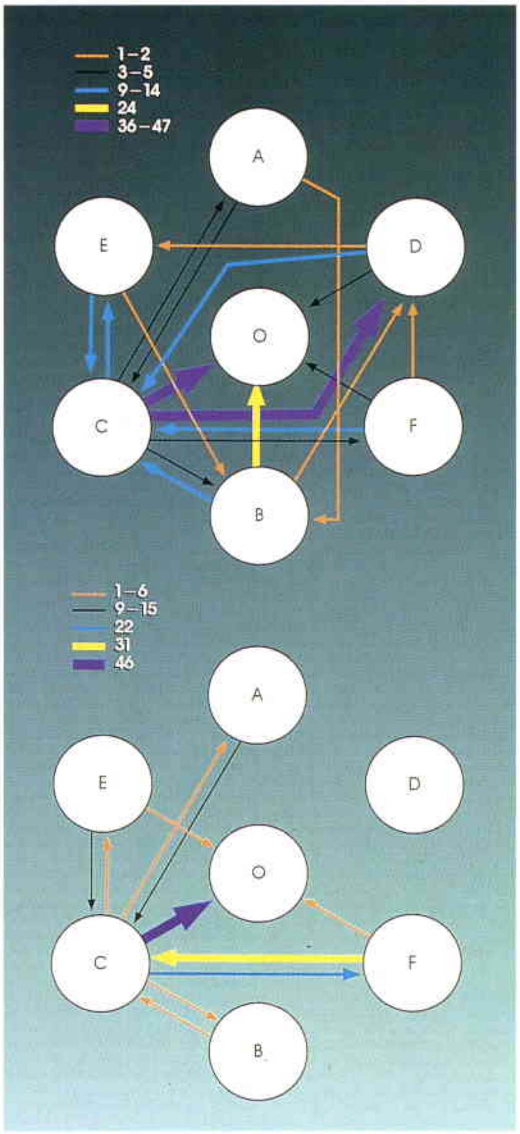


Figure 4. Evolution in the pattern of communications between EMSInauts for Day 2 (top) and Day 26 (bottom) of the isolation period. The increasing tendency for the Commander (C) to address the whole group (O) rather than a particular individual, and the reduced number of communications between individuals, are both apparent here.

correlated very well with the total water output (r=0.81 n <0.05), but evaporative fluid losses, for instance, went hand in hand with low urine outputs and vice versa. A circaseptan rhythm in the water intake, urine output, and sodium and potassium excretion was observed. These rhythms disappeared during the fourth week. This means that physiological data elaborated on Monday/Tuesday differ from the Thursday/Friday values, which could have a considerable impact as far as similar future ground- and space-based studies are concerned.

A Lower-Body Negative Pressure (LBNP) experiment was adopted for ISEMSI on the basis that inactivity and hypokinesia during confinement could be expected to cause some cardiovascular de-conditioning in the subjects and, in particular, orthostatic intolerance. In fact, the results did not show any significant variation in cardiovascular parameters during sessions of LBNP exposure. This was mainly attributed to the fact that the subject's life in the confined habitat did not actually impose a significant drop in their physical activities; even the limited exercise possibilities available in the chambers were sufficient to avoid cardiovascular-deconditioning symptoms.

More difficult was the interpretation of the immunology study results, which were affected by a delay in the blood sampling after the end of the isolation period. Some modifications were indeed noticeable, such as a slight trend towards immune-system activation, with some increase in the lymphocyte count. However, further studies are required before any firm conclusions can be drawn.

Conclusion

In general terms, the goal of autonomy set for Europe pre-supposes the latter's mastery of a number of human-related problems, which are currently only being addressed in the USSR and, to a lesser extent, in the USA.

Already some conclusions can be drawn for Europe:

- Such mastery cannot be gained via theoretical as opposed to experimental study. Human factors can only be studied conclusively by conducting investigations with human subjects in the loop.
- The necessary studies can only proceed at a rate commensurate with the slow adaptive processes inherent in living organisms; in other words, studies of human factors of this nature take time.
- Human-factor studies involve a large spectrum of disciplines, thereby making an interdisciplinary approach mandatory.
- Statistical data are essential where humans are involved.

Studies such as those performed in the framework of ISEMSI are a very rich source of information and help us to begin to establish the database that Europe must have if it is to embark safely on manned system operations in space.

The limitations encountered during ISEMSI as far as the statistical validity of results and their straightforward applicability to space scenarios is concerned have been outlined above. The need to continue and further expand the research is therefore quite clear, and planning has already started of future simulation campaigns, exploiting such diverse analogous environments as undersea habitats and polar expeditions. These will also help to filter out the 'background noise' from the data sets for a particular environment when comparing results from small groups in different settings. It is essential to repeat this kind of study, in order to build up the database, varying different parameters (duration, number and sex of crew members, stress factors, etc.) according to a well-defined study programme over a period of several years.

Many more simulation studies involving humans are necessary in order to model successfully the conditions that our astronauts embarking on future space missions in a European-designed space system will encounter. Some of these simulations should be international endeavours, bearing in mind such exploratory initiatives as a manned mission to Mars. In this respect, the planned 'Arctic Drift', to celebrate the one hundredth anniversary of Fridtjof Nansen's trip across the ice pack, during which a crew will be left isolated for two years in an extremely hostile environment, will provide an ideal analogy for such a flight to Mars.

Interactive Graphical Simulation of Humans in Space

U.K. Mortensen & F. Bagiana
Simulation & Electrical Facilities Division, Automatics & Informatics Department, ESTEC, Noordwijk, The Netherlands

Simulation of the activities of astronauts aboard manned space systems plays an important role in the design and eventual utilisation of such systems. Many design aspects and mission plans are validated by such simulations, which can also play a primary role during astronaut training. Particularly in the early design phases, simulation is often the only means of validating important aspects of the mission design, such as accommodation, accessibility, ergonomics, visibility, operations time-lining, etc.

The dominant factor affecting human activities in space is the absence of gravity. This novel feature also constitutes a strong technical challenge when attempting to achieve sufficient realism in ground-based simulations. Different technologies are used to provide distinct types of simulation, each having its own specific advantages and drawbacks in terms of the degree of realism provided.

Ground-based mock-ups

By building ground-based full-size mock-ups of space systems, very faithful representations of the mechanical and electrical systems involved can be achieved. However, such representations can cover only a small subset of the actual human activities that can take place during flight. An astronaut can, for example, handle equipment weighing (on Earth!) several hundred kilograms with ease, and can access any location by floating to it.

Submerged mock-ups

One way of compensating for Earth's gravity on the ground is to exploit the buoyancy effect in water to achieve so-called 'neutral buoyancy' for the crew members in a tank equipped with submerged mockups of the space systems. This allows the astronauts to handle large or heavy objects more like they can in space, but the electrical and mechanical realism of the mockups suffer from the need to be compatible with water immersion.

The dynamics of and time needed for all movements are also less realistic, due to the friction generated with the water. Since the astronauts need to use diving suits in the tank, a good degree of realism vis-a-vis space-suited operations can be obtained, but the 'shirt-sleeve' working environments of, for example, spaceborne laboratories cannot be simulated in this way.

Parabolic flights

Gravity compensation can be achieved without the drawbacks of water immersion by making what are known as 'parabolic flights'. The aircraft is flown on a near-parabolic curve such that the aircraft's acceleration matches that caused by gravity inside its cabin. Those in the aircraft thereby perceive no gravity during the flight along the parabolic path, and are rendered 'weightless' for some 15–20 s at a time. Other constraints of this approach are the residual accelerations due to imperfections in the flight path,

Figure 1. ESA astronaut Wubbo Ockels at work during a Spacelab flight.

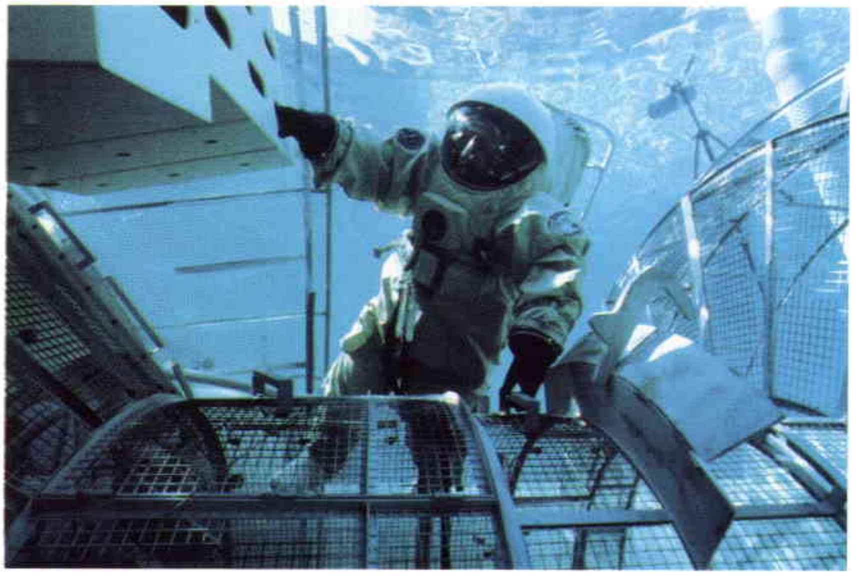


Figure 2. Neutral-buoyancy simulation for EVA in space.

combined with the obvious operational and accommodation constraints.

Analytical simulation

Analytical simulations of human activities, relying on Computer-Aided Design (CAD) tools to represent the movements graphically, are also used for space mission modelling. The main advantage here lies in the versatility available to study different design configurations, and the highly accurate representation of the structural environment. Since no interactivity is possible, however, and only static snapshot-like outputs are produced, this method is mainly applicable to the study of accommodation tolerances and the verification of mechanical-engineering designs (Fig. 3).

Graphical simulation

A new alternative for simulating astronaut activities in space has recently emerged as a result of the technological advances made in the last five years in four particular areas:

- Relatively inexpensive computer work stations can now provide the massive computational power required to calculate the complicated movements and articulation of human motion in space. Previously, such computing power was only available on large and very costly mainframe systems.
- Recent advances in computer-generated graphics now allow the production of images with photographic realism, at a rate enabling continuous motion to be visualised.
- New developments in the mathematical formulation of the dynamics of multi-body problems have resulted in very efficient mathematical models, thereby allowing realistic real-time simulation of the many elements and degrees of freedom of the human body.
- New devices have been developed that allow the user to interact with and control the many degrees of freedom in an intuitive and interactive manner. An example of such a device is the data-glove, which can emulate the many degrees of freedom of the human hand.

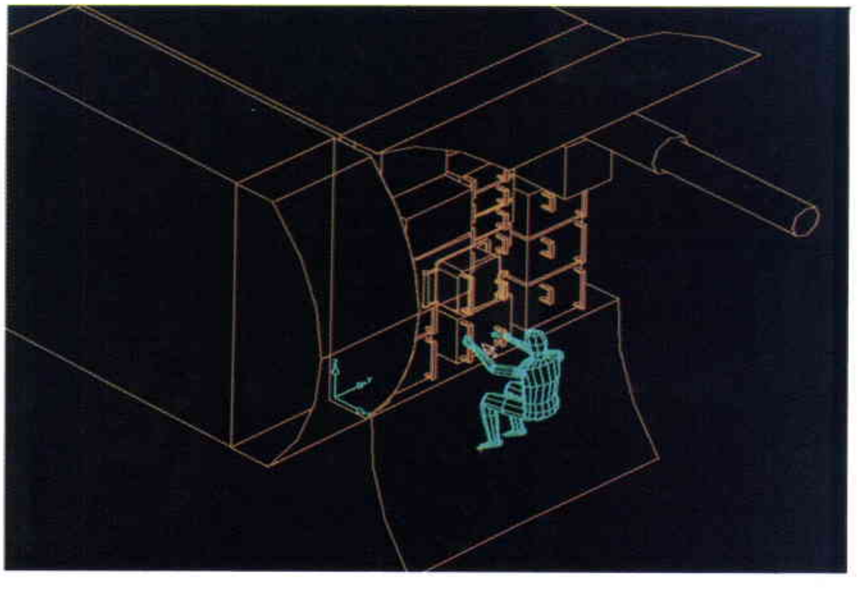


Figure 3. CAD simulation: Columbus Free-Flying Laboratory servicing.

By combining these technological ingredients into a single system, the Agency has been able to develop a new means of simulating man's activities in space. The first results of this 'DYNAMAN' activity have led to an operational system in the form of a software package implemented on a Silicon Graphics work station.

DYNAMAN allows the kinematics of mechanical systems, including humanoid models, and the interaction between the various models and their environments, to be simulated and examined on the screen in real time. Typical fields of application for the system in the space context include:

- astronaut motion and trajectory studies
- habitability and working-environment design and validation
- object manipulation in a complex environment
- spacesuit design validation
- kinematic simulation of extravehicular activities.

To facilitate realistic simulation, DYNAMAN includes in its geometrical database three-dimensional graphical models of astronauts of different physical builds. It also takes into account the fact that after some 30 h in space, the average astronaut increases in height by 3% due to spine straightening. Each DYNAMAN humanoid model is based on twenty-two major anthropometric meas-

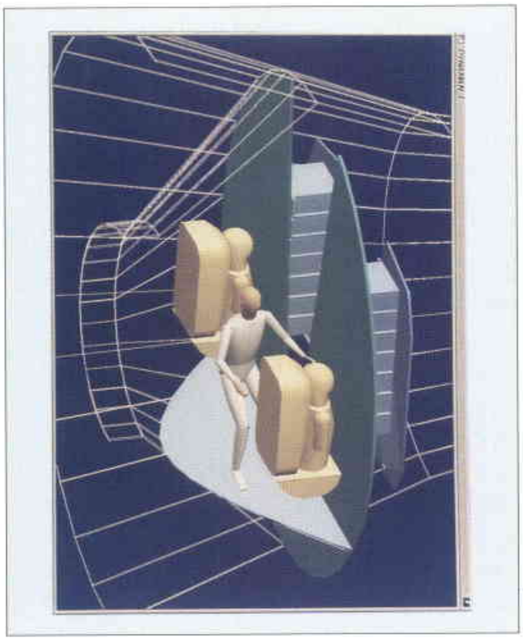


Figure 4. DYNAMAN: Hermes Resource Module and space suits.

Figure 5. DYNAMAN: Hermes EVA egress.

urements, derived from an international human biometry and ergonomics databank. The database includes both 'naked' models of differing statures under 1-g and zero-g (microgravity) conditions, and space-suited models for EVA simulations.

Each geometrical model has an associated mathematical model, simulating the biomechanical behaviour of the anatomical joints, except for the fingers and feet where only one joint has been modelled, and for the spine which has been simplified to consist of just two joints. Thus a 'naked' model has thirty-nine angular degrees of freedom, and a space-suited model thirty-six. The mathematical model includes biomechanical limits for each joint, so that unrealistic human motions cannot be generated. In the case of the space-suited model, the limits are generally those imposed by the suit.

The DYNAMAN database also contains pre-defined postures, both to facilitate the manipulation of the humanoid models and to allow the simulation session to commence from a realistic initial position. These pre-defined postures are:
- a standard standing posture in 1-g conditions
- a relaxed posture in zero-g conditions, and
- a seated and a transfer posture under zero-g conditions (to be implemented).

A virtual camera is coupled to each humanoid model's head, allowing the astronaut's field of view to be visualised.

DYNAMAN is an 'open system', which means that geometrical models can be imported from other commercial Computer-Aided Design (CAD) packages used in the aerospace industry, such as CATIA, EUCLID and ESABASE. In addition, DYNAMAN allows the user to create kinematic models of mechanisms which, like the humanoid model itself, can be controlled interactively during the simulation session. All in all, therefore, the DYNAMAN user is able to generate a complex and realistically simulated space working environment.

DYNAMAN also includes two other major features: collision detection and configuration change. The collision-detection feature runs throughout a simulation session and alerts the user to any collision detected between the humanoid model and its environment. This is a highly valuable input when space

Figure 6. DYNAMAN: Columbus rack manipulation.

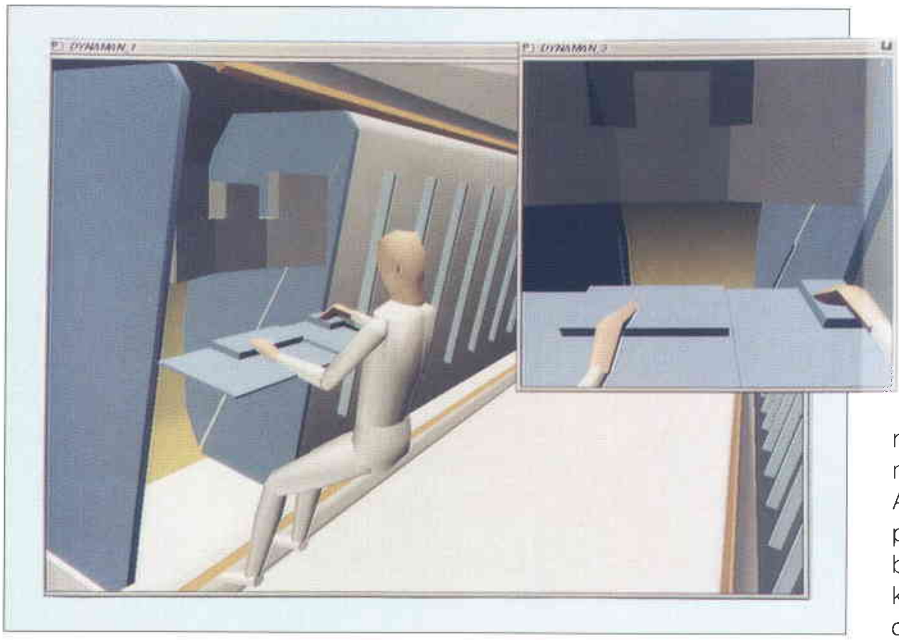


Figure 7. DYNAMAN: Columbus' Crew Work Station.

accommodation and astronaut trajectory studies are being performed. The configuration-change feature allows the user to link objects together interactively. This feature can be used, for example, to simulate the grasping and manipulation of an object by the humanoid model's hand or to attach the model to the end effector of the Hermes Robotic Arm (HERA) for combined HERA/EVA simulation studies.

As already noted, DYNAMAN is a real-time simulation system (10 frames per second) and therefore the interface with the user is highly interactive. Its main features in this respect are the ability to:
- activate up to six parallel views of the simulation scene
- control the viewing-point characteristics per view
- activate and control the lighting conditions (with up to six light sources)
- activate and control virtual cameras
- record and play back the simulation session
- control the humanoid model's motion
- control the motion of other mechanisms.

Figure 8. DYNAMAN: Rack manipulation.

One of the main goals with the DYNAMAN system is to graphically reproduce truly human behaviour. Specific emphasis has been put on controlling the model's various joints to generate natural motions, without having to command the many degrees of motion individually. Algorithms for typical movements such as push/pull, reach, grasp, rise/sit, etc. have been incorporated so that just by turning a knob the user can control the execution of a complex movement. Because the variety of human movements is extremely wide, the user can also command each joint individually, if so wished, to produce the desired movement.

To prepare and run a simulation session, the typical procedure is to: import the desired environment designed on a CAD system; create kinematic models of mechanisms if required; execute the simulated scenario by controlling the humanoid models and the mechanisms interactively; and record the session on disk for subsequent analysis.

During the first year of its existence, DYNAMAN has been used to perform a number of important case studies, including:

- trajectory to egress and ingress Hermes during EVA
- identification and improvement of the astronaut's field of view when wearing the EVA helmet
- single- and double-rack manipulation within the Columbus modules
- design and pre-validation of the Columbus crew work-station layout
- positioning of the Columbus Attached Pressurised Module's interior cameras for monitoring purposes
- interior architectural design for the European Manned Space Infrastructure (EMSI) Project.

The results of the studies are in a form of a written report, supported by a video tape containing the graphical animation. The simulation session, composed of files containing the geometrical and mathematical models, is archived on disk and can therefore be used for additional investigations.

Despite the fact that DYNAMAN is an unique system due to its high performance, it still does have some limitations and efforts are in progress to further improve it. For example, the DYNAMAN humanoid models simulate the actual motion (kinematics) without calculating the underlying forces and accelerations (dynamics). This approach is well-suited for the current application areas where the motion, rather than the forces and accelerations, is known in advance.

However, the multi-body simulation model embedded in DYNAMAN does also support the calculation of the full dynamics. Inclusion of this capability has therefore been considered in the programme of further developments, which will allow new application areas to be treated. These could include calculation of the forces exerted by an astronaut during a rack exchange manoeuvre, or the body strain imposed during the transportation of an astronaut by a space robot.

A limitation also remains in the method used to reproduce complex human movements under microgravity. Few data are available on astronaut comfort in terms of postures and movements, those that are available originating primarily from NASA's Skylab and some Russian missions. Currently it is very difficult to extract the necessary algorithms. To remedy this, an experiment for the Columbus Precursor Flight Programme, namely the 'Anthropodynamics Experiment', has been proposed to acquire numerical data and create a database on astronaut motion. As well as containing valuable items such as algorithms to drive the DYNAMAN humanoid models, this database will provide the user with feedback concerning both the comfort and efficiency of a given posture.

The interface between DYNAMAN and the user is another key element of the system. The feasibility of replacing the traditional input/output devices by a more sophisticated technology, know as 'virtual reality', is currently being investigated. A helmet-mounted display with a head-movement tracking system will then replace the colour monitor, providing the user with a stereoscopic view of the simulated scenario.
A pair of 'data gloves' worn by the user will allow virtual objects to be manipulated and provide tactile feedback. The glove has optical sensors stretched along each finger and across the palm, so that it can report the changing configuration and position of the hand to the computer to drive the simulation (Fig. 10).

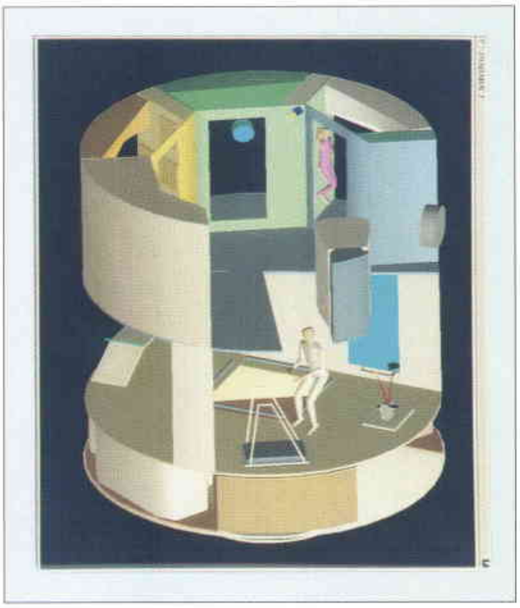


Figure 9. DYNAMAN: Habitability study.

Figure 10. Data glove.

The data gloves will also be used to control the humanoid model's displacement through a virtual interface, instead of the current mouse and dial/button box interfaces. The goal is to be able to totally immerse the user in the simulated environment.

A programme of work that melds the capabilities of these two new technologies is now under way at the Agency.

Acknowledgement
The DYNAMAN activity was initiated at ESTEC and the main development work has been undertaken under contract to ESA by the Centro Estudios d'Investigasione Technica in San Sabastian (Spain), in collaboration with the Laboratoire d'Anthropologie Appliquée in Paris (France).

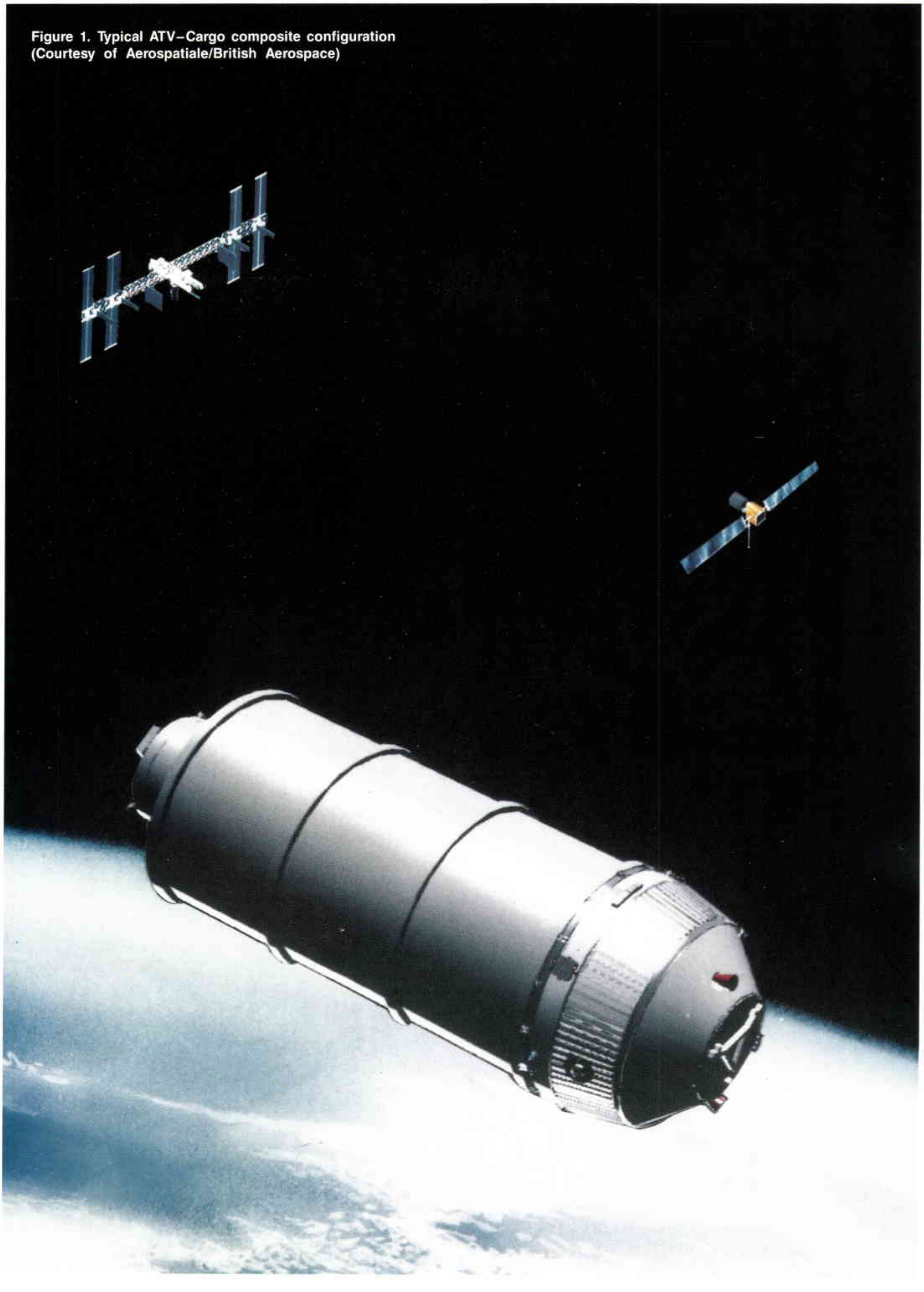


Figure 1. Typical ATV–Cargo composite configuration (Courtesy of Aerospatiale/British Aerospace)

The Ariane Transfer Vehicle (ATV) System Studies

U. Thomas & A. Thirkettle
STS Technology Programme and Projects Office,
ESA Directorate for Space Transportation Systems,
ESTEC, Noordwijk, The Netherlands

Within this decade, NASA and its partners, including ESA, will build an in-orbit infrastructure which will require periodic resupply, servicing and removal of waste products. The current planning foresees the Shuttle, and at a later stage Hermes, as the only systems performing this service. The high-performance Ariane-5 vehicle, if combined with an 'intelligent' expendable upper stage (Fig. 1), could provide Europe with an alternative cost-effective means of supplying logistics cargo and building elements to the International Space Station 'Freedom' (SSF) and a European Manned Space Infrastructure (EMSI).

Introduction

ESA first initiated studies of an 'Ariane Transfer Vehicle' (ATV) in 1986. The main purposes of this vehicle, which is a smart, expendable transfer stage derived from hardware already under development, are to:
- provide a cost-effective, expendable orbital transfer system
- transport a variety of cargoes from injection orbit to a circular Low Earth Orbit (LEO) and navigate to/rendezvous with existing in-orbit-infrastructure elements
- enable the cargo to be exchanged at the infrastructure element
- minimise the impact of logistics resupply on in-orbit-infrastructure element operations
- de-orbit itself or/and cargo containing waste products to a safe, destructive but controlled re-entry
- support construction and logistics for SSF and/or EMSI.

To meet all of these requirements, the ATV has to be a versatile vehicle capable of accommodating a large number of different cargoes, such as are depicted in Figure 2. The variety of cargoes that can be transported by an ATV, especially an ATV in combination with a pressurised/unpressurised logistics carrier, makes it the basis for a logistics vehicle.

Two conceptual approaches are currently under study. The first is based on the existing Ariane-5 upper stage and Vehicle Equipment Bay (VEB), with some enhancements to meet ATV mission requirements. In this scenario, the VEB would provide nominal guidance to Ariane-5 during ascent and would serve the ATV after separation. The second concept does not incorporate any Ariane-5 functions into the ATV and would replace the upper stage. It is therefore not limited by potential constraints of existing upper stages.

Both concepts need to be able to:
- transport a variety of cargoes from an Ariane-5 injection orbit to a circular Low Earth Orbit
- perform proper phasing and rendezvous with an infrastructure element
- provide the means to be grappled and berthed by the in-orbit element
- be attached externally to an in-orbit element and stay there for up to six months
- allow for payload and/or cargo carrier exchange
- be released from the in-orbit element and perform a controlled, destructive re-entry.

Depending on the final design selected for the ATV, launchers other than Ariane-5 could be used, such as the American Titan-IV or Japanese H2.

ATV reference mission

Mission analyses have shown that a mission to Space Station Freedom (SSF) would envelope most of the constraints of the other missions envisaged and it was therefore chosen as the reference. The principal mission scenario is illustrated in Figure 3.

In this scenario, the ATV–Cargo composite will be injected by the Ariane-5 lower composite into an elliptical orbit with an inclination of 28.5°. The SSF is in a circular orbit between 330 and 500 km altitude. The ATV orbit-phasing capability of 360° maximum was mandated to avoid imposing restrictions on launch date and launch time. The ATV–Cargo composite will circularise its orbit at the SSF altitude after proper phasing.

Some fine tuning will bring the ATV–Cargo composite to the edge of the SSF's Command and Control Zone (CCZ), which is a 'shell-type' safety zone around the Station. The edge of the CCZ represents a hold point, where the ATV's health status will be checked. The ATV will enter the CCZ only after an authorising command. Several hold points are incorporated in the approach trajectory marking events where, for example, changes from free drift to forced trajectory, or from hot-gas to cold-gas propulsion systems, take place.

In the event of an anomaly occurring between hold points, the ATV will retreat to the previous hold point. The failure will be analysed by the onboard fault-detection and recovery system and the operations centres. The spacecraft will then be reconfigured and a decision taken to continue the approach or abort the mission, depending on the particular failure and the recovery action needed. Inside the CCZ, the SSF crew will have a manual-override capability to abort a rendezvous manoeuvre if necessary.

The proximity operations end with the ATV–Cargo composite reaching the berthing box where the Remote Manipulator Arm (RMS) of the SSF will grapple it and transfer it to the desired location at the SSF.

The composite will follow a so-called 'safe trajectory' inside the CCZ, which means that in the event of a failure it will always drift away from the SSF, thereby avoiding any possibility of a collision. The ballistic factors of both the target and the chaser must be known and intensive mission analysis must be undertaken to ensure both short- and long-term safety.

The nominal time between launch of the ATV–Cargo composite on Ariane-5 and berthing at the SSF will be no more than 48 h. However, the design allows for an additional contingency of 40 h to support the 'hold point' activities. Due to the SSF safety and contamination requirements, it is currently assumed that the use of hot-gas systems in the vicinity of the SSF might not be permitted. A cold-gas system has therefore been included for use over the last 100 m of the approach trajectory.

The ATV will be in a nominally dormant mode during the attached phase. This means it will draw some power from the SSF and provide a data interface for critical-parameter health monitoring; however, no direct thermal interface to the SSF is foreseen. The stay time of up to six months requires careful analysis of the meteorite and debris protection that might be needed for the ATV's subsystems.

The departure from the SSF will be initiated by moving the ATV–Cargo composite with

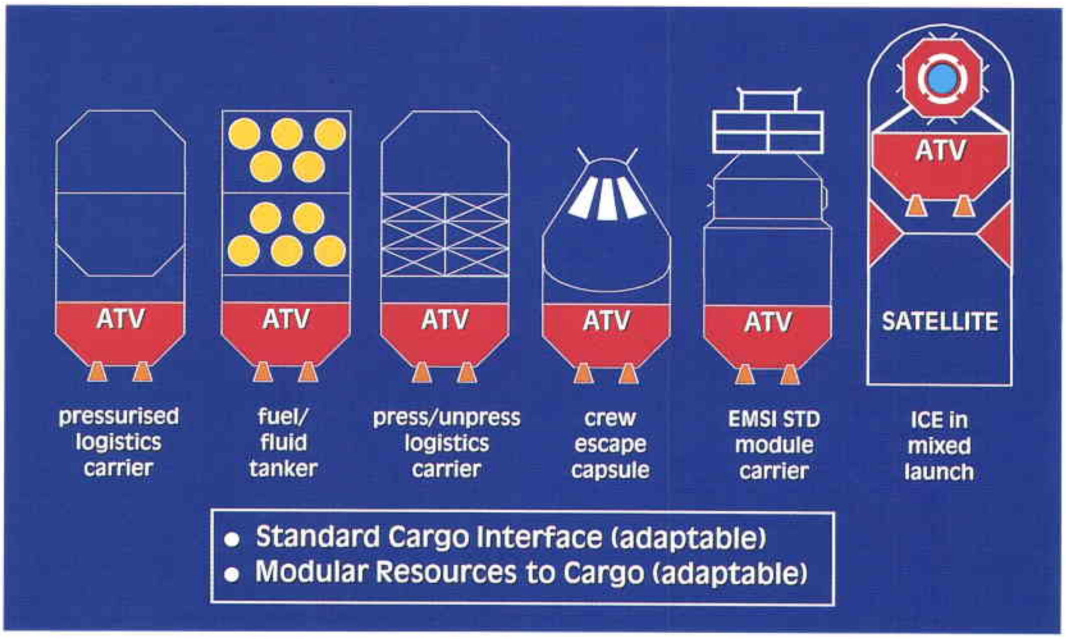


Figure 2. Potential ATV cargoes

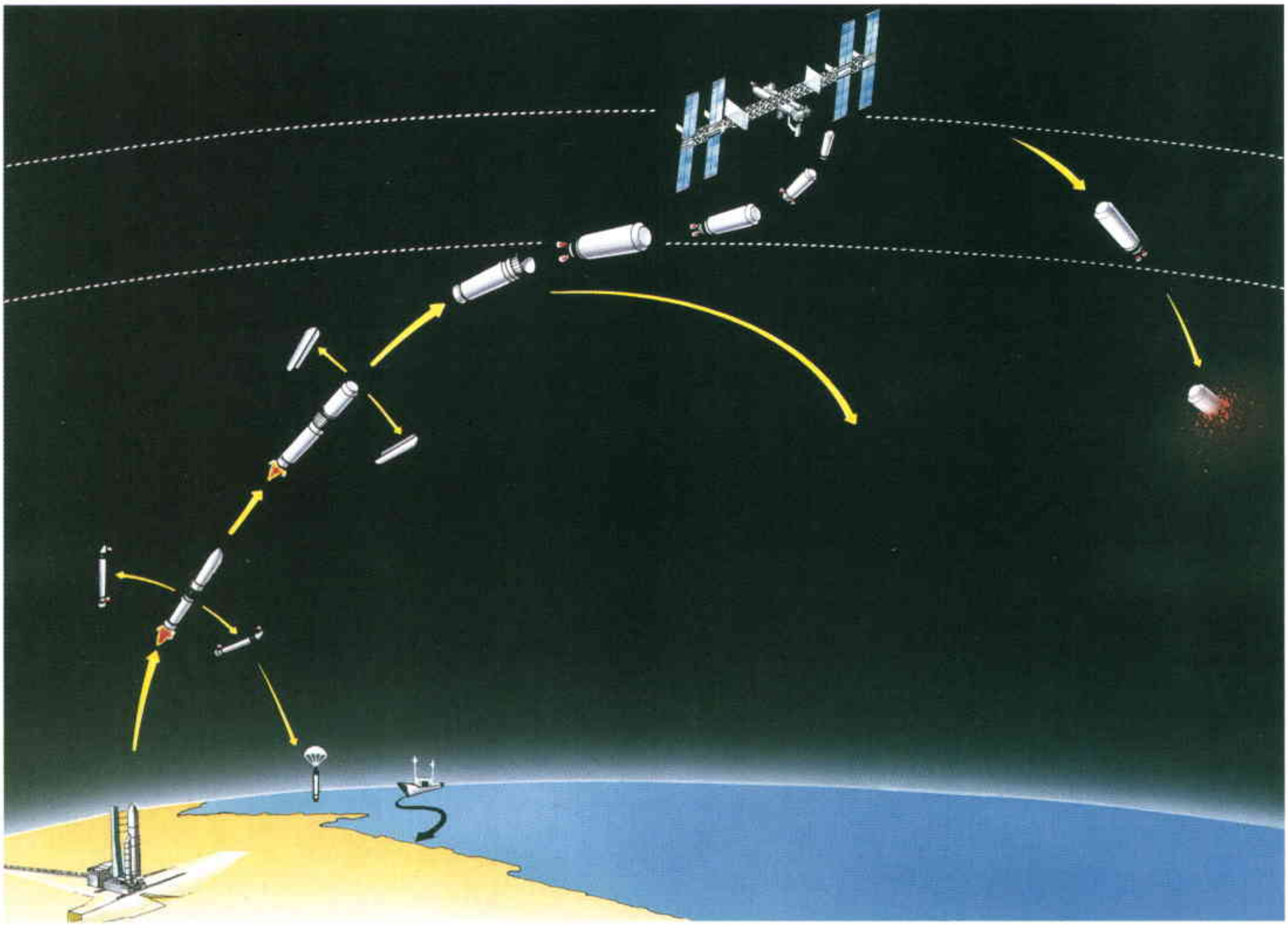


Figure 3. ATV reference-mission scenario (Courtesy of Aerospatiale/ British Aerospace)

the RMS to a pre-determined position below the SSF. After release from the RMS, the ATV–Cargo composite will drift away on a safe trajectory. About two orbits later, the ATV's main engines will be ignited to put the composite on a safe re-entry trajectory. As an alternative to the free-drift method, the use of the cold-gas system could be considered to lower the perigee faster.

