european space agency

esa bulletin

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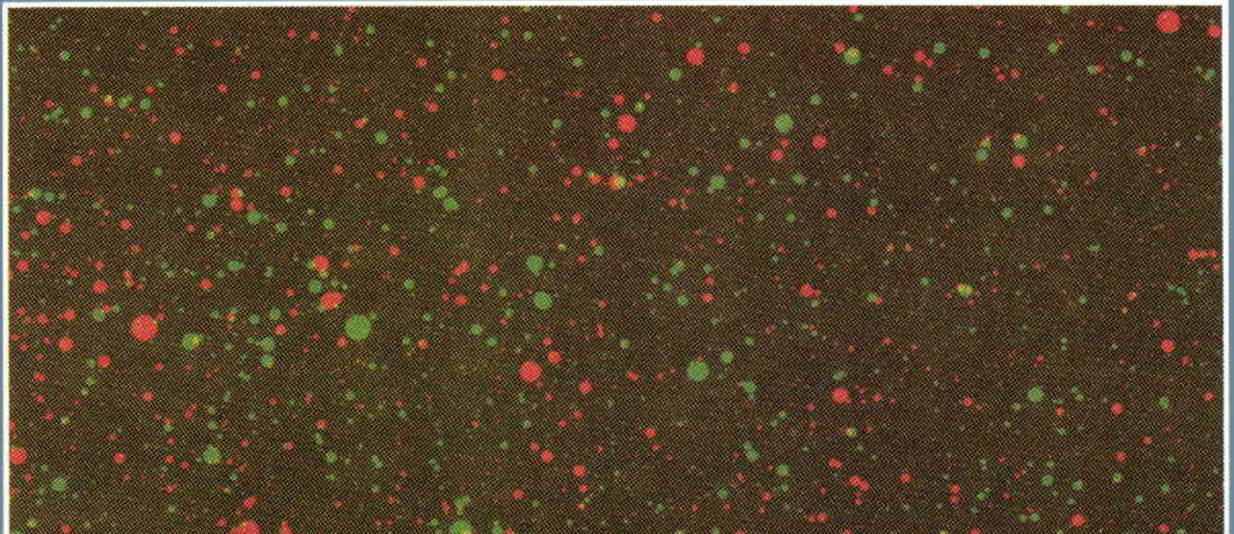

number 77

february 1994

european space agency

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

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The ESA HEADQUARTERS are in Paris.

The major establishments of ESA are:

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

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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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ESRIN, Frascati, Italie.

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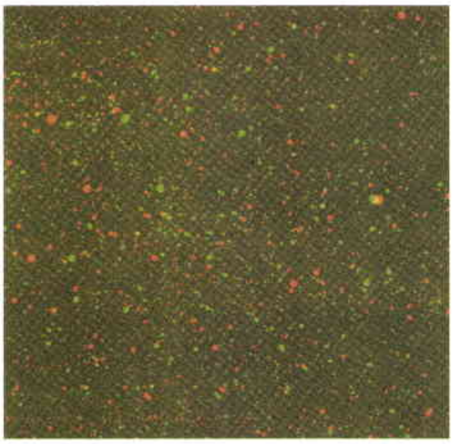

Cover: Hipparcos three-dimensional image of the constellations of Cygnus and Lyra (see top of page 45)

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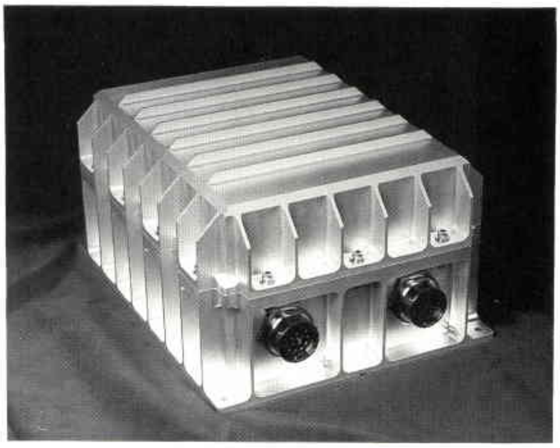

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SSAC(93)7
Paris, 24 September 1993

European Space Agency
Space Science Advisory Committee

Selection of Cornerstones 3 and 4

The SSAC at its 68th Meeting, held in Paris on 23 September 1993, considered the ordering of the third and fourth Cornerstone missions of Horizon 2000, namely FIRST (Far-Infrared Submillimetre Space Telescope) and ROSETTA (Cometary Rendezvous mission).

Presentations were given by the teams preparing these missions and the Committee were very favourably impressed with the science and technical development of both missions.

It was recognised that both missions fulfilled the requirements of a Cornerstone of the Horizon 2000 Programme.

The Committee also appreciated the large involvement of the European scientific community and the European lead that had been established by the studies of both missions.

The Committee recommended that ROSETTA be implemented prior to FIRST.

This Recommendation was based on programmatic considerations. A better balance between disciplines in the Horizon 2000 Programme is achieved by this order. The launch of ROSETTA in 2003 and FIRST in 2006 still results in the science return from FIRST being earlier than that from ROSETTA, because of the extended interplanetary transit of ROSETTA.

Under no circumstances should the FIRST science be descoped further. The extended development time for FIRST can be very effectively used for further qualification of critical technologies for the telescope and the cooling system. The need to define the payload requirements in association with such developments led the Committee to recommend that the current Science Advisory Group be kept in close contact with all technical and scientific developments in the project until the release of the Announcement of Opportunity.

The Committee recommended that for both missions all avenues be explored with regard to international cooperation, to reduce the cost of the programme without jeopardising the science. It requested that the Director of Science report back on progress in the international negotiations within one year.

'Rosetta' – ESA's Planetary Cornerstone Mission

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The Planetary Cornerstone Mission of ESA's Long-Term Programme for European Space Science, known as 'Horizon 2000' (Fig. 1), was foreseen as a 'Mission to Primordial Bodies including the Return of Pristine Materials'. The return of primordial material from primitive bodies – asteroids and comets – was seen as one of the major themes for planetary research during implementation of the Long-Term Programme and as an area in which Europe could take a lead, building on the success of the Giotto mission.

Programmatic difficulties encountered by ESA's intended partners in this complex and ambitious mission have required its reassessment as a purely ESA undertaking. As a result, it will no longer be possible to bring back samples for analysis in terrestrial laboratories; instead, we have to take the 'laboratories' to the comet!

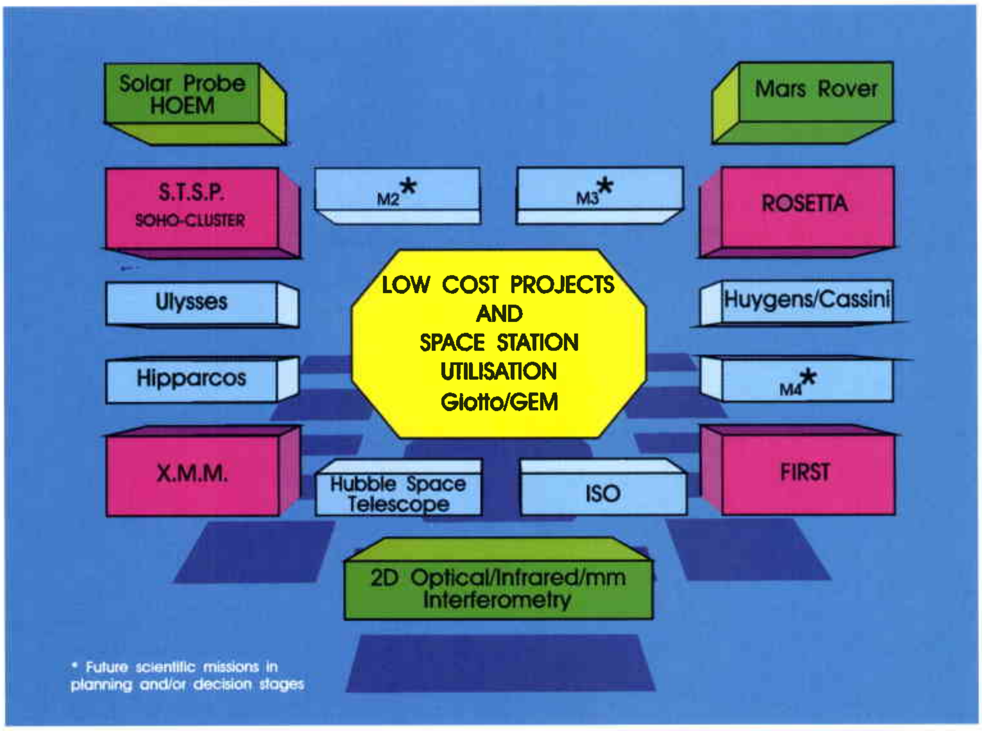
Background

In May 1985, after extensive discussion by the European members of the ESA/NASA Primitive Bodies Science Study Group, the ESA Solar System Working Group recommended a Comet-Nucleus Sample-Return mission – later named 'Rosetta' – as the Horizon 2000 Planetary Cornerstone mission. This mission was to encompass both the in-situ study of comets and the return of samples. A joint ESA/NASA Science Definition Team was formed by the end of 1985 to define the scientific objectives for a joint ESA/NASA mission in detail.

Financial and programmatic difficulties experienced by NASA, the envisaged partner for the original mission concept, made it necessary to study alternative concepts in early 1992. The prime consideration was to define a core mission that would attract the support of the scientific community at large and that could be performed by ESA alone on the basis of European technology. The opportunity for other agencies to join and augment the scientific return should, it was felt, be left open.

The new baseline mission is a rendezvous with a comet and at least one, but probably two fly-bys of asteroids. The in-situ investigation of the cometary nucleus by surface-science packages (e.g. surface station, penetrator) has been assigned the highest priority by the science community.

Figure 1. The Long-Term European Programme for Space Science 'Horizon 2000' as foreseen in 1991



As far as possible, the mission will satisfy the objectives of the original comet-nucleus sample-return mission and will concentrate on the in-situ investigation of cometary matter and the structure of the nucleus, with the added potential of studying the evolution of the cometary processes as a function of heliocentric distance.

Our knowledge of small solar-system bodies, the comets and asteroids, has dramatically improved over the last 20 years. The major milestones were undoubtedly the first fly-bys of Comet Halley by the Giotto, Vega, Sagigake and

Susei probes in 1986 and, in December 1991, the first near encounter with a main-belt asteroid, Gaspra, by the Galileo spacecraft on its way to Jupiter. During the same period, telescopic observations performed on the ground or in Earth orbit have drastically expanded and diversified. They constitute the basis for understanding small bodies as a population, since we can now compare observations of a large variety of objects, and can undertake investigations of the variability of cometary activity.

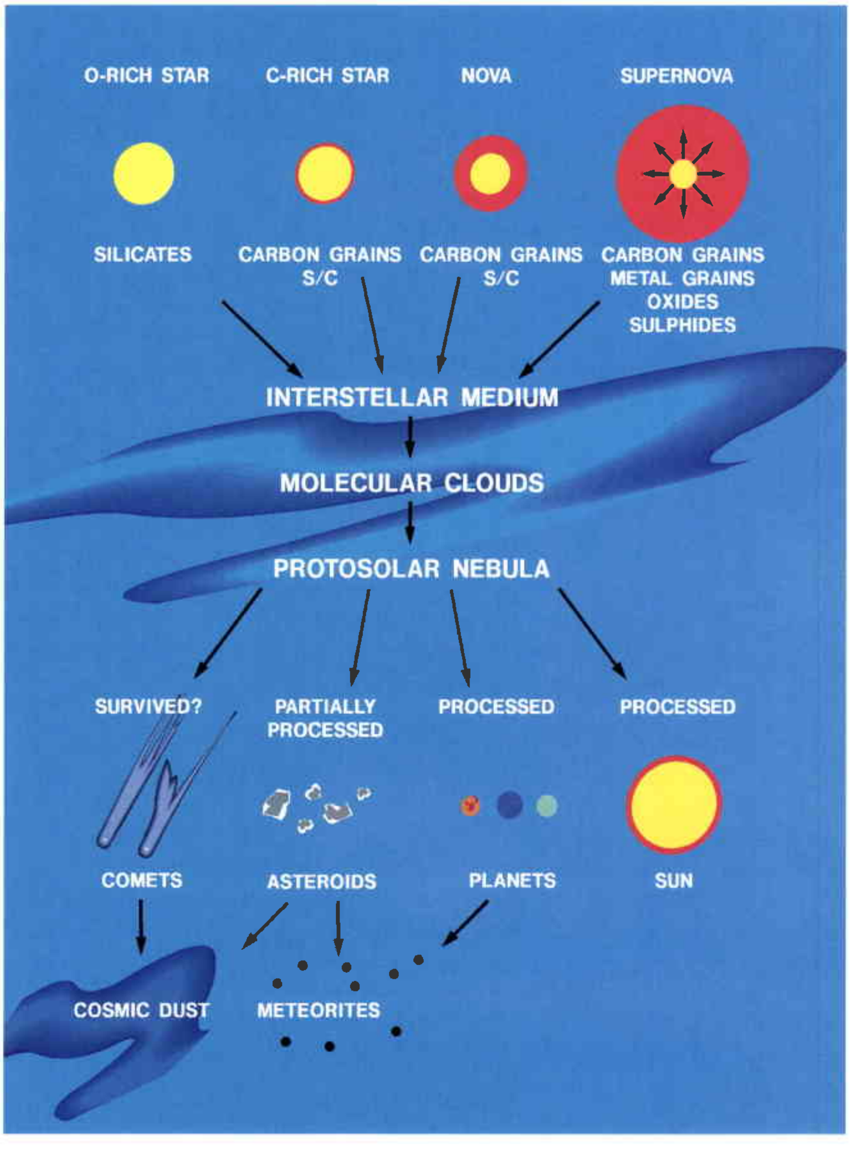


Figure 2. Schematic history of circumstellar dust grains, from their birth in stellar atmospheres to their arrival in the inner Solar System

Systematic observations in the visible spectrum are performed for short-period comets as well as main-belt and near-Earth asteroids, and it is now possible to observe cometary nuclei very far from the Sun from the ground and with the Hubble Space Telescope. Furthermore, small bodies can now be studied systematically at all wavelengths from the ultraviolet (with IUE), via the infrared (with IR telescopes on Mauna Kea, Hawaii, the spaceborne IRAS telescope, and soon with ESA's Infrared Space Observatory), to microwave and radio wavelengths.

From this wealth of new information, it is becoming apparent that small Solar System bodies, asteroids and comets, constitute an almost continuous suite of progressively less evolved objects, reflecting the radial gradient in the swarm of planetesimals during the formation of the Solar System (Fig. 2). Indeed, the outermost asteroids present spectral similarities with the bare cometary nuclei observed far from the Sun. The most distant 'asteroid', Chiron, whose orbit is outside Saturn's, is often considered as a giant cometary nucleus. Furthermore, short-period comets should ultimately evolve into asteroids after the depletion of their volatile components. A better understanding of the relationship between asteroids, comets and planetesimals throughout the solar nebula is an essential step in unravelling the first stages of the formation of our Solar System.

Cometary material has been submitted to the lowest level of processing since its condensation from the protosolar nebula. It is considered likely that pre-solar grains may have been preserved in comets. As such, cometary material should constitute a unique repository of information on the sources that contributed to the protosolar nebula, as well as on the condensation processes that resulted in the formation first of planetesimals, then of larger planetary bodies. While tantalising results were obtained in situ from cometary grains, and on interplanetary dust particles collected on Earth, the latter cannot be considered as fully representative, in particular in terms of their organic and volatile complement.

Direct evidence on cometary volatiles is particularly difficult to obtain, as species observable from Earth, and even during the Halley fly-bys, result from physico-chemical processes such as sublimation, interaction with solar radiation and the solar wind. The currently available information on cometary material gained from in-situ studies and ground-based observations demonstrates the low level of evolution of cometary material. The latter's tremendous potential for providing information on the constituents and early evolution of the solar nebula has yet to be exploited (Fig. 3).

Scientific objectives

Studying cometary material represents a major challenge, owing to the very characteristics that make it a unique repository of information about the formation of the Solar System, namely its high volatiles and organic material content. Two solutions to the problem of obtaining unaltered material can be considered: returning to Earth a sample of a cometary nucleus (the original Rosetta concept) or staying close to the comet and performing comprehensive in-situ analyses of material from the surface and the coma.

The first approach had the undisputed advantage of bringing the full range of current, and even future, analytical techniques that are, or will be, available in the laboratory to bear on investigations of the Probe material. Limiting thermal and mechanical stresses to acceptable levels during cruise and recovery, and even defining these acceptable levels, represented a significant scientific and technological challenge. The new approach, which results in a simpler and cheaper mission, guarantees by design minimal perturbations of the cometary material, as analyses are performed in situ, at low temperatures and in a microgravity environment. It also provides the opportunity of observing at close range the onset and development of cometary activity, which results in the spectacular displays that have captured the imagination of mankind over the centuries.

A fundamental question had to be addressed both for the original sample-return concept and the new in-situ analysis concept: to what extent can the material accessible to analyses be considered as representative of the bulk material constituting the comet, and of the early nebular condensates that constituted the cometesimal 4.57×10^9 years ago? This representativity issue must be addressed by first determining the global characteristics of the nucleus (mass, density, rotation state), which can provide clues concerning vertical gradients, and hence the relationship between the outer layers and underlying material.

The dust and gas activity observed around comets, as well as its rapid response to changes in illumination, guarantees the presence of volatiles at or very close to the surface in active areas. Analysing surface material in active areas will therefore provide information on both the volatile and the refractory constituents of a cometary nucleus. The selection of a site for surface-science investigations should be relatively straight forward with the extensive remote-sensing observation phase provided by the new Rosetta concept. The surface science site(s) can be monitored during surface activities, as well as during a large fraction of the activity cycle, which should bring clues concerning the compositional heterogeneity of active regions (e.g. from the observation of outbursts).

The dust-emission processes are induced by very low density gas outflows and should preserve the fragile texture of cometary grains. These grains can be collected at low velocities (a few tens of metres per second) by the spacecraft after short travel times (a few minutes), which minimises alterations induced by solar radiation. Similarly, gas analysed in jets or in the inner coma should yield information on the volatile content of cometary material in each source region.

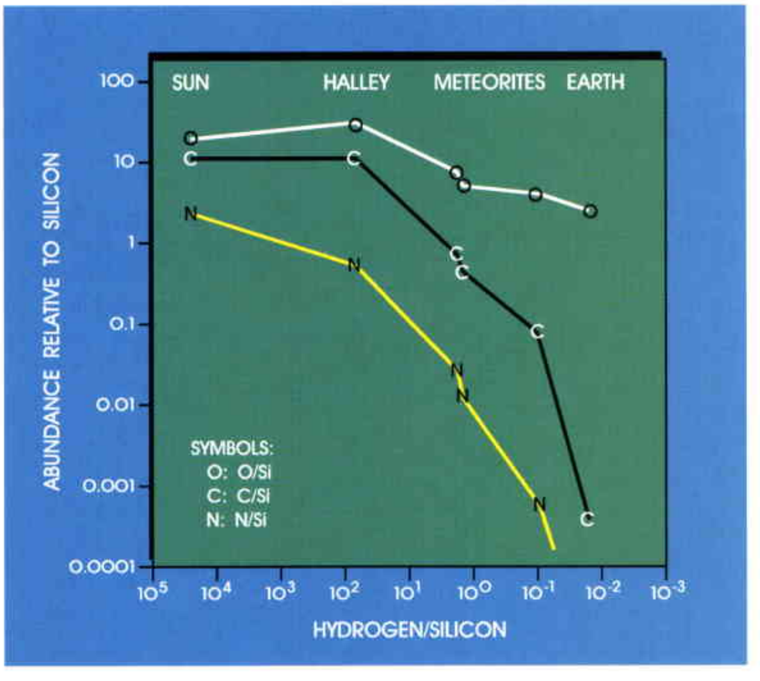


Figure 3. Chemical-element abundances in the Sun, CI-chondrites and Comet Halley

The Rosetta mission will make a detailed study of a comet lasting at least one year, from the onset of activity beyond 3 AU heliocentric distance through its perihelion (typically around 1 AU). On its long journey to the comet, it will pass close to one (or possibly two) main-belt asteroids.

The model payload

The model payload has been specified to focus on the scientific objectives as defined above. It can be subdivided into two major experiment groups:
- the Remote-Sensing Investigations, and
- the In-situ Investigations

for which the individual instruments and respective goals are listed in Tables 1 and 2.

The Science Team also considered additional instruments that would significantly increase the science return of the selected baseline mission, such as a Microwave Radiometer/

Table 1. Rosetta model payload

Nucleus Detection

Remote Imaging System

- Determine nucleus rotational state
- Detect and characterise active and inactive areas
- Determine variability of surface feature
- Characterise the topography of the nucleus
- Investigate surface morphology with resolution better than 1 m
- Characterise and monitor dust and gas jets
- Determine scale length associated with the outflow of material from the nucleus (dust acceleration)
- Determine shape and volume of the asteroid
- Determine the asteroid's rotational state
- Determine geomorphological features on the asteroid

Visible and IR Spectral and Thermal Mapper

- Characterise the nucleus surface in terms of concentration of ices, the mineralogical composition of dust and the characteristics of organic compounds
- Determine the surface temperature distribution, gas and dust distribution in the inner cometary coma
- Map the asteroid's surface mineralogical composition

Gas and Ion Mass-Spectrometer

- Elemental, molecular and isotopic composition of volatiles
- Temperature, density and bulk velocity field of gas and ions
- Homogenous and heterogenous reactions of gas and ions in dusty cometary coma
- Strength and distribution of gas activities on nucleus

Cometary Mass Analyser

- Elemental composition of individual dust particles (all elements)
- Isotopic composition of key elements (H, C, N, Mg, etc.) in individual dust particles
- Information on molecular composition, especially of the organic material

Scanning Electron Microprobe

- Size, shape, texture and morphology of individual dust grains
- Abundance of elements ($Z > 10$) in individual dust particles
- Mineralogy of individual grains

Dust Production Rate and Velocity Analyser

- Dust flux
- Dust size distribution
- Dust velocity

Plasma Package

- Investigation of the solar-wind/comet interaction is not a primary goal of the mission and the plasma package is limited to an Electron Density and Temperature Probe and a Solar Wind Flux Monitor.

Surface Science Package

- *Accelerometer:* Study during landing of the mechanical strength of the cometary crust and subsurface material
- *Permittivity Probe:* Measurement of electrical properties of cometary material close to surface, providing 'ground truth' for possible microwave experiments
- *Thermal and Evolved Gas Analyser:* Measurement in a pyrolysis cell of the thermal behaviour of cometary material and study with a gas chromatograph and/or a mass-spectrometer of the chemical nature of the evolved gases

The addition of a fluorination cell using the decomposition of K_2NiF_6KF as F source would allow δ170 and δ180 determination for the silicates and evolved gases.

Gamma-Ray Spectrometer: Determination of the major elemental composition (H, C, O, Si, Fe) of the cometary near-surface material. Instrument detects characteristic gamma-rays from capture of cosmic-ray-produced neutrons in elements. Volume probed $\approx 1\ cm^3$.

Alpha – Proton – X-Ray Spectrometer: Determination of abundance of light (C, N, O) and rock-forming elements (Mg, Al, Si, Ca, Fe) in cometary surface material. Instrument carries α's, protons from α, p reactions, and characteristic X-rays exited by α's. Surface area of several tens of cm^2 probed to a depth of about 10 micron.

Neutron Spectrometer: Determination of hydrogen concentration. Measures ratio of epithermal to thermal neutron flux for the cosmic-ray-produced neutrons. Probes to a depth of 0.5 to 1 m.

In-situ Imaging System: Study of characteristics of local surface (morphology, texture). Set of panoramic and monitoring cameras, some with fibre-optics systems. Resolution mm to about ten microns.

Spectrometer and a Microwave Mapper/ Sounder. However, these instruments have not been included in the baseline model payload, either because of possible constraints on mission design and mass budgets or because there is a certain amount of pre-development required to prove their technical readiness. However, the relatively long time scale for the implementation of the third Cornerstone makes significant technological advances very likely in the interim.

Mission analysis

During 1992, the Rosetta mission scenario underwent a considerable evolution as the mission had to be redefined from a comet-nucleus sample return to a mission that had to fit within the financial and technological envelope of a

Table 2. Rosetta science objectives and payload complement

- Global characterisation of the nucleus, determination of dynamic properties, surface morphology and composition, using:
  - Remote Imaging System
  - Vis and IR Mapping Spectrometer
- Chemical, mineralogical and isotopic compositions of volatiles and refractories in a cometary nucleus, using:
  - Neutral Gas and Ion Mass Spectrometer
  - Cometary Matter Analyser
  - Scanning Electron Microprobe
  - Surface Science Package
- Physical properties and interrelation of volatiles and refractories in a cometary nucleus, using:
  - Cometary Matter Analyser
  - Neutral Gas and Ion Mass-Spectrometer
  - Scanning Electron Microprobe
  - Dust Flux Analyser
  - Surface Science Package
- Study the development of cometary activity and the processes in the surface layer of the nucleus and in the inner coma (dust – gas interaction) using:
  - Neutral Gas and Ion Mass-Spectrometer
  - Surface Science Package
  - Cometary Matter Analyser
  - Scanning Electron Microprobe
- Origin of comets; relationship between cometary and interstellar material; and implications for the origin of the solar system, using:
  - Cometary Matter Analyser
  - Neutral Gas and Ion Mass Spectrometer
  - Scanning Electron Microprobe
  - Surface Science Package

'Cornerstone' in ESA's Scientific Programme. The technological constraints were set by:

- the use of solar power
- the use of an Ariane launch vehicle
- the use of ground stations belonging to ESA Member States.

First, various near-Earth asteroid- and comet-rendezvous and sample-return mission options were studied; in particular, missions to such objects as Oljato and 1979 VA alias P/Wilson-Harrington. The improved capabilities of solar-array technology at low temperatures and the enhanced capabilities of Ariane-5 (using a delayed ignition of the upper stage and utilising more complicated planetary gravity-assist tours) then turned out to enable ESA to perform a rendezvous mission to a 'true' comet with European technology. The spacecraft design study also indicated that such a mission was feasible within the financial limits.

Consequently, a comet-rendezvous mission with in-situ analysis of the material on the surface of the comet by means of a 'surface package' emerged as the new Rosetta baseline. It also became possible to include in the mission design fly-bys of one or two asteroids on the way to the comet.

Reachable targets for a comet rendezvous are those short-period comets with low inclination with respect to the ecliptic plane and perihelion radii near 1 AU. The aphelion radii of such objects are typically around 5.2 AU.

Table 3. Rosetta comet rendezvous opportunities for a launch in 2003/4

Rendezvous with comet	Asteroid fly-bys at	Type	Launch arrival perihelion (date)	Mission Δv (km/s)	Ariane-5 performance (kg)	Spacecraft at launch (kg)	Remarks
Schwassmann-Wachmann 3	Fennia 1985 QD1	VEE	2002/04/19 2009/12/31 2011/10/12	0.735	2708	1539	Early launch date
Wirtanen	Ministrobell Shipka	MEE	2003/01/22 2011/08/28 2013/10/21	1.490	2990	1948	
Schwassmann-Wachmann 3	Brita	ME	2003/07/18 2008/06/10 2011/10/12	1.924	2426	2232	98% tank filling
Finlay	1990 OK	MEE	2003/07/17 2013/09/05 2014/12/09	1.837	2597	2172	
du Toit-Hartley		VEE	2003/10/20 2012/11/05 2013/08/16	1.884	3504	2204	One or two fly-bys above tank filling
Wirtanen	1982 DX3 1983 AD	VEE	2003/11/03 2012/10/23 2013/10/21	1.327	2698	1850	Rendezvous at 2.92 AU
Haneda-Campos	Isis	VEE	2003/11/21 2013/06/23 2016/11/08	1.465	2571	1932	Two fly-bys above tank filling
Schwassmann-Wachmann 3	1990 TJ	VE	2003/11/29 2008/10/28 2011/10/12	1.930	2352	2236	98% tank filling
Finlay	1982 BB Lunacharsky	VEE	2004/05/11 2013/12/01 2014/12/09	1.073	2651	1709	Maximum sun distance 5.8 AU
Brooks 2	Carr 1983 WM	VEE	2004/05/25 2011/11/23 2014/05/23	1.740	2413	2106	Minimum sun distance 0.6 AU

Ariane-5's capabilities are insufficient either for direct missions or for missions using one Earth-gravity assist (delta-VEGA). Table 3 lists the comet-rendezvous mission opportunities that have been found for an Ariane-5 launch, using two or three gravity assists at Earth, Venus and Mars and with a launch in 2003 or 2004. In some of the cases, the Rosetta spacecraft may even be launched on an Ariane-44L. The duration from launch to comet rendezvous has been limited to 9 yr.

To maximise the mass at the comet rendezvous, both manoeuvres during the interplanetary cruise arcs and powered planetary swing-bys were admitted. Under these conditions only missions of the types VEGA (Venus–Earth gravity assist), VEEGA (Venus–Earth–Earth), MEGA (Mars–Earth) and MEEGA remained in the catalogue. In fact, the last gravity assist always turned out to be at Earth, preceded by a Venus or Mars fly-by or a Venus–Earth or Mars–Earth tour. For the shorter-duration types of mission (VEGA and MEGA), a large manoeuvre (i.e. involving more than 700 m/s) is necessary during the Earth fly-by, whereas the longer missions (VEEGA and MEEGA) may in some cases be possible without such a manoeuvre.

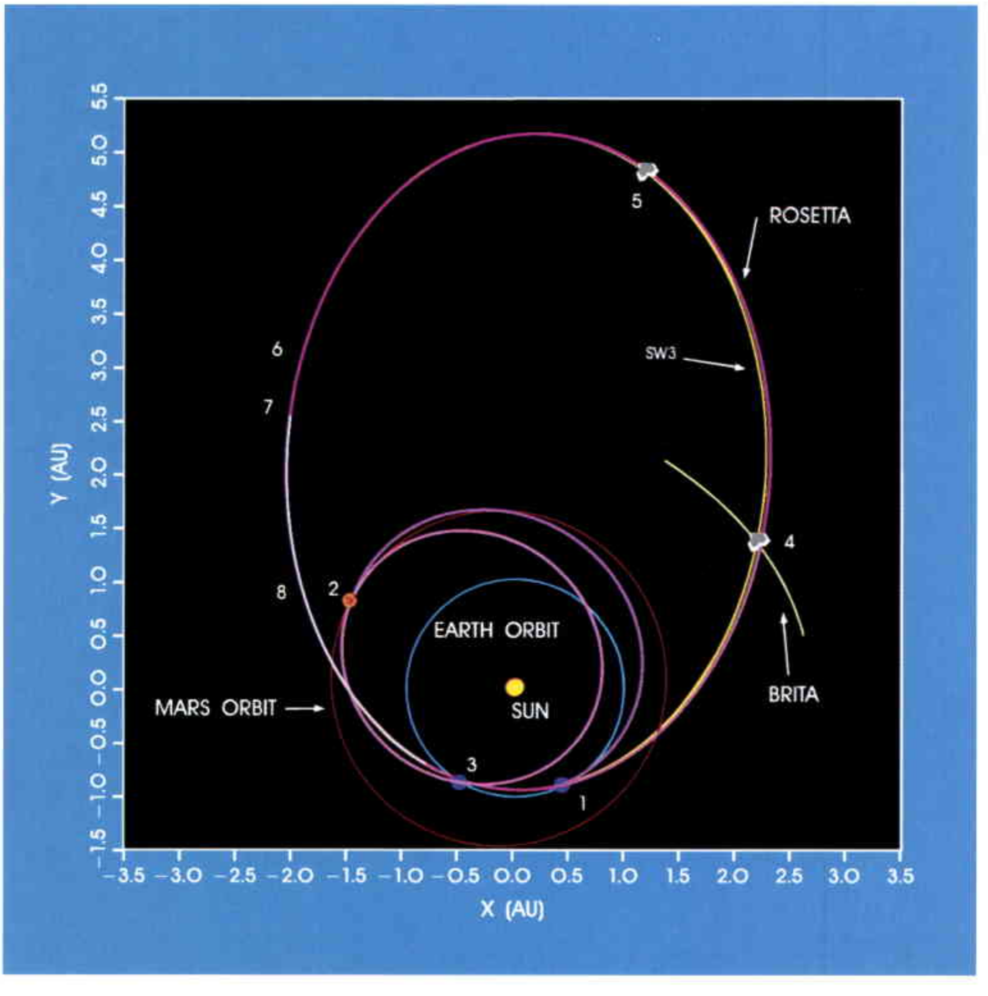


Figure 4. Ecliptic projection of the reference interplanetary orbit for a mission to Comet Schwassmann-Wachmann 3

Figure 4 shows the ecliptic projection of the interplanetary orbit for MEGA mission number 1 to Schwassmann-Wachmann 3. This mission, which has one of the shortest durations from launch to rendezvous, has been taken as a reference. The spacecraft has been designed to satisfy all conditions of possible mission scenarios, so typically the tank is sized for the baseline mission, and the thermal design has to cope with the Venus fly-by, etc.

The main events for the reference mission are:

1. Launch and Earth escape
2. Mars gravity assist
3. Earth gravity assist
4. Asteroid fly-by
5. Comet rendezvous
6. Comet approach and observation
7. Surface package delivery
8. Nucleus monitoring to perihelion.

Before arrival at the comet, the scientific instruments will only be operated during the asteroid fly-by and for checkout purposes. This means that mission operations will consist mainly of maintaining the spacecraft's health and achieving the right orbit.

To this end, several large orbit manoeuvres will have to be executed. In addition, small correction manoeuvres will be necessary immediately after departure from the Earth, before and after the planetary and asteroid fly-bys, and during the interplanetary cruise. Their size and direction depend on random errors and they will be calculated from the orbit determination by the ground operations system. The estimates have been derived by means of covariance-analysis methods. The estimated state variables are augmented by parameters to model coloured noise processes, e.g. due to radiation pressure, and considering systematic errors in the tracking system, e.g. station co-ordinate and ranging biases. The propellant statistics assumes that for larger corrections the spacecraft main engine is turned in the required direction.

The largest orbit correction will have to be carried out shortly after launch.

Other mission phases that require statistical orbit correction above the 1 m/s level are the planetary gravity assists and the asteroid fly-bys. In the reference case, the Mars fly-by is about 2.6 AU from Earth and so the orbit determination accuracy is worse than near Earth. Nevertheless, an accuracy of better than 20 km can be achieved at the fly-by pericentre, which is at an altitude of more than 2000 km, so that there is no risk of an impact on Mars.

The Earth fly-bys are not critical in terms of targeting accuracy, as the ground tracking provides an extremely precise orbit prediction. The orbit correction after the Earth fly-by in the reference case requires 12 m/s, which is mainly due to the execution error of the large manoeuvre at the fly-by (727 m/s).

The navigation process during the planetary fly-bys is assumed to rely on conventional tracking only. The fly-by accuracies could be enhanced by means of optical navigation, i.e. by using images of Phobos or the Moon with respect to the star background to locate the spacecraft with respect to the target planet.

Asteroid fly-bys

The sample asteroid fly-by of (1071) Brita in the reference mission will be at a distance of 2.52 AU from the Sun, the fly-by velocity will be 15.8 km/s and the Sun/asteroid/spacecraft (illumination) angle during approach will be 16.7°.

The fly-by geometry has been chosen such that the spacecraft passes the asteroid on the sunward side with a minimum distance of 500 km. This is the closest distance from which the body-mounted science instruments can observe the asteroid continuously, given the maximum rotation rate of the spacecraft and the fly-by velocity of 16 km/s.

Comet detection and approach

In the previous Rosetta (sample-return) mission scenario, quick execution of approach, mapping, sampling and departure was mandatory, so that the return-to-Earth opportunity would not be missed. The new mission is designed to ensure that the spacecraft stays with the comet at least until the perihelion passage. In addition, the current solar-array sizing does not allow the full payload to be operated at a distance of more than 4.4 AU from the Sun, although detection operations may start at a distance of as much as 4.85 AU from the Sun. Critical near-nucleus operations, which require the support of two ground stations, cannot commence before the communications distance falls below 3.25 AU, because only one European ground station (Weilheim) is capable of communicating with the spacecraft at a distance greater than that. Consequently, the approach operations may have to be delayed. This has led to the introduction of a long drift phase (700 days in the reference mission) from the deep-space manoeuvre that globally matches the start of the comet approach with cometary orbit conditions. Typically, the final conditions of the drift phase will be chosen such that at a distance of about 500 000 km the spacecraft will approach the comet at a relative velocity of about 100 m/s, with a bias of the orbit towards the Sun (100 000 km) to obtain good illumination of the nucleus.

At execution of the major deep-space orbit manoeuvre, the cometary ephemeris is known from ground-based astrometry only. Comet detection by one of the spacecraft cameras, under reference-mission viewing conditions, might be possible from several million kilometres, as the comet reaches magnitude 12 at about 3×10^6 km. Nevertheless, the nominal detection operations will not start before the spacecraft reaches a distance of 500 000 km from the comet.

At this distance, the field of view of the narrow-angle camera (3.5°×3.5°) will easily cover the cometary ephemeris-error ellipsoid (less than 10 000 km) and the image of the comet nucleus will still be smaller than the area of a single pixel. After detection, knowledge of the comet ephemeris will be drastically improved by the inclusion of the on-board observations in the orbit-determination process.

During the approach, from a distance of 500 000 km to a distance of between 500 km and 50 km from the comet (50 nucleus radii), a manoeuvre strategy will be implemented to:
- progressively reduce the relative velocity
- retain an apparent motion of the comet with respect to the star background, at least as long as the nucleus has not been detected
- retain the illumination angle (Sun/comet/spacecraft) below 70°
- avoid the danger of an impact with the nucleus in failure cases, i.e. limit the effect of manoeuvre execution errors.

The approach manoeuvre sequence will be implemented as planned, even if the comet is not immediately detected by the narrow-angle camera. The wide-angle camera (nucleus tracker), which is primarily designed for near-nucleus operations (within about 50 km), can be used for nucleus detection from ranges of about 100 000 km.

When the comet nucleus extends over several pixels in the image of the narrow-angle camera, its spin-axis orientation and possible motion

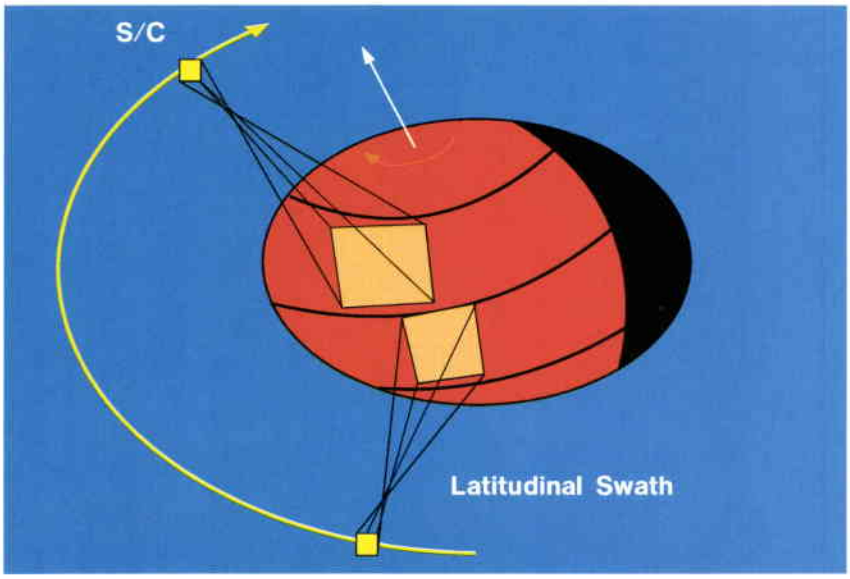


Figure 5. Schematic of the mapping strategy for a fast-spinning small nucleus

(tumbling) and the spin rate and phase will be determined. Later, when the comet image increases, more detailed and accurate kinematic properties, such as spin-axis orientation and rotation period, will be determined.

The first series of mapping images will be obtained towards the end of the approach phase, when the comet extends over 500×500 pixels in the narrow-angle camera. From these images, a better estimate of the comet nucleus's rotational state, including nutations, can be derived. Moreover, accurate knowledge of the relative motion of the spacecraft will be obtained from observing directions of landmarks against directions of stars in the background. The gravitational constant becomes detectable at about the same distance (100 to 50 nucleus radii).

Mapping and surface package delivery

In spite of the low gravity, it will be possible to orbit the nucleus. Simulations show that orbits can be chosen which remain stable over hundreds of days, even when the 'sphere of influence' shrinks to 7 km, for a 'small' comet with a mean radius of 1 km, approaching its perihelion. Moreover, even in the gravity field of a nucleus of extremely irregular shape, quite close orbits that do not encounter the body can be constructed.

Remote observations of the surface of the nucleus will be performed in two stages. First, the illuminated surface will be mapped to a resolution of better than 2000 pixels across the comet, corresponding to 100 m, in the visible and infrared spectrum. Then, typically, the spacecraft will pass over five selected areas on the surface at altitudes below one nucleus radius. (A range of mean radii from 1 km to 10 km has been studied.)

Mapping will be performed from elliptic polar orbits, the apocentre of which is chosen to lie near the equator. This reduces oversampling of the polar regions and simplifies the transfers from and to the mapping orbit. It has also been found to be advantageous for the navigation process based on viewing landmarks on the surface. The orbital period will usually be greater than the spin period, which means that, unlike the case of Earth observation, horizontal swaths will cover the surface (Fig. 5). Usually, it will be possible to map the whole surface during half a revolution. The semi-major axis of the orbit will be chosen as a function of comet gravity and spin rate, taking into account the following constraints:

- coverage without gaps
- safety, i.e. proximity to an irregular surface
- volume of data, especially for real-time transmission
- time limit to complete the required coverage and orbit stability
- resolution and viewing angle to surface normal
- continuous communications to Earth.

In the case of slowly rotating or non-rotating comets, it becomes necessary to use more than one revolution in the same orbit with camera slewing (large comet), or more than one orbit by means of plane-change manoeuvres (small comet).

On the basis of the mapping data and the other remote-observation data, some five areas (500 m×500 m) on the cometary surface will be selected for 'close observation', over which the spacecraft will fly as low as possible. The lower altitude limit will be set by the navigational accuracy and by shape and surface-topology constraints, but fly-over altitudes of one mean nucleus radius appear feasible.

Manoeuvre strategies have been devised for sequences of close-observation orbits over different surface points, taking into account:
- continuous illumination of solar arrays
- uninterrupted communications
- safe orbits (no encounter with nucleus in failure cases; not possible, for long time intervals, around a highly nonspherical nucleus)
- illuminated observed area, and a viewing angle (to the local surface normal) below 30°
- avoidance of debris and gas and dust jets.

Surface package delivery will be from an eccentric orbit (pericentre altitude as low as possible, e.g. 1 km) with a pericentre passage near the desired landing site. The time and direction of separation have to be chosen such that the package arrives with minimum vertical and horizontal velocities relative to the local (rotating) surface. The attitude of the spinning device at separation should also be aligned to the surface normal expected at impact, if possible. A spin-eject mechanism will separate the surface package from the spacecraft with a relative velocity of less than 2 m/s.

Several scenarios, including active, autonomous control at separation or at impact, have been studied but a passive scenario is preferred. Damping at impact will be necessary to reduce the rebound, which could lead to the surface package escaping the comet's gravity field. In the selected design, the surface package is still expected to rebound and come to rest as much as several hundred metres from the initial impact point. Prediction of the final 'landing site' may thus be difficult and the package's final attitude cannot be guaranteed, so the design will have to cope with 'topple-over' situations.

The Rosetta spacecraft

The spacecraft's design, based on an existing 'Eurostar' telecommunications satellite platform, is very well suited to the requirements of the proposed potential mission scenarios in terms of allowable mass at launch and tankage capabilities.

The configuration of the spacecraft, with a typical example of a surface Probe attached, is shown in Figure 6. The model spacecraft's dry mass is 1035 kg, and its launch mass for the reference mission to Comet Schwassmann-Wachmann 3 is 2245 kg, including the launch adapter. The corresponding launch margin is 180 kg for the reference mission. For the alternative mission options, this launch margin varies between 90 kg and more than 1000 kg.

As the mission-analysis discussion in the preceding section shows, a wide range of relative Sun/spacecraft/comet, Sun/spacecraft/Earth and Target/spacecraft/Earth angles will be experienced during the mission. The only way to avoid complex sequential operations is to consider a spacecraft with solar arrays, directional

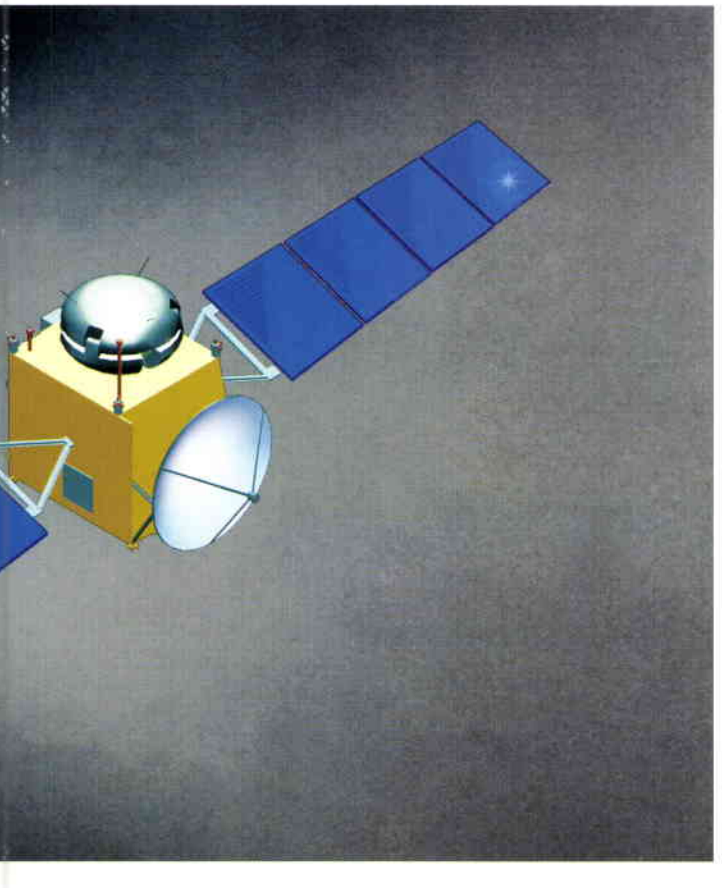


Figure 6. The Rosetta spacecraft configuration

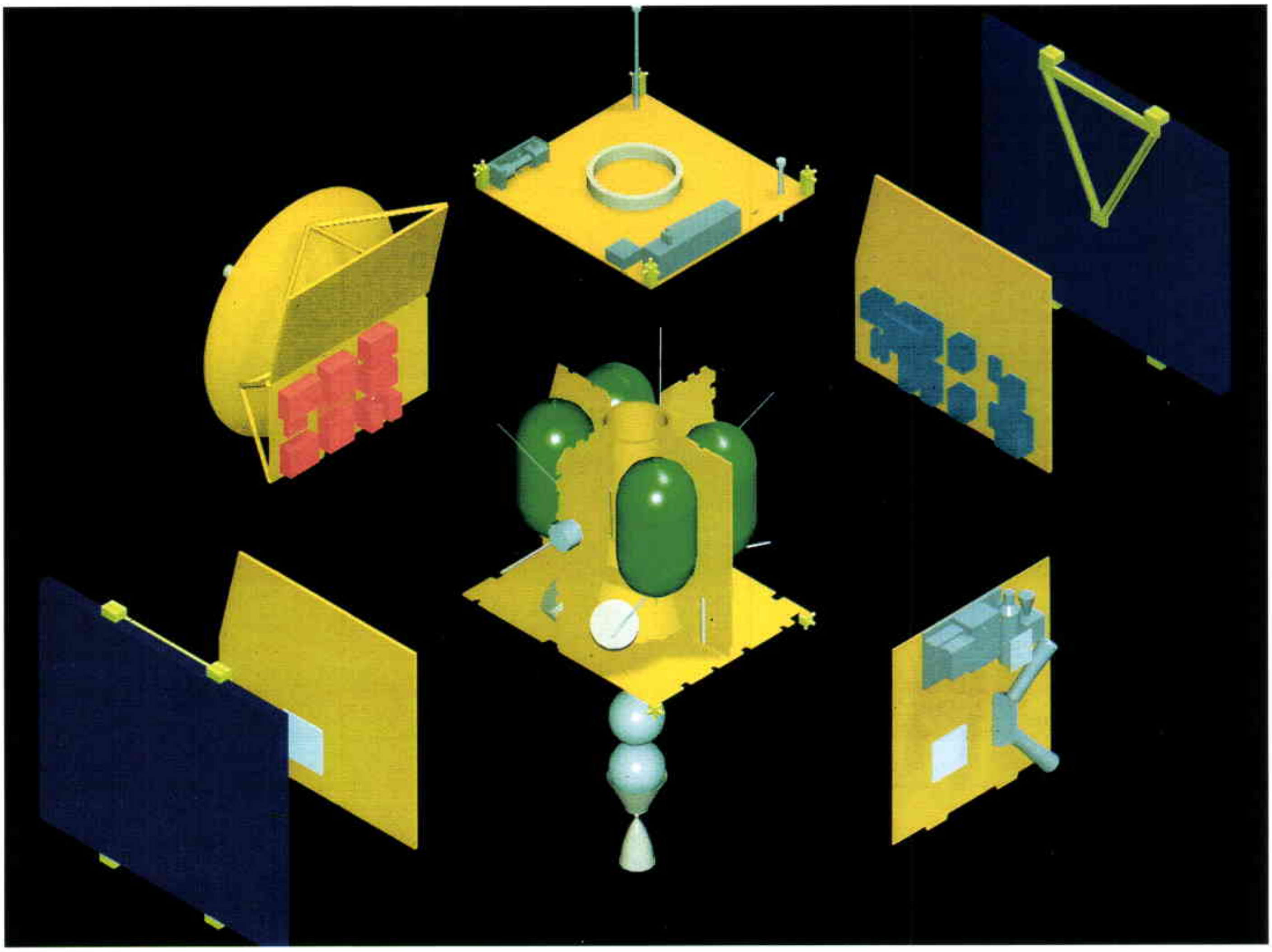


Figure 7. Exploded view of the Rosetta spacecraft

antennas and scientific sensors that can be pointed in different directions independently of one another. The solution retained for Rosetta is to have a one-axis-gimballed steerable solar array, a two-axis-gimballed steerable high-gain antenna, and body-mounted instruments for science and spacecraft navigation.

The specific accommodation of instruments and equipment within the spacecraft results from the adoption of a modular approach aimed at simplifying development, integration and testing. One of the spacecraft's side walls and its upper wall are devoted to the science payload, while the other side walls are each devoted to a single subsystem, as shown in the exploded view (Fig. 7).

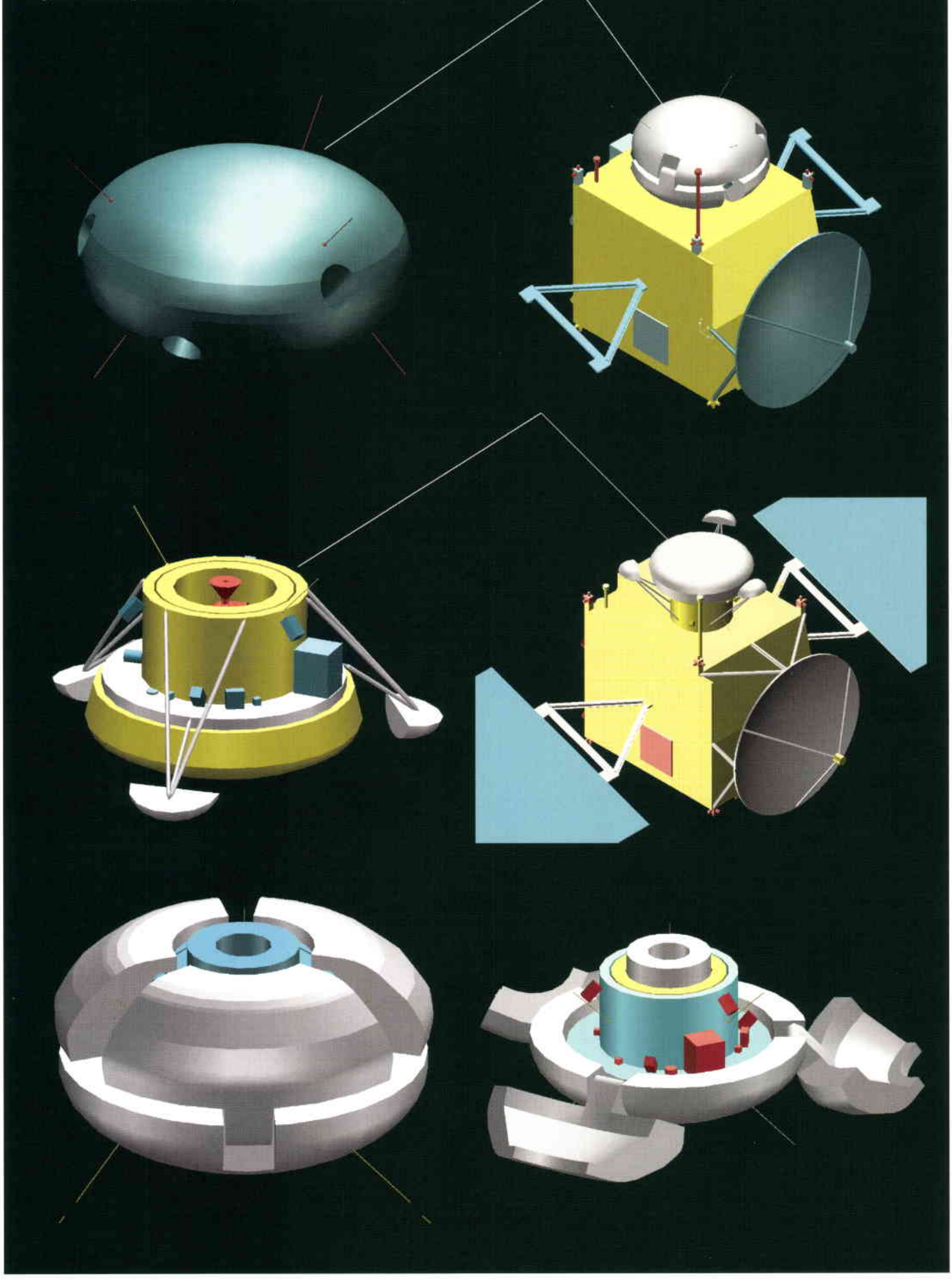
Despite the wide range of solar fluxes, mission phases and solar-aspect angles with which Rosetta will have to cope, a very simple thermal design is possible. This will be achieved by using passive insulation, by means of multi-layer insulation and black paint, and the use of electrical heaters. For communication, Rosetta relies on a combined S/X-band system, with an S-band telecommand uplink and an X-band telemetry and science-data downlink.

For the critical phase after separation from the launcher, a downlink capability via the omni-coverage low-gain antenna is provided. A steerable 2 m-diameter parabolic dish will allow command reception and high-rate science-data transmission to Earth, and a combination of a medium-gain antenna and a pair of low-gain antennas will serve as a back-up for emergency commanding and low-rate telemetry when the high-gain antenna cannot be used.

Five different downlink telemetry rates can be selected based on the distance between the spacecraft and the Earth, and on the capabilities of the ground station, which in the all-ESA baseline scenario will be either the GSOC Weilheim station (30 m dish) or ESA's Perth and Villafranca stations (15 m dishes).

Rosetta's data-handling system has to provide the link between the onboard instruments and the ground, and to configure and control all the subsystems in accordance with the mission constraints and prevailing real-time environment. Autonomous data-handling is required because of:
– the communication delays for the time-

Figure 8. Some possible configurations for the surface Probe



critical operations in all mission phases, during which quasi-real-time closed-loop control via the ground is excluded
- the long periods without ground contact, e.g. one ground contact every two weeks (baseline) to minimise operations costs during the quiet cruise phase
- the need to keep the high-gain antenna pointed towards the Earth during mission phases occurring at an intermediate distance from Earth, i.e. more than 1 AU, when the low-gain antennas can no longer receive commands from Earth, and less than 2.5 AU, when the Earth and the Sun are not yet simultaneously in the field of view of the medium-gain antenna.

Rosetta's power is provided by a 48 m^2 two-wing solar array, with four panels per wing, which provides 472 W at a distance of 5.2 AU from the Sun. Two 7 Ah nickel-cadmium batteries provide energy storage and satisfy peak power demands.

The surface Probe

The surface Probe is a multi-sensor Principal Investigator instrument designed for in-situ analysis of the cometary surface over a period of several tens of hours. It is to be deployed from the Rosetta spacecraft at the end of the observation phase.

The basic concept for the Probe's flight phase between ejection from Rosetta and impact on the comet surface is that of a spinning, unguided ballistic body. The flight duration and the conditions at impact are strongly dependent on the Probe's ejection altitude and the comet's gravity. The physical size of the capsule is limited by the allowable mounting area on the spacecraft, the fields of view of the other scientific instruments, and the space required for communications antennas and attitude thrusters, rather than by the space inside the launcher fairing (4.5 m diameter).

The Probe's shape is governed mainly by the landing dynamics. Two main alternatives can be envisaged: active or passive landing scenarios. The two scenarios actually differ only in the design of the shock-absorber/stabiliser concept, but both can be built around the same Probe primary structure, and can accommodate the same sensors and equipment, except for communication antennas.

The Probe's primary structure consists of a cylinder supporting the spacecraft's separation interface and some sensors (such as the cameras of the in-situ imaging system) and a circular plate supporting all the items of equipment. In support of the surface-science package instruments, the Probe equipment comprises four lithium/sulphur-dioxide primary batteries (800 Wh), a control unit common to all the equipment items and science sensors, a power distribution unit, and a VHF-band communications package for data transmission. The total weight of support equipment is 15 kg, including margins.

For simplicity, there is no telecommanding foreseen between Rosetta and the Probe on the surface, the single link being the science data transmission at 0.2 kbit/s from surface to spacecraft.

Owing to the Probe's spin during the descent flight, its attitude with respect to the comet's surface at first impact can be determined with good accuracy, but it will not be predictable for the following impacts. The Probe will therefore have to be covered with impact-damping material, preferably comprising several layers with different damping properties, external layers being used to absorb small shocks, and internal layers to absorb larger shocks (Fig. 8).

A simple way to avoid the Probe rebounding after the first impact would be to open a press-down thruster as soon as ground contact is detected. A single 50 N thruster operating for 10 s would be sufficient to stabilise the Probe on the surface. This concept offers the advantage of ensuring a top-down Probe attitude for science observations, and allows a wide field of view free of any obstacles for instruments (Fig. 8).

Three legs could be used to enlarge the base area so as to prevent any tip-over at impact in the event of encountering an unexpected obstacle.

Compared with the purely passive concept, the mass increase due to the stabilisation system is fully compensated for by the potential mass saving on the damping device, which is then required to operate in only one direction.

The Probe design elements presented here are just some of the many possibilities, which might eventually include penetrators or smaller stations with fewer sensors that could even be operated for several months on the cometary surface.

Following the successful mission and return of the European Retrievable Carrier and its instruments to Europe, the EURECA Project at ESA is planning to hold a

EURECA Symposium

at which the technical and operational achievements of Europe's largest and first reusable spacecraft will be presented by the project team, the operations team and by representatives of the industrial consortium. The discussions will include a summary of the scientific accomplishments of the mission, as well as first results of the post-flight investigations currently underway at various laboratories and companies, where scientists and engineers are taking advantage of the unique opportunity to examine an entire spacecraft after 11 months in orbit.

The Symposium will cover aspects such as

- specific EURECA design features
- the performance in orbit
- the mission preparation and ground control
- cooperation with NASA (shuttle deployment/retrieval)
- the payload integration and operations, etc.

Emphasis will be on experience gained and the lessons learned for the benefit of future missions and spacecrafts.

27 - 29 April 1994
ESTEC Noordwijk (The Netherlands)

For further information, please contact:

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Figure 1. The Cassini spacecraft's trajectory

Huygens
– A Technical and Programmatic Overview

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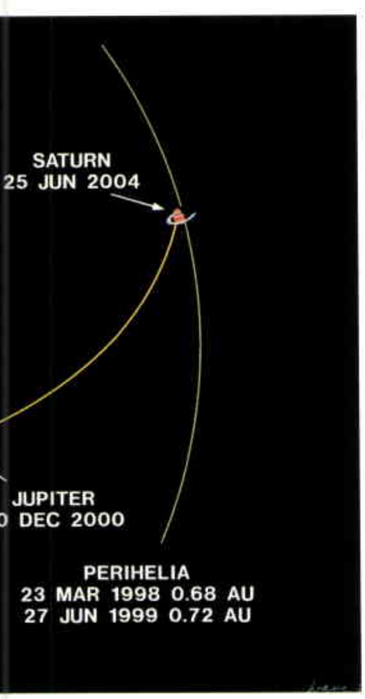
Huygens is the ESA-provided element of Cassini/Huygens, the joint NASA/ESA planetary mission to the Saturnian System. Titan, the largest moon of Saturn, is a major target of the mission. The Saturn Orbiter is to be provided by NASA, with a significant contribution from the Italian Space Agency under a bilateral NASA/ASI agreement. The spacecraft will be launched in October 1997, with Huygens attached to the Saturn Orbiter. Released from the mother spacecraft after a seven-year-long interplanetary journey to Saturn, the Huygens Probe will plunge into Titan in late 2004. Huygens is designed to enter and brake in Titan's atmosphere in order to parachute a fully-instrumented robotic laboratory down to its surface.