The de-boost strategy and the thrust level of the ATV main engines are related because of the relatively high delta-V requirement. This could mean an extended burn duration for low-thrust engines, for which they might not be qualified. If small main engines were to be used, a multiple-burn strategy could overcome this problem.

Typical delta-V values (without margins) for the reference mission are as follows:

Propulsion system	Delta-V (m/s)
Bi-propellant	186 for ascent 127 for descent
Hot gas	10 total
Cold gas	8 total

ATV design drivers

Ariane-5 LEO capability

The total ATV–Cargo composite mass must not be more than 23 000 kg injected into LEO. In order to benefit from potential Ariane-5 growth, the ATV itself is being designed for an assumed total composite (i.e. ATV plus cargo) mass of 25 000 kg.

Safety and failure-tolerance requirements

The ATV will approach a manned vehicle in space. Strict failure-tolerance requirements and safety factors must therefore be imposed on the vehicle to ensure proper levels of reliability and safety during all mission phases. A controlled de-orbiting manoeuvre has to be possible at any time and the system has to have a fault detection, isolation and recovery capability.

Micrometeorite and debris protection

The in-orbit stay time of up to six months and the requirement to be able to withstand micrometeorite impacts with a probability of 99.5 % influences the overall architecture. Most vulnerable to impacts are the propellant tanks and the electrical equipment. The electrical equipment, however, is redundant to fulfil the failure-tolerance requirement, and therefore the main effort has to be directed towards the tanks.

Propulsion

The propulsion system has to:
- provide the required delta-V's for orbit transfers
- guarantee attitude and orbit control throughout the mission
- ensure a controlled re-entry after two failures inside the CCZ or one failure outside the CCZ
- satisfy SSF safety requirements.

A bi-propellant system is the most efficient solution for orbital transfers. A trade-off study for the attitude and orbit control showed that a cold-gas system alone would be much too heavy, and an additional hot-gas system is therefore required. The final choice of propulsion-subsystem constituents is based on accommodation criteria.

Communication

The ATV must communicate with ground stations, in-orbit-infrastructure elements, the GPS navigation system, Ariane-5, and potentially the Data-Relay Satellite also (currently being evaluated). Communication links in the Ku-, S- and L-bands are required. The overall system communication links are shown in Figure 4.

ATV designs

As mentioned above, two different design approaches, denoted here as Concepts 1 and 2, are under study. One based on upgrading Ariane-5 items was chosen as likely to be the cheapest to develop. The other – a dedicated design 'optimised' to meet the specific requirements – was chosen as likely to lead to the most operationally efficient system. A choice between the two would be made based on overall life-cycle cost efficiency.

Concept 1: ATV based on an existing upper stage and the Ariane-5 Vehicle Equipment Bay

This design is derived from the baseline Ariane-5 upper stage (EPS) and consists of an upgraded upper stage, an upgraded Vehicle Equipment Bay (VEB) and a new adapter design (Fig. 5).

The Ariane-5 upper stage will need both upgrading and man-rating, especially in the following areas:
- structure (for extra cargo mass)
- bi-propellant propulsion system (for fault tolerance)
- thermal protection (for up to six months in orbit)
- electrical systems (for fault tolerance and six months' durability).

The VEB will require enhancements in:
- structure
- hydrazine attitude-control system
- avionics

for reasons similar to those cited above.

The adapter is a new development which serves as the interface and load-carrying structure between cargo and VEB/EPS. It houses the power supply, data-management (DMS), communication, guidance, navigation and control (GNC), and cold-gas systems.

The propulsion system requires considerable modification to meet the safety requirements

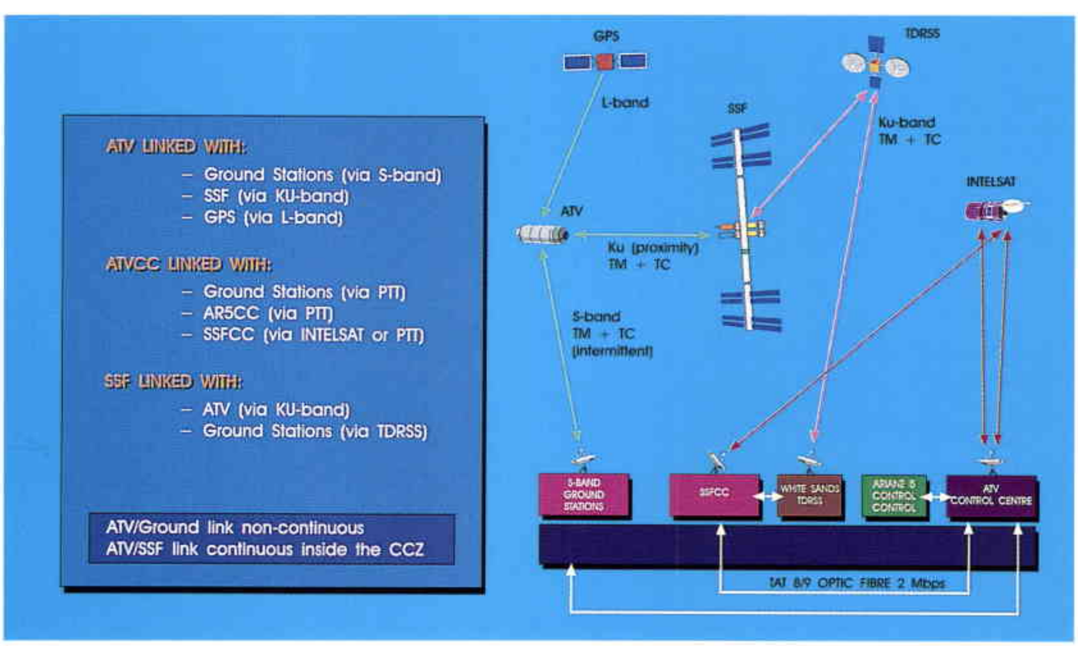


Figure 4. ATV system end-to-end communications

for approaching a manned Space Station. The accommodation of the additional equipment is a major challenge in this design. The bi-propellant and the hydrazine systems are upgrades, while the cold-gas system is an added feature.

Electrical power is supplied by batteries only. Hermes-type lithium cells are physically clustered in packages of two cells. The total capacity of all batteries is 126 kWh, which includes about 50 kWh for subsystems, 50 kWh (mission-dependent) for cargo, and associated margins. The electrical power is distributed via three power distribution boxes and three buses. The voltage at equipment level of 52 V is compatible with Ariane-5 basic equipment. During the time the ATV is attached to an in-orbit element, the latter will supply power to the ATV for vehicle subsystem status monitoring and, if necessary, to heaters.

The thermal-control subsystem is passive, i.e. no fluid loops are used. Multi-layer insulation, paints and heaters are sufficient to keep the temperature within the limits required for all mission phases. Heaters may become necessary only for tanks, piping and thrusters.

The avionics architecture is an upgraded version of the standard Ariane-5 system, with some equipment like star sensors and GPS receiver added. A third bus is implemented to fulfil the two-failure-tolerance requirement. In addition, the buses are interconnected in such a way that any of them can control all of the equipment. High-level monitoring of system performance and health is conducted using a switching logic that is able to delegate the master role to any of the onboard computers in order to guarantee the requisite autonomy during flight. When attached to an in-orbit element, the avionics subsystem is in a dormant mode.

The communication subsystem uses a communications process formatter for the interface between the ATV avionics buses and the communications equipment. It allows high-level telecommands from the ground to be passed directly to the equipment. The S-band ground link uses 10 kbit/s for the downlink (including cargo provisions) and 2 kbit/s for the uplink. Communication with in-orbit elements is performed via Ku-band using three channels.

The closed-loop GNC subsystem compares the reference trajectory with the calculated current trajectory based on sensor inputs.

During launch, the inertial reference units of the nominal VEB are used. These inertial reference units are updated several times during phasing operations to compensate for any drift. The attitude measurements are updated with the help of coarse star sensors (flown on ECS). Absolute position is determined with the help of the GPS navigation system. Differential GPS is used inside the CCZ for relative-position measurement. In the vicinity of the SSF, rendezvous sensors will be employed for the final approach. The two-failure-tolerance requirement means that all sensors will have a redundant backup except the inertial reference units, which are triplicated.

Figure 5. ATV derived from Ariane-5 upper stage and VEB: Concept 1 (Courtesy of MBB-ERNO/ Matra)

Concept 2: ATV as payload to Ariane-5

This concept employs the Ariane-5 version without an upper stage. The ATV–Cargo composite is considered to be a standard payload, which is accommodated under a standard fairing using the standard launcher interface. The launch processing is identical to that for a normal satellite launch. The ATV–Cargo composite therefore does not affect the launcher's ascent control hierarchy.

This concept is not based on existing upper stages and therefore the design can be optimised according to the specific mission's requirements (Fig. 6).

An enveloping structure was chosen as the best means of solving the micrometeorite problem, the external structure serving as the first wall and the electronic case or the tank as the second. Antennas and sensors are accommodated on the maximal diameter at the cylindrical shell. Electrical equipment is concentrated on dedicated panels following the equipment-bay approach.

Two gimballed bi-propellant thrusters are located in the lower conical shell. Attitude-control and cold-gas thrusters are grouped in common pods since they have to perform similar tasks. The numbers and locations of these pods are derived from controllability and safety requirements.

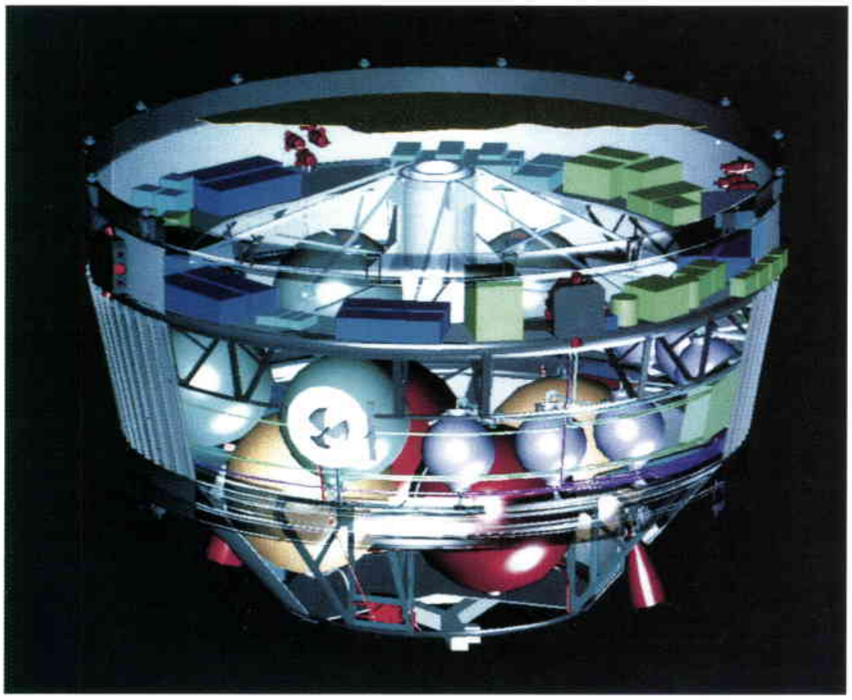


Figure 6. ATV as payload to Ariane-5: Concept 2 (Courtesy of Aerospatiale/ British Aerospace)

The power subsystem uses lithium-thionyl-chloride cells, as foreseen for Hermes. The total ATV mission power requirement, including margins, is in the order of 50 kWh. A further mission-dependent set of battery kits can be added to provide up to 50 kWh of power to the cargo. A voltage of 28 V was selected for safety and qualification-status reasons, and therefore power interface units to Ariane-5 and the SSF are needed.

Thermal control will be achieved via passive means such as multi-layer insulation, paint and heaters. The worst case is the cold one, requiring a metallic shell to dissipate the internal fluxes. Heaters will be necessary for tanks, feed lines and batteries.

All elements of the avionics subsystem are triplicated, with the exception of the gyros, which have internal redundancy. Each computer monitors the information of other buses and compares the outputs to detect failures. The first failure is coped with onboard, while a second failure stops the system in a controlled manner, enabling the operations centre to diagnose the failure and reconfigure the mission.

The communication subsystem uses S-band for the ground link, with a data rate of 1.5 kbit/s for both the up- and down-links. Inside the CCZ, Ku-band communication is used, with a forward and backward data rate of 4 kbit/s. The GPS signals are received via L-band. The proposed architecture optimises the use of equipment that is common to the S- and Ku-bands.

The GNC subsystem consists mainly of computer, coarse Sun and conical scanning Earth sensors, rendezvous sensors and inertial reference units. The interface to the data-handling system has to allow rapid access for safety-critical operations. Both systems therefore run independently, at the same time offering a communication link between them with minimum delay.

Concept comparison

A brief comparison of the propulsion systems and the overall mass budgets is given in the two accompanying tables (Tables 1 & 2).

The propulsion systems strongly reflect the ground rules under which the respective studies started. However, neither concept would need specifically developed hardware, although additional qualification will be necessary due to configuration modifications.

Table 2 gives a mass and performance comparison for a 500 km circular SSF orbit. The Ariane-5 VEB mass has to be added to the Concept-2 mass budget in order to allow a proper performance comparison.

In addition to the technical performance parameters, production and integration aspects are of major importance. The 'man-rating' of the standard Ariane-5 upper stage (Concept 1) has proved to be difficult. The accommodation of the additional equipment needed (extra valves in the bi-propellant and hydrazine systems, adding of a cold-gas sytem, etc.) causes problems. All in all, it appears that both studies are converging towards a single design solution.

ATV programmatics

Figure 7 shows a potential development plan, which foresees a five-year development

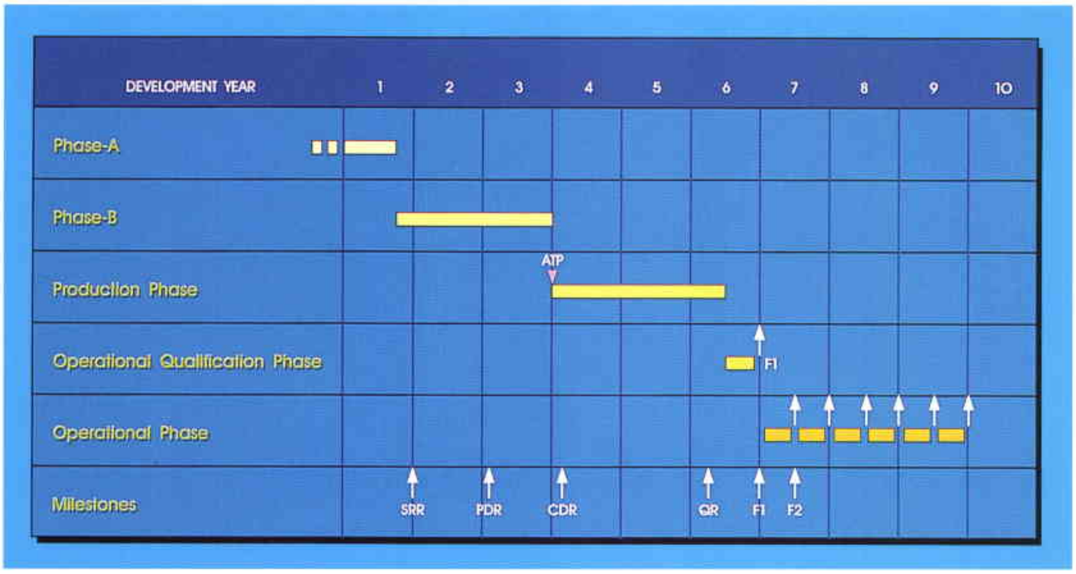


Figure 7. Potential ATV development plan

phase with one protoflight model. An ATV could therefore very well be available in the second half of 1990s. Typical recurring production times for a flight unit would be around 30 weeks for manufacture, 15 weeks for integration, and 15 weeks for tests, giving a total of 60 weeks.

Analyses have shown that no additional ground facilities would be required for either of the concepts for pre-launch processing or for in-orbit operation.

The current assumption is that an ATV qualification flight would be necessary before declaring the system operational. This flight could well be used to validate rendezvous techniques, not only for the ATV itself but also for Hermes and the Columbus Free-Flying Laboratory, thereby benefitting those projects also.

Current analyses show that during the building of Space Station 'Freedom' up to eight NSTS (National Space Transportation System/Shuttle) flights per year could be necessary. The permanently manned Station will subsequently require about five dedicated NSTS flights per year to cover crew rotation, experiment exchange, and logistics resupply (spares, consumables and expendables). The ATV–Cargo delivery capability is comparable to that of the NSTS, and therefore the availability of an ATV-type vehicle for SSF operations could relieve the Shuttle schedule and provide a viable backup system to the NSTS for SSF resupply.

Conclusion

Two different ATV concepts have been analysed, both of which make use of hardware that either already exists or is under development. ATV-type vehicles could deliver in-orbit-infrastructure building elements and logistics resupplies at competitive costs. The maturity of the studies would permit an early programme start if so desired.

Table 1. ATV propulsion systems comparison

	Concept 1	Concept 2
Main propulsion	MMH/N_2O_4 1 × 27.5 kN (gimballed) 314 s I_{sp} 4 tanks from L7	MMH/N_2O_4 2 × 500 N (gimballed) 309 s I_{sp} 4 × ϕ1085 mm tanks
Attitude control	N_2H_4 16 × 350 N 220 s I_{sp} 8 × ϕ460 mm tanks	N_2H_4 16 × 250 N 220 s I_{sp} 6 × ϕ461 mm tanks
Cold-gas system	N_2 16 × 10 N 66 s I_{sp} 11 × ϕ588 mm tanks	N_2 4 clusters of 20 N 68 s I_{sp} 4 × ϕ828 mm tanks
Pressurisation	He 2 × ϕ828 mm tanks	He 1 × ϕ828 tank

*Table 2. ATV mass and performance comparison**

	Concept 1		Concept 2	
Ariane-5 capability	23 000	25 000	23 000	25 000
ATV dry mass	4 216	4 216	2 942**	2 942**
Total propellant mass	2 819	3 064	3 178	3 454
ATV total mass	7 035	7 280	6 120**	6 396**
Cargo capability	15 965	17 720	16 880	18 604

* All values in kg
** Incl. VEB

First Scientific Results from the Ulysses Mission

R. G. Marsden & K.-P. Wenzel
Ulysses Project Scientists, ESA Space Science Department,
ESTEC, Noordwijk, The Netherlands

The successful launch of the Ulysses spacecraft on 6 October 1990 from the Space Shuttle 'Discovery' marked the start of a five-year exploratory journey to study the Sun and its environment from a unique vantage point, a solar polar orbit. Although currently still in the ecliptic plane, the scientific payload carried by Ulysses is already returning new and valuable data.

Introduction

After many frustrating delays, the joint ESA/NASA Ulysses mission to study the Sun and its environment finally got underway in October last year when ESA's Ulysses spacecraft, carried into space on board Space Shuttle 'Discovery', left Earth orbit on the first leg of its unique journey. The amount of energy imparted to the small space probe by the powerful upper-stage motors used to propel it away from the Earth was so large that Ulysses became the fastest-moving man-made object in the Universe!

The high-energy injection was needed in order to eventually place the spacecraft in a polar orbit around the Sun, from where it will make the first-ever measurements of the Sun's environment far out of the ecliptic plane and above the solar poles. Direct injection from Earth into a solar polar orbit cannot, however, be achieved using today's launch vehicles. A gravity-assist from the giant planet Jupiter is needed to swing Ulysses out of the ecliptic and back over the poles of the Sun. Consequently, the first phase of the mission takes Ulysses away from the Sun to encounter Jupiter on 8 February 1992. During this part of the journey, the trajectory is still in the ecliptic; nevertheless, the combination of new instrumentation and the range of heliocentric distances covered (1 to 5.2 Astronomical Units, AU) means that the data acquired are of high scientific interest.

The initial results from a selection of Ulysses experiments presented here are largely based on limited samples of 'quick-look' data obtained during the first six months of the mission.

The scientific payload and experiment data

The investigations to be undertaken using the scientific instrumentation carried on board Ulysses encompass studies of the solar wind, the heliospheric magnetic field, solar radio bursts and plasma waves, solar X-rays, solar and interplanetary energetic charged particles and galactic cosmic rays, interplanetary dust and the interstellar neutral gas, all as a function of solar latitude.

The scientific instruments are grouped into nine hardware experiments that have been provided by international teams of scientists, each team being headed by a Principal Investigator. A schematic of the payload layout is shown in Figure 1. (See the special Ulysses Launch Issue of the ESA Bulletin, No. 63, August 1990, for a complete description of the spacecraft, its scientific payload and the mission).

Switch-on of the scientific payload was carried out sequentially during the first 60 days of the mission, and data coverage has been close to continuous since then. Unfortunately, the production of fully-validated experiment data tapes at NASA's Jet Propulsion Laboratory has suffered serious delays, so that the teams of investigators have not yet had access to their complete data sets for the initial period. This situation is expected to improve in the near term, reducing the necessity to rely on the limited samples of quick-look data that can be accessed remotely.

Initial results

Solar wind

Two experiments on board Ulysses make direct measurements of the solar-wind plasma; these are SWOOPS (Solar-Wind Observations Over the Poles of the Sun)

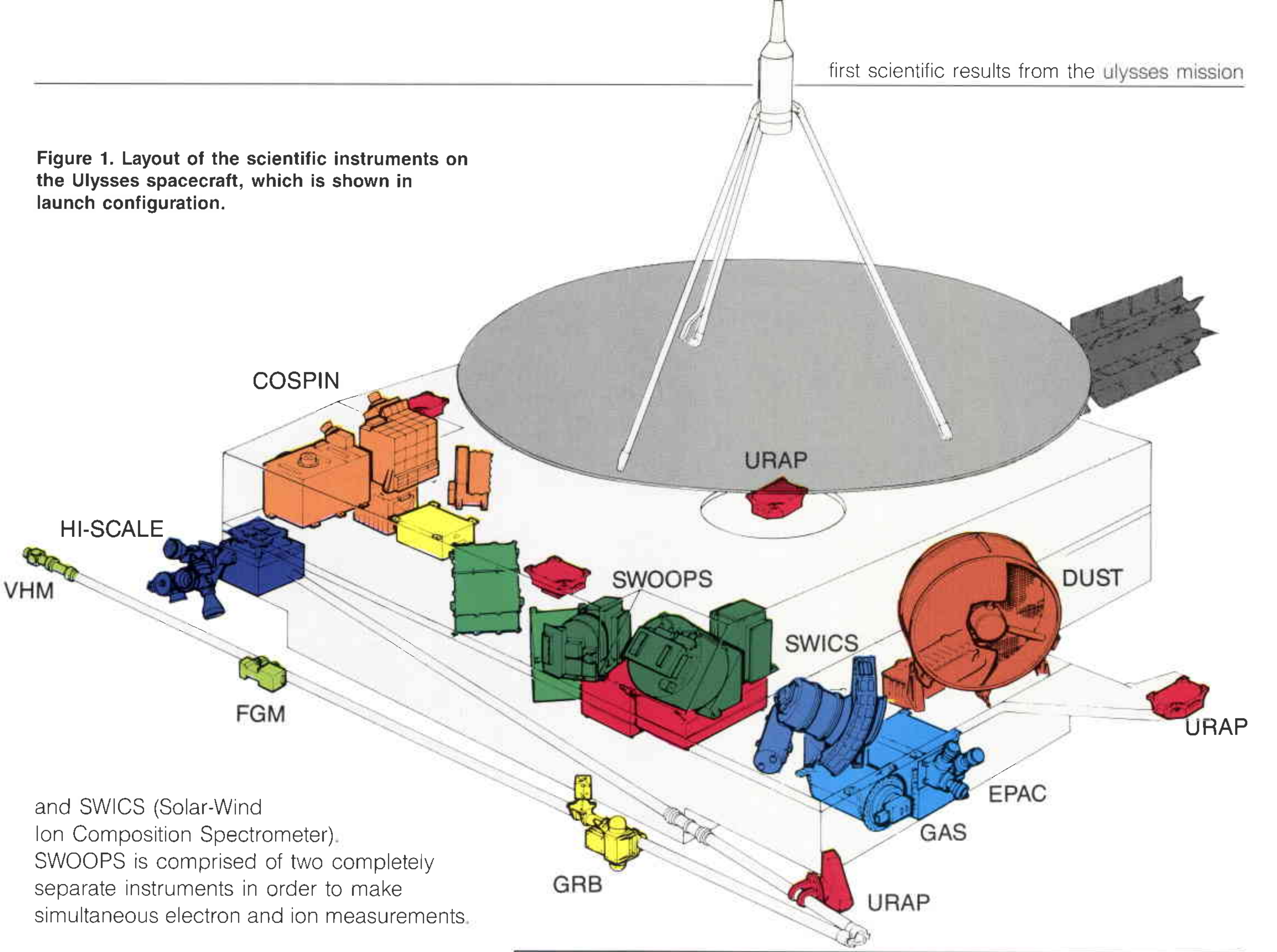


Figure 1. Layout of the scientific instruments on the Ulysses spacecraft, which is shown in launch configuration.

and SWICS (Solar-Wind Ion Composition Spectrometer). SWOOPS is comprised of two completely separate instruments in order to make simultaneous electron and ion measurements.

Figure 2 is a so-called 'stacked plot' of SWOOPS ion data in which a set of energy-per-charge spectra is shown stacked one below another in a vertical time sequence. Such spectra normally show two prominent peaks, one due to protons and a second due to doubly-ionised helium. Changes in the position and shape of the peaks then correspond to changes in the solar-wind flow properties. In the data shown here, the proton peak occasionally exhibits a 'dimple', which is evidence for two solar-wind streams of slightly different speeds flowing together.

Figure 3 is a colour spectrogram of data from the electron instrument. In this plot the colour-coded solar-wind electron intensity is shown as a function of time. In panels 3, 4, 5 and 6, angular distributions are also presented in four energy bands. By combining the information contained in plots of the type presented as examples here, a detailed picture of the solar-wind flow conditions at all points along the Ulysses trajectory will be constructed.

The SWICS experiment makes high-resolution measurements of the composition

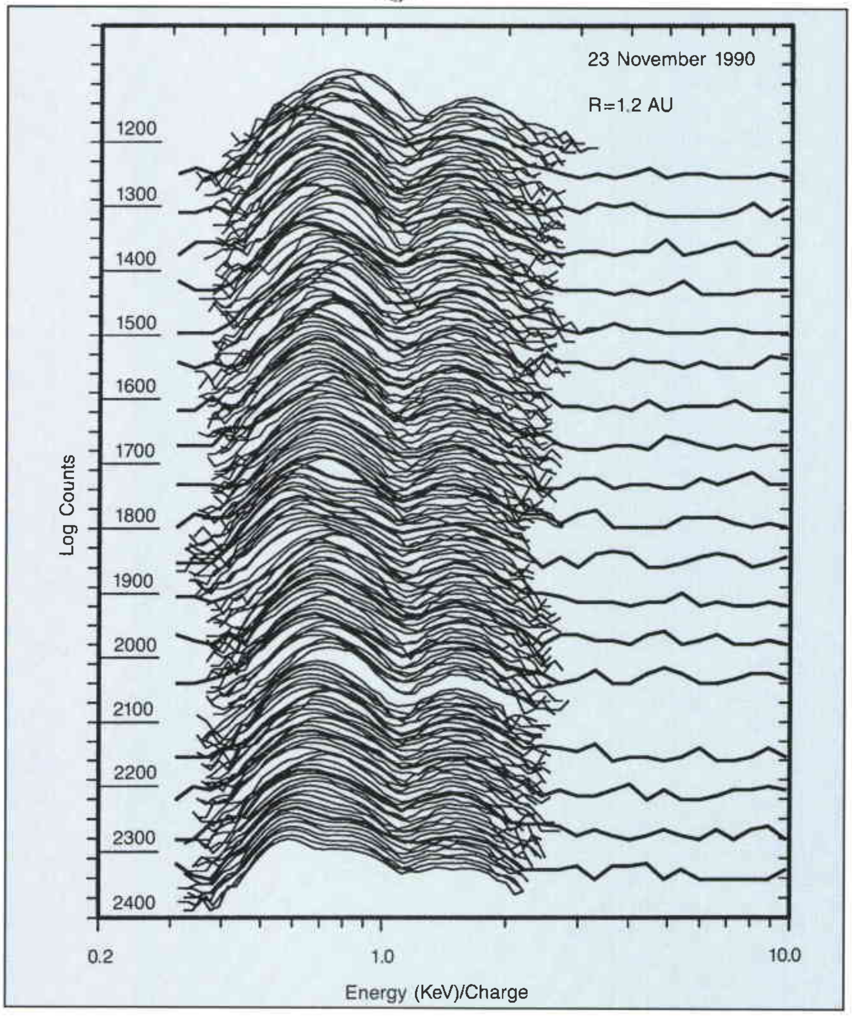


Figure 2. Data from the SWOOPS solar-wind ion experiment, showing a time sequence of energy-per-charge spectra.

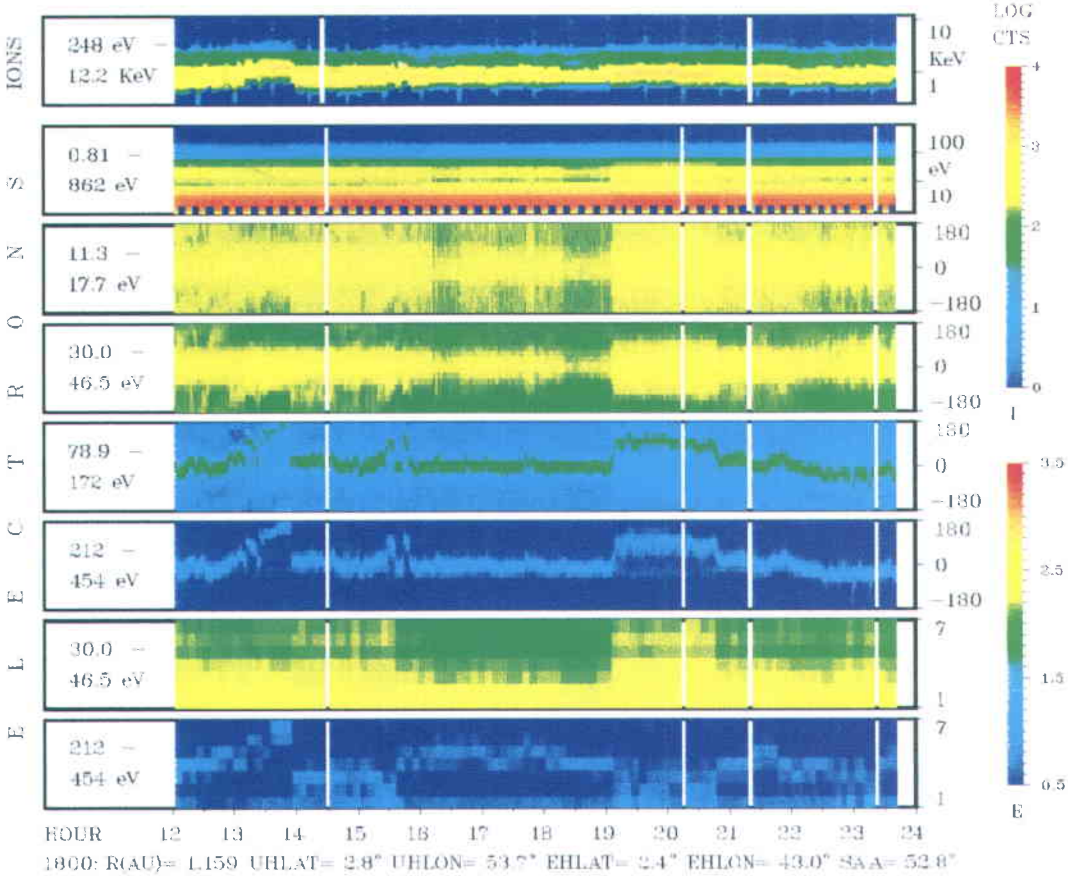


Figure 3. A colour spectrogram of SWOOPS solar-wind electron data showing intensity and angular distributions as a function of time.

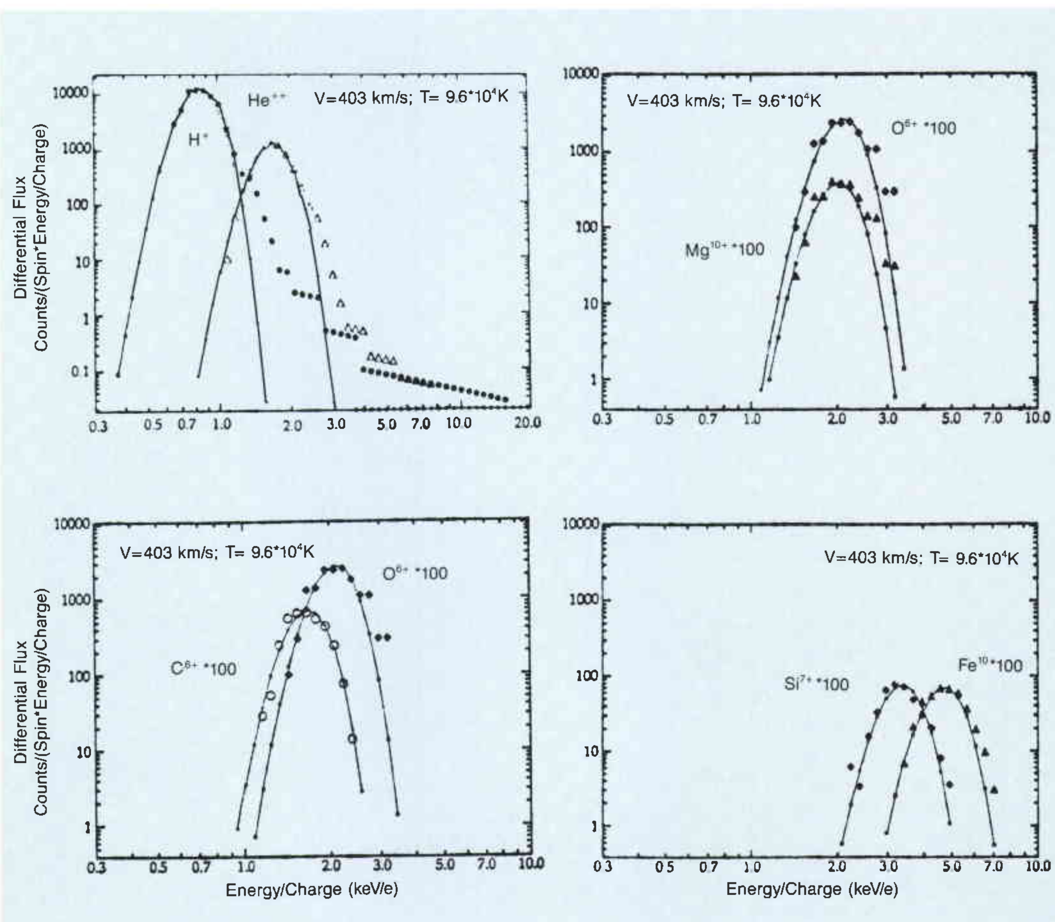


Figure 4. Differential intensity spectra for individual solar-wind ion species as measured by SWICS. The smooth curves are fits to the data and indicate a common bulk speed for all species.

and charge states of the ions found in the solar wind, and is the first instrument of its kind to be flown on an interplanetary mission like Ulysses. Such measurements enable routine determinations of the bulk speed, density and kinetic temperature of a large number of individual ion species with good time resolution.

Differential intensity spectra measured in one experiment cycle (13 min) for H^+ and He^{++} (top panel), C^{6+} and O^{6+}, Mg^{10+} and O^{6+}, and Si^{7+} and Fe^{10+} are shown in Figure 4. The smooth curves are fits to the data points using the same bulk speed and temperature/mass as input parameters for all species. Clearly, the fit is very good in all cases, indicating a common bulk speed and kinetic temperature.