From the scientific viewpoint, the main Huygens mission phase, which is designed to last 2 to 2.5 hours, will be the parachute descent through Titan's atmosphere. Scientific measurements will also be performed during the entry phase, which will last just a few minutes. The Probe resources are sized to allow scientific measurements even after it has impacted on Titan's surface for at least a few minutes. The Probe's radio link will be activated early in the descent phase and the data will be relayed to the Cassini Orbiter for on-board storage and subsequent transmission to Earth.



Historical backgound

In October 1997, an American robotic spacecraft will begin a journey of many years to the vast and exciting realm of Saturn. With a dry mass of roughly 2500 kg (5510 lb) and carrying 3000 kg (6615 lb) of propellant, it needs a boost from the Titan-IV launch vehicle and several planetary gravity assists (Fig. 1). Both are needed if Cassini is to reach Saturn with sufficient propellant to brake into orbit around the planet and accomplish its mission: to deliver the ESA Probe to the large, hazy moon Titan, and then tour the Saturnian system for nearly four years.

The Cassini mission is being undertaken by NASA and ESA and is named in honour of the French-Italian astronomer Jean Dominique Cassini, who discovered the prominent gap in Saturn's main rings (now called the 'Cassini Division'), as well as the icy moons Iapetus, Rhea, Tethys and Dione.

The Probe that Cassini will deliver to Titan is named after the Dutch scientist Christian Huygens. Using improved telescope optics, he found in 1659 that the strange 'arms' noted decades earlier by Galileo were actually a set of rings. Whilst observing Saturn, Huygens also discovered the moon Titan, and hence the choice of his name for the ESA Probe.

During its descent, and possibly for a short time once it reaches Titan's surface, Huygens will beam data to the Orbiter spacecraft for storage and subsequent relay to Earth. Once these valuable data have been safely received on Earth, the Orbiter will begin using its three dozen scientific sensors intensively to examine the vast Saturn system.

In June 1982, the Space Science Committee of the European Science Foundation and the Space Science Board of the National Academy of Sciences of the USA set up a Joint Working Group (JWG) to study possible cooperation between Europe and the USA in the area of planetary science. One of the potential cooperative missions recommended by the JWG was a Saturn Orbiter and Titan Probe mission.

A joint ESA/NASA Assessment Study of such a mission was conducted in mid-1984/85. In February 1986, the ESA Science Programme Committee (SPC) approved Cassini for a Phase-A study, with a conditional start in 1987. During the course of 1986, the outlook for a timely mission with NASA materialised and, upon recommendation by ESA's Space Science Advisory Committee (SSAC), in November 1986 the SPC approved the ESA Executive's proposal to proceed with a Phase-A study for the Cassini Titan Probe. This study was subsequently carried out by a European industrial consortium led by Marconi Space Systems, from November 1987 to September 1988.

Following the completion of the Phase-A study, NASA and ESA simultaneously released coordinated Announcements of Opportunity in October 1989, which called for proposals for investigations using the Saturn Orbiter and/or the Huygens Probe.

The ESA Announcement of Opportunity solicited two types of proposals:
(i) Principal Investigator (PI) instruments, and
(ii) Interdisciplinary Scientist investigations (IDS).

ESA received 20 PI-instrument proposals and eight IDS proposals. The ESA Huygens selection, which comprises six PI-instruments and three IDS investigations, was announced in September 1990 (Fig. 2).

The tight Huygens project schedule required an early Phase-B start, in January 1991, which implied that the preparatory Phase-B activities had to be initiated in early 1990; in particular, the Invitation to Tender was due to be released to Industry in April 1990, well before the payload was selected. Special efforts were therefore required to coordinate the payload-selection activities with the early Phase-B proposal preparation. The competing industrial Prime Contractors were invited to technically evaluate the proposed experiments, which resulted in an early definition of the payload interfaces.

The Phase-B study started in January 1991 with Aerospatiale, the winning Prime Contractor, taking the lead role. Initially, the Phase-B was planned to last 12 months, but due to a change in the Cassini schedule the launch date was postponed from April 1996 to October 1997. Consequently, the Huygens Probe Phase-B was extended by 13 months in order to take advantage of the increased time available. This resulted in a cost increase, but also provided a highly desirable opportunity for the design to mature before the start of Phase-C/D, the main development phase.

The overall schedule is presented in Figure 3.

At the time of writing, the project has successfully carried out three major system-level reviews:
– a System Requirements Review (SRR), in April 1991
– a Preliminary Design Review (PDR), in February 1992, and
– a System Design Review (SDR), in October 1992.

The Phase-C/D was started in May 1993 and the Prime Contract was signed in September 1993.

Technical and programmatic challenges

The Huygens Probe is ESA's first planetary atmospheric entry mission and some of the technologies required are very different from those needed for more traditional satellite missions. This presents a considerable challenge both to the Agency and to European Industry. Special systems such as the Thermal Protection System (TPS) and parachutes have to be developed specifically for the entry into Titan's atmosphere. These factors and ESA's geographical-return requirements presented special management problems which had to be solved in order to achieve the prescribed objectives.

The Industrial Team was finalised at the end of Phase-B. As Figure 4 shows, it represents a very broad spectrum of European space industry. The technical and programmatic

Figure 2. Instruments selected for the Huygens Probe

PI Instruments	Mass (kg)	Power (c/o during cruise) (W)	Energy (during descent) (Wh)	Data Volume during Descent 120–150 min (Mbits)	Data Rate on Surface (bps)
Huygens Atmospheric Structure Instrument (HASI)	6.7	20	41	4.1/5.1	625
Gas Chromatograph & Mass Spectrometer (GCMS)	19.5	44.5	110	6.5/8.1	900
Aerosol Collector and Pyrolyser (ACP)	6.7	13.3 (71.5)	55	0.8/1.0	120
Descent Imager/Spectral Radiometer (DISR)	8.5	31	46	31.5/40.0	4250
Doppler Wind Experiment (DWE)	2.1	15	25	0.07/0.09 2.8/3.6	10
Surface Science Package (SSP)	4.2	15	26	3.5/4.1	660

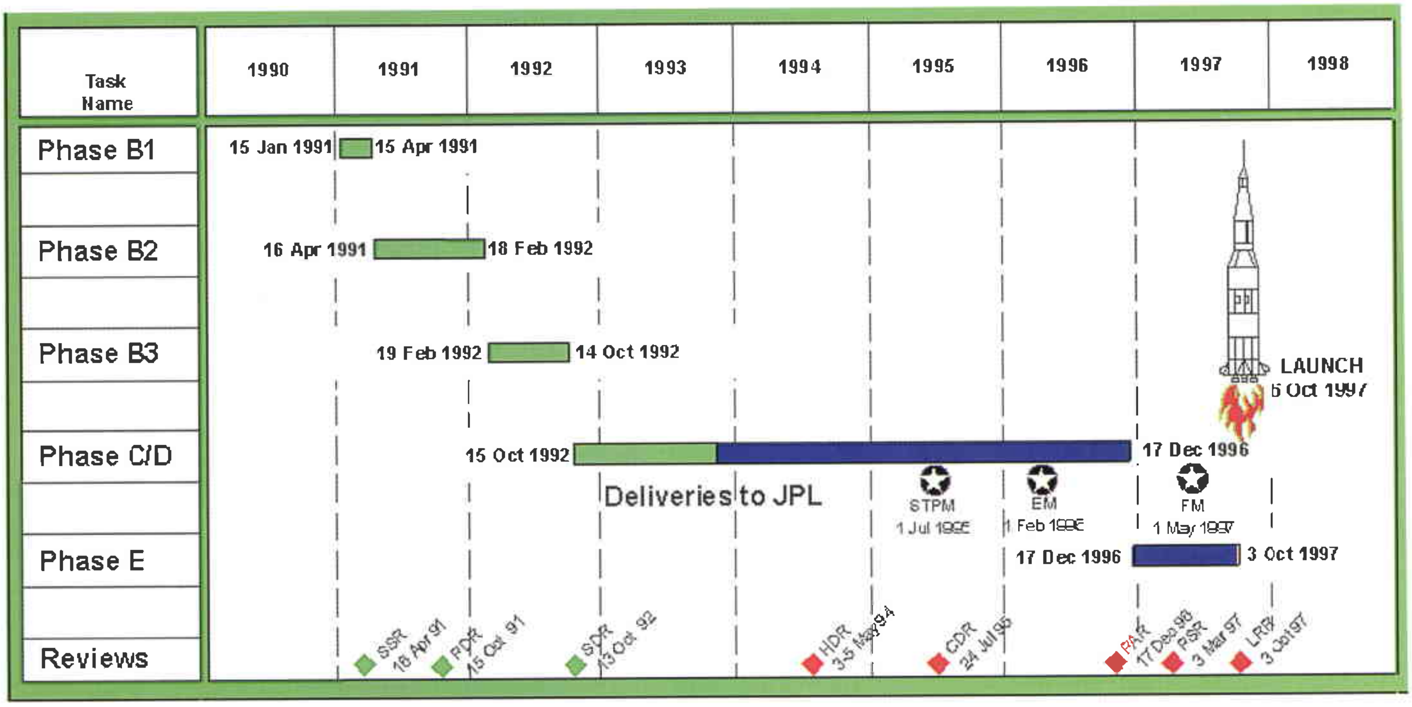


Figure 3. Pre-launch mission schedule

status of the project, including the experiments remains satisfactory, although by its special nature the future development effort will require extra vigilance on the part of the Agency and Industry. In addition, the Huygens/Cassini interface has to be worked on intensively with NASA/JPL, which also represents a formidable challenge as both projects are being developed in parallel.

The Huygens Probe System and its mission
The Huygens Probe System consists of the Probe itself and the Probe Support Equipment (PSE). The Probe will descend onto Titan while the PSE remains attached to the orbiting Cassini spacecraft. The PSE consists of the electronics necessary to track and recover data from the Probe during its descent and to process this data for delivery to the Orbiter, from where it will ultimately be downlinked to the ground. The PSE also provides a command and data link to the Probe whilst the latter is attached to the Orbiter.

Following its launch in 1997, the Probe System will remain in a dormant state for the next seven years as it follows its cruise trajectory via Venus, Earth and Jupiter, before finally entering the Saturnian system in 2004, dormant that is except for its scheduled bi-annual health checks. These checkouts will follow the pre-programmed descent-scenario sequences as closely as possible and the results will be relayed to Earth for examination by Probe system and payload experts.

On reaching Saturn, the Cassini spacecraft will enter a highly eccentric capture orbit around the planet (Fig. 5). About 100 days after this

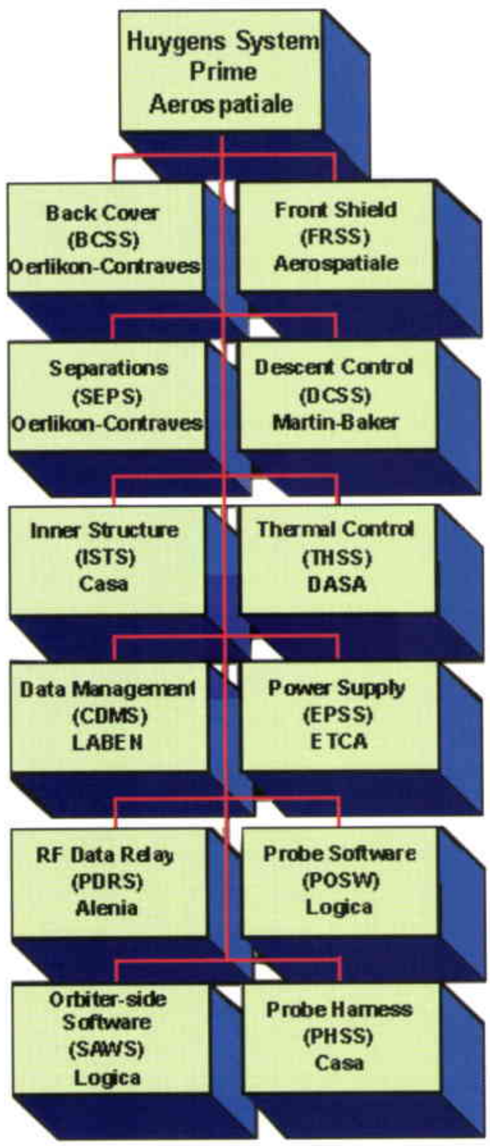


Figure 4. The Huygens Industrial Team

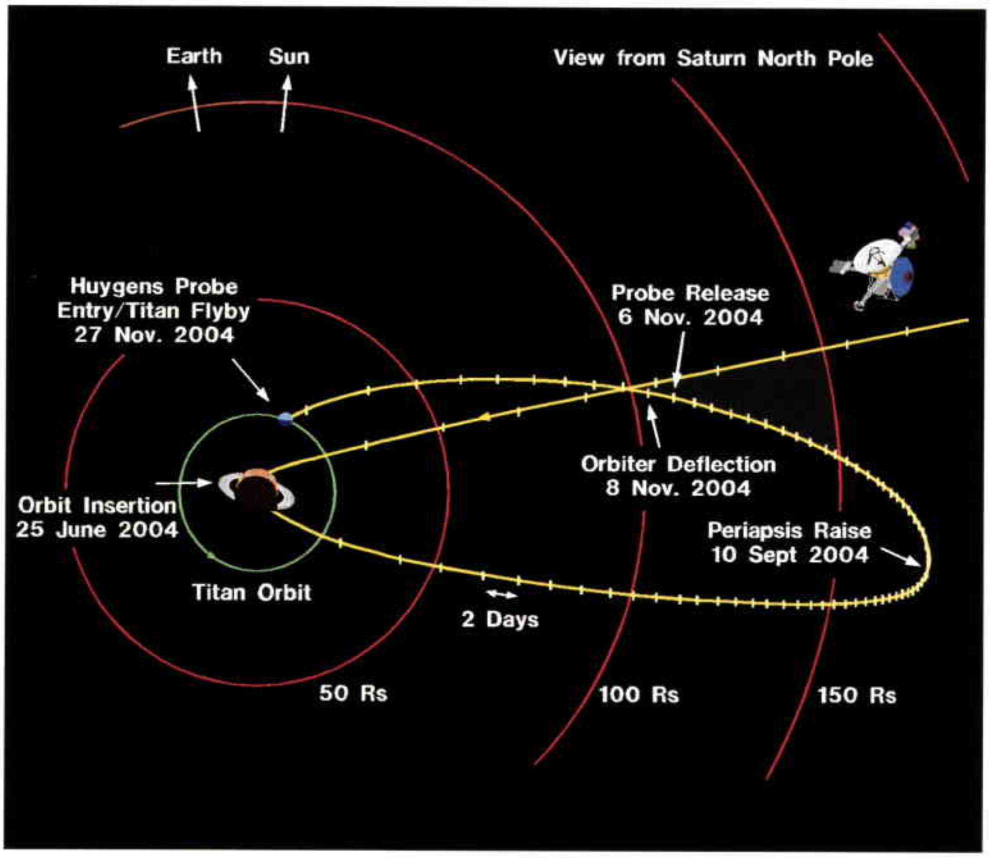


Figure 5. The Saturn orbit

event, a trajectory-correction manoeuvre will be initiated to raise the periapsis and target Cassini for its encounter with Titan. About 22 days before Titan encounter – and 60 days after the trajectory-correction manoeuvre – the Probe will be spun up and released from the Orbiter. Two days later, the Orbiter will initiate a deflection manoeuvre to avoid Titan and optimise its position for the acquisition of Probe data during its descent.

Prior to the Probe's separation from the Orbiter, a final health check will be performed and the coast timer will be loaded with the precise time necessary to 'wake up' the Probe systems 15 minutes prior to encountering Titan's atmosphere. For the next 22 days the Probe will simply coast to Titan with no changes imposed on the attitude parameters acquired at separation and with no systems active except for its wake-up coast timer.

At the end of its 22-day coast period, the Probe will be switched on via its triple-redundant coast-phase timer. After system initialisation, the payload instruments will be activated in a pre-programmed sequence; broadcast data will be distributed to the instruments, containing such information as spin rate, time, temperature, altitude and special-event flags, whilst on the other side scientific data will be collected and packetised for relay back to the Orbiter.

The mechanical system

The Huygens mechanical system consists of two major parts, namely the outer 'shell', consisting of a front shield and back cover which protects the Probe from the high heat fluxes that it will encounter during Titan atmosphere entry, and the inner descent module which will carry the experiment complement through the cold Titan atmosphere. Since the Probe is carried to its destination by the Cassini Orbiter, the interface between these two spacecraft is also very important.

During launch and subsequent cruise phase, the Probe will be attached to the Orbiter. This combined configuration can be seen in Figure 6. The launch phase is mainly a design driver for the interface fittings. The cruise phase following launch has a duration of 7 years, which is a driver for part of the thermal design since the Probe has to go from a very hot environment at the Venus flyby to a very cold one at the interplanetary distances. The mechanical system is also dormant during this long cruise period.

However, close to Titan, after the spacecraft has flown through the rings of Saturn, the Probe will be released from the Orbiter and will coast for 22 days before entering Titan's atmosphere. The approach velocity of the Probe will be 6 km/s and hitting the moon's atmosphere at this speed will produce the most dramatic environment of the entire mission for the mechanical system! This entry phase will last about 3 minutes, during which the Probe's velocity will fall to around 400 m/s. The Probe's impact on Titan's atmosphere (mostly nitrogen, with some methane and argon) will cause a shock wave to form in front of the 2.7 m-diameter front shield. The plasma in the shock, just forward of the shield, will reach a temperature of around 12 000°C. Simultaneously, the deceleration force on the Probe will reach its maximum of around 16 g. This high temperature and deceleration level is a design driver for most of the structure.

At the end of this entry phase, a sequence of mechanical events will be triggered which are probably the most critical of the entire mission. When the on-board accelerometers detect a velocity of Mach 1.5 near the end of the deceleration phase, a command will be sent that causes the pilot chute to deploy. This will be followed immediately by release of the back cover and then deployment of the main parachute. During a period of about 30 seconds, the Probe's velocity will fall from Mach 1.5 to Mach 0.6. The front shield will then be released and the descent module will descend slowly below the main parachute for about 15 minutes while initial scientific measurements are made. Thereafter, the main parachute will separate from the Probe and release a smaller stabiliser chute, causing the Probe to descend faster.

The total descent time from deployment of the first parachute at some 170 km above the Titan surface will be 2.5 hours. Following the impact on Titan's surface at a velocity of around 8 m/s, there will be a chance to perform some limited surface-science measurements, assuming that the Probe survives the impact.

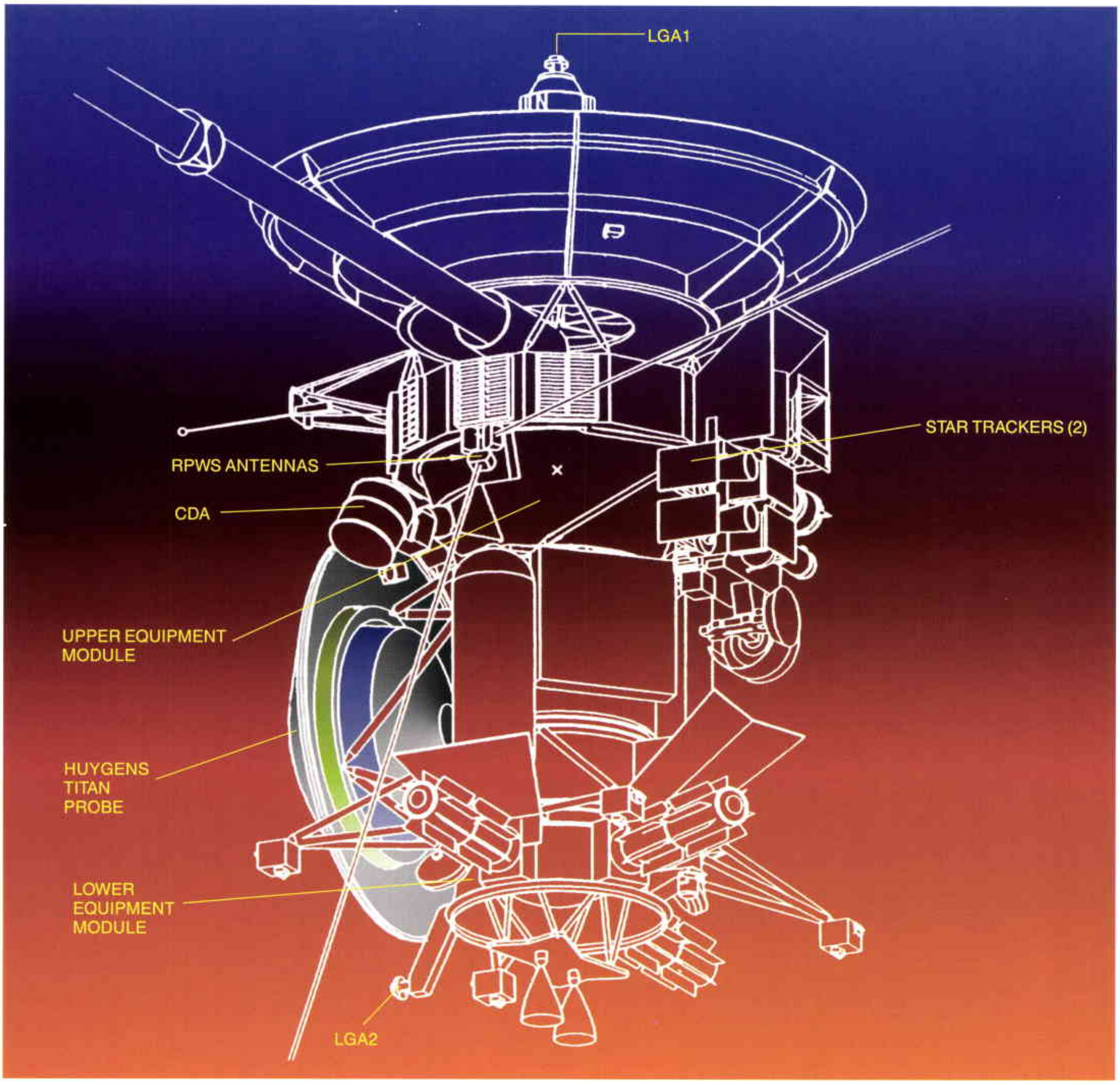
The mechanical subsystems

Mechanisms

The Probe mechanism subsystem consists of three interface fittings, connected together by a ring of 1.9 m outside diameter, carrying a spin-and-eject device and front-shield and back-cover release mechanisms.

During launch and through all mission phases until in the vicinity of Titan, the Probe will remain clamped to the Orbiter by pyrotechnic release bolts that bypass the spin-and-eject

Figure 6. Configuration of the Cassini/Huygens composite (Orbiter and Probe) during the launch and cruise phases



device. These explosive bolts will be 'fired' during the approach to Titan, thereby releasing the Probe from the Orbiter under the action of three springs, each exerting a force of 500 Newton. A curved track and roller system will ensure that the Probe spins at about 7 rpm and leaves the Orbiter with a relative velocity of 0.3 m/s. Extensive analyses of the dynamics of separation have been performed by both ESA and JPL, and the system is now optimised to take account of, for example, impulse load limitations on Orbiter-mounted experiments, and Probe lateral-velocity error limitations.

Signature of the Huygens industrial contract. Seated from left to right, L. Gallois, President of Aerospatiale, J.-M. Luton, ESA's Director General, and R. Bonnet, ESA's Director for Scientific Programmes

The back-cover mechanisms are in fact three rod cutters which hold the back cover to the interface fittings. These rod cutters are pyrotechnically and mechanically redundant (double initiators and dual cutting knives). To release the back cover, simultaneous commands will be sent to all three devices and the rods then cut. The same type of rod cutters are used for the front shield. These will be fired 30 seconds later than the back-cover mechanisms to allow the Probe to descend through the unstable transonic region. Three springs will push the shield away to ensure that it does not collide with the Probe just after separation.

Thermal protection

The thermal-protection subsystem is specifically designed to protect the Probe from the entry heating. It consists of a back cover made from suitably stiffened aluminium sheet and a front shield of carbon-fibre face-sheet honeycomb.

The front shield is covered by tiles of a material known as 'AQ60' developed by Aerospatiale (F). This is essentially a low-density 'mat' of silica fibres. The rear side of the Probe will reach much lower temperatures and there a spray-on layer of 'Prosial' material is used. This consists of small spheres of silica and is suitable for use at these lower temperatures. Extensive analytical predictions have been performed as well as sample testing at high temperatures in plasma arc jets, for example, on material samples. Due to the predicted levels of methane and argon in Titan's atmosphere, different chemical reactions are expected in the plasma compared with Earth-atmosphere re-entry. This leads to high expected levels of radiation heating, but also to higher uncertainty because not all the necessary experimental data is available for the high temperatures involved. For this reason, generous margins are included in the predictions.

The tile thickness on the front shield is calculated to ensure that the structure will not exceed 150°C. This will ensure that Probe internal temperatures do not rise to high values during entry, so that conventional structural engineering can be used. The mass of this thermal-protection subsystem is more than 100 kg, which is almost one third of the entire Probe mass.

Parachutes

Three parachutes are to be used during the Probe's descent. The pilot parachute, of about 2 m diameter, will first be ejected at a Probe velocity of Mach 1.5 by means of the pyrotechnic ejection device. A cartridge will be fired causing a piston to eject the parachute pack through the back-cover break-out patch at a velocity of 30 m/s.

The pilot chute will then pull away the back cover, which is attached via a lanyard to the main chute. The main chute, which is some 8 m in diameter, will then deploy, rapidly slowing the Probe down and stabilising it through the transonic region.

When the front shield is released, the main parachute will pull the descent module away. This main chute is sized specifically to separate the descent module from the front shield. It is too large to be compatible with the mission descent time to the surface of Titan of 2.5 hours. Therefore, after about 15 minutes, three more rod cutters attaching the main chute to the descent module will be fired releasing the main chute, which in turn will release a smaller stabiliser parachute that will allow the module to descend faster.

All three parachutes have the same so-called 'disc-gap-band' design. A comprehensive series of wind-tunnel test campaigns were performed early in the programme, for both supersonic and subsonic conditions, to measure the aerodynamic characteristics of models of the parachutes, entry module and descent module.

Descent module

The descent module itself consists of a main and an upper platform, both made of aluminium honeycomb, enclosed by a fore dome and after cone made from thin aluminium sheet, suitably stiffened (Fig. 7).

upper platform is in fact the pilot chute's ejection device, which induces of load of 13 500 Newton on the top platform for some 5 ms, inducing a complex response in the platform and its equipment.

In addition, the heat losses from the equipment to the exterior have to be minimised during the cold descent phase. For this reason there is a gap between the main platform and outer shell. The main load path into the platform is via three large radial struts integrated into platform inserts. These struts are made from titanium tubing, again to minimise heat conductance.

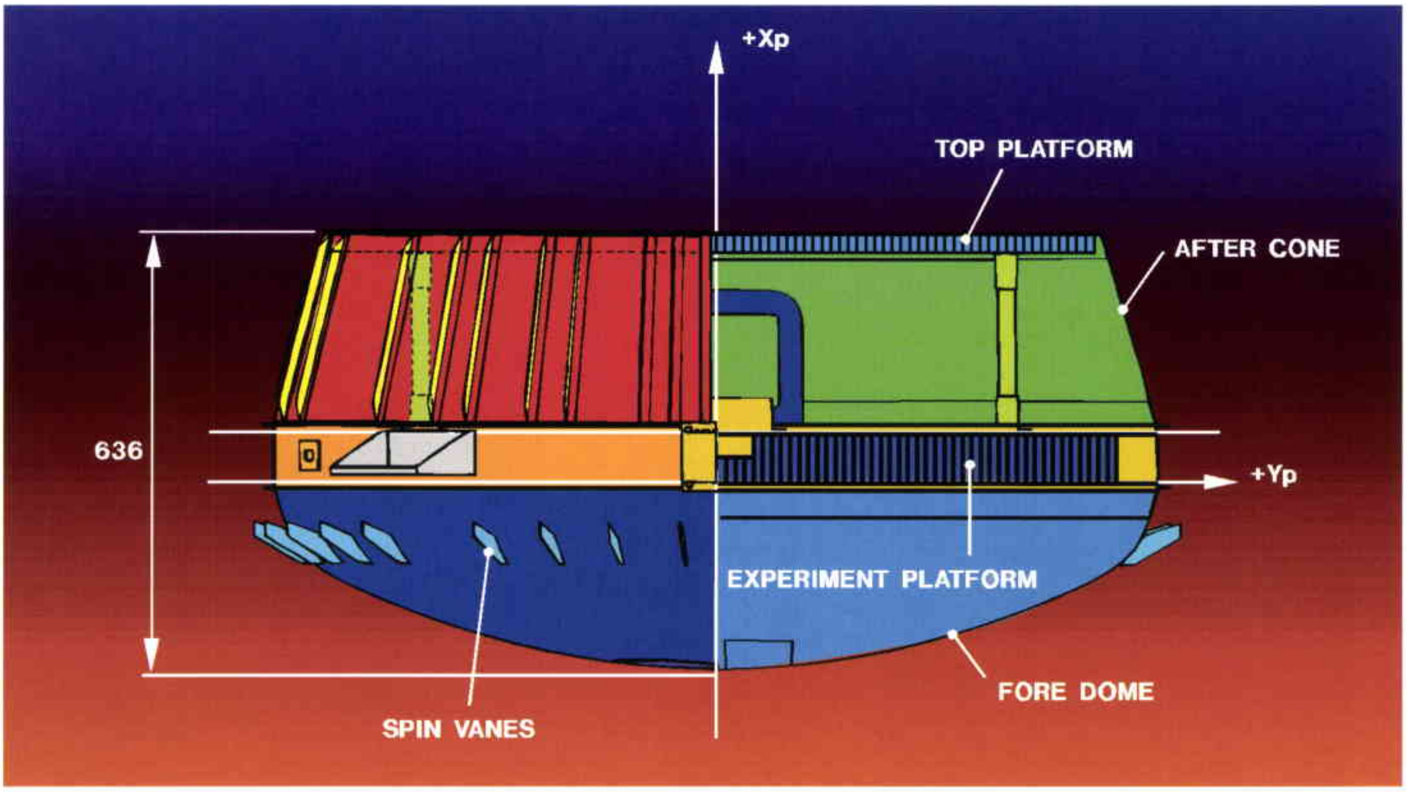


Figure 7. The descent module

The fore dome also has external spin vanes to produce a controlled rotation during the descent. This rotation is decoupled from the parachutes by means of a swivel bearing mounted in the parachute line. The controlled spin is required for the scanning of the scientific camera (DISR).

The descent-module structure has several different design drivers. The main driver in terms of structural strength is the 16 g entry load. However, the outer shell must also be designed to avoid buckling when descending through the extremely cold (−200°) Titan atmosphere.

The main platform carries almost all the housekeeping equipment and experiments, whereas the upper platform is mainly designed to carry the parachutes. The main driver for the

Thermal control

Finally, the thermal control of the Probe, which is the responsibility of DASA in Munich, is essentially driven by the battery requirements. The batteries have to be cold during storage and warm during operation. Unfortunately, the external environments during the mission are exactly the opposite!

A passive control approach is used, but this differs from that for conventional spacecraft because of the combination of 'usual' deep-space thermal control, using multi-layer insulation, with convective cooling during the descent through the Titan atmosphere, where foam insulation has to be used.

For the coast phase also, after the Probe has left the Orbiter, the temperatures internally have to be prevented from falling too low by using radioactive heater units supplying some 30 watts.

The 2.5 hour operating time for the actual mission is thermally only a transient phase and, despite the approximately 300 watts of power dissipation, it is difficult to produce a reasonably high temperature for battery operation when the temperature of the outside atmosphere is around −200°C.

Another problem occurs in the early part of the cruise phase when the spacecraft flies by Venus at a distance of 0.6 AU from the Sun. To avoid Probe internal temperatures becoming too high, it must be shaded from the Sun by the Orbiter's high-gain antenna. Some limited solar exposure for telecommunications purposes can, however, be tolerated.

The electrical system

The electrical system design for the Huygens Probe posed a number of unique design challenges for the Agency and its European contractors, such as:

- a seven-year dormant phase between launch and mission operations
- environment extremes due to a variation in Sun–spacecraft distance from 0.6 to 8.5 AU
- natural and induced radiation
- a round-trip communication time of more than 2 hours when the spacecraft is at Saturn
- mass and volume constraints associated with a deep-space mission.

During the Probe's descent to Titan's surface, the data acquired are to be transmitted to the Orbiter in real time via a hot-redundant S-band link. The highest data rate required will be 8 kbit/s. The output power of each Probe transmitter is 10 W, which is the state of the art limit for solid-state amplifiers. The Probe antenna gain is limited by the need for a wide beam, capable of covering a Probe aspect angle as seen from the Orbiter ranging from about 30° to 50°. The aspect angle of the Probe depends on its targetting on Titan; the selection of the target, however, is dominated by payload requirements and entry-trajectory constraints.

On the Cassini Orbiter, the link will be received via a high-gain antenna pointed towards the Probe's nominal position. This antenna is also to be used for communication with the Earth, which means that real-time downlinking of the Probe data is not possible. It will therefore be stored on-board the Orbiter until after completion of the Probe's mission. At that point, the Orbiter will be slewed so that its high-gain antenna is Earth-pointing and transmission of the data gathered by the Probe can commence.

The Huygens Probe will have to operate in an autonomous and fault-tolerant manner during its Titan descent as neither ground control nor failure recovery will be feasible due to the extreme distance and signal propagation delay involved. Therefore, no telecommand access to the Probe is provided for after its separation from the Orbiter. A schematic of the Probe's electrical architecture which provides this autonomy and fault tolerance is shown in Figure 8.

On-board software residing in the Probe's redundant Command and Data Management Units (CDMUs) will be initialised at Probe switch-on, redundant accelerometers will detect its entry into Titan's atmosphere, and this in turn will initiate the descent sequence. The first commands will be to deploy the pilot chute, to release the back cover and to release the front shield. Next the transponders (Tx) will be powered up and experiment activation will continue. Ten minutes later, the main parachute will be jettisoned and, at a time corresponding to an altitude of about 20 km, the radar altimeter will be activated.

The electrical subsystems

The Electrical Power Subsystem (EPSS)

Whilst the Probe is attached to the Cassini Orbiter, power will be provided by the latter's three Radio-isotope Thermoelectric Generators (RTGs) in the form of a regulated 30 volt bus. After separation, the Orbiter will continue to provide power to the PSE, but the Probe's power during the coast and descent phases will be supplied by its own lithium sulphur-dioxide ($LiSO_2$) primary batteries.

The EPSS architecture (Fig. 9) is organised around an energy source of five batteries, each consisting of two thirteen-cell modules. Each battery is connected via a relay to its own Battery Discharge Regulator (BDR), the output of which is connected to a common power bus. Each user is provided with a nominal and a redundant output via a separately switchable solid-state current limiter. The subsystem can survive the loss of any one of its five parallel strings – i.e. one battery, one relay or one BDR – and still support a complete mission.

The Command and Data Management Subsystem (CDMS)

The CDMS provides the monitoring and control of all Probe subsystem and payload functions, as well as providing the interface with the Probe Data Relay Subsystem (PDRS) in order to support communications with the Orbiter's

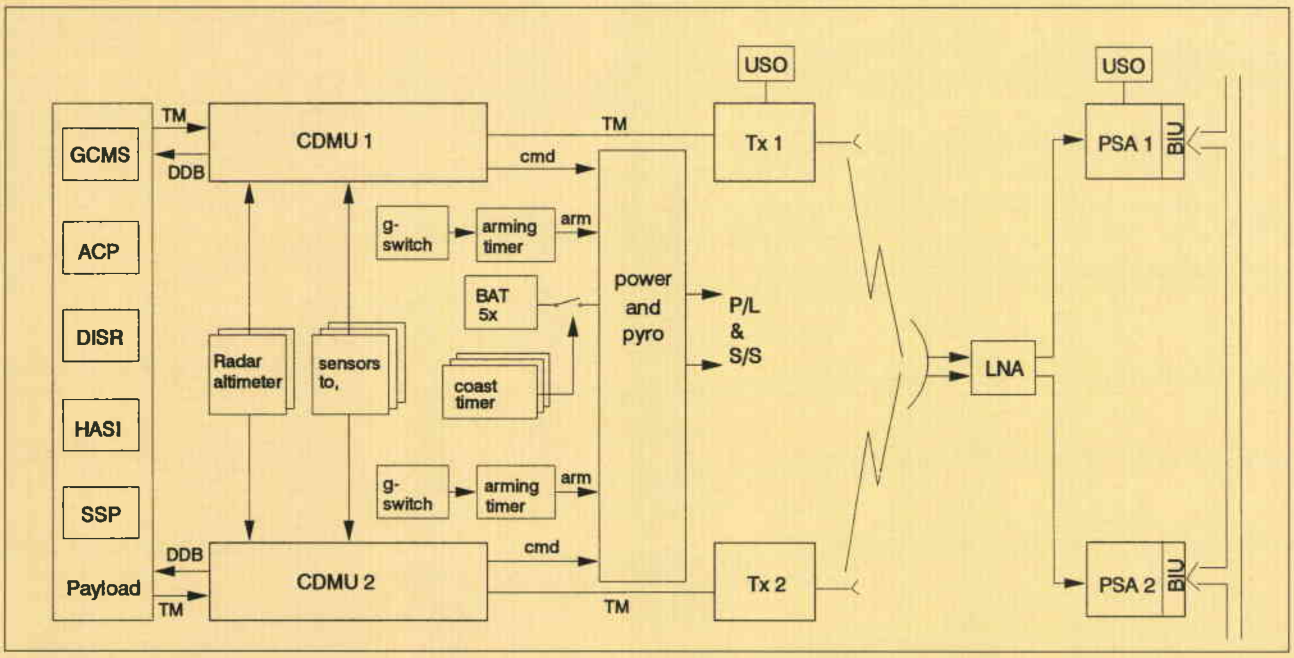


Figure 8. The Huygens Probe's electrical architecture

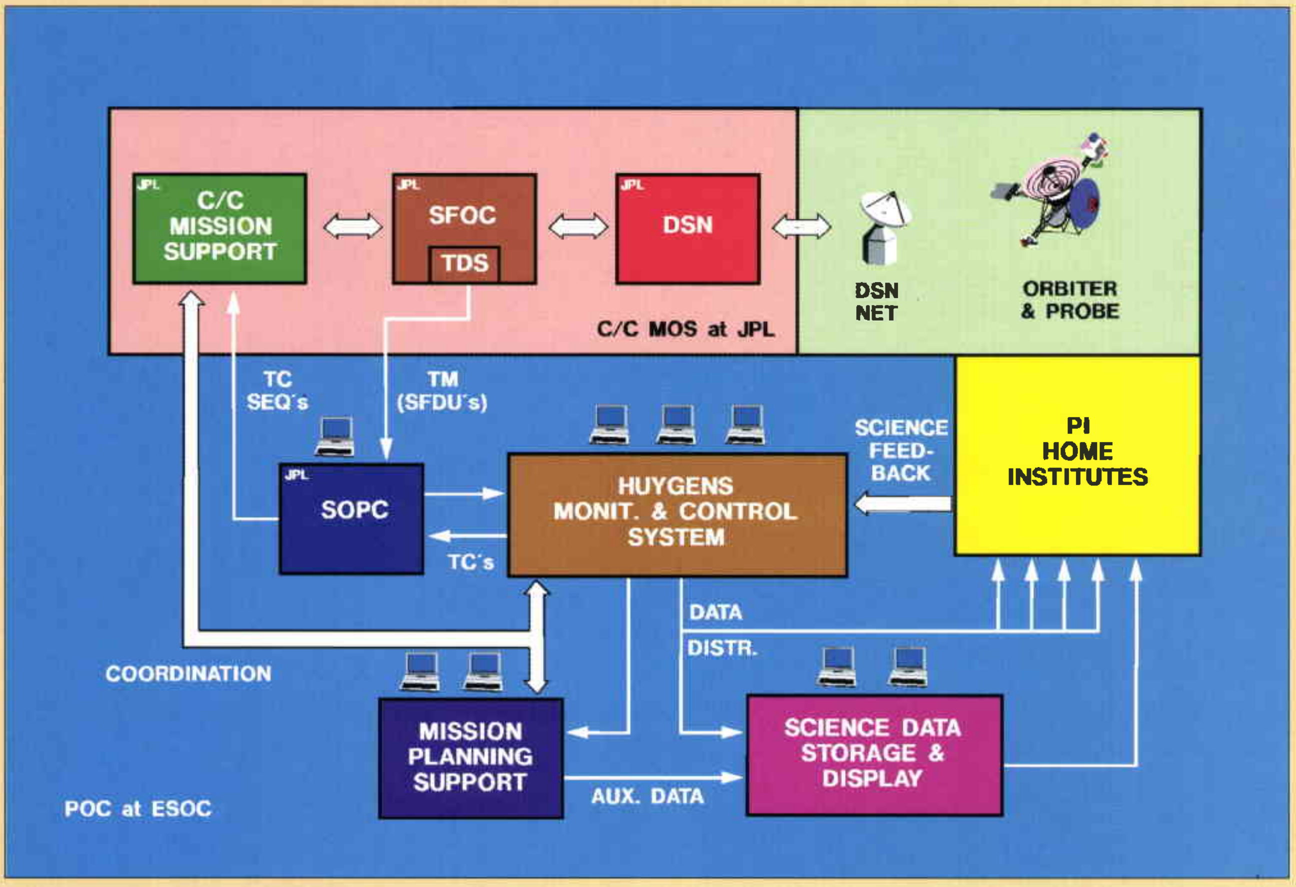


Figure 9. The flow of Probe data between ESOC in Darmstadt (D) and JPL in California (USA)

data-handling subsystem. These functions are supported via two identical hot redundant Command and Data Management Units (CDMUs; Fig. 8).

The CDMS also includes an Arming Timer whose function is to supply pyrotechnic arming commands, following a hard-wired sequence which is initiated on detection of the peak entry 'g-forces'. This provides a hardware-managed timelining that is fully independent of the processor and Probe on-board software operation.

The Mission Timer Unit (MTU) also forms part of the CDMS, this is a triple-redundant hardware programmable clock whose role is to 'wake up' the Probe after an in-orbit duration of nominally 22 days.

The remaining components of the CDMS are a Radar Altimeter (RA) and a Sensor Package. The RA operates from an altitude of about 20 km until near the surface and its measurements are critical for experiment operation.

The CDMS sensors perform the following functions:

- a g-switch function for unambiguous detection of entry into Titan's atmosphere and activation of the arming timer
- a spin-measurement function performed by radially mounted accelerometers
- an axial acceleration measurement function using axially oriented accelerometers.

The Probe Data-Relay Subsystems (PDRSs)
The PDRs can be broken down into two main blocks (Tx 1 & 2), which are sited on the Probe itself and in the Probe Support Avionics (PSA 1 & 2) which remain on the Orbiter (Fig. 8).

Each Probe transmitter consists of an oscillator and synthesiser module, a modulator and a 10 watt solid-state power amplifier. Data received from the CDMUs is modulated and upconverted to S-band before being fed to the output stage and antenna. The transmitters operate in hot redundancy, each having a separate antenna, one of which is right-hand and the other left-hand circularly polarised. The transmit frequencies are also separated by 20 MHz to provide optimum channel isolation.

The PSA architecture has an analogue and a digital section. The former is mainly devoted to the signal down-conversion from S-band to the IF frequency, while the latter performs the signal-acquisition and tracking task. In addition to controlling the scientific and PSA housekeeping data flows, the digital section also controls data communications with the Orbiter.

Launch and operations

The Cassini spacecraft will be launched from Cape Canaveral in October 1997 by a Titan-IV/Centaur launcher. Probe operations will be conducted from the Probe Operations Centre (POC) at ESA's European Space Operations Centre (ESOC) in Darmstadt (D), in coordination with the Jet Propulsion Laboratory (JPL) in Pasadena (USA), which will be responsible for interactions with the Orbiter. All commands to the Probe will be routed from the ESOC POC to the NASA Mission Support Area at JPL for uplinking via the Orbiter.

During in-orbit checkouts during the cruise and Saturn-orbit phases, and during the descent phase to Titan's surface, near-real-time Probe science data will be processed at the POC. Whenever the presence of investigators is required or useful, they will be present at the POC for evaluation of the telemetry coming from the scientific instruments.

Figure 9 is a schematic of the data flow and a typical data-handling task distribution between ESOC and JPL.

Conclusions

The design of the Huygens system and subsystems is now largely frozen and at this moment engineering-model hardware is being produced at the equipment suppliers throughout Europe. Although required to support only some days of free-flying operation, the Huygens system design has presented some unusual design challenges. These challenges have been met successfully and workable solutions have been found for all problems so far encountered.

The current Probe baseline is designed to meet all scientific and mission objectives with an optimised design whose performance allows us to satisfy the requirements with adequate system-design margins. It would be premature and over-optimistic to claim at this stage that all problems have been solved, but we can already look forward with confidence to receiving pictures from Titan's until-then hidden surface early in the next century.

Huygens – The Science, Payload and Mission Profile

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Cassini/Huygens is a very ambitious and exciting planetary mission designed to undertake an in-depth exploration, during the first decade of the next century, of the Saturnian system in general and the moon Titan in particular. It is being pursued as a collaborative effort by ESA and NASA, with ESA providing the Huygens Titan Probe. The scientific community in the ESA Member States is making significant contributions to the payloads of both the Huygens and Saturn-Orbiter payloads by developing many of the payload instruments.

Cassini/Huygens will provide a wealth of data that will allow several generations of scientists to study the most beautiful and most complex planetary system in the Solar System. The in-situ exploration of Titan by the Huygens Probe will allow the moon's organic chemistry to be studied in an environment thought to be similar to that prevailing on Earth 4.5 billion years ago before life began.

Figure 1. Voyager image of Titan

Titan

Titan, the largest moon of the planet Saturn, was discovered in 1655 by the Dutch Astronomer Christiaan Huygens, who was then observing Saturn's rings. The presence of an atmosphere around Titan was suggested by the Spanish Astronomer Jose Comas Sola in 1908, but was only confirmed in 1944, when an American astronomer of Dutch origin, Gerard Kuiper, discovered gaseous methane at Titan through spectroscopic observations. Titan's atmosphere was then thought to be mostly composed of methane, until Voyager-1 revealed that nitrogen is its major constituent, as on Earth. Voyager also confirmed the presence of gaseous methane, but in concentrations of only a few percent.

Unlike most of the other newly observed Solar-System bodies, the wonders of which have been revealed from imagery, Titan, in the images taken by Voyager (Fig. 1), showed a featureless orange face. Most of the excitement during the Voyager encounter was produced by the infrared spectroscopic observations, which revealed methane, ethane and several more complex organic molecules in Titan's atmosphere. Hydrogen was also detected in appreciable quantities (0.2%). The confirmation of the suspected presence of hydrogen cyanide (HCN), which is a critical building block for the more complex molecules of life, and therefore of great significance to exobiologists, confirmed the unique nature of Titan in the Solar System.

Voyager-1 flew within 4000 km of Titan and radio soundings made during the flyby allowed the moon's atmosphere to be probed down to its surface. Among other things, this allowed the radius of the moon's invisible surface to be measured precisely, while analysis of the spectroscopic and radio-sounding data provided the moon's main physical parameters (Table 1).

Table 1. Properties of Titan

Surface radius	2575 ± 0.5 km
Mass	1.346×10^{23} kg (2.2% of M_{Earth})
GM	8978.1 km^3/s^2
Surface gravity	1.345 m/s^2
Mean density	1.881 $g \times cm^{-3}$
Distance from Saturn	1.226×10^6 km (20.3 R_{Saturn})
Orbital period	15.95 d
Rotation period	15.95 d
Surface temperature	94 K
Surface pressure	1496±20 mbar

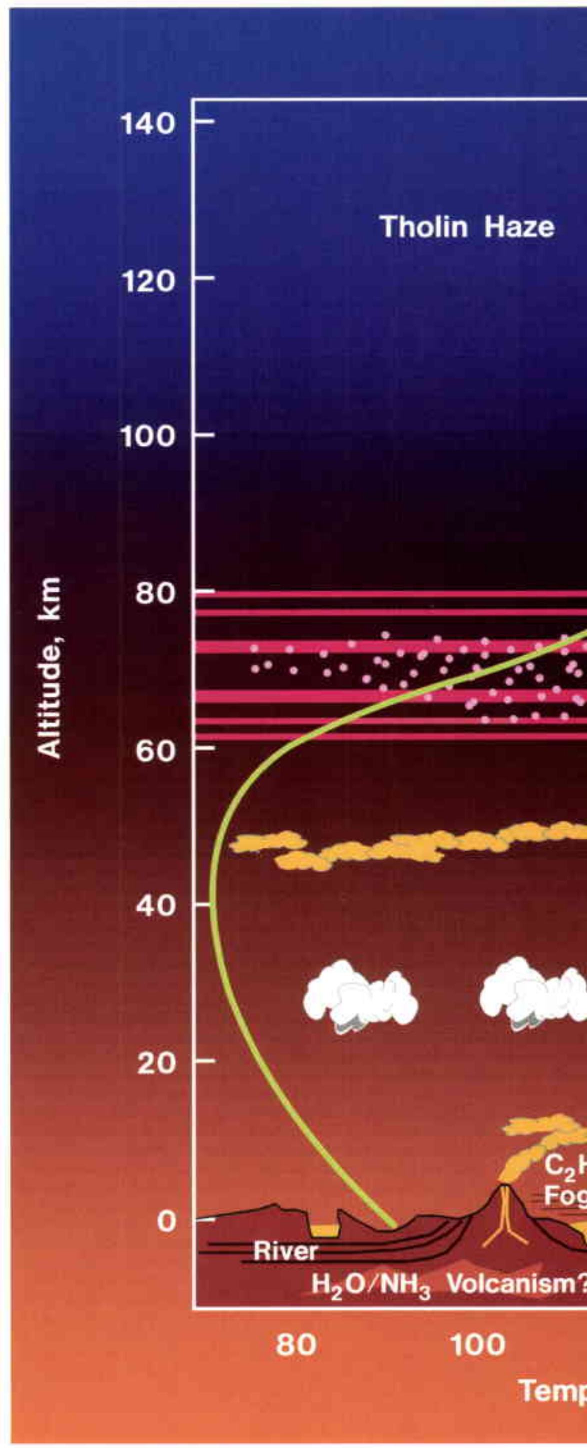
Considering the size of the solid body itself, Titan is the second largest moon in the Solar System after Jupiter's Ganymede, and is larger than the planet Mercury. If, however, its thick atmosphere is included (the 1 mbar pressure level is at 200 km), Titan can be considered the largest moon in the Solar System.

Initiated by solar ultraviolet radiation and high-energy electron impact, which induces CH_4 and N_2, a complex photochemistry is at work in Titan's atmosphere. It produces a lot of organic compounds – ethane (C_2H_6), acetylene (C_2H_2), propane (C_3H_8), ethylene (C_2H_4), propyne (C_3H_4), diacetylene (C_4H_2), hydrogen cyanide (HCN), cyanoacetylene (H_3CN), cyanogen ($C_2N_2$2), and dicyano-acetylene (C_4N_2) – which have already been detected with mixing ratios of 10^{-5} to 10^{-8} in the gas phase of the atmosphere. Two O-compounds, CO (mole fraction 10^{-4}) and CO_2 (mole fraction 10^{-8}) have also been detected. This complex organic chemistry also gives rise to a photochemical fog, the so-called 'Titan haze', which shrouds the moon.

Analysis of the Voyager images and infrared spectroscopic measurements have provided a great deal of information about the physical properties of haze particles, called 'aerosols', which are probably organised into several layers, with the top layer as high as perhaps 500 km. Haze particles are composed of a wide variety of H, C, N compounds and opaque refractory materials, but very little is known about their chemical composition or the chemistry at work in the solid and liquid phases of those particles.

At first, the Voyager scientists were disappointed because the surface remained hidden from the spacecraft's cameras. However, the understanding of the atmosphere, and the use of simple thermodynamics laws, led to the hypothesis that Titan's surface was covered by a global ocean of ethane/methane and nitrogen, which is soluble in both. The presence of an ocean would have profound implications for the atmosphere and the CH_4 'hydrological' cycle. The putative oceans themselves, for the complex organic chemistry that would be at work there, and the potential exobiological implications, are the subject of numerous studies.

The main features of the atmosphere and surface of Titan are illustrated in Figure 2.



The birth of the Cassini mission

Voyager-1 indeed confirmed the uniqueness of Titan in the Solar System. The chemical composition of Titan is very similar to that of the primordial Earth 4.5 billion years ago. The major difference between the two bodies is that Titan is much colder than the Earth; this cold temperature prevented life from appearing on Titan. Study of the organic chemistry on Titan will, however, provide important clues regarding the prebiotic chemistry that was at work on Earth after the birth of the Solar System. Scientists consider Titan as a deep-frozen Earth.

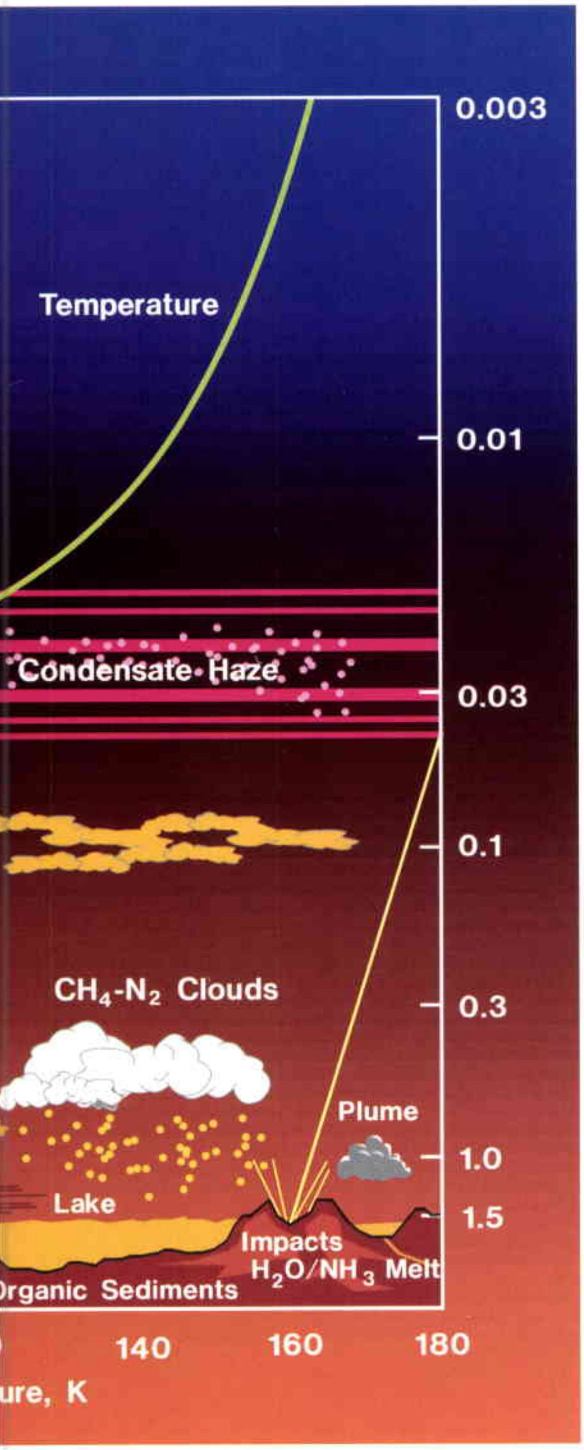


Figure 2. A cross-section of Titan's atmosphere

In the wake of the excitement about the Voyager-1 observations (and those made by Voyager-2 six months later), several European scientists, D. Gautier, W. Ip and others, responded to a regular 'Call for Ideas' issued by ESA's Director of Science in late 1982, with a proposal to embark on a new mission to revisit Saturn and in particular Titan, in collaboration with the Americans. The Cassini mission was subsequently born and was studied jointly by ESA and NASA, supported by a joint science team composed of both European and American scientists.

In 1988, ESA's participation in the Cassini mission, the Titan Probe, was selected as the first medium-size mission for ESA's long-term Space-Science: Horizon 2000 Programme. During the selection process, in order to clearly identify ESA's contribution to Cassini, it was given the name 'Huygens', in honour of the scientist who discovered Titan. The Cassini/Huygens programme officially got underway in 1990 and today's planning foresees a launch in October 1997.

Preparing for Cassini/Huygens

The detailed nature of Titan's surface will probably remain an unsolved puzzle until the arrival of Cassini and the Huygens Probe. However, prior to and particularly since the mission's selection, there has been a substantial programme of ground-based observations of this object. The Hubble Space Telescope has also contributed to the recent Titan observations, and it is hoped that it will soon be providing even better observations with its corrected optics.

Since 1988, annual ground-based radar observations using the Goldstone facility in California as the transmitter and the Very Large Array in New Mexico as the receiver, have revealed a highly reflective surface to Titan, which is inconsistent with a global ocean of light hydrocarbons. The large observed day-to-day variability in the radar reflectivity is also quite puzzling. Although the ever-improving optics of modern ground-based telescopes are making Titan's surface more accessible to today's astronomers, these new data are tending to complicate the puzzle about the nature of Titan's surface rather than resolve it.

Apart from the surface question, the hunt for new molecules in Titan's atmosphere is also the subject of many ground-based observations. Recently the acetonitrile molecule, CH_3CN, was discovered in Titan's atmosphere by French astronomers. Its presence was predicted by photochemical models and it has significant implications for those who look at

Titan as an 'Earth before life'. The presence of argon in the Saturnian moon's atmosphere is also the subject of continuing research, since it would provide important clues about the origin of Titan's atmosphere. Any argon concentration also has important consequences for the aerothermodynamic heat fluxes that Huygens will experience during the entry.

Another topic of research that is actively being pursued is the question of the zonal circulation of Titan's atmosphere, which is super-rotating like that of Venus. Knowledge of these zonal winds is also important for the design of the Huygens Probe mission, since a large uncertainty in their magnitude could impose severe constraints on the design of the link between the Probe and the Orbiter.

Our knowledge to date of Titan was summarised, for the benefit of all scientists preparing for the Cassini/Huygens mission, at the 25th ESLAB Symposium held in Toulouse (F) in September 1991. The Proceedings of this Symposium, organised by ESA Space Science Department in collaboration with the Observatoire Midi-Pyrénées (F), serve as a sound reference both for the mission and instrument developers, and for the scientists working on Titan.

The scientific objectives

Broadly speaking, the scientific aims for the Cassini/Huygens mission are to:

- determine the dynamical behaviour of Saturn's atmosphere
- determine the chemical composition and the physical structure and the energy balance of Titan's atmosphere
- observe the temporal and spatial variability of Titan's clouds and hazes
- characterise the Titan surface
- determine the structure, composition and geological history of Saturn's icy satellites
- study the structure of the rings and the composition of the ring material, and
- study the structure, chemical composition and global dynamics of Saturn's magnetosphere.

An important aspect of the Cassini mission is the study of the interactions and interrelations between the various parts of the system. The study of the interrelation between the rings and the icy satellites, and that between the satellites and the ionosphere of Titan with the magnetospheric plasma, are key Cassini mission objectives.