The highest-resolution composition and charge-state information is obtained by plotting the individual event data in the form of a mass versus mass per charge matrix. An example of such a matrix is presented in Figure 5, where the colour scale has been adjusted to reveal the presence of rarer ions. Well-resolved peaks of the major solar-wind heavy elements and their dominant charge states (e.g. C^{6+}, C^{5+}, O^{7+}, O^{6+}, Si^{9+}, Si^{8+}, Si^{7+}, Fe^{11+}, Fe^{10+}, Fe^{9+}, Fe^{8+}) can be identified.

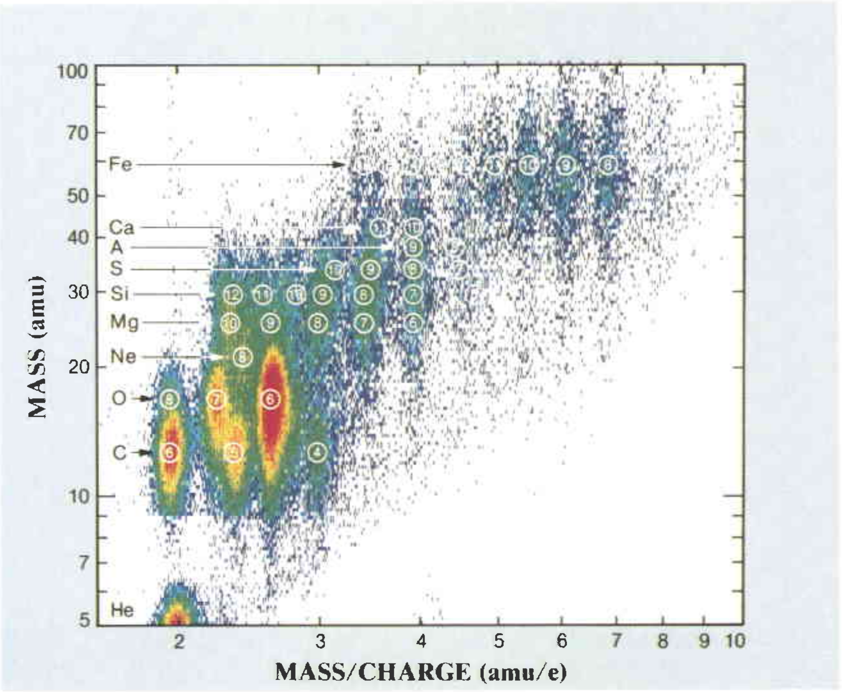


Figure 5. SWICS solar-wind ion data, showing the resolution of the different charge states of the individual species.

Magnetic field

The Ulysses spacecraft carries two magnetometer sensors located on its 5 m radial boom: a Vector Helium Magnetometer (VHM) at the end of the boom, and a Fluxgate Magnetometer (FGM) 1.2 m inboard from the VHM.

The observations from late October 1990 to March 1991 show that the interplanetary field at this phase of the solar cycle is highly disturbed: several potential shock waves and a large number of rotational and tangential discontinuities have been observed.

Data from the VHM obtained on 9 November 1990 are plotted in Figure 6. The spacecraft crossed the heliospheric current sheet that separates regions of opposite interplanetary field polarity twice on that day, first at about 10:25 UT, then again at about 19:26 UT. This can be seen from the reversals in field direction in the two panels of Figure 6. Several such crossings have been observed to date.

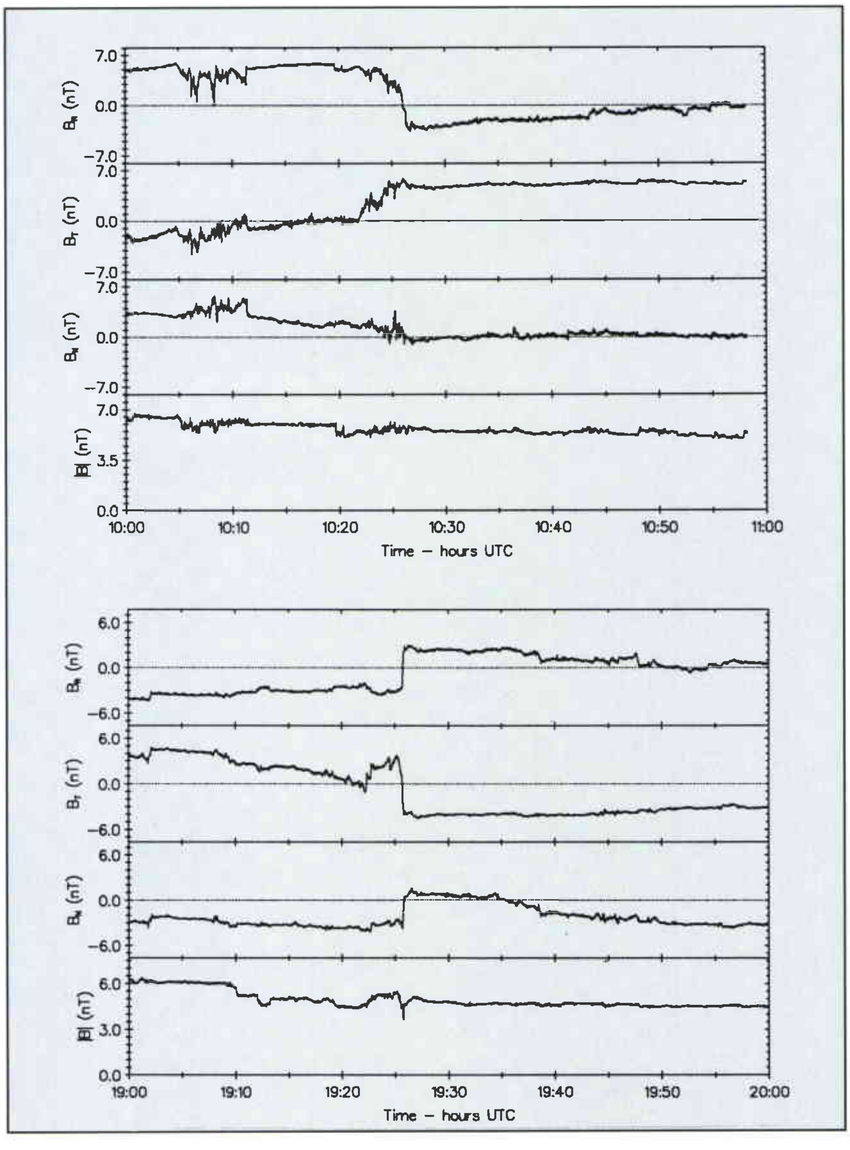


Figure 6. Two crossings of the heliospheric current sheet observed by the VHM magnetometer on 9 November 1990.

Radio and plasma waves

The Ulysses Unified Radio and Plasma Wave (URAP) experiment consists of a complete set of wave-measuring instruments, including a radio receiver to study radio emission generated in distant regions and a suite of instruments to analyse in-situ plasma waves. The experiment sensors consist of a 72.5 m electric dipole wire-boom antenna in the spacecraft's spin plane, a 7.5 m electric-field monopole along its spin axis, and a pair of search-coil magnetic antennas.

Figure 7 shows the wide variety of phenomena that can be observed with just one of the URAP instruments. This figure is a dynamic spectrum observed on 4 January 1991 by the Radio Astronomy Receiver portion of URAP. The abscissa is time and the ordinate scale shows observing frequency. Examples of type-III solar radio bursts, terrestrial auroral kilometric radiation, Jupiter emissions and the thermal plasma line can be seen in the figure. By tracking such type-III bursts as a function of frequency, a three-dimensional 'snapshot' of the large-scale magnetic field structure along which the radio burst propagates can be obtained.

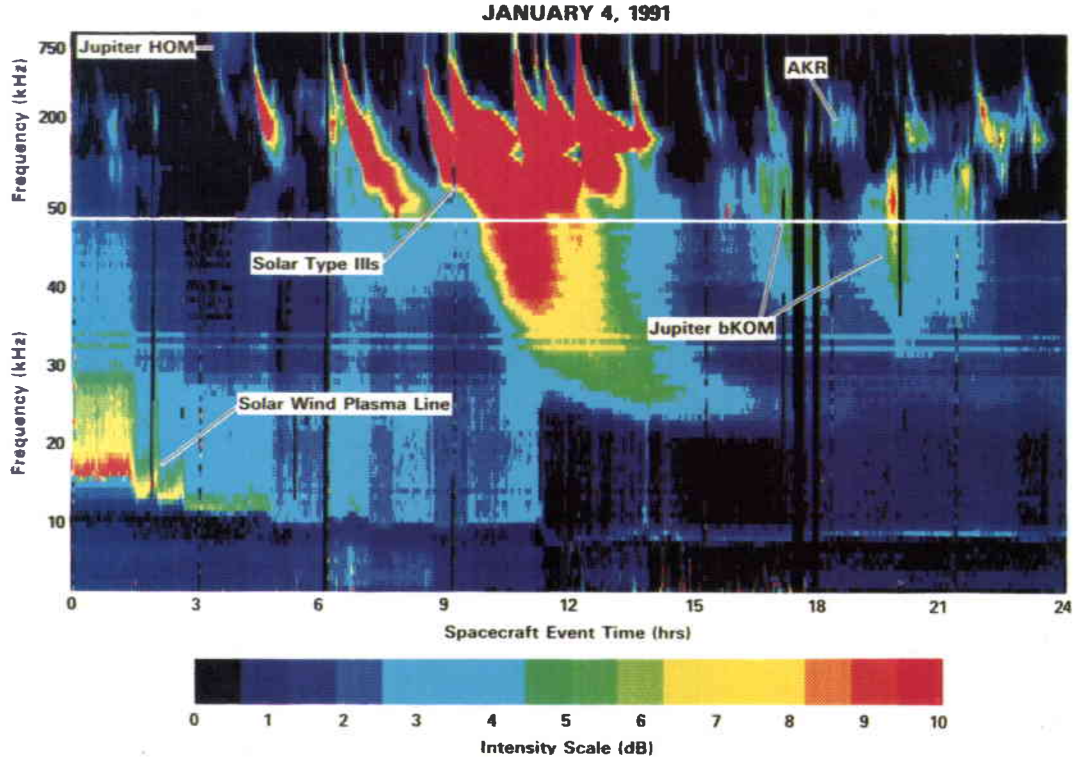


Figure 7. Data from the URAP Radio Astronomy Receiver, showing the signatures of solar radio bursts, terrestrial auroral radiation, Jupiter emissions and plasma waves.

Energetic particles and cosmic rays

Ulysses carries three experiments designed to measure the properties of energetic charged particles and cosmic rays: HI-SCALE, EPAC and COSPIN. These experiments employ a variety of instruments covering a wide range of energies and species. The in-ecliptic phase of the mission, from launch to Jupiter encounter in February 1992, is occurring during the peak of solar activity in solar cycle 22. As a consequence, the particle experiments have observed a large number of intensity enhancements related to solar activity. In particular, a major solar flare that occurred on 22 March produced very large fluxes of charged particles, which were detected both at the Earth and at the location of Ulysses (2.5 times further away from the Sun).

Figure 8 shows a plot of the proton intensity as a function of time for the period 18 February to 6 April 1991 in five different energy intervals, as measured by the COSPIN Low-Energy Telescope (LET) instrument. The large flare event can be seen as the sharp rise in intensity in all channels on day 82 (23 March).

In addition to acquiring data of the kind shown in Figure 8, all three experiments measure the chemical (atomic) composition of the particle populations in interplanetary space. An example of composition data for the March event taken from the HI-SCALE instrument is shown in Figure 9. The 'tracks' on this plot correspond to different chemical species.

Interstellar gas

The properties (density, bulk velocity relative to the solar system and temperature) of the local interstellar gas, represented by neutral helium penetrating the heliosphere, are being measured directly for the first time by the Ulysses GAS instrument. By employing the solar gravitational field as a natural velocity analyser, these properties can be derived from the angular distributions of neutral helium particles measured at widely separated points along the Ulysses trajectory.

An example of such an angular distribution is shown in Figure 10, in which the instrument count rate is plotted as a function of the viewing direction. At the time this measurement was made, the spacecraft moved through the area of neutral gas enhancement caused by the gravitational focusing effect of the Sun, giving rise to the 'banana-shaped' distribution at azimuth 270, elevation 80. Other regions of high count rates seen in the figure are due to sunlight scattered into the instrument field-of-view.

Conclusion

By the time this article appears, Ulysses will be five times further away from the Earth than the Sun, heading towards its encounter with Jupiter. At this distance, round-trip radio communications with the spacecraft take 1 h 23 min. All scientific experiments on board Ulysses are functioning nominally and are returning important in-ecliptic reference data that will be compared with observations made during the subsequent out-of-ecliptic phase of the mission.

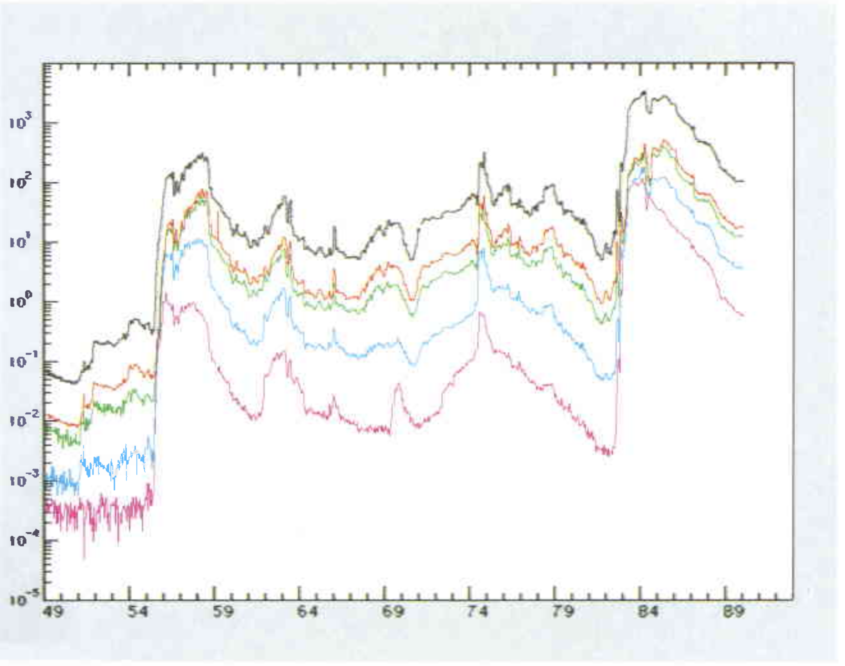


Figure 8. A plot of proton intensity as a function of time in five different energy bands as measured by the COSPIN LET instrument. The large enhancement on day 82 (23 March) is associated with a major solar flare.

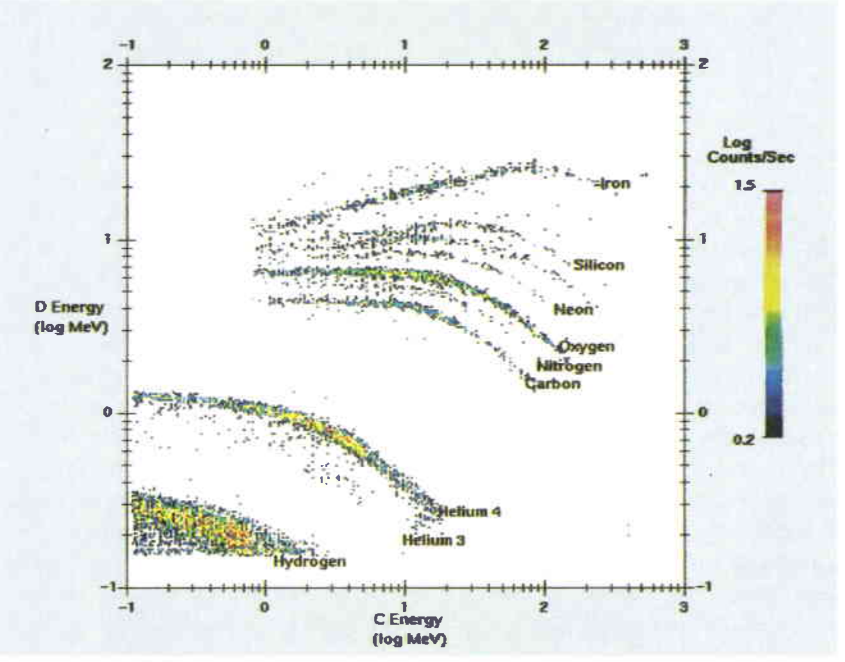


Figure 9. Energetic-particle composition measurements made by the HI-SCALE experiment.

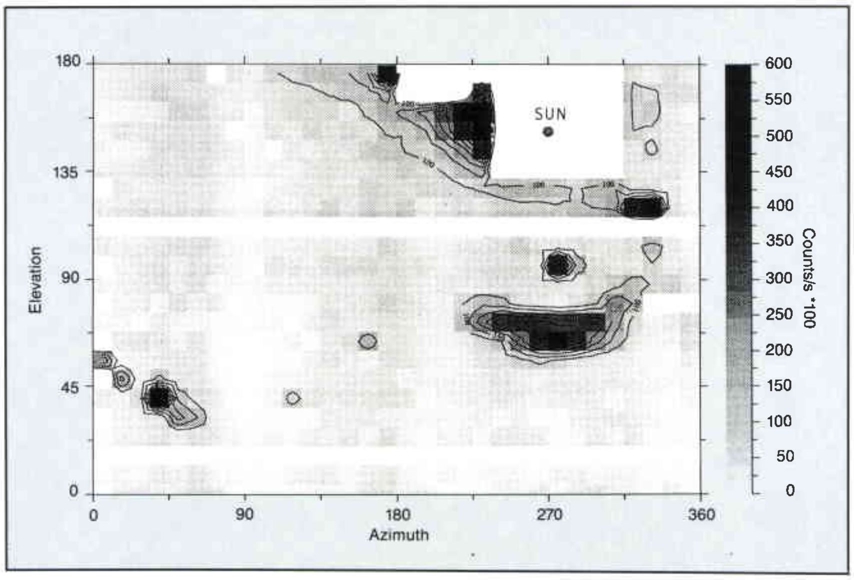


Figure 10. Measurements of the angular distribution of interstellar neutral gas taken from the GAS instrument. The 'banana-shaped' feature at azimuth 270 corresponds to an enhancement in the flux of neutral helium particles.

Meteosat Monitors Humidity in the Earth's Troposphere

L. van de Berg & J. Schmetz
Meteosat Exploitation Programme, European Space Operations Centre (ESOC), Darmstadt, Germany

The distribution of water in the Earth's atmosphere, its transport and seasonal change play a decisive role in determining our weather and climate. Water vapour is the most effective greenhouse gas and the water-vapour feedback to climate perturbations is known to be of great importance. It is therefore essential to observe the Earth's humidity field continuously on a global scale. The first results of a clear-sky climatological study of the upper-tropospheric relative humidity at altitudes of between approximately 4 and 9 km based on observations from the European Meteosat geostationary meteorological satellite system have recently become available.

Introduction

In the last decade, the effect of an increasing amount of trace gases, due to increased anthropogenic emission and pollution, on the Earth's climate has been studied intensively. Generally, it is believed that a doubling of the carbon-dioxide content will lead to a mean global warming at the surface of between 1.5 and 4.5° C. These estimates for the magnitude of the global warming have been obtained from model calculations that try to simulate the relevant physical mechanisms operating in the Earth's atmosphere and ocean.

An important aspect in these model simulations is the correct description of feedback mechanisms, which can be either positive, and hence amplify the warming induced by trace gases, or negative. Important feedback mechanisms are due to water vapour and liquid water or ice in the form of clouds. In particular, the latter remains a largely unsolved problem and one that needs to be settled before conclusive scenarios for future climate change can be outlined.

The problem is that a change in the distribution and the amount of clouds can affect both the influx of solar radiation to the Earth-atmosphere system and the loss of heat through radiation to space, i.e. clouds can both increase the Earth's albedo and reduce the outgoing long-wave radiation.

Recent experimental studies from dedicated Earth-radiation-budget satellites have shown, for the first time, that the present cloud distribution has a net cooling effect on the Earth. Since clouds are closely related to the Earth's humidity field, there is a growing interest in the analysis of humidity data.

The generally held view on the role of water vapour is that it induces a positive feedback mechanism in our climate system. That is quite understandable based on the fact that warmer air can take up more water vapour which, in turn, will increase the greenhouse effect and amplify the warming. Some 40% of the anticipated global warming caused by a doubling of the carbon dioxide is due to the water-vapour feedback.

It is conceivable that this simple picture of a positive water-vapour feedback is incorrect, because of drastic changes in global atmospheric dynamics. The hypothesis put forward in this respect is that a moister atmosphere leads to increased deep convection in the equatorial zone, which may cause an enhanced downward motion over the wide subtropical regions. In these regions of descending air, the long-wave radiative energy loss to space could be increased, thus exerting a negative feedback mechanism.

Preliminary data analyses suggest that the above negative-feedback mechanism is unlikely to exist, thus eliminating yet another hope for a robust climate that can cope with the man-made changes. Further and continuous monitoring is warranted to provide the data needed for understanding the mechanisms that are really occurring in our climate system.

Only satellite data can provide the horizontal coverage required for the analysis of global humidity fields. From the so-called 'water-vapour' images from Meteosat, an example of which is shown in Figure 1, an 'Upper-Tropospheric Humidity' (UTH) product can be derived wherever medium- or high-level clouds are absent, a process known as 'clear-sky climatology'. The monthly averages of these UTH products, or 'fields', can be correlated with the general circulation of the atmosphere.

Although the accuracy of the present data (of the order of 5% relative humidity) is not good enough for quantitative climate research, results to date have clearly shown the potential of continuous monitoring. They have demonstrated in particular that changes in the large-scale circulation that may well be associated with climate change are indeed observable with present satellite technology.

The available data

The UTH product is derived from the Meteosat water-vapour image. For each Meteosat segment – an area about 200 km square – that contains neither medium - nor high-level clouds, a UTH value can be derived (typically for about 2000 out of 3500 possible segments) which is an estimate of the mean upper-tropospheric relative humidity of the layer between about 600 and 300 hPa, which equates to about 4 to 9 km. The exact boundaries vary with satellite zenith angle and different atmospheric profiles. For a tropical atmosphere and a satellite zenith angle of 0°, for example, about 10% of the radiation is emitted from layers beneath 600 hPa, becoming less for an increasing satellite zenith angle or a more moist atmosphere.

The retrieval of the UTH is based upon look-up tables that relate satellite-observed water-vapour radiances to upper-tropospheric relative humidities. These tables are constructed with the aid of a radiative-transfer model, using forecast temperature profiles from the European Centre for Medium-Range Weather Forecasting (ECMWF) in Reading (UK) as input and varying humidity profiles in the relevant layer. The relative humidity above this layer decreases linearly from the value at 300 hPa to 0% at 100 hPa. For altitudes below 600 hPa, the ECMWF humidity profile is taken, though it has little effect on the UTH retrieval because the lower atmosphere contributes little to the outgoing radiation in the water-vapour band. (A detailed description of the retrieval method, by Schmetz and Turpeinen, can be found in the Journal of Applied Meteorology, 1988, pp. 889-899).

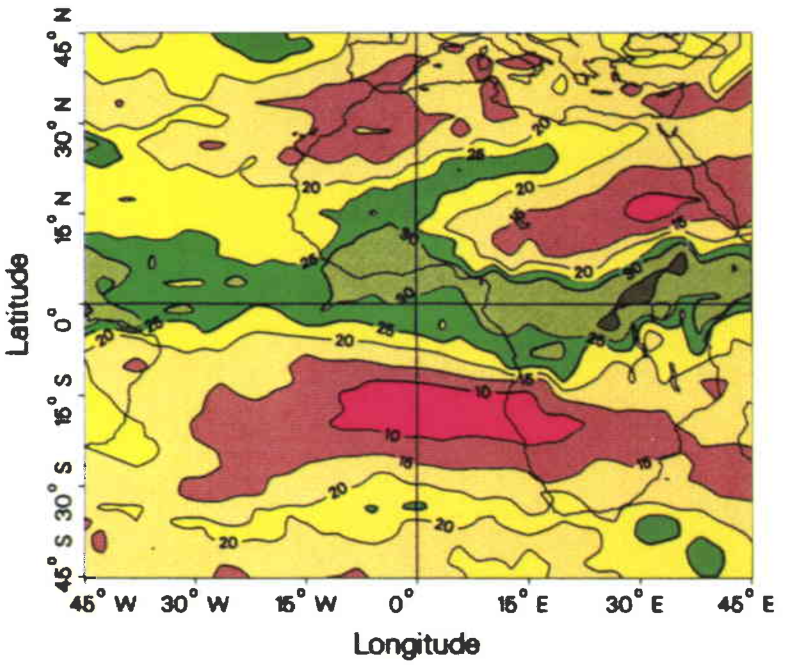
Monthly mean UTH fields

Monthly mean UTH fields are constructed by averaging the UTH values of every segment for all operational UTH products, whenever a value is determined. This implies that the number of data points available for each segment average may vary within a month, from well over 50 values in the relatively cloud-free subtropics to about 10 in some parts of the Inter-Tropical Convergence Zone (ITCZ). These monthly means typically range from 5% in high-pressure areas to 60% in areas with deep convection. UTH values exceed 60% only occasionally, as clouds are then usually detected in the segment by the operational automatic image analysis, or during the manual quality control of the product.

Figure 1. Meteosat image taken in the water-vapour channel (5.7–7.1 micron) on 1 May 1991 at 12.00 h GMT

During all seasons, some common features can be observed, which may however vary in strength and position (Figs. 2–5). The ITCZ is always indicated by a band of high UTH values: over the African and South-American Continents, they may be well over 30%, while over the Atlantic they are around 25%. The higher values over the continental part of the ITCZ are related to the stronger deep convection over land when compared to the oceanic part, due to the surface warming by insolation.

The latitudinal position of the ITCZ varies throughout the year, according to the annual cycle of the zenithal position of the Sun. Over the African Continent, it is located around the



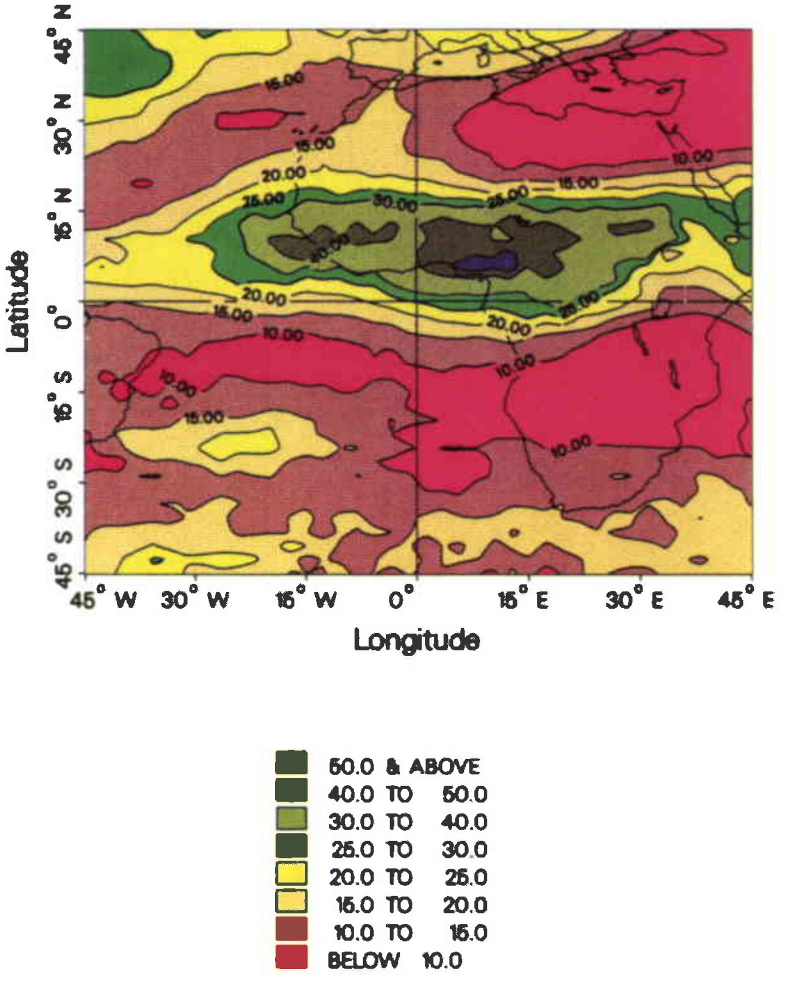


Figure 2. Monthly mean Upper-Tropospheric Humidity (UTH) for April 1990

Figure 3. Monthly mean Upper-Tropospheric Humidity (UTH) for July 1990

equator during the equinoxes (Figs. 2 & 4). In July (Fig. 3) it is shifted to a position around 10°N, while during Southern-Hemisphere summer it is located between 5°N and 17°S (Fig. 5). When the ITCZ is located over the part of South-America within Meteosat's field of view, we observe the same latitudinal positions as over Africa (Figs. 2 & 5). In January, it is located south of the equator over the Amazon Basin. Over Brasil, therefore, the strongest convection occurs during the austral summer, which is reflected in the monthly mean UTH field for January having the highest values (up to 50%) compared with the other months.

Over the Atlantic Ocean, we observe a lesser latitudinal variation during the year. While the ITCZ in April is located around the equator (Fig. 2), it is positioned between 5°N and 10°N in July and October. This rather northerly position of the ITCZ over the Atlantic in October is indicative of the time lag in the Zone with respect to the zenithal position of the Sun. Furthermore, it is clear that the latitudinal extension over the continents is larger than over the Atlantic.

In January, the oceanic part of the ITCZ is masked by another phenomenon. A band of high UTH values with maxima of over 50% stretches from the deep convective region over South America, to the Sahara (Fig. 5). It is associated with the subtropical jet transporting humid air northwards from the ITCZ. This subtropical jet dominates the winter-time upper-tropospheric circulation of the Northern Hemisphere at lower latitudes. The jet can also be noted in April and October (Figs. 2 & 4), though it is positioned further east, with maximum UTH values of over 25%.

In July 1990, the maximum UTH values (more than 50%) are to be found over Cameroon and Central Africa (Fig. 3). The air reaching Cameroon is moistened over the Gulf of Guinea and the deep convection here is strengthened by the forced ascent over the Cameroon highland. In January 1991, the area with the strongest convection over Africa lay over southeastern Zaire, with UTH values of more than 50%. The north-westerly winds pick up a lot of moisture over the Congo Basin and very moist air is therefore available for the development of very large deep convective clouds.

In West Africa, maximum UTH values of over 40% in July and over 30% in October are found south of 10°N from 5 to 20°W. This band of relatively high UTH values lies south of the surface discontinuity of the ITCZ at about 10°N and might be caused by the uplifting of warm continental air masses by relatively cold oceanic air masses of the monsoon flow. This uplifting may be strengthened due to forced ascent over the mountain regions of Guinea and Liberia.

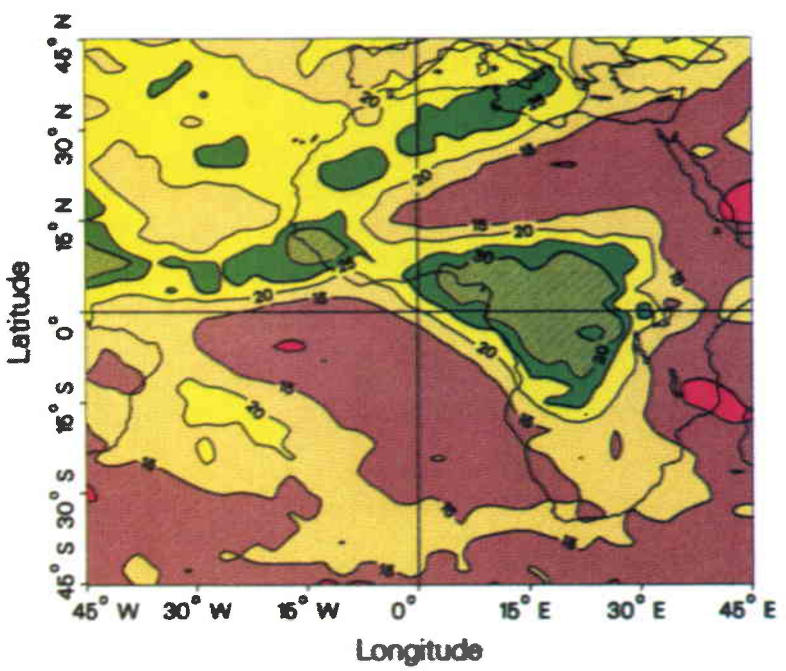
In both hemispheres, low UTH values are observed during all seasons over the subtropical high-pressure areas. These low-UTH areas are located on the eastern side of the subtropical high-pressure areas, where the strongest subsidence occurs. Furthermore, to the poleward side of the high-pressure areas, moist air may be advected by protruding disturbances from the mid-latitudes, leading to higher mean UTH values.

In the Southern-Hemisphere winter circulation, a large-scale meridional movement known as 'Hadley circulation' is most vigorously developed, which is well indicated by the large area with low UTH values (less than 10%) associated with descending air in the subtropical high covering a large part of the South Atlantic (Fig. 3). In this low-UTH field, there is only a slight zonal gradient from southern Brasil to southern Africa. In the Northern Hemisphere, low UTH values are found over the northeastern Sahara, the Middle East, and the Azores.

During the Southern-Hemisphere summer (Fig. 5), a distinct cell shows up in the area of low UTH values, stretching from South Africa in a northwesterly direction. This indicates the relative weakness of the Hadley circulation in the Southern-Hemisphere summer. Furthermore, we observe a pronounced zonal gradient in the Southern Hemisphere, possibly related to areas with ascending air over South-America and Africa, and descending air over the Atlantic. Another area of low UTH values is found over the western part of the North Atlantic.

Conclusion

Based on our studies using the operational Meteosat Upper-Tropospheric Humidity (UTH) product, we have already been able to draw a number of interesting conclusions. For example, regions with relatively high UTH values are generally strongly correlated with regions characterised by ascending motions such as the Inter-Tropical Convergence Zone. Regions with low UTH values are associated with areas in which subsiding motions occur, such as the



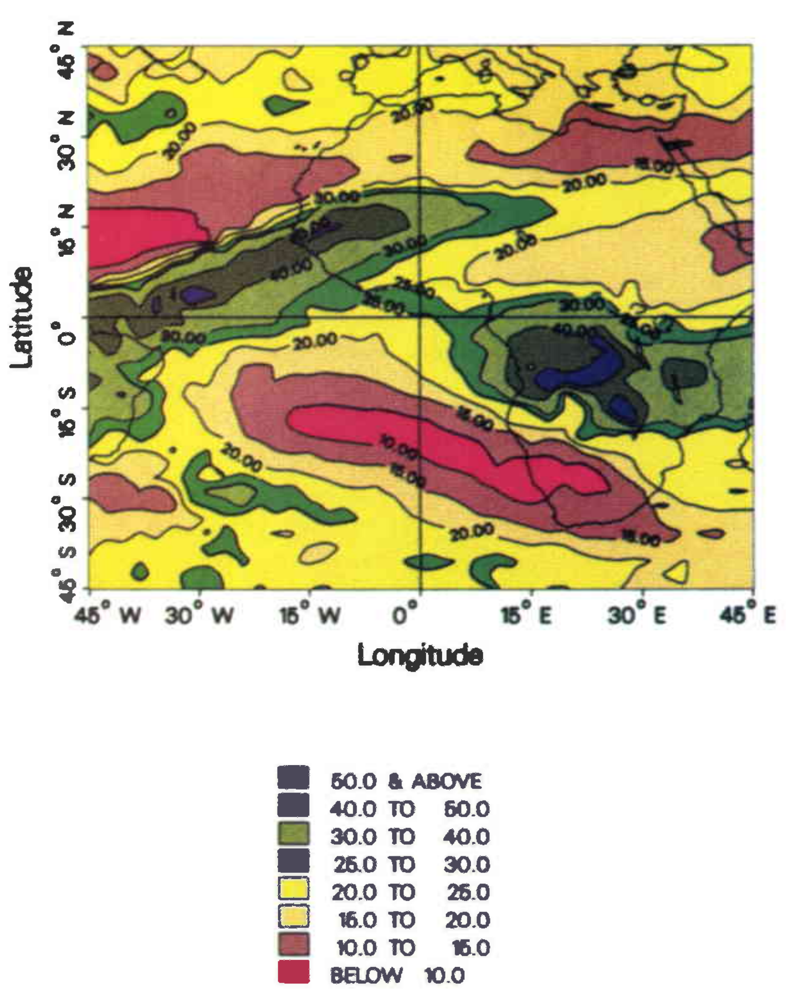


Figure 4. Monthly mean Upper-Tropospheric Humidity (UTH) for October 1990

Figure 5. Monthly mean Upper-Troposperic Humidity (UTH) for January 1991

descending branches of the Hadley circulation. The monthly mean UTH patterns reflect global circulation systems, such as the Hadley Cell in the low latitudes or the boreal wintertime subtropical jet, and thus may serve as a tracer for the corresponding large-scale atmospheric dynamics. We have demonstrated that the seasonal variation of the Hadley circulation is reflected in the changing patterns of the monthly mean UTH fields. Future work will encom pass yearly changes in the mean UTH fields.