More specifically, at Titan it is hoped to:
- determine the physical characteristics of the atmosphere, particularly its density, pressure and temperature as a function of height
- determine the abundance of atmospheric constituents, including any noble gas; establish isotope ratios for abundant elements; constrain scenarios of formation and evolution of Titan and its atmosphere
- observe vertical and horizontal distributions of trace gases; search for complex organic molecules; investigate energy sources for the atmospheric chemistry; model the photochemistry of the stratosphere; study the formation and composition of the aerosols
- measure winds and global temperature; investigate the cloud physics, general circulation and seasonal effects in Titan's atmosphere; search for lightning discharges

Table 2. The Huygens investigations

Instruments	Objectives	Principal Investigator
Huygens Atmospheric Structure Instrument (HASI) *Mass 6.7 kg*	Atmosphere temperature and pressure profile, winds and turbulence. Atmospheric conductivity. Search for lightning. Surface permittivity.	M. Fulchignoni, University of Rome (I)
Gas Chromatograph & Mass Spectrometer (GCMS) *Mass 19.5 kg*	Atmospheric composition profile. Aerosol pyrolyzats analysis.	H.B. Niemann, GSFC, Greenbelt (USA)
Aerosol Collector & Pyrolyser (ACP) *Mass 6.7 kg*	Aerosol sampling and three temp. step pyrolysis.	G.M. Israel, SA Verrières-le-Buisson (F)
Descent Imager/Spectral Radiometer (DISR) *Mass 8.5 kg*	Atmosphere composition and cloud structure. Aerosol properties. Atmosphere energy budget. Surface imaging.	M.G. Tomasko, University of Arizona, Tucson (USA)
Surface Science Package (SSP) *Mass 4.2 kg*	Titan surface state and composition at landing site.	J.C. Zarnecki, University of Kent, Canterbury (UK)
Doppler Wind Experiment (DWE) *Mass 2.1 kg*	Probe Doppler tracking from the Orbiter for zonal wind profile measurement.	M.K. Bird, University of Bonn (D)

- determine the physical state, topography and the composition of the surface; infer the internal structure
- investigate the upper atmosphere, its ionisation, and its role as a source of neutral and ionised material for the magnetosphere of Saturn.

The Huygens Probe will address the first five of these objectives by making local in-situ and remote-sensing measurements all along its trajectory. The Cassini Orbiter, during its repeated flybys of Titan, will address all six objectives in a complementary manner and on a global scale.

Cassini/Huygens mission overview

The current development plan calls for the Cassini/Huygens spacecraft to be launched in October 1997 by a Titan IV/ Centaur rocket from Cape Canaveral in Florida. Weighing more than 5.5 tons at launch, the spacecraft is too heavy to be injected directly onto a trajectory to Saturn and so will require the boosts of several planetary 'gravity assists'. The interplanetary trajectory therefore includes fly-bys at Venus (in April 1998 as well as June 1999), Earth (in August 1999) and Jupiter (in December 2000). As a result, the October 1997 launch opportunity allows Saturn to be reached in about seven years. Other launch opportunities (degraded because they do not include a Jupiter fly-by) exist in December 1997, and in 1998 and 1999, but are less favourable from the launch-performance and/or scientific stand-points.

Arrival at Saturn is planned for 2004. The Probe is to be released from the Saturn Orbiter during the initial orbit around Saturn, nominally 22 days before Titan encounter. Shortly after Probe release, the Orbiter will perform a deflection manoeuvre to set up the radio-communication geometry necessary between it and the Probe during the latter's descent phase. This manoeuvre will also set up the initial conditions for the satellite tour after the completion of the Probe's mission.

Huygens' encounter with Titan is actually planned for 27 November 2004. The Orbiter will act as a relay station and the Huygens Probe's data will be received via the Orbiter's High-Gain Antenna (HGA), which will be pointed at the Probe throughout its mission. This configuration will preclude a simultaneous real-time link to Earth from the Orbiter and so the Probe data will be stored on the Orbiter's two solid-state recorders for later transmission to Earth.

A Titan encounter scenario is being worked out that will allow remote-sensing observations of Titan's atmosphere near the Probe's entry site from the Saturn Orbiter immediately after completion of the Probe's mission. Simultaneous remote-sensing observations from the Orbiter and local in-situ observations from the Probe will allow the Huygens observations to be put into a global context. The quasi-simultaneity of the observations will allow the Probe data to be used to provide 'ground-truth' calibration of the Orbiter's observations.

At the end of the Probe mission phase, the Saturn Orbiter, equipped with 12 scientific instruments of its own, will start a four-year tour of the Saturnian system. This so-called 'satellite tour' involves more than 40 Saturn-centred orbits, connected by Titan gravity-assist fly-bys or propulsive manoeuvres. The size of these orbits, their orientation to the Sun–Saturn line, and their inclination to Saturn's equator are dictated by the various scientific requirements, which include: Titan ground-track coverage, icy-satellite fly-bys, Saturn, Titan or ring occultations, orbit inclinations and ring-plane crossings. The Saturn Orbiter will observe Titan during each of its fly-bys of the moon.

The Huygens scientific payload

Huygens investigations, involving six instruments provided by Principal Investigators and three Interdisciplinary Investigations, were selected by ESA in September 1990 (Table 2 and Fig. 3).The six instruments to be provided by the scientific community are as follows:

The Gas Chromatograph and Mass Spectrometer (GCMS)

The GCMS is a very versatile gas chemical analyser designed to identify and quantify the

Collaborating Institute(s)
Univ. of Padova (I), Univ. of Kent (UK), IAU, Rome (I) FMI, Helsinki (SF), LCPE, Orlean (F), Univ. of Graz (A) SSD/ESA, Noordwijk (NL), IAA, Granada (E),
Univ. of Michigan (USA)
Univ. of Graz (A), SRI, Graz (A)
DESPA, Meudon (F), MPIA, Lindau (D), TU Braunschweig (D)
RAL, Didcot (UK), UMIST, Manchester (UK) ESA/SSD, Noordwijk (NL), SRC, Warsaw (P)

abundances of the various atmospheric constituents. It will analyse argon and other noble gas and make isotopic measurements. The GCMS's inlet system is located at the apex of the Probe near the stagnation point, where the dynamic pressure will drive the gas into the instrument.

The instrument can work either in a direct mass-spectrometer mode, or in a more powerful mode in which the gas sample is passed through gas-chromatograph columns, thereby helping to separate components of similar mass before analysis. The instrument is also equipped with gas samplers, which will be filled at high altitude for analysis later in the descent when there will be more time available.

The instrument is equipped with a separate ionisation chamber for analysis of the aerosol pyrolysats fed from the ACP instrument described next. The GCMS will also be able to measure the composition of a surface sample if the Probe makes a safe impact that allows it to gather and transmit surface data for several minutes.

The Aerosol Collector and Pyrolyser (ACP)

The ACP is designed to collect aerosols for chemical-composition analysis. The instrument is equipped with one deployable sampling device which will be operated twice in order to collect the aerosols in two layers; the first sample will be taken from the top of the atmosphere down to about 40 km, and the second sample from about 23 km down to 18 km.

After extension of the sampling device, a pump will draw the atmosphere and its aerosols through filters, which will capture the aerosols. Each sampling device can collect about 30 µg of material. After each sampling, the filter will be retracted into an oven where the aerosols will be heated in three different temperature steps in order to conduct a step pyrolysis. The volatiles will be vaporised first, then the more complex, less-volatile organic material, and finally the cores of the particles. The pyrolysis products will be flushed to the GCMS, which will perform the analysis and provide spectra for each temperature step.

Figure 3. The Cassini/Huygens spacecraft

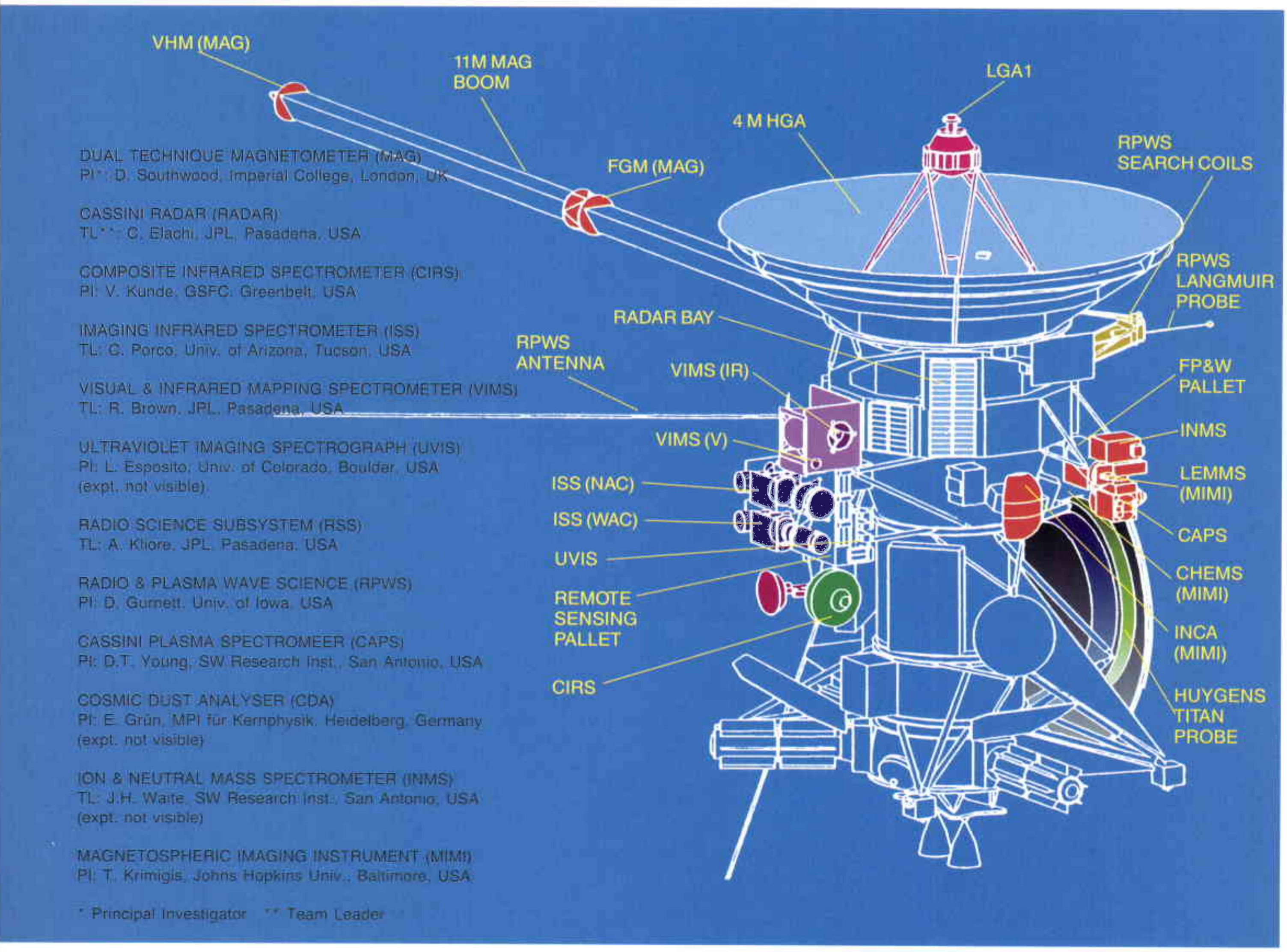


Figure 4. A few hundred metres before impact, the DISR will switch on its surface lamp in order to acquire spectra of the surface material

The Descent Imager/Spectral Radiometer (DISR)

This instrument can take images and make spectral measurements using several sensors covering a wide spectral range from the ultraviolet to the infrared (0.35 to 1.70 microns).

An important feature of Titan is its thick atmosphere containing aerosols whose temperature structure is determined by the radiative and convective heat-transport processes. The DISR will measure both the upward and downward heat fluxes. A solar aureole sensor will measure the solar intensity in the 'halo' around the Sun, which will indicate the amount of sunlight scattering caused primarily by the aerosols in the atmosphere along the sensor's line of sight. This in turn will allow the physical properties of the aerosol particles to be deduced.

The DISR will also be equipped with a side-looking horizon-viewing imager to take pictures of the clouds.

The DISR also has the ability to address one of the prime objectives of Huygens, namely to investigate the nature and composition of Titan's surface. Two imagers – one visible and one infrared – looking downward and outward will observe the moon's surface as the Probe spins slowly. Mosaic panoramas can be assembled by panning several exposures. By taking several panoramas at different times during the last part of the descent, it may be possible to infer the Probe's drift, provided the surface is not featureless, thereby contributing to the wind measurements.

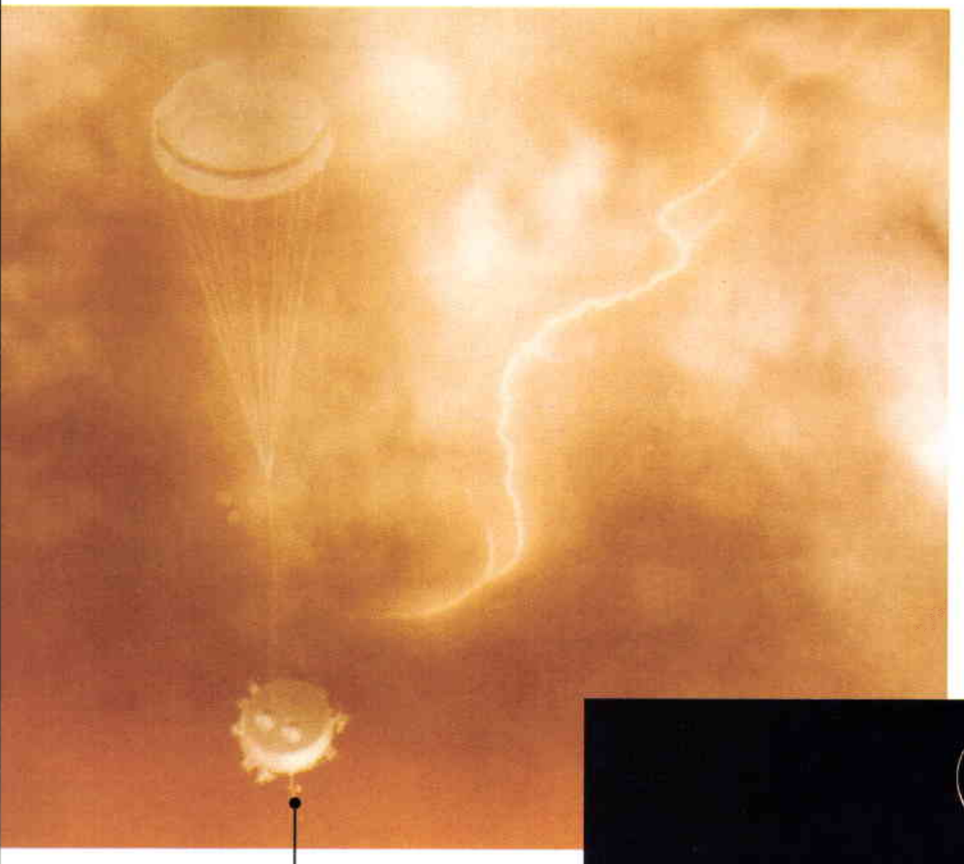
The amount of light striking Titan's surface is about 350 times that striking the Earth's surface during full-Moon. While this surface illumination is sufficient for imaging, a special lamp on the Probe will be activated a few hundred metres above Titan's surface to provide enough light in the methane absorption bands to be able to make spectral-reflectance measurements. These will provide unique information for studying the composition of the surface material (Fig. 4).

The Huygens Atmosphere Structure Instrument (HASI)

The HASI comprises several sensors, including accelerometers, a temperature sensor, a pressure sensor and an electric-field sensor array, for measuring the physical properties of the atmosphere, including its electrical properties. The set of accelerometers will be optimised specifically to measure the Probe's entry deceleration in order to infer the atmospheric density in the upper stratosphere.

The electric-field sensor consists of a relaxation probe to measure the ion conductivity of the atmosphere and a quadrupolar array of electrodes for measuring the permittivity of the atmosphere and that of the surface material after and possibly prior to the impact. Two electrodes of the quadrupolar array are also to be used as an electrical antenna to detect electromagnetic waves in Titan's atmosphere, such as those produced by lightning flashes (Fig. 5).

Recently, the ability to process the surface-reflected signal of the Radar Altimeter, which is



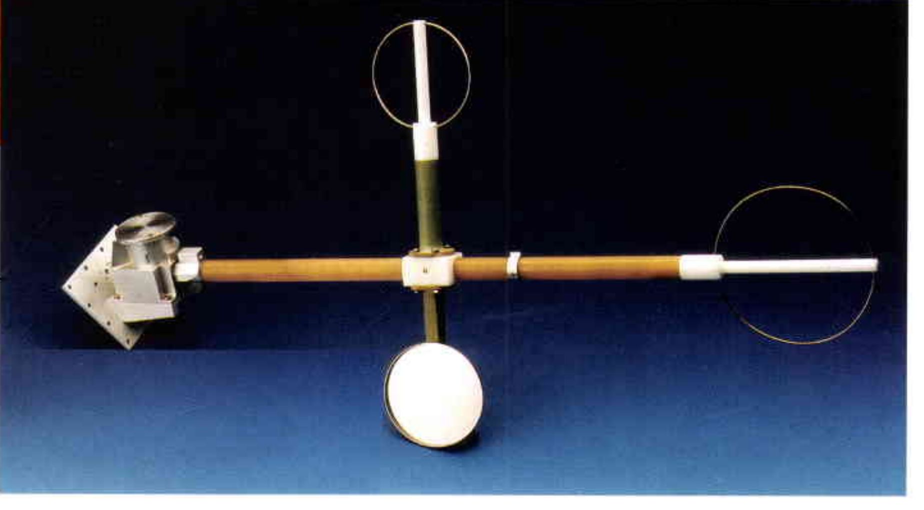


Figure 5. HASI has the ability to detect lightning during the Probe's descent, by means of sensors mounted on deployable booms. The inset shows a development model of a boom

the altitude sensor provided as part of the Probe system, has been added to the HASI. This will allow important information to be sent back about the surface topography and its radar properties below the Probe, along its descent track.

The Doppler Wind Experiment (DWE)

The DWE requires the addition of two Ultra-stable Oscillators (USO) to the Huygens Probe data-relay subsystem. The Probe Transmitter USO (TUSO) will provide a very stable carrier frequency for the Probe-to-Orbiter radio link; the Receiver USO (RUSO) on-board the Orbiter will provide an accurate clock for the Doppler processing of the received carrier signal. The Probe drift caused by the winds in Titan's atmosphere will induce a measurable Doppler shift in the carrier signal. The Doppler signature in the Probe radio signal will be extracted on-board the Orbiter and merged into the Probe data stream recorded on the Orbiter's solid-state recorders.

It is hoped that these Doppler measurements will be so sensitive that, by having the Probe transmitting antennas offset from the spin axis by just a few centimetres, it will also be possible to determine the Probe's spin rate and spin phase. The swinging motion of the Probe beneath its parachute and other radio-signal-perturbing effects, such as atmospheric attenuation, may also be detectable from the signal.

The Surface-Science Package (SSP)

The SSP is a suite of sensors designed to determine the physical properties of the surface at the impact site and to provide unique information about its composition. The package includes an accelerometer to measure the impact deceleration, and other sensors to measure the index of refraction, the temperature, the thermal conductivity, the heat capacity, the speed of sound and the dielectric constant of the (liquid) material at the impact site. It also includes an acoustic sounder, which will be activated a few hundred metres above Titan's surface. A tilt sensor is also included in the SSP to indicate the Probe's attitude after impact.

Although the SSP objectives are primarily to investigate the moon's surface, several of the SSP's sensors will be able to contribute significantly to the study of the properties of Titan's atmosphere during the descent phase.

The payload accommodation

All the payload elements described above are accommodated on the Payload Platform, as shown in Figure 6. The ACP and the GCMS are single-box instruments, with their inlets protruding beneath the Probe to gain direct access to the gas flow. The DISR consists of two boxes: the sensor head and the electronics box; the sensor head is mounted on the

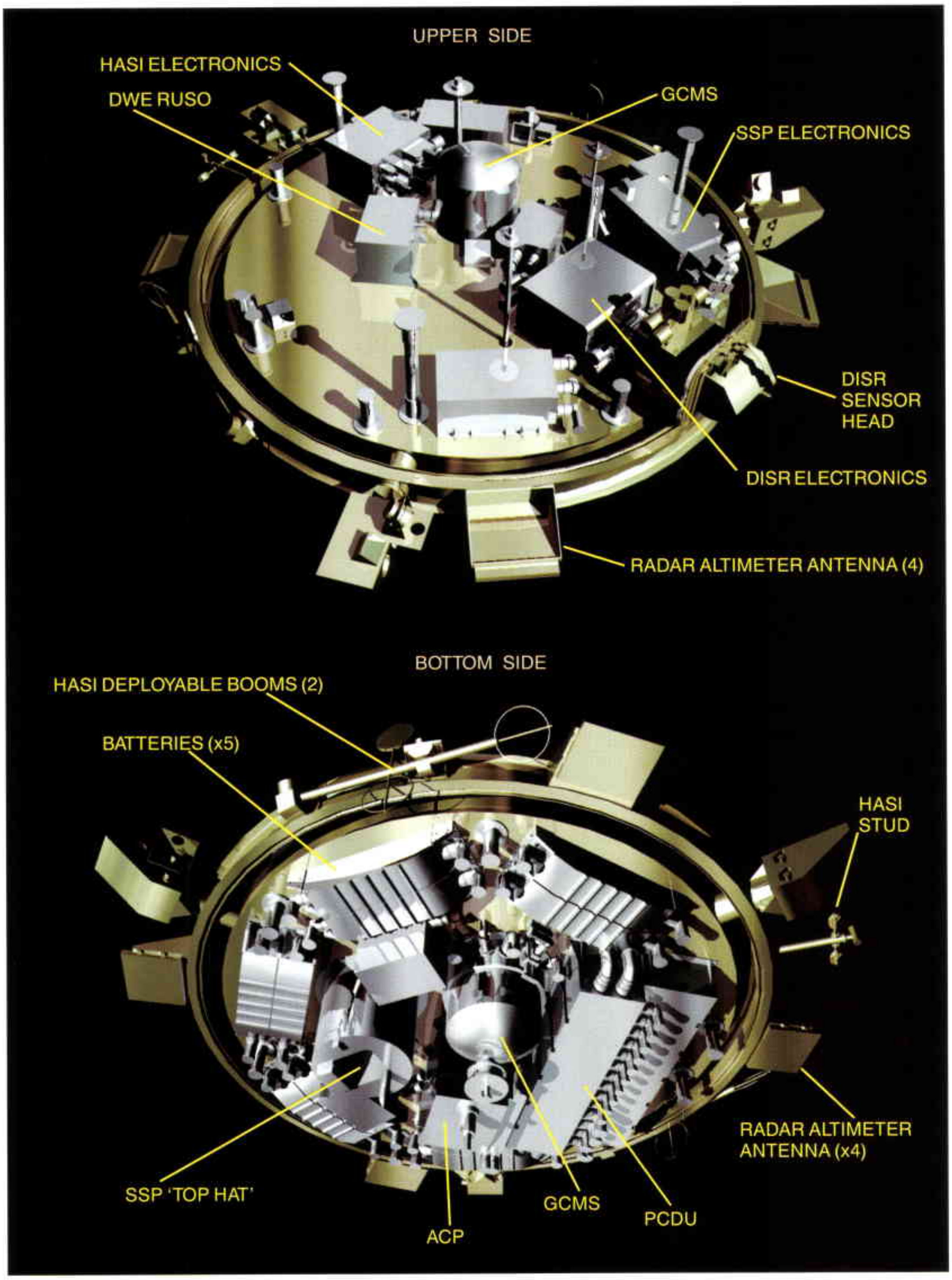


Figure 6. The instrument platform of the Huygens spacecraft (viewed from above and below)

periphery of the platform, in order to accommodate the field-of-view and scanning requirements; the electronics box is mounted on the inner part of the platform and connected to the sensor head via a short harness. The HASI sensors, with the exception of the accelerometers, are mounted either on a fixed stud or on deployable booms, to meet the gas-flow access requirements for the pressure and temperature measurements, and also to minimise any perturbations in the electrical-charge distribution at the field sensors caused by the body of the Probe. The accelerometers are located near the Probe's centre of gravity in its entry configuration.

The SSP consists of two boxes: the so-called 'top hat' structure, which accommodates all the sensors, and an electronics box. The top hat is located beneath the platform, to provide for sensor wetting in the event of the Probe landing in a liquid. It is also equipped with a 'pylon' designed to transmit the impact deceleration to the accelerometers located on the platform.

The TUSO of the DWE is also housed on the experiment platform, while the RUSO is accommodated in the part of Huygens that will remain attached to the Orbiter, namely the Probe Support Equipment (PSE).

The Huygens mission phase

The descent sequence is illustrated in Figure 7, which shows the major events. The batteries and all other resources are sized for a Huygens mission duration of 153 min, corresponding to a maximum descent time of 2.5 h and at least 3 min, but possibly half an hour or more, on Titan's surface.

Only one experiment, HASI, will perform measurements during the entry phase. These data and other data acquired by all other instruments before establishing the radio link to the Orbiter will be buffered within each instrument. Each channel of the redundant link to the Orbiter is designed to operate at 8 kbit/s throughout the descent.

The instrument operations will be based on Probe time in the upper part of the descent, and on measured altitude during the lower part. During the last 20 km of the descent, the Probe's height above the Titan surface will be measured by a radar altimeter.

The Probe will impact the surface of Titan with a velocity of about 5–6 m/s. The probability of the Probe's survival cannot be estimated on purely engineering grounds, since there are too many unknowns. Science measurements will be programmed to go on for at least 30 min after impact. The Orbiter will 'listen' to the Probe for 3 h in total, i.e. for at least 30 min after impact. The Probe's end-of-mission is set to occur at the end of this 3 h-long communication window with the Orbiter, at which time the latter's high-gain antenna will be turned away from Titan.

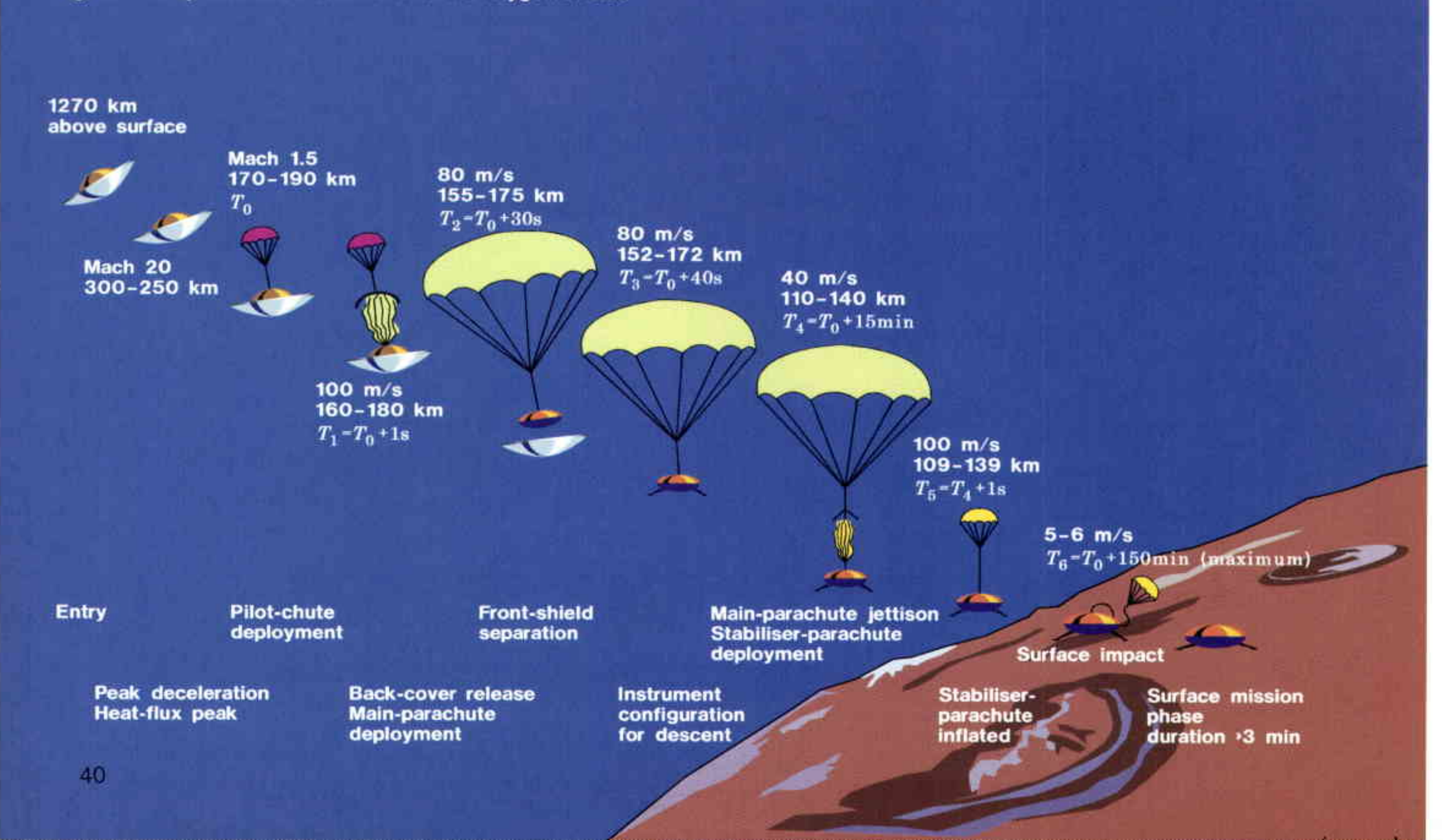
If the Probe should survive the impact, the depletion of its batteries or its cooling to about −180°C are thought to be the two most likely causes of mission termination.

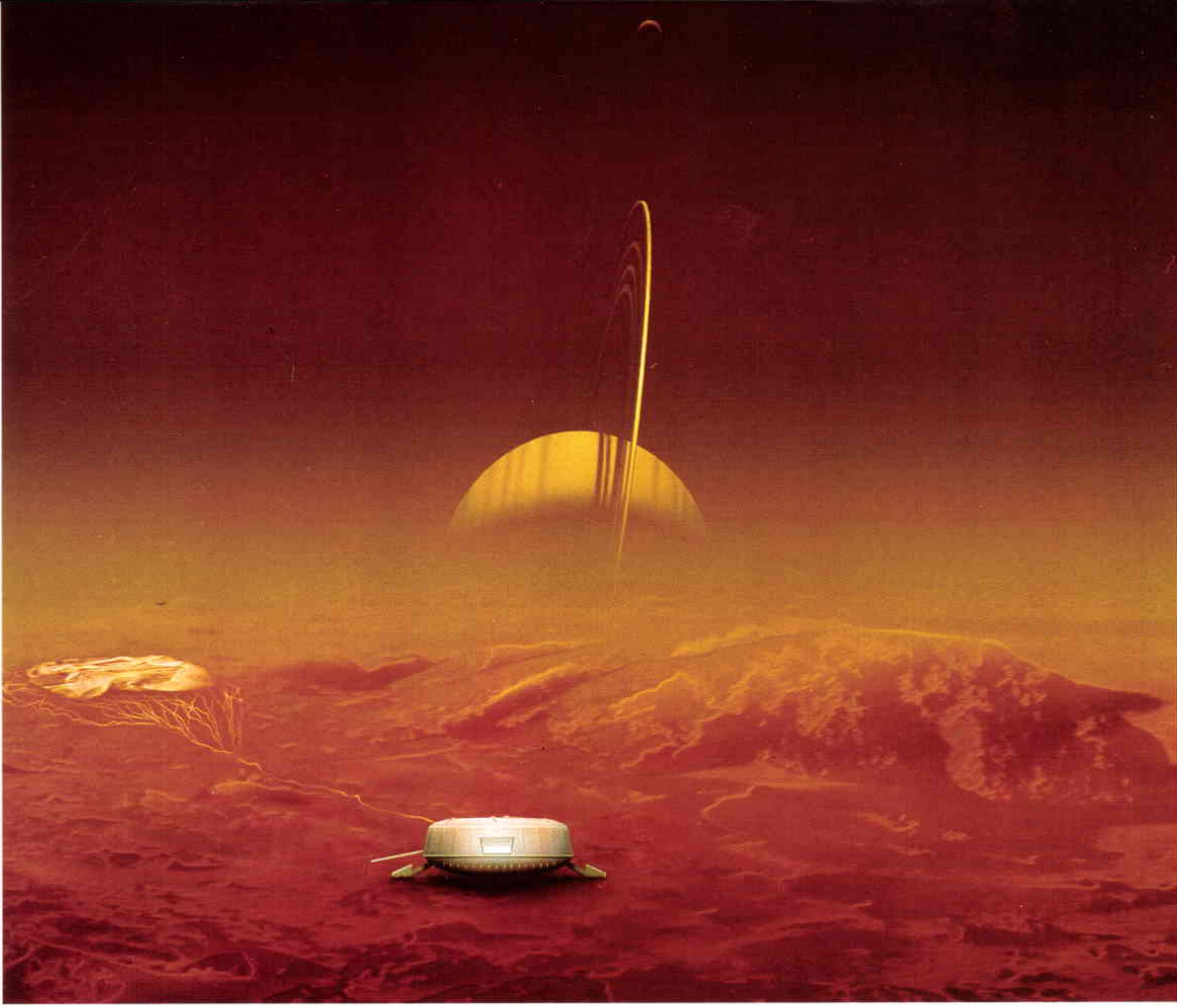
Figure 8 is an artist's rendering of the Huygens Probe sitting in the Titan landscape, in which plausible meteorological and surface features – methane/ethane rain and geysers – are also illustrated.

The Huygens science operations

After separation from the Orbiter, the Probe will operate autonomously, the radio relay link to the Orbiter being one-way for telemetry only. Up to that point, telecommands can be sent via an umbilical link from the Orbiter (which also provides electrical power to the Probe), but this facility will be used only during the Cruise and Saturn-Orbit phases for monitoring the health of the subsystems and calibrating the instruments during the six-monthly checkouts. There will be no scientific measurements prior to Titan arrival, and for most of the cruise the Probe will be switched off. During the 22-day Coast Phase after separation from the Orbiter, only a timer will operate to activate the Probe shortly before the predicted entry into Titan's atmosphere. The programming of this timer and the activation of the Probe's batteries will be the last activities initiated by command from the ground.

Figure 7. Entry and descent scenario for the Huygens Probe





Operation of the Probe, and the collection of telemetered data, will be controlled from a dedicated control room, known as the Huygens Probe Operations Centre (HPOC) set up at ESOC in Darmstadt (D). Data collected by the Probe will be passed to the Orbiter and stored on solid-state recorders for subsequent transmission to Earth at times when the Orbiter is visible from one of the Deep-Space Network (DSN) ground stations. From there the data will be forwarded to the Cassini Mission Support Area (MSA), where the Probe data will be separated from other Orbiter data before being stored in the Cassini Project Database (PDB). The HPOC Operators will then access this database to retrieve Probe data.

Probe subsystem housekeeping data will be used by ESOC to monitor the Probe's performance, while data from the science instruments will be extracted for forwarding to the investigators. During the Cruise Phase, these data will be shipped to the scientists' home institutes via public data lines or on a hard medium such as diskette or CD-ROM.

The Huygens Science Working Team (SWT)

At the time of payload selection, ESA also selected three Inter-Disciplinary Scientists (IDSs) specialised in the fields of: Titan Aeronomy (D. Gautier, Observatoire de Paris, Meudon); Titan Atmosphere/Surface Interactions (J.I. Lunine, Univ. Arizona, Tuscon); and Titan Organic Chemistry and Exobiology (F. Raulin, LISA/Univ. Paris XII, Creteil).

All Huygens Principal Investigators and Inter-Disciplinary Scientists are members of the SWT, the role of which is to advise the Huygens Project Manager on science-related design issues and resource sharing between the different experiments, and to advise on the development and implementation of the Huygens Probe Operations Centre.

Figure 8. Artist's impression of the Huygens Probe sitting on Titan's surface on a rainy afternoon!

Some Insights Into the Hipparcos Results

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ESA Space Science Department, ESTEC, Noordwijk, The Netherlands
Hipparcos Project Scientist

and the Members of the Hipparcos Scientific Consortia

The scientific motivation underlying ESA's Hipparcos space astrometry mission has been to establish an extremely precise stellar reference frame and, in the process, to determine the physical parameters of a very large number of stars, in particular those lying relatively near (in galactic terms) to our Solar System. The accurate measurement of stellar distances leads to the possibility of transforming observed quantities – such as apparent magnitude, angular diameter, and angular motion projected onto the celestial sphere – into absolute physical quantities – such as absolute luminosity, stellar radius, and the star's velocity through the Galaxy. Accurate determination of these quantities is of great importance in advancing present theories of stellar evolution, in gaining further understanding of stellar structure, and for unravelling the kinematic and dynamic complexities of our Galaxy's structure and motion.

The only rigorous way to determine the distance to a star is through the measurement of its trigonometric parallax. This utilises the angular displacement of the stellar image as observed from widely separated points, such as the different positions of the Earth in its orbit around the Sun. Observational difficulties associated with the measurement of this tiny effect through the Earth's atmosphere have hitherto limited use of the parallax technique to the several hundred stars lying within a few tens of light years from the Sun. One of the goals of Hipparcos has been to drastically expand the space in which accurate trigonometric distances are measured.

The Hipparcos satellite, which completed its mission in August 1993, furnished enough data to completely fulfil, and indeed very significantly surpass, all of its original scientific goals (see earlier articles in ESA Bulletins 69 and 75). The immense data-processing task is still proceeding, and the global iterations and data verifications are expected to require a further two years before a satisfactory stellar catalogue becomes widely available. Nevertheless, preliminary stellar catalogues have been produced, and the 100 000 stars in the programme now have their parallaxes estimated to better than 0.002 arcsec, sufficient for distance estimates to be made for stars as far as 1000 light years distant from the Sun.

First Accurate Three-Dimensional Mapping of the Celestial Sphere by Hipparcos

The extremely accurate positions, motions and stellar distances determined from the Hipparcos data will eventually result in an enormous stellar catalogue of unprecedented accuracy and scientific importance, which will place ESA's contribution to the measurement of star positions in a remarkable historical context. Over the last two thousand years, stellar positions have been compiled into catalogues furnishing increasingly more accurate two-dimensional coordinates projected onto the celestial sphere. Depiction of the heavens has also evolved through the ages, and has included the celestial globe, the astrolabe (commonly used during Medieval times to help locate celestial objects and solve practical problems in astronomy and navigation), the armillary sphere (an open framework emphasising the principal coordinate circles), and the star charts, devoted to celestial cartography, or uranography.

These tremendous works combined remarkable scientific, artistic, and decorative skills, and aimed to assist in the visualisation of the arrangement and extent of the ancient constellations, written descriptions of which date back to the works of Ptolemy in his classic Almagest of the Second Century A.D. Famous examples of these star charts include the Uranometria atlas of Johann Bayer (1603), the Prodromus Astronomiae of Johannes Hevelius (1690), the Atlas Coelestis of John Flamsteed (1729), the Uranographia atlas of Johann Bode (1801), and the Uranometria Nova of Friedrich Argelander (1843). Huge and numerous celestial mapping programmes of considerable scientific importance have continued since then, all of them concentrating on the determination of the two-dimensional coordinates of the stars, with increasing accuracy, increasing numbers of stars, or increasing limiting magnitude.

A dramatic indication of both the scientific objectives and the remarkable success of the Hipparcos mission are the accompanying three-dimensional sky images, which are being published here for the first time, based on the global solution of the first 30 months of the mission data. A nonlinear transformation between real and apparent distance has been used for these images, partly to enhance and facilitate appreciation of the depth effect, and partly to limit the scientific information conveyed in these images in advance of catalogue completion. The three-dimensional images correspond to the view of the celestial sphere that would be obtained with a separation of about 2 light years between the left and the right eye (rather than the 0.00003 light year used by Hipparcos, namely the diameter of the Earth's orbit). Stellar images are shown with a size proportional to their apparent brightness (except for stars fainter than about 9 mag which are all shown the same size). The accompanying black and white images are the corresponding regions of the sky, as they appear to the naked eye and from which, of course, depth information is entirely absent.

It should be stressed that the stellar distribution perpendicular to the plane of the sky is, for the vast majority of stars, and for the very first time, using the tremendous depth and precision of the Hipparcos data, an accurate reflection of the true stellar distribution in space.

The 3-D images on the following pages should be viewed using the red/green coloured glasses provided, with the red filter covering the left eye, and the green filter covering the right eye. The images should be viewed in good lighting conditions, from a distance of some 50–100 cm, with the line joining the two eyes parallel to the horizontal sides of the image. As the two separate images for the two eyes 'fuse' into a single image, the depth of the stellar distribution should become clear. It may take several minutes of viewing for this effect to become fully apparent. It may be worth experimenting with different viewing distances, and with and without spectacles if these are usually worn.

Scientific Involvement in the Hipparcos Mission

Four European consortia collaborate with ESA in the scientific conduct of the Hipparcos Project. Representatives of these Consortia form the Hipparcos Science Team, which has advised ESA on all aspects of the mission since the Project's acceptance within the ESA Scientific Programme in 1980. The members are M.A.C. Perryman (Chairman), U. Bastian, P.L. Bernacca, M. Crézé, F. Donati, M. Grenon, M. Grewing, E. Høg, J. Kovalevsky, F. van Leeuwen, L. Lindegren, H. van der Marel, F. Mignard, C.A. Murray, R.S. Le Poole, H. Schrijver and C. Turon.

The active leading Scientific Consortia participants are:

FAST Consortium: J. Kovalevsky (Team Leader), M. Badiali, P.L. Bernacca, H.H. Bernstein, G. Borriello, B. Bucciarelli, F. Donati, J.-L. Falin, M. Froeschlé, R. Hering, M. Lattanzi, H. Lenhardt, J.F. Lestrade, H. van der Marel, F. Mignard, B. Morando, R. Pannunzio, J.L. Pieplu, R.S. Le Poole, R.A. Preston, S. Röser, H. Schrijver, G. Seryés, H. G. Walter and R. Wielen.

NDAC Consortium: L. Lindegren (Team Leader), D.W. Evans, E. Høg, F. van Leeuwen, C.A. Murray, M.J. Penston, C. Petersen and S. Söderhjelm.

TDAC Consortium: E. Høg (Team Leader), G. Bässgen, U. Bastian, P.L. Bernacca, D. Egret, M. Grewing, V. Grossmann, J.L. Halbwachs, J. Kovalevsky, F. van Leeuwen, L. Lindegren, V. Makarov, H. Mauder, H. Pedersen, C. Petersen, P. Schwekendiek, M.A.J. Snijders, K. Wagner and A. Wicenec.

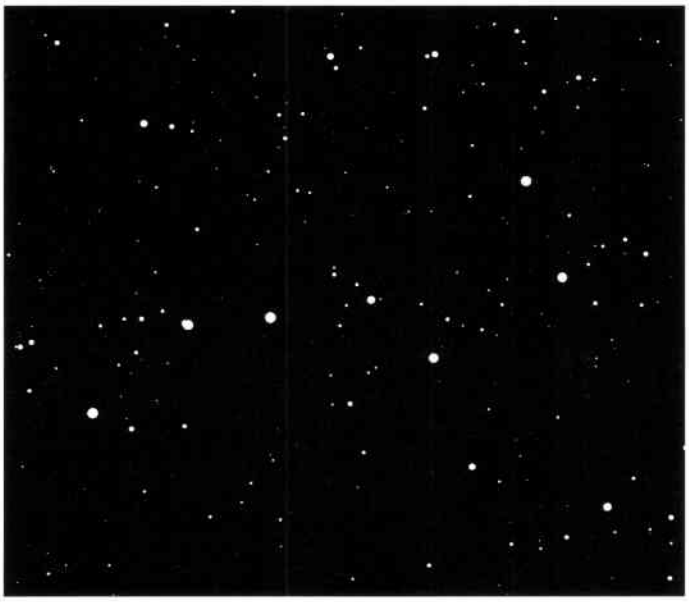
INCA Consortium: C. Turon (Team Leader), M. Crézé, D. Egret, A. Gómez, M. Grenon, H. Jahreiss, Y. Réquième, A.N. Argue, A. Bec-Borsenberger, J. Dommanget, M.O. Mennessier, J.C. Mermilliod, L. Prévot, F. Arenou, M. Chareton, F. Crifo, D. Morin, B. Nicolet, O. Nys and M. Rousseau.

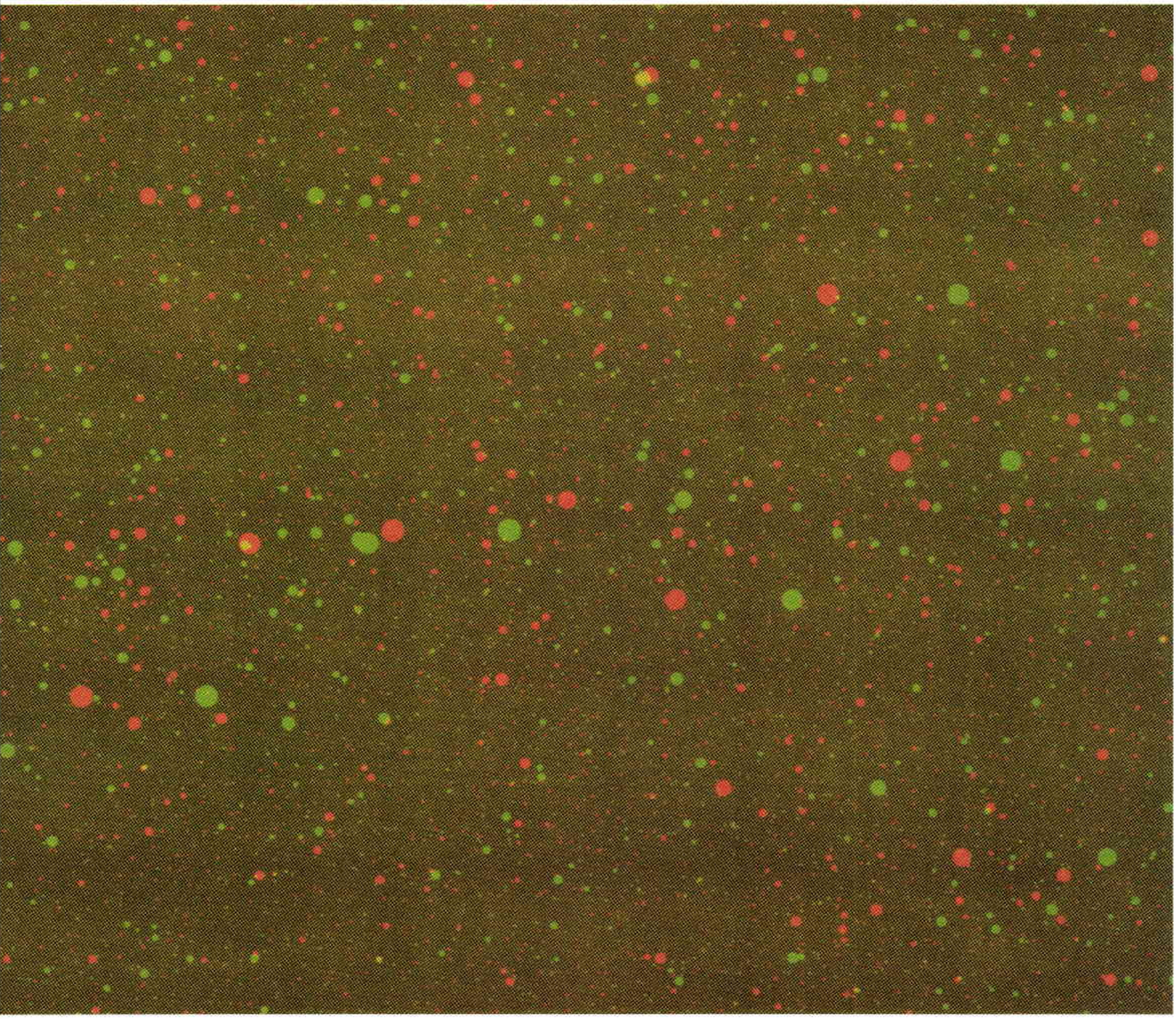
These names represent the involvement of some 150 scientists who have been, or still are, involved in the preparations for and execution of the data analysis and observing programme preparation. A full description of the scientific organisation of the project was given in ESA Bulletin No. 69, pp. 34–35.

The authors acknowledge the outstanding contribution to the scientific success of the Hipparcos mission provided by industry (including the prime contractor Matra Marconi Space), the ESA Project Team, and the ESOC satellite operations team.

URSA MAJOR

The 3-D illustrations on these two pages cover the constellation of Ursa Major (centred at about 12 h in right ascension and +60 deg in declination, and covering a region of about 36 x 31 deg). The black and white image (right) shows the field as it appears to the naked eye. The image below shows the three-dimensional spatial distribution of stars in the region of the constellation as it appears now. The right-hand page shows the same area of the sky, but with the stellar distribution as it will appear 60 000 years from now. This has been extrapolated into the distant future using the very accurate determinations of the proper motion for each star derived from the satellite data. The seven stars forming the well-known constellation stand out well in front of the background stars. These stars have their own distinct motion in space, and in several thousand years' time their relative motions will make the constellation quite unrecognisable compared with its present form.



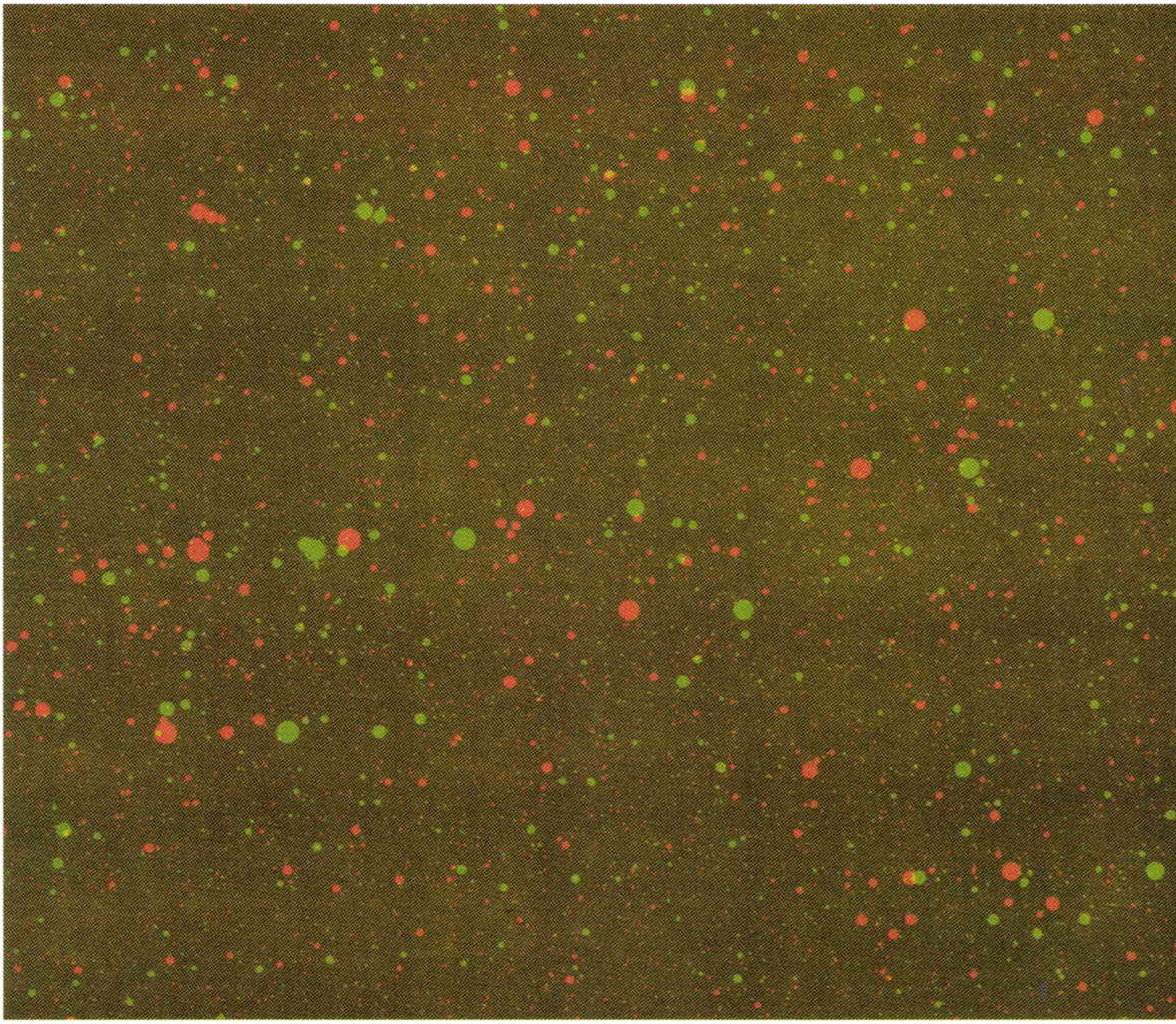


CYGNUS and LYRA

(Front Cover)

The cover illustration is of a 40 x 35 deg area of the sky including the constellations of Cygnus and Lyra, and is centred at about 20 h in right ascension and +40 deg in declination. The black and white image (right) shows the same field as it appears to the naked eye. The brightest star in the constellation of Cygnus, to the top left of the field, is the first-magnitude star Alpha Cygni, or Deneb. The brightest star in the constellation of Lyra, in the middle right of the field, is the zero-magnitude star Alpha Lyrae, or Vega.

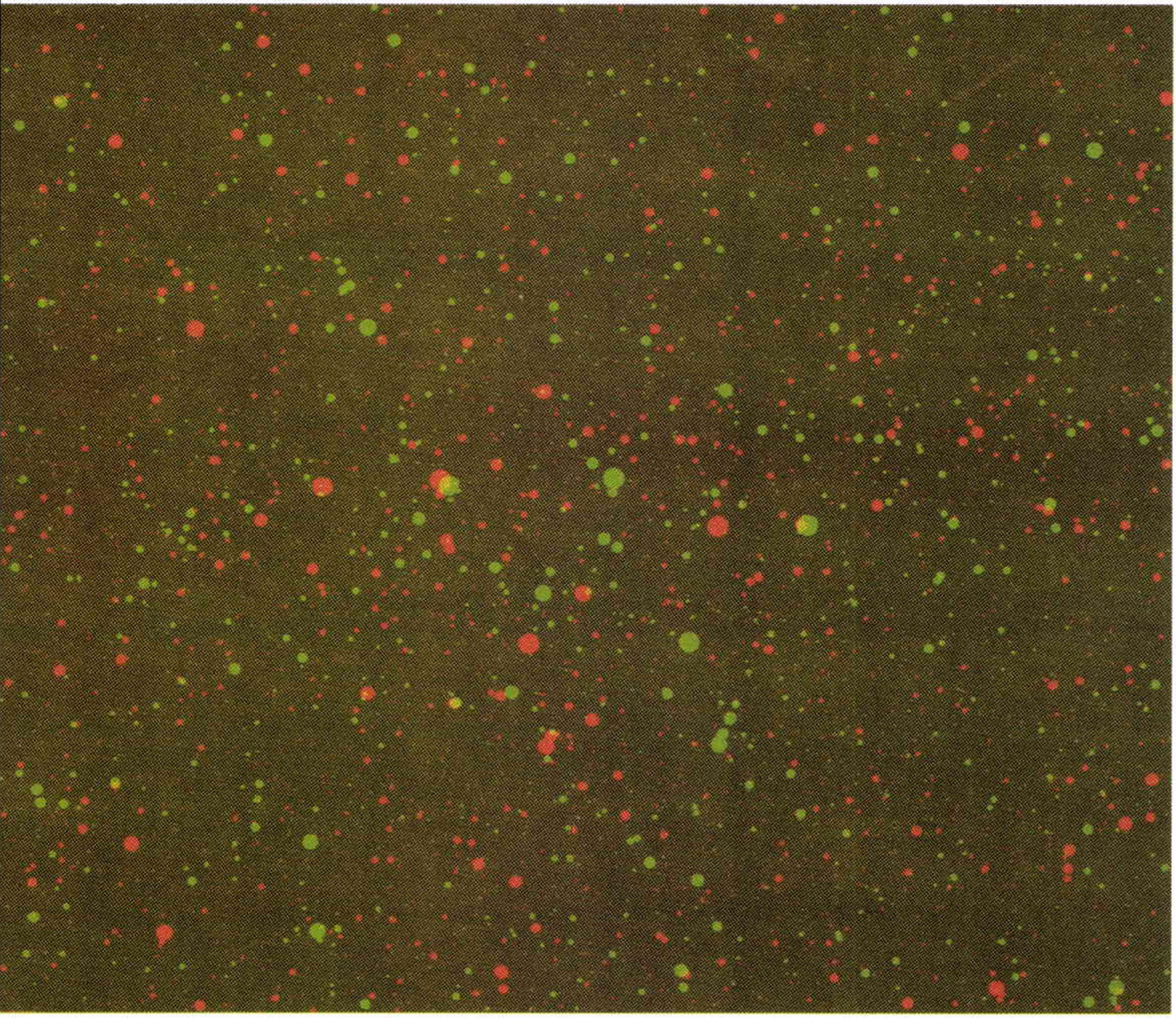
Below: The constellation of Ursa Major as it will appear 60 000 years from now.



CASSIOPEIA

The illustration below covers the constellation of Cassiopeia (centred at roughly 1 h in right ascension and +60 deg in declination, and covering a region of about 31 x 26 deg). The distinctive 'W' formed by the five brightest stars in this well-known constellation is evident in the black and white image (right), showing how the field appears to the naked eye.

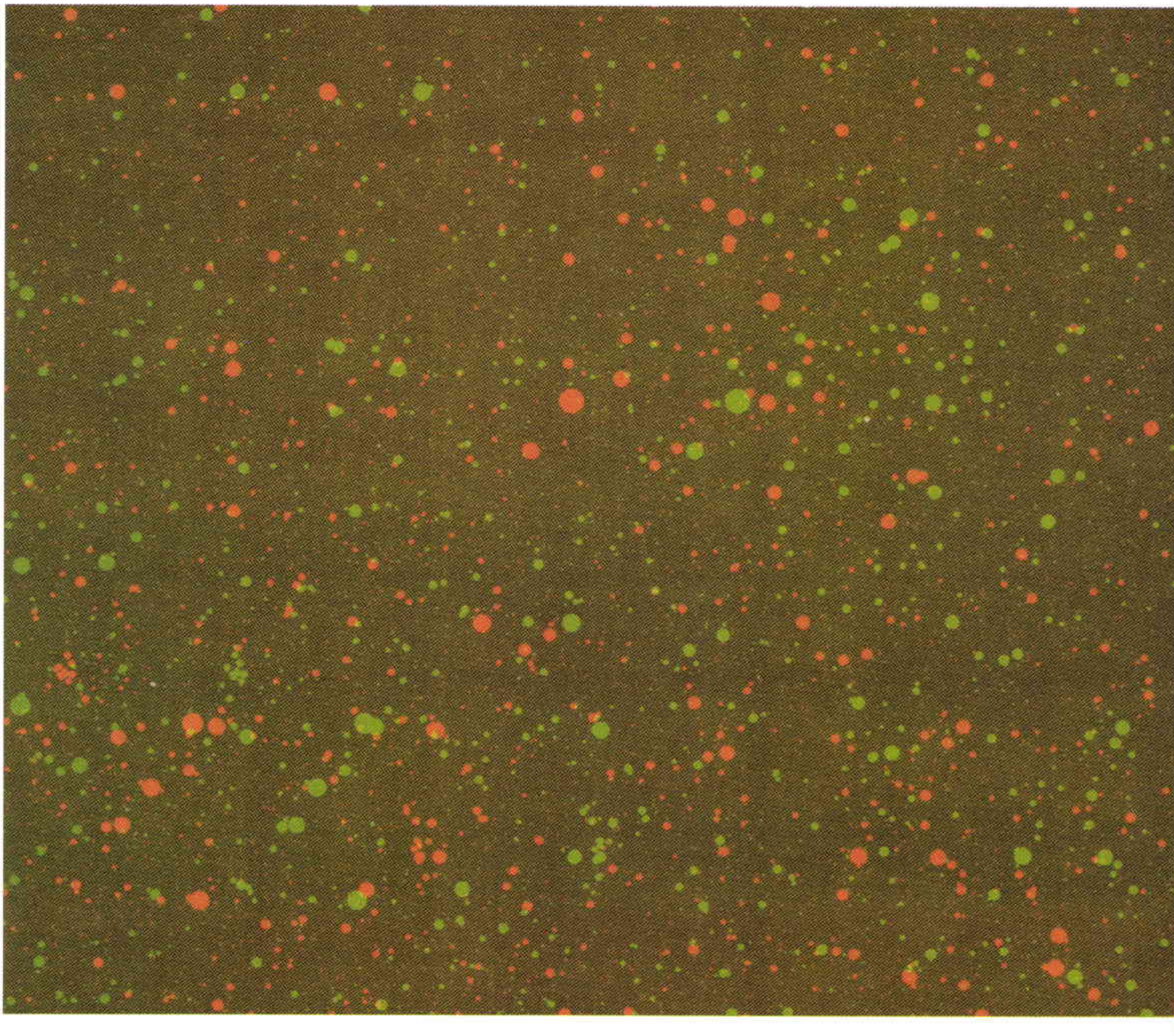
The ancients regarded the heavens as a ceiling or dome over the Earth, and later as a sphere surrounding it. The constellations have little practical relevance to modern astronomers or astrophysicists, and are not physical associations of stars. Rather, they were used to represent the pattern of stars in the sky using depictions of imaginary people, creatures or objects.



SCORPIUS

This illustration is of the constellation Scorpius, visible from the Southern Hemisphere. It is centred at roughly 17 h in right ascension and −30 deg in declination, and covers a region of approximately 42 x 36 deg. In the naked-eye representation (right), the constellation extends from the cluster of bright stars at the bottom left of the field, and sweeps up vertically through the line of bright stars, including the brightest in the constellation – the first-magnitude star, Antares – to the collection of slightly fainter stars to the top right of the field.

The four 3-D fields illustrated here together cover about one tenth of the entire sky, all of which has been mapped by the Hipparcos satellite. The Scorpius region, typical of the celestial sphere mapped by ESA's astrometry satellite, contains some 5000 stars included in the main Hipparcos observing programme, and nearly 50 000 measured astrometrically and photometrically with the Tycho experiment.



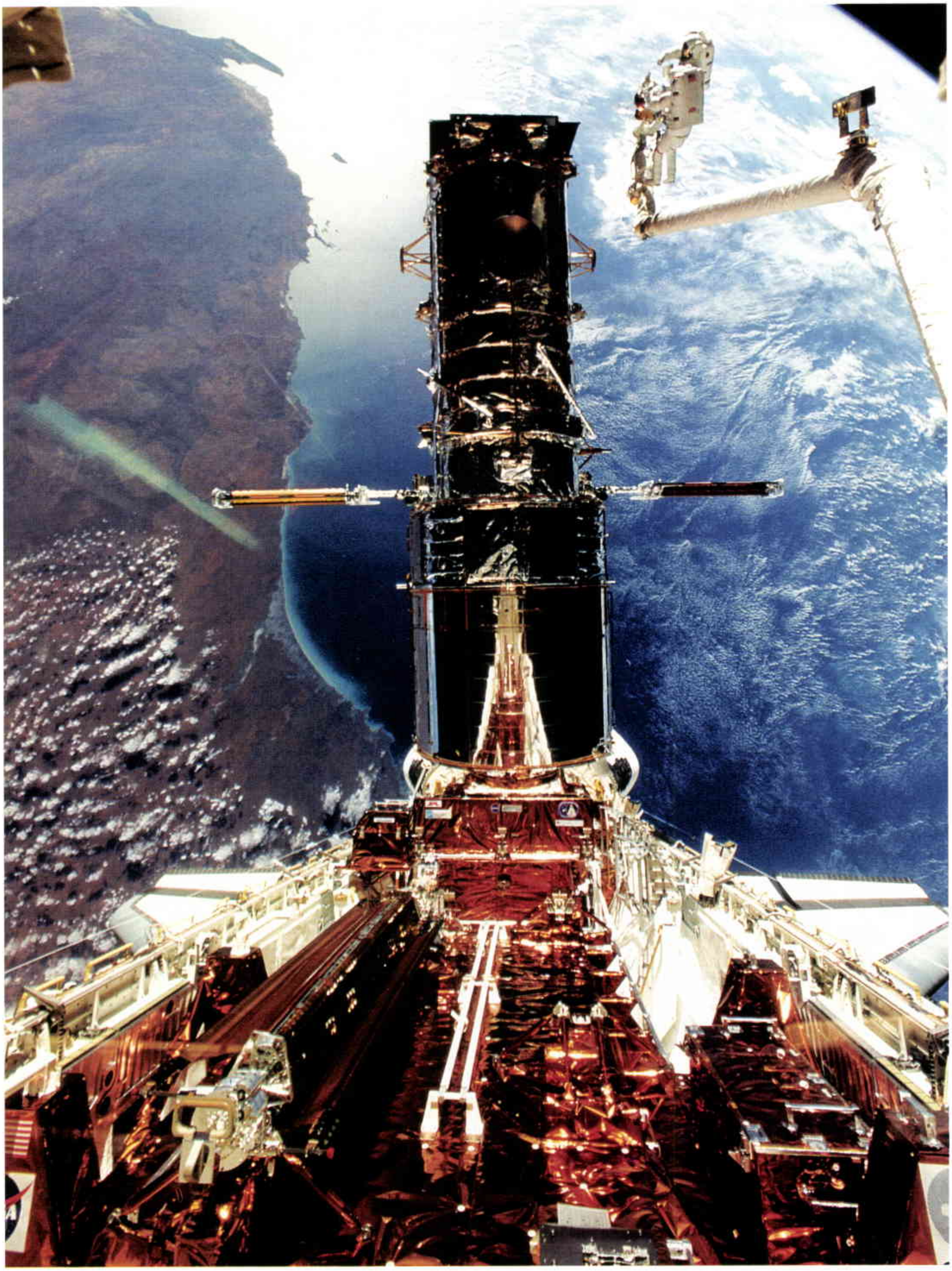


Figure 1. Orbiting Earth at an altitude of 325 nautical miles perched on a foot restraint on the RMS arm, astronauts Story Musgrave and Jeffrey Hoffman complete the last of the five space walks. Australia's west coast can be seen in the background

The HST First Servicing Mission – A Fantastic Success

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In the last issue of the Bulletin (No. 76, November 1993), I reported on the final preparations for the Hubble Space Telescope (HST) First Servicing Mission. Now happily, it can be recorded that the Mission has been an outstanding success, achieving, and in some cases surpassing, the hopes of all of the participants. The four EVA astronauts, with dedicated support from the ESA astronaut, Claude Nicollier, who operated the Remote Manipulator System (the Shuttle's robotic arm), completed all planned tasks within the five scheduled days without needing to use any of the contingency days built into the overall programme.

Introduction

Prior to the launch of STS-61, which was the official NASA Space Transportation System designation for the HST First Servicing Mission, it had been widely billed to be 'the most ambitious NASA mission since the days of the Apollo Moon shots'. In fact, even the most optimistic people were prepared to settle for only a small fraction of all of the planned tasks being accomplished.

Table 1 shows the complete list of hardware changes envisaged, but the official definition of a minimally successful mission included only the replacement of the failed gyroscopes with new ones and the fitting of either the New Wide Field and Planetary Camera or COSTAR (Corrective Optics Space Telescope Axial Replacement) to correct for the spherical aberration introduced by the HST primary mirror's faulty shape.

Table 1. Hardware to be carried on the Shuttle for the First Servicing Mission

Primary items to be installed:
- Wide Field/Planetary Camera II (WFPC-II)
- Corrective Optics Space Telescope Axial Replacement (COSTAR)
- Space Telescope Solar Array 2 (STSA-2)
- Two gyroscope units (RSU-2 and RSU-3 electronics)
- Magnetometer-1
- Solar Array Drive Electronics (SADE) unit

Secondary items to be installed:
- Goddard High Resolution Spectrometer (GHRS) repair kit
- Magnetometer-2
- DF-224 Coprocessor
- Gyro-1 fuses (RSU-1)

The success of the Mission was not serendipitous. Although public attention, understandably, was focussed on Space Shuttle Endeavour's seven-man crew, there were thousands of engineers and technicians working 24 hours per day throughout the 10 days of the flight to support them, to investigate and resolve problems (euphemistically known as 'anomalies'), and to make decisions in near-real-time whenever necessary.

In order to provide this support, there were countless meetings and an intensive training programme extending over several years. These started at local level and gradually became more and more complex until ultimately, in the last five months before launch, there was a series of Joint Integrated Simulations (JISs) where everyone involved, from the junior technicians to the senior managers, had to be in the physical locations they would occupy during the actual Mission. For these JISs, Endeavour's crew was in a simulated Shuttle cabin and the EVA astronauts in a large water tank at Marshall Space Flight Center (MSFC) or at Johnson Space Center (JSC), carrying out the tasks that they would later have to perform in orbit.

During these simulations, a team of experts introduced possible problems that might arise during the mission in order that the astronauts and the engineers and managers of the ground teams could practise the communication techniques, carry out the type of investigation that would be needed during the mission, and come to decisions on the steps necessary to resolve the anomalies.

Although these JISs were not very popular at the time, involving as they did much travelling and extremely unsocial working hours, their value was very evident when difficulties arose during the mission itself.

The daily round

Table 2, reproduced from the previous Bulletin article, shows the overall Mission planning based on a 2 December 1993 launch date. Subsequent to this, the launch date was advanced one day to increase the margin for completing the mission prior to Christmas. However, wind forces at the Kennedy Space

Table 2. Summary timeline for the mission in relation to Mission Elapsed Time (MET) and Greenwich Mean Time (GMT)

MET	Major Event	GMT		
D H M		D	H	M
00:00:00	Shuttle launch (1 December 1993)	335	09	30
01:03:00	Close HST aperture door	336	12	30
01:23:45	Manipulator arm grapples HST	337	09	15
02:00:40	Berth HST			
	EVA-1:			
02:19:35	Change out Gyros 2, 3 and Magnetometer-1	338	05	05
03:01:35	Prepare SAC for SA change out	338	11	05
03:02:15	SA +V2 Wing retraction	338	11	45
03:03:30	SA −V2 Wing retraction	338	13	00
	EVA-2:			
03:19:35	Change out SA	339	05	05
04:01:35		339	11	05
	EVA-3:			
04:19:35	Change out WFPC	340	05	05
05:01:35	Install GHRS repair kit	340	11	05
	EVA-4:			
05:19:35	Replace HSP with COSTAR	341	05	05
06:01:35	Change out Gyro electronics 1, 3	341	11	05
	EVA-5:			
06:19:35	Change out SADE-1, Magnetometer-2 and fuse plugs	342	05	05
07:01:35	Install DF224 co-processor	342	11	05
07:02:20	SA +V2 Wing deployment	342	11	50
07:04:00	SA −V2 Wing deployment	342	13	30
07:20:05	Manipulator arm grapples HST	343	05	35
07:21:00	Unberth HST	343	06	30
07:21:1-	Manoeuvre HST to release position	343	06	40
07:23:20	Open HST aperture door	343	08	50
08:00:45	Release HST	343	10	15
10:21:45	Orbiter landing	346	07	15

Center (KSC) landing runway (known affectionately as the 'Skid Strip') were too strong on 1 December to permit a return-to-launch site landing in the event that some Shuttle anomaly required that the mission be aborted. A 24 hour delay was therefore necessary. Happily, on the second night conditions were excellent and the launch took place as planned. This table is therefore correct for the STS-61 mission as it took place, except for the landing, since this had to be advanced one orbit after completion of all tasks in orbit because of the threat of impending poor weather conditions at KSC. Consequently, the overall STS-61 mission, which had the possibility of lasting 14 days if all three contingency days were used, reverted to the planned nominal 11 days.

It is perhaps necessary to mention here a convention used in the remainder of this article.

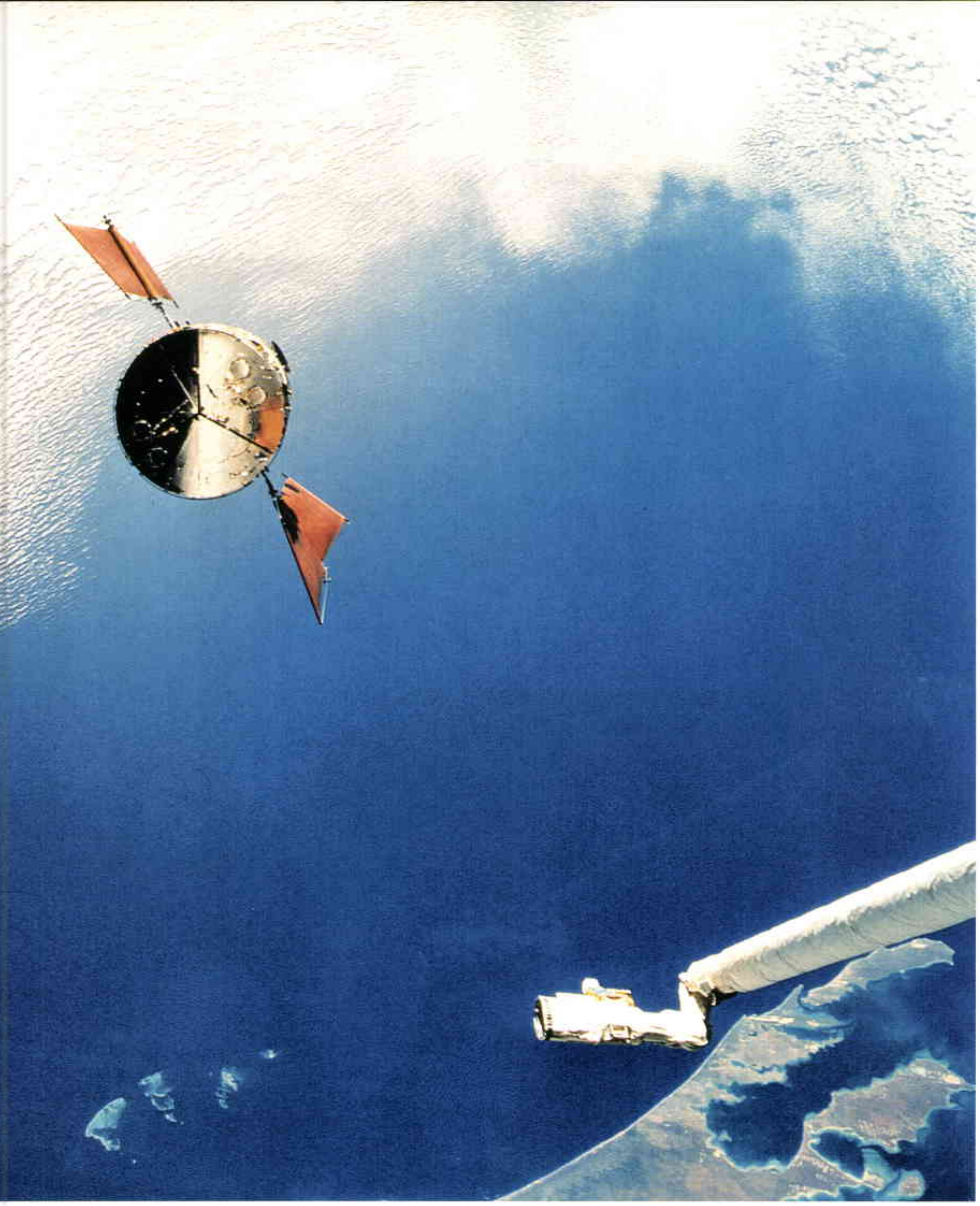


Figure 2. The Hubble Space Telescope (HST) seen from Space Shuttle 'Endeavour' just prior to rendezvous. Denham Sound and Shark Bay on Australia's west coast can be seen below the waiting arm of the Shuttle's Remote Manipulator System

The Extra-Vehicular Activities (EVAs) started at approximately 23.00 h each day JSC (Houston) time (06.00 h European time) and lasted for some 6 to 8 hours. Despite the fact that these activities were occurring in the middle of the night at JSC, they were always referred to as 'day' activities, and those occurring during crew's sleep periods as 'night' activities. This article maintains that nomenclature when describing the EVA tasks.

Table 3 shows the operations planned for each EVA day during the Mission. With one or two very minor exceptions, this overall schedule was maintained for the complete duration of the HST FirstServicing Mission. However, hidden behind this statement, which makes the activity schedule look conservative and easy to accomplish, were a number of almost daily incidents, which tested both the ingenuity of the astronauts and the resourcefulness of the ground crews to their limits. They also demonstrated the value of the various simulations and JISs.

Apart from the delayed launch, the difficulties started when the Shuttle approached HST in preparation for 'grappling' it with its robotic arm and berthing it in the cargo bay. The astronauts reported that one of the four solar-array blanket assemblies of STSA-1, appeared to have a severe bend in one of its booms and was badly distorted. Unfortunately, at this time the antenna that could transmit live video pictures to the ground was being used for the Shuttle's approach radar to enable it to rendezvous safely with HST, and so those of us on the ground could only conjecture how bad the situation really was.

Following the incredibly smooth capture of HST by ESA astronaut Claude Nicollier operating the Shuttle's Remote Manipulator System, the Telescope was berthed in Endeavour's cargo bay and we could see the extent of the distortion for the first time. For the ESA and British Aerospace engineers who had been responsible for designing and building both STSA-1 and its successor STSA-2, it was not a pretty sight! One boom was distorted out of its correct plane by about 60 cm (2 ft) and the boom itself appeared to be kinked in two places.

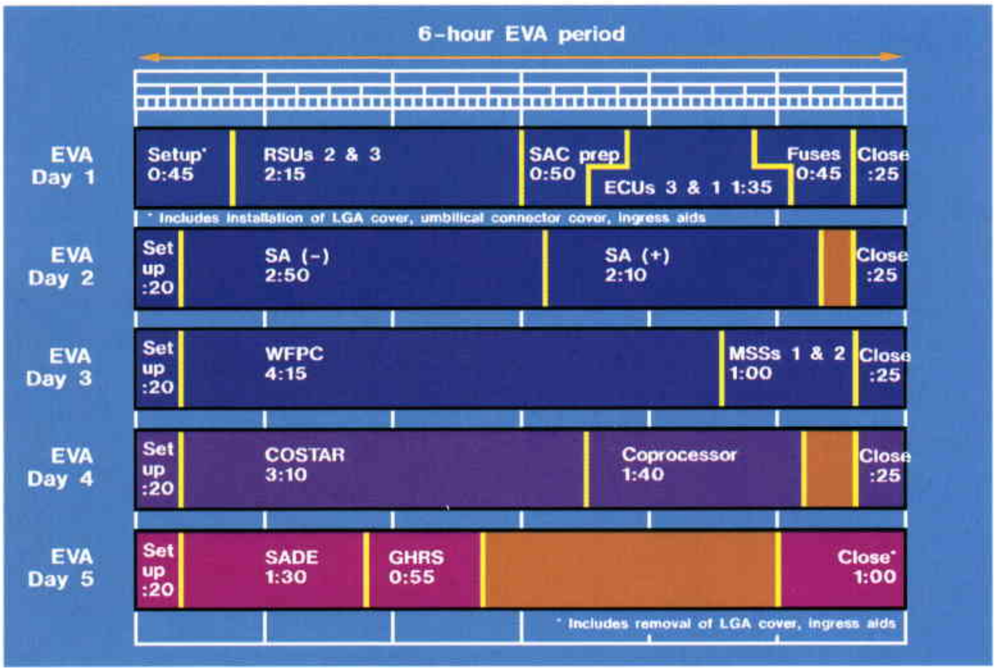


Table 3. Mission outline for each EVA day.

It was thought that retraction of the wing, scheduled for the end of the first EVA, might shake the boom free and so it was decided to leave the original planning in place, but to retract the 'good' wing (i.e. the undistorted one) first.

The next day, the first EVA day, revealed two problems. Following a smooth exchange of the faulty gyroscopes, a major difficulty arose in closing the doors of the HST bay that housed them. This was because when the doors were open during the exchange process, one was in sunlight and the other in shade. The temperature difference between sunlight and shade in space is of the order of 150°C and as a result the doors would no longer mesh correctly to close. Overcoming this problem took about one and a half hours of strenuous activity and it was finally resolved by a brute-force approach. The handle of the recalcitrant door was attached to a firm part of the HST by an adjustable tether. This could be attached to the two elements and then shortened via a handle to pull them together, rather in the way that it is possible to winch a car out of a ditch. After some sterling efforts by Story Musgrave and Jeff Hoffman, the two astronauts selected for the first EVA, this finally worked and the doors were successfully closed.

Later that same 'day' (actually at about 6 a.m. US Central Time), after the astronauts had completed the first EVA and were back inside the Shuttle cabin, the two solar-array wings were retracted. The first, the non-buckled one, retracted smoothly from a mechanical viewpoint, although there were one or two halts in the retraction, believed to be due to a marginally set microswitch turning off the drive electronics. However, when the buckled wing was retracted, it was clear that there would be significant difficulties. As the wing retracted, the bowing became worse, since the distortion was now a greater percentage of the still-deployed length, until finally, as the retraction reached the point of the major kink in the array, the solar blanket itself became slack, indicating that one boom had stopped moving. In accordance with the agreed Flight Rules, the astronaut stopped the retraction at this point to allow time for reflection by the ground crew.

This did not take long. Basically, it was felt that we had one successfully retracted wing to bring back to Earth for examination or to use as a flight spare if, for some reason, difficulties were encountered in installing the new array. On the other hand, if further attempts were made to retract the buckled array, there was a slight danger that the boom might fracture and thereafter constitute a hazard for the astronauts during the second EVA. The decision was therefore taken to jettison the wing at the start of the second EVA day.

Curiously, the intermittent stopping of retraction of a wing due to microswitch failure and the inability to retract a wing due to physical deformation had both been simulated during one of the JISs.

The first EVA day had been an exhausting one both physically and mentally. The EVA activities had lasted almost eight hours and the ground crew had had a 13-hour day, with some difficult decisions having to be taken near the end of the shift.

On the second day, the EVA astronauts were Tom Akers and Kathy Thornton, and it was

Kathy who, early in the shift, had the task of carrying the damaged array, whilst she was standing on the robotic arm, to the highest possible point above the Shuttle and then releasing it to become a further piece of space debris. However, as it will re-enter the Earth's atmosphere within about a year, it will not pollute space for long.

Tom and Kathy then installed the new solar arrays on HST and stowed the remaining wing of STSA-1 in the solar-array carrier for return to Earth.

A small thing that did not proceed exactly as planned on that second EVA day was that a microswitch guard on the HST latch for the Primary Deployment Mechanism (PDM) on each wing had suffered during its three years in space and could not be operated. After several unsuccessful attempts to fix the problem, it was decided to leave it as it was. Later, this was found to have an effect upon STSA-2 PDM deployment operations (see below).

And so to the third EVA day, with Story and Jeff once more performing the space walk. The main task for this day was to replace the Wide Field and Planetary Camera, and this went very well. During the secondary task of adding additional magnetometer units (MSSs), however, part of the thermal insulation became loose and was lost. The absence of this insulation could give rise to a light-contamination problem and so the crew, once back in the Shuttle cabin, fabricated a replacement cover to be installed during a subsequent EVA.

EVA day four saw Tom and Kathy conducting their second EVA of the mission. Their prime task this time was to install the telephone-kiosk-sized COSTAR, which would hopefully correct for the spherical aberration caused by the incorrectly shaped HST primary mirror. Once again, this installation went very smoothly, as did the secondary task of adding the co-processor unit, which would increase the HST memory.

Unfortunately, during the checking-out of this latter unit towards the end of the day, after the EVA was over, the ground engineers detected what they thought to be an error in the co-processor. After working all night, the GSFC engineers concluded that the problem was not in the co-processor itself, but rather was a result of the limited communications links between the Shuttle and the ground. Early the next day, a test was organised in which HST communicated with Earth directly via the TDRSS satellite chain rather than via the Shuttle. This test proved successful and so the co-processor was given a clean bill of health!

The fifth EVA day was to be Story's and Jeff's third, and hopefully final, space-walk. The major task for that day was to replace the Solar-Array Drive Electronics (SADE) unit, which had failed earlier in 1993. This was one of the units within HST which was not designed for replacement, and therefore some difficulty in making the exchange was expected. This proved to be the case and the task took considerably longer than expected.

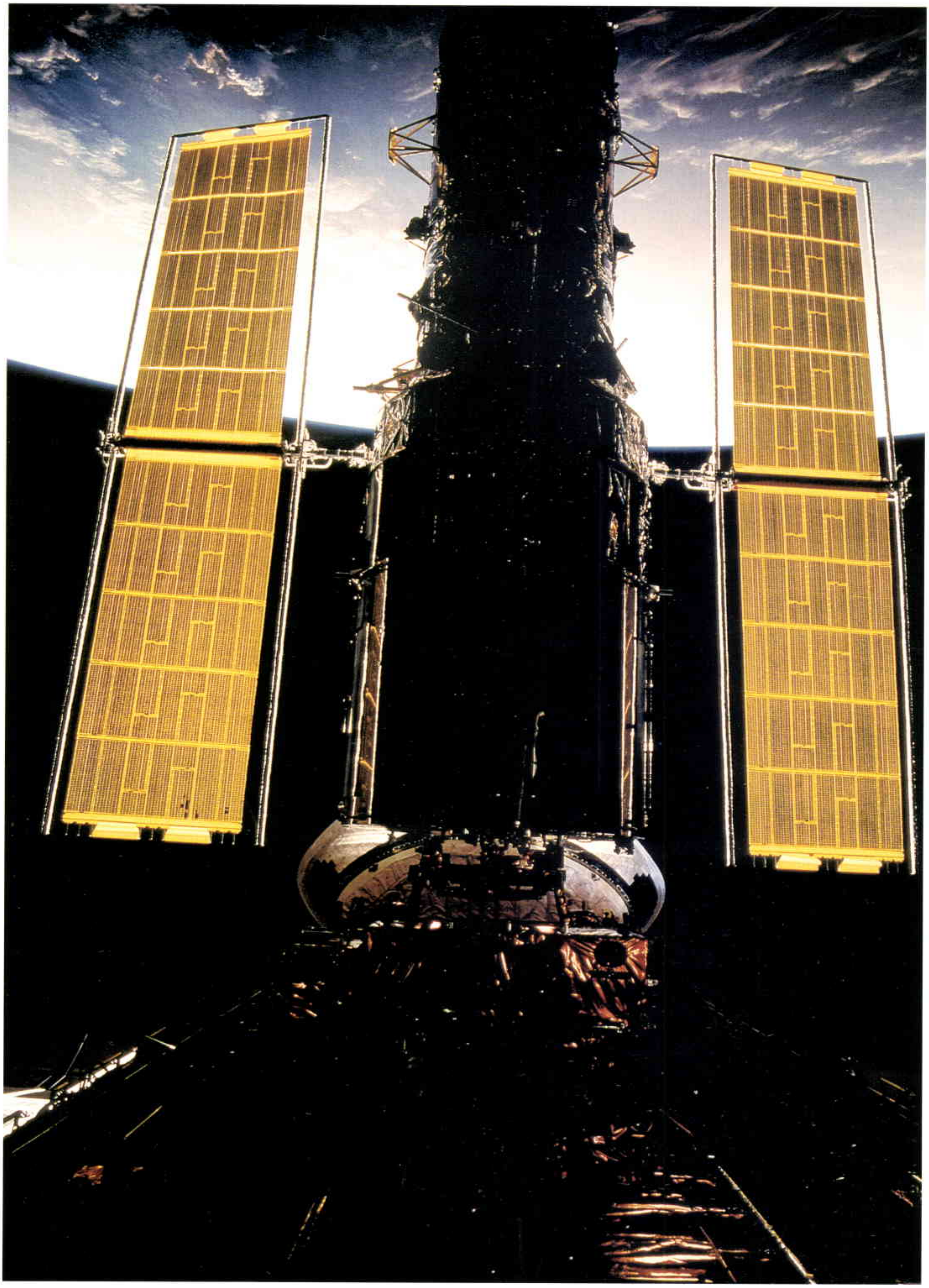
One memorable moment of that fifth day was that, during the above operation Story, who was standing on the robotic arm, dropped a small nut and it started to float down into the cargo bay. Story alerted Claude Nicollier, who was operating the arm, and he panned the arm down so accurately that Story was able to pluck the escaped nut in mid-space and return it to its rightful position.

A further task accomplished during this EVA was the fitting of the astronaut-manufactured magnetometer covers.

One minor problem arose during this EVA. The Primary Deployment Mechanisms (PDM), which move the furled solar arrays from their initial position lying alongside HST's body to be perpendicular to it, were scheduled to be operated under ground command from Goddard Space-Flight Centre (GSFC, in Maryland) whilst the EVA crew observed. Due to the inability to re-stow the microswitch guard on EVA day 2, there was extra friction occurring and the motors were unable to drive the PDMs as expected. The design had allowed for this eventuality and the crew were able quite easily, using the normal tool kit, to make the deployment manually.

Thereafter, the deployment of the solar arrays themselves proceeded flawlessly and was generally regarded as one of the most dramatic highlights of the Mission. For ESA and BAe, which had been the Prime Contractor for the HST solar arrays, this was the successful culmination of many years of effort.

Happily, although there were some anxious moments, everything was finally accomplished within the allocated five days of EVA and the next day HST was released by Endeavour to become once again the free-flying observatory that it was designed to be. The crew reconfigured the Shuttle cabin for re-entry, were interviewed by the President and Vice-President of the United States, and finally came



back to Earth, touching down at KSC at 00.26 h Eastern Standard Time on 13 December 1993.

The most ambitious space mission since the Apollo Moon shots had been accomplished 100% successfully and on schedule!

The European Team's role in the First Servicing Mission

Obviously, the major part of the FSM was conducted by NASA. However, the ESA/BAe team needed to support all operations involving the solar array and those for the SADE. Consequently, we had a major role in three of the five EVA days. On day one, we needed to supervise the retraction of STSA-1; on day 2 we were deeply involved throughout the day in the replacement of STSA-1 by STSA-2; and on day 5 there was the replacement of the failed SADE with its successor plus, the moment of truth, the deployment of the new solar arrays.

We also needed to be present in case anything went wrong during any part of the mission when we were not directly involved. This included keeping a very watchful eye on temperatures in the unusual thermal environment HST was experiencing attached to the Shuttle and, of course, making sure that other operations could not affect the solar arrays or the instrument for which ESA has prime responsibility, namely the Faint Object Camera.

Our greatest problem in carrying out these tasks was the shortage of manpower. Whereas GSFC were able to deploy over a hundred engineers at JSC and even more at GSFC itself, the combined key expertise of ESA and the Prime Contractor (BAe) totalled 15 persons. With this small number, we needed to maintain a 24 hour watch at both JSC and GSFC, whilst still having the key persons available, and fresh enough to make difficult decisions if necessary, during the critical points of the Mission. Add to this the need to attend Press Conferences and, for the more senior members of the team, repeated requests for interviews both from the press and from television, and it can be seen that the pressure was enormous. On top of this, assistance was needed in preparing the daily television summaries sent by satellite link to Europe. Table 4 shows the ESA and BAe project and management personnel who carried this load at JSC and GSFC throughout the campaign.

Perhaps also because of the fact that the 'day's' activities typically started at 8.00 in the evening and ended, usually with staff in a somewhat emotionally excited state, at about

Table 4. The USA-based ESA/BAe Project Team for the HST First Servicing Mission

	JSC	GSFC
ESA	R.M. Bonnet D. Dale D. Eaton B. Henson K. Leertouwer Y. Knudson	G. Haernquist H. Schroeter G. Beere L. Gerlach
BAe	M. Newns J. Huxtable A. Fromberg	C. Hazell R. Turner C. Finch

10.00 in the morning, this was felt by very experienced launch-campaign attendees to be the most exhausting they had ever participated in.

The proof of the pudding...

There is an old English saying that the proof of the pudding is in the eating. In other words, there is no value in making something look attractive unless it also serves the purpose for which it was created. So it was with the First Servicing Mission. Although it had passed off very successfully as a Mission, it would be valueless unless it also significantly improved the health and scientific value of the Hubble Space Telescope. Consequently, as soon as the Telescope was released from the Shuttle, and before the latter's landing at KSC on the morning of 13 December, feverish activity was under way at GSFC and at the Space Telescope Science Institute in Baltimore to find out whether the hoped-for improvements had in fact been achieved.

The results were in fact incredible – even better than the engineers and scientists had dared to hope! The jitter caused by the solar arrays had been much reduced and even though there was a small residual jitter, the cause of which has not yet been established, it was immediately clear that this would not be a problem. Of much more significance, however, was the scale of the improvement in the Wide Field and Planetary Camera images and in the instruments served by the COSTAR. It is certain that in future issues of the Bulletin there will be articles from the scientific community about the exact degree of improvement, but one example can already be given.

One of the ways of measuring the performance of a telescope is via the so-called 'encircled energy'. This is the percentage of the available light contained within a 0.1 arcsecond solid angle. The original specification for HST before

Figure 3. HST's new solar-array panels, photographed against the blackness of space from the aft flight deck of the Shuttle (facing page)

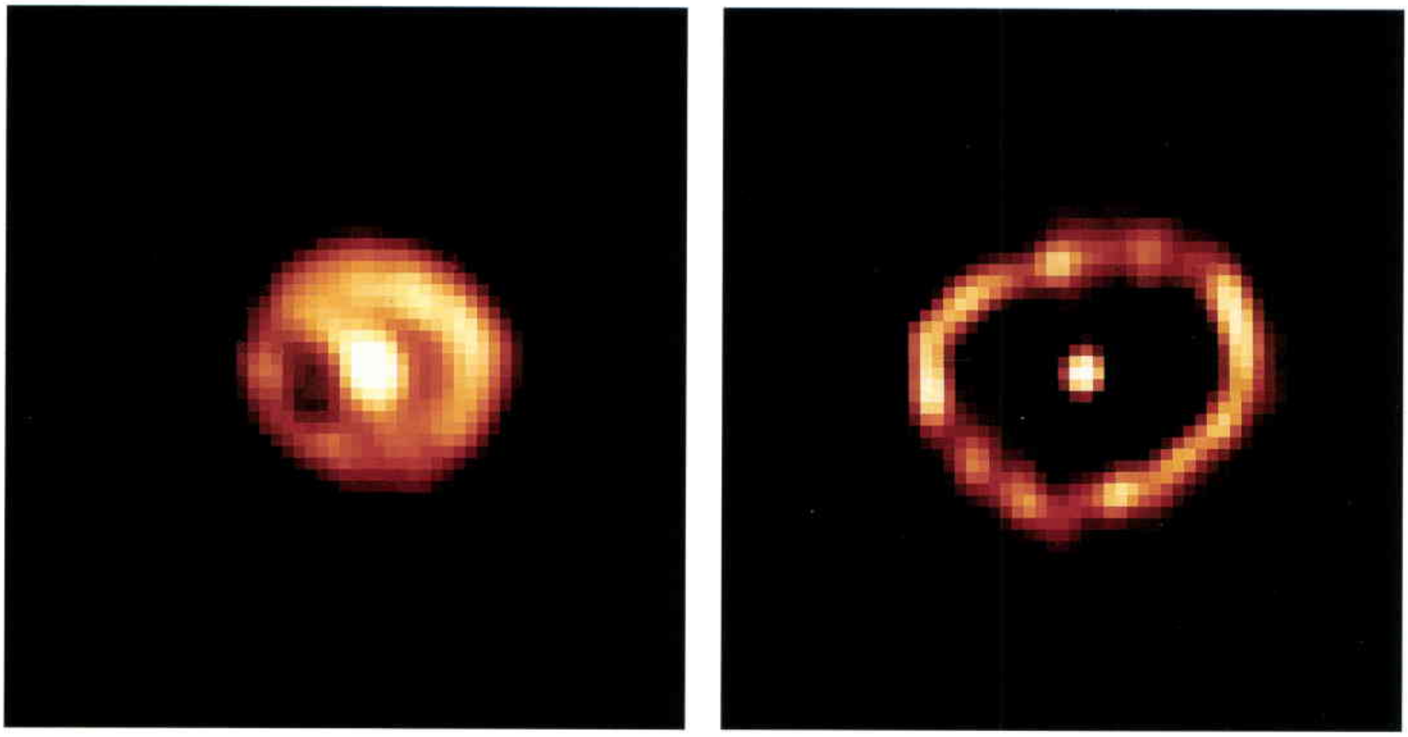


Figure 4. Nova Cygni 1992 photographed by ESA's HST Faint Object Camera before and after the mounting of the corrective COSTAR optics

PRE-COSTAR

WITH COSTAR

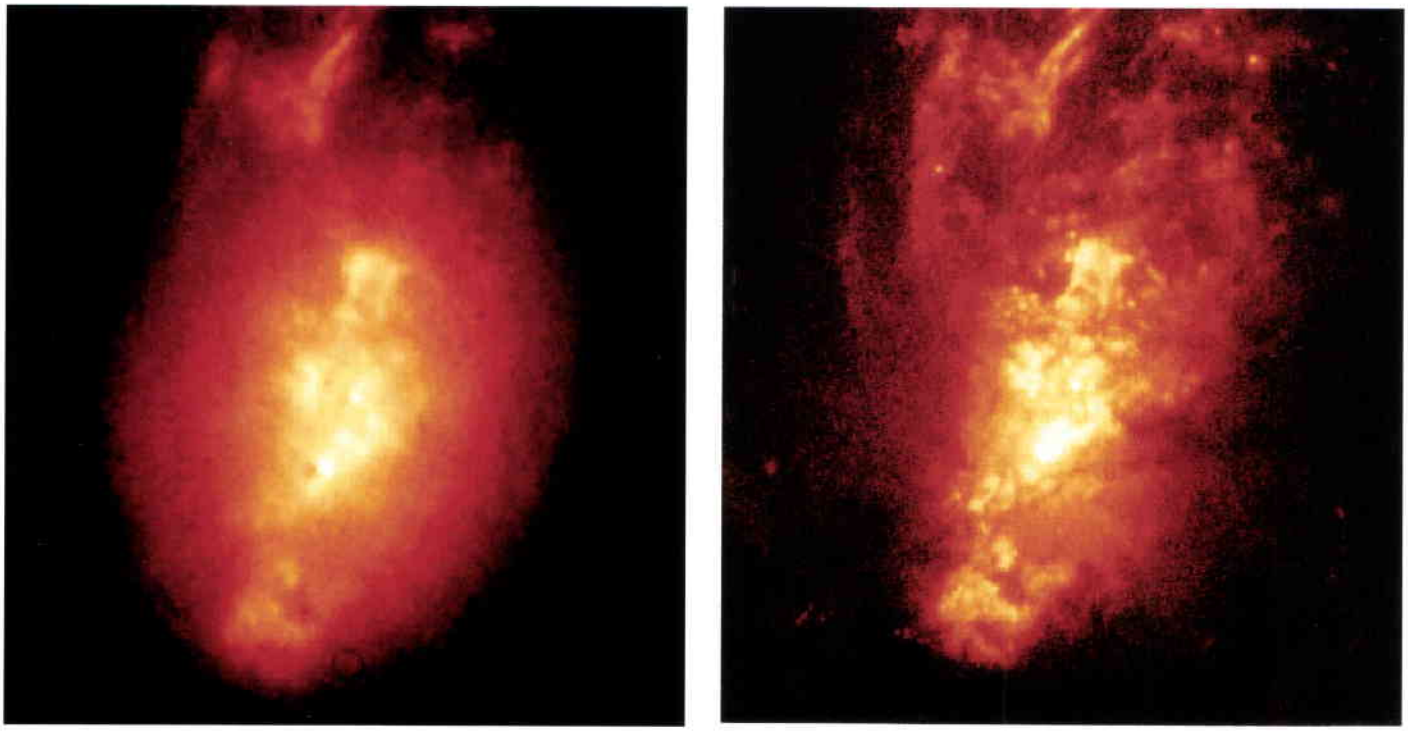


Figure 5. The central region of the Active Galaxy NGC 1068 photographed by ESA's HST Faint Object Camera before and after the mounting of the corrective COSTAR optics

its launch in 1990 was that this figure should be at least 70%. After launch, due to the spherical aberration caused by the imperfection in the primary mirror, the actual encircled energy was about 15%. When it was decided to attempt a remedy via COSTAR, the target value, due to the introduction of two additional mirrors, was 65%. The tests carried out so far have all indicated actual encircled-energy figures well in excess of the original 70% goal.

In other words, the corrected HST is substantially better than the original expectations. Needless to say, the scientific community is overjoyed and anxiously looking forward to exploring the edges of the Universe!

The investigation of STSA-1

Although one wing of the first solar array (STSA-1) had to be jettisoned, the other wing has been successfully brought back to Earth and is the subject of an intensive investigation within ESA. Any item that has spent some time in space and then been recovered is an extremely important element in extending the technical knowledge that will lead to even better spacecraft in the future.

ESA has already carried out such investigations on its part of LDEF (the Long-Duration Exposure Facility) and on Eureca. However, STSA-1 is a particularly valuable acquisition since it contains solar cells, interconnects,thermal blankets, and a number of mechanisms, all of which have been exposed to the harsh environment of space for more than three and a half years. Study of all of these subsystems will give ESA valuable information for the building and testing of similar subsystems for its future projects.

Apart from the investigation of units and other hardware, the STSA-1 will be a further source of scientific data. The total area of this wing, when deployed, was approximately 30 m^2, and thus it constituted a substantial catchment surface for micrometeorites and other space debris. The fact that one side of the array was constantly pointed towards the Sun whereas the other was in shade adds to the interest.

And finally....

The completion of the First Servicing Mission brings to an end the hardware involvement in HST of ESA and its contractors, apart from the investigation of STSA-1 and some analytical work to prove the efficiency of the modifications introduced into STSA-2. The industrial and ESA teams will be re-assigned to other projects or will retire and the residual hardware will be disposed of.

However, there will still be a strong ESA involvement in HST through the teams of European scientists working in the Space Telescope Science Institute in Baltimore and at the European Southern Observatory (ESO) in Garching, Germany. Nevertheless, for many this is the end of a Programme that has lasted some sixteen years, and one that has had its moments of anguish as well as its moments of jubilation.

It is appropriate that this long project should have finished on such a high note and it is certain that all those who have worked so hard for so long will follow with interest and with pride the scientific achievements that their efforts over the years have made possible. Apart from the scientific return, however, the comradeship between ESA and European Industry and between Europe and the USA which this Project has created and nurtured will live with all of us who have worked on it for the rest of our careers and beyond.

Figure 6. The jubilant crew of the Hubble Space Telescope Servicing Mission (STS-61). In the front row are the three crew members who assisted from inside Endeavour's cabin throughout the five space walks: from left to right, ESA astronaut Claude Nicollier (Mission Specialist), with NASA astronauts Kenneth Bowersox (Pilot) and Richard Covey (Mission Commander). In the back row, again from left to right, are the four spacewalking astronauts: Story Musgrave (Payload Commander), Jeffrey Hoffman, Kathryn Thornton and Thomas Akers (Mission Specialists)

Using Lunar Resources – The Next Step?

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When the Soviets launched a small metallic sphere called 'Sputnik' into space back in 1957 nobody imagined that it constituted the prelude to some of the most gigantic projects of the 21st Century. Now, as we stand on the verge of the second millenium, is the era of such mammoth projects as Apollo over forever, or will man walk again on the surface of the Earth's own natural satellite?

Introduction

The general public's stunned reaction to the launch of Sputnik was a good indication of the impact that space endeavours would have on public opinion in the years ahead. Just a few years later, in the context of a cold war, John F. Kennedy reacted immediately to the launching of Yuri Gagarine into orbit by embarking on a 'conquest of the Moon', not merely for scientific goals, but to bolster the USA's national image and prestige.

More than 5% of the annual federal budget was to be assigned by the United States during the mid '60s to fund an $ 80 billion (cumulative figure in 1990 dollars) programme. In the whole history of mankind, never had so much money been spent in so short a period on a prestige programme.

What enabled the starting, and the subsequent success, of the Apollo Programme was the convergence of a strong political will, of a formidable financial capacity, and of a sufficiently mature industry to allow its development towards a lunar programme. In order to establish whether a return to the Moon is desirable, we must first check whether this convergence of factors is still with us today.

The technology that was developed by the USA to go to the Moon, and then later through other space programmes, by the USA, the USSR and Europe, is certainly sufficiently advanced today to allow us to land safely and precisely, without any further major development effort.

On the other hand, the political will that was the foundation of the Apollo Programme vanished with the pulling down of the Berlin Wall. It will therefore be necessary to find a new political consensus.

Financial capacities have also eroded since the Apollo days. That funding was essentially derived from the wealth accumulated during the so-called '30 glorious years' that followed World War II. However, this period of conspicuous prosperity has been followed by a period of economic crisis, in which we still find ourselves. It is a World crisis linked mainly to the creation of a global economy, with the deepening of the gap between the countries of the 'triad' (North America, Western Europe and the Asia–Pacific zone) and countries of the south (mainly in Africa). The emergence of Eastern Europe from a socialist economy must also be taken into account: this evolution is not taking place under optimal conditions and necessitates – and will more and more necessitate – investment by the more industrialised countries. At this stage, what we see is not a short-term crisis, but probably the state of the World's economy until the end of the century. This factor must also be taken into account.

To those factors, two further pre-occupations have cropped up which were not with us at the time of the Apollo Programme: the availability of raw materials and their exploitation under environmental constraints. This is particularly true as far as energy is concerned. More precisely, the 21st Century will probably be marked by a water shortage, but it could also see a depletion of its main energy resources taking into account economic as well as environmental factors. The successive oil shocks of the '70s and '80s can be considered the forerunners of this major problem.

Space can provide an answer to this energy-resource problem in the 21st Century cleanly and safely if we pursue a well thought out exploitation of lunar resources. As explained later, the exploitation of the Moon's store of helium-3 is just one of several such possibilities. Of course, to do so, it would be necessary to invest large amounts of money. Given the present state of the global economy, massive investments must not be sought today for a problem that we will not face until several tens of years hence. However, it is necessary that, from now on, we keep this option open ready for the moment when such decisions will indeed have to be taken. We already need to begin preliminary studies and appropriate tests on Earth, and then later in space.

If the necessary steps are taken progressively, one by one, mastering the technological, environmental and economic challenges as we go, it should be possible to minimise the need for public funding by encouraging private investment. These private funds would not be the sort of short-term financing often referred to in the space context in the past, but long-term funding of the type invested in such projects such as the Channel Tunnel or, on a lesser scale, the Prado-Carénage tunnel in Marseilles (F).

Such a reasonable and progressive approach, in a context of international cooperation, can create a new political will because it solves an energy problem, linked with developing countries, in a safe and environmentally friendly manner. It would also boost R&D and thus create real jobs for tomorrow.

There might indeed, therefore, be an opportunity to return to the Moon, based on proven technologies and on an optimum use of public and private funding. The feasibility of such an endeavour has been demonstrated by the recent 'SYSTEMSI' study, led by ESA's Long-Term Project Office, which has taken into account not only techniques developed in the space industry, but also in the fields of construction and the financing of large-scale terrestrial infrastructures.

The next century's energy problem

Increasing demand

In the past, mankind's consumption of energy has always been on the increase. Now, for the first time, due to increasing savings and better control, energy consumption in the industrialised countries is tending to stabilise, and even starting to fall in some instances.

On the other hand, as industrialisation keeps on expanding in the Third World, the consumption of energy in these countries is bound to increase, constituting 65% of the World's demand by 2020 (Fig. 1). Thus, despite a new tendency towards a decrease in industrialised countries, the global demand for energy will keep on increasing in the century to come (Fig. 2).

Consequently, one of the most critical energy-linked problems that civilization is facing today is the development of safe, clean and economical sources of energy to support the 11 or 12 billion people expected to inhabit the Earth in the 21st Century.

Current supplies

Fossil fuels

In coping with a relentlessly increasing demand during the last century, man's only

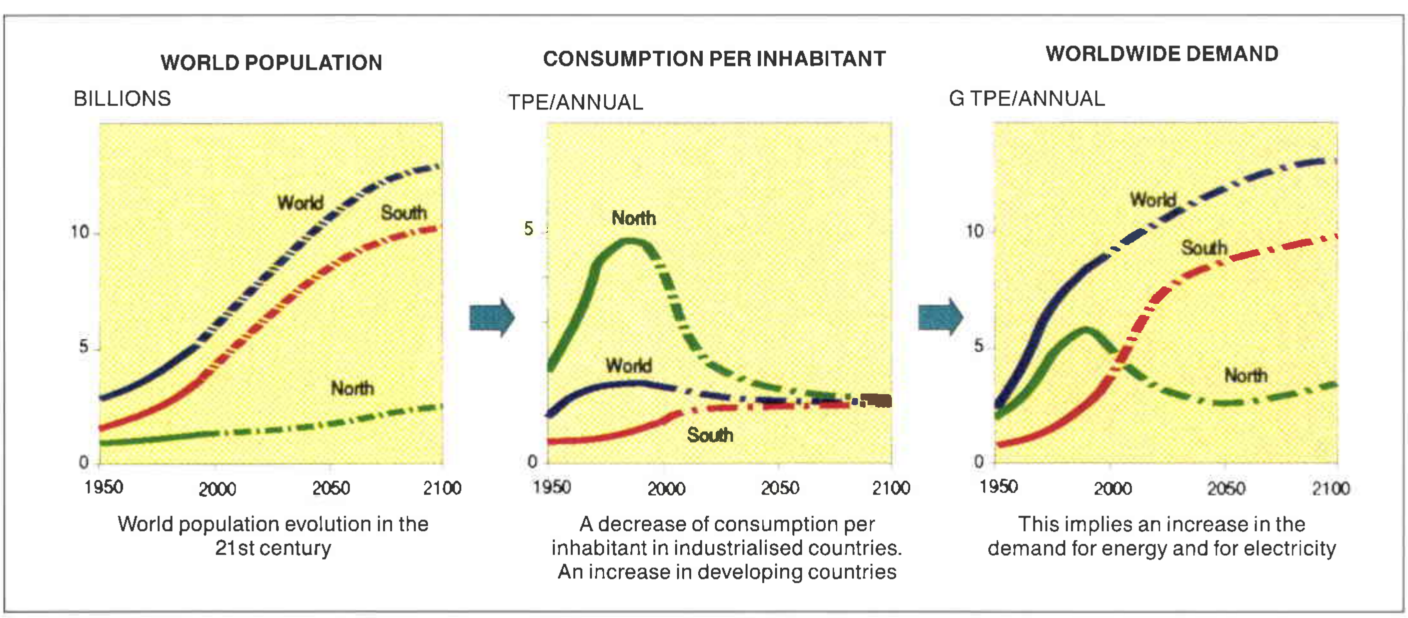


Figure 1. The factors contributing to the World's energy problems (from '2100, récit du prochain siècle, Ed. Payot)

pre-occupation with energy has been with its production. First with coal, and then with the oil that soon replaced it thanks to its greater profitability and better transportation facilities, mankind is consuming fossil-fuel reserves faster than they are being renewed. The search for new coal and oil fields under the seas and glaciers to keep pace with the demand for fossil fuels will become more and more costly, and ultimately will merely postpone the depletion of the reserves for just a few decades.

As regards oil, for example, the previous expected depletion date of 2030 cannot be pushed back beyond 2050, as experts believe that most of the World's main oil fields have already been discovered. With coal and gas, despite the substantial resources, today's high consumption – serving about 90% of the World's energy needs – will bring the first signs of depletion within the next 100 years.

No matter how long it takes before the depletion problem is felt, the first priority is to face the environmental problems that fossil-fuel consumption is causing. Until now, its impact has only been considered on a local scale. Today, however, we know that it is responsible for the greenhouse effect as well as for acid rain, which on a global scale have turned out to be much more harmful to the environment than we ever expected.

Nuclear fission

Given the need to develop different sources of energy, nuclear fission appeared to be the most attractive of the exploitable candidates. It had a number of obvious advantages in that the electricity it provided relied neither on oil supply nor on the climate, the availability of water to cool down the reactors being one of the few constraints. In the event, however, this new energy source did not develop very rapidly, its prospects for success being hampered by the high technology requirements and the inherent risk of nuclear proliferation. The few recent accidents, added to the still unresolved issue of radioactive-waste storage, have also served to slow the spread of new nuclear-fission plants.

Thus, during the 20th Century the considerations governing energy production have changed in two main respects: while energy savings have been encouraged, the nature and the quality of the primary sources have had to diversify and the use of renewable energy sources – geothermal, terrestrial solar power plants, hydroelectricity, wind energy, etc. – has been developed with the corresponding R&D. However, these new sources can only provide limited quantities of electricity in terms of the huge energy shortfall that will be encountered in the next century.

Various space-based concepts for generating energy have been elaborated, including both Solar Power Satellites built with lunar materials and Lunar Power Stations built on the Moon's surface. Another option is the use of lunar-sourced helium-3 in terrestrial nuclear-fusion reactors.

Nuclear fusion

Primarily two types of fusion cycle are presently being researched: the deuterium–tritium and deuterium–helium-3 cycles. The second of these produces less radioactivity than the first, but requires more energy and is dependent on a fuel found only on the Moon for large-scale energy production.

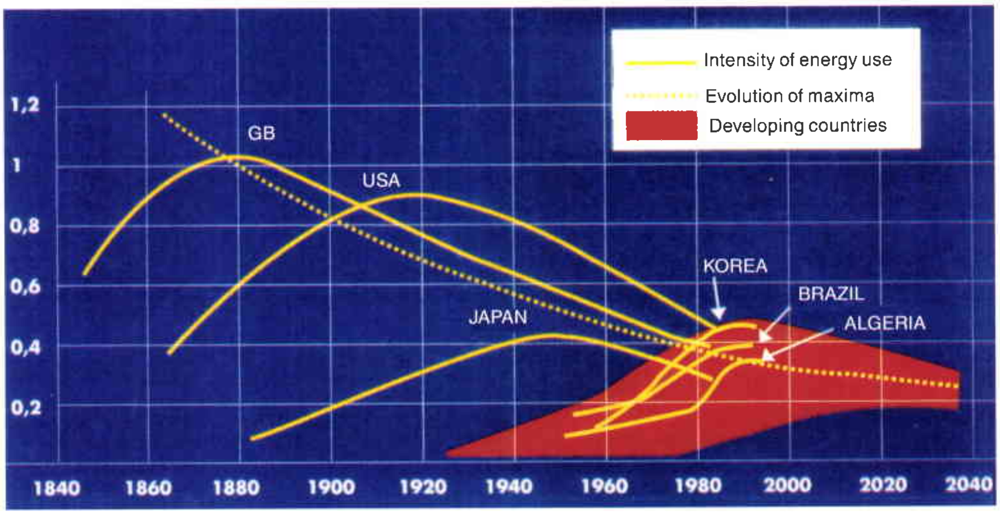


Figure 2. Quantity of energy spent for each unit of Gross Domestic Product (GDP) by countries in various stages of development (from '2100, récit du prochain siècle', Ed. Payot)

A NASA Task Force set up to study the provision of energy from space has compared the deuterium–helium-3 and deuterium–tritium cycles. It concluded that 'although the physics requirements for D–He3 are more demanding, the overwhelming advantages resulting from the two orders of magnitude reduction of neutron flux are expected by many fusion-reactor designers to lead to a shorter time to commercialisation than for the D–T cycle'.

The thermonuclear fusion of deuterium and helium-3 has been studied in the USA on the assumption that it might possibly be developed in the next century. It would generate less than 0.01% of the long-lived radioactivity per kWh of electricity that the corresponding fission reactor produces. In addition, it could provide energy with a higher

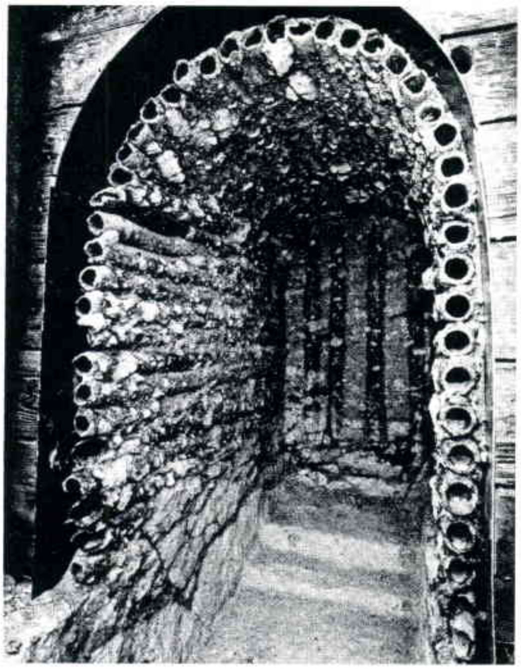


Figure 3. A prototype 'melted-in-place' structure, 2 by 1 m at the opening and 2 m deep, the interior's rock and soil having been excavated after the construction of arch and walls (from Lunar Bases and Space Activities of the 21st Century, 1985)

efficiency – approximately twice that of current fission reactors – and there would be no danger to the public from radiation.

The helium-3 needed for this reaction could come from terrestrial sources during the development phase up to, and including the first commercial power plant. Thereafter, the larger supplies that would be needed for large-scale production could be found on the Moon. Lunar helium-3 sources have been identified in reviewing data from samples collected by Apollo astronauts and samples analysed by the Soviet Luna probes. About 1 million tons could be embedded in the lunar regolith, mainly in areas containing the mineral elements found primarily in basaltic maria. Thus, this scenario, if proved to be realistic, will require the use of lunar resources.

Lunar regolith could also be used to generate oxygen (analysis of Apollo mission samples shows that chemically-bound oxygen constitutes 42% by weight of lunar rock), which could be used as a propellant to power the lunar lander up to lunar orbit and back down to the lunar surface. Lunar materials could also be used in fuel cells, to power rovers or to provide some of the power to the lunar outpost and, to a lesser extent, for life-support systems. Metals such as iron and aluminium could be co-produced during the process of extracting oxygen from the lunar rocks and soils.

This production and use of lunar resources is based on an ability to mine materials on the Moon, which seems feasible, with moderate technological risk.

Limited technological risk vis-a-vis equipment

A first analysis shows that the equipment needed to mine on the Moon could be an extrapolation of that used on Earth, after taking into account the lunar conditions of gravity, vacuum, temperature, hazardous solar radiation, particle bombardment and abrasive dust.

The best way to reduce the technological risk of this venture would be to create teams made up both of engineers specialised in the field of construction, and experienced space engineers. This would allow critical choices to be made based on real experience of job-site hazards (building dams or other major infrastructures in very hot/cold climates, at sites far from civilisation, etc.), coupled with real knowledge of severe lunar conditions. This approach was already followed in the SYSTEMSI study by asking the EIFFAGE group of companies* to join established space contractors led by DASA/ERNO.

That part of the study devoted to lunar equipment was performed in two phases, the first of which was a critical literature study; the second phase involved proposing equipment options.

Lunar-equipment concepts: state of the art

The current state of construction equipment concepts for lunar civil engineering has been analysed by studying approximately 550 papers (about 6000 pages) in the Proceedings of the most relevant conferences on the subject. 98 of those 550 articles have direct relevance to 'lunar construction equipment' in that they address one of five fields of specific interest in this context, ranging from lunar environmental requirements or the concept and design of lunar structures, to detailed mechanical applicability of equipment technology under lunar conditions (motors, seals, piping, heat removal, dust cleaning, abrasion, wear, tele-operating mechanism, etc.).

These papers have been evaluated by the 'EIFFAGE Scientific Committee', which gathers together a handful of the most experienced engineers in every field of construction. They have concluded that several of the papers contain views, concepts and considerations of interest in the lunar context; others give qualitative recommendations for construction and mining under lunar conditions. Only a few papers have potential in terms of establishing requirements, design criteria, and test recommendations for equipment and materials to be used for lunar construction and mining.

Some relevant examples

Drilling, boring and coring are basic civil- and mining-engineering tasks when carrying out

* EIFFAGE (previously Fougerolle–SAE), is a leading European group of companies specialised in all fields of international construction (bridges, offshore platforms, etc.) and civil engineering (dams, nuclear power plants, etc.). It employs 48 000 staff and has an annual turnover of 5.5 billion ECUs.

civil works (e.g. anchoring, ground penetration, explosives bore holes). Rotary and percussive drilling are common terrestrial techniques, but new drilling methods may prove more suitable for the Moon, such as concentrated solar power, lasers, heat or nuclear-powered rock-melting techniques, etc. (Fig. 3).

Total systems for excavation and earth-moving in a lunar environment have been envisaged, such as a bucket-wheel excavator and movable conveyor. An even more ambitious 'concept for a continuous earth-moving system' has also been put forward (Fig. 4).

A mobile lunar miner is designed to be a self-contained machine which can excavate the regolith down to a depth of 3 m, separates particles smaller than 50 microns from the rest, heats them, collects the evolved gases in high-pressure cylinders, and finally ejects the processed regolith back onto the lunar surface. The energy is beamed to the mobile miner by a permanently mounted solar disk of approximately 110 m in diameter, which tracks the miner while beaming the energy to its small 10 m-diameter receiver dish. A mobile miner of this type would collect about 33 kg of helium-3 per year (Fig. 5).

In a NASA-sponsored study, concepts for two pieces of equipment for lunar-surface mining operations were drawn up by the US Department of the Interior's Bureau of Mines: a Ripper Excavator Loader (REL), also capable of operating as a load-hauling dump vehicle, and a Haulage Vehicle (HV) capable of transporting feedstock from the pit, liquid-oxygen containers from the processing plant, and materials during construction (Fig. 6).

Following a scenario established by the Lunar Base System Study Team at NASA's Johnson Space Center, six construction tasks have been identified as activities likely to be performed at an early lunar base. All six tasks can be performed with only three common vehicles and some shared equipment: a rover, a truck and an excavator (Fig. 7).