From the seasonal variation in UTH, it is evident that the distribution of UTH patterns is asymmetric with respect to the ITCZ. The most extensive regions with low UTH occur in both hemispheres in the winter season, while the large areas with high UTH occur in their summer season. This indicates that the Hadley Cell is most vigorously developed in the winter hemisphere. Furthermore, the strongest latitudinal UTH gradients are found over the continents, indicating strong deep convection in the ascending branches of the Hadley circulation induced by solar warming of the surface.

These results, among others, have convinced us that it is already possible with today's satellite technology to monitor the Upper-Tropospheric Humidity field in the cloud-free atmosphere and to make meaningful studies of the role of water vapour, which is an important greenhouse gas, in our global climate system.

Acknowledgements
The authors wish to thank R. Haemmer for his assistance with the production of the coloured graphs presented with this article.

Evolution of the Agency's Software Infrastructure for Spacecraft and Mission Control

N. Head & J.F. Kaufeler
ESA Computer Department, European Space Operations Centre (ESOC), Darmstadt, Germany

In 1974 ESOC decided to develop reusable spacecraft control system infrastructures for ESA missions operated under its responsibility. Today there are two main such infrastructure platforms in use at ESOC: the Multi-Satellite Support System (MSSS) and the Spacecraft Control and Operation System (SCOS). Both of these systems have evolved through different implementation generations in order to cope, on the one hand, with the increasing complexity of the missions to be operated and, on the other, with the constant technological progress in the area of computer and software engineering.

Introduction

A Spacecraft Control System (SCS) is a computer system used to operate a spacecraft from the ground during the so-called 'Launch and Early Orbit Phase' (LEOP) and/or the subsequent routine-operations phase. An SCS is connected to a network of ground stations via which it receives (usually in real time) telemetry for monitoring purposes, and to which it sends telecommands for uplinking to the spacecraft.

The classical functions of an SCS are therefore the monitoring of spacecraft telemetry (e.g. limit checks, status checks, etc.), the manual or scheduled generation of telecommands with pre-transmission validity checks and execution verification, the filing of all mission data (telemetry and telecommands) in 'history files', the display in various forms of mission data either in real time or retrieved from the history files, the long-term archiving of the mission data, and the production of various types of reports.

We will attempt here to summarise the various generations of SCS infrastructure that have been used at ESOC, their main functional characteristics, the rationale behind their architecture, the problems encountered and ESOC's plans, based on this long experience, for the future-generation SCS, the SCOS-II.

The past

The very first reusable SCS was the first-generation Multi-Satellite Support System (MSSS) which was put into service for the first time in 1976 for the Geos-1 scientific-satellite mission.

With the computing power provided at that time by conventional machines, a load analysis rapidly demonstrated that the functions required of an SCS could not be handled in a single computer, but would need to be distributed across several computers. A combination of Siemens-330 (front-end) and CII-10070 (back-end) machines was selected to build the architecture shown in Figure 1.

This network of computers was fairly expensive and, for financial reasons, had to be able to support several missions in parallel. The decision was therefore taken that the software should be data-driven and, in particular, driven by mission-specific spacecraft-characteristic files. Three principal data flows drive the architecture of an SCS system, represented in Figure 1 in blue for the telemetry (TM) path, in red for the telecommand (TLC) path, and in green for mission data retrievals from the main repository (the history files).

This SCS was composed of a number of dedicated computers:

- The On-line Processing front-end (OP), which received telemetry from the ground stations and performed all the necessary monitoring before transferring it to the DT and RT computers.
- The Display and Terminal front-end (DT), which was in charge of handling the user interface (single screen, functional keyboard) and provided telemetry displays and telecommanding facilities.
- The Message Router (MR), which was a kind of logical message transfer unit designed to make the various hardware (backup) reconfigurations transparent.
- The Back-end Display (BD) computer,

which was foreseen as the backup for the MR, but which was also the relay for retrieval requests issued for DT, and data accessed on RT.

- The Real-Time back-end (RT), which was supposed to file all data routed from MR, to serve the data-retrieval requests, to perform daily printouts, and to hold the spacecraft-characteristics database with all the associated maintenance tools. The Development back-end (DV) was the back-up for RT and in the nominal situation was used as a development and maintenance computer.

All the software was written in Assembly language, the communication technique was in-house engineered, and the system was therefore expensive in terms of communication overheads, testing and maintenance effort. The system was able to support a total telemetry rate of 60 kbit/s for three to four spacecraft concurrently, with up to 15 single-screen displays. It was used for a total of six missions.

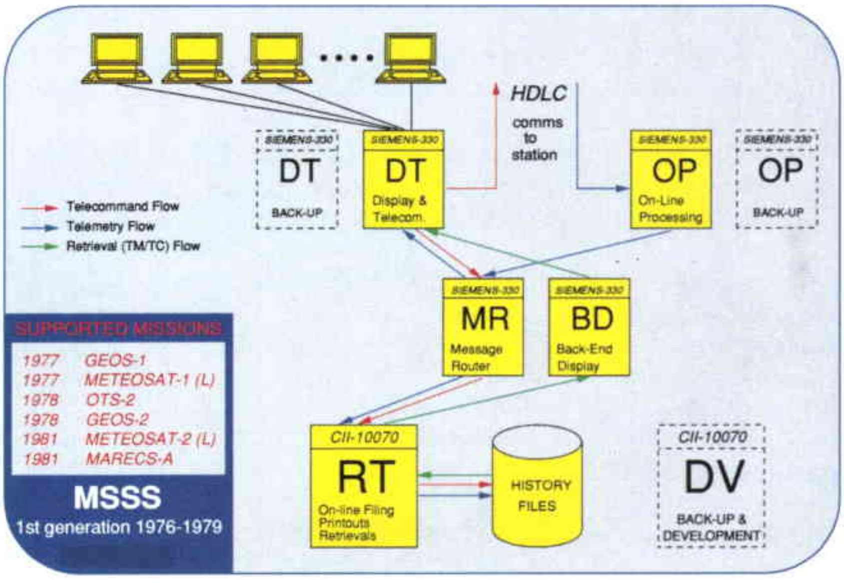


Figure 1. The first-generation ESA Multi-Satellite Support System (MSSS), 1976–1979

In view of the complexity of the above system and the subsequent advent of much more powerful computers, it seemed more effective to use a single computer large enough to host all the SCS software for the following reasons: no overheads in inter-computer communications; simpler software; simpler backup reconfiguration. However, because missions were still being operated on the existing system, and because it would have been too expensive to implement a completely new infrastructure immediately, it was decided to proceed step by step and to replace only the RT and DV back-end computers with more powerful SEL/Gould 32/77 machines initially. The resulting configuration is shown in Figure 2 (elements shown in yellow retained from the previous configuration).

The installation of these new computers was performed in a fully interface-compatible manner. During the change-over period, the old and the new RTs and DVs ran in parallel connected to the MR, thereby allowing extensive testing of the new system.

The software on the SEL/Gould machines was written in Fortran with a layered architecture, with the intention of enabling the DT and OP functions to be integrated at a later stage. This configuration was the so-called 'Interim MSSS', which went into operation in 1979 and eventually supported a total of seven missions. Figure 2 shows that some missions (listed without a date) were phased over from the previous configuration to the interim one. Missions that were supported only for launch on this system are indicated with an (L) (i.e. their routine operations were carried out on another SCS system). The performance of this system was essentially identical to that of the previous one.

In 1984, the move to the second generation of MSSS (called 'MSSS-A') fully resident on a central SEL/Gould host configuration was completed. All functions carried out on the OP, DT, MR and BD computers were then relocated (redesigned and rewritten in Fortran) to the host computer. However, instead of using normal display terminals, which would have consumed too much CPU time on the host, it was decided to develop in-house a semi-intelligent, multi-screen work station based on an Intel microprocessor (powerful work stations with standard software were not available at that time). These Intel work stations are connected to the host with a serial V24 interface via a switch panel, thus allowing easy and rapid reconfiguration. Much of the screen data presentation processing is performed on the work station, thus relieving the host application of the burden of formatting the screens (the original SEL/Gould CPU configuration was only later upgraded with more powerful 32/67 CPU units).

A further major step in the second-generation MSSS was the replacement of the communications network to the ground stations with a packet-switching system (X25). This made the SCS system easily connectable to any ESA ground station, and allowed several SCS implementations to be connected to that same network.

This system is still in operation today at

ESOC and also at the Agency's Redu (B) and Fucino (I) stations. A licensing agreement was negotiated in 1989 with the International Maritime Satellite Organisation (Inmarsat), which also uses the system.

Compared with the previous generation, the performance capacity of this system is greatly improved. The overall telemetry load is still in the order of 64 kbit/s, but up to 17 triple-screen work stations can be operational simultaneously for up to six spacecraft in parallel.

Also in 1984, the ESA Computer Department had to decide which SCS platform should be used for the Agency's future Hipparcos, Eureca, and ERS-1 missions. The needs of these missions, with their quite heavy mission-specific tasks and higher telemetry rates, could not be accommodated on an MSSS-A configuration even by running it in a single-spacecraft mode.

The concept of a single hardware configuration to be shared between different missions (as the MSSS had been) was abandoned because of the non-negligible and disturbing interferences between missions with very different profiles and lifetimes (e.g. one being in routine phase while another is in a pre-launch phase). It was decided that dedicated hardware configurations for each mission was the correct solution. These configurations are now known as 'Dedicated Mission-Support Systems' (DMSS).

A pair of DEC/VAX computers – a real-time (RT) computer and a backup and development (DV) machine – form the basic hardware configuration for all DMSS software for a given mission, the size of the VAX being dependent on the load profile of the particular mission.

The investment that ESOC had made in the procurement and installation throughout the Control Centre of Intel-based work stations could not just be discarded, and it was therefore decided that, at least for the beginning of this new SCS infrastructure, those work stations had to be reused in a fully compatible manner.

The final question was to decide what software should be provided, and whether it should be mission-specific or based on a reusable-core software infrastructure. This decision was further complicated by the fact that one mission (Eureca) uses the latest telemetry and telecommand packet

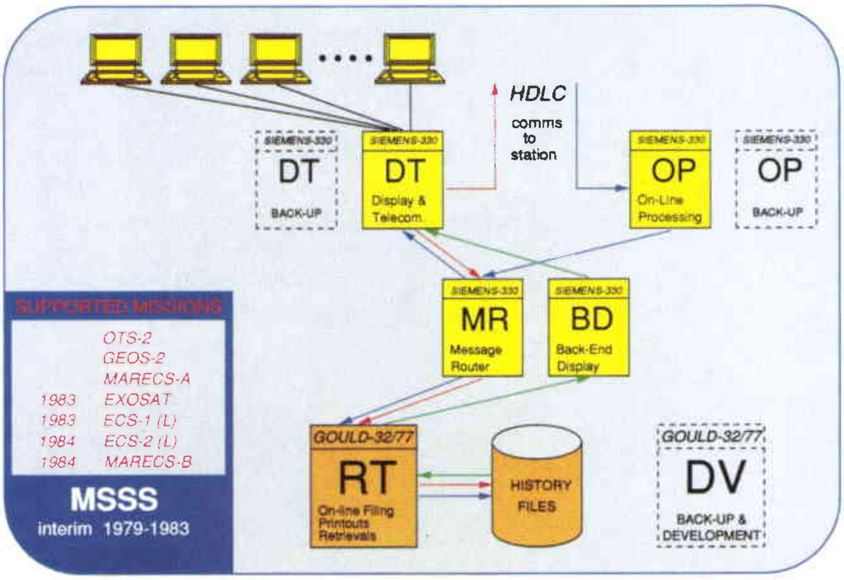
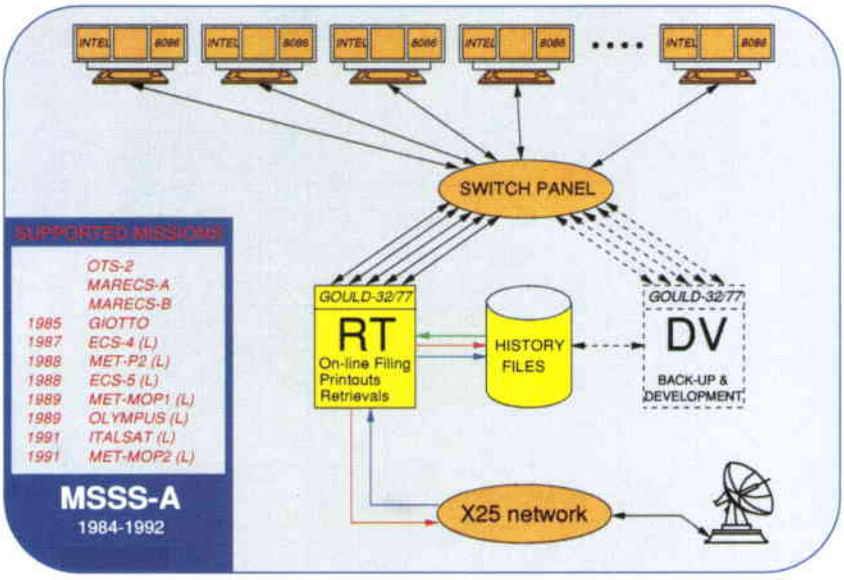


Figure 2. The Interim MSSS, 1979–1983

standards, whereas the others rely on the conventional standards.

Finally, it was decided to implement a new SCS core infrastructure – the Spacecraft Control and Operation System (SCOS) – with the objectives of:
- covering all functions related to telemetry, in both packetised and fixed format (handled as a single-packet case)
- providing a layered architecture so that mission-specific tasks, and in particular the telecommand-related applications, can be easily interfaced
- providing a general and user-friendly relational database (e.g. Oracle) infrastructure that holds all the spacecraft characteristics that drive the system and is used intensively by the operations engineers during the mission-preparation phase
- making the system highly configurable so that it can eventually support several missions (of the same family) concurrently

Figure 3. MSSS-A, 1984–1992



– retaining all (telemetry-related) MSSS functions.

The novelty of this very first SCOS – called 'SCOS-A' – is the rather complex handling of the telemetry data structures found in packets, and its efficient use of a relational database. The architecture is still of a centralised nature (at least for a given mission), but with higher real-time performance (e.g. 64kbit/s per spacecraft, three to five times more telemetry processing capacity).

SCOS-A entered into service in 1989 supporting Hipparcos as its first mission and, after a thorough optimisation phase, has proved to be a very reliable product meeting the initial objectives.

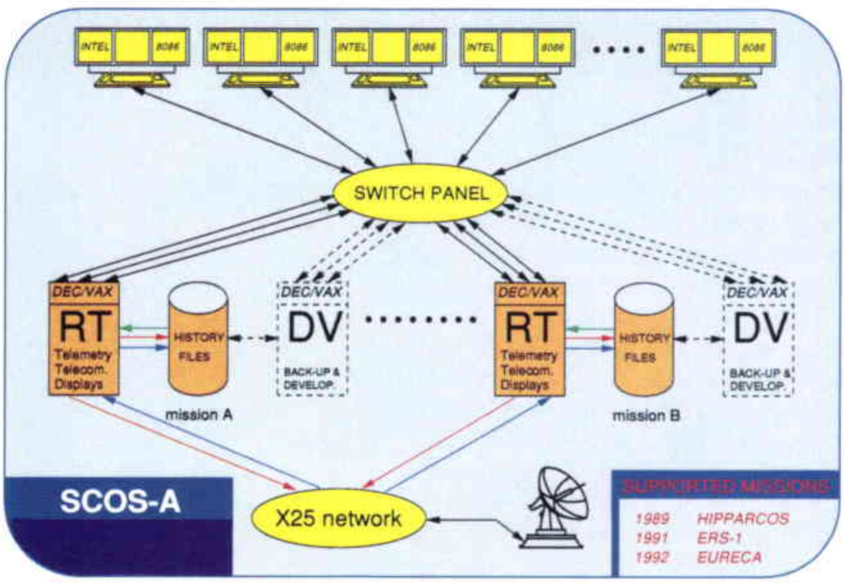


Figure 4. SCOS-A, 1989–1991

The next step in the modernisation of ESOC's SCS infrastructure is the replacement of the now obsolete Intel work stations with more modern and more powerful Sun units. Ths Sun Operational Work Station infrastructure, although containing an emulation package that retains full compatibility with the existing SCOS-A host-resident applications, will permit new applications using more advanced data-presentation techniques (e.g. use of mimic diagrams for telemetry display or point-and-shoot commanding) to be implemented (either locally on the Sun or remotely on the Vax host). This modernisation activity began in early 1989, and will be completed by the end of 1991.

The new combination, called SCOS-B, will enter into operation in 1991 and be used first for ERS-1, then possibly for Eureca, and for future missions up to 1996. Like SCOS-A, it still does not support the basic telecommanding functions, which require a mission-specific implementation.

As the SCOS-B Sun work stations (in emulation mode) are plug-compatible with the old Intel work stations, they can in principle be used also for the Gould-based MSSS-A system. It is planned to make this MSSS configuration upgrade, logically called MSSS-B, available at almost the same time as the SCOS-A to SCOS-B upgrade for those MSSS centres needing to modernise their existing work stations.

This brief summary has shown that, in 17 years, ESOC has undertaken five major implementations or upgrades of its SCS infrastructure, which has so far supported 19 missions and will support at least a further four. The SCS architectural concept has changed considerably during this period, starting with a distributed architecture (MSSS first generation), moving to a fully centralised architecture (e.g.MSSS-A), and now becoming again semi-distributed in nature (SCOS-A/B).

From an implementation viewpoint, however, the upgrading process has been evolutionary rather than revolutionary, with only a subset of the system elements being replaced at each stage. For those missions that have a long lifetime, this approach has allowed a phase over from one SCS system to the next with minimum impact on operations.

The future

Having reviewed the past histories of the ESOC SCS systems and their architectures, we will turn to the future and the plans for the next generation of SCS system now being formulated. This next generation will be known as 'SCOS-II', although it will bear almost no resemblance to the SCOS-A or SCOS-B systems currently in use. The plans for SCOS-II are some of the most ambitious since the original conception of the first MSSS, and it is hoped the resulting system will be an equally large step forward in both software- and hardware-technology terms, as well as in user comfort and satisfaction.

A number of lessons can be learnt from the previous SCS implementations: each has been successful in its own way, but each has also had its own share of difficulties. The future SCOS-II system will hopefully combine the advantages of each, whilst avoiding the difficulties and problems of its predecessors.

The first-generation MSSS system was, for various reasons, built around a non-homogeneous, distributed hardware environment. The use of multiple processors allowed a considerable amount of processing power to be brought to bear on the problems at hand, at least in comparison with other systems of the day, but also brought with it a considerable number of problems:

- the maintenance of a non-homogeneous hardware and software environment was complex and expensive
- the distributed nature of the software, combined with the fact that the flexibility of the system was achieved by making extensive use of data tables (referred to as a 'database'), meant that many failures were due to the use of incompatible database versions at the various nodes of the system
- the communications between the system nodes required the use of custom-written software, which was difficult and expensive to produce
- the implementation of the backup policy and the insertion and removal of nodes from the system (e.g. for preventive maintenance) was cumbersome and subject to error
- failure detection and diagnosis was a black art; seen from the user's point of view, the symptoms of a problem were very difficult to relate to the actual cause (usually the failure of one of the processors or a communications link somewhere in the system).

Despite all of these problems, this version of the MSSS probably offered better interactive performance to the individual user than all subsequent SCSs. The response time to user requests was good, telemetry displays were regularly updated at 1 s intervals, and the manual stack responded instantly to command-uplink requests. Of course, the level of functionality offered by the first MSS was very much lower than that currently available, but this increase in functionality has not been matched by an increase in available processor power.

The second generation of MSSS, after an interim period during the phased changeover from the first generation, was a centralised system with all functions supported on a single processor. Limited support was also provided by the microprocessor-based user work stations. This configuration suffered from undue influences of one mission on another, particularly during LEOP operations (deemed to be extremely critical and where a large number of users are involved). It was not unusual for the controllers of the other missions running on the system to be forbidden to use certain functions (e.g. data retrieval or graphical display) to avoid impacting on the launch operations. This situation was somewhat relieved by the upgrading of the processor itself and by the addition of more memory, but the fact that the limited resources must be shared between missions remains a problem of the second-generation MSSS to this day.

Although many of the difficulties with inter-processor communication were removed with the move to a centralised system, they were replaced with problems in the communication between the single processor and the user work stations. The speed of the serial links used is not sufficient to counteract the fact that the work stations have no local storage and that, therefore, all data for the user interface (display layouts, colour schemes, etc.) must be downloaded from the central system together with the actual

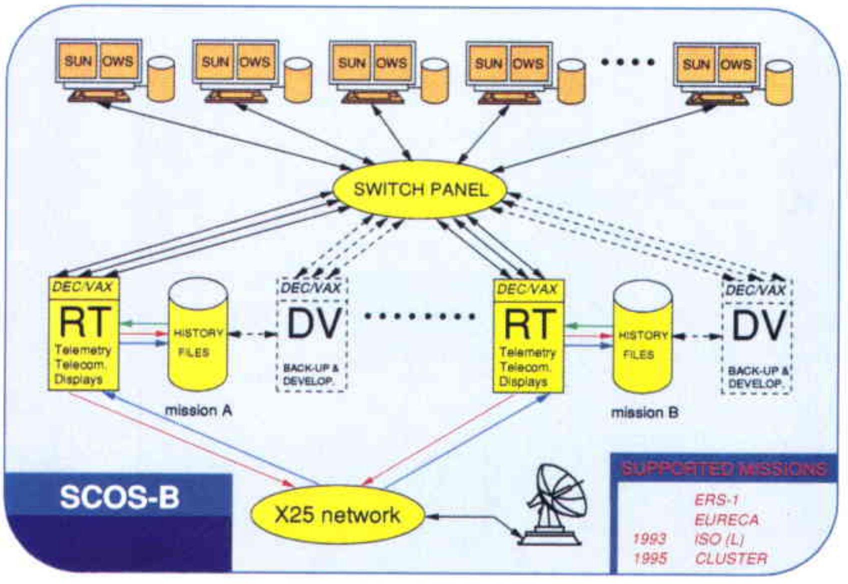


Figure 5. SCOS-B, 1991–1996

data (e.g. telemetry or telecommands) to be displayed. A number of optimisations have been made in an attempt to circumvent this problem and an acceptable level of performance has now been achieved.

The intra-mission dependencies of the second-generation MSSS were removed by the next step, namely the Dedicated Mission-Support Systems (DMSS), which are mission-specific, centralised systems based on DEC/Vax hardware and the SCOS-A or SCOS-B software. Many advances have been made in the functionality of these systems; for example, telemetry with irregular layout and time characteristics ('packetised' telemetry) is now supported, relational-database technology is used to replace the line-oriented approach to defining the spacecraft characteristics and, in some cases, layers 4 and 5 of the OSI standard are being applied for communication with ground-station equipment.

These advances are, for the most part, possible because the underlying hardware and software systems are very widespread and are well supported by the third-party software industry.

Resource and performance-related problems unfortunately still exist, albeit in a slightly different form; the increase in functionality and the increasing use of third-party software have led to an explosive growth in the overall processing needs of an SCS, which has not been matched by the increase in processing power made available by the improvements in the hardware capabilities.

The SCOS-II SCS must attempt to resolve some of these remaining problems, in particular to move the balance between performance and functionality back towards the performance side, while of course still offering a flexible and comfortable environment for the user. It should also be specified and designed so as to allow the easy absorption of future technological advances in the areas of both hardware and software as they become available. This will help to extend the life of the SCOS-II SCS and allow the development costs to be amortised over a longer period.

With these and a number of other factors in mind, the designers of the SCOS-II system have adopted the following guidelines and directions in their efforts to specify and later to implement the leap to the next generation of SCS, which will support ESA missions well into the next century:

1. The SCOS-II system should be a dedicated system, and should not offer multi-mission support. This is not to say that only single spacecraft should be supported, but rather that each SCOS-II SCS should be configured to support spacecraft of a particular family, whose operational characteristics are essentially identical. This will allow a rather more directed approach to performance optimisation, where advantage can be taken of the characteristics of a spacecraft family rather than attempting to be 'all things to all men'.
2. In a return to the original MSSS concept, the SCOS-II SCS should be implemented as a distributed system; this will allow a more or less arbitrary amount of computing power to be provided for a specific mission, subject of course to financial constraints. It should, however, be a homogeneous system; all nodes in the system should be identical, or at least should be provided by the same manufacturer, in order to ease hardware and software maintenance problems.
3. Wherever possible, standard commercial software or hardware should be used (in-house developments are expensive and subject to development risks).
4. As a consequence of the desire to make maximum use of commercial software, the SCOS-II SCS should have clear and well-defined interfaces between its various areas. The third-party software (or hardware) can then be tailored to meet this interface rather than extending its influence throughout the system and rendering a later replacement by an improved but different product impossible. This approach is often referred to as employing an 'open architecture', and successfully specifying such an architecture is possibly the single largest challenge in designing the SCOS-II system.
5. Wherever possible, functions that are performed on behalf of a particular user (e.g. telemetry retrieval) should utilise resources dedicated to that user and should not draw on resources that must be shared among the overall user community.
6. The use of any shared resources in the SCOS-II design should be optimised to the greatest possible extent. Apparently inefficient use of non-shared resources should be acceptable where it would reduce shared-resource usage.
7. The SCOS-II system should be a free-standing system; it should not require the use of other items of the ESOC infrastructure to provide a complete service. Note that where the infrastructure is available (in systems located at ESOC), it is probable that, for reasons of convenience and economy, certain items will be configured into local SCS installations.
8. As far as possible, SCOS-II functions should be compartmentalised; failures in certain functional areas should have only a minimal impact on other functional areas. Similarly, failures related to a specific user should have little or no impact on other system users.

The SCOS-II project is in its very early stages at the present moment. Careful engineering and a certain amount of ingenuity will be required in order to realise the full potential of the current generation of software and hardware, but it is confidently expected that SCOS-II will put ESA at the forefront of the technology that they led with the initial MSSS implementation.

Risk Management at ESA

H. Schimrock
Risk Management Office, Directorate of Administration, ESA, Paris

A few years ago the Agency – with objectives similar to those of large industrial companies – established a Risk Management Office (RMO) within its Directorate of Administration. Those who are somewhat sceptical about the merits of such 'modern management' approaches might well ask: 'How necessary and how useful is such an endeavour?' Unlike industry, ESA is not profit-oriented. Nevertheless, its assets and operations have become both very complex and very costly over the years and every means must be pursued in order to avoid any major loss occurring, to safeguard the interests of the Agency's Member States. This requires the systematic assessment of the elements of risk within its programmes, their possible consequences, and remedies in the broadest sense, which is a process known as 'risk management'.

Introduction

Risk management consists, in principle, of three successive steps:
- risk identification: the assessment of potential physical damage, consequential losses and liabilities
- risk reduction: corrective organisational measures and transfer of risk by means of legal provisions, and
- risk financing: establishing adequate financial backups (internal funds or insurance).

The scope of any risk-management exercise depends on the nature of the company or organisation under review. ESA, as a procurement agency, has a very specific and complex risk profile. Without taking into consideration project-execution exposures – which in principle are transferred to industry – the Agency faces substantial risks in such areas as:
- loss or damage to assets, in particular sites and infrastructure
- security of computers and computer operations
- injury to staff and other persons
- interruption exposures/consequential losses, and
- legal and contractual liabilities.

Site and infrastructure protection

The assets of ESA's infrastructure are fundamental to the Agency's activities and constitute a considerable investment. Their protection and the prevention of potential disruptions of current programmes are prime objectives of the Agency's 'Safety and Security Policy'. These objectives are pursued by means of a number of measures, including:
- identification of hazards
- risk assessment in respect of potential physical damage and interruption of activities
- recommendation of safety and security measures
- consultation during the design phase of new buildings
- compliance reviews of existing operations.

The role of risk reduction throughout the Agency is growing steadily and gaining in acceptance. Many recommendations made by the RMO, both for work under way and for existing buildings, have already been implemented. Nevertheless, further efforts are required to achieve a coherent level of protection, for which the introduction of Agency-wide guidelines and common standards is a pre-requisite. Such standards are designed as minimum requirements to complement any national requirement, without taking the place of statutes or regulations already applicable in the individual Member States.

A distinction has to be made here between these 'common standards' which are to be applied ESA-wide, and for which the RMO is responsible, and 'specific standards' for individual Establishments, to be issued under the authority of the particular Establishment concerned.

Against the background of physical and organisational remedies, it is also necessary to evaluate the 'risk financing' available in the event of any major damage occurring.

In the past, the policy set out by ESA was geared to the philosophy of 'self-insurance' of property. In reality, this has meant 'non-insurance' in the sense that the Member States are not usually in a position to set aside reserves to cover an immediate refund. To rectify this anomalous situation, it has been decided to subscribe to a comprehensive insurance for all assets that are the responsibility of the Agency.

Computer security

Of all the aspects of risk management, that relating to computer systems is possibly the most challenging. It is true to say that there is no such thing as total security, and the management of computer-related risks is no exception in this respect.

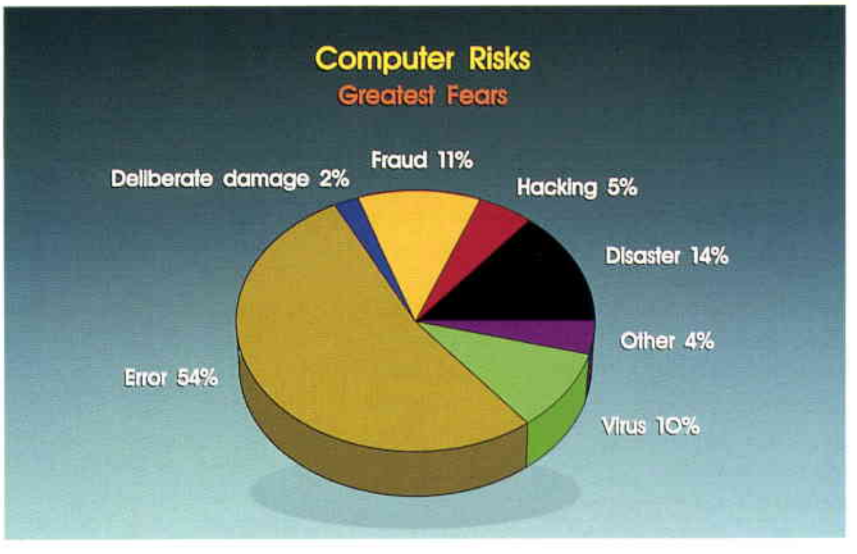


Figure 1. Computer-related risks

The Agency's computing resources represent one of the largest, most complex and diverse computer environments in Europe. These resources are managed on a decentralised basis and include mainframe computers, minicomputers, micro- and personal computers and an array of networks. The scope of the data processing ranges from administrative to scientific and engineering computing, to information-retrieval and real-time satellite-control applications.

Much publicity has been given recently to the risks to which computers can be exposed, such as:
- unauthorised access (so-called 'hacking')
- physical damage due to disasters
- industrial espionage, including electronic eavesdropping and scavenging ('trashing')
- fraud, including unauthorised use of computer resources, and
- malicious damage.

ESA is therefore faced with a widespread exposure to such risks and consequently the Risk Management Office has made a significant investment in addressing computer risk. The primary objectives of the ESA computer security programme are to protect against:
- deliberate or accidental actions that would render ESA computer resources unavailable
- deliberate or accidental corruption of ESA programs and data that would result in loss of integrity
- deliberate or accidental disclosure of classified ESA information that would compromise its confidentiality
- data-processing- and data-communication-related incidents that would result in financial loss for the Agency.

In determining the 'sensitivity' of the Agency's computer applications, the data 'integrity' and 'availability' issues are of greater concern than 'confidentiality', because the majority of ESA's data is ultimately considered to belong to the public domain. Nevertheless, in many ways the three are interrelated, and access to the Agency's systems must be restricted to those who have the authority to use them.

Work is being undertaken to determine the optimum balance between ease of access to and the security of computer systems. That balance is not easily achieved in that too much security can result in greatly reduced efficiency, while too little can prove to be a recipe for disaster.

As part of an Agency-wide data-security programme, the RMO has developed a Data Security Policies and Procedures Manual which, when issued, will provide a benchmark for computer security. It will form the basis for compliance reviews to ensure that ESA's data security policies and procedures have been correctly implemented. This activity will also include data-security awareness courses.

Other exposures

Any risks that could result in injury to staff are naturally a major concern. It is the policy of the Agency to ensure actively that its premises are both safe and healthy places to work. In order to maintain the highest standards and to prevent occupational accidents, the promotion of staff health and safety is an essential element of the RMO's activities. It involves the development of procedures and standards for safe working methods, the motivation of the staff themselves to do everything possible to prevent injury, and compliance reviews of the relevant health and safety procedures.

Another complex area is that of exposure to 'interruption' and consequential loss. Although there is no doubt that certain potential incidents could have substantial adverse effects and far-reaching consequences, quantification of the latter remains difficult and one can contemplate thousands of hypothetical scenarios. The overall aim, therefore, remains one of the regular screening of activities and avoidance of liabilities that could result in unpredictable consequences.

Needless to say, ESA's activities involve a complex international legal and contractual environment with a great variety of commitments and exposures. Identifying possible liabilities and assessing the impact that such exposures might have on the Agency calls for a careful look at the existing terms and provisions. The wide-ranging field to be covered includes such elements as:
- procurement contracts
- launch contracts
- consultancy contracts
- test-facility contracts
- Memoranda of Understanding
- insurance-policy wordings.

Typical issues to be addressed are clauses regarding indemnification, transfer of custody and title, third-party liability, professional liability, damage to equipment or facilities, subrogation, etc.

Obviously, the ideal situation would be for ESA to impose very strict conditions on its contractors, such as disclaiming all liability or limiting liability by setting ceilings or excluding certain kinds of loss. On the other hand, it is clear that the very role of ESA prevents it from imposing draconian conditions on its contractors, who are usually European institutes and industrial groups which it is supposed to encourage, and certainly not deter or penalise. In many situations, therefore, insurance will be the only possible remedy against the exposure, be it legal or contractual liability or risks related to assets and activities or, last but not least, the risks associated with launches.

Insurance cover

ESA's decision-making process on insurance involves, and has to maintain a balance between, two diametrically opposed approaches: the traditional non-insurance route favoured by government bodies, and the seeking of protection through insurance, for which most industrial companies involved in comparable activities would opt.

While in the early days of ESRO non-insurance was the prevailing attitude, the Agency's overall operations have now become so complex and involve such large sums of money that it is unlikely that, in the event of a serious accident or major disaster affecting a programme, additional contributions would be availble from the participating Member States to fully rectify the situation.

The policy that has been developed and pursued more recently against that background advocates that the risk of small losses, which can be absorbed within the regular ESA budget, should be self-insured, while for catastrophic losses and major liabilities, which cannot easily be absorbed within operating budgets, insurance cover should be sought. Such insurance would usually include self-participation, involving so-called 'deductibles' of a pre-agreed level in order to reduce premiums.

Figure 2. The Lloyd's building, an innovative symbol of the world's insurance market

In this light, ESA's RMO has negotiated and placed:
- An ESA all-risk property policy which covers loss or damage, from any cause, to ESA property and items of others while in the Agency's custody, anywhere in the World. This 'all risks' approach differs significantly from the traditional 'named perils' insurance. It has the advantage of embracing causes of loss or damage of any kind, whereas the 'named perils' cover is limited to exposures identified in advance.

In accordance with the above-mentioned policy principles, this insurance, for a total of more than half a billion ECUs, includes self-participation by the Agency which results in a 50% saving on the premium.

- A general-liability policy to meet the financial consequences of liabilities resulting from personal injury, death or property damage caused to third parties.

  Again, in accordance with the policy provided by the RMO, the sums insured have been increased and the scope of the coverage has been extended to include, for example, conferences, fairs and exhibitions. Again, 'deductibles' for amounts to be absorbed by the ESA budget have been introduced in order to keep the premium at a reasonable level.

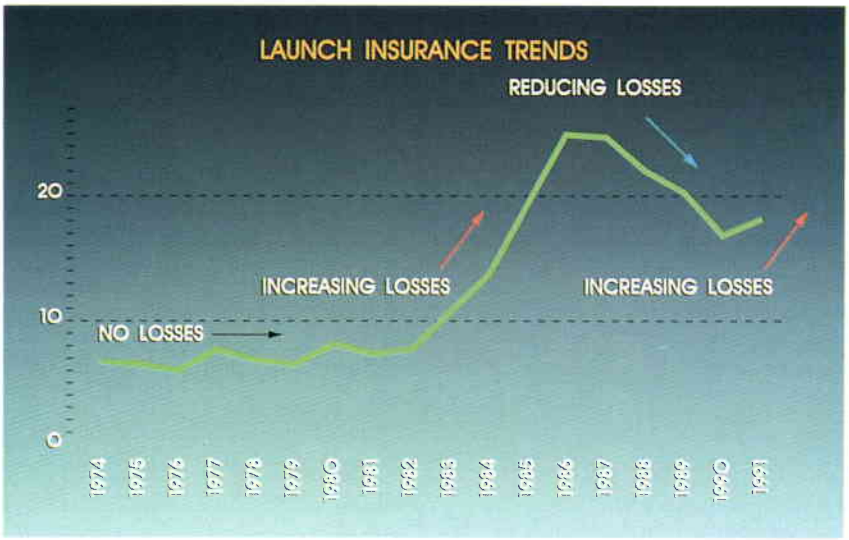


Figure 3. Launch insurance trends. The enormous variation, between 7 and 25%, is caused by the market's reaction to the costs of losses

Launch/operations insurances

The Agency entered the so-called 'space insurance' market in 1977 for its OTS telecommunications satellite, which unfortunately was destroyed due to the failure of its American launcher. The Agency was reimbursed US$30 million on that occasion and was thereby encouraged to continue taking out insurance for its subsequent Marecs, ECS and Olympus application satellites. For these missions, the Agency had made commitments and given guarantees to other organisations such as Inmarsat and Eutelsat and failure to meet these commitments would have had considerable financial implications.