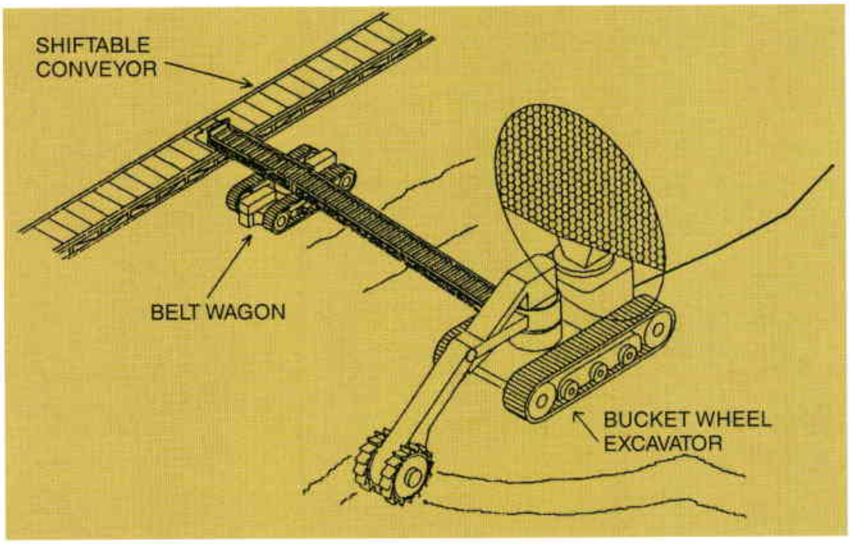


Figure 4. Bucket-wheel excavator (from the Proceedings of Space '90)

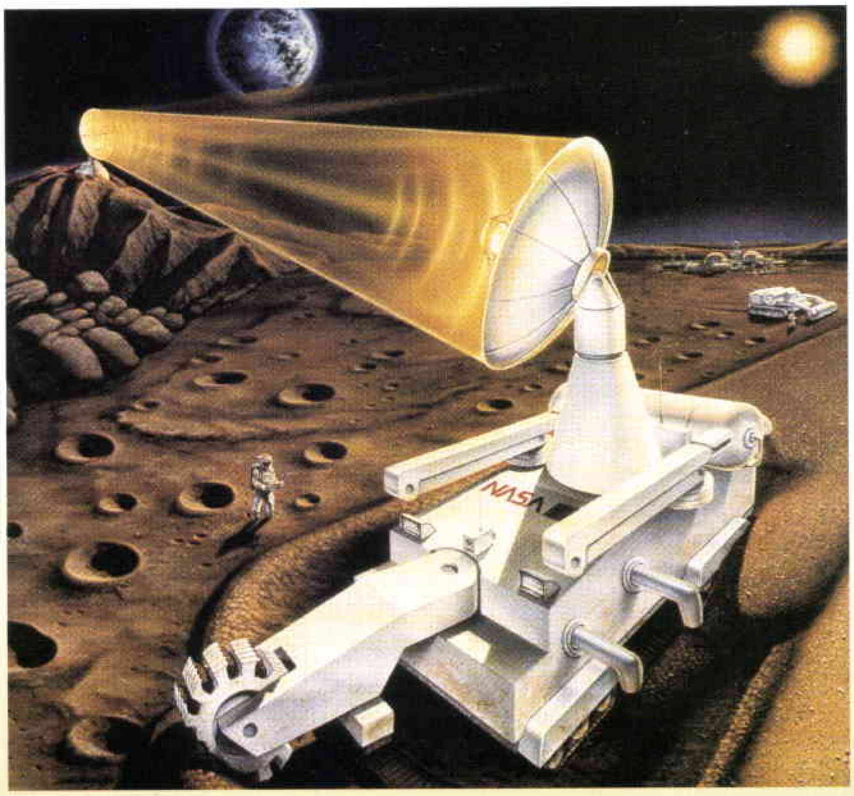


Figure 5. Artist's impression of the University of Wisconsin Mark II lunar miner (from Using Space Resources, NASA/JSC, 1991)

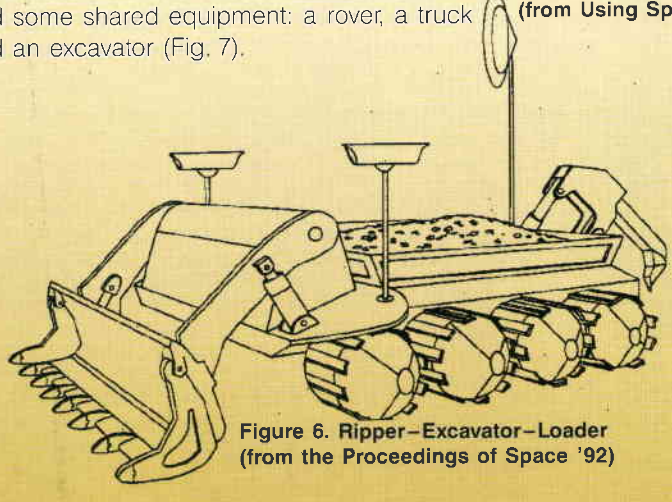


Figure 6. Ripper–Excavator–Loader (from the Proceedings of Space '92)

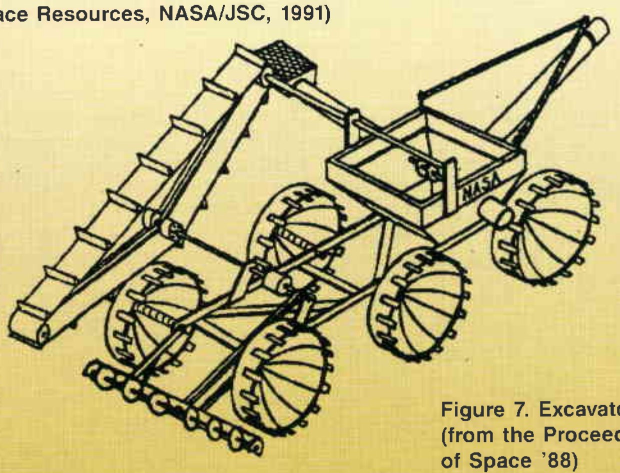


Figure 7. Excavator (from the Proceedings of Space '88)

Equipment options

Throughout the very impressive list of published papers, it is noticeable that the major concepts for lunar equipment and lunar operations in construction and mining have been pioneered and extensively addressed. The harvest of views, ideas, opinions, approaches, concepts and scenarios is actually rich in many aspects, but can still sometimes lead to completely contradictory recommendations in terms, for instance, of the mass of the equipment needed, depending on whether or not the general strategy involves manned EVA/IVA activities.

'High-tech dinosaurs'

A series of proposed pieces of equipment have masses that range from hundreds to thousands of tons, which one might term 'high-tech dinosaurs'. Some are based on single-purpose applications, while others are multi-purpose machines. They are designed to achieve high production rates by employing a substantial degree of automation.

Terrestrial experience with such equipment has shown that its assembly and on-site transport and startup can involve substantial effort and sometimes great difficulties. In addition, maintenance and the provision of spare parts can be challenging and costly aspects. Thus, due to their limited versatility and relatively low reliability, they may not be suitable for initial operations at an 'Outpost Lunar Base'. In the longer term, however, they might be worthy of reconsideration when the space technology, energy resources and human experience has attained higher levels.

'Tele-robotic ants'

Another approach that comes to mind, but one which has not in fact been worked out in previously published papers, relies on much lighter equipment, weighing perhaps less than five tons. One can envisage an army of small robots with one, two or at most three functions: one robot could work, mine and transmit ore to another robot in charge of processing it, which in turn transmits the end product to a third 'tele-robotic ant', etc. 'Coordinating robots' would be necessary to organise the job site. 'Doctor robots' might also be envisaged, which could administer 'first aid' (running diagnostics and doing light maintenance tasks).

The whole system would be managed from Earth or from lunar orbit, by engineers working in teams, perhaps on a shift basis. Those teams would monitor information coming from the robots' sensors, such as indications of the presence of boulders. The robots could even stop work for a few minutes whilst awaiting a decision, because there would be no pressing time constraints.

The design of such lightweight equipment will require robotics, or tele-robotics management, rugged tele-operating systems, and virtual-reality systems, using high-tech sensor systems, plus reliable and simple mechanics which can be easily changed during maintenance activities.

One of the most difficult development areas would probably be the robots' sensors. Present advanced terrestrial technology cannot be directly adapted to lunar operation for two main reasons. On the one hand, the robots presently used on Earth are often awkward when mobile. It would therefore be necessary to improve their 'discernment' ability whilst on the move. For instance, the Apollo astronauts perceived their proximity to a lunar geological fault when they saw the shadow of the side of the break on which they were standing projected onto the facing wall of the fault. Such decision making by the robotic ants would require a completely new generation of sensors. In addition, all such tasks are to be performed in a new environment. When people enter a room, they perceive at first glance the position of a table, its colour, its toughness, etc., because it pertains to their usual surroundings. This ability is not yet applicable to a human on the Moon, and still less so to robots.

For robots to operate successfully in such a new and 'hostile' environment, new sensor technologies will need to be developed, in terms of both the mechanics (e.g. hardware) and intelligent computerised systems (e.g. high levels of power and software sophistication). It will be necessary for these developments to have reached a level of maturity that allows new levels of parallel creativity. Progress will need to be tested first on Earth, in the short term, before moving into space.

The choice of 'high-tech dinosaurs' or 'telerobotic ants' – or a mixture of the two – would only be taken after comparing the costs with those of having astronauts operating in the same lunar environment. Historical examples can also be of some help in this respect; training during World War II by the Japanese army in very cold environments appeared to indicate that small and flexible teams of well-trained soldiers were much more efficient than large platoons of disciplined soldiers!

Limited environmental risk on the Moon

The setting up of a programme to exploit lunar resources would benefit the Earth very substantially. If the helium-3 cycle proves to be viable, this new energy source could replace the traditional ones such as coal, gas, nuclear fission, etc. The accompanying reductions in radioactive waste, greenhouse effects, acid gases and terrestrial mining would have a major impact on the terrestrial environment, although this great benefit must not be gained at the detriment of the lunar environment!

In mining the lunar regolith, about half of the material constituted by particles larger than 50 microns would be immediately discarded in the trench made by a mobile miner (Fig. 5). The remaining particles would be heated to approximately 700°C to release the helium-3. Large amounts of hydrogen and water would also be produced in the process. After heating, mined regolith would also be discarded so that, at the end of the process, the trench would be refilled with regolith. This scheme is completely different from the processes employed for extracting minerals on Earth, where the mined material is processed outside the mining area, resulting in unsightly scars on the terrestrial landscape.

Exploitation of delimited fields

What might be the negative impacts of such exploitation? Firstly, it could prevent later scientific analysis of original materials. To avoid this, helium-3 extraction fields could be carefully selected in areas where conservation measures would be taken before beginning mining. These measures could be based on those used by archeologists on Earth.

Some people might also raise the objection that mining would alter the view of the Moon from Earth. The removal and subsequent discarding of the regolith would change the albedo of the mined surface slightly. This type of change can be seen, for instance, in the Peruvian desert, where very large pictures were drawn by the natives around 500 AD. Maria Reiche, a German mathematician, and other scientists have shown that those large drawings were made by turning brown stones upside down. To avoid this type of problem, the mining trenches would be of limited length and, as noted above, would also be constrained within very limited areas.

The lunar mobile miner shown in Figure 5, which would produce 33 kg of helium-3 per year, would cover an area of approximately 1 km^2 in that period (a small number of such miners would be needed on the Moon, despite less conservative assumptions made in certain papers). By comparison, the biggest strip mine on Earth, in Germany, covers an area of 21 km^2 and is 350 m deep! On the Moon, the material would be continuously returned to the trench, the only lasting scar being caused by the cutting itself. Studies suggest that the resulting change in albedo and the removal of small craters would not be visible from Earth even through telescopes.

Impact on the lunar atmosphere

Last but not least, we must consider the effects of dust and pollution on the Moon's atmosphere. Some studies indicate that there might be problems if one were mining some 15 billion tons of regolith per year (the equivalent of all surface mining on Earth each year). In theory, this situation could be reached after the year 2050, but other constraints will undoubtedly come into play before then, and possibly other ways of finding energy. The main point is that we should proceed cautiously, keeping the situation under strict control.

The dust will also create problems for the exploitation itself, because it takes a long time to settle. Tests are needed in order to limit the number of breakdowns and to optimise the exploitation effort under the prevailing dusty conditions. In any event, the mining sites will have to be far from all other sites of habitation or areas of scientific interest, and if possible on a part of the Moon not too visible from Earth.

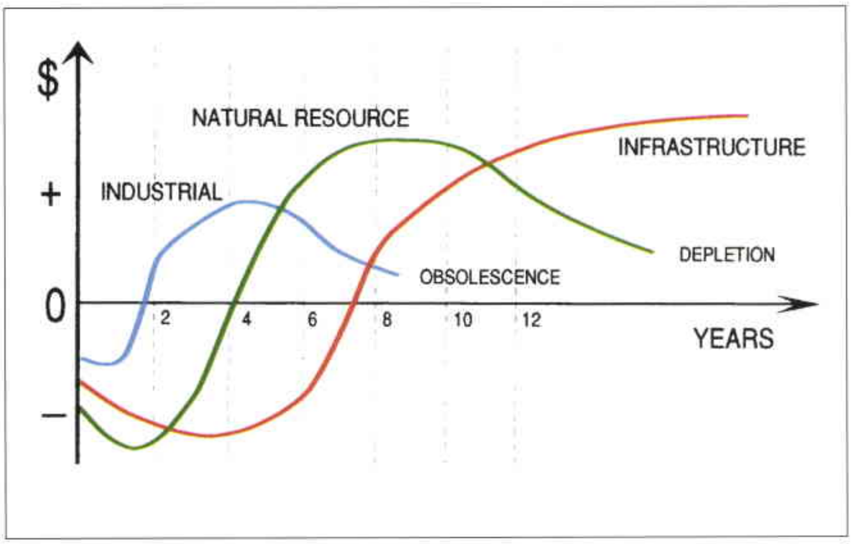
Given responsible management and the containment of the technological and environmental risks, as outlined above, the potential profitability for investors and the large benefits for mankind of a return to the Moon could stimulate a mix of public and private funding to support such a venture.

Financing by a mixture of public and private funds

Infrastructure projects

Major projects can be broadly classified into three categories: namely industrial, natural-resource, and infrastructure projects (Fig. 8).

Figure 8. Projected cash-flow profiles for large industrial, natural-resource and infrastructure projects



Industrial projects, such as the construction of communication satellites, are characterised by large cash outflows at the beginning. They need to have a fast payback period, because of the obsolescence effect: for instance, rapid technological change will soon require older satellites to be replaced by newer, more efficient types. This type of scenario is now considered a normal business risk and such projects can be financed with the help of insurance companies and short-term financing techniques such as leasing.

Natural-resource projects, such as prospecting for and exploiting oil fields, involve very large initial outflows and high cash flows are needed to enable backers to recover their investments. Such ventures can be financed via the traditional project-financing techniques.

Infrastructure projects have a very specific cash-flow profile over time. A huge amount of financing is needed at the outset and it expands over a very long period. The first returns are not forthcoming before the end of the project life-cycle, such as with the launching of a communications satellite! In this case, traditional leasing or borrowing techniques are not possible because the risks are too high. On the other hand, once the revenue starts to be generated it will be almost never ending, the Channel Tunnel being one such example. Once the Tunnel has been bored, it will be available forever: the rails may have to be changed periodically, but the infrastructure will always be there. Hence, the long-term positive cash flow can be used to promote the financing of the large initial investment.

User needs
In Europe, before the 1980s, there was a clear distinction between the public-service and the private sectors. Public services and goods were provided by public entities, paid for by the tax payer and given freely as a citizen's right. Nowadays, demand for public services is increasing and there is a trend towards many infrastructure costs being paid by the user rather than the tax payer, the latter funding only that part of the infrastructure that benefits society as a whole.

This practice has been apparent in France and in other European countries and is now being extended to, for instance, Eastern European countries. For example, drivers on motorways are a specific category of the population in that not every tax payer owns a car. It is therefore considered normal that they should pay a toll for this service. These tolls generate cash flows that can be used to reimburse private loans set up with the help of so-called project financing techniques.

Importance of the private sector in such projects
The role of a private operator is very important for the success of such an operation. The operator must first carefully assess the feasibility of the project, for which they may be expected to fund up to 20% of the total cost. They must assess the market and the potential revenues, the technical feasibility for a given budget (based on the potential market and the costs of running the operation) and finally the financial feasibility. They also have to establish, in conjunction with the public authority, which parts of the investment will benefit society as a whole and will therefore be financed by public funds.

The private operator will generally guarantee, in full or in part, the cost of the infrastructure. Last but not least, they will run the operation based on the logic of private enterprise, which is very important because the cash flows needed to reimburse the loans and capital depend heavily on the quality of this management.

In the above context, lunar-resource exploitation projects would fall into the 'natural-resource' and 'infrastructure' project categories, generating sufficient cash over a long period to allow the use of concession-scheme-type project financing. The Eiffel Tower is one of the most famous examples of this type of funding (Fig. 9).

The Eiffel Tower example
The Eiffel Tower project had all the characteristics of a modern concession-type project: it was a risky venture with cost overruns linked to the pioneering nature of the operation and it was financed with private funds together with public subsidies. The task was to build a tower in time for the opening of the World Fair of 1889. A 'Request for Proposals' was issued and Mr Gustave Eiffel won the contract. The financing was arranged as shown in Table 1.

Table 1. The financing of the Eiffel Tower (in millions of French Francs, at 1889 prices)

Costs incurred		Sources of finance	
Construction	5.0	Gustave Eiffel	2.5
Fast-track programme	1.5	Banks	2.5
		Total equity	5.0
		Subsidy	1.5
Total cost	6.5	Total financing	6.5

2.5 million of the 5.0 million French Franc construction costs were financed by Mr Eiffel himself, with three banks providing the other 2.5 million. Because the construction had to be completed extremely quickly, the public authorities provided a subsidy of 1.5 million French Francs. To reimburse this financing, the concessionary company was given the right to collect the fares paid by visitors for the first twenty years. In fact, it took only one year for Mr. Eiffel and the banks to be reimbursed, because there were so many visitors during the International World Fair of 1889! At the end of the concession (which was renewed several times), the Eiffel Tower's exploitation passed to the City of Paris.

Generally speaking, a concession package nowadays involves the following four steps:

(i) The infrastructure is built by the promoters of the project.
(ii) The infrastructure is financed, over a long period, by the promoters, at their own risk, often with subsidies from the Public Authority to finance spin-offs for society.
(iii) Loans and equity are reimbursed by fares or tolls paid by the users.
(iv) The infrastructure reverts to the Public Authority at the end of the concession period.

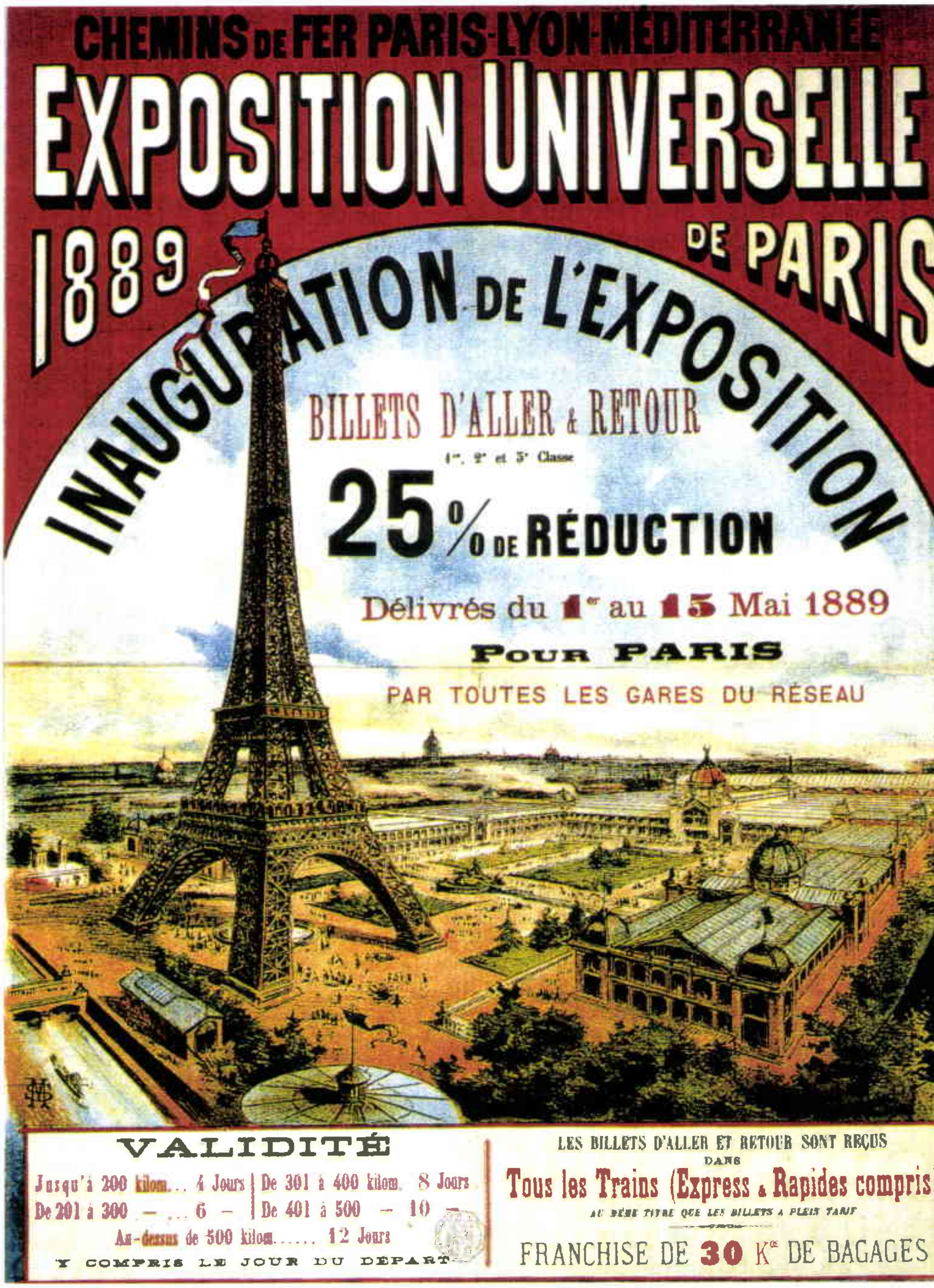


Figure 9. The Eiffel Tower in 1889

Application to lunar-resource projects

Neither the Outer Space Treaty nor the Moon Treaty formally precludes the exploitation of the Moon's resources even by private enterprises. In fact, one concept for organising the exploitation of lunar-derived helium-3 has already been proposed (known as 'Interlune'). It seems that the existence of property rights is also not totally excluded. Large-scale projects, such as those producing energy, would obviously be of an R&D nature and Public Authorities could therefore be expected to finance their early phases. Later on, private funding could complement government investment.

This funding could be completed with monies from development banks, such as the World Bank or the Bank for International Reconstruction and Development. The setting up of nuclear-fusion power plants would require the provision of a local infrastructure and sufficient administrative and technical expertise, which Developing Countries usually cannot themselves supply. The implementation of more sophisticated technologies in the Developing as well as the Industrialised Countries could facilitate a political consensus for the longer term and thereby a global financing package also.

A practical case study of the potential profitability of using lunar-sourced helium-3, under a concession-scheme agreement, has been developed by one of the authors (M. LdM). The profitability of a nuclear power plant has been studied in the context of the financial contribution it could generate to the investment needed for the mining of helium-3. The results show that such a plant could indeed provide a significant part of the investment required whilst still providing a reasonable return on equity.

Conclusion

Who would have said 10 years ago that all the information included in a huge library consisting of tens of thousands of books could be squeezed onto one small disc? Nowadays, with compact-disc technology, this once seemingly impossible task is taken for granted.

We now know that in the middle of the 21st Century there will be a depletion of fossil fuels, exacerbated by the environmental constraints on their use. If nuclear-fusion technology proves to be viable, the use of lunar-sourced helium-3 could be a solution. More generally, the use of lunar resources will be a must during the next century. Although such a concept might seem as 'foolish' at first sight as the idea of storing a complete library on a single CD did just a decade ago, the exploitation of lunar resources poses a far from insurmountable challenge.

The necessary launcher technology already exists, though it may need to be improved to reduce costs (Delta Clipper system, etc.). The technology needed to set up and to run a lunar helium-3 facility could be extrapolated from the joint experiences of the space industry and those construction companies used to managing large operations under demanding environmental constraints.

What needs to be created still is the political will for such a forward-looking undertaking.

POLITICAL WILL
- Need for energy in the 21st Century
- Reduction of environmental constraints
- Help to Developing Countries

ECONOMIC JUSTIFICATION
- Value for the whole of society
- Environmental benefits
- R&D creating new job opportunities

TECHNICAL FEASIBILITY
- Creation of lunar equipment based on terrestrial experience
- Application of current space technology

FINANCIAL FEASIBILITY
- Public funding based on spin-offs
- Possible introduction of private funding.

To pave the way to achieving such a consensus, a number of studies and tests need to be conducted in parallel with the development of nuclear fusion. A first series could consist of checking in detail the effective concentrations of helium-3 on the Moon. Some precursor missions could then be undertaken to evaluate the best ways of mining, processing and bringing back to Earth the helium-3, or other lunar resources. This phase could be prepared for with Earth-based equipment testing and 'televirtuality' experimentation (a mixture of computer science, telecommunications, and 'traditional' audio-visual techniques which could be used to operate and monitor equipment on the Moon remotely).

If all of these studies and tests confirm the feasibility of the helium-3 cycle and this lunar-exploitation scenario, then this would be a viable solution to be offered for political endorsement when the spectre of a global energy shortages begins to loom large, probably at the beginning of the next century.

If this project is approached sensibly and conservatively, in a spirit of international cooperation, its eventual financing with a mix of public funds, funds from Development Banks, funds from commercial banks and monies from the general public, seems not unrealistic, given its perhaps critical role in safeguarding the future of mankind.

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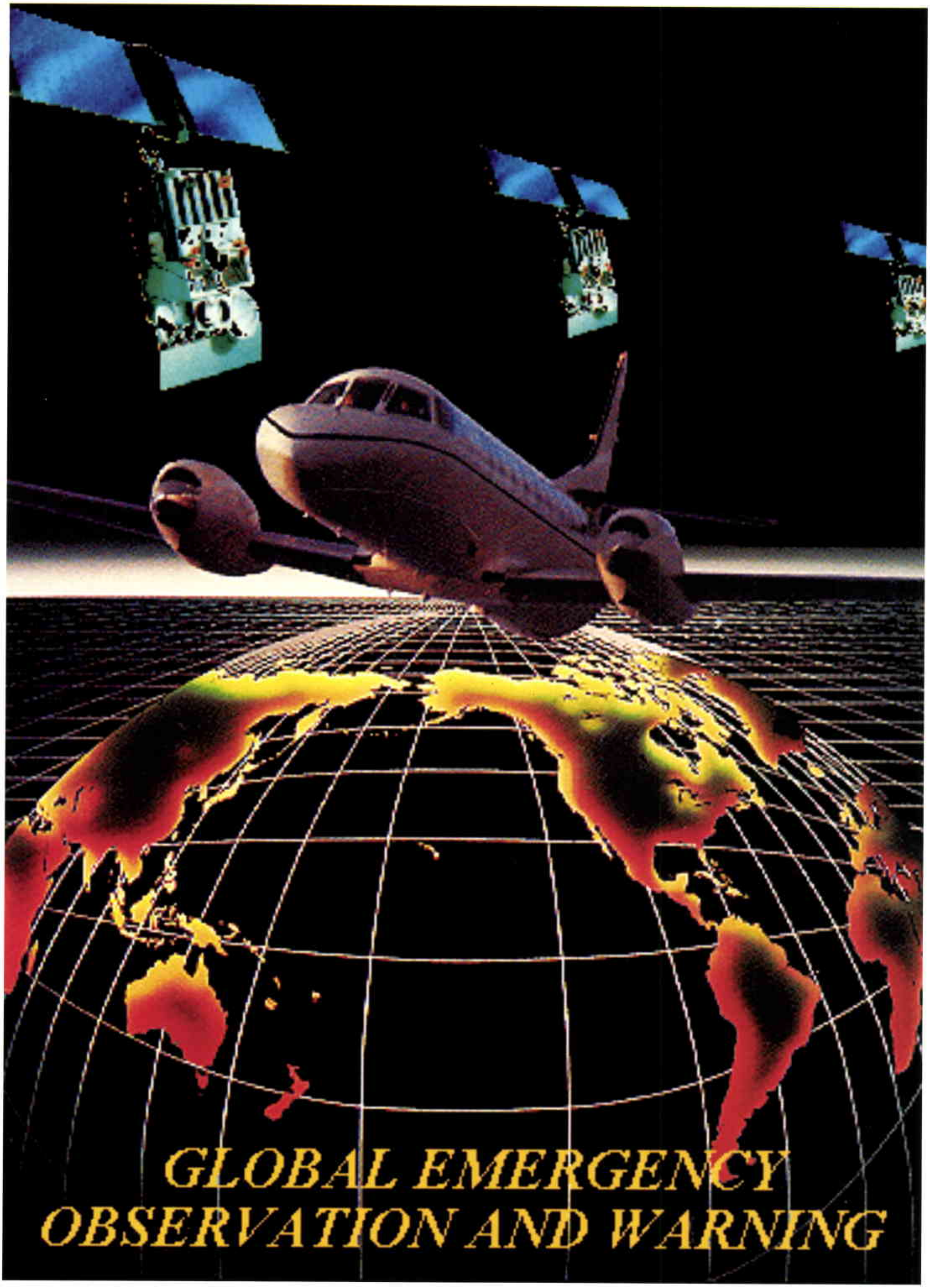
GLOBAL EMERGENCY
OBSERVATION AND WARNING

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GEOWARN was devised as a design project at the International Space University's 1993 Summer Session (19 June – 27 August). Based on a combination of remote sensing and satellite communications, it constitutes a global system for disaster warning and relief support management. This system design proposal was elaborated by ISU participants from ESA, NASA and space-related establishments in 16 countries.

Introduction

Recent advances in remote sensing, mobile satellite communications and data processing have made the application of space technology for disaster warning and relief purposes a realistic proposition. Global high-resolution measurements of critical hazard indicators through remote sensing enable improved disaster warning. Frequent detailed coverage of affected areas allows rapid damage assessment and prediction of the evolution of a disaster situation. Satellite communication ensures flexible and reliable distribution of essential information to devastated disaster sites and improves the relief effort. Existing technology is sufficient for the application envisaged, but a global approach and international cooperation are required to make it a success.

In this the 'International Decade of Natural Disaster Reduction', it is time to pursue the development of a global disaster warning and relief system. The need for such a system is endorsed by the immense impact of disasters on human life and infrastructure. With increasing population densities in urban areas and the coastal regions of the World, where the majority of natural disasters tend to occur, we will be even more susceptible to disasters in the future.

It is possible to initiate a programme now aimed at demonstrating the feasibility of the disaster warning and relief concept, by using the existing space-based infrastructure, ground-based hardware and computer networking capabilities. By adding a minimum of additional infrastructure, applying available technology, a complete global disaster warning and relief system can be implemented. With a phased system implementation, gradually expanding with new sensors and computing capabilities, the proposed GEOWARN system can be implemented at reasonable cost over the next decade. It would be a highly cost-efficient space system that would have real utility and provide a high return on investment.

The need for GEOWARN

Just within the time span of the 1993 ISU Summer Session, the Mid-west region of the United States was devastated by floods, Southern Japan suffered great losses from mud slides, earthquakes rocked Northern Japan and Guam, and tropical storm 'Bret' ravaged Caracas and its environs in Venezuela. A few weeks later, an earthquake caused the deaths of 10 000 people and adversely affected a further 150 000 people in India.

With the migration of greater numbers of people from the countryside to already densely populated cities and coastal areas, the impact of disasters has become ever more severe. The problem is growing both in terms of human suffering and financial loss, with an increase in the global population and the fact that an estimated 50% of the World's population will be concentrated in urban areas by the turn of the century.

Hurricanes, earthquakes, floods, droughts and other disasters are common phenomena in highly populated regions and there is often insufficient warning. In the hours immediately following such a catastrophic event, it is often impossible to communicate with the affected

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area in order to obtain a preliminary damage assessment and to initiate relief efforts.

When hurricane 'Andrew' struck Southern Florida in 1992, only Miami, which suffered minimal damage, had operable communications links after the storm. Consequently, initial reports indicated less serious damage than was expected. Aerial surveys two days later revealed that the affected area had been devastated and four days were needed just to fully assess the damage.

The fact that a four-day time-lag occurred in one of the most highly developed nations demonstrates the need for improved communications capabilities in times of disaster. A system is needed that can rapidly establish lines of communication and thereby provide the information required to make quick and accurate damage assessments and to support the relief efforts.

An examination of statistics on the impacts of disasters on humanity further justifies the need for a system such as GEOWARN (Fig. 1). The Office of US Foreign Disaster Assistance estimated that a total of 1185 million people were affected by disastrous events, including civil strife, between 1964 and 1990. On average, 44 million people were affected each year over this period. The number of people affected by droughts, floods or earthquakes each year has increased between three and eleven times since the 1960s.

The annual global economic losses due to earthquakes, hurricanes and wind storms in the 1960s were \$3.5 billion, rising to \$6.5 billion in the 1970s and reaching \$12.5 billion in the 1980s. It is estimated that in 1978 the total cost to the global economy due to natural disasters was at least \$40 billion. Today, the figure exceeds \$100 billion annually. Indirect costs, such as reduced productivity due to destruction of the infrastructure or reduced Gross National Product (GNP) due to loss of population are not included in these figures.

There are many meteorological agencies and international, governmental, and private relief organisations throughout the World. Yet, in many cases, warnings are still insufficient and relief aid arrives late. Part of the problem with current disaster management is a mismatch between the needs and the services provided. A central system that facilitates the communication of critical information to the disaster site would enable the organisations that provide and coordinate relief to perform their functions more efficiently.

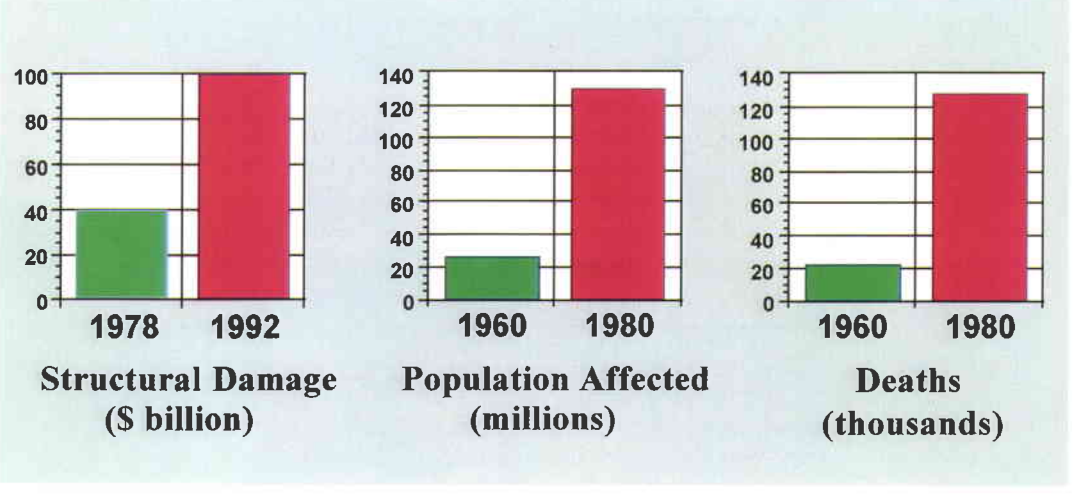

Figure 1. Annual impact of disasters

The conclusion must be that GEOWARN can have a significant multiplier effect by rapidly providing essential communications and information, and thus bringing aid more quickly and more efficiently to the affected area.

System considerations

The primary system goals for GEOWARN are to:

- reduce the impact of disasters on human lives
- provide a global disaster warning service
- provide relief support
- facilitate emergency communications
- provide data for research purposes, and
- support humanitarian relief activities.

Disaster warning involves identifying, tracking and predicting a hazard that may lead to a disaster. The disaster-relief stage is the period immediately following a disaster, when determination of its extent and severity are of paramount importance. GEOWARN directly addresses both the warning and the relief stages of disaster management.

The primary users of the system would be the Governments of affected countries and the United Nations. The secondary users would be those explicitly authorised, by an affected primary user, to receive GEOWARN warning and relief information. This could include local authorities, emergency agencies, relief agencies, and the media. Tertiary users would be those requesting access to the GEOWARN geographical information system database and archives for humanitarian research purposes. This third group would include universities, research institutes, and possibly commercial enterprises.

The proposed organisational structure for GEOWARN incorporates a Central Directorate, responsible for the general management of the organisation. The operational arm would consist of a number of regional 'Multi-National Centres' (MNCs) distributed around the World. These Centres would house the experts, computers and communications equipment needed to generate the warning and relief information.

The monitoring data required can be collected from earth-observation satellites and aircraft equipped for remote-sensing and operated by GEOWARN itself, as well as from other sensing systems including meteorological satellites. This requires cooperation in a non-competitive manner with organisations working in various fields, including remote sensing, meteorology, telecommunications and disaster management. After processing and interpretation, the information would be distributed to the Government of the affected country, local field centres and relief teams in the disaster area. The transmission of sensor data to the MNCs, the information distribution from the MNCs to the users, and communications to and from the disaster area would rely primarily on commercially available satellite communications links.

Warnings and disaster notifications would be dispatched automatically to the primary and authorised secondary users. During the relief efforts, information regarding on-going disaster development, situation maps, damage assessment, and relevant historical data would be dispatched. Historical hazard and disaster data could also be made available to the tertiary user group for research purposes.

Disaster characterisation

By assessing a disaster as a function of its severity, in terms of lives lost and economic losses, eight major types of disaster can be identified (Fig. 2). These are approximately ten times more severe than other types of disaster examined, and each causes more than 2000 deaths per year or economic losses of more than $5 billion annually.

Major armed conflicts and the irresponsible use of chemical pesticides have been excluded from GEOWARN, for which the technical requirements have been based on the remaining six major types of disaster: floods, tropical wind storms (e.g. hurricanes), earthquakes, droughts, insect infestations and crop diseases.

System architecture

For each of the six major disaster types noted above, the spatial, temporal and spectral resolutions needed to monitor the observables for warning and relief-support purposes were compiled. From this list, the sensor types required for GEOWARN were identified and a system architecture giving global coverage of affected areas was proposed (Fig. 3).

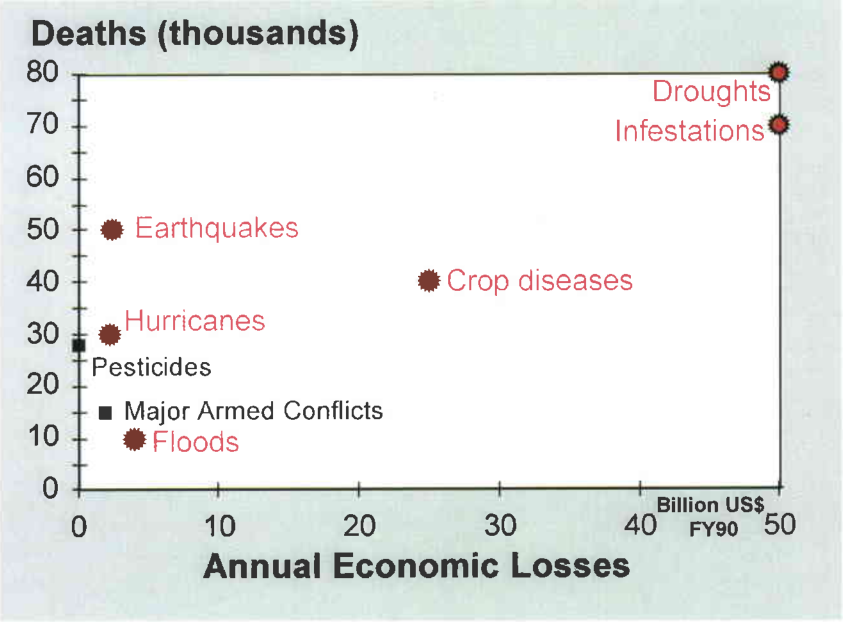

Figure 2. Disaster characterisation

The system's 'brain' is located in five relatively autonomous Multi-National Centres, each providing GEOWARN services to a designated part of the globe. The data are collected, processed, interpreted, and archived at each of these MNCs. Teams of experts make the necessary decisions, disseminate disaster alerts, detailed warning information and disaster notifications. The MNCs serve as information centres which respond to disaster-information requests and organise the GEOWARN relief support.

The GEOWARN Headquarters and MNCs are interconnected through high-capacity satellite communications links, as well as via public telephone networks and computer

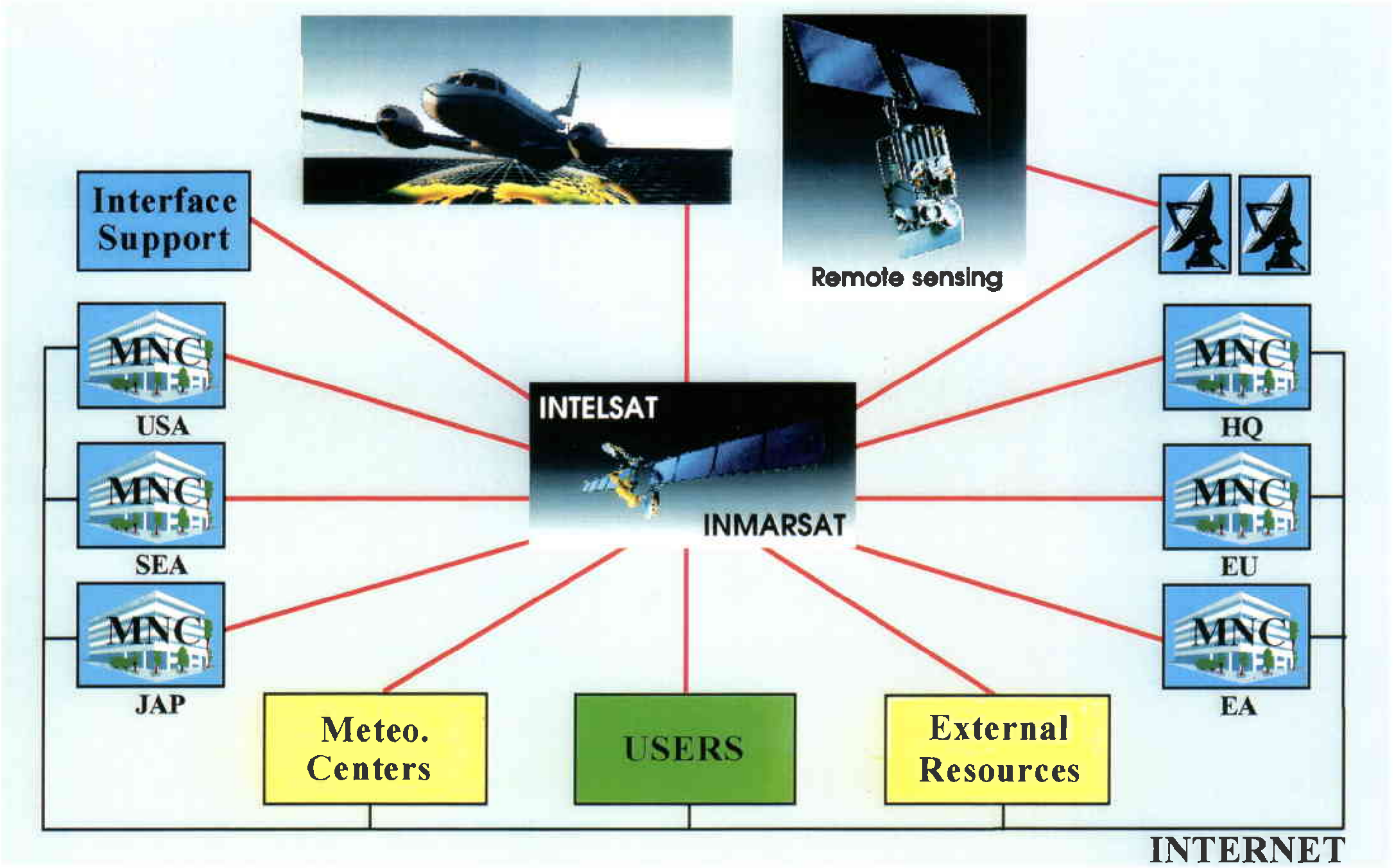

Figure 3. System architecture
HQ = Headquarters
EU = Europe
EA = East Africa
SEA = South-East Asia
JAP = Japan

networks. When communicating with its users – especially the mobile units – priority is given to the satellite links, which may well be the only operational means of communicating with a disaster area.

An 'interface support group', which can be sent into disaster-affected regions if so requested, is based at each MNC. Equipped with mobile satellite communication terminals, these groups can help the local users to interact efficiently with the GEOWARN system. The terminals can be used for communication with relief teams as well as with GEOWARN Headquarters.

For satellite communications, GEOWARN relies on both existing and planned commercially available systems, the two major suppliers INTELSAT and INMARSAT offering ample capacity.

In terms of meteorological sensors, a combination of the existing or planned INSAT, GMS, Meteosat, GOES and GOES-Next sensors should meet GEOWARN requirements for drought, crop-disease, and hurricane warning purposes. GEOWARN would cooperate with the organisations that collect and process data from these satellites and with agencies operating ground sensors installed at various locations around the World, in order to gain access to relevant data.

Additional infrastructure

Although there are many low-Earth-orbit (LEO) observation satellites either operating or planned, the required combination of high spatial and temporal resolution needed for GEOWARN is not presently available. Particularly as regards sensors capable of penetrating cloud cover and darkness, existing systems lack adequate spatial resolution. A wide range of system options were therefore considered in a trade-off study to identify a cost-efficient solution.

A relative measure of the potential benefit of implementing a specific option was calculated using a parametric model. A calculation was made for each option by weighting the requirements' compliance with the magnitude of the disaster and the relative importance of warning and relief for that type of disaster. By summing these figures, a relative measure of the potential benefit of implementing a particular option was obtained.

As a result of this study, the additional infrastructure proposed to meet GEOWARN requirements incorporates a constellation of LEO observation satellites and an airborne system of Synthetic-Aperture Radar (SAR) sensors. (A proposed ground-based earthquake system was eventually excluded due to its extremely high cost in relation to relatively modest potential benefits).

The addition of these sensors allows critical parameters associated with the six types of major disaster to be addressed by GEOWARN to be measured with both higher frequecy and greater precision than ever before. Furthermore, as a spin-off, these sensors will also facilitate limited warning and relief activities for less-major disasters such as bush fires, volcanic eruptions, deforestation, dust-storms, thunderstorms and tsunamis (violent displacement of sea water).

The satellites

It is proposed that the GEOWARN satellites should carry a visible/infrared and passive microwave radiometer sensor suite with spatial resolutions of 30 m and 5 km, respectively. Five such satellites (plus one in-flight spare) in 700 km-high LEO orbits with 98° inclinations would allow a temporal resolution of less than three days for the visible/infrared radiometer and one day for the microwave radiometer (Fig. 4).

The satellite constellation would be controlled from GEOWARN's Headquarters and would deliver earth-observation data to the MNCs via two ground stations. The latter would transmits their data to the MNCs via leased transponders on commercially available communications satellites. Existing ground stations at Fairbanks in Alaska and Tromsø in Norway would offer frequent visibility of the GEOWARN satellites.

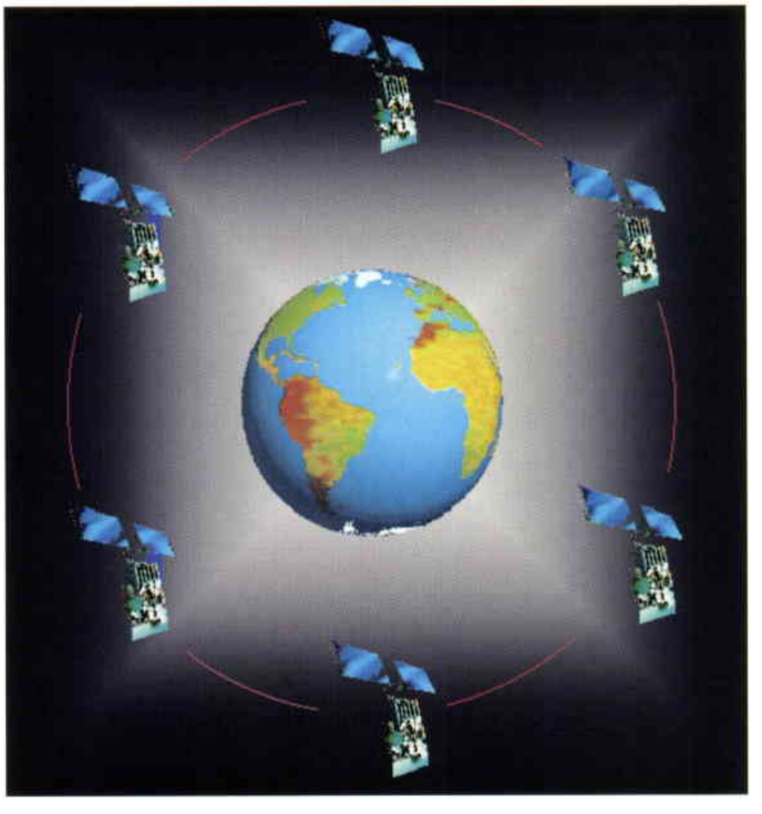

Figure 4. Proposed satellite constellation; 700 km altitude, 98° inclination, Sun-synchronous orbits

The aircraft

The primary mission of the air segment would be relief support during hurricanes, earthquakes and floods. The key requirement for disaster relief support is very high spatial and temporal resolution imagery of the affected area under all visibility conditions. The sensor best suited for night imagery and cloud penetration is the active microwave SAR.

The minimum spatial resolution needed for relief support and damage assessment is 5 m. Sensors onboard aircraft meet this requirement today, but operational space-based SAR systems are not expected to be able to do so for at least a decade. Consequently, the airborne system will be needed at least until the improved space-based SAR sensors become available and affordable.

The secondary mission of the GEOWARN air support would be to provide information that can improve hurricane warnings by conducting close-range observations and measurements on a request basis for the hurricane warning community.

The GEOWARN aircraft could make use of existing airfields in the main areas affected by hurricanes, earthquakes or floods (Fig. 5). To minimise the refuelling distance, a system based on a central airfield and secondary airfields distributed over the region, is proposed for each operating area. Global coverage of affected areas with revisit times of less than 6 h would be feasible with 30 small aircraft operating from 20 airfields around the World.

Data being gathered by the aircraft would be forwarded directly to the appropriate MNC via a high-capacity satellite communications link.

Data processing

An important operational characteristic of GEOWARN is that no warnings would be issued without the potential hazards first being analysed and verified by experts. It is therefore desirable for the data processing to take place at locations accessible to regional expertise. The data-processing functions are therefore divided among five regional processing

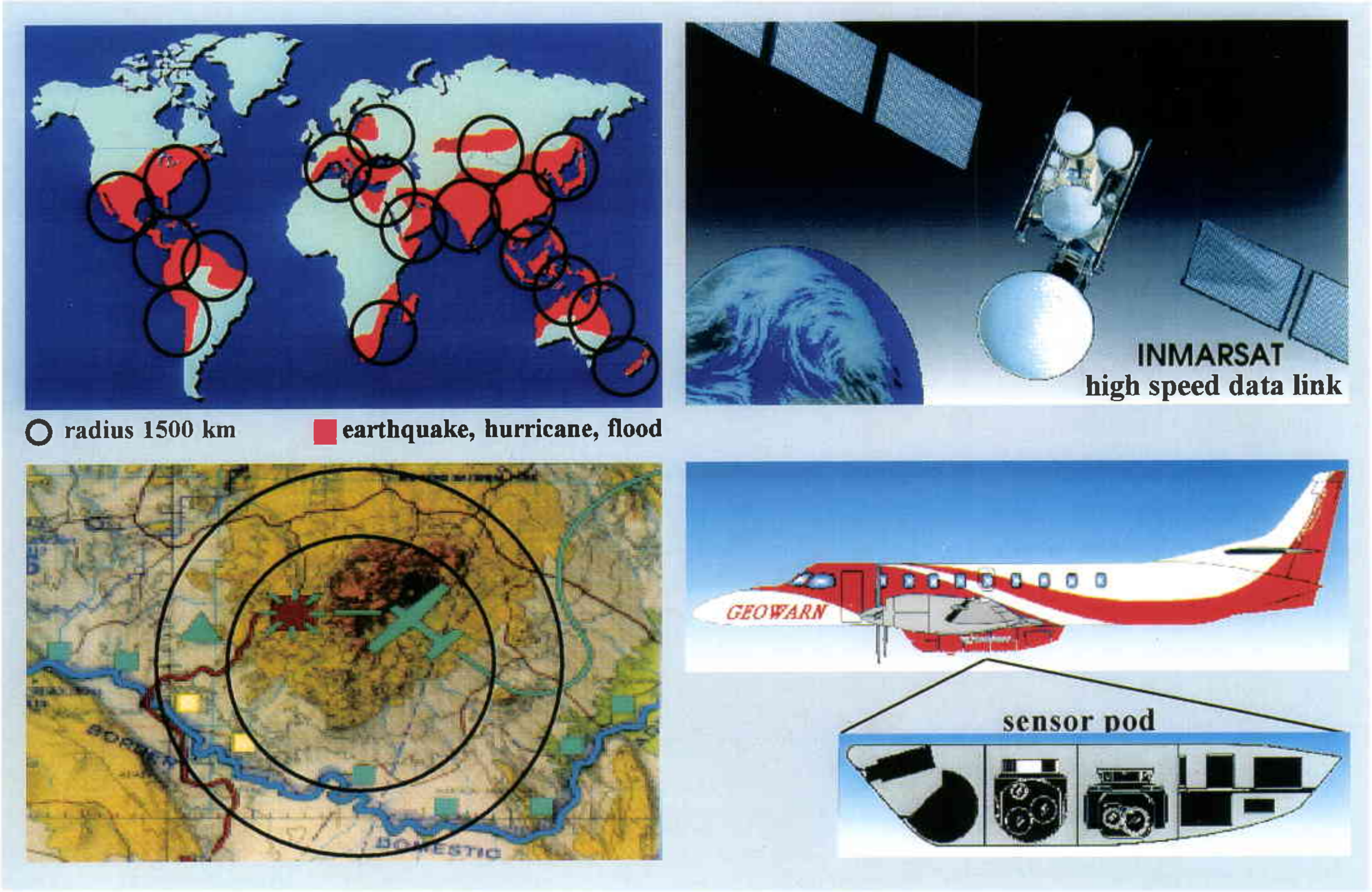

Figure 5. Proposed aircraft system (all aircraft pictures courtesy of Fairchild Aircraft)

centres, the MNCs, responsible for the data-processing, warning-distribution, and relief-support functions for particular parts of the World (Fig. 6).

Each MNC, which would be as automated as possible, would maintain an up-to-date Geographical Information System (GIS) for its region of responsibility. It would also maintain an archive of information about the development, impact, and relief of past disasters, which can be useful in predicting the likely development of new hazards and disasters of similar type.

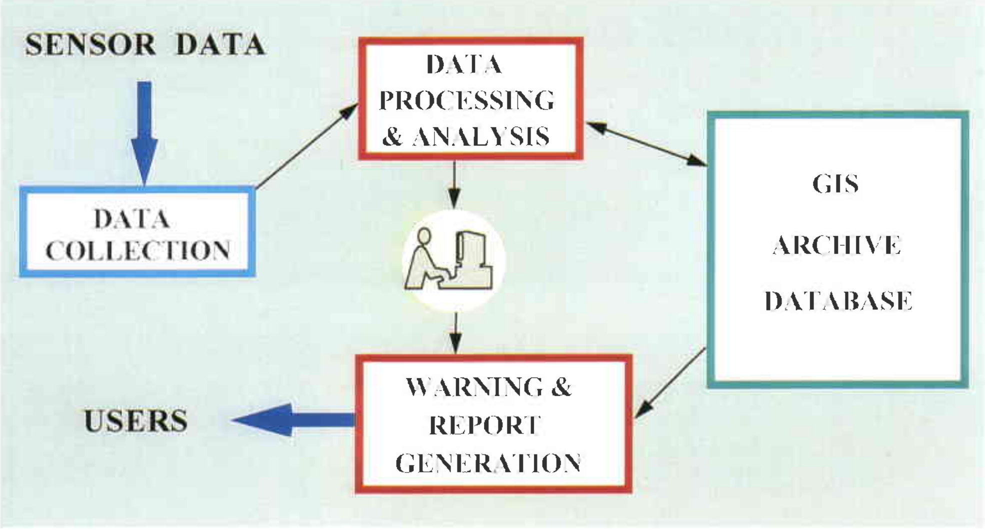

Figure 6. Data processing

Organisational structure

There are a number of legal considerations associated with the establishment of a GEOWARN organisation, with many existing treaties, memoranda of understanding, and aspects of international law to be considered. Having studied comparable structures of existing agencies, a non-profit-making international consortium of government shareholders would seem the most appropriate approach (Fig. 7). Once GEOWARN were established as an International Organisation, the option to apply for UN Specialised Agency status could be considered (the organisation should be open to all nations regardless of their ability to invest as shareholders).

Implementation of GEOWARN

It is envisaged that GEOWARN would be implemented in three distinct phases. In the initial phase, the organisation itself would be founded and the legal basis for the entire programme established. The first three MNCs would be gradually built up and connected to existing information networks and to related organisations. 'Requests for Proposals' to procure the GEOWARN aircraft and satellites would be prepared.

In addition, various processing tests, training programmes, and model validation studies using external data, including satellite images and GIS data sets, would be performed. By the end of this initial phase, GEOWARN would be able to provide limited relief-support services.

During the second, so-called 'transition' phase, GEOWARN would be expanded by building up the two remaining MNCs, adding the GEOWARN air bases, and establishing the necessary data-dissemination network. Additional relief-support services would thereby become available. At the end of the transition phase, the GEOWARN satellite sensor system would be delivered and the total system would become operational.

During the third, 'operational' phase, GEOWARN would provide global relief support and warning services with continuously maintained system capacity. By incorporating new technology, the initial GEOWARN services could also be expanded, for example by providing disaster-preparedness support services, or by augmenting system capabilities to cover additional types of disaster.

The projected annual costs for the major GEOWARN segments calculated over the lifetimes of the aircraft (12 years) and satellites (5 years) are an average of $470 M. This corresponds to less than 0.5% of the annual cost of damage caused by natural disasters (Fig. 8).

The major cost items in the annual budget are the development and operation of five satellites, plus one spare (66%), organisational costs including communications (24%), and the purchase and operation of 30 aircraft equipped with remote-sensing capabilities (10%).

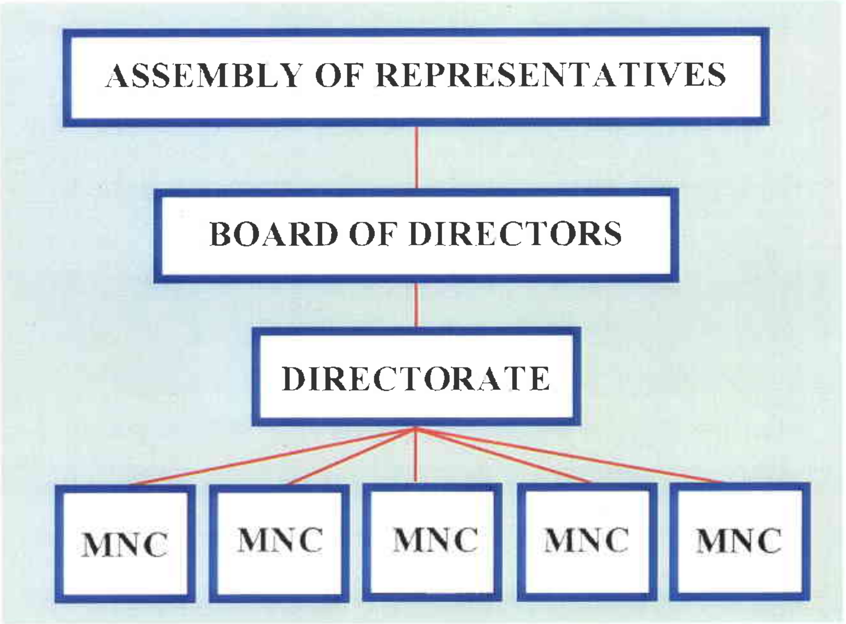

Figure 7. Proposed organisational structure (MNC = Multi-National Centre)

Conclusions

With the immense and annually increasing loss of life and damage as a result of disasters, the need for a global monitoring system is abundantly clear, although it is difficult to quantify its potential impact precisely. GEOWARN would also promote cooperation of paramount importance between existing disaster management, relief, meteorological, and government agencies. It would also fill gaps not covered by the many agencies and organisations operating in the disaster-management arena, by fostering cooperation without competition.

By making maximum use of the existing infrastructure, GEOWARN would be a comparatively inexpensive system, without compromising on critical performance aspects. It also has the capacity to expand and continuously incorporate exploitable advances in technology.

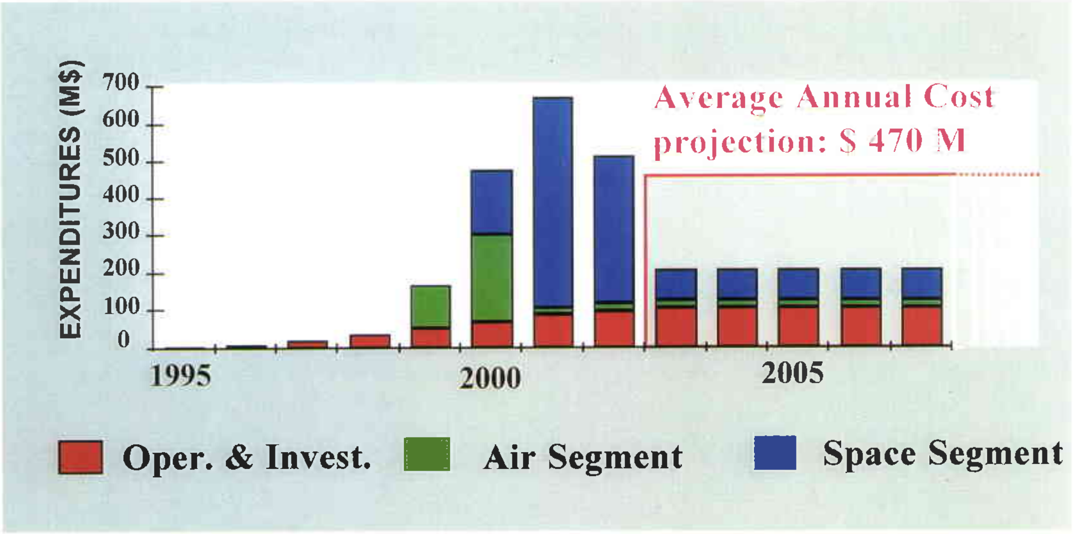

Figure 8. Cash flow and average annual cost

The International Space University (ISU) was founded in April 1987 as a non-profit, non-governmental institution intended to become the World's leading centre for the education and training of tomorrow's space professionals. The ISU brings together international space experts from academia, industry and government to educate students in multi-disciplinary and advanced issues in space development. One of the goals of ISU is to conduct design projects of interest to industry which also provide the students with a challenging problem.

At the 1993 Summer Session of ISU held at the University of Alabama in Huntsville, 38 students from 16 countries worked to design the GEOWARN system to address the growing impact of natural disasters on humanity. The material presented in this article is based on the final report and the unique experience of the two authors, who participated in this design project.

Given the overall benefits it offers humanity throughout the World, a global disaster warning and relief system like GEOWARN has to be one of the most logical global cooperative programmes for Governments to pursue. If just 0.5% of the annual economic damage caused by disasters can be prevented, the cost of GEOWARN is already justified, notwithstanding the great number of lives that it would undoubtedly save.

Acknowledgement
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Collection and Distribution of Ecological Data by Satellite — A Service for a Better Environment

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The ecological status of the Earth is of growing concern to many governmental authorities, research institutes, and commercial and private enterprises. They are interested in cheap, reliable, easy-to-install, ready-to-use communication networks for local, *in situ* environmental monitoring, often as a complement to remote sensing by satellite.

Many existing ecological networks can be upgraded and expanded if satellite communications are used, particularly when users require network autonomy, versatility, prompt availability and coverage of remote or inaccessible areas. Service and maintenance costs could be reduced, particularly given the current deregulation of satellite communications in Europe. Furthermore, satellite communications are the sole and unique means for implementing ecological networks for *in situ* data in Eastern European countries within a very short time.

Introduction

As a complement to remote sensing by satellite, the collection and distribution of *in situ* measured ecological data (data on, for example, water or air quality, that is measured locally at one station in a network) has become an important part of environmental monitoring. Many international, national, regional and local bodies, including governmental authorities, research organisations, and commercial and private enterprises, are interested in objective, reliable and comparable information about the status of the Earth's environment. For example, at the European level, this interest is demonstrated in the European Community (EC) Council Regulation No. 1210/90, which forms the basis for the creation of the European Environmental Agency:

> "At the European level, the collection, processing and analysis of environmental data are necessary in order to provide objective, reliable and comparable information that enables the Community and the Member States to take the requisite measures to protect the environment, to assess the results of such measures and to ensure that the public is properly informed about the state of the environment."

In many cases, existing ecological data networks could be profitably upgraded, expanded or exported if satellite communications were considered. However, many potential users underestimate or misunderstand the benefits that satellite communications offer. Those benefits include:

- coverage of areas that lack a developed terrestrial communications infrastructure (e.g. Eastern European countries), and of remote or inaccessible areas in general
- prompt availability and short installation time of a satellite-based network (a fundamental feature during catastrophic events)
- network autonomy and high versatility with respect to user requirements.

Satellite communications services, indeed, are competitive, even unique, and can offer their full potential when factors like availability and performance drive the desires of the ecological user.

ESA's CDEDS study

ESA has carried out an analysis of the potential contribution of systems for the Collection and Distribution of Ecological Data by Satellite (CDEDS). A study contract was awarded to a consortium led by Elektronik System GmbH (Germany), with sub-contracts to TUeV Bayern (Germany), the Finnish Technical Research Centre (VTT), and Stanbrook and Hooper (Belgium). ESA, recognising the need for the demonstration of space technologies, also required the study team to identify and elaborate proposals for potential pilot projects that promote satellite communication services to ecological users.

The primary objectives of the study were:

- to assess the factors by which communication satellite services for the collection and distribution of *in situ* measured ecological data could develop in Europe
- to quantify the demand for utilisation of existing and planned communications satellite systems and services
- to assess the suitability of available ground-terminal technology and the competitiveness (in terms of performance and cost) of European space industry products, providing recommendations for their further development
- to define communication scenarios and concepts for collection and distribution of ecological data by satellite
- to identify market sectors (ecological areas and user groups) where space services and products are needed and where it is worthwhile demonstrating them through ad hoc pilot projects.

The CDEDS scenario — user and service requirements

The EC Council regulations currently in force regarding environmental protection provided the starting point for the study. Because they are binding rules on the measurement of ecologically-relevant parameters, such as the reference method of measurement, the minimum frequency for sampling and analysis, and the mode of expression, the regulations provide a unique method of forecasting the requirements of a large, heterogeneous user community in Europe. This is based on the assumption that legislation is and will be the predominant factor in the development of environmental networks and information systems, as it has proven to be in Europe up to now.

The EC Council environmental regulations focus mainly on air and water quality rather than on the biosphere and soil. The networks and information systems that are already in place have therefore mainly been implemented in those areas.

In order to characterise the user community, the study team identified, analysed and classified 35 existing information systems and many measuring networks operated by national and international organisations. The objectives and requirements of each user group differ depending on the ecological application (e.g. air or water), the function (e.g. monitoring, research or control), the service (data collection, processing or distribution), the geographical area of competence or authority (international, national, regional or local) (Fig. 1).

The typical volume of data being transmitted is quite low — between 50 bytes and 20 kbytes per transaction at the local/regional level — and the frequency depends greatly on the ecological application. Figure 2 shows a tentative scheme for a general ecological data flow model. The purpose of the model is to aid in the derivation of a global view of the communication service requirements rather than to provide a fixed model.

In terms of service required, today's ecological users face very typical problems when dealing with measurement networks:

- data access is restricted and retrieval is complicated
- data is not distributed quickly enough
- data transfer is expensive
- there is no standardisation for data collection equipment, data collection intervals and accuracy, data formats for transmission and storage, or data content

Figure 1. Potential users of a European environmental monitoring system

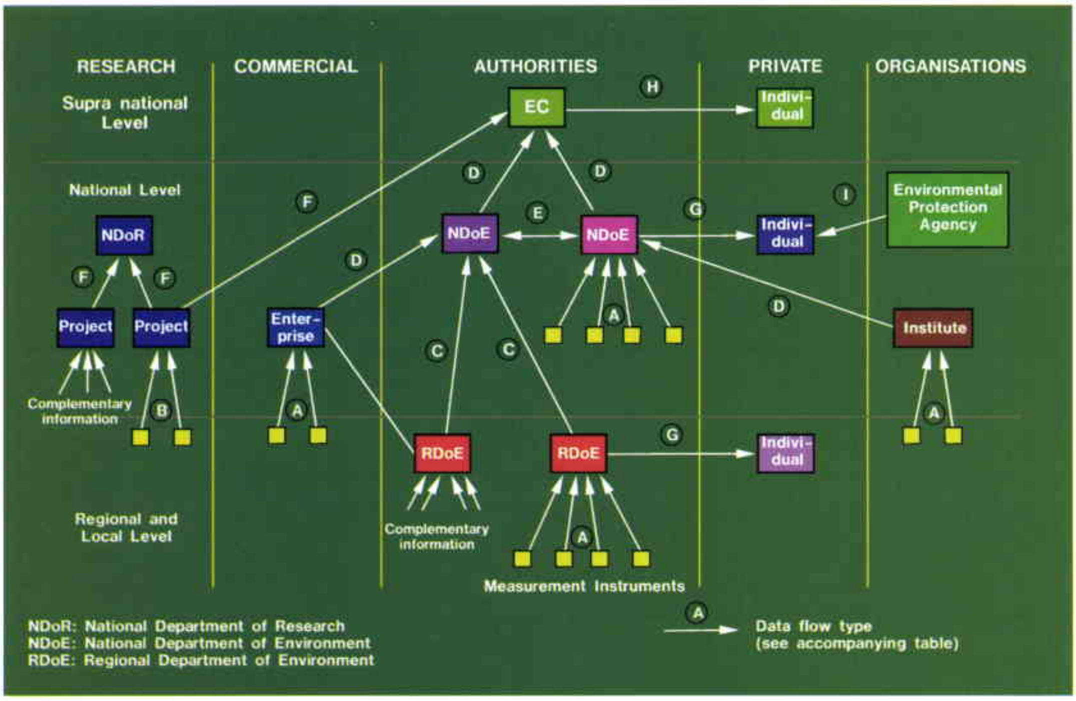


Figure 2. User model for European environmental monitoring

Data Flow	Data Type	Exchange Method	Transaction Frequency (*)	Data Volume / Transaction (*)	Category
A	Preprocessed	Data communication	2/hour – 1/day	50 bytes – 20 kbytes	Data
	Preprocessed	Site inspection	1/week – 1/month	20 kbytes – 500 kbytes	collection
B	Raw	Data communication	4/hour – 1/week	100 bytes – 20 kbytes	(Multipoint-to-point)
	Raw	Site inspection	1/week – 1/month	50 kbytes – 500 kbytes	
C	Preprocessed	Data communication	2/day – 1/day	5 kbytes – 50 kbytes	Data
D	Processed	Printout	1/month		distribution
E	Processed	Printout	1/month		(Point-to-point)
F	Processed	Report	2/year – 1/year		
G	Processed	Minitel	8/day – 1/day		Data
		Papers	1/day		distribution
		Printout	50/year – 5/year		(Point-to-multipoint)
		Report	1/year		
H	Processed	Printout/Magnetic tape	50/year – 5/year		
		Report	1/year		
I	Processed	Printout	1/week – 1/month		
		News			

(*) Typical values

— overall network implementation takes too long
— remote areas or areas with a poor terrestrial communications infrastructure are not properly covered.

Suitable satellite communications services can be targeted to deal with the above problems and can contribute to solve them, at least partially. A suitable service scheme will require that the CDEDS user can acquire the requested information in a simple, fast and cheap way. This will imply setting up a service infrastructure that will allow users to obtain the desired products while encountering the minimum number of interfaces with the 'jungle' of manufacturers, vendors, telecom service providers and operators.

Satellite communications service concept and systems

In general, *in situ* ecological data is collected from mobile and/or fixed measurement stations and transmitted to a data acquisition centre (multipoint-to-point communication) (data flow types A and B in Figure 2) at a low data-rate. The data acquisition centre processes the measurement data and makes it available to individual users and/or to an information system (point-to-point communication) (data flow types C,D,E,F). Through the information system, the processed data is then distributed to a large user community by various broadcasting methods (point-to-multipoint communication) (data flow types G,H,I).

A CDEDS communication service can be established using different technical concepts; an example is provided in Figure 3. It should be noted that, in this example, the measurement stations are connected to their data collection and processing facility by satellite while the data distribution to authorities and users can be performed by point-to-point satellite transmission, satellite broadcasting or terrestrial lines.

Existing or planned satellite systems and services have been identified and their suitability for *in situ* data collection at low rates assessed. Two of the latest developments in the area of ground terminals, both sponsored by ESA, are particularly interesting and suitable for CDEDS:

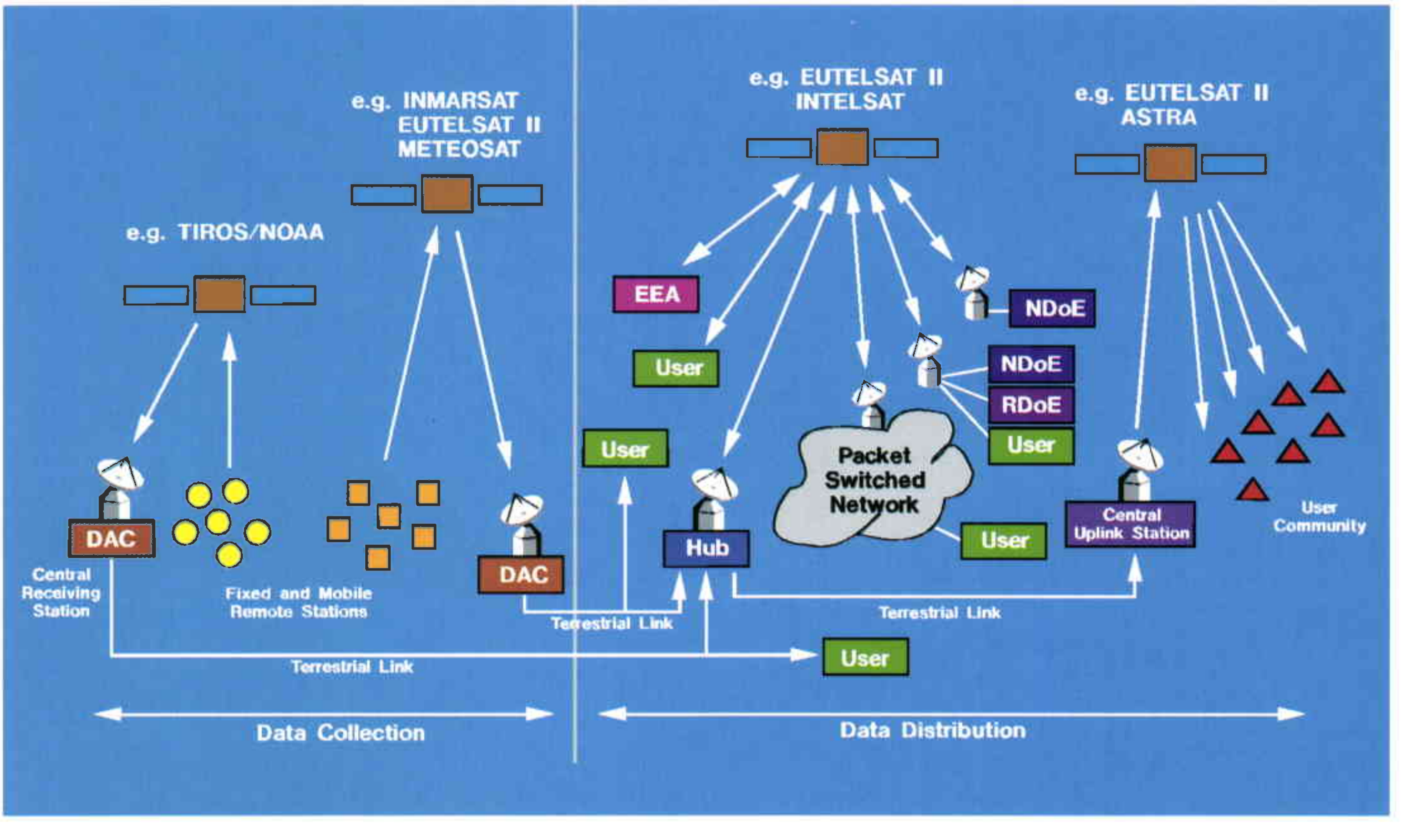
- PRODAT is a mobile data and messaging system operating in the C- and L-bands via geostationary satellites. It is still an experimental system, providing almost free-of-charge transmission during the current pre-operational phase. It is fully compatible with CDEDS requirements and particularly suitable for the demonstration of pilot projects. Plans to begin commercial operation are well underway.
- TSAT 2000 is a Very Small Aperture Terminal (VSAT) system operating in the Ku-band and developed by Normarc (Norway). It can operate with any Ku-band satellite transponder, e.g. Eutelsat-II or Intelsat V, and uses satellite transponder power and bandwidth very efficiently, resulting in lower communications services costs. TSAT 2000 is also fully compatible with CDEDS requirements for fixed communication services.

The Meteosat-DCP data collection and dissemination system offers another opportunity for CDEDS, but with very specific administrative limitations and conditions. It is a uni-directional system and therefore can only be used for those applications that do not need active remote control of the measurement stations. It uses the Meteosat satellite operated by Eumetsat.

Other commercially available, fully operational services like Inmarsat-C or Euteltracks could also be used. Their prices could become competitive for CDEDS when the planned deregulation of the PTT's monopoly in the European Community member states comes into force.

Furthermore, systems with Low Earth Orbiting (LEO) satellites can be of interest if real-time data collection and dissemination are not required. Worldwide commercial systems are available, e.g. ARGOS which exploits TIROS/NOAA's satellite communications capability in polar orbit. The terminals used can be small, inexpensive and operate at low power due to the low altitude of the satellites. Some initiatives are underway in Europe to develop

Figure 3. System concept for CDEDS



systems in LEO for environmental data collection and distribution. For example, TEMISAT, a satellite developed and built by the Italian subsidiary of Kayser-Threde (Germany) under contract to Telespazio (Italy), will provide a dedicated service for CDEDS-type applications in Italy.

For data distribution, various systems can be used based either on an existing commercial broadcasting satellite service or a terrestrial one. Several solutions that provide the user with an economical solution can be envisaged today using, for instance, spare capacity in digital radio or TV channels.

The service demand for CDEDS
In order to assess the competitiveness of European ground terminal technology and the direction of any further development, the evolution of the market demand for a CDEDS service must be evaluated, together with the factors that can influence it.

At present, legislation is considered to be the driving force for the development of networks for the collection of ecological *in situ* measurement data. Among the various user groups, the different levels of authorities represent the most significant source of demand.

Other factors influence the development of ecological networks and information systems; the study showed that the total number of implemented *in situ* measurement stations is driven primarily by:

— general environmental awareness and press coverage
— available funding and existing investment profiles
— expected price of equipment
— legislative pressure (as already mentioned).

Service demand in Western Europe
In EC and European Free Trade Association (EFTA) countries, the relative weights of each factor and their trend can be forecast on the basis of the recent past statistics.

In Western Europe, the forecast is based on the fact that the influencing factors are expected to maintain a steady weighting and behaviour. The availability of satellite communications technology will not play a decisive role in the development of the demand since users have the alternative to use the terrestrial communications infrastructure which is already well developed. In other words, in Western Europe, the selection of a communication service — whether terrestrial or satellite based — is mainly driven by economic factors, and the evolution of the overall demand is quite independent from the communication technology used.

Figure 4 shows the forecasted growth in demand in the number of measurement stations and data volumes for various ecological areas for the next 10 years. The major increases are expected in the areas of 'air quality' and 'bathing water'; the large number of stations makes them suitable potential candidates for

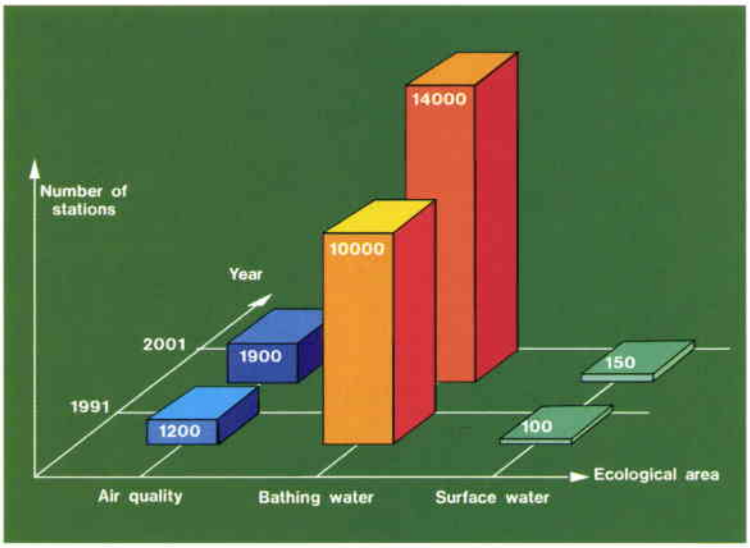


Figure 4. Expected evolution of the demand for measurement stations

satellite communications. 'Drinking water' has not been considered as a candidate for satellite data collection services because, although the 'drinking water' area has the greatest number of stations already implemented (more than 60 000 in EC countries in 1991), automatic methods for measuring the quality of drinking water are not yet available. Probes are, in fact, taken from the site manually on a regular basis and analysed in a laboratory. Thus, 'drinking water' measurements cannot yet be collected by satellite.

Overall, in EC countries only in the next decade, the number of candidate stations for satellite communications is expected to increase from about 11 000 to 16 000, with an increase of 80% in the data volume to be transmitted.

During the study, it was also discovered that other areas relating to the environment but not regarded as ecological areas, such as agriculture, hydrology and seismology, or other sectors such as the gas and oil transport industry where leakage detection is required, could represent a more significant source of demand. Their importance must be further investigated.

Another model was developed in the ESA study, to predict the future demand development for the installation of satellite communications terminals and the potential replacement of end-of-life terrestrial equipment. The key factors influencing the gain in market share of satellite terminals over terrestrial equipment are:

— purchase cost of communications equipment
— licence cost
— service cost
— data volume to be transmitted.

Given those factors, the model predicts the break-even point for satellite communications over the public telephone system in Western Europe will be after 1997, provided that full deregulation of satellite communication services is enforced and the imposed licence cost is negligible. This also assumes that efforts to lower the price of satellite terminals and the transmission cost are encouraged and pursued, together with promotion campaigns for these technologies.

Service demand in Eastern Europe

In Eastern European countries, however, the fact that existing legislation has not been sufficiently enforced, combined with existing legislative disorder, implies that it is almost impossible to forecast the evolution of the demand in the way that it has been done for EC countries.

In Eastern Europe, priority is currently given to the reduction of hazardous waste, the improvement of air and water quality by preventive measures, and the introduction of strict compliance obligations for manufacturers rather than placing importance on monitoring. Although several countries consider monitoring as a medium-term priority (due to budgetary constraints) and plan to use current EC regulations as a basis for any legislative scheme, it is not expected that this priority will be achieved before the next decade. In addition, in Eastern European countries, an alternative to satellite communications is not often available, and the availability of cheap, reliable, easy-to-install and ready-to-use means of satellite communications becomes a necessity. The relevant technology development must be ready to cope with this necessity today and with the legislative enforcement requirements and the increasing market demand in the next decade.

The pilot projects

The need for the demonstration of satellite technologies has been a key factor in the development of CDEDS services in Europe. The study team spent considerable effort on identifying, defining and elaborating potential proof-of-concept demonstrations. More than 15 proposals were presented and a reduced set was selected according to various criteria, which included the users' willingness to cooperate, the capability of using existing, readily available equipment at minimum cost (at least in the demonstration phase) and the potential for expansion from a regional to an international scale.

Based on these criteria, the Agricultural Information System (AGRIS) was selected as the first pilot project. AGRIS is an existing advisory system operated by Germany's Bavarian Ministry of Food, Agriculture and Forestry within the framework of their Ecological Plant Cultivation programme. (This provides further evidence that there may be great market potential for CDEDS in agriculture.) The objectives of the programme are two fold:

— to reduce the amount of fertilisers and pesticides being used by optimising the application of these substances
— to provide comprehensive individual and specific information to farmers in order to allow for well-aimed measures in the areas of plant protection and nitrogenous fertilising.

The existing AGRIS consists of:

— a measurement network, consisting of 117 agro-meteorological stations spread throughout Bavaria and which periodically monitor regional meteorological and soil data
— a central processing facility, consisting of an expert system, databases and program suites running agricultural prognosis, advisory and decision models, based on the collected meteorological data and other data
— a communication system, which provides the farmers and wine-growers with individual information for their day-by-day decisions.

The measurement network for the data collection and the communication system for the distribution of the individual information are based on the Deutsche Bundespost Telekom's BTX service.

The feasibility of the AGRIS via satellite was tested in two new German states, Thuringia and Saxonia, which lack a developed terrestrial infrastructure (BTX service is not available). Two institutions, namely the Agricultural Research Institute LUFA in Thuringia, and a farming association BUDISSA in Saxonia, agreed to operate a PRODAT point-to-point satellite network for experimental purposes.

Figure 5 shows the set-up used in the initial phase of the pilot project. Up to 20 of the existing AGRIS measuring sites in Bavaria and some new sites in Saxonia are equipped with a PRODAT terminal, which is connected to the farmer's PC. As in the original system, the PC is linked to the measuring station by a short terrestrial line. The measuring station and the PC preprocess the data according to the same procedures as used in the existing system. The PRODAT terminal then uplinks the data to the MARECS-B2 satellite. The data is downlinked by the satellite and received by the PRODAT Ground Earth Station (GES) in Fucino, Italy. This station acts like a hub station in a VSAT network. The Network Control Centre (NCC) associated with the GES uplinks the data to the satellite again, resulting in a double-hop transmission in the overall data delivery. The data uplinked by the GES is included in the Time Division Multiplex (TDM) outbound stream in a way that enables it to be received by the PRODAT terminal located in Munich. This terminal is connected to the Bavarian Agricultural Information System (BALIS) host computer, the central point of AGRIS.

The transfer of measurement data from the farmer's site to the BALIS is shown in Figure 5. According to this scenario, the double-hop link via the PRODAT GES replaces the existing BTX-connection of the agro-meteorological network in Bavaria and connects new measurement stations in Saxonia and Thuringia to the BALIS system.

Based on the successful completion of the initial test phase, the project will continue. In the next phase, the new, improved version of the PRODAT terminal (PRODAT-2) will be installed.

Another pilot project has been established recently, using the TSAT-2000 system. A satellite communication network has been set up in the Eastern part of Germany to monitor and control a large pipeline network in the energy industry. Although primarily designed for commercial purposes, this network will support the detection of leaks and will thus contribute to conserving the environment.

Conclusion

A large number of users are interested in using cost-effective, reliable, easy-to-install and ready-to-use communication networks as a complement to remote sensing by satellite, for the collection and distribution of *in situ* measured data for environmental applications.

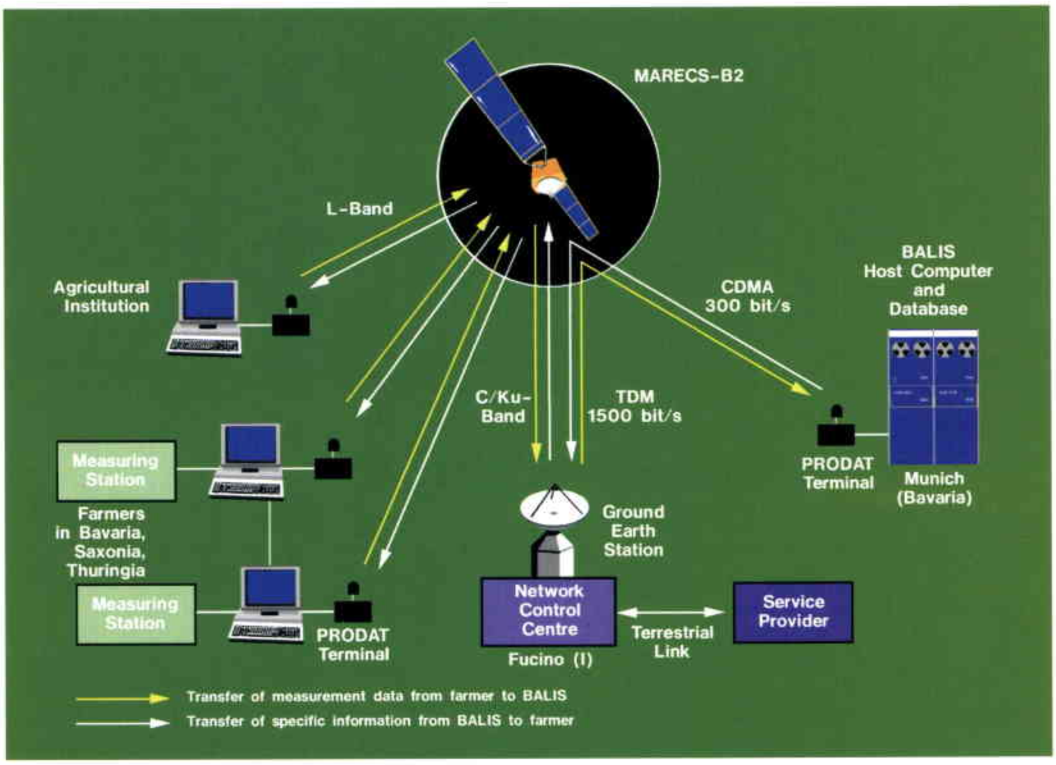


Figure 5. Communication set-up used in the initial phase of the AGRIS pilot project

Any ecological application based on *in situ* measurements will require very low data rates and volumes from the individual measurement stations to the network centre (or to the user). The satellite technology is already available to implement *in situ* ecological monitoring networks and absorb a significant share of the existing and of the developing market.

Today, however, regulatory and economic barriers hinder the success of the satellite market. In EC countries, the study shows that the economic break-even point between satellite and terrestrial communications for the collection and distribution of ecological data will not be achieved under existing conditions before 1997 despite the size of the market. If the satellite communications market was fully deregulated today, it would reach its break-even point as early as 1995.

In Eastern Europe, no accurate forecast is possible. At present, satellite communications are the only means of implementing an *in situ* ecological network within a short time. When the legislative requirements and the budget allocations for environmental monitoring become more significant, satellite technology must be ready to offer a suitable, cheap and reliable service.

Two suitable and interesting satellite terminals for CDEDS are PRODAT-2, which operates in the C- and L-bands and is primarily for mobile applications, and TSAT 2000, which operates in the Ku-band and is primarily for fixed applications. Both of those new technological developments have been sponsored by ESA. In order to gain competitiveness in this market sector, developments that lower the cost of small, autonomous and handy satellite terminals must be supported.

All parties interested in satellite communications should also apply maximum pressure for a rapid enforcement of the EC Green Paper on the deregulation of the communications market in Europe. Due to the unfamiliarity of potential users with satellite services, and their doubts associated with the utilisation of new technology, suitable proof-of-concept demonstrations must be provided and sponsored in all the different ecological areas.

Acknowledgement
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Two Years of ERS-1 Data Exploitation

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The ERS-1 mission has fully lived up to expectations and today, after two years of operations, it continues to demonstrate the ability of such a sophisticated remote-sensing system to provide valuable earth-observation data to several categories of users, ranging from the real-time operators involved in meteorological, oceanographic and environmental applications, to long-term research-project groups working off-line.

The ERS-1 system is also being exploited for a wide range of commercial applications, thereby opening up new horizons in the earth-observation field. Its success is further underlined by the very large number of national and foreign stations acquiring or planning to acquire ERS-1 data, already allowing coverage of the majority of globe's land masses. They represent by far the largest community of international operators covered by a single project.

ESRIN, via its ERS Exploitation Division, has operational responsibility for the ERS-1 Payload Data Ground Segment as well as the related User Services.

The Payload Data Ground Segment

The overall ERS-1 Payload Data Ground Segment is composed of the following facilities:
- the ESRIN ERS Central Facility (EECF)
- the ESA Ground Stations network
- the ESA Processing and Archiving Facilities (PAFs)
- the National and Foreign stations.

Figure 1 shows the overall interfaces between these facilities and their relationship to the User Community.

The ESRIN ERS Central Facility (EECF)

The EECF, located in Frascati, includes the User Services, the Product Control Service (PCS), and the Reference System. It provides:
- the user interface
- definition on tasks for the whole ERS Ground Segment

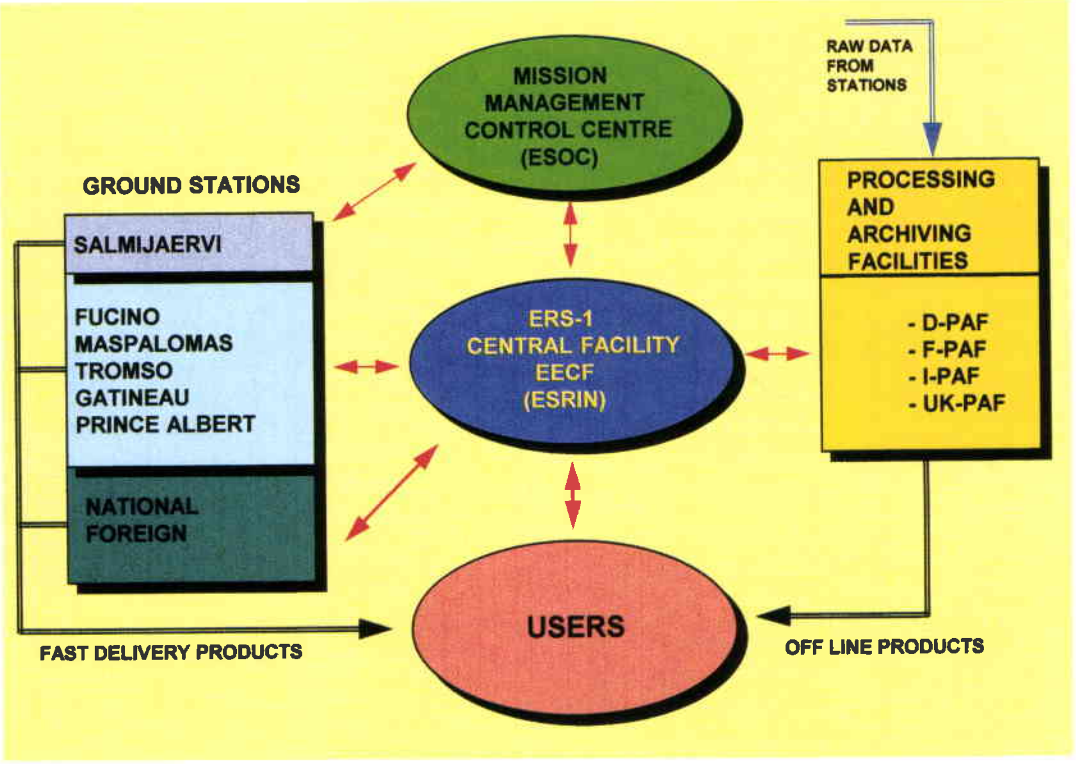


Figure 1. Schematic of the overall ERS-1 ground segment

- mission planning in conjunction with the Mission Control Centre at ESOC
- management of a facilities network for the acquisition, archiving, processing and distribution of fast-delivery and off-line products
- coordination of the national and foreign stations network
- routine monitoring of sensors
- fast-delivery and off-line product quality checks
- the interface to the industrial consortium charged with the promotion and distribution of data to commercial users
- maintenance of data-processing software for the entire ESA network.

The User Services unit is responsible for planning the ERS-1 mission in line with the user requests and for scheduling the world-wide data acquisition accordingly. In addition, it supports the end users, maintains the centralised catalogue of acquisition and production, and handles user requests and product orders.

Another important activity of the User Services unit at ESRIN is the support it provides for training programmes for Developing Countries in the application and exploitation of ERS data. The User Services also covers the promotional activities in conjunction with the industrial consortium for the ERS-1 commercial applications development, including the preparation of materials for symposia, conferences and public-relations purposes.

The Product Control Service's operational tasks include the monitoring and control of ERS data-product quality and assessment of the compliance of system performance with the system specifications. Another of its main roles is to assess instrument behaviour and the related margins. This information represents vital feedback for future programmes, including the analysis and development of algorithms for calibration and validation activities.

The Maspalomas Station, in the Canary Islands

The Product Control Service uses a range of systems, including the so-called 'Reference System' for the High- and Low-Rate Fast-Delivery Processing chains, which also supports the maintenance of the operational software installed at the ESA Ground Stations.

The ESA station network

The ESA station network has been set up not only to ensure that the satellite telemetry data are correctly acquired along the orbits, but also to allow the maximum coverage over the European area for the Synthetic Aperture Radar (SAR) and Low Bit Rate (LBR) payload data acquisitions.

The ERS-1 payload data network, managed by ESRIN, includes six ground stations, sited at Salmijaervi (Kiruna, Sweden), Fucino (Italy), Maspalomas (Canary Islands), Tromsø (Norway), and Gatineau and Prince Albert (Canada). These stations have already been operational for two years.

Except for Salmijaervi, which is operated by ESOC and is fully dedicated to ERS operations and telemetry, tracking and control (TT&C) activities, all of the other stations are multi-mission in nature. Under contract to ESRIN, they perform the operations and services for ERS-1 payload data acquisition, processing and dissemination, as well as hosting the ESA equipment for the requisite operations. They also provide similar operational services vis-a-vis other international earth-observation satellites, such as Landsat (USA), Spot (France), JERS-1 (Japan), and Tiros (USA).

ESA's Salmijaervi ground station on northern Sweden

The sharing of tasks and responsibilities between these stations takes into account the constraints related to the high- and low-rate payload data characteristics:

- Salmijaervi
  - Global Low Bit Rate (real-time and on-board tape-recorder data dumping)
  - Regional SAR over Northern Europe and the North Pole
- Fucino
  - Regional SAR and LBR over the Mediterranean area, North Africa and Central/Southern Europe
- Maspalomas
  - Global LBR
  - Regional SAR over Northwest Africa and the Eastern Atlantic
- Tromsø
  - ATSR data real-time processing and operational backup for Kiruna acquisitions
- Gatineau
  - Global LBR
- Prince Albert
  - Global LBR.

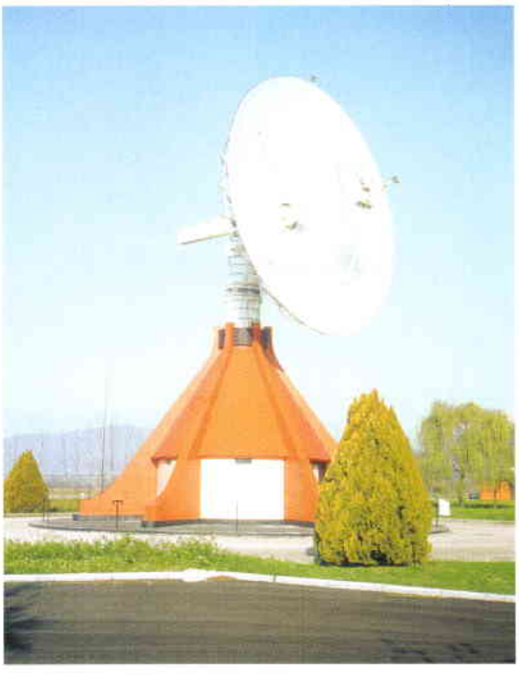
This network ensures global LBR data acquisition (mainly from the on-board recorder dumping) on a daily basis. The typical daily activities of the stations can be summarised as:

- satellite tracking and scheduled data acquisition
- recording of the data on high-density magnetic tapes
- processing of the Fast Delivery (FD) Products to be made available within three hours of data sensing, to nationally nominated centres
- processing of scheduled products for distribution to users
- reporting of the activities to the EECF
- transmission to the Product Control Service at ESRIN of relevant parameters and products for routine sensor-performance monitoring.

During the first two years of operations, more than 10 000 LBR and 12 000 SAR passes (typically a few minutes of transmission each) have been acquired and high-density tapes carrying approximately 40 terabytes of raw data have been stored at the ESA archiving facilities.

The ESA Processing and Archiving Facilities (PAFs)

The PAF concept was derived from proposals by some ESA Member States to implement facilities dedicated to specific scientific and application domains, based on the existence of groups or institutes in their countries already internationally active in these fields. Consequently, the PAFs were established as joint



The Fucino station's ERS antenna

The French Processing and Archiving Facility (PAF) in Brest, at the IFREMER site

national/ESA endeavours to support and expand the applications of ERS-1 with an extensive products list.

The four PAFs, managed under contract to ESA are:
- F-PAF in Brest, France, operated by IFREMER, with the primary role of:
  - archiving all the LBR data (Wave, Scatterometer, Radar Altimeter and Wind) over oceans and generating the associated products
  - backup archiving of the ATSR (Along-Track Scanning Radiometer) global dataset, and generation and distribution of ATSR Microwave Sounder data
  - storage of relevant ESA-provided campaign data.
- UK-PAF in Farnborough, UK, operated by NRSCL, with the task of:
  - primary archiving of SAR and global ATSR data and Altimeter data over ice and land
  - secondary archiving of LBR data
  - processing and distribution of SAR, ATSR and Altimeter data over ice and land.

The UK Processing and Archiving Facility (PAF) in Farnborough

The German Processing and Archiving Facility (PAF) at Oberpfaffenhofen

- D-PAF in Oberpfaffenhofen, Germany, operated by DLR, with the allocated tasks of:
  - archiving and processing the SAR data acquired at the O'Higgins Antarctica station as well as selected data sets acquired at other ESA and foreign stations
  - primary processing centre for SAR precision and geocoded image data
  - high-level Altimeter product generation and precision orbit calculations.
- I-PAF in Matera, Italy, operated by the Italian Space Agency and charged with:
  - archiving, processing and distribution of regional SAR data acquired by the Fucino and Maspalomas stations
  - archiving, processing and distribution of LBR products covering the Mediterranean area.

The PAFs are the core of the ERS-1 product distribution system and their overall role can be summarised as:
- long-term ERS-1 payload data archiving and retrieval
- generation and distribution, on request, of the offline geophysical standard products to users as instructed by the EECF via product orders
- support to ESA for sensor data calibration, data validation and long-term sensor performance evaluation.

Each PAF receives the relevant ERS-1 payload telemetry data on a regular basis from the ground stations and ensures the long-term archiving, the routine production and the distribution of the data. Their activities are managed and monitored from ESRIN.

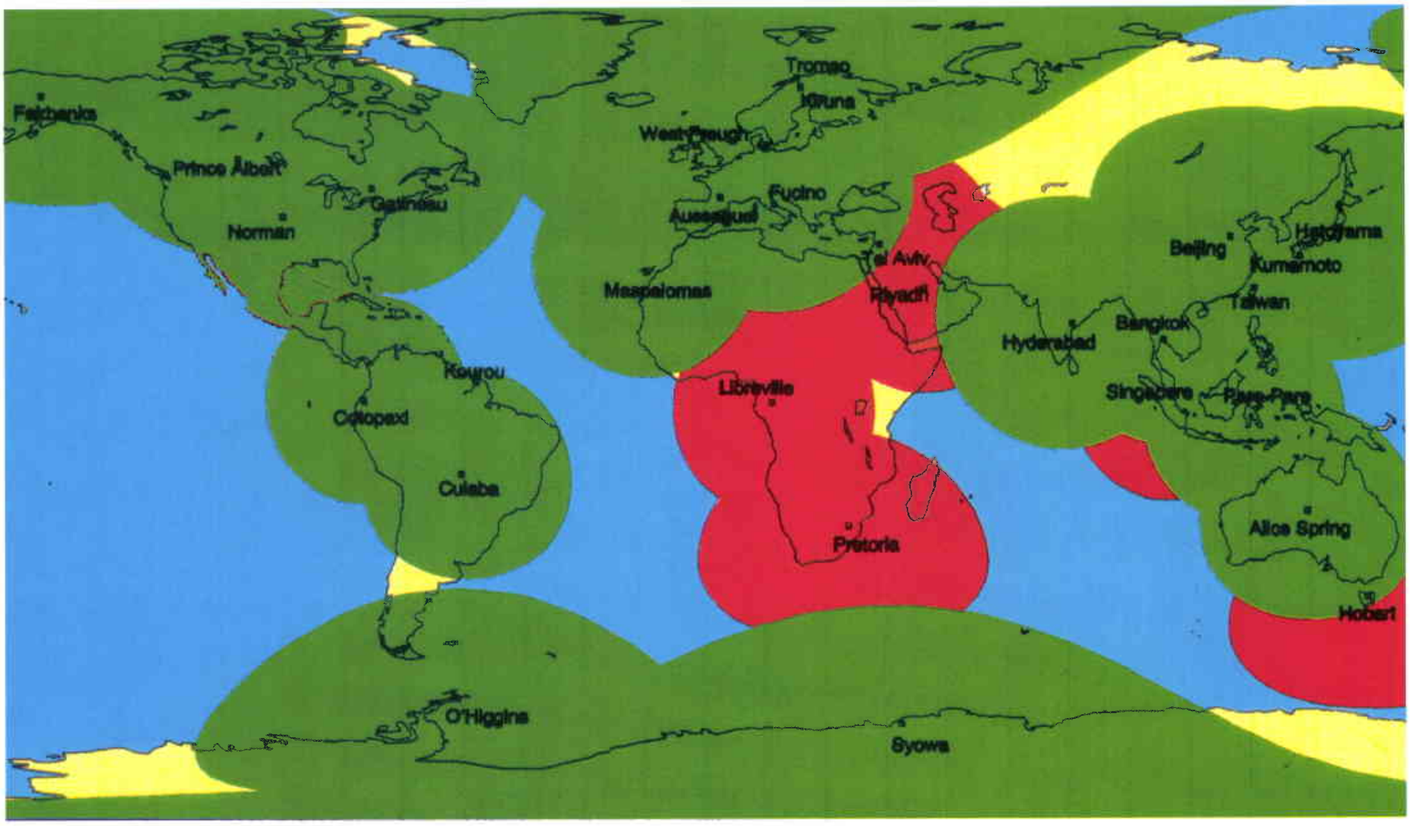


Figure 2. Total planned ERS-1 ground-station coverage

The **National** and Foreign stations

In addition to the ESA station network, some national (i.e. belonging to countries participating in the ERS-1 Programme) and foreign (belonging to non-participating countries) ground stations have been set up or are in the process of being set up around the world in order to acquire ERS-1 SAR payload data.

The current situation is summarised in Table 1. These stations operate under the terms and conditions of a standard Memorandum of Understanding with ESA.

All ERS-1 ground stations receive, from the EECF in Frascati, the input data needed to acquire, process and distribute the SAR data and they report back to the EECF on their station activities and status. These stations generate and distribute products developed nationally to ESA Principal Investigators, Pilot Projects and commercial users. In particular, low-resolution near-real-time products are distributed as a service from the Tromsø and Gatineau stations.

The stations listed in Table 1 will, together with the ESA stations, provide the world-wide data coverage presented in Figure 2.

Data flow and product generation

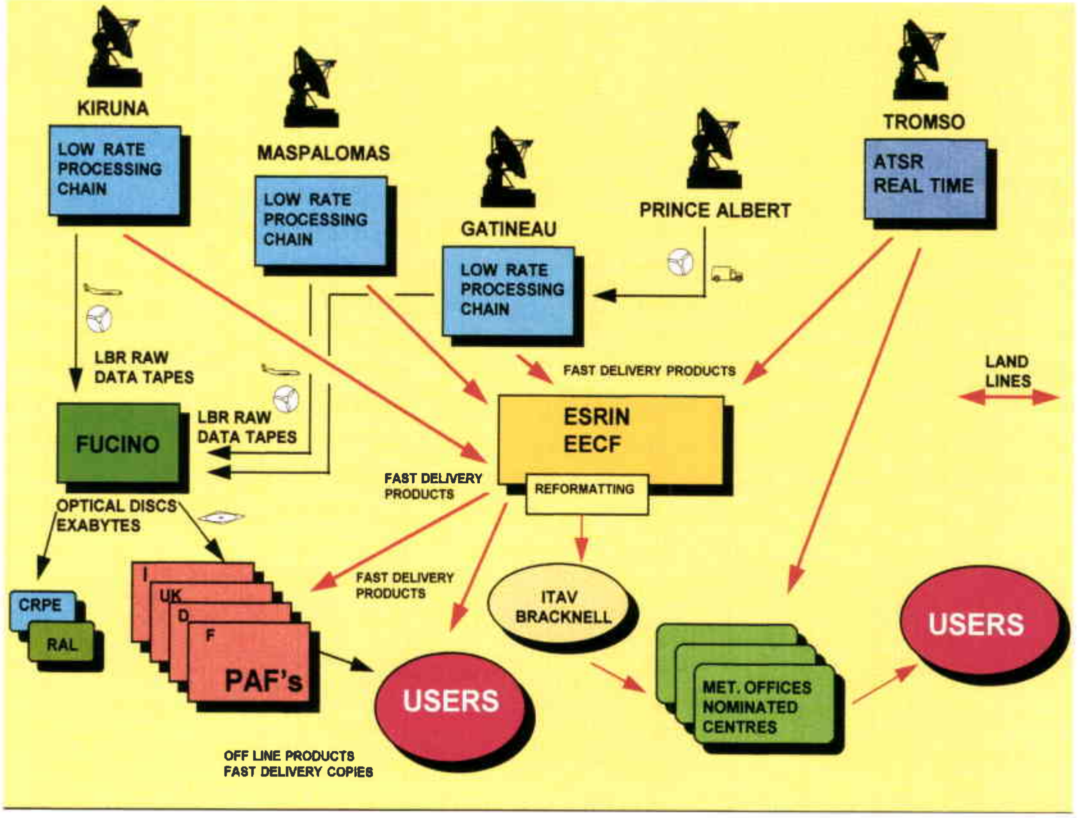
ERS-1 LBR and SAR products are distributed to users either on a routine basis or on specific request. The full list of currently available products is shown in Table 2.

The flow of the ERS-1 LBR data is summarised in Figure 3. These LBR data – obtained from the Wind-Scatterometer, the Radar Altimeter and the Active Microwave Instrument (in Wave mode) – are processed immediately after reception to so-called 'Fast Delivery' level (UWI, URA, UWA) at the ESA stations. They are then collected at the ERS Central Facility and,

Table 1. Status of national and foreign ground stations acquiring, or planned to acquire, ERS-1 SAR data

Tromsø	Norway	Operational
Aussaguel	France	Operational (campaign basis)
West Freugh	UK	Operational
O'Higgins	Antarctica, D	Operational (campaign basis)
Fairbanks	Alaska	Operational
Cotopaxi	Ecuador	Operational
Gatineau	Canada	Operational
Prince Albert	Canada	Operational
Hyderabad	India	Operational
Alice Springs	Australia	Operational
Kumamoto	Japan	Operational
Hatoyama	Japan	Operational
Syowa	Antarctica, J	Operational (campaign basis)
Cuiaba	Brazil	Operational
Bangkok	Thailand	Acquisition only; processing by end-93
Hobart	Australia	Planned for end-93 (acquisition only)
Riyadh	Saudi Arabia	Under test
Pare-Pare	Indonesia	Under test
Beijing	China	Under test
Taipeh	Taiwan	Under test
Tel Aviv	Israel	Planned for end-93
Libreville	Gabon, DLR-D	Planned for early-94 (campaign basis)
Pretoria	South Africa	Planned for mid-94
Singapore	Singapore	Planned for end-94

Figure 3. Global low-rate data flow



after being converted, are injected into the Global Telecommunication System (GTS) of the World Meteorological Organisation (WMO), as well as being disseminated to selected facilities and users (including the PAFs, from which they can be obtained as offline copies).

For the ATSR data, real-time processing is performed at Tromsφ for the generation of the Sea Surface Temperature Measurement, and the data is sent thereafter directly to the meteorological offices and also collected at ESRIN for further distribution.

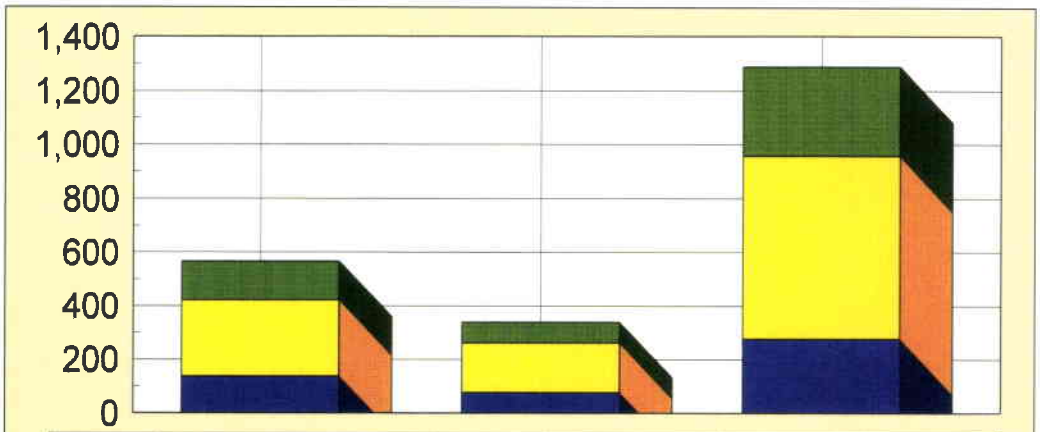
The full LBR data set is archived at the PAFs for the offline generation of precision products.

Figure 4 shows the number of LBR Fast Delivery Products distributed during the various mission phases: Commissioning Phase (August – December 1991, 3-day repeat cycle), First Ice Phase (December 1991 – March 1992, 3-day repeat cycle), Multidisciplinary Phase (April 1992 – December 1993, 35-day repeat cycle), etc.

ATSR data are also archived at RAL in the United Kingdom and CRPE in France for their internal investigations and support to ESA production activities.

The SAR data flow for the ESA station is represented in Figure 5. The SAR data are processed to Fast Delivery level at the ESA ground stations and disseminated via the BDDN (Broadband Data Dissemination Network, under ESRIN control), which allows the transmission of SAR Fast Delivery images from Kiruna or Fucino nominally within 24 h of data sensing to Nominated Centres (one per country in Europe), using a Eutelsat satellite link for image transmission.

Figure 4. Distribution of Low Bit Rate (LBR) Fast Delivery products



	Phase A	Phase B	Phase C
URA	136	75	275
UWA	286	187	682
UWI	145	78	332
TOTAL	567	340	1,289

(Values in thousands of products)

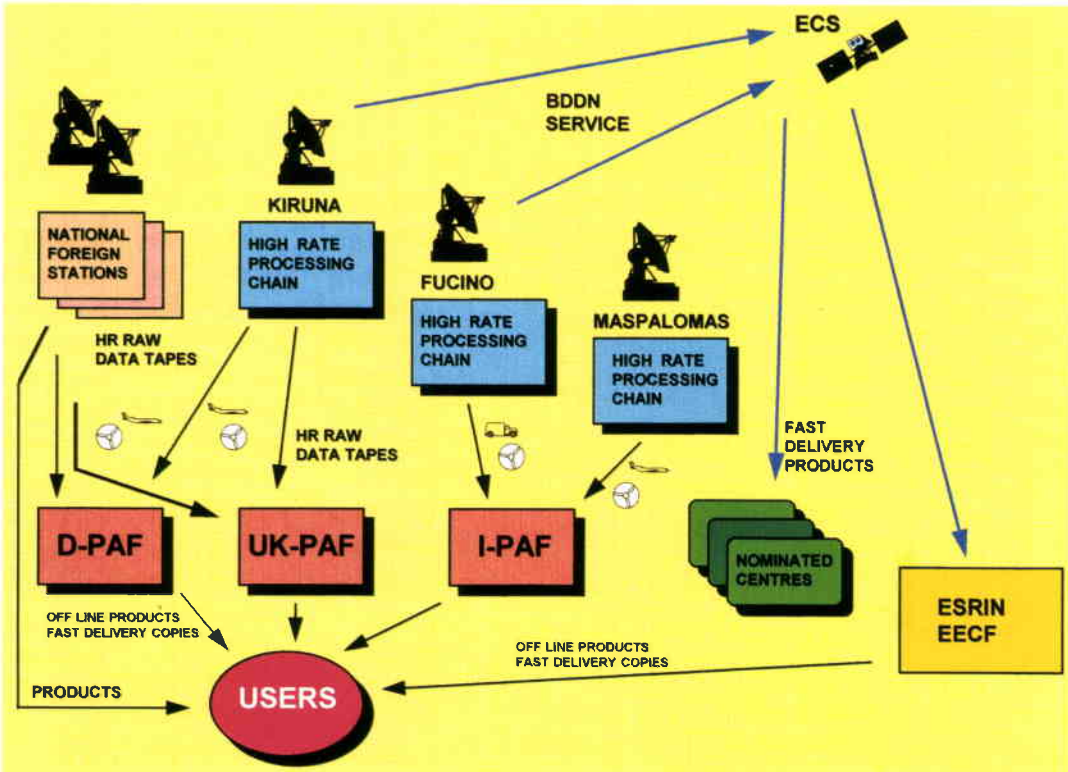


Figure 5. Global high-rate data flow

The Nominated Centres then distribute the data to the final users. The raw data are sent to the PAFs for the offline generation of ESA standard products (PRI, SLC, Geocoded, Fast Delivery copies, etc.).

Figure 6 shows the numbers of each ESA product type delivered to the users by the ESA processing facilities. Figure 7 shows the distribution of products by user category, and Figure 8 that by production facility.

User Services

The User Services unit provides support to the ERS-1 user community via:

- User interface functions, performed via the ERS Help Desk (for queries, documentation, etc.) and via the ERS Order Desk (for data requests from Principal Investigators, Pilot Project leaders, Ground Station operators, etc.). The requests from commercial and research users are dealt with by the ERSC Customer Service, where ERSC represents a Consortium formed by Eurimage, Radarsat International and Spotimage.
- Internal functions, including mission planning, production planning, data dissemination control, telecommunication network monitoring, system and database management.