Scientific missions, a major part of the Agency's Programme since the days of ESRO, have never been insured, the arguments advanced being fourfold:
- these missions are unique and often not repeatable (a typical example being Giotto)
- they are of a research and development nature and therefore hardly insurable
- the premium required is not available in the scientific budget
- the missions are self-insured.

The question is whether these arguments are still valid and still apply today. In fact, the concept of 'self-insurance' pre-supposes either that there will be a great number of launches, implying a calculated loss from time to time, or the setting aside of specific financial reserves. If these conditions are not met, the use of the term 'self-insurance' is erroneous and it is rather a case of 'non-insurance', which means the risk of a loss is accepted as such.

The wisdom of this may not be readily apparent from a responsible management point of view, and hence another task of the RMO is to reconcile this current difference in treatment of Europe's scientific and applications missions.

Conclusion

The overall task of the RMO is both far-reaching and complex. Its role is firstly an advisory one on an Agency-wide basis, without compromising the responsibilities of those services and Directorates to whom advice is given. This often requires more than a little diplomacy, but has proved to be a reasonably successful approach so far. The advice given is well-accepted in most cases and the identified exposure to risk reduced accordingly. The RMO also has an executive role with regard to certain insurance decisions for which the Office has its own budget.

Without such an organisational instrument as the RMO, the Agency would simply not meet modern management standards. Its primary functions are to assist in safeguarding the collective interests of ESA's Member States by:
- increasing the degree of confidence in the Agency's ongoing activities, and
- ensuring that Member States will not be faced with unexpected losses and unforeseen financial requirements.

All in all, risk management is a must for any large organisation claiming to have an up-to-date management approach and it is undoubtedly a discipline that will become increasingly important in the years to come.

ESA's On-line Directory of Space and Earth-Science Data

M. James*, L. Fusco & D. Lloyd**
Earthnet Programme Office, ESRIN, Frascati, Italy

Research and operational data needs in the 1990s require integrated data-management systems accessible to users at many sites. The ESA Prototype International Directory (ESA PID) is the European node of an international system of directories that is being sponsored by the Committee on Earth-Observation Satellites (CEOS) and NASA in order to support users of data from past and current missions, from field campaigns, and from the polar platforms currently planned by both NASA and ESA.

Introduction

A new, on-line information service is now available to the scientific community in Europe – the ESA node of the Prototype International Directory (ESA PID). Its primary role is to provide the European scientific-data user community with free on-line information about geophysical data sets available throughout the World. In addition, the ESA PID contains summary information about space and Earth-observation data centres, on-line systems, scientific campaigns, instruments and platforms.

The ESA directory is one of four principal PID nodes that have been established as part of an international data-management initiative sponsored by the Committee on Earth Observation Satellites (CEOS) Catalogue Subgroup. The other PID nodes are in Japan (the National Space Development Agency (NASDA)/Earth Observation Centre), the USA (National Aeronautics & Space Administration (NASA)/National Space Science Data Center), and Canada (Canada Centre for Remote Sensing, CCRS).

PID support staff at each PID node work not only to provide directory services to users throughout their region, but also to investigate issues involved in populating and maintaining an international, co-operative on-line data service. Since new PID entries produced at one node are distributed to the other three nodes, the contents of the four principal PID nodes are essentially the same.

The ESA PID shares several useful features with the other PID nodes, the most important of which are:

- Remote on-line access
  The directory is updated on an almost daily basis to include new data-set descriptions or to incorporate changes in archive, contact, or media/volume information. This means that directory users always have access to the very latest information about data sets.
- Interdisciplinary co-operation
  Descriptions of data for all space- and Earth-science disciplines are available, including in-situ, remotely-sensed, and derived data.
- International co-operation
  The directory contains descriptions of data from agencies throughout the World. Thus, European directory users can learn about data held in North America and Asia, and likewise users outside Europe can learn about data held at the European centres.
- Simple system design
  The directory works with simple terminals (even teletypes) and requires no special user training.
- Access to remote data systems
  The directory provides automatic connections to several independent on-line data systems in the United States, Japan and Europe.

Directory services

Data-set descriptions

The main function of the ESA PID is to provide information about geophysical data sets: what data sets exist, whether an existing data set is available, and where and how to obtain data of interest. Data-set descriptions are written, and exchanged, using a Directory Interchange Format (DIF), which is an international data-set description standard that is being promoted and used by CEOS, CCRS, Deutsche Forschungs-

* Current affiliation:
ST Systems, Washington, USA
** Tecnodata, Frascati, Italy

anstalt für Luft und Raumfahrt (DLR), ESA, NASA, NASDA, the National Oceanic and Atmospheric Administration (NOAA), the Royal Aerospace Establishment (RAE), and many others.

```
Entry_ID: EARTH_IMAGES_TIROS
Entry_Title: Earthnet Programme Office NOAA-TIROS AVHRR and TOVS data
Start_Date: 1978-11-06
Originating_Center: ESA EPO > ESA Earthnet Programme Office
Sensor_name: AVHRR > Advanced Very High Resolution Radiometer
Sensor_name: TOVS > TIROS Operational Vertical Sounder
Source_name: TIROS_N
Source_name: NOAA_6
Source_name: NOAA_7
Source_name: NOAA_8
Source_name: NOAA_9
Source_name: NOAA_10
Source_name: NOAA_11
Group: Author
        Last_name: ESAPID Staff
End_Group
Group: Technical_Contact
        First_name: L.
        Last_name: FUSCO
        Email: TELEMAIL > [esa.lfusco]telemail
        Phone: +39 6 941801
End_Group
Group: Data_Center
        Data_center_name: ESA EPO> ESA Earthnet Programme Office
        Dataset_ID: Earth_Images_TIROS
        Group: Data_Center_Contact
                First_name: G.
                Last_name: CALABRESI
                Phone: +39 6 941801
        End_Group
End_Group
Storage_Medium: Computer Compatible Tapes
Storage_Medium: High Density Digital Tapes
Storage_Medium: Optical Disk
Storage_Medium: Paper Quick Looks (faxable)
Storage_Medium: Photographic Quick Looks
Parameter: EARTH RADIATIVE PROCESSES > RADIANCE
Parameter: ATMOSPHERIC COMPOSITION > HUMIDITY
Parameter: ATMOSPHERIC COMPOSITION > OZONE
Parameter: ATMOSPHERIC DYNAMICS > ATMOSPHERIC TEMPERATURE > Temperature Profiles
Parameter: ATMOSPHERIC DYNAMICS > HUMIDITY
Parameter: ATMOSPHERIC DYNAMICS > PRESSURE
Parameter: RADIANCE AND IMAGERY > INFRARED > Thermal IR Imagery
Parameter: RADIANCE AND IMAGERY > VISIBLE > Visible Imagery
Parameter: OCEAN DYNAMICS > SEA ICE
Parameter: GEOGRAPHY AND LAND COVER
Discipline: EARTH SCIENCE > ATMOSPHERE
Discipline: EARTH SCIENCE > LAND
Discipline: EARTH SCIENCE > OCEAN
Location: AFRICA > North West
Location: SEA SURFACE
```

Figure 1. An example of a completed 'DIF' (Directory Interchange Format).

An example of a completed 'DIF' is shown in Figure 1, from which it may be seen that the ESA PID provides the following data-set information:
- descriptive summary
- temporal coverage
- geographical coverage
- instruments ('sensors') and platforms ('sources') used for acquisition
- geophysical parameters
- discipline and location keywords
- size of data set and storage/distribution media
- investigator and technical contact
- bibliographic references
- archive/distribution contact.

Most of this information can be easily retrieved from the ESA PID user interface. For example, a user may search for data on winds in the equatorial region using a geophysical parameter, 'WINDS', and a longitude/latitude specification.

Figure 2 shows a sample of the results from such a search. First, the list of data sets that contain the desired wind information is retrieved (left figure). By entering a selection number, the user can then view the detailed data-set information contained in the directory (right figure).

Currently, the directory contains some 1000 data-set DIFs. Most of these relate to Earth geophysical data (Fig. 3), and most describe data held in the USA, a consequence of the fact that the directory effort began in the USA back in 1987. However, as ESA PID support staff continue to work with centres in Europe, and as additional entries are provided by the Asian PID node, it is expected that the directory will come to

```
QUERY_RESULT                  Titles Menu                   Page 5 of 6
                      36 directory entries selected

 26. Monthly Average Tropical Winds from 80 Years of COADS

 27. SEASAT SASS Level 2.5  Wind Speed and Wind Direction

 28. SEASAT SMMR Sea Surface Temperature, Wind Speed, Water Vapor, Atmospheric
     Liquid Water and Rain Rate (Level 2.5)

 29. SEASAT Altimeter Sea Surface Height, Satellite Height with respect to the
     Reference Ellipsoid, Wind Speed, Wave Height, and Automatic Gain Control

 30. Geosat Altimeter Sea Surface Height and Satellite Height With Respect to
     the Reference Ellipsoid, Automatic Gain Control and Wind Speed (Level 2.0)

 31. GEOSAT Geophysical Data Records for the Exact Repeat Mission


Help,Exit,Refresh,Next,Prev,Page #,Main_menu,Comments,Quit_PID
ENTER SELECTION # or COMMAND >
```

Figure 2. Sample search results from the ESA PID

reflect better the global distribution of available geophysical data.

Other information

In addition to data-set information, the ESA directory includes supplementary descriptions of sensors, sources (or platforms), data systems and archives and scientific campaigns and projects. Sensor information is a very brief description of the measuring instrument, including bandwidths, geophysical properties measured, and scanning or imaging characteristics. Platform information includes summary information about the location, orbit characteristics and lifetime of the platform. Scientific projects and campaigns are described in terms of their objectives and the data used and produced. A contact name for scientific projects and campaigns is also given should further information be required. Data-system descriptions provide details of the data, services, access and ordering procedures, costs, and contact personnel at important data-holding centres. Currently over 70 institutes and on-line systems are described in the directory.

Many of the data systems described in the ESA directory provide on-line data services to which a directory user may connect directly. Thus, in the course of a directory session, users may notice a command option 'LINK' appearing on the screen (Fig. 2, below). This is an indication that the user may transfer, if desired, to the top level of a remote on-line data system.

Direct access to other data systems using LINK is an especially useful feature of the directory because it is a free service that requires no special password. Currently, LINKs are available from the ESA PID to more than thirty data systems, including the European Space Information System (ESIS) and the ESA Information Retrieval Service (IRS). New LINKs are also being investigated,

```
Location: POLAR
Location: MID-LATITUDE
Location: EQUATORIAL
Location: ARCTIC OCEAN
Location: BOUNDARY LAYER
Location: TROPOSPHERE
Location: STRATOSPHERE
Location: ATLANTIC OCEAN > North Atlantic Ocean
Location: EUROPE > European Coastal
Location: EUROPE > European Continental
Location: MEDITERRANEAN SEA
Keyword: CLOUD COVER
Keyword: LAND COVER
Keyword: MAPPING
Keyword: METEOROLOGY
Keyword: OCEANOGRAPHY
Keyword: VEGETATION
Group: Coverage
        Minimum_Latitude: 5S
        Maximum_Latitude: 90N
        Minimum_Longitude: 45W
        Maximum_Longitude: 50E
End_Group
Revision_Date: 1990-09-13
Group: Summary
        The Earthnet NOAA-TIROS archive contains High Resolution Picture Transmission (HRPT), produced
        by the Advanced Very High Resolution Radiometer (AVHRR), and Tiros Operational Vertical Sounder
        (TOVS) data. These data have been acquired by data receiving stations at Tromso (Norway), Dundee
        (Scotland), DLR (Germany), Rome (Italy), Maspalomas (Gran Canaria, Spain), and Niamey (Niger).

        The Earthnet NOAA-TIROS archive includes HRPT and TOVS data from all NOAA-TIROS missions.
        These data are available currently (August 1990) in two formats - raw HRPT ("full acquisition") and
        SHARP level 1. The SHARP 1 product contains up to 4 minutes worth of acquired HRPT, formatted
        according to the Committee on Earth Observing Satellites (CEOS) Standard Family Format. A quick-
        look product is also available for all Earthnet TIROS data in SHARP format. Although it is intended
        that the entire Earthnet TIROS archive should be in SHARP 1 format on optical disks (all new TIROS
        data is archived this way), a substantial number of historic full acquisition images have yet to be
        processed.

        Further details of the Earthnet TIROS data archive may be obtained from the online Earthnet
        catalogue, Earth Images, or from the contacts listed.
End_Group
Group: Reference
        ESA-EPO, 1989, SHARP-1: Technical Specification of CCT Format (release 1.1) (ESA Earthnet
        Programme Office, ESRIN: Frascati, Italy) 51pp.

        ESA-EPO, 1990, Earthnet Tiros AVHRR Catalogue User Guide (ESA Earthnet Programme Office,
        ESRIN: Frascati, Italy).

        Fusco, L. and Muirhead, K., 1987, AVHRR data services in Europe - the Earthnet approach. ESA
        Bulletin, 49, 9-19.
End_Group
```

Fig. 1 cont.

```
BRIEF                         SECTION 1 of 5                  Page 2 of 2
Geosat Altimeter Sea Surface Height and Satellite Height With Respect to the
Reference Ellipsoid, Automatic Gain Control and Wind Speed (Level 2.0)

     This data set contains LEVEL 2.0 automatic gain control data, sea
surface height, satellite height (with respect to the reference ellipsoid)
and wind speed data. In addition to its main parameters, this data set contains
corrections for the influences of wet and dry atmospheric path, ionosphere and
tides.  Corrections for altimeter bias,  electromagnetic bias, and
residual orbit error are not included.  The wet atmospheric correction
is based on a long wavelength model (Fleet Numerical Ocean Center) and
does not reproduce perturbations at length scales of a few hundred km.
Data are available on 6250 bpi magnetic tapes. One 6250 bpi tape holds 17 days
worth of data.  Typically, the data are available from NODC within 2 months
after collection. NODC accepts subscriptions allowing regular deliveries
of data.  Data set status:  Data collection is ongoing.


Help,Exit,Refresh,Next,Prev,Page #,Supplement,Display,Comments,Quit_PID,LINK
Return for ATTRIBUTES display or Command>
```

Fig. 2 cont.

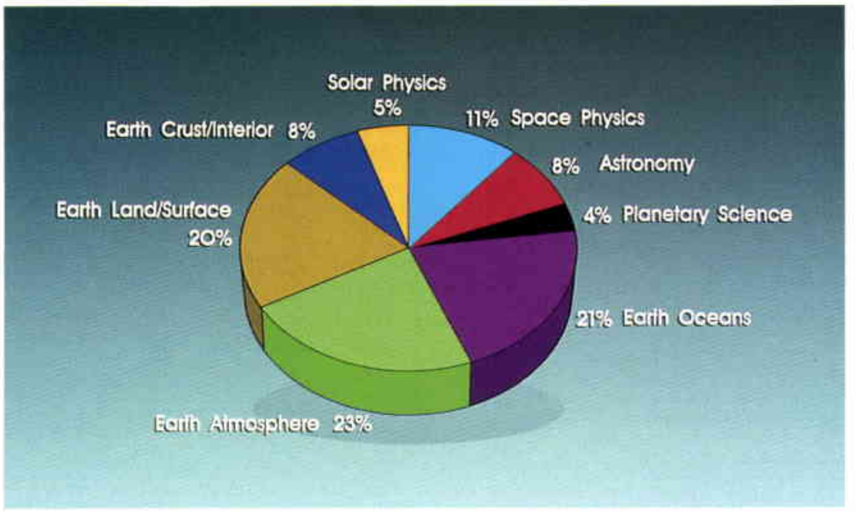


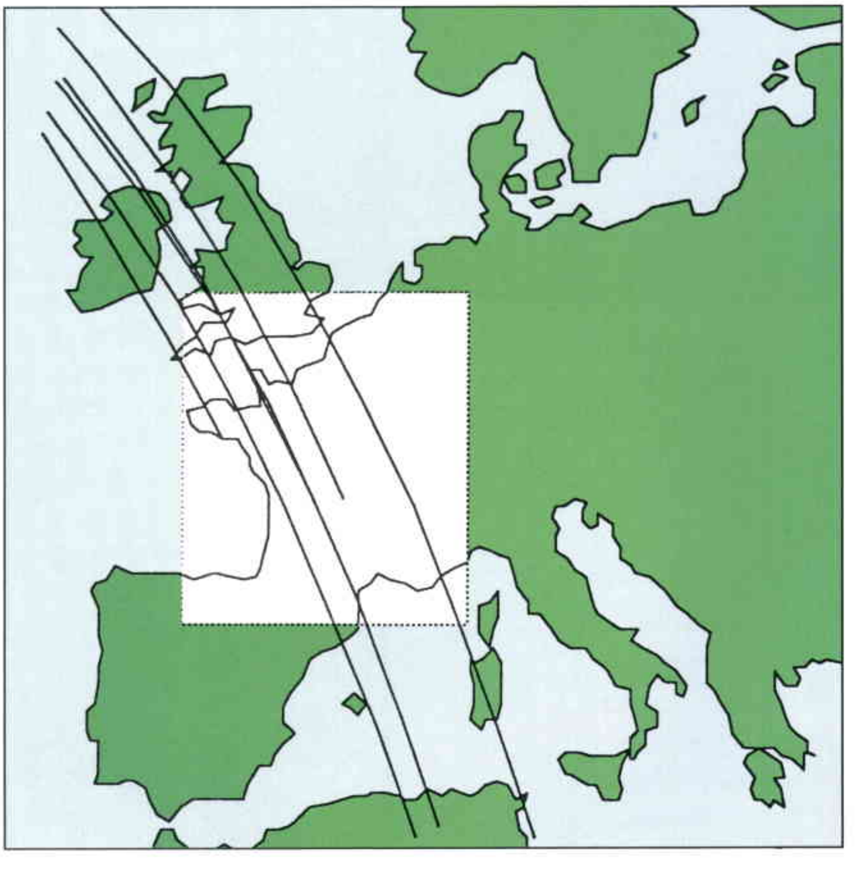
Figure 3. Summary of data sets contained in the ESA PID (by discipline)

for example with the Columbus User Information Service (CUIS).

Configuration and access

The ESA PID is a free service that resides on a MicroVAX 3800 located at ESRIN in Frascati (I). The directory software was developed originally for the NASA Master Directory (which has provided data-set information to more than 4000 user sessions over the past two years). This software is intended to serve as many users as possible and therefore consists of a simple system of menus and prompts requiring no special terminal emulation.

Figure 4. Sample Seasat coverage map displayed by the SAR Data Catalogue (Jet Propulsion Laboratory, California, USA) as accessed by the ESA PID using Tektronix terminal emulation



Users with more advanced terminals, however, can take advantage of special services offered by some of the systems to which the directory connects (via LINK). Thus directory users with terminals capable of emulating graphics terminals can display coverage maps or browse data in several on-line data systems (Fig. 4).

The ESA PID may be accessed in a number of different ways:

- Via SPAN nodes
  $ SET HOST 29628
  Username: ESAPID
  (no password required)

- Via the Packet-Switched Public Data Networks
  The Network User Address (NUA) of the ESA PID for international calls is 02222650014761. However, in most European countries users can also access the ESA PID by calling within their country (at local charges) the following numbers:

Country	NUA
Austria	2618108061
Belgium	221044361
Denmark	30106384161
Finland	20407661
France	17500039461
Ireland	3605922261
Italy	2650014761
Netherlands	129017661
Norway	11062761
Spain	21406232161
Sweden	710401661
United Kingdom	21920115661

- Via ESA Information Retrieval Service (IRS) as 'File 21' of ESA Quest. Further details of this method of access can be obtained from the Quest Help Desk, at ESRIN (tel. 39.6.941 80226).

- Via a dial-in telephone line with the number 39.6.941.7336.

Access via Internet will be available in the near future.

Users familiar with access methods for other ESRIN on-line services such as ESIS and the IRS system will find access to the ESA PID equally straightforward. Although a brief ESA PID User's Guide is available from the ESA PID User Support Office, the directory is a simple system which requires no special training (Fig. 5). Any problems or queries that do arise can be directed to ESA PID User Support staff.

The role of directories today and tomorrow

Scientists working on the US polar platform have placed a clear requirement on the builders of the ground segment (EOSDIS) to provide the research and operational community with 'one-stop shopping'. This requirement means that directories, catalogues and inventories should be sufficiently well integrated to allow a researcher to find out what data exist, to determine if those data are appropriate (by browsing the data or reading about validation procedures, etc.), and to order the data selected, all from uninterrupted sessions at a single computer terminal. It is in this context that the complementary nature of current data and metadata management initiatives is most apparent.

The ESA PID is just one of several directories, data catalogues and data inventories providing distinct types and levels of information and access (e.g. the NASA Master Directory software is being used by other organisations in Europe, including RAE and DLR, to assist with the management and provision of information locally). The intention is that the ESA PID should make available not only information of interest to the general scientific-data user community, but also, via the LINK facility, specialised information contained in local data systems. The increased co-operation among directory and inventory activities that this objective implies are essential if 'one-stop shopping' for data from large, integrated missions such as ERS-1 and the US and European polar platforms is to become a reality during the 1990s.

Acknowledgements

The ESRIN team working on the ESA PID include Gerhard Triebnig, Helen Palmer and Martin Spence. The authors of this article would like to acknowledge the substantial effort made by this team in the improvement, expansion and maintenance of the operational services associated with the PID.

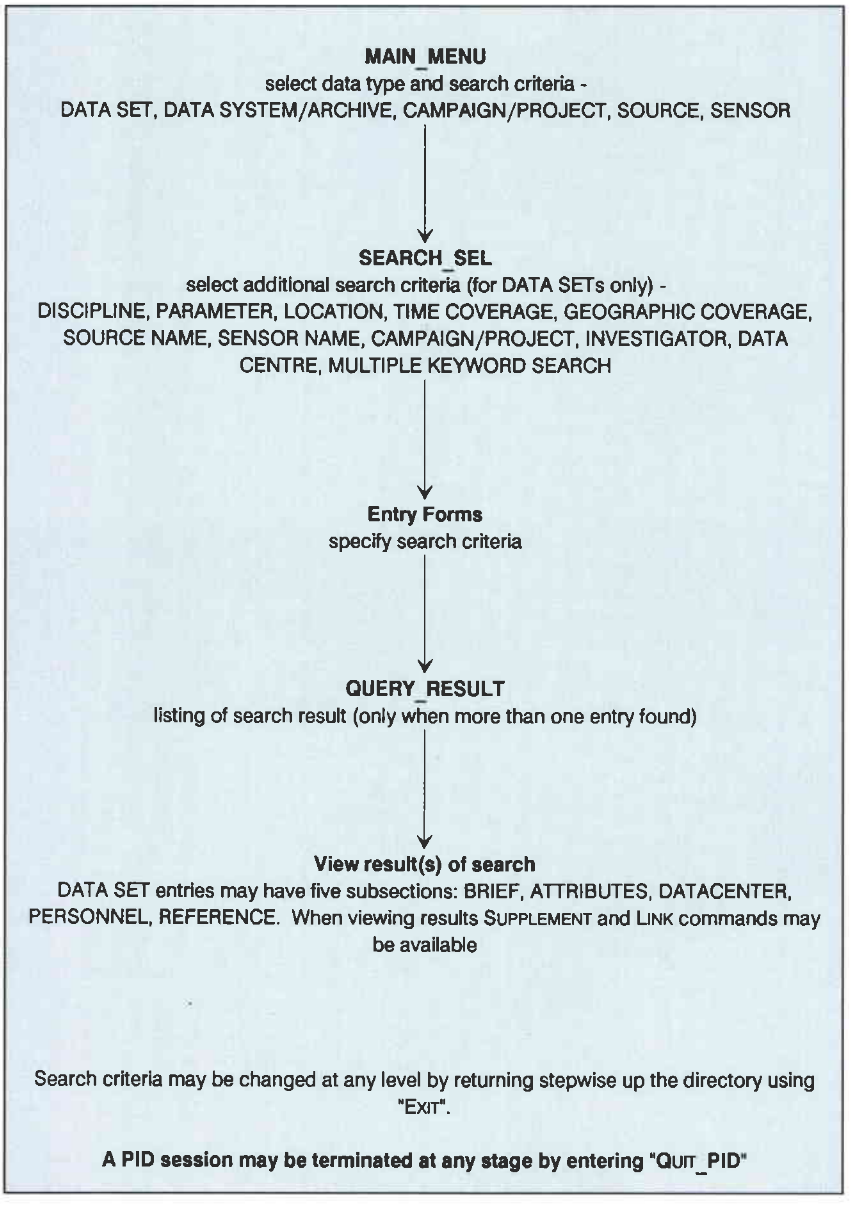
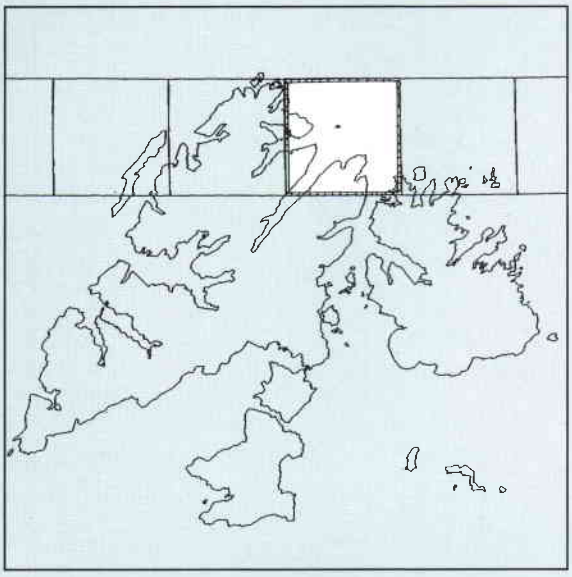
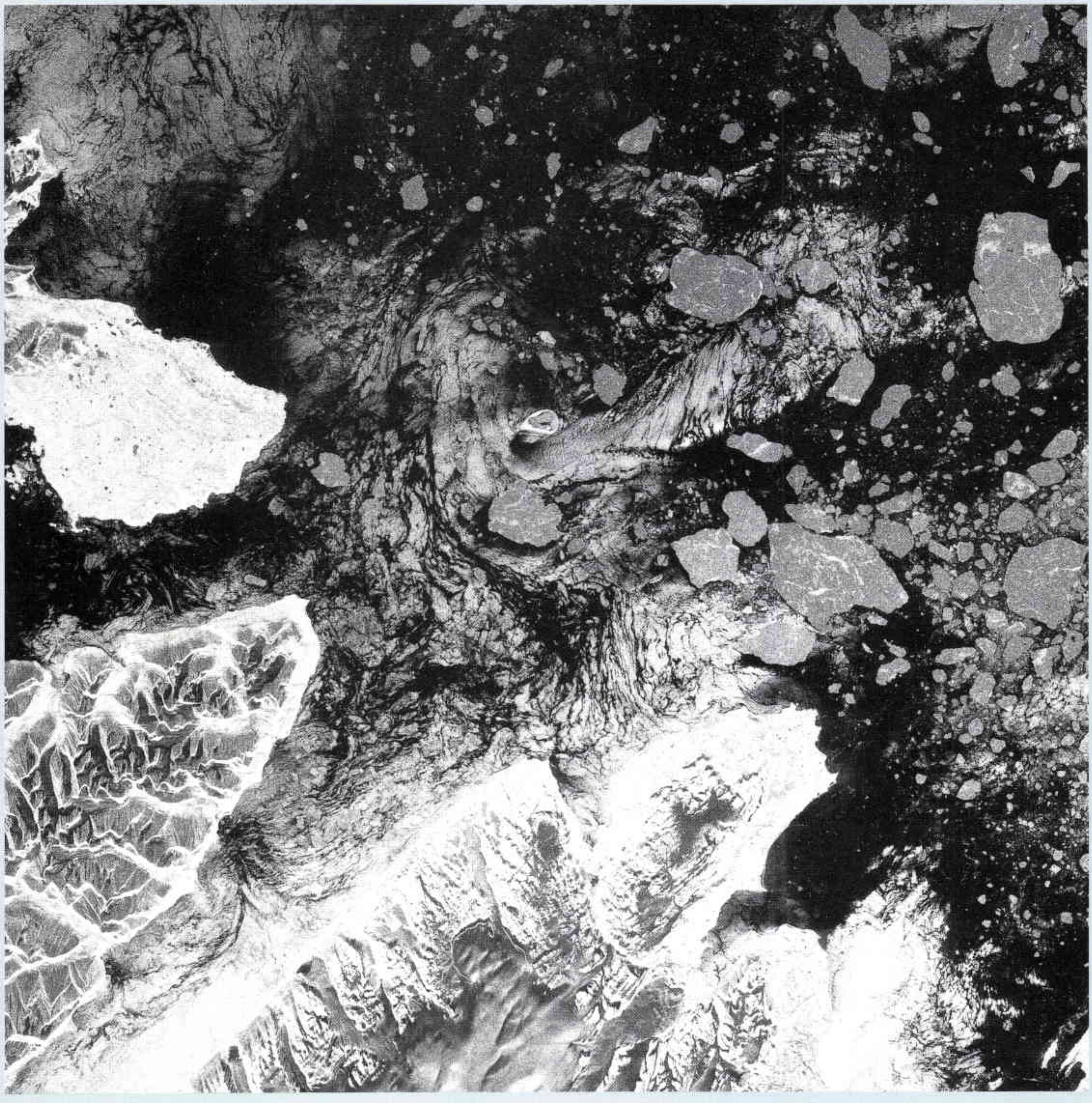


Figure 5. Summary structure of the ESA PID

Focus





Earth

Image Parameters

- Acquired at the ESA Network's Salmijaervi Ground Station on 27 July 1991 at 11:50:31 UTC.
- Processed with the Kiruna Fast-Delivery SAR Processor.
- Spatial resolution: 25 m.
- Location of the image centre:
  Latitude: 80.02°N
  Longitude: 15.15°E.

Spitzbergen, Norway

This is the first ERS-1 image acquired at the ESA Network's Salmijaervi Ground Station (Kiruna, Sweden) on the afternoon of 27 July 1991 at 13.50 h. It is a Synthetic Aperture Radar (SAR) image taken at C-band (5.3 GHz, equivalent to 5.66 cm wavelength).

The scene covers an area of approximately 95 km x 95 km around the island of Spitzbergen, which lies between the latitudes of 77 and 81°N. Together with one other large island and several smaller ones, it forms the 'Svalbard Archipelago', which is under Norwegian jurisdiction.

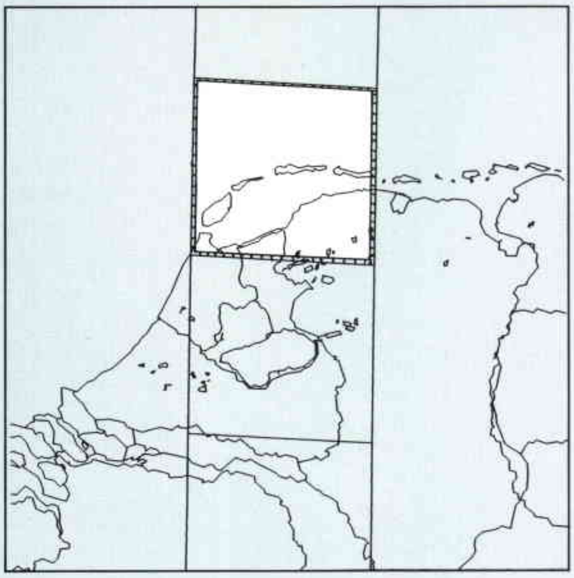
The landscape is dominated by mountains (rising to 1700 m) and glaciers, some of which flow down into the fjords. The pack ice reaches the islands throughout the year in the northeast, but the fjords on the southwest side of the island are navigable almost year round.

The island, which has approximately 2000 inhabitants, is surrounded by rich fishing grounds, and Norwegian and EEC trawlers penetrate as far as possible into the pack ice.

The image shows the northernmost shores of Spitzbergen, and the entrances to 'Wijdefjorden' and 'Woodfjorden' fjords. A glacier runs down into the first of these fjords.

The fjords themselves contain a considerable amount of glacier ice. In the open sea, north of Spitzbergen, large floes of multi-year ice (3 to 5 years old) are visible, with diameters of up to 10 km and thicknesses of up to 3.5 m.

The light-grey areas are mostly multi-year ice broken into 'small' (10 to 50 m diameter) pieces, and 'slush' ice. Shipping can easily penetrate these areas.



Focus

Earth

Image Parameters

- Acquired at the ESA Network's Fucino Ground Station on 27 July 1991 at 21.40 UTC.
- Processed with the Verification Mode Processor at ESA/Earthnet in Frascati (Italy).
- Pixel size: 12.5 m.
- Spatial resolution: 25 m.
- Location of the image centre:
  Latitude 53°15' N
  Longitude 5°18'E.

The Frisian Islands, The Netherlands

This is the first ERS-1 image acquired at the ESA Network's Fucino (Italy) Ground Station during the night of 27/28 July 1991 at 23.40 h. It was taken with the spacecraft's Synthetic Aperture Radar operating at C-band (5.3 GHz, equivalent to 5.66 cm wavelength).

The scene covers an area of approximately 95 km × 95 km in the northwest of The Netherlands, including the western Frisian Islands. The agricultural regions of Friesland (bottom right) and the Wieringermeer polder (bottom left) exhibit a regular pattern of agricultural fields. The radar has a clear sensitivity to different crop types.

The towns appear in very bright tones. Leeuwarden can be seen on the right-hand side of the image, at the confluence of various easily identifiable roads and railways. The structures of the harbour of Den Helder can be seen to the bottom left.

The most remarkable feature in this image, however, are the water patterns in the North Sea (top) and in the Ijsselmeer, which is separated by a long dike (the 'Afsluitdijk', bottom centre) from the Waddensee, which is the belt of water between the mainland and the Frisian Islands.

Numerous ships are identifiable (isolated bright points), some producing wakes that can be traced back for more than 20 km. Close examination of the image shows that the vessels are sometimes displaced from their wakes, due to a combination of the Doppler effect of the radar system and the ship's motion.

The features apparent in the North Sea (at the top of image) are due mainly to variations in the surface state of the water creating various kinds of surface roughness. When the watar surface is flat, it appears in the image in a very dark tone. This is the case near the island of Texel (top left) and in the lakes in the bottom part of the image. If the water surface is choppy, it appears in bright tones in the image.

Other notable features include waves breaking on beaches of the west coast of North Holland (bright line, extreme bottom left corner of the image), and the land-reclamation areas on the north coast of Friesland.

ESA Point of Contact

Earthnet User Services
ESRIN
Via Galileo Galilei
00044 Frascati, Italy

Tel. 39 6 9401218/210
Telex 616468 EURIME I
Fax. 39 6 9426285

In Brief

ESA Appoints Two New Directors

At its Meeting on 27 June 1991, the Council of the Agency, chaired by Prof. Francesco Carassa, unanimously adopted a proposal by Mr Jean-Marie Luton, ESA's Director General, to appoint Mr Adalbert Plattenteich as the Agency's new Director of Administration, and Mr Félix García-Castañer as its new Director of Operations.

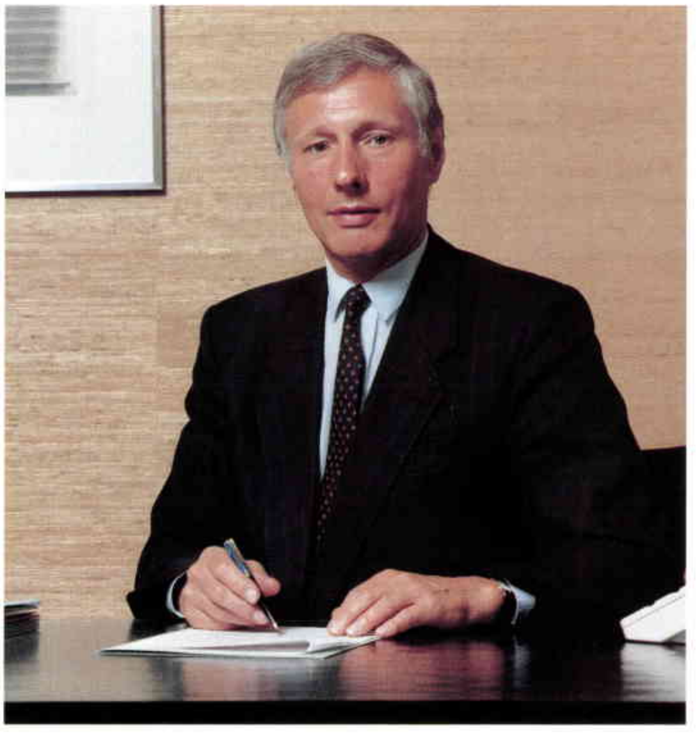
Mr Adalbert Plattenteich, who will take up his new duties on 1 December 1991, was born on 30 September 1934. After obtaining his law degree at Münster University, he began his professional career with the German Federal Ministry for Research and Technology in Bonn. From there he moved, in 1971, to the Von Laue-Langevin Institute in Grenoble, France, to become its Director of Administration, a post which he held until 1977.