Table 2. ERS-1 products

Data type	Code	Production facility [1]
SAR		
Annotated Raw Data	SAR.RAW	D-PAF, UK-PAF [2]
Fast-Delivery Image	SAR.UI16	Fucino, Kiruna
Fast-Delivery Copy	SAR.FDC	D-PAF [2]
Single-Look Complex Image	SAR.SLC	D-PAF, I-PAF [2]
SLC Full	SAR.SLCF	UK-PAF
Precision Image	SAR.PRI	D-PAF, I-PAF, UK-PAF [2]
Ellipsoid Geocoded Image	SAR.GEC	D-PAF
Terrain Geocoded Image	SAR.GTC01	D-PAF [3]
SAR WAVE MODE		
Fast-Delivery Product	SWM.UWA	Gatineau, Maspalomas, Kiruna
Fast-Delivery Copy	SWM.FDC	F-PAF
WIND SCATTEROMETER		
Fast-Delivery Product	WSC.UWI	Gatineau, Maspalomas, Kiruna
Fast Delivery Copy	WSC.FDC	P-PAF
ALTIMETER		
Fast-Delivery Product	ALT.URA	Gatineau, Maspalomas, Kiruna
Fast-Delivery Copy	ALT.FDC	F-PAF
Ocean Product	ALT.OPR02	F-PAF
Sea-Surface-Height Model	ALT.SSH	D-PAF
Quick-Look SSH [4]	ALT.SSHQL	D-PAF
Quick-Look OPR [5]	ALT.QLOPR	D-PAF
Ocean Geoid	ALT.OGE	D-PAF
Ocean Topography	ALT.TOP	D-PAF
ORBIT		
Preliminary Orbit	ORB.PRL	D-PAF
Precise Orbit	ORB.PRC	D-PAF

[1]D-PAF, F-PAF, I-PAF and UK-PAF, respectively, indicate German, French, Italian and United Kingdom PAFs; [2]Back-up production capability possible at ESRIN; [3]If terrain model exists at D-PAF; [4]SSH = Sea Surface Height; [5]OPR = Ocean Product

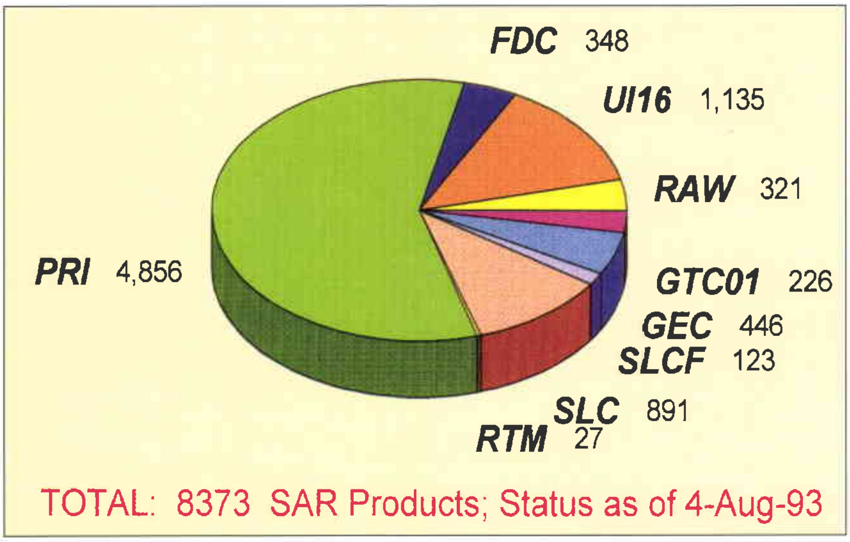


Figure 6. Synthetic Aperture Radar (SAR) products distributed, by type

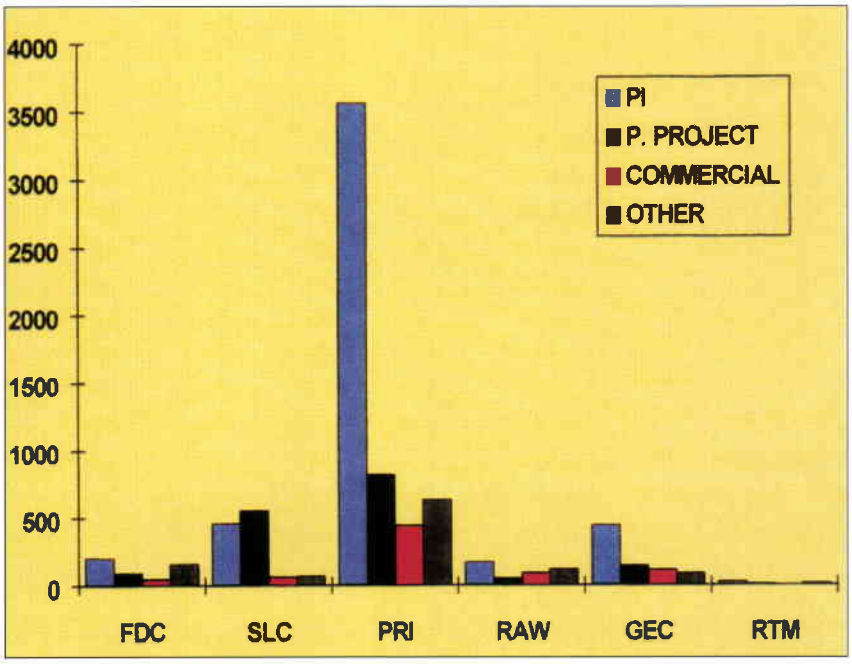


Figure 7. Synthetic Aperture Radar (SAR) products distributed, by user category

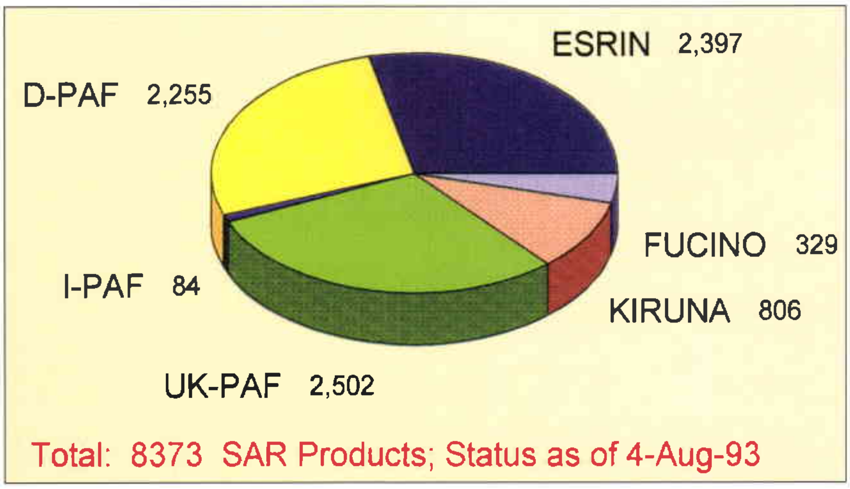


Figure 8. SAR products distributed to users from ESA facilities

Figure 9 shows the User Services organisation, with the various user categories at the top, the ERS ESRIN services in the central area and the external facilities below, controlled and operated via the telecommunications infrastructure.

The user requirements are generally expressed in the user requests (including the type of product required, the geographical area and the time window) with the exception of the LBR products, for which the distribution is performed on a global basis.

Figure 10 shows the number of SAR user requests per country and mission phase. The processing flow of the requests for SAR products is shown in Figure 11.

The SAR user requests may involve data already acquired and archived: hence those requests are converted into production orders for the PAFs, where the required products are generated and dispatched to the end user. In cases where the request concerns data still to be acquired, the relevant acquisition is planned taking into account possible conflicts, alternatives, or anticipated needs and then confirmed in cooperation with the Mission Management and Control Centre (MMCC) at ESOC.

Upon confirmation of data reception from the relevant ground station, the product order is placed and data delivered to the end user either via the BDDN (Fast Delivery products) or by the relevant processing facility (offline products).

The mission planning performed at ESRIN includes a 'baseline' mission, which adds expected and future needs as well as repetitive coverage for multi-temporal analysis to the specific user requests. It permits the optimal use of satellite resources, by limiting the number of SAR on/off switchings per orbit and exploiting the SAR for close to its 12 minute limit per orbit.

The results of this planning are shown in Figures 12 (world-wide acquisition for Multidisciplinary Phase C) and 13 and 14 (acquisitions by station for the three mission phases).

As well as all the other information, the EECF maintains a Catalogue of the ERS-1 data acquired worldwide and of the products archived at the PAFs. This Catalogue is regularly updated whenever the new acquisition reports are generated at the acquisition stations and the data is ingested into the database.

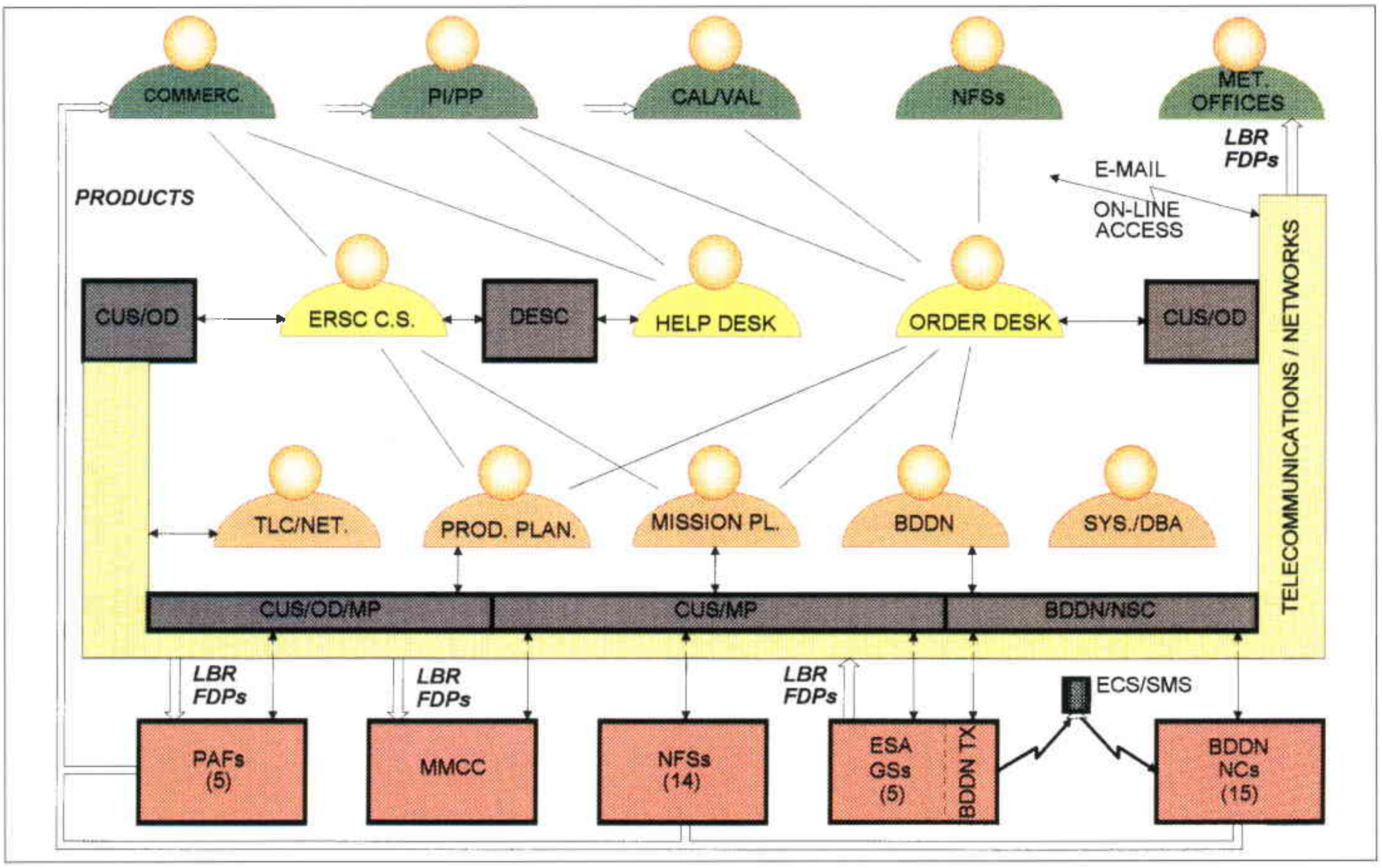


Figure 9. ERS-1 User Services organisation

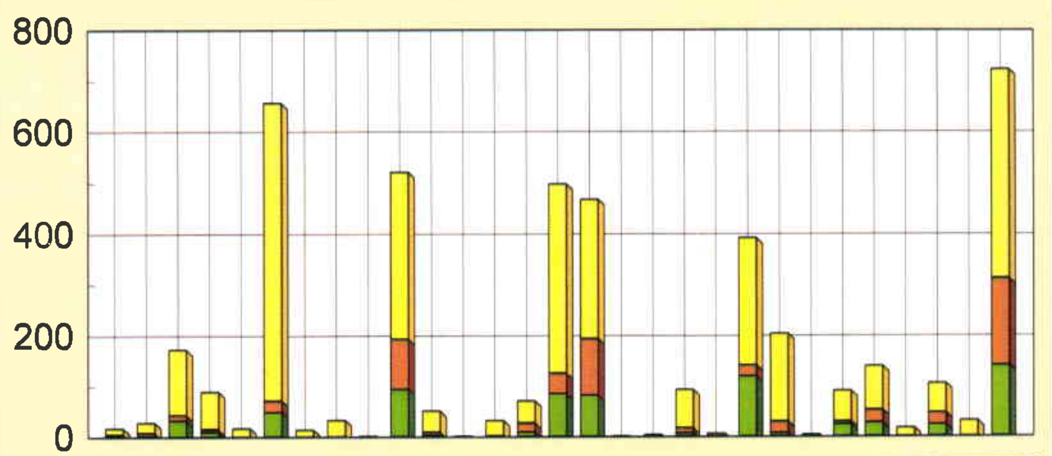
Users can query on-line the SAR catalogue or the Global Activity Plan (GAP), which contains updated information on the planned operations of the different payload instruments. Users can also browse through a simplified version of the SAR Catalogue on their PC using the 'Display ERS-1 SAR Coverage' (DESC) software package. This tool can also support the users in defining their requirements for products and services.

and to the Quick Look OPR products. In addition, a database of world-wide articles and documents related to ERS-1 applications and findings is available online and continues to grow as new input is regularly generated.

In February 1992 ESA signed an agreement with the ERSC Consortium under which the latter has world-wide commercial distribution rights for data from the ERS-1 satellite.

Also generated at ESRIN, in collaboration with ESA Publications Division at ESTEC, is the printed material for supporting the user activities and training, such as the ERS User Handbook, the ERS System Description, the ERS Products Specification document, and the CD Guide to ERS-1, etc. In addition, the user can make use of an on-line server via Internet, Span or X.25, which provides free access to the GAP, to the weekly update of the DESC catalogue files, to the database of the ERS-1 SAR Low Resolution Images, generated daily at Kiruna,

Figure 10. Number of user requests received, by country



	AR	AT	AU	BE	BR	CA	CH	CO	CS	DE	DK	EC	ES	FI	FR	GB	IE	IL	IN	IS	IT	JP	MX	NL	NO	PL	SE	TH	US
PHASE-A	3	1	32	9		49				94	3		2	9	85	82		1	7	1	119	7	1	24	27		23		140
PHASE-B	2	7	11	6		23				99	6			18	41	112		2	10		22	23	1	6	26		24		171
PHASE-C	13	21	130	75	18	585	15	34	2	329	43	2	31	45	373	275	2	1	77	6	251	174	2	62	87	18	59	32	412
TOTAL	18	29	173	90	18	657	15	34	2	522	52	2	33	72	499	469	2	4	94	7	392	204	4	92	140	18	106	32	723

Figure 11. User request processing flow for SAR products

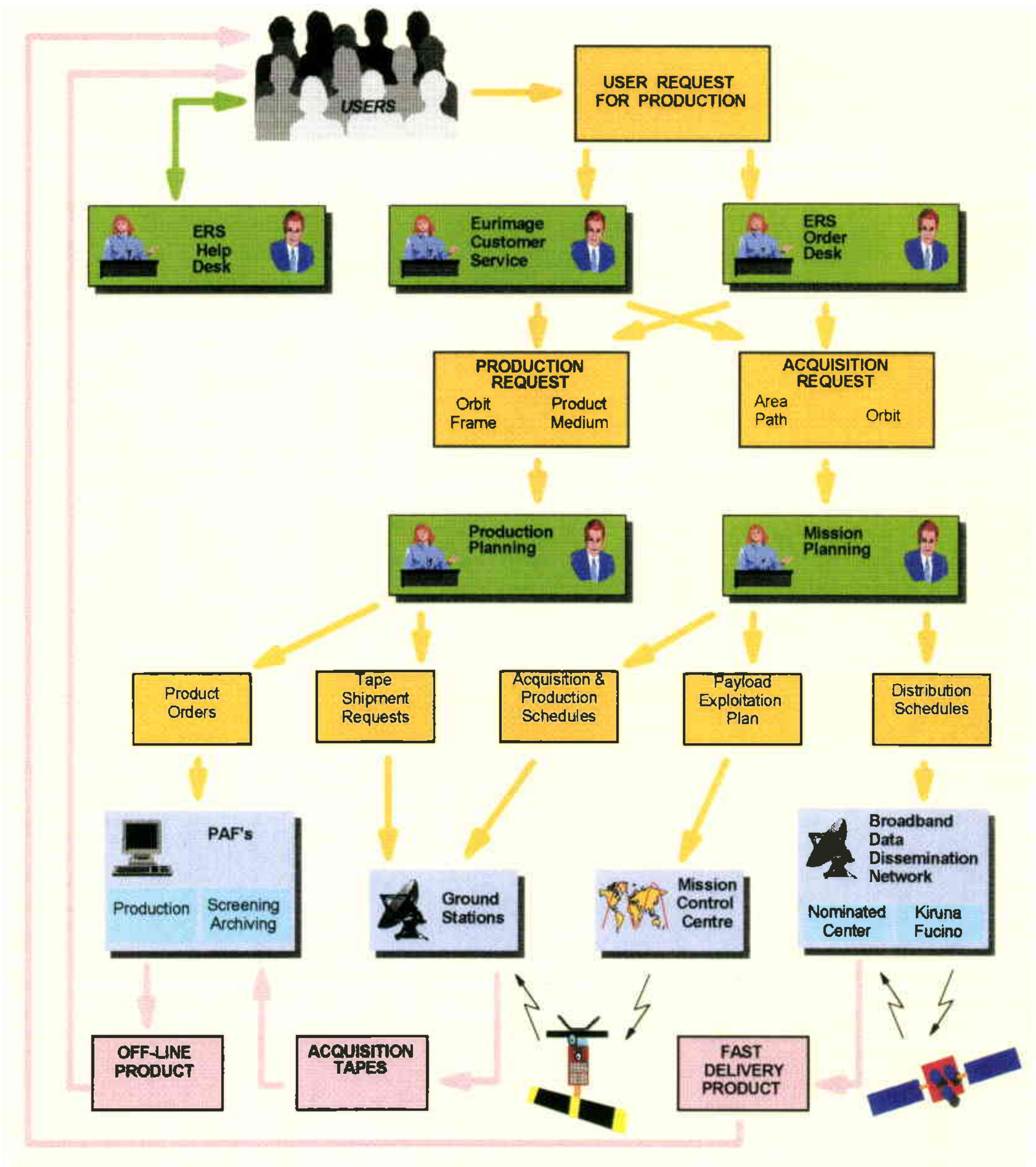
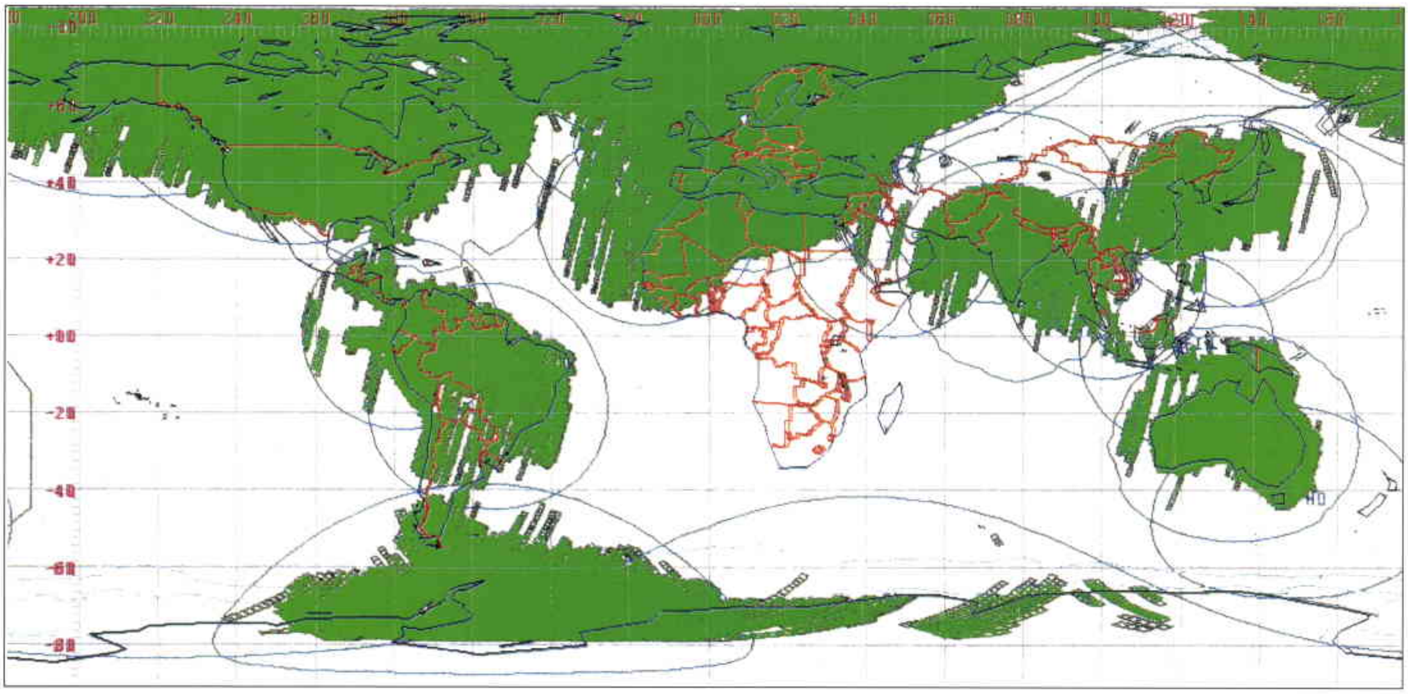


Figure 12. SAR acquisition worldwide for the Multi-disciplinary Phase-C



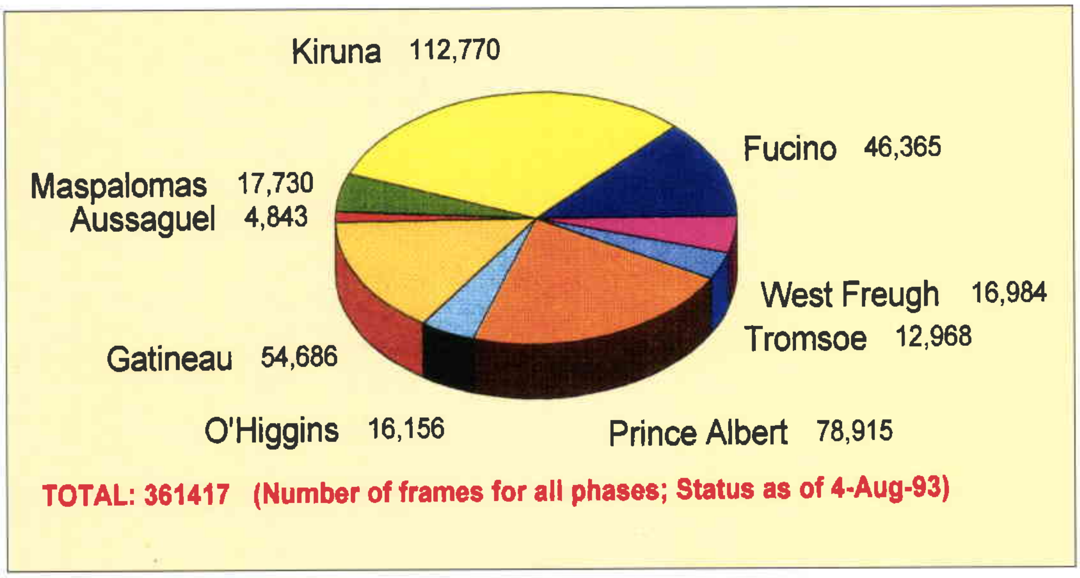


Figure 13. SAR acquisition by ESA and national stations

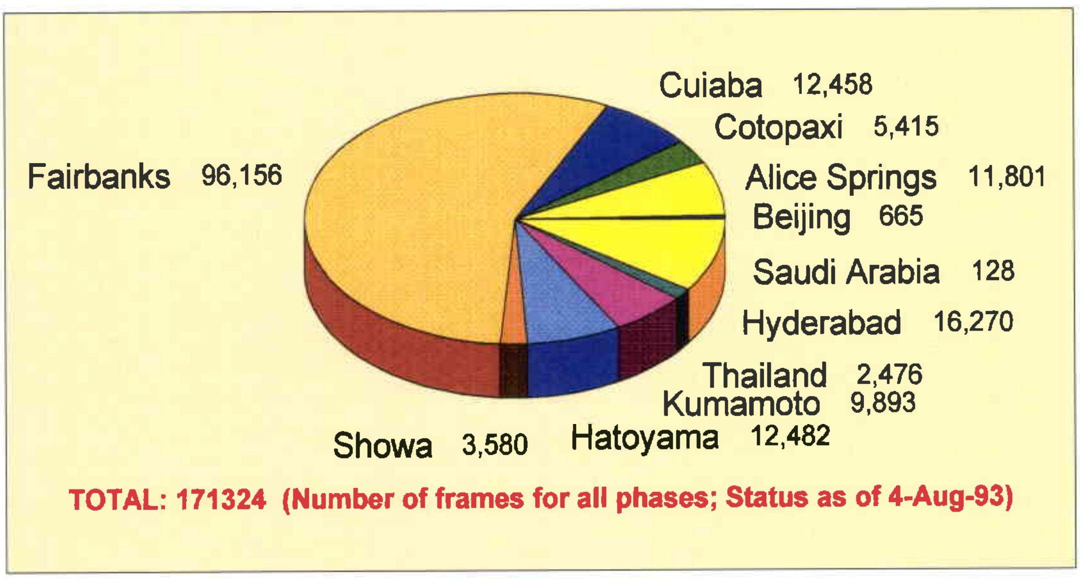


Figure 14. SAR acquisition by foreign stations

The three companies in this Consortium – Eurimage, Radarsat International and Spotimage – have a wealth of experience in the promotion, marketing and distribution of earth-observation satellite data. Each member of the Consortium is responsible for the users of a specific geographical coverage: Eurimage for Europe, North Africa and the Middle East; Radarsat International for Canada and the United States; and Spotimage for all other parts of the world.

Conclusion

ERS-1's first two years have been those of a very successful demonstration mission that has experienced only minor satellite hardware/software problems. The payload has performed well, in terms of both data quality and sensor availability (around 96%). ESRIN and the facilities under its management have successfully overcome early teething troubles, typical in the start-up phase of such a complex venture, to provide users with the high-quality products and support information necessary to allow them to make optimum use of the data being distributed.

ESRIN is currently working hard to improve its services still further, especially those oriented towards enhancing the user application aspects, the integration of data from different sensors and satellites, the timely distribution of information, and the promotion of ERS-1 data utilisation.

ESRIN is also presently actively involved in further upgrading the ground-segment network in time for the launch of ERS-2 at the end of 1994.

Using Non-ESA Missions to Prepare for Envisat

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Earth observation from space, which started with experimental single-study missions, is now moving towards a more mature era in which the globe is being studied as a complete system and where the need for measurements goes well beyond the limits of a single type of observation, both spatially and temporally. This implies that satellite missions and the data they provide must henceforth be seen as an integrated system in which maximum synergy is assured.

In preparing for the Envisat mission in particular, optimum re-use of experience accumulated through the exploitation of its predecessor missions, including those of relevant non-ESA satellites, is mandatory in order to take maximum advantage of Envisat's enhanced capabilities.

Introduction

The Earth-observation-related activities at ESRIN, which started with the establishment of the Earthnet Programme in 1978, have been providing European users with access to imagery and data from a number of non-ESA missions as well as from the Agency's own ERS-1 satellite. Data from five successive Landsat missions, Seasat, HCMM, Nimbus-7, Tiros, MOS and JERS-1 have been acquired, pre-processed, archived and made available to the remote-sensing user community over the last fifteen years.

In this same time frame, as the space and ground technologies have developed, so too Earth Observation Science has evolved from what was initially a single-discipline approach to a more comprehensive multi-disciplinary concept. Land, ocean and atmosphere are no longer studied only as separate subjects, but their interactions, which are responsible for complex physical and bio-geochemical processes, are now attracting increasing interest.

This new 'global' view forms the basis for the design of ESA's future Envisat mission (described in detail in the last issue of ESA Bulletin), for which experience acquired both through the Agency's own ERS-1 and ERS-2 missions and with non-ESA missions will be of primary importance in order to provide a unique source of data for the understanding of the Earth's environmental system. In particular, the use of non-ESA missions will allow us to provide users with long time-series of data, to develop new algorithms and new data-analysis techniques, to experiment with the usefulness of data products in term of content, amount of data, mode of distribution vis-a-vis the user application, and finally to promote and prepare the users for the exploitation of the new data.

The relevance of the non-ESA missions

The experience already gained or still being acquired with Nimbus-7, with Tiros and, from 1994, with SeaWiFS, is a good example of how activities performed with non-ESA missions can provide useful input in preparing for Envisat. In fact, these three missions – the first expired, the second still active, and the third to be launched in 1994 – with their different spatial resolutions, spectral ranges and overall mission objectives, can be considered as precursors of the MERIS and AATSR instruments that will be flown on Envisat. They have provided valuable experience particularly in the exploitation of the data products needed to meet new application requirements and to offer new services to the users.

Nimbus/CZCS

The Nimbus-7 mission was launched in October 1978 by NASA to acquire experimental data for oceanography, meteorology and pollution control. Its payload complement included a Coastal-Zone Colour Scanner (CZCS), a scanning passive radiometer with six bands specifically tuned for sea observation (see Tables 1 and 2).

The mission lasted until June 1986 and the CZCS has generated the only set of global space data dedicated to ocean and coastal-zone water monitoring so far available.

ESRIN has collected and archived CZCS data acquired at the Maspalomas Station (E), at Lannion (F), and at Dundee (UK), as well as data received from NASA, all covering marine regions of European concern. Original raw data have been recorded on Computer-Compatible Tapes (CCTs), while a photographic quick-look archive and a catalogue have also been generated.

The increasing interest in ecological problems affecting coastal areas has led to extensive exploitation of this CZCS data and new algorithms and data-analysis methods have been developed by the scientific community in the process.

Table 1. Nimbus-7 mission parameters

Orbit altitude	955 km
Orbit inclination	99°
Orbital period	104 min
Equator crossing	1200 h mean solar time
Repeat cycle	83 orbits

Table 2. CZCS instrument parameters

Spatial resolution	825 m (at nadir)
Scan angle	78.68°
Swath width	1566 km
Data rate	800 kbit/s
Spectral bands	443, 520, 560, 670, 750 and 11500 nm

The effort to promote and coordinate CZCS data exploitation has been undertaken in the context of the joint European Commission (CEC) and ESA project known as 'OCEAN'. As a result of this activity, the full CZCS European data set consisting of more than 20 000 scenes on tape has been reprocessed, digital quick-looks have been generated, and all data have been archived on optical disk.

From this baseline archive, a number of scenes suitable for higher-level processing have been selected and an archive of geophysical products (level-2) providing marine and atmospheric reflectances, pigment concentrations, water-quality information and apparent water temperature have been generated. Time series of geo-mapped and large-scale-composite images have also been generated from the level-2 database and are in the course of being archived into a level-3 final archive (Fig. 1).

As part of the OCEAN project activity, algorithms for the generation of high-level geophysical products have been developed by a team of scientists coordinated by the CEC's Joint Research Centre (JRC) and the resulting software has been installed at ESRIN. To

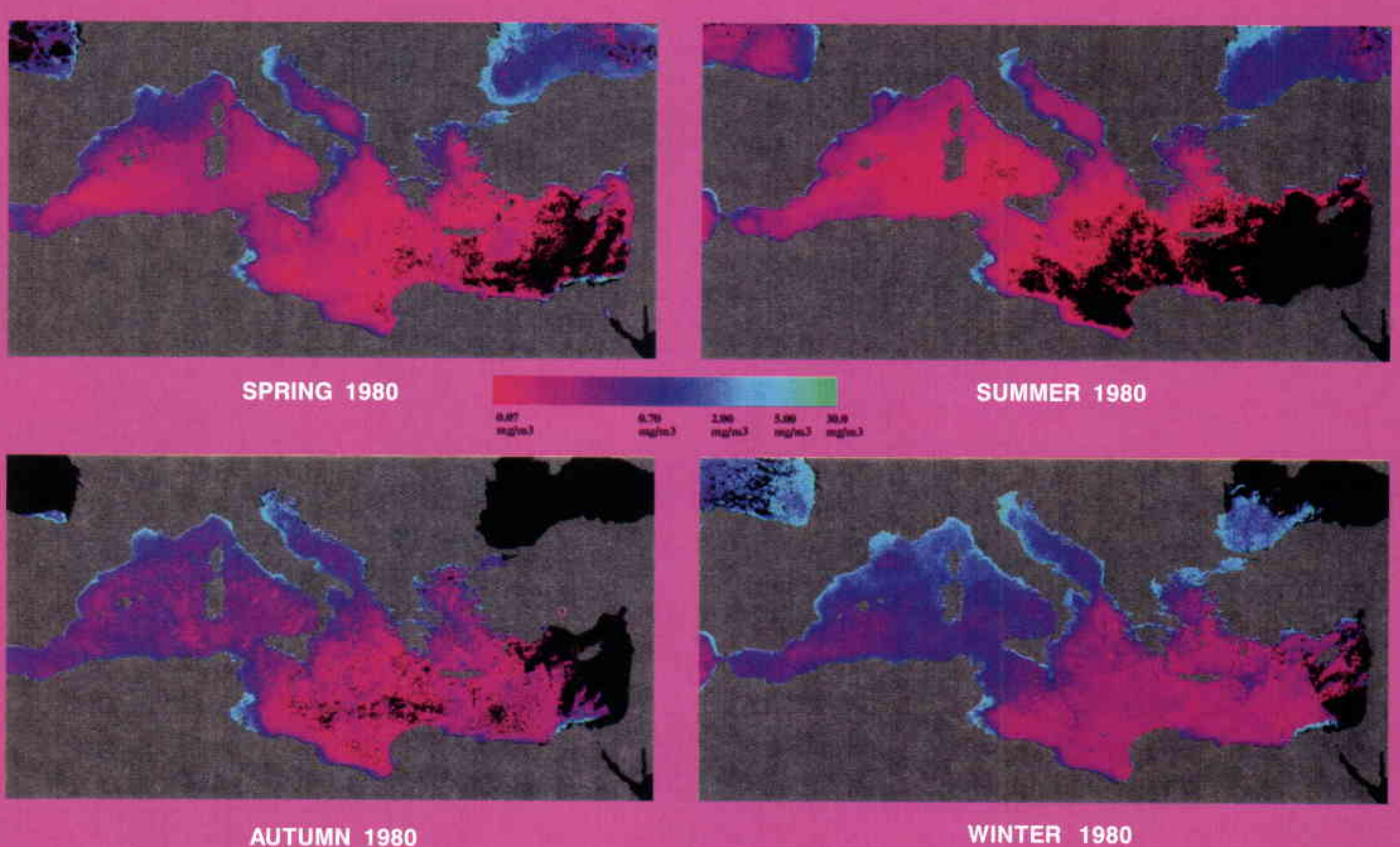


Figure 1. Example of a CZCS large-area multi-temporal composite of chlorophyll-like pigment in the Mediterranean Sea during 1980. The four images processed with the OCEAN software are obtained by spatial co-registration and averaging of all daily acquisitions of CZCS over the Mediterranean during a three-month period. Seasonal variations in pigment concentration can be easily seen

improve accessibility to the available data set still further and allow easy user selection of scenes of interest, quick-look images have been collected on a double CD-ROM package called the 'OCEAN CD-Browser', which includes more than 12 000 images. With this tool, the user is able to search for and display images and catalogue information on his own PC, and even has the possibility of generating an order for products from the same software.

These CZCS data products are used by scientists working in a variety of research areas, involving such tasks as the generation of long-term ocean-colour time series for the monitoring of coastal spatial patterns, the composition of large-scale seasonal images to assess plankton dynamics, blooms, upwelling and fishing potential, and the inclusion of ocean-colour data in the modelling of ecological and climatic processes.

The results of these studies, together with the experience gained in the data-management aspects, are directly relevant to the preparation of future marine environmental programmes, and specifically for the implementation of Envisat's MERIS ocean mission.

NOAA/AVHRR

The NOAA satellite series, which followed on from the experimental Tiros-N spacecraft, has been in continuous operation since June 1979. The operational configuration includes two satellites in complementary near-polar Sun-synchronous orbits, one of which has an afternoon/night equator crossing time, and one a morning/evening equator crossing. Their orbital altitude is 854 km, their period 102 min, and the longitudinal spacing between two successive orbits is 25.3° at the equator. NOAA-11 and 12 are the two satellites that are currently operational.

The NOAA series of satellites was designed primarily for meteorological applications and the two principal payload instruments serving this role are the Tiros Operational Vertical Sounder (TOVS) and the Advanced Very High Resolution Radiometer (AVHRR). However, over the years increasing interest has been shown in using the AVHRR data for a wide variety of remote-sensing applications, such as regional and global vegetation monitoring, snow/ice mapping, oceanography, and geology.

The AVHRR is a passive scanning radiometer with one visible channel at 630 nm, one near-infrared channel at 910 nm, one mid-infrared channel at 3540 nm, and one (on morning platform) or two (on afternoon platform) thermal-infrared channels at 10.8 and 12 microns, respectively. Its scanner, based on a rotating mirror, sweeps out a continuous 3000 km-wide swath of the Earth with a ground resolution of 1.1 km^2 at nadir. This, together with the orbit characteristics, allows twice daily and twice nightly coverage of any point at the equator with the two satellites operating in parallel. Data are either down-linked in real time at L-band, or recorded on-board and dumped to one of the NOAA stations during a subsequent pass.

There are several NOAA/AVHRR acquisition stations both within Europe and outside, which are operated by national entities carrying out local observation programmes. With the purpose of coordinating the European activities for NOAA/AVHRR and in order to provide the European users with uniform access to wide-coverage data through a common archive and a central catalogue, ESRIN has set-up a network of ground facilities known as the ESRIN Coordinated Tiros Network, or ECTN, which is composed of a number of existing acquisition stations and a central facility at ESRIN.

The ECTN's tasks are:
- the collection of data at a number of European and non-European receiving stations
- the generation of standard products
- the creation and maintenance of a central archive and a catalogue at ESRIN
- the distribution of products to the users
- the development of algorithms and processing software.

Stations have been equipped with a standardised hardware and software system.

AVHRR data products

The present activity includes the generation and archiving of standard level-1 products and digital quick-looks, the generation of level-2 products and of a set of application-oriented 'special products'.

Level-1 is the reference archive product and provides navigated raw AVHRR scenes containing 4 min of data acquisition. A digital, classified, colour-coded quick-look is extracted from the level-1 product, archived and printed in a simplified mode as a black and white hard copy for user consultation. Level-1 is the most widely distributed product and is used mainly as input for user-specific processing.

Level-2 products include a level-2a product that gives top-of-atmosphere calibrated radiances in all bands and a level-2b geophysical product that contains the Normalised Difference Vegetation Index (NDVI) over land, and Sea Surface Temperature (SST) over the oceans (Fig. 2).

An experimental AVHRR quick-look collection on CD-ROM has recently been generated which includes a selection of worldwide-acquired data together with the software needed for user browsing.

Besides 'standard' products, special application-oriented products have also been experimented with to meet specific user requirements for time-sensitive campaign-based observations. Examples include a product for active fire mapping that incorporates an algorithm for the detection of fire areas and consists of a reduced-area scene (typically 512 by 480 pixels) suitable for transmission via a network link (Fig. 3). Work is in progress to deliver this product operationally in near-real-time to the user for a fire-monitoring project over Senegal.

Another example is a product that has been developed as an aid to navigation in the Antarctic Sea, which exploits a user-provided algorithm for the classification of sea-ice in various concentrations and consists of a full-resolution reduced-size image (Fig. 4).

The 'Global Land 1-km AVHRR Data Set' Project

The need for a 1 km-resolution multi-temporal data set of AVHRR observations of the global land surface has been identified by several international groups, including the International Geosphere-Biosphere Programme. Following up on this requirement, a cooperative activity has started involving NOAA, NASA, the US Geological Survey (USGS) and ESA, and a number of coordinated ground receiving stations, in order to acquire worldwide, archive and distribute full-resolution AVHRR data.

ESA data, collected at all ECTN ground stations, are exchanged with other parties' data collected by the US Geological Survey at the EROS Data Center, including that provided by

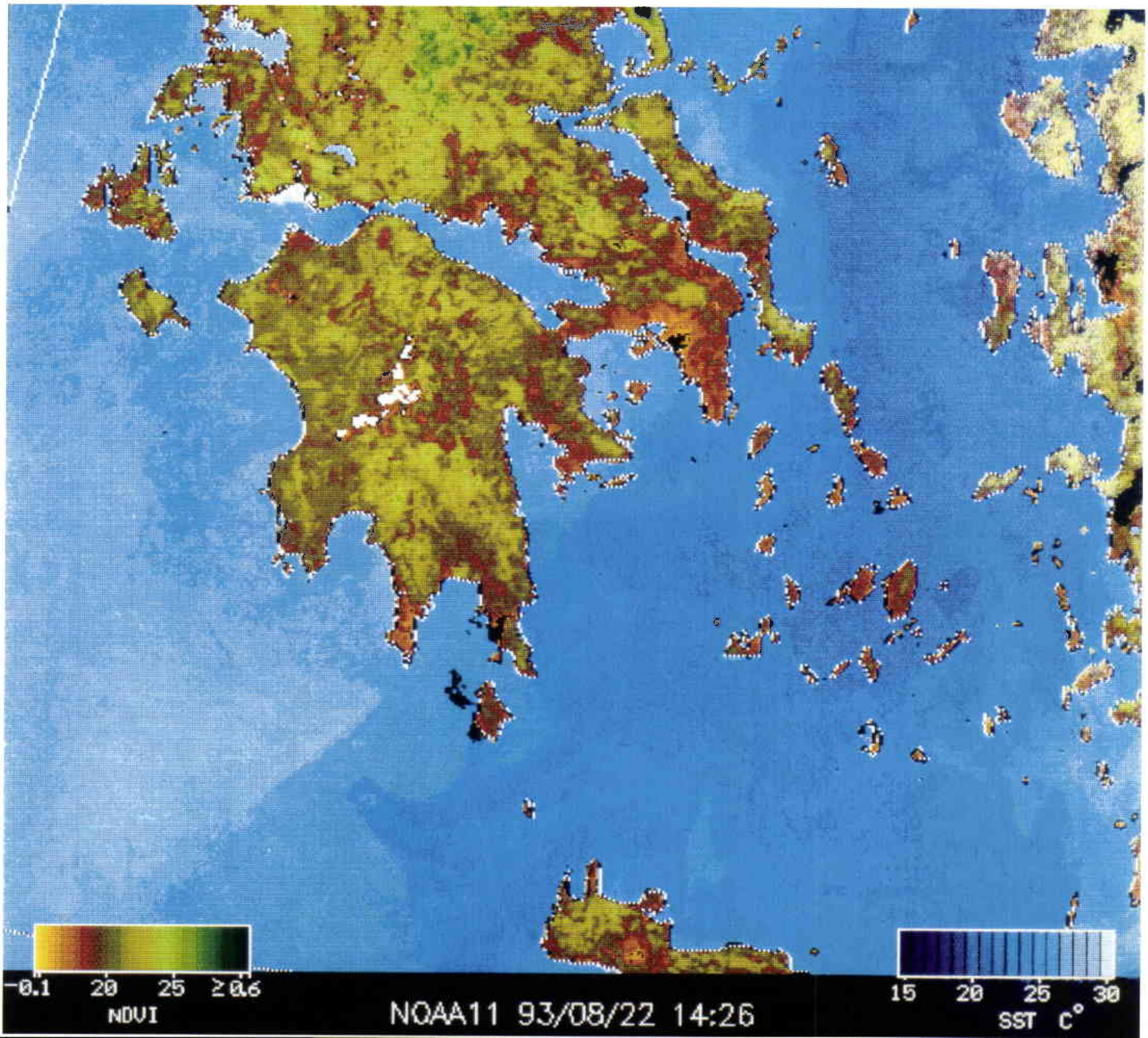


Figure 2. Example of an AVHRR level-2 product. The AVHRR image is first classified to identify land, sea and cloud areas, and a Normalised Difference Vegetation Index (NDVI) is then computed on land and coded in brown-to-green tones, while Sea Surface Temperature (SST) is computed over the sea and coded in blue tones. Clouds are represented in white

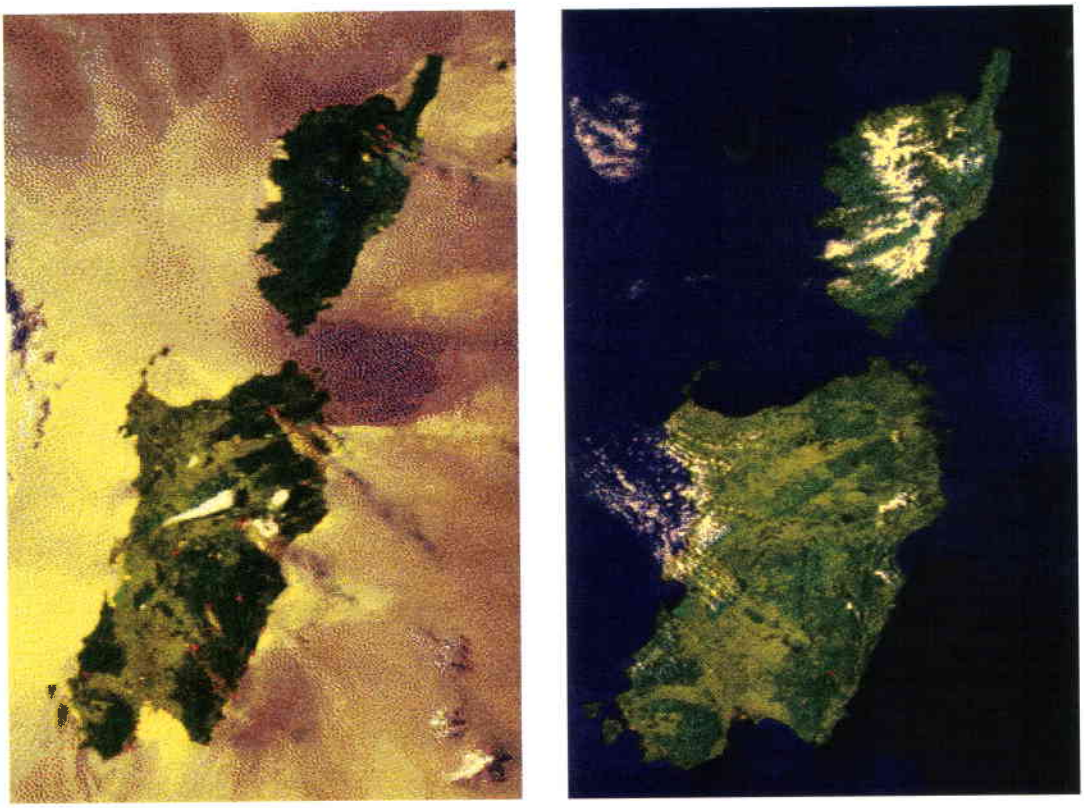
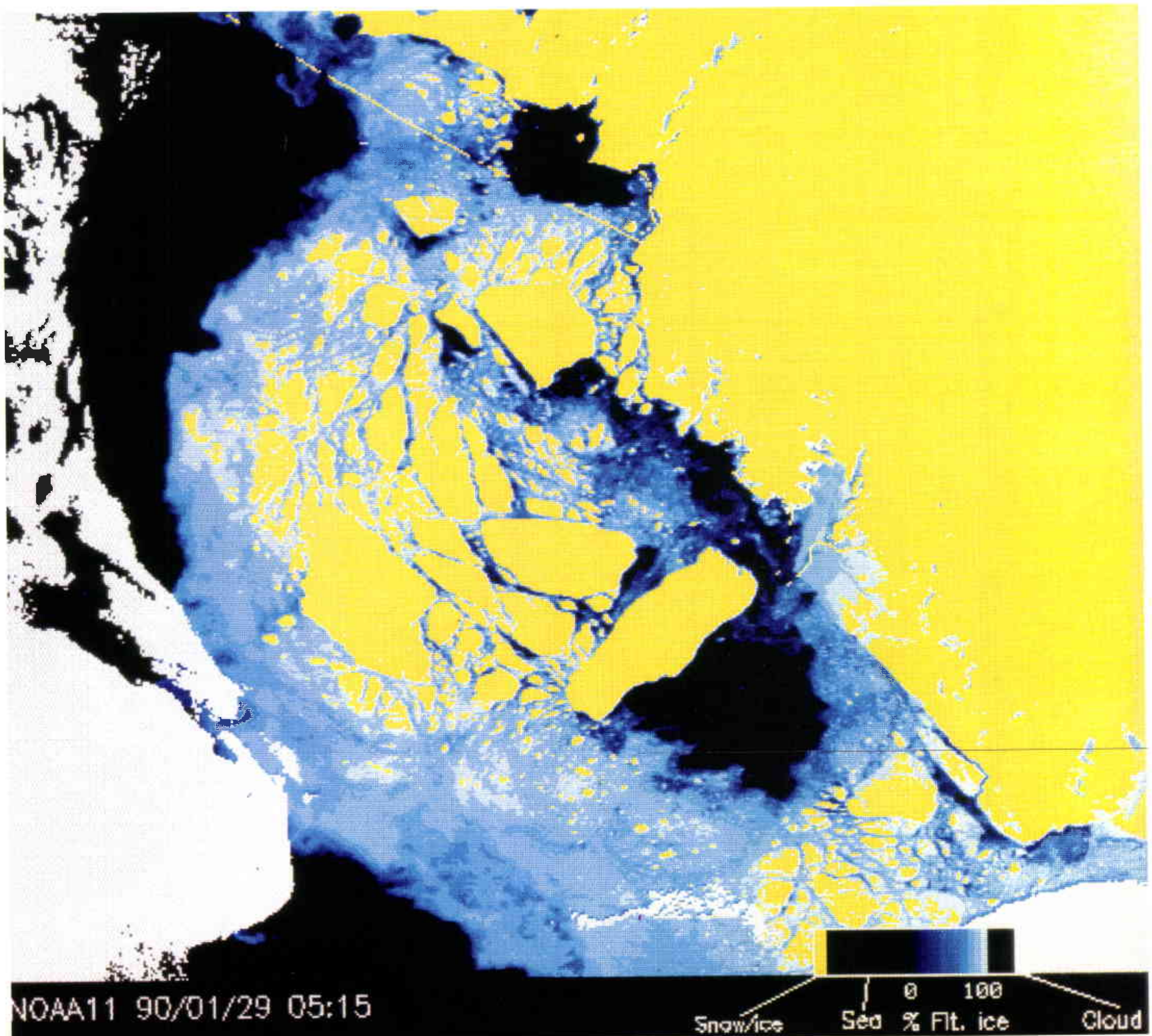


Figure 3. Example of active fire monitoring with AVHRR. The two scenes acquired at different times during successive daily passes of NOAA-11 show the detection of a series of fires that occurred on Corsica and Sardinia in August 1993. Red pixels in the left-hand image indicate active fires detected by the algorithm, while the associated smoke plumes are also clearly visible. The right-hand image shows the same area after the fires had been extinguished; the burned areas appear dark. The yellow tone in the sea in the left-hand image is due to Sunglint at the edge of the scan

Figure 4. This image is an AVHRR sea-ice product for the Ross Sea (Antarctica). Snow and solid ice are represented in yellow, while different sea-ice percentages are represented in dark-blue to white tones



NOAA, from their on-board recorders, over areas not covered by ground stations. One copy of the full data set is maintained at ESRIN and is archived on optical disk. This huge data set will include global daily acquisitions from NOAA-11 (and its successor) from April 1992 to September 1994, amounting to a total of about 2.8 terabytes.

Processing of this data set will produce a series of global 1 km-resolution 10-day multi-temporal composites of NDVI over land for the entire time span of the project. An example of the processed product as generated at USGS/EDC is shown in Figure 5.

Due to the operational nature of the mission, which ensures data continuity over a long time span, and to the intrinsic AVHRR instrument characteristics, which allow global daily coverage in the visible and infrared bands, the NOAA mission provides a unique reference for the development of new global Earth-observation missions. The possibility of accessing a long time-series of consolidated AVHRR data, centrally archived in a uniform way, the large amount of scientific work that is being carried out in the 'global-change' domain using these data for land, ocean and atmosphere observations, and the experience gained in the management of these data, together constitute a solid background for the optimum exploitation of the enhanced capabilities of the Envisat mission, particularly as regards the use of the MERIS and AATSR instruments.

SeaStar/SeaWiFS

SeaStar is a mission developed and operated by Orbital Science Corporation (OSC). With a planned launch in July 1994, the primary applications of this mission will be environmental monitoring (phytoplankton growth, pollution, algae blooms), ocean fishing, marine navigation and ocean research. Data for operational and commercial applications will be commercialised by OSC, while NASA will be in charge of providing access to the data for the research community.

SeaStar will be launched into a circular Sun-synchronous orbit with a noon equator crossing time. It will fly the Sea-viewing Wide Field-of-View Sensor (SeaWiFS), an 8-channel scanning, visible to near-infrared, multi-spectral radiometer. Data will be available at full resolution (1 km at nadir) as Local Area Coverage (LAC) downlinked to licensed receiving stations in real time, and at reduced

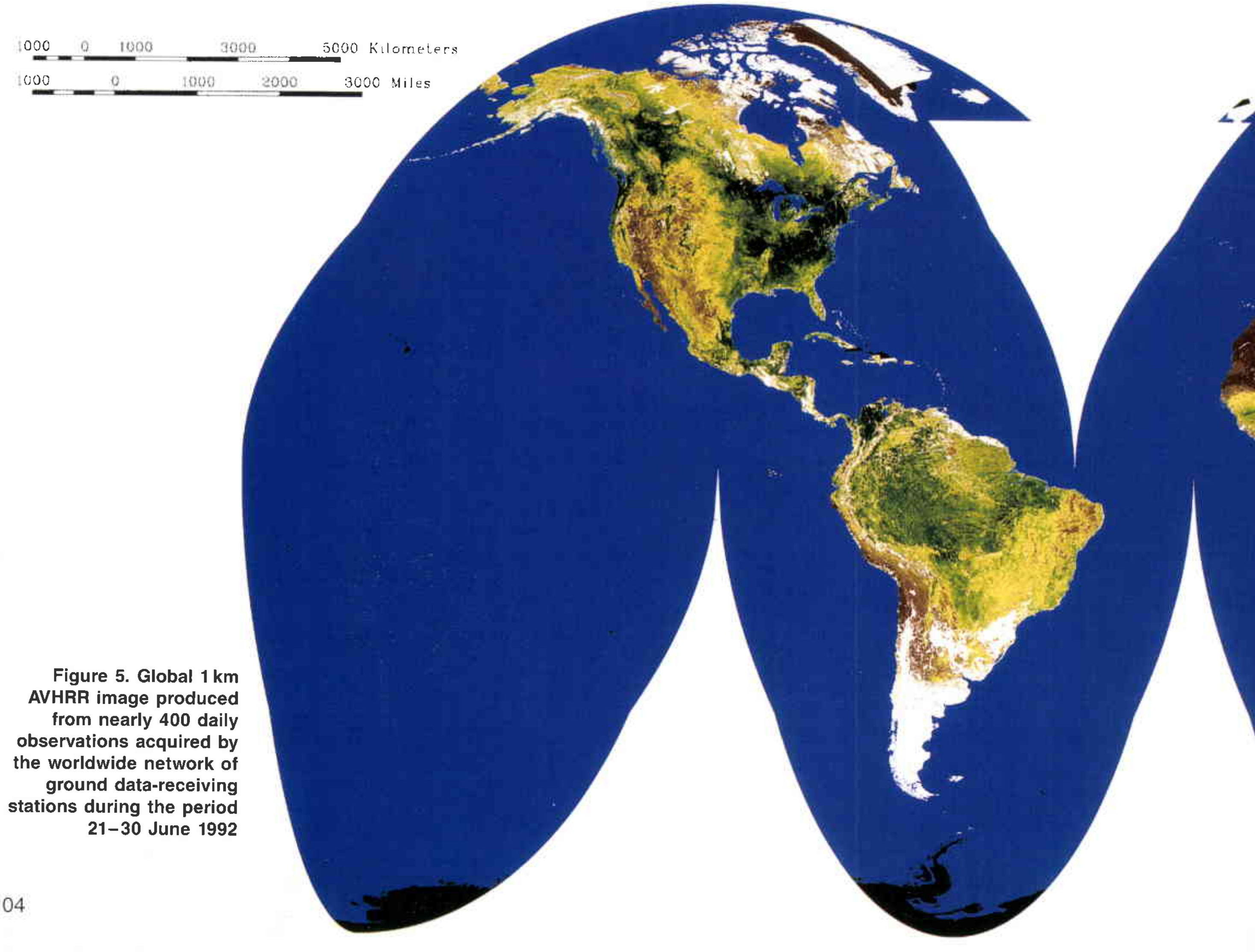


Figure 5. Global 1 km AVHRR image produced from nearly 400 daily observations acquired by the worldwide network of ground data-receiving stations during the period 21–30 June 1992

resolution (4 km) as Global Area Coverage (GAC) recorded on-board and downlinked to a central location.

The new sensor characteristics in terms of spectral resolution and sensitivity will provide a major improvement with respect to CZCS and, together with the inclusion of three new bands for the measurement of the atmosphere, will allow the determination of geophysical parameters like phytoplankton and chlorophyll level or aerosols above the ocean with a greater level of accuracy.

Activities at ESRIN

Taking advantage of the similarities between the SeaWiFS mission and the existing NOAA missions in terms of data linking and satellite data-stream formats, ESRIN is developing a SeaWiFS ground network based on a number of receiving stations co-located at existing NOAA/AVHRR stations and a central facility located in Frascati (I). Data received at the stations will be processed and archived locally in order to serve national programme requirements, while copies of the data will be sent to ESRIN where a long-term reference archive will be maintained together with the central catalogue service.

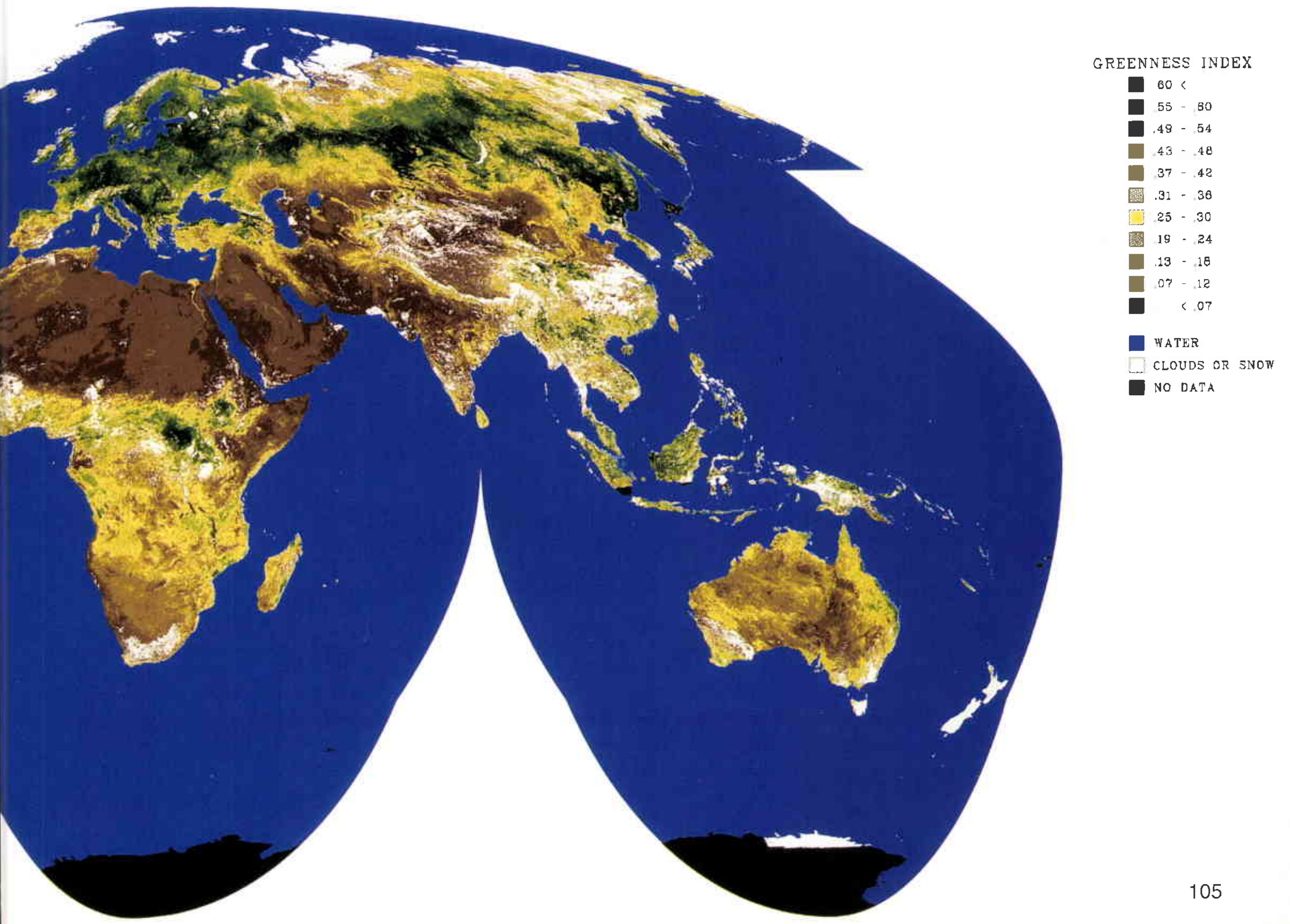
Through the SeaWiFS mission, ESRIN intends to service the strong demand for ocean data that has existed since the end of the CZCS mission in 1986, whilst waiting for Envisat/ MERIS data to become available.

A joint CEC and ESA project called 'OCTOPUS' has also been proposed in order to address the scientific use of the SeaWiFS mission data. ESA will have the role of providing access to the data through its acquisition stations and its archive and will also provide the processing capabilities needed to generate high-level products according the scientific guidelines developed by the CEC's Joint Research Centre (JRC).