Following a further spell at the Federal Ministry for Research and Technology, in 1979 he was elected Vice-President of the Management Board of the 'Forschungszentrum Jülich-KFA' near Aachen (Germany), where he is currently responsible for general administration, finance, personnel, contracts, legal affairs, internal audit, and public relations.

Mr Plattenteich has also been a member of the Council of JET (the Joint European Torus) since 1980.

Mr Félix García-Castañer, who is to take up his duties on 1 August 1991, is of Spanish nationality, and was born on 28 December 1936. He is a Physical Sciences graduate of the University of Madrid. After specialising in electronics and control systems at the Philips International Institute of Technology at Eindhoven in The Netherlands, in 1962 he worked as a trainee at the European Centre for Nuclear Research (CERN) in Geneva, subsequently joining the Spanish Nuclear Energy Commission. From 1966 to 1968 he worked in the petrochemical industry.

His career in the space sector began with INTA in Madrid, where he participated in and later managed the Apollo operations at the NASA/INTA stations at Maspalomas (Canary Islands) and in Madrid. In 1975, he was appointed Head of the Operations Department at ESOC.



Mr. Plattenteich (left)
Mr. García-Castañer (right)

Meteosat-2 Completes Ten Years in Orbit

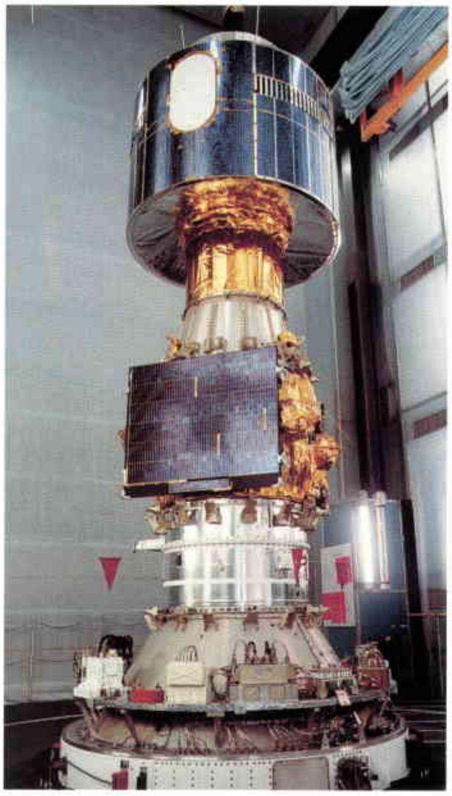
Wednesday 19 June was the Tenth Anniversary of the launch of Meteosat-2, the second in the ESA series of European meteorological satellites. Originally designed for a three-year lifetime in space, Meteosat-2 is still producing perfect imagery after more than three times as many years in orbit.

When it was launched in June 1981, by an Ariane-1 launcher, Meteosat-2 was eagerly awaited by Europe's meteorologists, who had already been exploiting the data products from the experimental Meteosat-1, launched almost four years earlier in November 1977. It entered service on 12 August that year and served as the primary satellite for the next seven years, until 11 August 1988, when Meteosat-3 took its place.

During the last three years, three more Meteosat satellites have been launched: Meteosat-3 in June 1988, Meteosat-4 in March 1989 and Meteosat-5 in March 1991. The latter two were financed and are owned by Eumetsat, the European Meteorological Satellite Organisation set up for the commercial exploitation of meteorological satellites.

The images transmitted to ground every thirty minutes from the Meteosat series of spacecraft have been used to derive a set of 'meteorological products', such as sea-surface-temperature maps, cloud-cover data, and many other specialised products which are now fed routinely into the European meteorological data networks.

Meteosat-2 will be de-orbited in a few weeks time to free its position in the crowded geostationary orbit for another spacecraft, thereby bringing to a close the operational service of one of Europe's longest living satellites to date.



Meteosat-2 ready for launch

SPC gives Go-Ahead for Giotto Extended Mission

At its meeting on 12 and 13 June, the ESA Science Programme Committee (SPC) approved the Director of Science's recommendation to undertake the Giotto Extended Mission (GEM), by which the Giotto spacecraft, which made a historic flyby of Comet Halley in March 1986, will make an encounter with a second Comet, Grigg-Skjellerup, in July 1992.

Launched on 2 July 1985 by an Ariane-1 vehicle from the Kourou Space Center, in French Guiana, Giotto journied for eight months to encounter Comet Halley and photograph the famous comet nucleus. The spacecraft survived and was put into hibernation two weeks after that spectacular encounter.

Experts at ESA's European Space Operations Center (ESOC) in Darmstadt, Germany, reactivated the probe in March 1990, at which time it had been in hibernation for four years and was a hundred million kilometres from Earth.

On 2 July 1990, the spacecraft passed within 23 000 km of the Earth and the first ever Earth-gravity-assist sent Giotto speeding towards its new target, Comet Grigg-Skjellerup.

Activities for the GEM mission itself are already underway (see paper in ESA Journal 91/2), and the next major milestone will be a second reactivation in the first week of May 1992, with a view to encountering Comet Grigg-Skjellerup on 10 July 1992 at approximately 15.00 h GMT.

The time of the rendezvous can be predicted with great accuracy because ESOC has already put the spacecraft into a very precise orbit in which, with no additional orbit-correction manoeuvres, it will pass within 15 000 km of Comet Grigg-Skjellerup's nucleus. With a few additional manoeuvres that are planned, Giotto should pass within about 1000 km of the comet.

ERSC to Distribute ERS-1 Data for ESA

ESA has selected the Eurimage/Radarsat International/Spot Image Consortium (ERSC) as the commercial distributor for ERS-1 data. Detailed negotiations are currently under way between ESA's representatives from Earthnet/ESRIN (Frascati, I) and this Consortium, led by Eurimage, and involving three of the World's leaders in the commercialisation of remote-sensing satellite data.

In particular, Eurimage intends to cover the European market, Radarsat International the North American market, and Spot Image the rest of the World.

For users, the availability of ERS-1 radar data from the same companies that are operating in the optical satellite data market will provide the advantage of having a single supplier for both types of data, and hence the possibility of obtaining combined product solutions to meet specialised needs.

ESA's ERS-1 Remote-Sensing Satellite Safely in Orbit

Launch of ERS-1

With a perfect launch aboard Ariane flight V44 on the morning of Wednesday 17 July at 03:36:31 h European time, ESA's remote-sensing satellite, ERS-1, was successfully placed into a polar orbit some 800 km above the Earth. The orbit injection and separation from the launcher were both achieved with very high accuracy.

Telemetry data received at ESOC just minutes after the launch showed the satellite to be in good condition. During the first four orbits, a series of critical manoeuvres were successfully completed, including the deployments of the spacecraft's solar generator and various antennas.

Under overall control from ESOC, seven ground stations around the globe were involved in the Launch and Early-Orbit Phase (LEOP) activities. With the satellite safely in orbit and the LEOP tasks for both the platform and its payload completed, orbit corrections were successfully performed on 26 July to put the spacecraft into the so-called 'Venice orbit' required for the main commissioning phase (this orbit provides a three-day repeat cycle passing over the city of Venice in Italy for payload calibration purposes).

The Active Microwave Instrumentation (AMI), the Radar Altimeter (RA) and the Along-Track Scanning Radiometer (ATSR) have now been switched on and tested in all operational modes. Large data sets have already been collected and are being processed at the ESA stations at Kiruna in Sweden and Fucino in Italy.

Preliminary analysis of these data indicates that the radar altimeter is performing well over both ocean and ice surfaces and that the information on wind fields at the ocean surface derived from the scatterometer measurements is of good quality, even though in-flight calibration of these instruments has not yet started. These instruments are operated continuously and the data recorded onboard ERS-1, to give worldwide coverage. The onboard tape recorders have also been checked and are functioning correctly. The excellent performance of all of the instruments at such an early stage provides great confidence for the routine operations to follow.

Extensive acquisition of data by the Synthetic Aperture Radar (SAR) is planned over Northern and Southern Europe, the Arctic, the Mediterranean and parts of Africa. These operations will be extended progressively to non-European stations, in North and South America, Australia, Asia, etc.

The first SAR images over Spitsbergen (Norway) and the Frisian Islands (The Netherlands) – reproduced in the 'Focus Earth' feature in this issue of the Bulletin – were officially released by ESA on 6 August. Sample products from the other ERS-1 instruments will be released in the coming weeks.

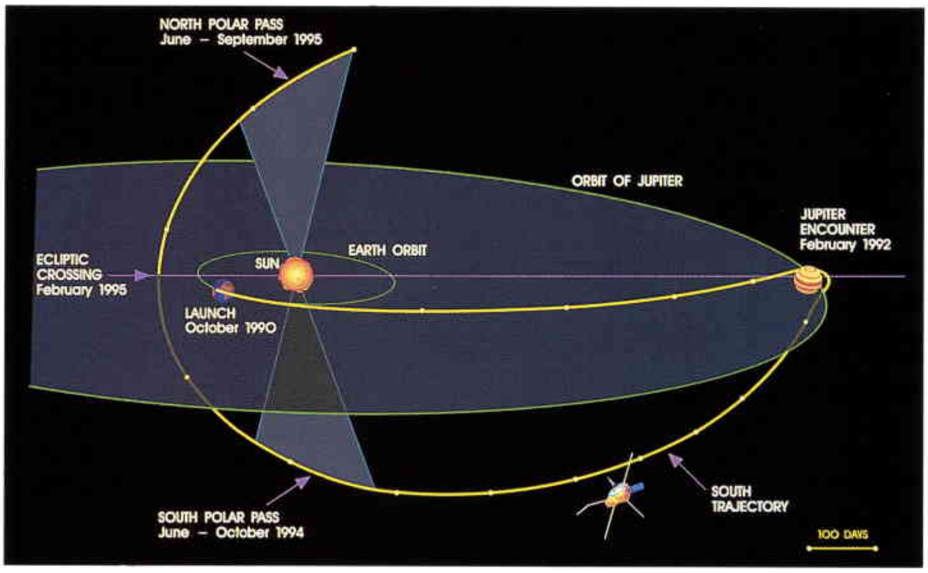
ERS-1, which is an advanced-concept satellite for scientific research and application demonstration, has been developed by a Europe-wide industrial consortium led by Dornier/Deutsche Aerospace (D) under contract to ESA. The ERS mission is expected to make a significant contribution to research into the climate and the Earth's environment.

Ulysses Sets Course for Jupiter Flyby

On Monday 8 July, two small thrusters on ESA's Ulysses spacecraft were fired to set the spacecraft on its final course for a rendezvous in early February 1992 with Jupiter. The Jupiter flyby will swing Ulysses into its final orbit, which will ultimately carry it over both poles of the Sun.

The trajectory-correction manoeuvre, conducted by ESA's controllers at the Jet Propulsion Laboratory in Pasadena, USA, was the last change to the spacecraft's flight path before Ulysses completes its 775 million km journey to Jupiter. Designed to alter the spacecraft's velocity by about 0.29 m/s, the correction will trim approximately 2 min off Ulysses' arrival time at Jupiter.

Ulysses is presently travelling in the ecliptic plane (the plane in which the planets of the Solar System orbit) at a heliocentric velocity of approximately 68 000 km/h. The spacecraft is slowing as it nears Jupiter, but is still closing on the planet at a speed of slightly more than one million kilometres per day.



During its approach, Ulysses will fly through the late-morning region of Jupiter's magnetosphere at about 30°N latitude. The closest approach to within 449 000 km (6.3 Jupiter radii) of the centre of the planet will occur on Saturday, 8 February 1992. The spacecraft will then exit the magnetosphere on the previously unexplored evening side of the planet, at high southern latitudes, having spent more than a week in Jupiter's magnetosphere.

The momentum gained from the gravitational pull of Jupiter during the encounter will swing Ulysses out of the ecliptic plane and onto a trajectory leading first over the Sun's southern pole. In June 1994, the spacecraft will reach 70°S solar latitude and begin its primary mission of exploring the polar regions of the Sun. It will pass over the Sun's northern pole the following year.

The first scientific results acquired from the Ulysses mission are reported in the article by R.G. Marsden and K.-P. Wenzel elsewhere in this issue.

EUROAVIA Design Workshop 1991

EUROAVIA, the European Association of Students of Aeronautics and Astronautics, and Dornier, with support from ESA/ESTEC, Fokker, Kayser-Threde, Universität Kiel, Imperial College London, LEGO and DARA, organised a Design Workshop in Friedrichshafen (D) from 8 to 19 April with the 'Ulysses Reference Mission' as its theme.

The idea of giving students the opportunity to work first-hand on a configuration study for a 'real' space mission was first conceived by EUROAVIA members in late 1989. Details of the event were distributed in December 1990 to 20 local EUROAVIA groups, 40 universities and colleges, and 20 space personalities working in education, information services, etc., thereby addressing students in 15 European countries.

Interested students were asked to write a paper (max. 10 pages) on a subject of their choice related in some way to space activities. A total of 57 responses were received from 13 countries, 48 of which proved to be valid entries for the contest. The respondents included not only aerospace, but also physics, astronomy, electrical and mechanical engineering, and chemistry students.

The Workshop itself was organised around a schedule allocating a total of 73 hours to study of the so-called 'Ulysses Reference Mission'. Working-group sessions were interspersed with plenary sessions to give all participants a general overview of the project. In parallel, one representative from each working group took part in an 'integration session', where the latest results were exchanged and the study objectives of the groups coordinated.

During the two weeks, a Preliminary, a Critical, and a Final Design Review were also held to assess the results of the design efforts. Experienced specialists were on hand during these sessions to provide both comment and council.

In the course of the 10 days, the 22 students chosen to participate succeeded in establishing a detailed baseline for the Ulysses Reference Mission.

At its meeting in Heidelberg on 30 April, the Ulysses Science Working Team received a report on the Ulysses Reference Mission activities. It expressed its scientific interest and supports the request to implement such a mission in time to serve as a reference for the solar-polar passages of Ulysses.

Further information on the Ulysses Reference Mission can be found in the Workshop Proceedings, which can be obtained from:

Cristian Bank
c/o EUROAVIA
Pfaffenwaldring 27
W-7000 Stuttgart 80, Germany
Tel.: +49-711-58 34 10
Fax: +49-711-685-3706

ESA Telescience Experimenter Facility for Sounding Rockets Tested for the First Time

On the basis of the successful ESA telescience experiments conducted on the Texus-23 and -26 sounding-rocket flights, ESTEC placed a contract with Techno System (I) (with subcontractors Mars Center, and MBB ERNO) to develop a general-purpose 'Telescience Experimenter Facility' to be offered to the international community of sounding-rocket users interested in interactive experimentation. It consists of a User Control Room, easily transportable within Europe, connected via a digital satellite link to the sounding-rocket ground system at Esrange in Kiruna, Sweden.

User control room at Mars Centre, Naples

On 8 May, during the Maxus-1 Spring'91 rocket campaign, the first in-flight operational test of the Telescience Experimenter Facility took place to prove both the technological and scientific validity of the system. The payload selected for verifying the system concept was a fluid-sciences experiment designed to study the onset of Marangoni oscillations in a silicone-oil liquid bridge.

The User Control Room was transported to the Principal Investigator's (PI) premises at the Mars Center in Naples. From here the PI could conduct his experiment by sending on-line commands and by receiving live video pictures and real-time data from the rocket for both qualitative and quantitative measurements. In addition, he had access to tools for experiment simulation, data and video storage, and post-flight experiment playback and data analysis.

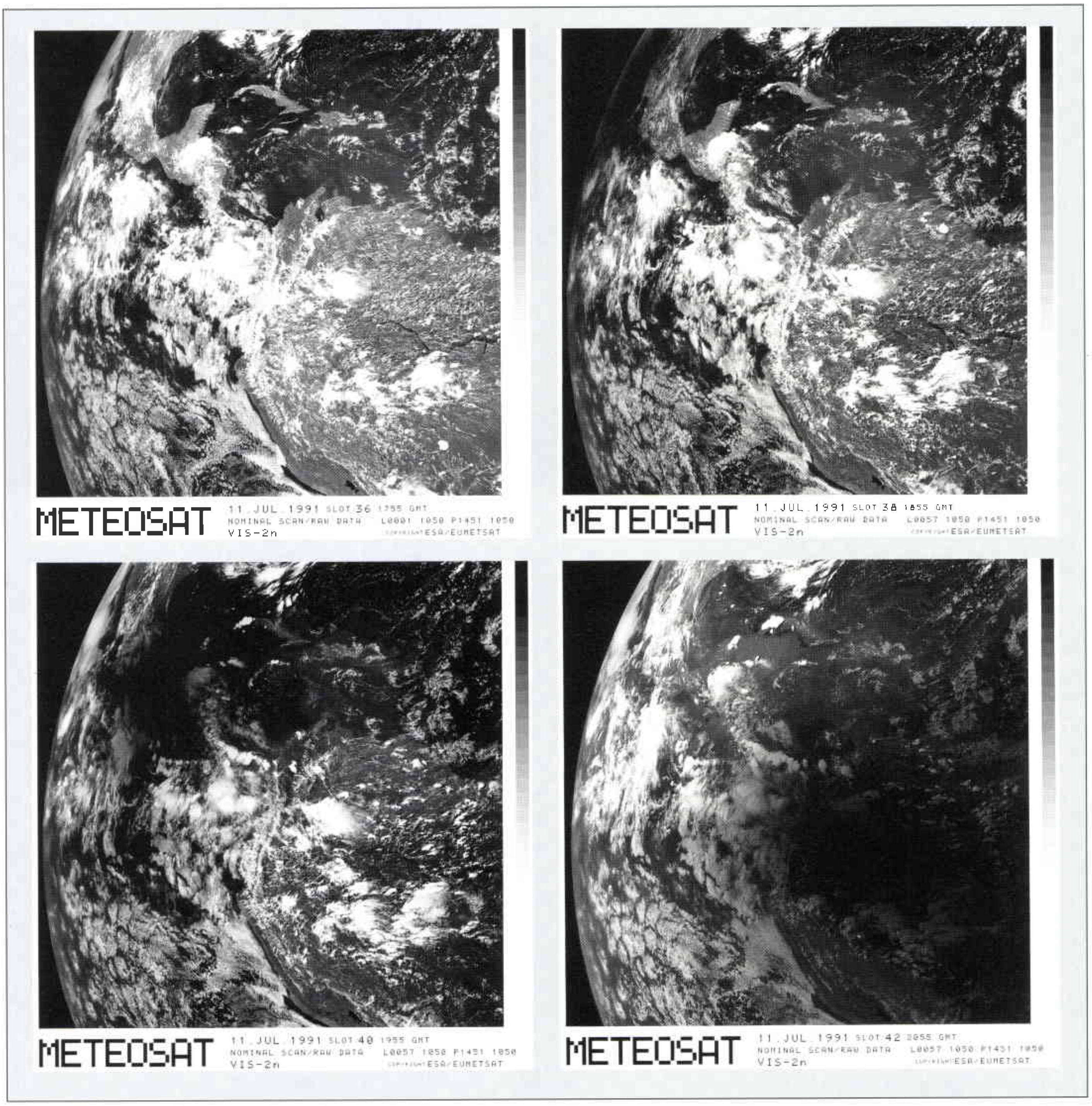
ESA's Olympus satellite (14/12 GHz payload) was used for the digital link, providing a 2 Mbit/s multiplexed video/audio/data signal in both directions between the small portable satellite ground station at the User Control Room and the one available in Kiruna.

Although the Maxus-1 rocket failed to reach its nominal maximum altitude of 800 km, (this was a proving flight), the Telescience Experimenter Facility proved to be fully functional and the telecommands, telemetry and experiment video were successfully transmitted, and received at the User Control Room.

Selection of further telescience experiments on the basis of experiment proposals to be submitted to ESA by PIs interested in the telescience application technique and consequent participation in future launch campaigns is currently being organised.

Further operational utilisation of the Telescience Experimenter Facility is now being planned, based on a decision to re-fly the Maxus-1 rocket next spring, as well as participation in a Texus sounding-rocket campaign this autumn.

A. Guerrazzi, ESTEC



Meteosat-3 Observes Solar Eclipse

On 11 July, the European meteorological satellite Meteosat-3 was ideally positioned (at about 46°W) to observe the total eclipse of the Sun by the Moon over the Central and South American region. For a period of 3 h, Meteosat scanned the Earth at 15 min intervals over the region affected by the eclipse (in contrast to its normal operation, where images of the full Earth's disc are taken every 30 min).

The shadow of the Moon on the Earth, and its motion with time, were clearly visible in the series of images acquired. Close inspection reveals the umbra (total eclipse) and penumbra (partial eclipse) regions on the Earth's surface.

The images were processed at ESOC in Darmstadt (D), where engineers are in the process of repositioning Meteosat-3 at 50°W, from where it will support global weather observation of the Western Atlantic and the Americas.

Launched in June 1988, Meteosat-3 is operated by ESA on behalf of Eumetsat, the European organisation for the exploitation of meteorological satellites.

Space Network Interoperability Recommendations Endorsed

ESA, NASA and NASDA (Japan) are all planning advanced data-relay satellite systems to connect low-orbiting spacecraft via geostationary satellites to Earth terminals in their own regions. Since 1987, the three agencies have been discussing the possibility of interoperability between the three data-relay satellite systems, through regular meetings of the Space Networks Interoperability Panel (SNIP). Such interoperability would permit a variety of cross-support services, such as emergency support in the case of failure of a data-relay satellite, zone-of-exclusion coverage behind the Earth, where each data-relay system has a different blind spot, interchange of data without expensive trans-oceanic data links, and flexible support of inter-Agency cooperative missions.

The first key to interoperability is the use of the same frequency bands. From the beginning, all three Agencies have been planning to use the 2.025—2.11 GHz and 2.2—2.29 GHz frequency bands (so-called 'S-band') for the Inter-Orbit Links (IOLs) between data-relay satellites and low-orbiting spacecraft, and detailed agreements on how these bands would be used for interoperability have been drawn up by SNIP and its Working Group. However, although these frequency bands are easy to use, they offer only limited capacity and competition for their use by terrestrial fixed-link and mobile radio services poses a continued threat to their use for space services and a constant risk of interference.

ESA has therefore pioneered the use of the 23.15 to 23.55 GHz and 25.25 to 27.5 GHz frequency bands ('Ka-band') for IOLs (see ESA Bulletin No. 51, August 1987), which offer the wide bandwidths required for multi-experiment platforms, Space Stations and advanced Earth-observation imaging systems into the 21st Century. In late 1989, first NASDA announced their intention to change earlier plans to use the 23.15 to 23.55 GHz and 32 to 33 GHz bands and to come into line with ESA for the Japanese Data Relay and Tracking Satellite (DRTS) and its experimental pre-cursor COMETS, and then NASA selected the same 23.15—23.55 GHz and 25.25—27.5 GHz bands for its Advanced Tracking and Data Relay Satellite System (ATDRSS). This opened up a new opportunity for 'Ka-band' interoperability, which SNIP has been quick to recognise and to explore.

The signing ceremony.
Seated, from left to right, S. Yamada (NASDA), K.G. Lenhart (ESA) and D. Fahnestock (NASA).

The first result has been a set of SNIP Ka-band Interoperability Recommendations, which were drawn up and signed at the recent SNIP Meeting at NASDA's Headquarters in Tokyo on 2 May 1991 (see photo).

The SNIP partners are already discussing specific programmes of tests to prepare for interoperability. Later this year, the prototype ESA Dual-Standard Transponder will be taken to Goddard Space Flight Centre in Greenbelt (USA). There it will undergo a comprehensive series of compatibility tests against NASA equipment, culminating in a live test over an operational Tracking and Data Relay Satellite. NASDA have asked for similar tests to be performed in Tsukuba, Japan.

S. Dinwiddy

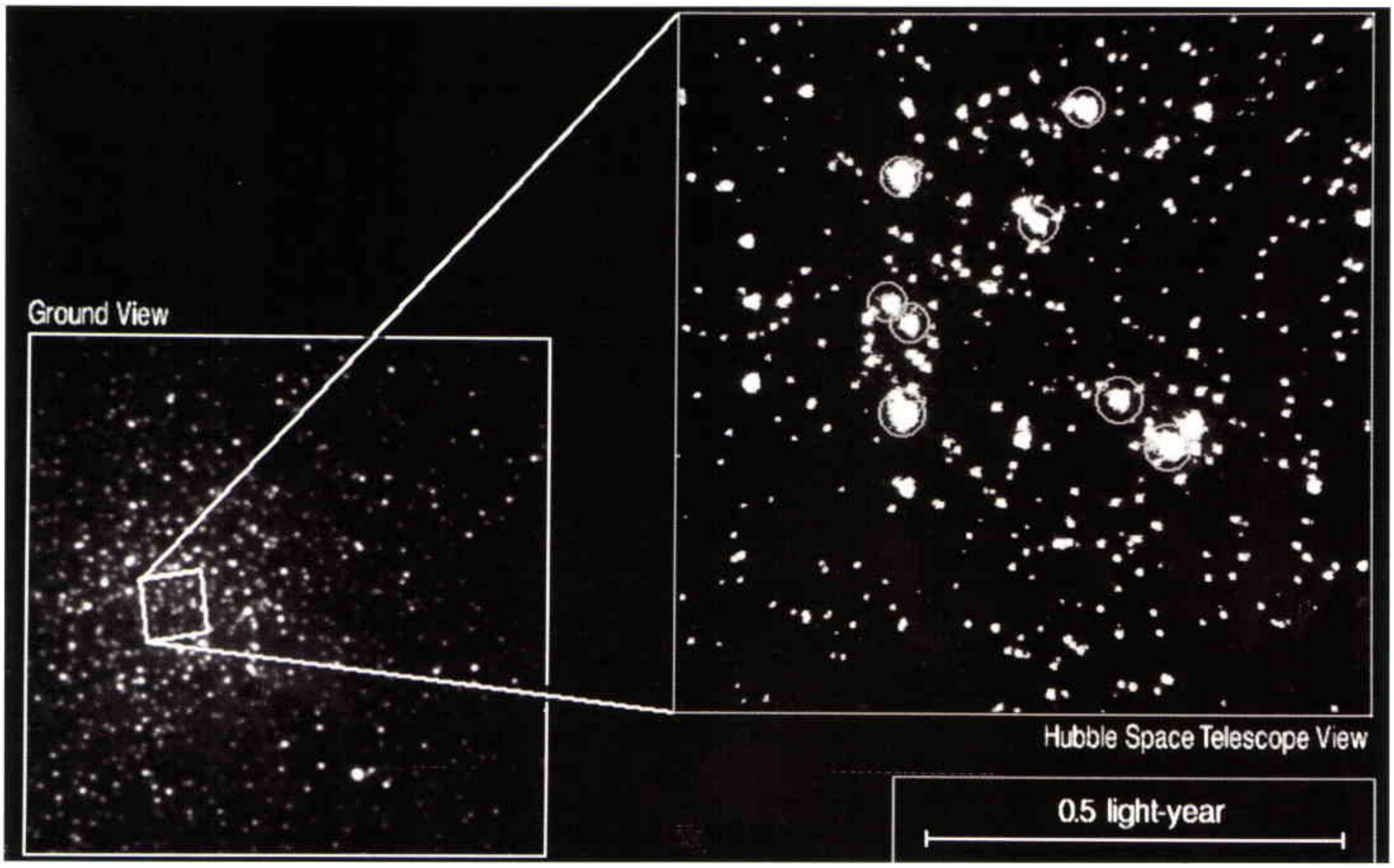
Inauguration of Earth-Observation Facilities in Kenya

On 12 July in Nairobi (Kenya), ESA and the Regional Centre for Services in Surveying, Mapping and Remote Sensing, which covers the countries of Eastern and Southern Africa, inaugurated a work-station-based installation for the processing and analysis of data from earth-observation satellites. This station will be able to undertake local processing of data from the American Tiros and European ERS-1 satellites, and will permit the exchange of information in a standardised format with ESA's Earthnet facility located at ESRIN, in Frascati, Italy.

This cooperation between the Kenyan Regional Centre and ESA started several years ago with the organisation of training courses in Nairobi for the benefit of users of remote-sensing data in Eastern and Southern Africa. Specialists from the Centre will now also be trained at ESRIN.

The value of ESA's contribution, including equipment, installation costs and the training to be provided, is approximately 500 000 ECUs.

The direct availability of the ERS-1 data to the Eastern and Southern African countries should make a significant contribution to environmental research in the region.



Hubble Space Telescope Finds Massive Stars in Globular Cluster

The core of the globular cluster 47 Tucanae as imaged by ESA's Faint Object Camera (right) and a ground-based image of the same cluster taken in blue light with a 2.2 m telescope in Chile (Courtesy of ESO).

The FOC resolves several hundred stars where ground-based images yield only a few dozen.

High-resolution observations of the core of the globular cluster 47 Tucanae, made with the Agency's Faint Object Camera (FOC) on board the Hubble Space Telescope (HST), provide new evidence that stars may collide and capture each other and gain a new 'lease of life' in the process. The FOC observations reveal a surprisingly high concentration of a unique class of stars called 'blue stragglers', which may evolve from 'old age' back to a hotter and brighter 'youth'. These stars may also play a critical role in the dynamic evolution of the cluster's core.

Globular clusters are 'beehive swarm' agglomerations of several hundred thousand stars each, and are among the earliest inhabitants of our Milky Way Galaxy. They formed in the vast halo of our Galaxy before it flattened to form a pancake-shaped spiral disc. Star formation essentially stopped in globular clusters 15 billion years ago, and astronomers use the cluster ages as a benchmark for estimating the age of the Universe.

Utilising HST's high-resolution and ultraviolet sensitivity to probe the dense centre of the cluster, two ESA Astronomers, G. Meylan and F. Paresce, M. Shara, and the FOC team at the Space Telescope Science Institute in Baltimore have resolved 21 blue stragglers. 'The 47 Tucanae blue stragglers are extraordinarily centrally concentrated, supportive of the view that they are the product of collisions, mergers or close encounters among stars', says Dr. Paresce. 'This surprising result explains why blue stragglers had, up to now, eluded detection with instruments that do not have the required high spatial resolution to resolve the dense core of 47 Tucanae'.

ESA/NASDA Earth-Observation Agreement Signed

A Cooperation Agreement between the ESA and the National Space Development Agency of Japan (NASDA) was signed on Thursday 20 June in the ESA Pavilion at the Paris Air Show, by Mr Jean-Marie Luton, ESA's Director General, and Mr Masato Yamano, President of NASDA.

This Agreement deals primarily with mutual access to data from two Earth-observation satellites, ESA's ERS-1, launched on 17 July, and Japan's JERS-1, to be launched in early 1992.

A particular feature of this Agreement is that it is based on the principle of reciprocity, enabling the Signatories to have direct access to data from both satellites via the ESA and Japanese ground-station networks.

ESA's Exhibition at the Paris Air Show

At this year's Le Bourget Air Show, in Paris, from 13 to 23 June, ESA endeavoured to bring both the specialists and the general public up to date on its main programmes, in a presentation broadly divided into three themes: Space Research, Present and Future; Earth Observation; Space Transportation; and the European In-orbit Infrastructure.

In addition to a wide variety of 1:4 scale spacecraft models, visitors to the ESA Pavilion were able to see:
- A full-scale model of ISO, the Infrared Space Observatory, scheduled for launch in 1993.
- A full-scale model of ERS-1, the first European Remote-Sensing Satellite, launched on 17 July.
- Full-scale models of Hermes and Columbus, key elements of Europe's future In-Orbit Infrastructure, in docked configuration.

The new Ariane-5 heavy-lift vehicle was the subject of an interactive exhibit, which allowed visitors to browse through a series of displays of the various missions that will be performed by the new launcher.

ESA's telecommunications programmes were represented by quarter-scale mock-ups of the Artemis and DRS satellites, due to be launched in 1994 and 1996, respectively.

For journalists, there was a chance to discuss European space activities with ESA's Director General, Jean-Marie Luton, at a Press Breakfast on Monday 17 June.

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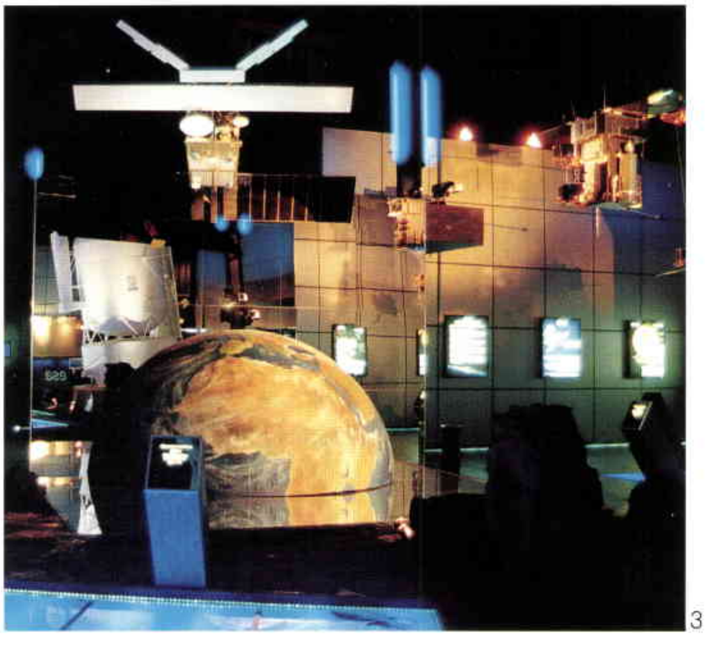
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1. Signature of the Cooperation Agreement between ESA and NASDA at the Paris Air show. Seated Mr J-M. Luton, ESA's Director General (left), and Mr M. Yamano, President of NASDA. Standing extreme left, Mr K-E. Reuter, ESA's Head of Cabinet.

2,3,4,5. The ESA Pavilion

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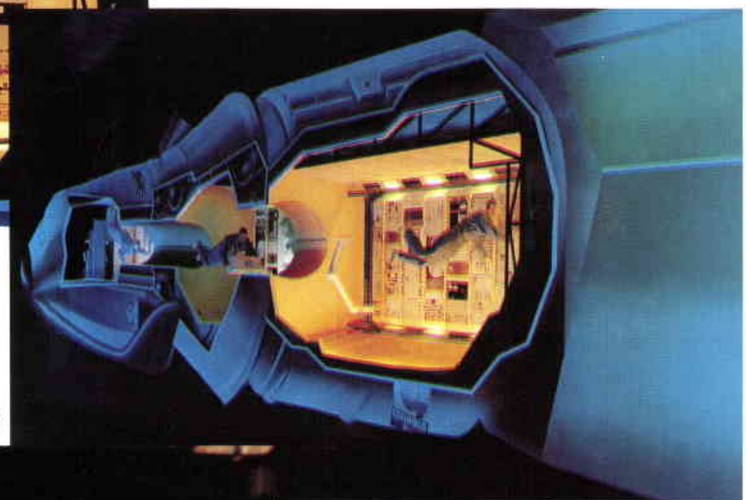

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6. *President François Mitterrand visiting the ESA Pavilion accompanied by Mr Paul Quilès, France's Minister for Posts, Telecommunications and Space (centre), and Mr Jean-Marie Luton, ESA's Director General (left)*

7,8. *The Press Breakfast, hosted by J-M. Luton, shown here with (from left to right) ESA Directors F. Engström, J. Feustel-Büechl and P. Goldsmith, responding to questions from the assembled journalists*

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Soho/Cluster Contract Signed

At ESA Headquarters in Paris on 11 July, the signing took place of the contract between the Agency and European Industry for the main development phase for the Soho/Cluster scientific satellites.

Present for the occasion were, from left to right Mr. G. Estibal of Matra (F); Prof. R. Bonnet, ESA's Director of Scientific Programmes; Mr. J.-M. Luton, ESA's Director General; and Messrs. M. Kübler and M. Hollstein of Dornier in Friedrichshafen (D).

Photo: J. Denimal for ESA

ESA at Satelcomm '91

In response to developments in Central and Eastern Europe, ESA, the European Telecommunications Satellite Organisation (Eutelsat) and the European Broadcasting Union (EBU) took the initiative of organising an International Conference and Industrial Exhibition on space communications in Bucharest, Rumania, from 24 to 28 April. This event, called 'Satelcomm '91', was organised in cooperation with the Rumanian Ministry of Communications and focussed on services and technology directly or indirectly related to space communications.

The primary objectives of the Conference and Exhibition were:

- to inform and demonstrate to possible user organisations and industries in Eastern Europe the potential of Western European systems and technology;
- to provide information on legal, institutional and regulatory aspects applicable to the provision of satellite communications within Europe;
- to identify specific user requirements for services, technology, support and applications which could be met by Western European technology;
- to provide an opportunity for users from East and West to explore the potential for joint production and business ventures.

The Conference served as a meeting-place for speakers and participants from all over Europe, and exhibitors were on hand to demonstrate their products, systems and services. Eutelsat and ESA also provided live demonstrations of telecommunications via satellite.

ELA-1 Launch Pad Dismantled

On 20 June, the servicing tower of Europe's first launch pad for Ariane vehicles was dismantled at the Centre Spatial Guyanais (CSG) in Kourou, French Guiana. Known as the 'Ensemble de Lancement Ariane No.1' (ELA-1), it was used for twenty-five launches over a ten-year period, including the very first Ariane launch on Christmas Eve 1979.

In all, eleven Ariane-1, five Ariane-2 and nine Ariane-3 vehicles have been launched from ELA-1, which has effectively been mothballed since the summer of 1989 when it was used to launch Olympus-1 with the last Ariane-3 vehicle.

Operations in Kourou are now centred on the fourth version of the Ariane vehicle, Ariane-4, which is currently the World's most successful commercial satellite launcher. Because Ariane-4 is taller and has more complex electronic ground systems than its predecessors, it was not possible to adapt the ELA-1 pad for its launching. The Ariane-4's now use a second launch pad known as ELA-2, which allows preparations and launch operations to be carried out simultaneously in two separate areas, thereby permitting ten launches per year to be handled comfortably using the one pad.

Since ELA-1 has therefore seen its last launch, engineers at CSG have begun the complex process of dismantling the pad. All the electrical equipment and salvageable building materials will eventually be shipped back to Europe. On 20 June, the most impressive element of ELA-1, the 70 m launch tower, was lowered to the ground.

Investigation Started into Olympus Satellite Anomaly

The Agency has started an investigation into the origins of the loss, on 29 May, of attitude and orbit control aboard its large Olympus communications satellite. In parallel, ESA has succeeded in acquiring additional evidence on the status of the spacecraft, thereby improving the chances for eventually recovering the mission. All services were interrupted as a result of the loss of control, with the satellite rotating once every 90 s, drifting eastwards at 5° per day.

The Enquiry Board set up to investigate the events of 29 May met for the first time on 11 June, under the chairmanship of Prof. Massimo Trella, ESA's Inspector General. It reviewed in detail the events that took place immediately before and after the loss of satellite control.

For reasons that are still unclear and which are currently the subject of a technical investigation, the satellite ceased to point towards the Earth at 03.21 h GMT and went into so-called 'Emergency Sun-Acquisition Mode', which is an automatic onboard safety procedure that is activated whenever the satellite loses its Earth-pointing reference signal. In recovering from the emergency to the normal mode, commands were sent to the satellite that did not conform to standard procedures. It appears that modifications to those procedures had been introduced in an attempt to have the satellite back in normal mode by 09.00 h EST for the start of broadcasting operations, but instead a sequence of events was initiated that eventually led to the loss of control. Another contributing factor, however, was the technical status of the satellite: one of its solar arrays had been inactive since January, and had the solar generator been fully operational the spacecraft would probably have recovered on its own.

The highly successful efforts of the Olympus Mission Recovery Team, set up on 3 June to lead activities designed to rescue the mission, are reported upon in an accompanying news item.

Olympus Recovery Operations Progressing Well – A World First for ESA and BAe

Following the sudden loss of attitude and orbit control of the Olympus communications satellite on 29 May, a team of ESA and British Aerospace (BAe) specialists, led by the Chief of Operations at ESOC in Darmstadt (D), has successfully recovered the spacecraft. BAe, which led the Industrial Consortium that developed Olympus, has provided engineering and planning expertise in support of this endeavour. The team, consisting of engineers from a variety of disciplines, has been hard at work since early June in planning and executing a very complex recovery plan.

When Olympus went out of control at the end of May, it entered a tumbling mode, eventually rolling about one axis. The spacecraft's power-supply system could neither maintain battery charging in this mode nor provide sufficient power to the onboard heaters for thermal control, because the solar arrays were then pointing away from the Sun. As a result, no telecommands could be executed onboard and spacecraft temperatures plunged to between −50 and −60°C, resulting in the fuel, oxidiser and batteries on board being frozen.

Thruster firings caused by autonomous system operations at the time of the anomaly had forced Olympus out of geostationary orbit and it was drifting eastwards at 5° per day, thereby moving out of range of the Fucino (Italy) tracking station.

The Olympus Mission Recovery Team (MRT) established on 3 June 1991 was charged by ESA's Director General with attempting recovery of the mission using all possible means. Additional tracking stations were brought in for support (with the cooperation of NASA and CNES), ESOC's Operations Control Centre (OCC) facilities were expanded, and a very detailed recovery plan was prepared.

In the course of June and July, several thousand telecommands were transmitted to the satellite from ESOC via tracking stations at Perth in Australia, Goldstone in California, Kourou in French Guiana, and Villafranca in Spain.

On 19 June, the spacecraft accepted and executed a series of commands for the first time since the end of May. The illumination angle of the solar panel had improved in the meantime and sufficient power had thereby become available for limited operations. In the first instance, the spacecraft was put into a safe state and all subsystems not essential for the recovery were switched off. There was then sufficient power to partially charge the nickel-hydrogen battery on board.

Using this power, on 1 July the solar array was successfully rotated to face the Sun more, allowing a fully regulated power supply of 50 V to be maintained and providing for continuous telemetry. This in turn made it possible to charge Olympus' nickel-hydrogen battery fully on 2 July, and its nickel-cadmium battery by 8 July. All battery-management and protection devices could then be enabled.

Operations continued to optimise solar-array pointing at regular intervals, and the gradual process of warming up the spacecraft was begun, in order to thaw the propulsion system, with a view to permitting thruster firings, regaining attitude control and stopping the easterly drift.

Thawing out of the propulsion system was completed somewhat earlier than expected, on 24 July, and heating was then maintained at a level sufficient to keep all elements of the system at operational temperatures. Tank pressures were re-established at their correct levels. While awaiting completion of this step, various equipment checks were made, including running up of the gyroscopes, the performance of which was still found to be nominal.

It was decided to allow the satellite to 'settle' thermally for a few days after thawing out the propulsion system, before attempting recovery, and during this period some thruster test firings were made. On 26 July, the spin period of the satellite was increased from 100 s to 104 s, confirming that the thrusters were indeed operational and could be used for the later Sun-acquisition manoeuvre.

Despinning of the satellite was started at 11.52 h local time on 29 July and was accomplished in two stages down to 2° per sec by 12.27 h local time. By 13.15 h local time, Sun-pointing mode was confirmed, with the spacecraft's

Members of the Olympus Mission Recovery Team at ESOC on 1 August, with Mr J.-M. Luton, ESA's Director General, Mr K Heftman, outgoing Director of Operations, and Mr F. García-Castañer, his successor.

north solar array oriented normal to the Sun direction.

After a further waiting period during which procedures were confirmed and tests with reaction wheels and other equipment made, Earth acquisition was finally achieved at about 17.00 h local time on 31 July.

At 07.11 h local time on 2 August, the first station-acquisition burn was performed, slowing the spacecraft's orbital drift rate to about 2° per day. Further burns will be performed in the coming days and the target date for Olympus to be back on station is currently 13 August.

A review of the re-commissioning plan will take place at ESTEC on 7 August 1991, and recommissioning tests are expected to start immediately thereafter. An Operational-Readiness Review will be held on 4 September 1991 but, with certain operational procedures still to be verified, service to the users is unlikely to be resumed before October.

In recovering the Olympus spacecraft, the joint ESA–BAe Mission Recovery Team has conducted a series of operations never (to the Agency's knowledge) accomplished previously for a space mission. On the 30 May there was no usable telemetry from Olympus, no telecommand capability, only marginal intermittent power, onboard systems and subsystems were frozen, and the satellite was drifting quickly away from Europe. The recovery operations described, which took place over a period of 60 days as Olympus drifted eastward over the Pacific and Atlantic Oceans, have brought what was to all intents and purposes a dead satellite back to life.

ESA Participates in the 'Microcosm Exhibition' at CERN

A special exhibition devoted to the Agency's Scientific Programmes was inaugurated at CERN, the European Centre for Nuclear Research, near Geneva, on 8 July. The exhibit forms part of CERN's permanent 'Microcosm Exhibition', which has been widely-acclaimed for its easily comprehensible presentations of scientific projects.

ESA's Exhibition at CERN has three main themes — Astronomy and Astrophysics; Solar-System Exploration; and the Agency's Programmes in general. Most current ESA scientific missions are on display, with special exhibits covering the Giotto, Ulysses, ISO and Soho/Cluster spacecraft.

The exhibition also includes videos, plus a large number of display panels, in both French and English, which describe the Agency's Scientific Programmes in detail. These panels have been designed to stimulate the imaginations of all those who wish to learn more about our Universe. The videos cover both the work of ESA as a whole and, more particularly, the pioneering missions of the Giotto and Ulysses spacecraft.

The Exhibition was inaugurated on 8 July in the presence of Prof. Roger Bonnet, ESA's Director of Scientific Programmes, and Dr. Pierre Darriulat, Director of Research at CERN. The ceremony was attended by numerous eminent scientists from both organisations.

Prof. Bonnet subsequently gave a special seminar in the main Auditorium at CERN, entitled 'Space Science in Europe', which was attended by many of CERN's staff and visiting scientists.

The ESA Exhibition was opened to the public on 9 July and will remain at CERN until the spring of next year. The Exhibition is open every day except Sunday, from 09.00 h to 17.00 h.

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

In Orbit / En orbite

	PROJECT	1991 – 1997	COMMENTS
SCIENTIFIC PROGRAMME	IUE		
	HIPPARCOS		OPERATIONAL 3 YEARS
	SPACE TELESCOPE		LAUNCHED 24 APRIL 1990
	ULYSSES		LAUNCHED OCTOBER 1990
APPLICATIONS PROGRAMME	MARECS-A		LEASED TO INMARSAT FOR 10 YEARS
	MARECS-B2		LEASED TO INMARSAT FOR 10 YEARS
	METEOSAT-3		LIFETIME 3 YEARS
	METEOSAT-4 (MOP-1)		LIFETIME 5 YEARS
	ECS-1		EXTENDED LIFETIME
	ECS-2		LIFETIME 7 YEARS
	ECS-4		LIFETIME 7 YEARS
	ECS-5		LIFETIME 7 YEARS
	OLYMPUS-1		LAUNCHED 12 JULY 1989

Under Development / En cours de réalisation

	PROJECT	1991 – 1997	COMMENTS
SCIENTIFIC PROGRAMME	SOLAR TERRESTRIAL SCIENCE PROG. (STSP)	SOHO, CLUSTER	
	ISO		LIFETIME 1.5 YEARS
	HUYGENS		TITAN DESCENT SEPT 2004
COMMS PROG	DATA-RELAY SATELLITE (DRS)	PHASE 1, PHASE 2	SYSTEM OPERATIONAL 1996
	ARTEMIS		READY FOR LAUNCH MID 1994
EARTH OBSERV PROGRAMME	ERS-1		LAUNCHED 17 JULY 1991
	ERS-2		
	EARTH OBS. PREPAR PROG. (EOPP)		
	POEM-1 PREP. PROG.		
	METEOSAT OPS. PROG	MOP 2, MOP 3	MOP 2 LAUNCHED 2 MARCH 1991
SPACE ST. & PLATF. PROG.	MICROGRAVITY	IML-1, EURECA, USML-1, D-2, IML-2	
	EURECA		READY FOR LAUNCH DEC. 1991
	COLUMBUS	PHASE 1, PHASE 2	
SPACE TRANS PROG	ARIANE-5		FIRST FLIGHT APRIL 1995
	HERMES		
TECH PROG	IN-ORBIT TECHNOL DEMO. PROG. (PH-1)		SEVERAL DIFFERENT CARRIERS USED

= DEFINITION PHASE
> PREPARATORY PHASE
▨ MAIN DEVELOPMENT PHASE
STORAGE
◇ HARDWARE DELIVERIES
~ INTEGRATION
↑ LAUNCH/READY FOR LAUNCH
• OPERATIONS
→ ADDITIONAL LIFE POSSIBLE
↓ RETRIEVAL

Hipparcos

C'est le 8 août que le satellite Hipparcos fêtera son deuxième anniversaire en orbite. Pendant plus de 18 mois, il aura fait une abondante moisson de données scientifiques de haute qualité sur les positions, mouvements et distances stellaires. Le fonctionnement d'Hipparcos continue d'être assez satisfaisant. Des anomalies techniques relativement mineures ont été enregistrées mais, en mettant en oeuvre des unités redondantes et des procédures de secours, on a pu réduire au minimum les pertes de temps d'observation et leur incidence sur les perspectives à long terme de la mission.

La perte de l'un des deux gyromètres fournissant des informations sur l'orientation de l'axe de rotation d'Hipparcos est le plus grave des problèmes rencontrés jusqu'ici. Les opérations se poursuivent avec l'unité redondante et l'on a pu mettre au point une solution de remplacement en apportant des modifications assez considérables aux logiciels embarqués et logiciels au sol de manière à remplacer les signaux du gyromètre par des données dérivées de modèles des couples perturbateurs et des poussées des propulseurs.

Les activités de traitement des données commencent à fournir des résultats substanciels: les deux principales équipes de réduction des données sont toutes deux parvenues à une première solution de la sphère conduisant aux premières positions et parallaxes stellaires de la mission. Leurs résultats concordent dans une large mesure, ce qui laisse bien présager de la qualité du résultat final de la mission. A l'issue d'une phase de validation approfondie du traitement des données, ces deux groupes ainsi que le consortium d'analyse des données Tycho viennent d'engager leurs activités systématiques de réduction de toute la gamme des données de la mission.

Soho

La phase-B de Soho dont Matra est le contractant principal s'est déroulée sans problème particulier; elle s'est achevée par une revue de conception système (SDR) et par une SDR mission qui se sont tenues à la mi-avril et à la mi-mai 1991, respectivement. Ces deux revues ont donné des résultats positifs de même que l'évaluation de la proposition de phase-C/D, ce qui a permis de tenir chez Matra, le 16 mai, la réunion de démarrage de la phase-C/D du projet.

Il s'est avéré que parvenir à la propreté nécessaire et respecter les calendriers des expériences constituaient deux défis majeurs. La criticité du mécanisme de pointage d'antenne (APM) de la mission a également suscité de graves inquiétudes et une base de référence modifiée a été adoptée pour la phase-C/D. Cette solution, crédible du point de vue du calendrier de développement, présente en outre des avantages techniques considérables.

Les impératifs techniques continuent d'être épurés et les bilans de masse, de puissance et des autres caractéristiques ont fait l'objet d'une analyse minutieuse de manière à ce que l'on dispose de marges suffisantes pour engager la phase suivante. L'ESA, les chercheurs principaux et les industriels accordent une attention particulière au dépoussiérage et à la propreté chimique du fait de l'incidence critique de ces facteurs sur le fonctionnement de la charge utile. Actuellement, l'essentiel des travaux consiste à déterminer si les installations nécessaires seront disponibles chez Matra et Marconi et, à un stade ultérieur, sur le site de lancement.

La coopération ESA/NASA se déroule sans problème particulier. En préparation de la revue de conception de la mission, une revue des impératifs du secteur sol a été conduite au Goddard Space Flight Center de la NASA, le 1 mai. Elle a donné de bons résultats. La réunion de démarrage lanceur avec General Dynamics et la NASA/Lewis (qui approvisionne l'Atlas IIAS de General Dynamics) se tiendra à la mi-juin.

Les revues de conception critiques portant sur l'enregistreur (Odetics, USA) et l'amplificateur haute puissance (Cubic, USA) ont été menées à bien en avril avec le soutien de la NASA et des représentants Soho et Cluster de l'ESA et de l'industrie.

Les travaux de développement de la charge utile de Soho se poursuivent comme prévu, toutes les expériences étant maintenant engagées dans la phase d'ingénierie finale bien qu'à des degrés divers. On dispose déjà de modèles structurels de haute fidélité de certaines expériences qui en sont à un stade avancé de développement.

Cluster

La phase-B prolongée de Cluster s'est achevée à la mi-avril à l'issue de la revue de conception système de la mission. Cette revue, présidée conjointement par le Directeur des programmes scientifiques de l'Agence et son Inspecteur général a permis l'examen de la mission de bout en bout, qui comprend le véhicule spatial, le véhicule de lancement, la charge utile et le secteur sol. Les recommandations de la Commission de revue seront intégrées à la base de référence du projet.

Les activités industrielles de phase-C/D ont commencé à la suite de la réunion de démarrage officielle tenue à la mi-avril avec le contractant principal, Dornier.

A sa réunion de juin, le Comité du Programme scientifique a approuvé le démarrage de la phase-C/D de Cluster et de Soho, à titre de première 'pierre angulaire' du Programme Horizon 2000 de l'Agence spatiale européenne.

Dans l'industrie, les activités se sont axées sur la consolidation du concept technique de référence en vue du démarrage de la phase-C/D. Des travaux de conception portant sur les sous-systèmes du véhicule spatial sont en cours tandis que la fabrication du modèle structurel du véhicule spatial est bien engagée. Ce modèle doit être prêt à l'assemblage début 1992 et le programme d'essais d'ambiance nécessaire à la qualification du concept doit commencer en mars 1992.

La mise au point des instruments scientifiques progresse conformément au calendrier et des modèles d'identification doivent en être livrés à Dornier à la mi-1992.

Le choix des passagers Ariane-5 APEX n'est toujours pas officiel mais Cluster devrait être affecté soit au vol 501 soit au vol 502, fixés à avril et septembre 1995 respectivement.

Hipparcos

On 8 August, the Hipparcos satellite will complete its second year in orbit, with more than 18 months of high-quality scientific measurements of star positions, motions and distances having been acquired. The satellite has continued to operate rather smoothly. Relatively minor technical anomalies have occurred, but through a combination of the use of redundant hardware units and other operational contingency procedures, it has been possible to minimise the loss of observing time and any impact on longer-term mission prospects.

The most serious problem encountered so far has been the loss of one of the two gyros providing spin-axis attitude information. Operations continue using the redundant unit, whilst substantial on-board and on-ground software changes have led to the availability of a backup solution, replacing the gyro signals with information derived from models of the perturbing torques and thruster calibration.

The data-processing activities are beginning to yield substantial results: both of the main data-reduction teams have successfully completed their first 'sphere solutions', yielding the first new positions and parallaxes from the mission. There is good agreement between their results, providing considerable confidence in the quality of the results that will ultimately come from the mission. After an extensive data-processing validation phase, these two groups, as well as the Tycho Data Analysis Consortium, have recently commenced their routine reduction of the full range of mission data.

Soho

The Soho Phase-B, with Matra as the Prime Contractor, has proceeded without major problems, and was completed by a System Design Review (SDR) and by a Mission-SDR held, respectively, in mid-April and mid-May of this year. Both reviews were successful and, together with the positive evaluation of the Phase-C/D proposal, provided the basis for the Phase-C/D kick-off at Matra on 16 May 1991.

Achievement of the required cleanliness and maintenance of the experiment schedules have proved to be major challenges. The mission criticality of the Antenna Pointing Mechanism (APM) has also proved to be a major concern and a modified baseline has been adopted for Phase-C/D. This solution offers both good development-schedule credibility and considerable technical advantages.

The technical requirements are still being streamlined and the mass, power and other system budgets will be carefully scrutinised to ensure that there is sufficient margin for the start of the next phase. Because of their critical influence on payload performance, particle and chemical cleanliness is receiving a lot of attention from ESA, the Principal Investigators and Industry. Work is currently concentrating on assessment of the availability of the required facilities at Matra and Marconi and, at a later stage, at the launch site.

The ESA/NASA cooperation is proceeding without major problems. In preparation for the Mission Design Review, a Ground Segment Requirements Review was successfully held at NASA/Goddard Space Flight Center (GSFC) on 1 May. The launcher kick-off meeting with NASA/Lewis (procuring the Atlas IIAS from General Dynamics) and General Dynamics will be held in mid-June.

The Critical Design Reviews for the tape recorder (Odetics, USA) and High-Power Amplifier (Cubic, USA) took place successfully in April 1991, supported by NASA and the Cluster and Soho representatives from ESA and Industry.

The Soho payload development effort is continuing as planned, with all experiments having entered, to various degrees, the final engineering phase. Some experiments are already at an advanced stage, with high-fidelity structural models available.

Cluster

The extended Phase-B for Cluster was successfully concluded in mid-April following the Mission System Design Review. This review, chaired jointly by the Agency's Director of Scientific Programmes and its Inspector General, examined the end-to-end mission, comprising spacecraft, launch vehicle, payload and ground segment. Recommendations from the Review Board will be incorporated into the project baseline.

Phase-C/D activities in industry were intiated by a formal kick-off meeting with Dornier, as the Prime Contractor, in mid-April.

At its June meeting, the Science Programme Committee (SPC) endorsed the initiation of Phase-C/D for both Cluster and Soho as the first 'Cornerstone' of the Agency's Space Science: Horizon 2000 Programme.

Activities in industry have concentrated on consolidation of the technical design baseline for the start of Phase-C/D. Design activities are in progress for spacecraft subsystems, whilst manufacture of the structural-model spacecraft is well underway. This model is scheduled for assembly early in 1992 and the environmental test programme for qualification of the design is scheduled to start in March 1992.

Scientific instrument development is proceeding on schedule, with engineering-model units due for delivery to Dornier in mid-1992.

Selection of passengers for the Ariane-5 Apex flight opportunities is still not formalised, but Cluster is expected to be allocated either to flight 501 or to flight 502, currently due for launch in April and September 1995, respectively.

Also at the June SPC meeting, unanimous approval was given to the selection of data centres for the Cluster Science Data System. The system to be used for dissemination of processed instrument data between co-operating groups of scientists is based on distributed data centres, interlinked by a computer network, which will be located in Austria, France, Germany, Sweden, the UK and the USA. Proposals for co-operation from Hungary and China were also accepted for study.

ISO

The four scientific instruments are making good progress. The flight models are all in acceptance testing, and some have started their very extensive perform-

A sa réunion de juin, le SPC a également approuvé à l'unanimité les centres de données retenus pour le système de diffusion des données scientifiques de Cluster. Ce système, qui doit servir à faire circuler les données traitées des instruments entre des groupes de chercheurs travaillant en coopération, repose sur des centres de données distribués, reliés par un réseau de calculateurs, centres qui seront établis au Royaume-Uni, en France, en Allemagne, en Autriche, en Suède et aux Etats-Unis. Des propositions de coopération émanant de Hongrie et de Chine ont également été acceptées pour étude.

ISO

Les travaux portant sur les quatre instruments scientifiques progressent de façon satisfaisante. Les modèles de vol ont tous atteint le stade des essais de recette et, pour certains, la campagne d'étalonnage et de caractérisation technique très approfondie a commencé. En ce qui concerne certains détecteurs très sensibles, des problèmes de fonctionnement mineurs ont été causes de retards qui pourront cependant être absorbés sans affecter le calendrier du projet.

Tous les sous-systèmes électriques du satellite font actuellement l'objet d'essais de qualification et les modèles de vols sont en cours d'assemblage. L'essai du logiciel du sous-système d'orientation progresse de façon satisfaisante et les unités électroniques sont peu à peu intégrées à la séquence d'essai, au fur et à mesure de leur livraison.

Il a été établi que le mirroir primaire du modèle de vol du télescope donnait des images de bonne qualité, même aux températures de l'hélium liquide. Le modèle de qualification du télescope a été installé dans le modèle d'identification du module de charge utile, qui fait actuellement l'objet d'essais en vibration.

Au second semestre 1991, les travaux prendront une nouvelle orientation étant donné que la livraison des modèles de vol des sous-systèmes permettra l'intégration parallèle des modèles de vol des modules de charge utile et de service.

Les travaux portant sur le secteur sol progressent de façon satisfaisante. L'accent est mis sur la recherche de moyens permettant de simplifier les opérations scientifiques et de remédier aux conséquences des retards. La constitution de l'équipe scientifique progresse plus lentement qu'il n'était prévu et les informations devant être fournies par les chercheurs principaux sont en retard car ces derniers s'attachent en priorité à terminer les activités relatives à leur matériel.

Un certain nombre de problèmes touchant au module de charge utile, au télescope et au sous-système de commande d'orientation ont été causes de retards. La revue des plans d'essai de l'ensemble du projet a cependant conduit à un calendrier compatible avec la date de lancement de mai 1993. Ce calendrier, qui ne comporte aucune marge d'aléas, suppose un travail à deux équipes sur toutes les tâches critiques. L'ensemble de ce plan, y compris le supplément de ressources indispensable pour résoudre ces problèmes, a été approuvé en juin par le Comité du Programme scientifique de l'ESA.

ERS

ERS-1

La préparation mécanique finale du satellite ainsi que son démontage pour le transport ont eu lieu en février. La plate-forme et le module de charge utile ainsi que les rechanges de vol et les équipements de soutien au sol (GSE) les plus importants ont été transportés par avion à Kourou début mars. La majeure partie des GSE avait été acheminée en Guyane par voie maritime à la mi-février.

La revue d'aptitude au vol du secteur sol d'ERS-1 (GSRR) s'est tenue à la mi-mars et il a été conclu que tout serait prêt pour un lancement début mai.

Arianespace ayant annoncé le 25 avril que la date de lancement d'ERS-1 était reportée du 3 au 6 mai pour dégager le temps nécessaire à un examen complémentaire des marges de fonctionnement du moteur du troisième étage, les activités relatives à ERS-1 se sont poursuivies conformément au calendrier jusqu'au 30 avril. A cette date le satellite était monté sur le lanceur et l'on avait procédé aux derniers essais électriques. Le satellite et le secteur sol ont reçu le 'feu vert lancement' lors de la revue d'aptitude au vol du 30 avril.

Le 1 mai, Arianespace a interrompu la campagne de lancement après avoir décidé qu'il fallait procéder à une modification sur le moteur du troisième étage afin d'améliorer les marges de fonctionnement du HM7 pendant la phase de décollage.

Des premières indications données par Arianespace en ce qui concerne le calendrier de qualification et de mise en oeuvre de cette modification, il résulte que le lancement d'ERS-1 ne pourra avoir lieu avant la deuxième quinzaine de juillet. Il a donc été décidé de retirer le satellite du lanceur en vue d'un stockage de moyenne durée, opération qui a commencé le 29 mai.

ERS-2

Les activités des contractants industriels ont progressé de façon satisfaisante et les dernières négociations contractuelles devrait s'achever dans le courant du mois de juin.

Les activités de phase-B de l'expérience de surveillance de l'ozone à l'échelle du globe (GOME) ont pris fin et l'industrie devrait envoyer au mois de juin sa réponse à la demande de prix portant sur la phase-C/D. Les travaux sur le PRARE-2 et sur le radiomètre hyperfréquence ATSR progressent conformément au calendrier.

Le calendrier du programme, qui se fonde sur l'utilisation des unités de rechange du matériel de vol et des équipements de soutien sol d'ERS-1, pourrait être affecté par le retard avec lequel sera lancé ce dernier.

EOPP

Aristoteles

En parallèle au supplément d'étude sur Aristoteles ont été conduites des activités de pré-développement qui ont donné de bons résultats: fabrication par l'ONERA et SAGEM et essais à l'ONERA d'un modèle de laboratoire (M4) de l'accéléromètre Gradio, et production et essai d'un premier montage table du mécanisme d'étalonnage de Gradio par TNO/TPD (NL). Ces deux activités se ance characterisation and calibration campaign. Some detail problems relating to the performance of the very sensitive detectors have caused delays, but these can be accommodated by the project schedule.

All satellite electrical subsystem units are being qualification tested and flight-model units are being assembled. The testing of the attitude-control subsystem software is proceeding satisfactorily and electronic units are being progressively introduced into the test sequence as they are delivered.

The primary mirror of the flight-model telescope has been found to have good image quality, also at liquid-helium temperatures. The qualification-model telescope has been installed in the payload-module development model, which is now being vibration tested.

The second half of this year will see a major change in emphasis in the project's work as the flight-model subsystems are delivered for parallel integration of the flight model's service and payload modules.

Progress with the ground segment is satisfactory. Emphasis is being put on finding ways to simplify the science operations and to cope with the effects of delays. The build-up of the science operations team is proceeding more slowly than expected and inputs from the Principal Investigators are late because they are giving the highest priority to completing their hardware activities.

A number of problems with the payload module, telescope and attitude-control subsystem have caused delays. Subsequent review of the overall project test plans has nevertheless yielded a schedule compatible with the May 1993 launch date. This schedule does not have any contingency and is based on operating two shifts per day for all critical activities. The total plan, including the extra resources needed to solve these problems, was endorsed by ESA's Science Programme Committee in June.

ERS

ERS-1

Final mechanical preparation of the satellite and de-mating for transport was completed in February 1991. Air transportation to Kourou in French Guiana of the payload module and platform, together with the flight spares and essential Ground-Support Equipment (GSE), was accomplished in early March. The bulk of the GSE was transported to Guiana by sea in mid-February.

The ERS-1 Ground-Segment Readiness Review (GSRR) was held in mid-March and it was concluded that everything would be in place for a launch at the beginning of May.

Following the announcement by Arianespace on 25 April of a delay in the ERS-1 launch date from 3 May to (likely) 6 May, to allow additional time for work on third-stage engine operating margins, ERS-1 activities were kept on schedule until 30 April. At that time, the satellite was on top of the launcher and the final electrical check was made. The satellite and the ground segment were declared 'green for launch' at the ERS-1 Readiness Review on 30 April.

On 1 May, Arianespace halted the launch campaign, having decided that a modification to the third-stage engine had to be made to improve the HM7's operating margins during the start-up phase.

Preliminary schedule indications from Arianespace for qualification and implementation of this modification lead to an ERS-1 launch date not before the second half of July. Consequently, it was decided to de-mate the satellite from the launcher for 'medium-term' storage, and this operation started on 29 May.

ERS-2

Industrial activities with contractors have progressed well, and the remaining contract negotiations are expected to be completed in the course of June.

The Phase-B activities for the Global Ozone Monitoring Experiment (GOME) have been completed and RFQ (Request for Quotation) documents for Phase-C/D are expected to be issued to Industry during June. Work on PRARE-2 and the ATSR-Microwave Radiometer is on schedule.

The programme schedule, which is based on the return of Ground-Support Equipment and flight-spare units from ERS-1 might be affected by the present delay in its launch.

EOPP

Aristoteles

In parallel with he Aristoteles Additional Study, pre-development activities have been successfully completed, with the manufacturing by ONERA and SAGEM, and the testing at ONERA, of a laboratory model (M4) of the Gradio accelerometer, as well as the production and testing of a first breadboard model of the Gradio calibration mechanism by TNO/TPD (NL). Both activities will be pursued in the framework of further technology contracts.

The differential testing on a special test bench of the M3 and M4 accelerometer models has verified their performance to accuracies of better than 10^{-9} g.

The industrial proposal for the system study of the new Aristoteles mission scenario, based on cooperation with NASA, has been received and evaluated. Subject to successful negotiations with Alenia Spazio (I), the Prime Contractor, the study will be initiated shortly.

A technical meeting at JPL with NASA, JPL and top US scientific advisors, has allowed the performance requirements to be defined for the on-board GPS receiver that would be delivered by NASA.

Preparation of the ESA/NASA Memorandum of Understanding has progressed to the fifth draft, following a thorough exchange of views between the two Agencies.

Meteosat Second Generation (MSG)

The Meteosat Second Generation programme has entered the Phase-A stage. In particular:

— The Phase-A study of the enhanced imager (which will have twelve channels compared with the three of the MOP satellites) has been initiated with Matra Espace (F).
— The Invitation-to-Tender for the space-segment Phase-A studies (to be based on spin-stabilised satellites) has been issued.
— Invitations for scientific participation in the programme have also been

poursuivront dans le cadre d'autres contrats de technologie.

L'essai différentiel des modèles d'accéléromètre M3 et M4 sur un banc d'essai spécial a permis de vérifier qu'ils fonctionnaient avec une précision meilleure que 10^{-9} g.

La proposition industrielle portant sur l'étude système du nouveau scénario de la mission Aristoteles, sur la base d'une coopération avec la NASA, a été reçue et évaluée. Si les négociations avec le contractant principal, Alenia Spazio (I) ont une issue positive, l'étude commencera à brève échéance.

Une réunion technique avec le JPL, la NASA et de hauts conseillers scientifiques américains, qui s'est tenue au JPL, a permis de définir les impératifs de fonctionnement du récepteurs GPS embarqué qui serait livré par la NASA.

Un cinquième projet de Mémorandum d'Accord ESA/NASA a pu être élaboré à la suite d'un échange de vues approfondi entre les deux Agences.

Météosat deuxième génération (MSG)
Les activités de phase-A du Programme Météosat de deuxième génération ont commencé:
- *L'étude de phase A de l'imageur amélioré (qui comportera 12 canaux au lieu de trois sur les satellites MOP) a commencé chez Matra Espace (F).*
- *L'appel d'offres relatif aux études de phase A du secteur spatial (qui se baseront sur des satellites stabilisés par rotation) a été lancé.*
- *Des offres de participation scientifique au programme ont également été lancées et quatre propositions devraient être soumises.*

POEM-1
La Déclaration relative au programme préparatoire de POEM-1 est entièrement souscrite (elle est même souscrite à plus de 100% ce qui permet d'augmenter l'enveloppe financière du programme). Le Programme, qui courra d'avril 1991 à avril 1992, comportera l'étude des configurations à utiliser pour la première mission de plate-forme polaire et les missions ultérieures et des études de phase-B ainsi que la réalisation de montages table d'un certain nombre d'instruments clefs. Le secteur sol nécessaire au soutien des missions POEM fera également l'objet d'une étude.

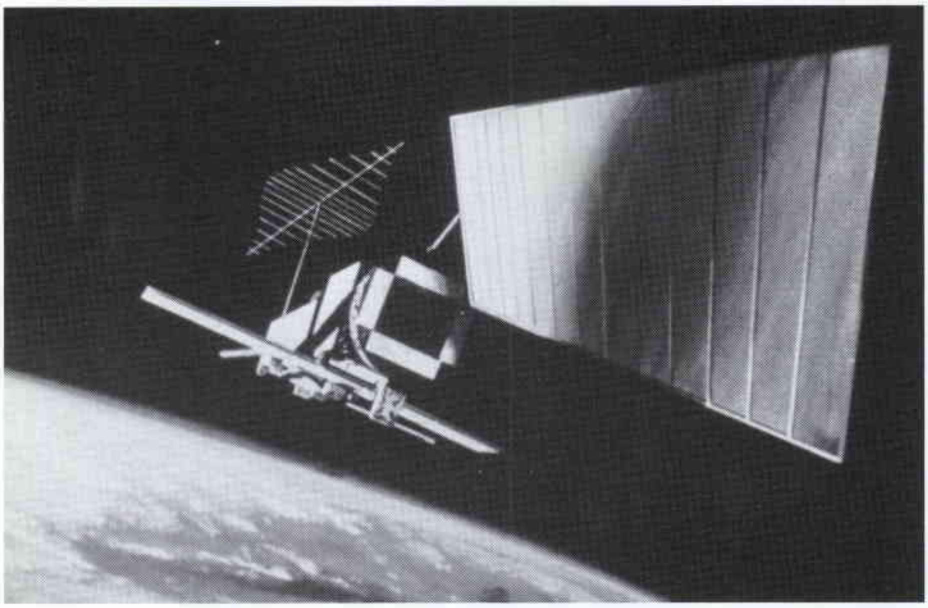
Les propositions industrielles portant sur le contrat principal de la mission (et également sur la phase-B des instruments) ainsi que sur le Radiomètre imageur multi-fréquences (MIMR) qui volera sur la plate-forme EOS américaine sont à l'examen; les contrats devraient être signés dans le courant de l'été.

La communauté internationale des utilisateurs de l'observation de la Terre a tenu une importante réunion fin mai à l'ESTEC. Entre autres, elle a conclu sa réunion par une recommandation au Conseil de l'ESA dans laquelle elle fait siens les objectifs du Plan à long terme d'observation de la Terre de l'Agence.

Plate-forme polaire
L'Agence ayant terminé fin 1990 son évaluation de la proposition de phase-C/D de la plate-forme polaire, des activités ont été conduites afin de résoudre les faiblesses recensées et de parvenir à une situation satisfaisante en ce qui concerne les aspects financiers du contrat.

Les principaux documents ESA relatifs aux impératifs (système, impératifs de gestion et assurance produit) ainsi que les spécifications d'interface (pour le lanceur et le DRS) ont été consolidés et ré-édités avec des mises à jours mineures.

Les travaux d'étude se sont axés sur l'amélioration de la définition du concept et ont permis de résoudre certains des problèmes repérés pendant l'évaluation du terminal en bande Ka, du générateur solaire et de l'unité de codage et de commutation. On a commencé à préparer la revue de consolidation de la base de référence. Les activités de développement se sont poursuivies conformément au calendrier de référence. Les articles à long délais de livraison du module de service ont en particulier été commandés et les échantillons d'essai destinés à la mise au point de la structure fabriqués.



Vue conceptuelle du Plate-forme polaire

Artist's impression of the Polar Platform

Pendant la période considérée, le contractant principal (BAe) et ses deux principaux sous-traitants (Dornier et Matra) ont accompli un gros travail de négociation avec les contractants de niveau inférieur en préparation des négociations finales avec l'Agence.

Les prochaines grandes étapes comprendront la revue de consolidation de la base de référence et la clôture des négociations contractuelles. Elles seront suivies par la présentation de la proposition de programme aux organes délibérants de l'ESA (Conseil directeur du Programme Columbus et Comité de la politique industrielle) pour confirmation des activités de phase-C2/D.

Météosat

MOP-2
La recette de MOP-2, lancé le 2 mars, s'est déroulée en deux étapes. Les

issued, and it is expected that four proposals will be submitted.

POEM-1
The Declaration for the POEM-1 Preparatory Programme has been fully subscribed (in fact oversubscribed, allowing the financial envelope to be increased). The Programme, which will run from April 1991 to April 1992, will study the configurations for the first and subsequent Polar Platform Missions, and undertake Phase-B studies and breadboarding of a certain number of key instruments. The ground segment needed to support the POEM missions will also be studied.

The industrial proposals for the mission Prime Contract (including instrument Phase-B's) and for the Multi-Frequency Imaging Radiometer (MIMR) which will fly on the US EOS Platform, are under evaluation and the contracts are expected to be placed during the summer.

A major meeting of the international Earth-Observation User Community was held at ESTEC at the end of May. This meeting was concluded with a recommendation to ESA Council, inter alia, endorsing the objectives of ESA's Long-Term Plan for Earth Observation.

Polar Platform
Following completion of the Agency's evaluation of the Polar Platform Phase-C/D Proposal at the end of 1990, activities have been conducted to resolve the weaknesses identified and to bring the financial aspects of the contract to a satisfactory status.

The major ESA requirements documents (System Requirements, Product Assurance and Management Requirements), together with the interface specifications (for the launcher and DRS), have been consolidated and re-issued with minor updates.

Engineering design work has concentrated on improving the design definition and resolved some of the problems identified during the evaluation of the Ka-band terminal, the solar generator and the Encoding and Switching Unit. Preparations for the Baseline Consolidation Review have been initiated. Development activities have been continued to support the baseline schedule. In particular, long-lead-time items for the service module have been ordered and structure development test samples have been manufactured.

During the reference period, the Prime Contractor (BAe) and its two major sub-contractors, Dornier and Matra, have made major efforts to negotiate with the lower-level contractors in order to prepare for the final negotiations with the Agency.

The next major milestones will include the Baseline Consolidation Review and the completion of contract negotiations. They will be followed by the presentation of the Programme Proposal to ESA Delegates Bodies (both the Columbus Programme Board and the Industrial Policy Committee) for the confirmation of Phase-C2/D activities.

Meteosat

MOP-2
The commissioning of MOP-2, launched on 2 March 1991, has been taking place in two steps. The telecommunication mission was first tested from 5 to 15 March 1991, followed by the imaging mission, with the first image being acquired on 19 April 1991. The tests for the imaging mission are still in progress. Meteosat-4 (MOP-1) is providing the operational service in the meantime until MOP-2 is declared operational.

LASSO
The Laser Synchronisation from Stationary Orbit (LASSO) experiment has not been operated since the start of MOP-2 commissioning.

Earthnet

The acquisition, archiving, processing and distribution of data from Landsat, Spot, MOS and Tiros has been performed regularly at the network stations. As regards future Tiros data, the NOAA-12 spacecraft was successfully launched on 14 May.

Based on the Agreement with the Kenyan Meteorological Office, an experiment has been initiated to transfer NOAA HRPT data to Frascati for archiving and redistribution under Earthnet's care. Arrangements have almost been completed for including the Kenya and La Reunion Tiros Stations in Earthnet's Tiros coordinated network. The NOAA AVHRR data collected through the HRPT acquisition campaign at the Italian Antarctica base (Terranova) have been made available to Earthnet, and have therefore become part of the Frascati archive.

The archiving on optical disk of CZCS European data from the 'Ocean Project' has progressed at Frascati and also at Maspalomas (Canary Islands), where this activity was started later.

In the framework of the TREES Project, preparatory work has started on two AVHRR/SAR Stations for installation at the Regional Remote-Sensing Centre in Nairobi (Kenya) and at INPE's facility in Cachoeira Paulista (Brazil).

The Commission of the European Communities (CEC/DG-1) has requested Earthnet's assistance, within the framework of the ASEAN Project, with the assessment of the technical and financial aspects of acquiring and preprocessing ERS-1 SAR and NOAA AVHRR data in that region.

A cooperative effort has also been started with the CEC aimed at the technical and financial definition of a European Global Environmental Data Network (which would in turn be the evolutionary precursor to the payload-data ground segment for the International Polar Platforms).

ERS-1
Senator L. Saporito, the Italian Under-Secretary of State, Mr. J.-M. Luton, ESA's Director General, and Prof. F. Carassa, Chairman of the ESA Council, inaugurated the Earthnet ERS-1 Central Facility (EECF) at ESRIN on 12 April. The team required to operate it is now being put in place and trained.

The Central User Service (CUS) and the associated Interface Subsystem (ISS) have been fully tested and accepted. An ERS-1 NEWS Bulletin Board has been established to keep the user community up-to-date on the status of the Programme and its services. A baseline mission plan to accommodate user requests related to the Announcement of Opportunity is in preparation and will be finalised once the detailed orbital elements are known.

essais ont d'abord porté sur la mission de télécommunication, du 5 au 15 mars puis sur la mission d'imagerie — la première image a été acquise le 19 avril. Les essais de la mission d'imagerie ne sont pas encore terminés. Météosat-4 (MOP-1) assure le service opérationnel intérimaire jusqu'à ce que MOP-2 soit déclaré opérationnel.

LASSO

Depuis le début de la mise en service de MOP-2, on n'a pas encore fait fonctionner l'expérience de synchronisation d'horloges atomiques à l'aide d'échos laser.

Earthnet

Les stations du réseau procèdent régulièrement à l'acquisition, à l'archivage, au traitement et à la distribution des données de Landsat, de Spot, de MOS et de Tiros. En ce qui concerne les futures données Tiros, le véhicule spatial NOAA-12 a été lancé avec succès le 14 mai.

Sur la base de l'accord conclu avec l'Office météorologique du Kenya, il a été engagé une expérience de transmission à Frascati de données HRPT de la NOAA pour archivage et redistribution dans le cadre d'Earthnet. Les arrangements visant à intégrer les stations Tiros du Kenya et de la Réunion dans le réseau coordonné Tiros d'Earthnet sont presque conclus. Les données du AVHRR de la NOAA obtenues lors de la campagne d'acquisition HRPT à la base antarctique italienne de Terranova ont été mises à la disposition d'Earthnet et font donc maintenant partie des archives de Frascati.

L'archivage sur disques optiques des données européennes du CZCS du Projet 'Océan' a progressé à Frascati de même qu'à Maspalomas (Iles Canaries) où cette activité a commencé plus tard.

Dans le cadre du projet TREES, des travaux préparatoires ont commencé sur les deux stations AVHRR/SAR qui doivent être installées au Centre régional de télédétection de Nairobi (Kenya) et au centre INPE de Cachoeira Paulista (Brésil).

La Commission des Communautés européennes (DG-1/CCE) a demandé l'assistance d'Earthnet, dans le cadre du Projet ASEAN, pour l'évaluation des aspects techniques et financiers de l'acquisition et du pré-traitement des données SAR d'ERS-1 et AVHRR de la NOAA dans la région sur laquelle porte le projet.

Une activité de coopération avec la CCE a également été lancée en vue de la définition technique et financière d'un Réseau européen de données sur l'environnement à l'échelle du globe (qui serait à son tour le précurseur du secteur sol pour les données des charges utiles des plates-formes polaires internationales).

ERS-1

Le Sénateur italien L. Saporito, Sous-Secrétaire d'Etat, M. J.-M. Luton, Directeur général de l'ESA, et le Prof F. Carassa, Président du Conseil de l'ESA, ont inauguré le 12 avril, à l'ESRIN, l'installation centrale ERS-1 d'Earthnet (EECF). L'équipe chargée de sa conduite est en cours de mise en place et de formation.

Le Service utilisateur central (CUS) et le Sous-système d'interface associé (ISS) ont été réceptionnés à la suite d'essais complets. Il a été créé 'une banque de données ERS-1 NEWS' afin de tenir les utilisateurs au courant de la façon dont se déroule le programme et des services offerts. Un plan de mission de référence est en préparation pour répondre aux demandes envoyées par les utilisateurs à la suite de l'Avis d'offre de participation; il sera définitivement arrêté lorsque l'on connaîtra les caractéristiques détaillées de l'orbite.

La mise à hauteur des stations sol de Maspalomas, Fucino, Kiruna, Gatineau et Prince Albert est terminée pour l'essentiel. A la station de Maspalomas on a notamment installé la capacité d'acquisition et de traitement des données SAR et procédé à sa recette. A Fucino, l'installation et la recette de l'installation de transcription sur disques optiques des données à faible débit (LBR) sont terminées. A Gatineau, la chaîne de traitement des données à livraison rapide est prête tandis qu'à Prince Albert, les travaux de mise à hauteur de la station pour l'acquisition des données LBR ont avancé.

En ce qui concerne les installations de traitement et d'archivage (PAF), les progrès ont été les suivants:

- *A Brest (France), une revue d'aptitude au fonctionnement a été conduite afin de s'assurer de la disponibilité de services fondamentaux tels que la transmission de copies à livraison rapide (FD) aux chercheurs principaux, l'archivage sur disques optiques et le traitement des produits de l'altimètre radar.*
- *A Oberpfaffenhofen (Allemagne), une revue de recette conduite en avril a confirmé que l'installation est prête à assurer un service opérationnel complet. De plus, une capacité de copie des données à livraison rapide du SAR a été intégrée au système.*
- *A Farnborough (RU), les installations ERS-1 ont été inaugurées le 16 avril.*
- *A la PAF italienne de Matera, l'installation des éléments de matériel est achevée et il est prévu d'intégrer le logiciel de services centralisés de la station (CSS) à la mi-juin au plus tard.*

Les essais de transmission de produits LBR à livraison rapide réalisés au moyen de produits LBR FD simulés ont donné des résultats satisfaisants. Les données simulées ont été reçues des stations, codées en format normalisé OMM et envoyées à l'Office météorologique britannique à Bracknell pour leur acheminement au Centre européen de prévisions météorologiques à moyen terme (ECMWF). Il est prévu de réaliser des essais similaires en juillet avec la participation de l'Office météorologique italien.

Au nombre des stations sol prêtes à traiter les données SAR d'ERS-1 figurent maintenant: Gatineau, Prince Albert, Tromsø, O'Higgins, West Freugh, Alice Springs, Fairbanks, Cuiaba, Cotopaxi, Hyderabad, Kumamoto, Hatoyama et Syowa.

Des négociations ont été engagées avec le consortium constitué par Eurimage, Spotimage et Radarsat International pour l'octroi de licences de distribution des données d'ERS-1.

Un ensemble de documents sur ERS-1/Earthnet destiné aux utilisateurs est en préparation.

The upgrading of the ground stations at Maspalomas, Fucino, Kiruna, Gatineau and Prince Albert has essentially been completed. In particular, at the Maspalomas Station, the SAR acquisition and processing capability has been installed and accepted. At Fucino, installation and acceptance of the Low-Bit-Rate (LBR) Optical-Disk Transcription Facility has been completed. At Gatineau, the Fast-Delivery Processing Chain has been readied for operations, whilst work has progressed at Prince Albert on upgrading the Station for the acquisition of LBR data.

Progress as regards the Processing and Archiving Facilities (PAFs) has been as follows:

- At Brest (France), an operational-readiness review has been conducted to ensure the availability of such basic services as: dissemination of Fast-Delivery (FD) copies to Principal Investigators, archiving on optical disks, and processing of Radar Altimeter products.
- At Oberpfaffenhofen (Germany), an acceptance review in April confirmed the full functionality and operational readiness of the facility. In addition, a SAR Fast Delivery data copying capability has been added to the system.
- At Farnborough (UK), the ERS-1 facilities were inaugurated on 16 April.
- At the Italian PAF in Matera, installation of the hardware components has been successfully completed, and integration of the Centralised Station Services (CSS) software is foreseen by mid-June.

LBR Fast-Delivery test transmissions using simulated LBR FD products have been performed with satisfactory results. Simulated data were received from the stations, encoded in the standard WMO format, and sent to the UK Meteorological Office in Bracknell for routing to the European Centre for Medium-Range Weather Forecasting (ECMWF). Similar tests with the participation of the Italian Meteorological Office (ITAV) are planned for July.

The ground stations that are now ready to handle ERS-1 SAR data include: Gatineau, Prince Albert, Tromsø, O'Higgins, West Freugh, Alice Springs, Fairbanks, Cuiaba, Cotopaxi, Hyderabad, Kumamoto, Hatoyama and Syowa.

Negotiations have been initiated with the consortium formed by Eurimage, Spotimage and Radarsat International with a view to awarding ERS-1 data-distribution licences.

A user-oriented Earthnet/ERS-1 documentation package is in preparation.

Eureca

With the Flight Unit Acceptance Review which took place in April 1991, the Eureca development programme has been completed. Subject to some re-testing of the system, including the remaining compatibility tests between the Eureca flight unit and the ESOC ground facilities, the system will be ready by the end of September for shipping to the launch site.

The previously planned launch date of February 1992 has had to be postponed until the June/August 1992 time frame due to the repairs necessary to the door drive-mechanism housing of the Space Shuttle 'Discovery' after its last flight.

Space Station Freedom/Columbus

Manned laboratories

After the evaluation of the revalidated proposal, completed at the end of February, the Executive has developed, with the Industrial Contractors, modified baselines for both manned elements in order to reduce the overall costs and bring them into line with the reduced funding profile requested by the Member States.

For the Attached Laboratory, the approach for the Phase-2 baseline is to reduce the length of the module in order to increase the initial payload at launch, simplify the internal structure, simplify/reduce the performances of the major functional subsystems in line with the overall down-sizing of the module, and replace the Scientific Airlock by an 'Exposed Payload Facility' capability.

Launch is planned for September 1998, consistent with the assembly schedule for Space Station 'Freedom'.

For the Free-Flyer, the requirement for servicing at the Space Station has been dropped in order to simplify the operational scenario and reduce the cost. This decision has been based on the following rationale:

- the average orbital altitude can be increased to achieve a better microgravity level together with a reduction in propellant consumption;
- the deletion of all functions previously needed for the active rendezvous and docking phases with the Space Station leads to design simplifications (including a reduction in the propulsion system) and cost reductions.

This Phase-2 baseline now incorporates servicing by Hermes once per year, with the Shuttle as back-up, simplification of system and subsystem configurations for development cost reduction, elimination of in-orbit Resource Module replacement, reduction of the lifetime to 10 years, elimination of the development risks associated with the evolving Space Station design, together with greater programmatic flexibility to match better the available funding profiles. Launch of the Free-Flyer is now planned for 2001.

The dialogue with NASA has continued via the established interfaces, focussing on the technical updates following the Space Station restructuring and on political support to the cooperation during the annual NASA budget-approval cycle.

Turning to the Columbus operations ground segment, recommendations concerning the architectural design and operational aspects for the Centralised Facilities, emanating from the Mid-Term System Architecture Support Review, have been processed and preparation of programmatic data has commenced. The Manned Space Laboratory Control Centre Facility Design Review was conducted in March.

On the utilisation side, the ESA initiative of proposing a programme of Columbus Precursor Flights (two Spacelab and two Eureca) is gaining momentum. About 500 proposals have been received following the Call for Proposals and Ideas for the four flights in the 1994/97 time frame. They involve over 1000 scientists and represent a wide range of disciplines. These proposals are currently being evaluated by scientific peer groups.

The ESA Member States have presented

Eureca

Le programme de développement d'Eureca s'est achevé sur la Revue de recette de l'unité de vol qui a eu lieu en avril. Sous réserve de quelques essais supplémentaires du système et des derniers essais de compatibilité entre l'unité de vol d'Eureca et les installations sol de l'ESOC, le système sera prêt fin septembre à être expédié au site de lancement.

Le lancement, jusqu'à présent fixé à février 1992, a dû être retardé à la période juin-août 1992, du fait des réparations à faire sur le logement du mécanisme de commande de fermeture de la soute de la Navette 'Discovery' à la suite de son dernier vol.

Station spatiale Freedom/Columbus

Laboratoires habités

A l'issue de l'évaluation de la proposition revalidée, qui s'est achevée fin février, l'Exécutif a élaboré avec les contractants industriels des bases de référence modifiées pour les deux éléments habités, afin de réduire les coûts d'ensemble et de les aligner sur le profil de financement révisé à la baisse demandé par les Etats membres.

En ce qui concerne le Laboratoire raccordé, la démarche adoptée pour la solution de référence de la phase-2 est la suivante: réduire la longueur du module en vue d'augmenter la charge utile initiale au lancement, simplifier la structure interne, simplifier ou réduire les possiblités techniques des principaux sous-systèmes fonctionnels en rapport avec la réduction de taille du module, et remplacer le sas scientifique par la possibilité d'utiliser une structure porteuse d'équipements externes.

Le lancement est prévu en septembre 1998, conformément au calendrier d'assemblage de la Station spatiale Freedom.

En ce qui concerne le Laboratoire autonome, il a été renoncé à l'impératif de desserte du laboratoire à la Station spatiale afin de simplifier le scénario opérationnel et de réduire les coûts. Cette décision repose sur le raisonnement suivant:

- *il est possible d'augmenter l'altitude orbitale moyenne pour obtenir de meilleures conditions d'impesanteur et une baisse de la consommation d'ergols;*
- *la suppression de toutes les fonctions qui étaient requises auparavant pour les phases actives d'accostage/ amarrage avec la Station spatiale conduit à une simplification de la conception (notamment à une réduction du système de propulsion) et à une réduction des coûts.*

Cette base de référence de la phase-2 prévoit maintenant la desserte par Hermès une fois par an, la Navette servant de solution de rechange, la simplification des configurations système et sous-systèmes en vue d'une baisse des coûts de développement, la suppression du remplacement en orbite du module de ressources, la réduction de la durée de vie à dix ans, l'élimination des risques en matière de développement associés à l'évolution de la conception de la Station spatiale, ainsi qu'une plus grande souplesse programmatique permettant une meilleure adaptation aux profils de financement retenus. Le lancement du Laboratoire autonome est maintenant prévu en 2001.

Le dialogue se poursuit avec la NASA par l'intermédiaire des interfaces mis en place, l'accent étant mis sur les mises à jour techniques faisant suite à la restructuration de la Station spatiale ainsi que sur le soutien politique de la coopération au cours du cycle annuel d'approbation du budget de la NASA. En ce qui concerne le secteur sol Columbus, il a été procédé à la mise en oeuvre des recommandations sur la conception architecturale et les aspects opérationnels des installations centralisées, formulées lors de la revue à mi-parcours de soutien de l'architecte système, et la préparation des données programmatiques a commencé. La revue de conception du Centre de contrôle des laboratoires habités (MSCC) s'est déroulée en mars.

Pour ce qui concerne l'utilisation, la proposition de l'Agence portant sur un programme de vols précurseurs de Columbus (deux vols Spacelab et deux vols Eureca) suscite un intérêt croissant. Quelque cinq cents propositions ont été reçues à la suite de l'appel aux propositions et aux idées relatif à ces quatre vols au cours de la période 1994-1997. Ces propositions intéressent plus de mille scientifiques et couvrent un large éventail de disciplines. Elles sont en cours d'évaluation par des groupes d'experts scientifiques.

Les Etats membres de l'ESA ont présenté leur liste de candidats astronautes sélectionnés au niveau national; l'Agence procédera au choix final d'un premier groupe de dix astronautes.

En ce qui concerne les activités du programme à long terme, le traitement des données de l'expérience ISEMSI est en cours (cf. articles sur l'ISEMSI dans le présent bulletin). SUBEMSI, expérience découlant de la précédente et portant sur l'isolement de six volontaires pendant deux mois en milieu sous-marin, est à l'étude.

Les études relatives à la future infrastructure spatiale européenne habitée se poursuivent.

Ariane

La nouvelle procédure de lancement avec désorbitation naturelle de l'étage H155 entraîne une augmentation de la masse d'ergol de l'étage L7, qui passe ainsi à 9,7 t pour une mission automatique, et demande qu'Hermès s'accommode d'une orbite de transfert à faible périgée.

La fabrication des premiers réservoirs cryotechniques progresse de façon satisfaisante (75% des soudures sont terminées) et l'usine d'intégration de l'étage cryotechnique a été inaugurée chez Aérospatiale et Cryospace aux Mureaux (F).

Le moteur Vulcain a subi avec succès un essai de mise à feu à pleine puissance et l'une des turbopompes à hydrogène liquide a maintenant fonctionné 700 s au total.

Compte tenu du comportement satisfaisant des éléments du moteur, un essai de mise à feu de Vulcain a pu être mené à bien pour la première fois le 13 juin pendant la durée nominale de 600 s.

Le premier malaxage d'ergols solides

their lists of nationally chosen candidate astronauts and the Agency will now make the final choice of an initial group of ten astronauts.

Among the 'Long-Term Programme' activities, processing of data from the ISEMSI experiment is under way (see ISEMSI articles in this issue) and a follow-on experiment, SUBEMSI, involving six volunteers being isolated in submarine habitats for two months is being studied.

Studies on the future European Manned Space Infrastructure are under way.

Ariane

The new launch procedure leading to natural re-entry of the H155 stage entails an increase in the propellant mass for the L7 stage to 9.7 t for an automatic mission and acceptance by Hermes of a low-perigee transfer orbit.

Manufacture of the first cryotechnic tank is progressing satisfactorily (75% of the welding has been finished), and the new stage-integration plant has been inaugurated at Aérospatiale and Cryospace in Les Mureaux (F).

The Vulcain engine successfully underwent a full-power firing test for 200 sec for the first time in May and one LH_2 turbopomp has now achieved a cumulative run time of 700 sec.

In view of this satisfactory behaviour of the engine elements, a Vulcain firing test could be carried out successfully for the first time on 13 June 1991 for the nominal 600 sec duration.

The first active mixing of solid propellant for the P230 booster has been successfully completed in French Guiana. Because of a delay in the delivery of the booster casing to Kourou, the first P230 'battleship test' (B1) is now foreseen for March 1992.

The first casings for the M1 ('near-to-flight model') tests have been delivered to Colleferro in Italy for their internal thermal protection to be fitted before being transported to Kourou.

Hermes

Industrial work has concentrated on the further definition of the space vehicle's subsystems, updating of the system budgets, and detailed configuration evaluation.

Two major reviews have been conducted: the System Concept Review and the second part of the Preliminary Space Vehicle Review. These reviews have confirmed the overall validity of the system design and the overall feasibility of the space vehicle, but a number of points of concern require further action. Evaluation of possible changes to the Hermes servicing scenario has started, given the recent choice of the Columbus Free-Flying Laboratory concept. Modifications to the resource module may, for instance, be involved.

The documents needed for the decision on the transition to Phase-2 are being examined by the Ariane Programme Board and the Council Working Group. They cover re-evaluation of the Hermes cost-to-completion, a review of the programme's compliance with the objectives set in 1987, a technical report on the Phase-1 results, and finally an update to the programme proposal incorporating some changes in the development approach.

Industry has submitted an offer for the space vehicle's development which is under evaluation. A first part of the Phase-1 budget extension, needed to cover 1991 activities, has been approved by the programme participants.

TDP

Inflatable Space Rigidising Technology
The experiment has been reassessed. Two material-sample experiments are now planned in order to verify the in-orbit degradation.

Gallium-Arsenide Solar Array (GaAs)
This experiment, which consists of two patches of 10 (2 cm×4 cm) solar cells with soldered interconnectors, has been integrated into the Tubsat microsatellite. The Critical Design Review for a complete solar-array panel of 4 cm×4 cm cells with welded interconnectors is foreseen for the autumn.

Solid-State Micro-Accelerometer
This experiment was launched on 5 June aboard Shuttle flight STS-40.

Attitude-Sensor Package
The manufacture of the flight unit has been completed. Integration will start in July.

Collapsible-Tube Mast
The bridging phase has been completed and continuation of the experiment with a Phase-C/D will depend on the Columbus Programme's interest in using the mast as a multi-user facility.

Metal Deposition In Orbit
The final design is almost complete.

Two-Phase Flow
The detailed design is complete.

Atomic-Oxygen Detector
The Critical Design Review was held successfully in April.

Next flight opportunities
The Tubsat microsatellite carrying the GaAs patches will be launched in July 1991 as a piggy-back payload with ERS-1.

Launch of the Hitchhiker-G experiment (Attitude-Sensor Package) is foreseen for the second half of 1992, on-board STS-50. The STRV-1 launch, carrying the GaAs Solar-Array Panel, is foreseen for the end of 1992, while the Bremsat microsatellite, carrying the Atomic Oxygen Detector, is scheduled for launch by the end of 1992 on-board the Spacelab D-2 mission. Other flight opportunities will follow.

Flight/post-flight activities
The Solid-State Microaccelerometer launched by Space Shuttle 'Columbia' on 5 June has been activated according to plan, and the gathering of flight data is foreseen for early July.

TDP Next Phase
The period of subscription will close by end of June. Evaluation of the proposals received in response to the Call for Proposals and Ideas for the Columbus Precursor Flights is in progress and will be completed in September.

actifs destiné au propulseur P230 a été réalisé en Guyane. Compte tenu du retard de la livraison à Kourou de l'enveloppe du propulseur, le premier essai de structure lourde (B1) du P230 est maintenant fixé à mars 1992.

Les premières enveloppes destinées aux essais du M1 ('modèle proche du modèle de vol') ont été livrées à Colleferro en Italie pour fixation de la protection thermique interne avant leur acheminement à Kourou.

Hermès

Les travaux industriels ont été axés sur l'approfondissement de la définition des sous-systèmes du véhicule spatial, sur l'actualisation des bilans du système et sur l'évaluation de sa configuration détaillée.

Deux grandes revues ont été conduites: la revue de conception système et la deuxième partie de la revue préliminaire du véhicule spatial. Ces revues ont confirmé la validité générale du concept du système et la faisabilité globale du véhicule spatial mais des mesures doivent être prises pour résoudre un certain nombre de questions préoccupantes. On a commencé à évaluer les éventuelles modifications à apporter au scénario de desserte d'Hermès compte tenu du concept de laboratoire autonome Columbus qui vient d'être retenu. Il pourrait par exemple être nécessaire de modifier le module de ressources.

Le Conseil directeur du Programme Ariane et le Groupe de travail du Conseil examinent à l'heure actuelle les documents nécessaires à la prise d'une décision quant au passage à la phase-2. Ces documents comprennent une réévaluation du coût à achèvement d'Hermès, une revue de la conformité du programme aux objectifs fixés en 1987, un rapport technique sur les résultats de la phase-1 et enfin une mise à jour de la proposition de programme prenant en compte certaines modifications intervenues dans la doctrine du développement.

L'industrie a soumis une offre pour le développement du véhicule spatial: elle est en cours d'évaluation. Une première partie de l'extension du budget de phase-1, nécessaire à la couverture des activités de 1991, a été approuvée par les Participants au programme.

TDP

Technologie des structures gonflables, rigidifiables dans l'espace
L'expérience a été réévaluée. Il est maintenant prévu de réaliser deux expériences portant sur des échantillons de matériaux afin d'étudier leur dégradation en orbite.

Réseau solaire à l'arséniure de gallium (GaAs)
Cette expérience, qui comprend deux groupes de 10 photopiles (de 2×4 cm) à interconnecteurs soudés, sera embarquée sur le microsatellite Tubsat. La revue critique de définition qui portera sur un panneau solaire complet de photopiles de 4×4 cm à interconnecteurs soudés est prévue pour cet automne.

Micro-accéléromètre à état solide
Cette expérience a été lancée le 5 juin à bord de la Navette (STS-40).

Ensemble de détecteurs d'orientation
La fabrication de l'unité de vol est terminée. L'intégration commencera en juillet.

Mât à tube enroulable
La phase relais est achevée et une phase-C/D sera engagée si le Programme Columbus souhaite utiliser ce mât à titre d'installation à utilisateurs multiples.

Dépôt de métaux en orbite
La conception définitive est presque achevée.

Ecoulement diphasique
La conception détaillée est terminée.

Détecteur d'oxygène atomique
La revue de conception critique qui s'est tenue en avril a donné de bons résultats.

Prochaines occasions de vol
Le microsatellite Tubsat qui doit emporter les photophiles GaAs sera lancé en juillet 1991 comme passager auxiliaire d'ERS-1.

The GaAS TDP payload

Charge utile GaAs (TDP)

Le lancement du Hitchhiker-G contenant l'ensemble de détecteurs d'orientation est prévu pour le second semestre 1992 à bord de la Navette (STS-50). Le lancement du panneau solaire à l'arséniure de gallium sur STRV-1 est fixé à fin 1992 tandis que le microsatellite Bremsat qui emportera le détecteur d'oxygène atomique doit être lancé fin 1992 également mais dans le cadre de la mission Spacelab-D2. D'autres occasions de vol suivront.

Activités pendant et après le vol
Le micro-accéléromètre état solide lancé à bord de la Navette Columbia le 5 juin a été mis en service conformément aux prévisions et la collecte des données de vol doit avoir lieu début juillet.

Phase suivante du TDP
Les souscriptions seront closes fin juin. Les propositions reçues en réponse à l'appel aux propositions et aux idées pour les vols précurseurs de Columbus sont en cours d'évaluation; cette activité s'achèvera en septembre.

Publications

The documents that are listed here have been issued since the last publications announcement in the ESA Bulletin.

ESA Journal

The following papers have been published in ESA Journal Vol. 15, No. 2:

THERMAL ASSESSMENT OF GIOTTO FOLLOWING REACTIVATION IN 1990
WILSON R J

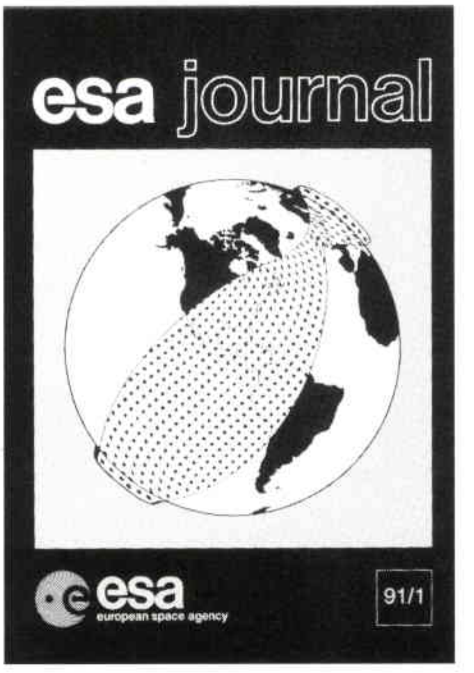
PREDICTION OF SOLAR AND GEOMAGNETIC ACTIVITY FOR LOW-FLYING SPACECRAFT
MUGELLESI R & KERRIDGE D J

TWO COMPLEMENTARY SYSTEMS ON-BOARD 'ARISTOTELES': GRADIO AND GPS
RUMMEL R & SCHRAMA E J O

INTERACTIVE IMAGING AND REAL-TIME POINTING IN AN AURORAL IMAGING OBSERVATORY
SHAHIDI F, WOOLLISCROFT L J C & STADSNES J

DESIGN METHODOLOGY FOR SPACE AUTOMATION AND ROBOTICS SYSTEMS
ELFVING A & KIRCHHOFF U

ASPECTS OF CODING FOR POWER-EFFICIENT SATELLITE VSAT SYSTEMS
TOMLINSON M, CERCAS F & HUGHES C D

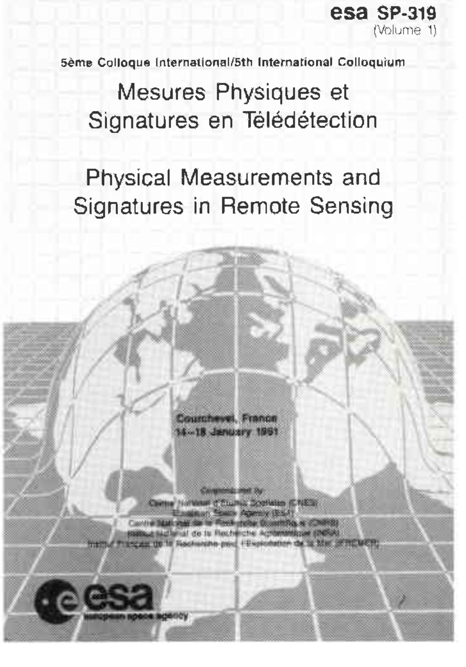


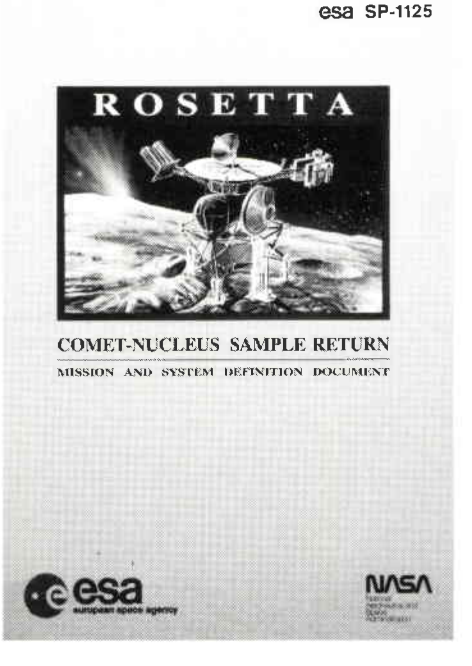
ESA Special Publications

ESA SP-318 // 550 PAGES
PROC. FIRST EUROPEAN SYMPOSIUM ON AEROTHERMODYNAMICS FOR SPACE VEHICLES, ESTEC, NOORDWIJK (NL), 28 – 30 MAY 1991 (JULY 1991)
BATTRICK B (EDITOR)

ESA SP-1125 // 190 PAGES
ROSETTA/CNSR: A COMET-NUCLEUS SAMPLE-RETURN MISSION. MISSION & SYSTEM DEFINITION DOCUMENT (JUNE 1991)
SCHWEHM G H & LANGEVIN Y
(EDITOR B BATTRICK)

ESA SP-319 // 850 PAGES (2 VOLS)
PROC. 5TH INTERNATIONAL COLLOQUIUM ON PHYSICAL MEASUREMENTS AND SIGNATURES IN REMOTE SENSING, COURCHEVEL, FRANCE, 14 – 18 JANUARY 1991 (MAY 1991)
HUNT J (EDITOR)





ESA Brochures

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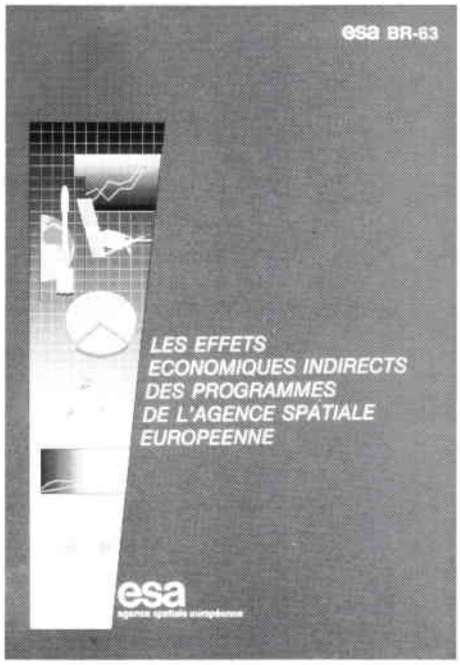
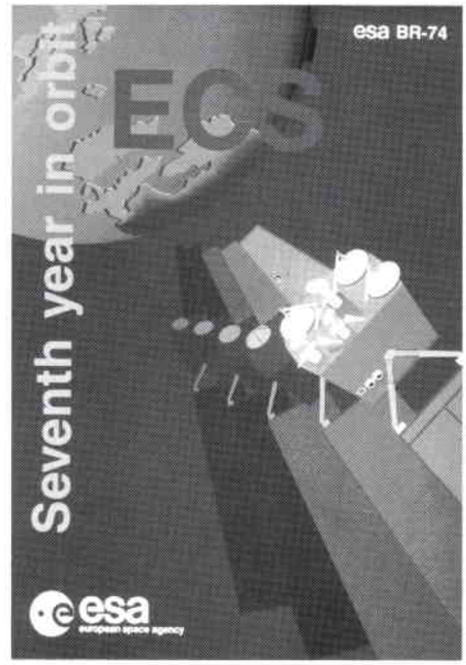
(PRESENTATION DE L'ETUDE MENEE EN EUROPE PAR LE BUREAU D'ECONOMIE THEORIQUE ET APPLIQUEE, STRASBOURG)
HIERONIMUS A-M (ED. T D GUYENNE)

ESA BR-74 // 26 PAGES
ECS: SEVENTH YEAR IN ORBIT
BASTON D W ET AL (ED. W R BURKE)





ESA Newssheets

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ESA PSS-04-106 ISSUE 1 // 74 PAGES
PACKET TELEMETRY STANDARD (JANUARY 1988)
ESA STANDARDS APPROVAL BOARD FOR SPACE DATA COMMUNICATIONS (ED. W R BURKE)

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	1/2 page vertical	91/265 mm high
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	1 ×	4 ×	8 ×
1/1 page B/W	2.000.—	1.600.—	1.200.—
1/2 page B/W	1.200.—	1.000.—	800.—
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Loose inserts (by application only) 1/A4 — 3.000.—.

Advertising Management

Brigitte Kaldeich
ESA Publications Division
ESTEC, Keplerlaan 1
2200 AG Noordwijk, The Netherlands
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