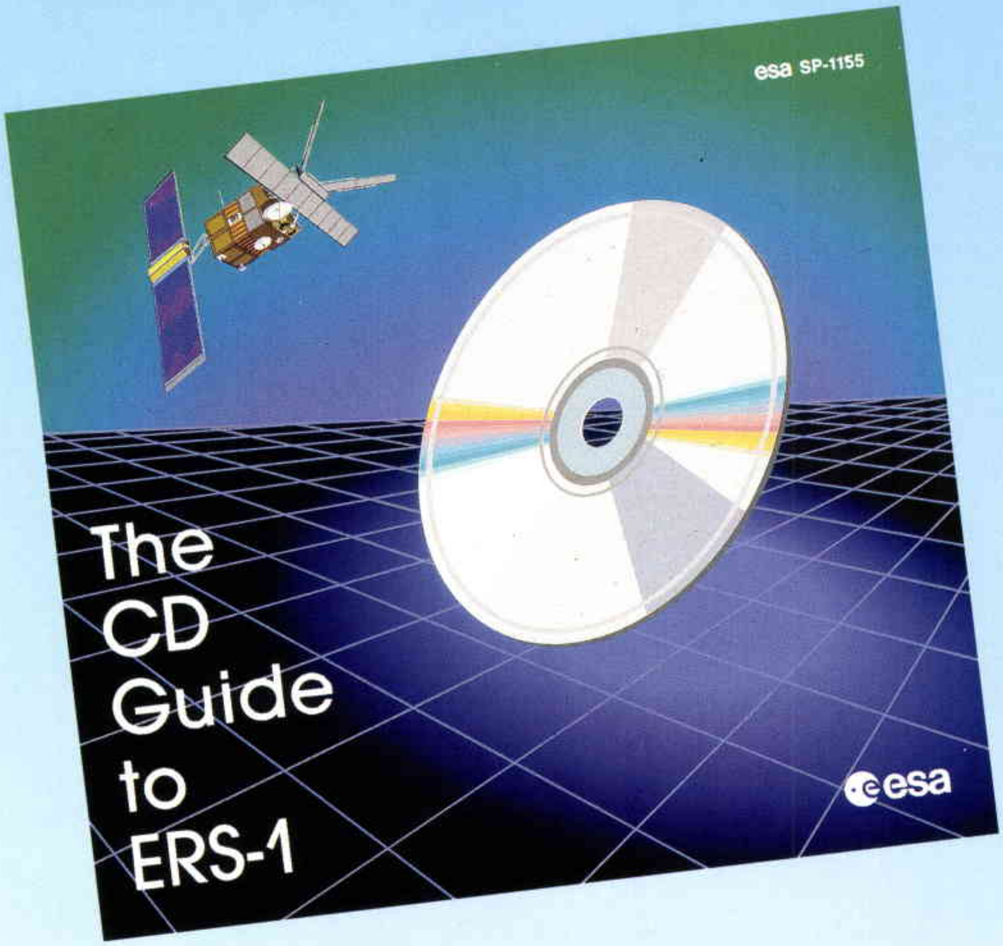
SeaWiFS data are expected to provide a substantial contribution to the improvement of our knowledge of ocean life, impacting both on the operational and scientific domains, and will provide continuity until MERIS data become available. The possibility of testing models and developing algorithms with an enhanced-capability instrument will serve to consolidate and extend the experience gained with the CZCS data.

Acknowledgements

This article is based on work carried out at ESRIN by a team including O. Arino, A. Buongiorno and J.M. Melinotte, who also generated the satellite images shown here.



The CD-ROM Guide to ERS-1



This is a multimedia disc containing information about the first ESA Remote Sensing Satellite ERS-1. Divided into three levels of detail, the CD Guide provides the user with a brief animated outline of the ERS-1 system, an overview of its most important features, and detailed information from user manuals. The Guide is easy to use and lets the user navigate around the subject they are interested in, skipping between different levels of detail at will. The Guide is well illustrated with diagrams, photographs, satellite images, and animated sequences.

A CD drive connected to a Macintosh, DOS PC (incl. MS Windows) or Sun Sparc station is required to access the disc.

The CD Guide to ERS-1 is available from:
ESA Publications Division
PO Box 299
2200 AG Noordwijk, The Netherlands

Orders must be accompanied by a Cheque/International Bankers Draft for *25 Dutch Guilders* made payable to ESA Publications Division

Focus Earth – Stereo Viewing from Space

Ph. Goryl, J. Lichtenegger, O. Arino & G. Calabresi
ESA/ESRIN, Frascati, Italy

Stereo viewing based on aerial photography is widely used for cartography and mapping. The first attempts at stereo viewing from space, although restricted to areas along overlapping swaths, date back to 1972, when the Multi-Spectral Scanner (MSS) instrumentation of the Landsat payload was made accessible. The concept was further developed in the Spot satellite system, which provided a steerable side-looking mirror capable of fully 'revisiting' an area previously acquired along another track. The Japanese JERS-1 satellite system employs a forward-viewing channel that allows the acquisition of a stereo pair of images along the same track with an interval of just 22 sec.

The JERS-1 OPS-VNIR along-track stereo technique is based on two of the eight spectral bands available, namely the nadir-looking band-3 and the 15.3° forward-looking band-4. This permits one to take advantage of the high degree of correlation between the two images observed, in contrast to the Spot lateral-viewing approach in which the area is revisited on a different date. Constraints in terms of cloud cover and changes in surface characteristics are also avoided.

The JERS-1 OPS-VNIR stereo image on the next page shows the Ubaye Valley in the French Alps. This image was acquired at Fucino on the 17 February 1993 and processed at ESRIN. The image is centred at 44 deg 20 min North and 6 deg 23 min East. The area represented is 35 km x 46 km, with a pixel spacing of 18 m x 24 m. The nadir image (band-3) and forward image (band-4) have been superimposed and printed in red and green, respectively. The 3-D glasses, when aligned with the parallax direction, allow one to appreciate the relief of the region (for ease of viewing, the image has been oriented with true north to the left).

The lake (altitude 800 m) and the dam of Serre Ponçon are visible in the upper left corner. The Ubaye River and Valley, famous for kayaking and river-rafting, are well-highlighted by the 3-D effect. To the right of the lake lies the Morgon Valley, the higher part of which forms a cirque with a crest rising to 2400 m. South of the lake, the 'Montagne Blanche' (White Mountain) rises to about 2500 m. At this time of the year, all of the higher mountains are snow-covered. Some small clouds are also apparent near the centre-right edge of the image.

The ERS-1 SAR image shown here is a very particular type of stereo view, firstly because SAR is an active sensor emitting and receiving microwaves, and secondly because the image geometry is much different from that with optical sensors, which view the Earth from close to the vertical. Radars, by contrast, are distance-measuring devices that view a scene obliquely. There is a further complication also in that the image geometry varies in a similar (but opposite) way when acquiring the same scene on different ground tracks. Although the characteristic distortion of radar imagery (foreshortening, etc.) is still present in the combined image, the 3-D effect can nevertheless be experienced.

The combined image pair consists of: ERS-1 SAR orbit 5034, frame 2843 of 26 November 1992 and SAR orbit 4304, frame 2843 of 7 August 1992, both acquired at Fucino and processed by ESRIN. A common subscene of each acquisition was chosen and superimposed by means of a simple shift to a 'best fit'. Subsequently, one 'channel' was displayed in red (scene to the west, to be viewed with the left eye) and one in green (the scene to the east, for the right eye). No further geometric corrections were applied in order not to destroy the slightly different geometry. In fact, it is this difference that lets the image become three-dimensional when viewed through the red and green glasses.

Further information on ERS-1 data access and availability can be obtained from:

ERS-1 Help Desk
ESRIN
CP 64
I-00044 Frascati, Italy

Tel. (39) 6 94180 600
Fax. (39) 6 94180 510

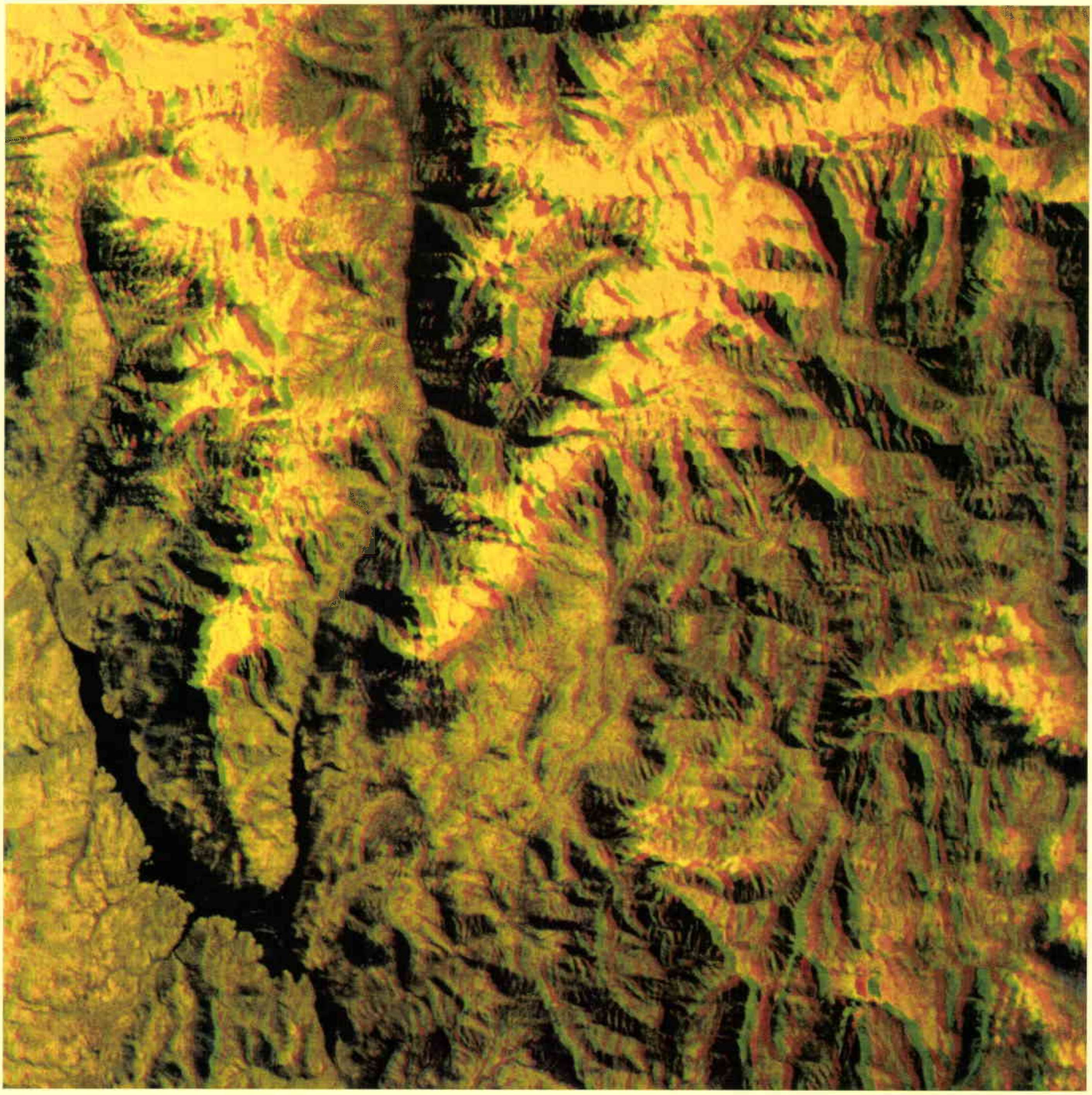
Eurimage ERS-1
Order Desk
ESRIN
CP 64
I-00044 Frascati, Italy

Tel. (39) 6 94180 478
Fax. (39) 6 9426 285

Focus

Investigators have already examined the accuracy of height measurements performed visually on such stereo pairs. Obviously, it cannot be compared with that achievable using optical data, largely because of the much higher inherent signal noise, but at the ERS-1 Symposium in Hamburg last October accuracies of better than 30 m were already being reported for relative height estimations. Consequently, this type of SAR imagery can still be useful for enhancing visual interpretations, especially for such applications as geomorphological and geological mapping.

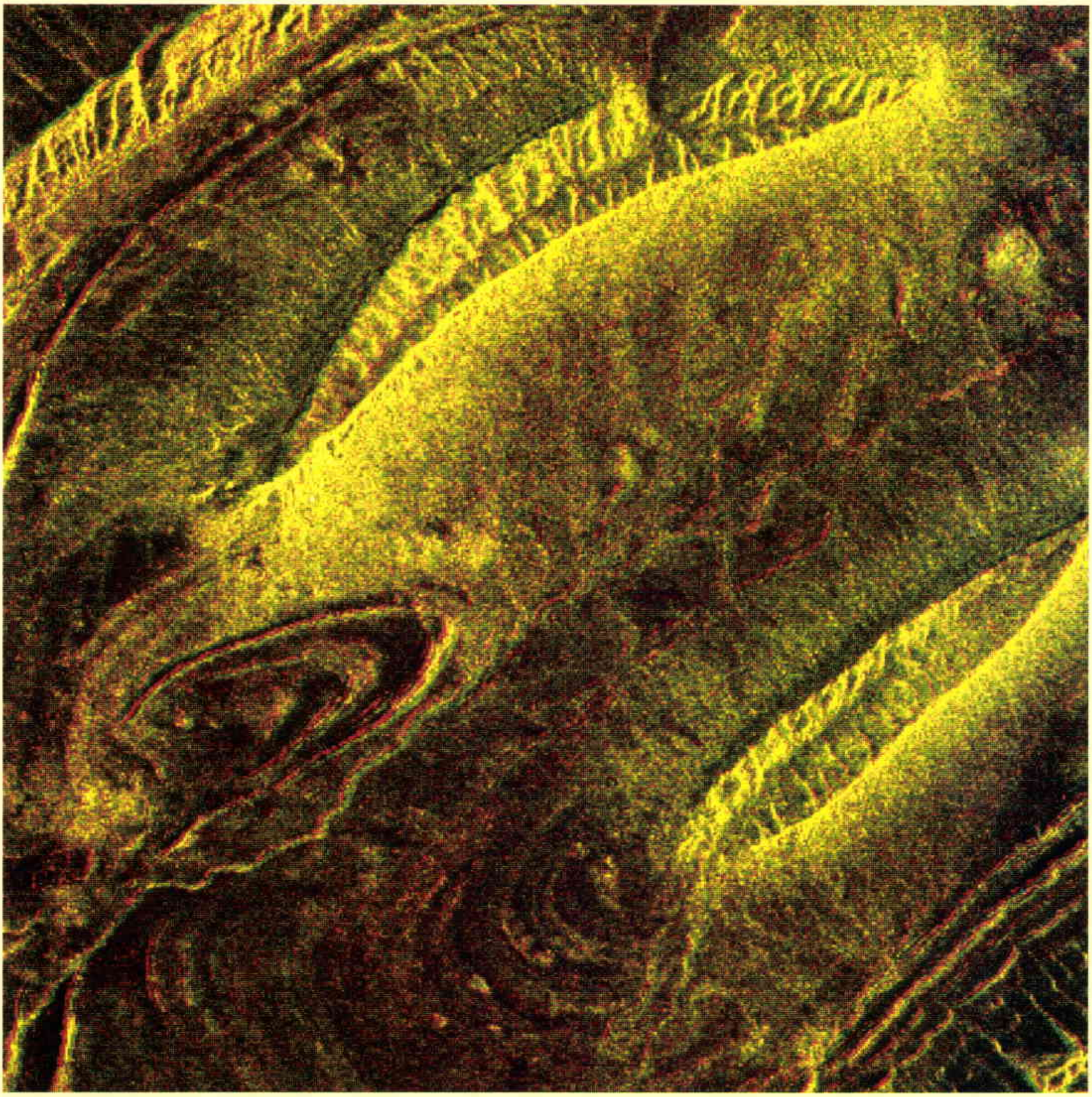
Ubaye Valley, Southern France



Earth

The ERS-1 stereo image shown below covers part of the Saharan Atlas region in Algeria, near the border with Morocco, east of the city of Ain Sefra. The two bright oblong mountain chains are down-eroded synclines with their foothills and central valley brightly marked by rock debris. The eye-shaped feature to the left is the remains of an anticline. The mountains near the top left and bottom right are also flanks of large anticlines with their outcrops of more resistant rock aligned parallel to the axis of the fold.

Saharan Atlas region, Algeria



A New Approach To Real-Time Water-Vapour Wind Extraction

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The prototyping and subsequent validation of a new image-resampling technique have shown that the geometric stability of presently available satellite-derived meteorological data could be improved without having a negative impact on the radiometric quality. Initial results have already shown that 10% more wind vectors pass the quality-control tests thanks to the improved geometric stability of the imagery data. Additionally, it has been proven that the derived products can be produced in real time, i.e. on a half-hourly basis. This will increase Meteosat's economic benefits, particularly in areas where real-time information plays an important role, such as the prediction of hurricane development, and forecasting for aviation, road transportation and ship routing.

Introduction

Pre-operational meteorological activities were started at ESA's European Space Operations Centre (ESOC) with the launch of the first Meteosat satellite in November 1977. The complete Meteosat system became fully operational on 23 November 1983 and since then has provided the user community with all of the types of data required for reliable weather forecasting, including both pre-processed image data and derived meteorological products (cloud-motion vectors, sea-surface temperatures, upper-tropospheric humidity, cloud-top heights, etc.).

In-orbit redundancy was achieved with the launch and successful commissioning of Meteosat-3 in June 1988. This satellite was the first of an improved design, with consumables for an operational lifetime of five years. This satellite launch was followed by several more, in the framework of the Meteosat Operational Programme, as shown in Figure 1.

As from July 1991, the Meteosat operations were extended by positioning one of the satellites at 50°W, thereby providing additional coverage of the Atlantic Ocean. This has subsequently been referred to as the Atlantic Data Coverage (ADC) mission. A later extension of the ground segment with the implementation of a Meteosat-compatible ground station at Wallops (USA) enabled the ADC Meteosat satellite to be moved to an even more westerly position. The satellite is currently located at 75°W and is referred to as the 'Extended Atlantic Data Coverage (XADC) mission'.

Currently, ESA is still operating all of the Meteosats: the European operational system, positioned at 0° on behalf of Eumetsat, and the satellite positioned at 75°W on behalf on the US National Oceanographic and Atmospheric Administration (NOAA). By 30 November 1995, Eumetsat will have established its own operational capabilities for the Meteosat satellite(s) positioned at 0°.

ESA, being first and foremost a research and development organisation, will continue its role in satellite meteorology through its active development effort for the so-called 'second generation' of meteorological satellites. ESA-funded R&D efforts conducted as part of the present operational programme have already produced improvements in the radiometric accuracy and geometric stability of Meteosat imagery, as well as leading to the production of real-time derived products such as wind vectors. The results of some of these studies are reported here.

Geometrical image compensation

Four images transmitted once every 30 min from each of the operational Meteosat spacecraft are received at ESOC in three spectral channels – the infrared window, water-vapour absorption band, and visible band (two images). Each of these images contains 2500 x 2500 pixels (2500 x 5000 for the visible channels), with 8 bits per pixel. Two such image data streams are currently processed in parallel at ESOC on one of two mainframe computers (Comparex 8/98's). The second mainframe serves as a backup, but is normally used for other purposes. These machines have been regularly upgraded to cope with the need for ever-greater computing power, progressing from about 2 Mips in 1981 to over 50 Mips today.

The Meteosat images processed and disseminated by ESOC are used by a wide research community as a means of gaining a better understanding of atmospheric processes. Success in this respect, however, is highly dependent on the radiometric quality and geometric stability of the image data. The latter is achieved by applying a data-correction process called 'image rectification'. Images transmitted from the satellite are distorted due to its various movements during the image-taking process. Since this prevents an accurate geographical identification of an image pixel, an evaluation of the image distortions and a consequent resampling of the image pixels is one way of reducing these geometrical errors.

The resampling method initially selected was so-called 'nearest-neighbour resampling'. It was fast and cheap, as the computational requirements were minimal, but it caused a residual statistical error. This resulted in a degradation of the absolute accuracy of the data points, as well as their relative stability (Fig. 2). In this type of resampling, some pixels are taken twice, others are missed completely and the rectified images are characterised by a blocky appearance with random shifts of large areas in the image.

In recent years, the determination of the image deformation has been significantly improved, such that the rectification errors averaged over an image are close to the theoretical minimum (in the absence of external perturbations such as eclipses). In order to improve the rectification quality still further, another resampling algorithm was needed to replace the original nearest-neighbour scheme.

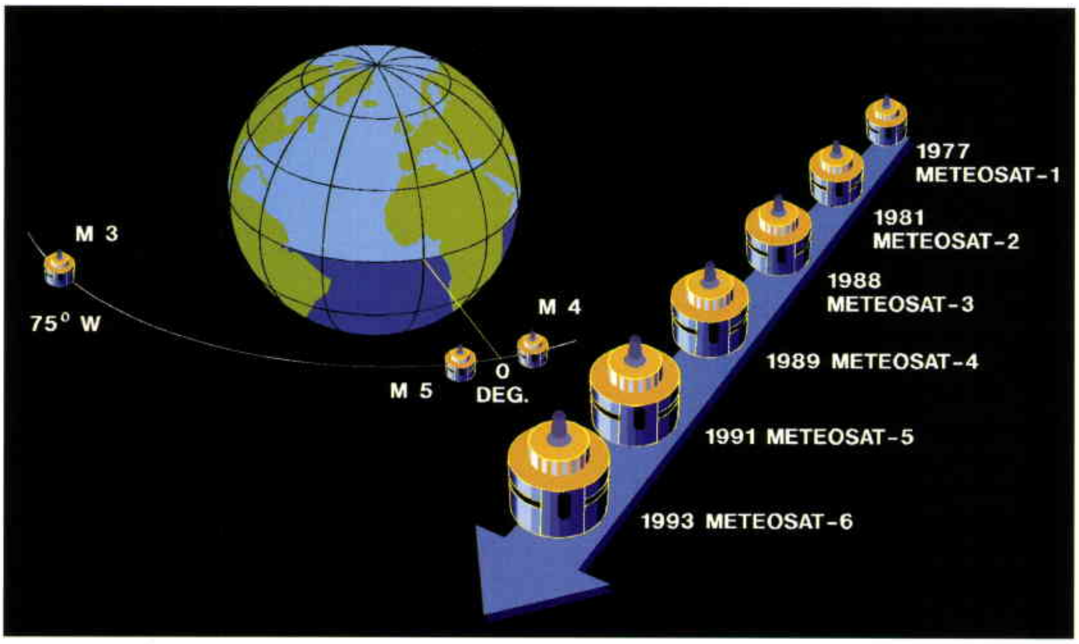

Figure 1. Meteosat launch scenario

It has become possible in the last few years to perform raw-image rectification for Meteosat in real time. Three main steps are involved. First, a number of varying parameters of the imaging systems need to be determined. They can be partly predicted, because most of the disturbing forces affecting the spacecraft parameters are periodic in nature and are partly derived from real-time measurements. Based on these parameters, the deformations on a series of grid points are calculated using a mathematical model. Finally, the raw image pixels are resampled according to the resulting deformation matrix to form the rectified image.

A variety of methods were possible, all based on the interpolation of weighted-pixel counts

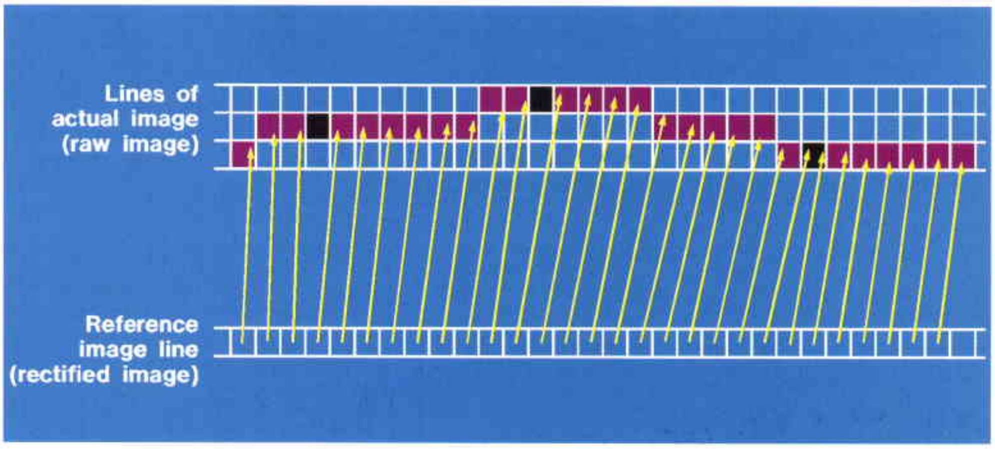

Figure 2. The principle of nearest-neighbour rectification

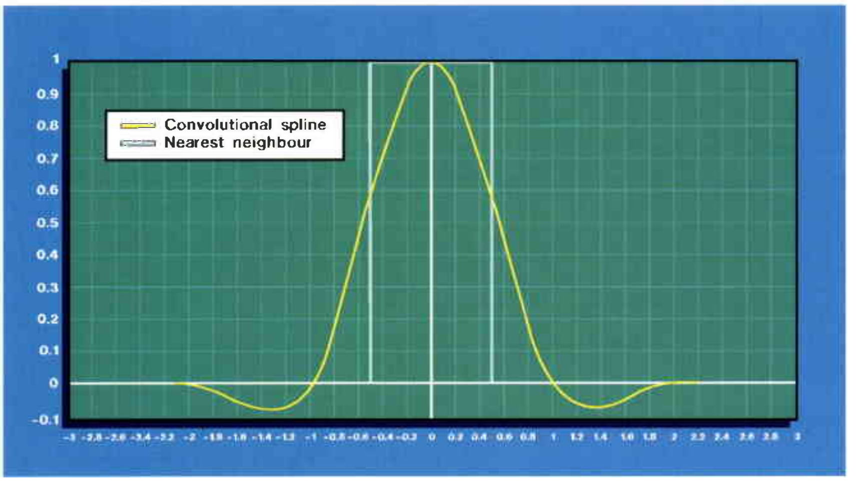

Figure 3. Pulse response functions

surrounding the pixel in question. Radiometric changes introduced in this way are well within the accuracy of the radiance figures themselves. They could even lead to an improvement by reducing the impact of the satellite's radiometer and associated equipment on the original image.

A study was initiated, using a software model of the sampling process of Meteosat's instrumentation and electronics together with on-ground sampling, to identify an optimal method for Meteosat image data resampling. Fourteen different resampling methods were tested. The most promising candidates (best behaviour for edges and smooth areas) were the bi-cubic spline function, a linear combination of B-splines, and the nonlinear Akima interpolation. All three methods showed significantly improved results compared with the nearest-neighbour technique when applied to deformed test images in initial trials (Fig. 3).

Real-time processing

The technical realisation of these very time-consuming resampling algorithms led to the development of a state-of-the-art transputer-augmented workstation (by the Austrian company GE.PAR.D) under ESA contract and with support from the Austrian government. The resulting Fast External Satellite Image Processing (FESIP) system is shown in Figure 4.

The scope of the contract was to develop a computer prototype (hardware and software) for the real-time resampling using the various interpolation techniques, product extraction, and rapid image display and processing. The FESIP prototype design supports interfaces to modules for further processing. Besides the rectification module, a second component is used for near-real-time data extraction. This module computes water-vapour wind vectors (WVWV) using an optimum pattern-matching algorithm. Various quality-control tools are then applied to the wind vectors, all with a minimum interaction with the present mainframe computer system.

Wind-vector extraction

The wind-vector fields extracted from successive images of the different Meteosat channels are the most important products that are presently derived at the Meteorological Information Extraction Centre (MIEC) in ESOC.

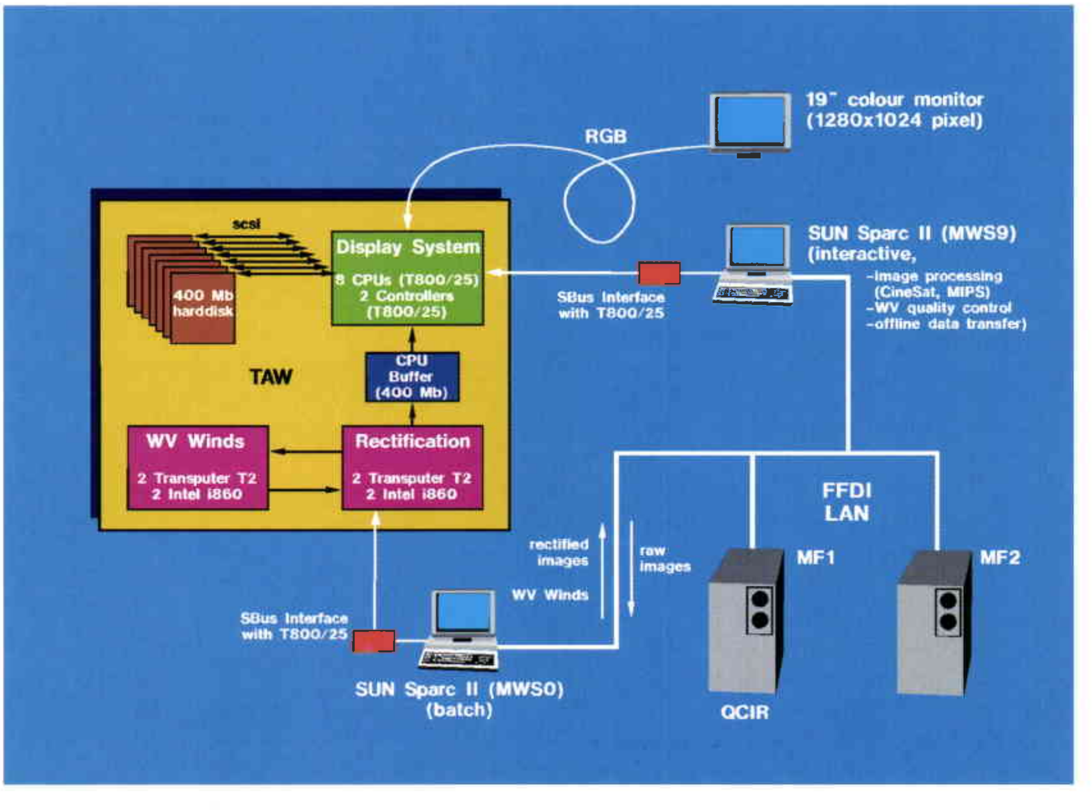

Figure 4. The Fast External Satellite Image Processing (FESIP) system

The Transputer-Augmented Workstation

The TAW is equipped with a total of 23 Central Processing Units (CPUs), distributed across four different modules. Its formidable capacity is highlighted by the processing power of just one of these modules for real-time image-data resampling, which achieves a floating-point performance of almost 200 Mflops.

The main components of the TAW are the resampling and WVWV modules, both of which consist of a combination of T800 transputers and Intel i860 processors. These functions are controlled via a SunSparc host computer, which also performs the image-data transfer from and to the ESOC mainframes in batch mode. Raw and resampled images are also automatically transferred via a buffer module to the TAW's display system.

Eight hard disks with a total of 3.2 Gbyte of storage, each equipped with a dedicated transputer for fast I/O processing, are available to store these images in a cyclic file system. This allows fast and parallel zooming, scrolling and loops of up to 500 infrared images or 125 full-resolution visible-channel (VIS) images (5000 x 5000 image pixels) on a high-resolution monitor.

Additional functions of this module are pixel inspections, window extraction and grey-value statistics, classifications and Fourier Transformations, overlays, etc.

The new TAW's (see above) high processing capability enables near-real-time extraction of these vector fields on a half-hourly basis. This means that 48 vector fields can be produced daily compared with the four fields presently produced operationally.

For the derivation of the meteorological products, each Meteosat image is divided into 3560 segments. If one tries to produce a vector in each segment and for every possible displacement, 15 million matching operations are required which, regardless of the matching method, would require an inordinate number of computations.

In order to reduce the amount of computation, the TAW matching is performed in two steps. In the first step only every third matching is performed, while in the second step the steepest gradient for each point in the first step surface is followed to a local minimum. The final matching is the global minimum found from the set of local minima. Elaborate testing with a full-search implementation has shown that the true minimum is found in this way for more than 95% of all vectors.

In its present configuration, the TAW is geared to near-real-time vector derivation from Meteosat's water-vapour channel. This channel was chosen due to its ability to track not only cloud displacement, but also moisture movement. Moreover, due to the water-vapour channel's response function, the measured radiance always originates from the mid- or upper troposphere, usually from above a pressure level of 600 hPa, which in a standard atmosphere is roughly equal to 4 km. This is especially important for several meteorological applications (see below).

The set of derived wind vectors are only useful if they can be assigned to an appropriate height. The TAW is capable of producing an 'Equivalent Black-Body Temperature' (EBBT), where the mean radiance of the coldest 25% of the pixels is converted into a temperature. If the atmospheric temperature distribution is known, the EBBT can then be related to a specific height.

In the typical WVWV field presented in Figure 5, it can be seen that the vector field is generally smooth. An important aspect for an automated derivation scheme is also revealed, however, in that some of the derived vectors do not follow true cloud or moisture patterns. They are a result of tracking noise or rapidly changing or evolving features but, as they do not contain any useful information, these vectors should be removed from the vector fields before the product is disseminated to the users. This is done by the automatic quality-control tool.

Automatic quality control (AQC)

Given the vast amount of data produced by the TAW, a manual quality-control scheme is out of the question. The only option is an automatic scheme capable of removing all odd winds. The solution adopted, which has evolved from the operational MIEC AQC scheme, supplements the existing MIEC features with many new ones. The TAW AQC implements three specific selection criteria that remove every wind exceeding a specific type of threshold (e.g. a vector with a magnitude of more than 100 m/s is unlikely to be correct even in high-wind-speed regions of the atmosphere), and fifteen quality tests, the combined results of which permit a final quality evaluation of each individual vector.

The TAW AQC tests are based on consistency in time and space, as well as on reliability of the vector derivation and their height assignment. As the final vector quality is obtained as a weighted mean of all tests, the derivation of an optimum AQC configuration is rather complicated and so the TAW is equipped with an interactive tool to help in this task.

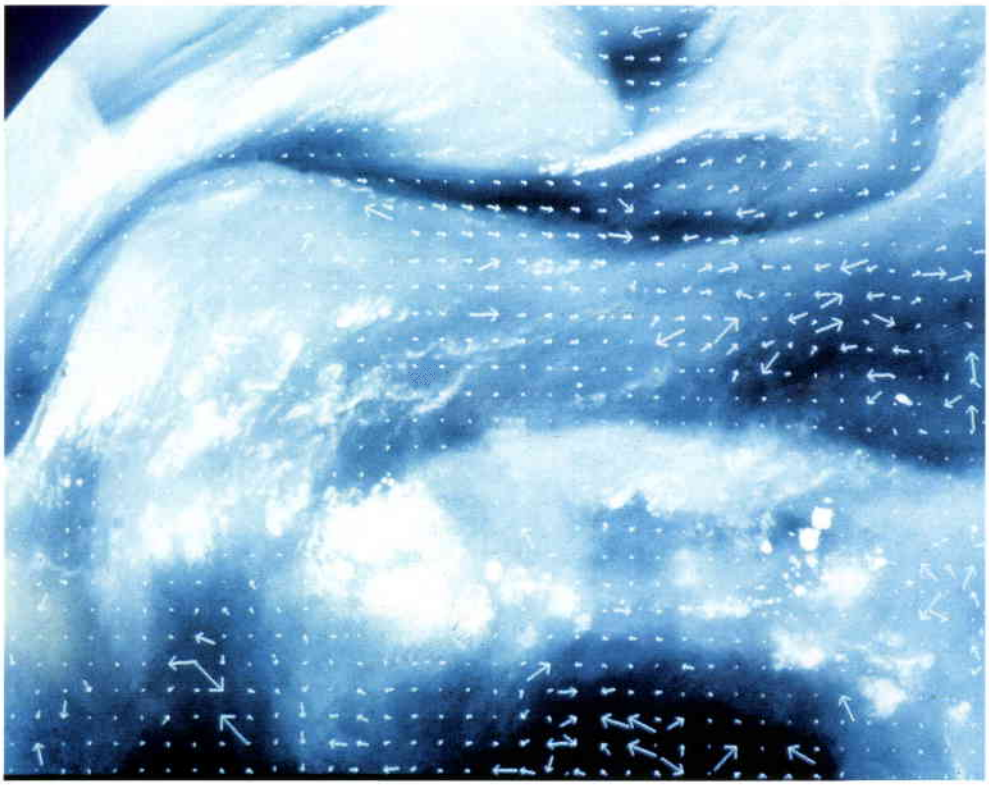

Figure 5. A typical Water-Vapour Wind Vector (WVWV) field

The interactive QC tool provides statistical information on the performance of any test or combination of tests. It allows the test configuration to be optimised until a setup is found that gives the best possible results.

Validation campaign

The TAW can provide wind fields derived from satellite images continuously for time intervals of 30 minutes. This information is extremely useful for the new analysis schemes for numerical weather prediction now being implemented at weather-forecasting centres.

The European Centre for Medium-Range Weather Forecasts (ECMWF) has already expressed a keen interest in running a one-month 'Real-Time Winds Validation Campaign' in which wind data derived from Meteosat's water-vapour channel are to be sent from the FESIP processing facility at ESOC in near-real time to the ECMWF in Reading, UK. The Cooperative Institute for Meteorological Satellite Studies (CIMSS) and NOAA/NESDIS in Madison, USA have also expressed interest in participating. Their intention would be to compare the ESOC water-vapour winds with the four-times daily snapshot of water-vapour winds produced operationally by NESDIS with data from the Meteosat located at 75°.

The significance of this study is twofold. Firstly, the technological challenge of real-time processing including an automatic online quality-control feature represents the ultimate test bed for FESIP. Secondly, it will be the first time that satellite-derived winds of such high quality and frequency have been delivered in near real time to an operational forecasting centre. In addition, the ECMWF's excellent data-monitoring capabilities will be able to provide an independent assessment of the wind vectors produced, the quality control and the quality indicator attached to each vector.

In addition to the use of FESIP products in numerical weather prediction, we see a large potential for their use in scientific applications, which can also be elaborated as part of this measurement campaign. For example:

(a) Radio-signal propagation through the Earth's atmosphere is affected by refraction. The corresponding excess propagation path varies with the total column water-vapour content. This so-called 'wet delay' is highly variable in space and time. The present work can contribute to the study of spatial variability of the 'wet delay'. A method has already been developed to infer the total column water vapour (TCW) from cloud-free infrared window radiances from Meteosat over sea. This product will be derived for a given Meteosat image by the FESIP station. The display will allow the identification of areas with maximum gradients. An overlay of the TCW product with the water-vapour winds provides a unique tool for estimating the displacement of areas with a high water-vapour content. Study of the spatial variability of the 'wet delay' would thus provide a quasi-global analysis including all climate zones over the oceans. It will be enhanced by the availability of displacement vectors, which can provide a quick means of forecasting a change in 'wet delay'.

(b) The animation of vector fields and the estimation of trajectories could be important in 'nowcasting'.

(c) An overlay of a cloud-analysis product will delineate 'pure water vapour' wind vectors from those derived from cloud tracking. The pure water-vapour winds have been shown to represent a mid-level wind field, which is indicative of the displacement of tropical storms and hurricanes.

(d) A joint analysis of Upper Tropospheric Humidity (UTH) with wind fields provides insight into the dynamics of the upper troposphere and its relationship to the moisture field. This tool would have great potential in climate-related studies.

Potential use of real-time wind vectors

As indicated in the previous section, one of the main uses of real-time wind vectors is in numerical weather-prediction models. Until this year, most global models were only capable of assimilating data derived at the main observation times, i.e. with a six-hour time interval. Now these models can also assimilate data derived at intermediate times but, with the exception of a fairly small number of automatic weather stations, only geostationary satellites are capable of producing high-frequency observations of the atmosphere. Therefore, the half-hourly vector fields provide an excellent opportunity for the user community to assess their new schemes. Simultaneously, the quality of the WVWV could be assessed.

A further use of real-time water-vapour vectors is in the area of short-term weather prediction and nowcasting. In these areas, the data would not be used merely by the national meteorological services. A potentially large user community can be found in aviation, for example, for whom an accurate description of the current atmospheric state is an important flight-routing consideration. An optimum route ensures minimum fuel consumption, not only by taking any tail winds into account, but also because more accurate fuel-consumption estimating allows the extra load that would be constituted by carrying unnecessary excess fuel to be removed.

Last, but not least, areas with strong wind shear and turbulence could be avoided, as well as areas where for example volcanic activities have ejected large amounts of dust into the upper troposphere. This in turn would ensure maximum passenger safety and comfort.

Another area of interest in which real-time WVWV could be utilised is the prediction of the 'wet delay'. The combination of the WVWV information with atmospheric-humidity measurements can be used to estimate the impact of atmospheric moisture on radio-signal propagation. This could have important benefits for telecommunication.

The ability of the water-vapour channel to detect motion even in cloud-free areas can also be utilised in hurricane tracking and forecasting. The wind vectors derived in the cloud-free areas represent a mean flow in the middle atmosphere which is relevant when the movement of tropical storms is being tracked. Owing to the complexity of hurricanes, any additional information related to these severe weather phenomenons is invaluable in reducing the damage they inflict.

The benefits of using the WVWV data in climate studies should not be underestimated. The complicated relationship between atmospheric humidity, wind fields and dynamics is of vital importance in improving our understanding of climate and climate change.

Conclusion

The automatic quality-control tools developed in support of the real-time Meteosat operations provide the potential for reduced human control for future operations, thereby leading to further cost savings. It has been demonstrated that it is possible to increase the frequency and quality of the Meteosat-derived products without calling for a satellite redesign. The important lesson to be learned here is that, as long as the intelligence of the system is vested in the ground segment, rather than on-board the satellite, improvements can be made at minimum cost by upgrading to the latest state-of-the-art equipment.

ESA Astronauts Prepare for EuroMir

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In anticipation of a European involvement in a future Manned In-orbit Infrastructure, flight opportunities for the members of the European Astronauts Corps had to be found in the context of cooperative missions with other parties. With this approach in mind, the profile and selection criteria for the new group of European astronauts, recruited in 1992, was tailored both to short-duration Space-Shuttle missions and to long-duration missions onboard the Mir station.

After introductory training at EAC, two of the Candidate Astronauts recruited by the Agency in 1992 joined that year's US Class for Mission Specialists, while the others continued with Basic Training at EAC. Also in 1992, a contract was signed between EAC and the Russian training centre for cosmonauts, ZPK, also known as 'Star City'.

In the meantime, cooperation with the Commonwealth of Independent States (CIS) has been strengthened still further and two flights aboard Mir for European Astronauts have been arranged in the context of the Columbus Precursor Flights programme. The contract with NPO Energia for these two Mir flights, known as EuroMir 94 and EuroMir 95, was signed in July 1993.

The technical objectives of these EuroMir missions were described in detail in a previous article in ESA Bulletin No. 75*. This article focusses on the astronaut-related aspects of these flights.

Astronauts assignments/tasks in the Russian concept

Until now, ESA and its astronauts have been more familiar with the American approach to manned spaceflight, involving frequent missions of short duration. Each of the crew aboard a Space Shuttle flight has certain pre-assigned tasks, for which they train specifically in a typically procedural way. Maintenance and refurbishments – of the Spacelab Module, for example – are executed on the ground after the Shuttle's return.

This is not the case with the Russian concept. With their approach, a relatively small crew is carried to and from the orbiting Mir space station in Soyuz-TM capsules. Supplies are transported separately, using the well-proven Progress system. The operations are thus kept simpler, but are more time-constrained, with longer gaps between missions.

Another important factor is that maintenance and repairs to Mir have to be done onboard – in stark contrast to the Shuttle/Spacelab concept – by a crew of just three:
- a Commander
- an Engineer, and
- a Research Cosmonaut.

Besides being involved in the important piloting phase during transfer, the Commander and Engineer must also undertake a large number of system activities once on board the Mir station. The Research Cosmonaut is also expected to participate in these tasks, contrary to his American counterparts.

The combination of smaller crews and longer mission durations adds another dimension to the Russian concept in that interpersonal skills, group dynamics, and psychological compatibility in general, play a paramount role. Having learned from past experience, the Russian concept places a strong emphasis on overall crew performance rather than individual achievements.

As a consequence, two crews are formed and fully trained in parallel in the run up to a Mir mission. These primary and back-up crews are nominated just three or four weeks before the actual flight is to take place.

These differences are, of course, reflected in the training programme. The Russian training is less procedurally oriented than the American and is based upon a broader background knowledge (multi-functionality). In addition, greater emphasis is placed on (fixed) crew training.

The roles of the ESA Astronauts (Figs. 1 & 2) will differ on the two EuroMir flights. During the first, EuroMir 94, the ESA Astronaut will stay onboard, as a Research Cosmonaut, for a longer period than in the American scenario. The second flight, EuroMir 95, will be unique, however, in that it will be the first time that a non-

* Titled 'Cooperation with Russia in the Framework of the Columbus Precursor Flights', by W. Nellessen & H. Arend

Figure 1. The two ESA Astronauts selected for EuroMir 94: Ulf Merbold (left) and Pedro Duque

Russian citizen trained as an Engineer will be involved in onboard systems-related functions. In addition, the European Astronaut is scheduled to participate in Extra-Vehicular Activities (EVA) during this second flight.

All of these factors have been taken into account in the formulation of the training programme described below.

The EuroMir training programme

The training programme for the EuroMir missions has been established after a learning process that started as soon as the possibility of cooperation with Russia was envisaged. At that time, the EAC had just completed the Training Concept for the European Astronauts for the Hermes and Columbus Projects, including also the training for the flight opportunities with NASA. In essence, this Training Concept is based on three phases of training that the astronauts should follow consecutively: Basic Training, Specialised Training and Mission Training.

In the early contract with ZPK, the following training objectives were established:

- learning how the Russians train their cosmonauts
- implementation of part of the Basic Training defined in the European Astronauts Training Concept at ZPK
- definition of a preliminary training programme for the Mir missions.

To realise the first objective, bearing in mind that the best way to learn is a 'hands-on' approach, a four-week training period was arranged at ZPK in October/November 1992 for three astronaut candidates and one training engineer*. This session provided good spin-off not only from the training point of view, but also regarding logistics and personnel aspects.

* See article titled 'European Astronaut Candidates in Training in the CIS', in ESA Bulletin No. 73 (pp. 61–67).

Figure 2. The two ESA Astronauts selected for EuroMir 95: Thomas Reiter (left) and Christer Fuglesang

To achieve the second objective, a common Basic Training Plan was established and three months of this programme were contracted to be implemented at ZPK.

With respect to the third objective, a first draft training programme was defined for the Mir missions, harmonised with the Basic Training.

In summary, a Training Programme was derived by seeking answers to the following questions:

- What do the astronauts need to know in order to safely go to and return from the Mir Space Station aboard Soyuz?
- What do they need to know to live and work aboard Mir?
- What physical, psychological and physiological condition must they be in (involving psychological, biomedical and physical training)?
- What work/experiments need to be done onboard the orbiting complex?

The three phases of the overall training programme are shown in Figure 3.

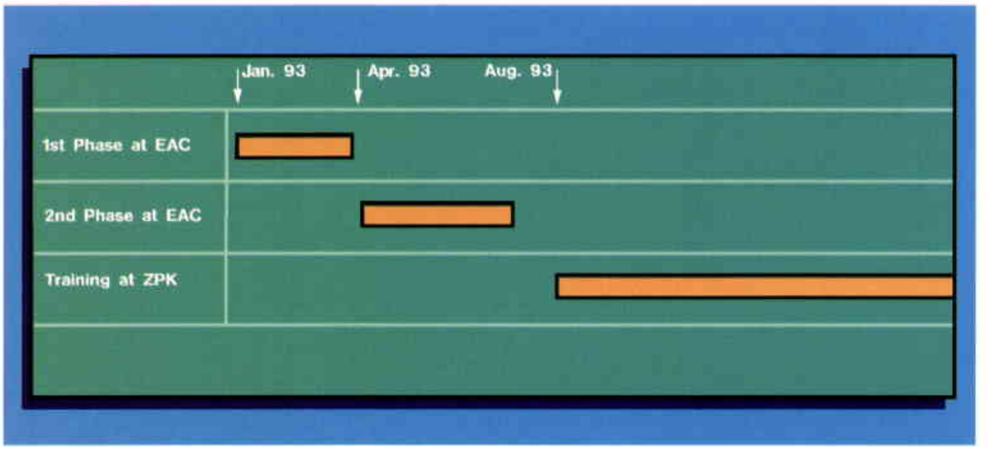


Figure 3. The overall EuroMir Training Plan

First phase of Basic Training at EAC

This phase lasted from January until March 1993 and the training focussed mainly on the fundamentals of several disciplines, a first Russian language course with a native Russian instructor, and other activities from the Basic Training curriculum, such as physical training and flight piloting training.

The following courses were followed:

Russian language:	100 h
Fundamentals, aerospace engineering:	20 h
Fundamentals, electrical engineering:	12 h
Fundamentals, space sciences:	16 h
Physical training:	25 h
Flight training*:	45 h

Second phase of Basic Training at EAC

The astronauts' training continued at EAC from April to July 1993, this period being dedicated primarily to an intensive Russian language course provided by the ZPK instructor, some fundamentals of life-sciences needed for a better understanding of the experiments (the majority of them dealing with life-sciences) to be performed aboard Mir, several courses on Soviet manned programmes provided by ZPK instructors, and a scuba-diving course.

Both the physical training and the flight-proficiency maintenance training were continued during this period, the time allocations being roughly as follows:

Intensive Russian language course:	200 h
Fundamentals of life sciences (biomedical training):	11 h
Soviet manned programmes, ground safety and flight safety:	11 h
Scuba diving:	approx. 40 h
Physical training and flight-proficiency maintenance:	approx. 35 h
Media skills, space law, space organisations:	11 h.

Training at ZPK

Thanks to the three months of Basic Training included in the EAC/ZPK contract, the European Astronauts' training for Mir missions could start in Star City by 9 August 1993. From this date onwards, the Astronauts have been following their training at ZPK on a continuous basis, except for some periods spent in Western Europe in between for the flight-proficiency maintenance and experiment training (Fig. 4).

The times allotted for the major subjects for EuroMir 94 and EuroMir 95 training are shown in Table 1.

Logically, the training at ZPK started with those courses that are least affected by knowledge of the Russian language, such as the vestibular, psychological and physical training, or with subjects that are not critical to mission success. In this way, the Astronauts have more time to become proficient in Russian before proceeding to the more essential training.

A standard week of training at ZPK in this first stage might be composed of:
- approximately 6 to 8 h of Russian-language training
- two sessions per week of physical training, totalling 4 h
- two sessions per week of vestibular training, totalling 2 h

* Two astronaut candidates with no previous flight experience obtained their Private Pilot's Licences (PPL).

Table 1

Training subject	EuroMir 94 (hours)	EuroMir 95 (hours)
Theory of manned space vehicles	30	30
Manned space-vehicle control systems	20	20
Fundamentals of space navigation	30	30
Transport spacecraft Soyuz-TM	75	75
Research onboard Mir	20	20
Biomedical training (including physical and psychological training)	325	630
Technical training	315	685
Russian language	160	280
Crew training (including experiment training)	630	870
EVA training	—	100

- two sessions per week of psychological training, totalling 2 h
- lectures and practical sessions on other subjects, totalling around 20 h
- private study and examinations, around 4 h in total.

Experiment training

We will focus here on the EuroMir-94 mission, during which some thirty experiments are to be performed. Not all of these experiments need training, some of them being pre- and post-flight experiments which only require Baseline Data Collection.

The experiment training has been structured as follows:

1. Experiment Introduction at EAC: From 18 to 22 October 1993, the Principal Investigators briefed the Astronauts on the scientific background behind each experiment.
2. Hardware and experiment familiarisation, which started in January 1994 at EAC.
3. Nominal Procedures training.
4. Non-Nominal Procedures training.
5. Refresher training, if needed.

This training takes place in Western Europe as well as at ZPK, and is harmonised with the Baseline Data Collection activities.

Operational aspects of the astronaut activities

At present, historical changes are taking place in the CIS. As a consequence, the country is in a transient stage whereby the old systems of working have lost much of their efficiency, but the new systems that must replace them are not yet fully in place. This demands a constant awareness of the changes taking place and a high degree of flexibility.

As far as communication is concerned, the public network is having great difficulty in coping with the exponentially increasing demand for communications lines and is heavily overloaded. With the assistance of ESA's European Space Operations Centre (ESOC) in Darmstadt (D), fax and PROFS connections are in place to ZPK using an X.25 interface. At present, this system is being extended to allow Internet access and database connections. Audio connections are still a concern and this is being remedied with satellite-based connections (inter alia by using an Inmarsat portable station).

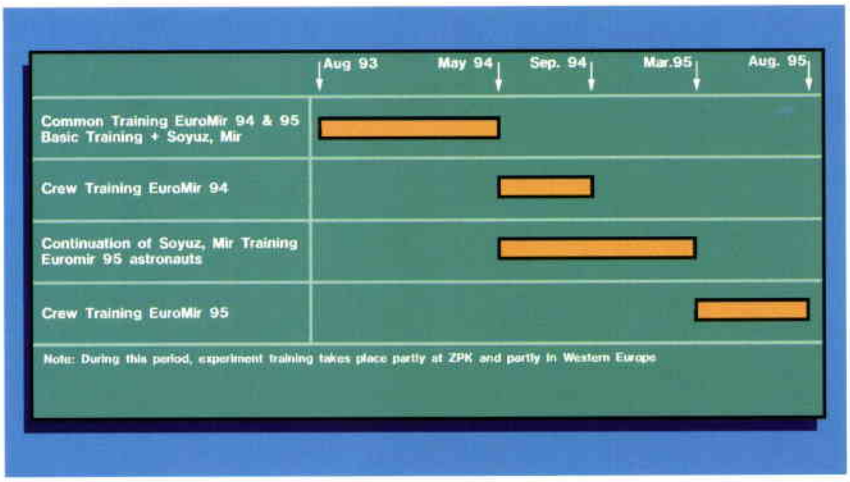


Figure 4. The ZPK Training Plan

A point-to-point audio/video communication system, using DICE, connects ZPK to the other centres concerned and allows satellite-supported links independent of the public networks.

Local logistics are also strongly influenced by the internal changes. It was, therefore, of paramount importance to have a permanently manned ESA office at ZPK for the EuroMir Project. This office houses the above-mentioned communications devices and services the many other office functions that are still difficult to provide in a flexible manner at the current time. Dr. S. Jähn who runs this office has previous Soviet flight experience (Salyut-6/Soyuz-31) and his knowledge of the

Figure 5. One of the ESA Astronauts training at ZPK in a Russian EVA suit

Russian language and customs is proving an indispensable asset.

EAC has established a dedicated team to support its Astronauts for the EuroMir missions, but here too tasks can be very demanding in the present constantly changing environment. The on-site support to the training is provided with a two-fold objective in mind: besides the support aspect, one should not forget the 'precursor nature' of these missions, allowing ESA to acquire both training and operational experience for future mission scenarios.

Because the long-duration EuroMir missions are specifically of interest for life-sciences, the medical-support aspect has been carefully examined. Baseline Data Collection will become a considerable but demanding task, strongly influencing the Astronauts' activities. The important role of Crew Surgeon has therefore been awarded to European doctors with specific experience in this field. A consortium of medical specialists from DLR in Germany and MEDES in France, supported by DAMEC of Denmark, is providing these crew surgeons, who have had previous experience with operational space medicine, in the framework of bilateral cooperative missions using Mir.

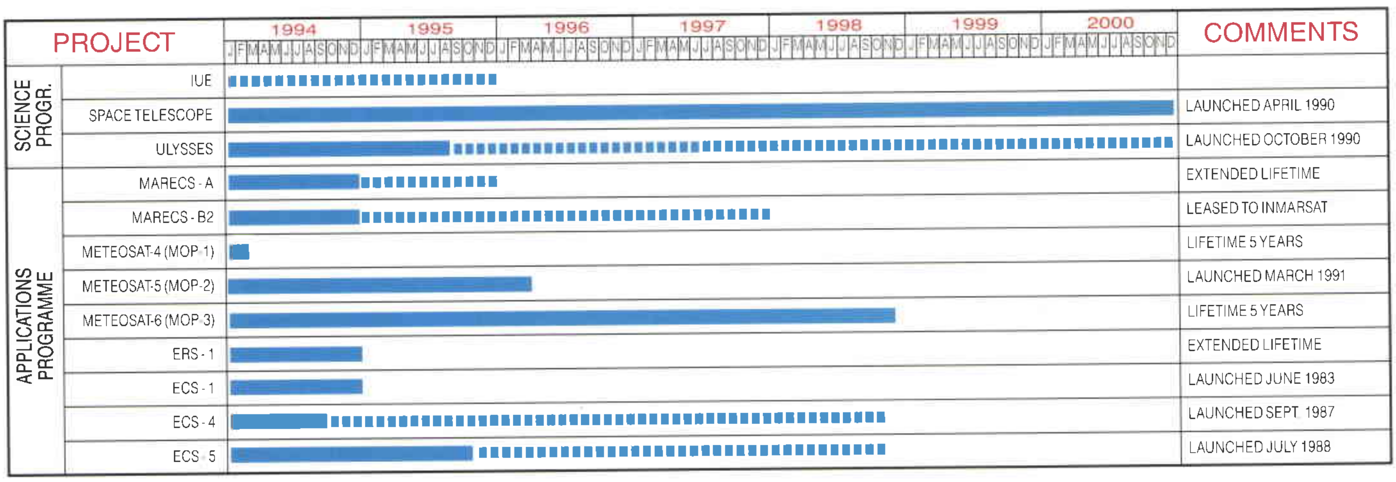
Conclusion

The political changes of recent years have offered ESA considerably enlarged scope for international cooperation in the provision and exploitation of space flight opportunities. This not only provides the scientific user community with an increased number of possibilities for experimentation in space, but also enlarges the scope thereof due to the longer durations of the new flight opportunities offered.

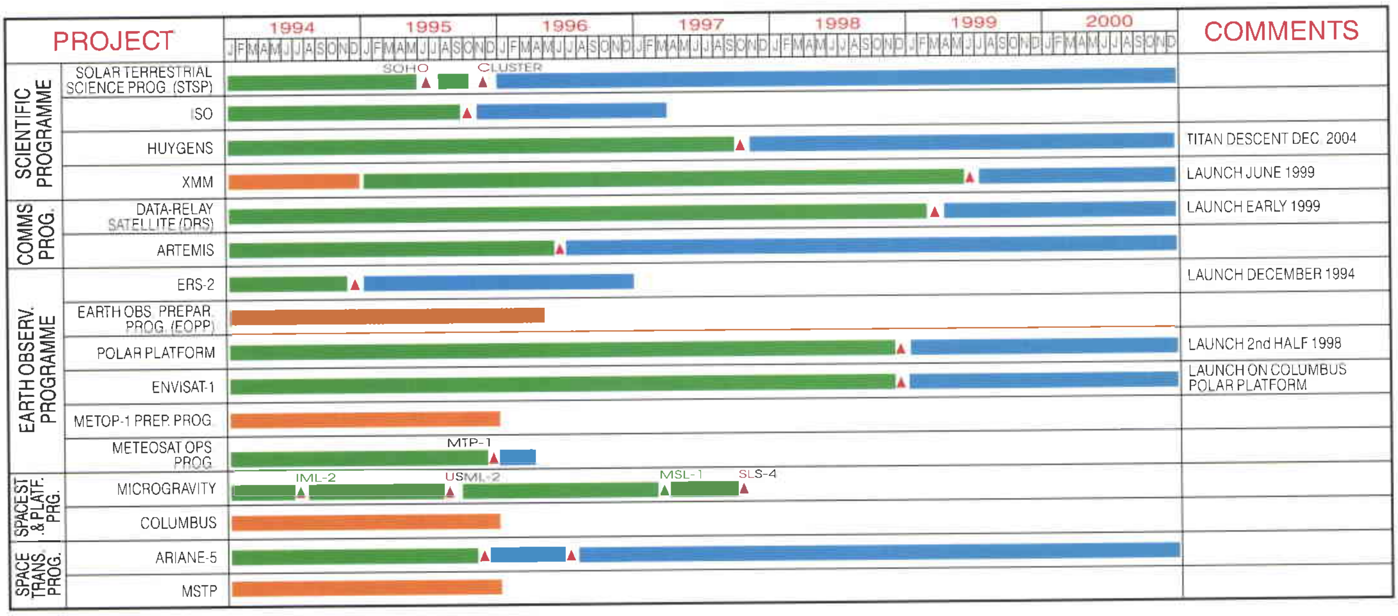
From the point of view of astronaut activities, the EuroMir missions will allow ESA to acquire in-depth knowledge of a different training approach and operational concept to that with which it has so far been familiar. In the context of further international cooperation in manned spaceflight, this could become an important asset. Expanded joint activities in the future will require joint training in a well-structured and 'standardised' manner. By being involved in an unbiased way in both training concepts, ESA could play a catalytic role at the time when it becomes necessary to decide upon a common concept acceptable to all parties involved in the cooperative space missions of the future.

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

In Orbit / En orbite



Under Development / En cours de réalisation



DEFINITION PHASE
OPERATIONS
MAIN DEVELOPMENT PHASE
ADDITIONAL LIFE POSSIBLE
▲ LAUNCH/READY FOR LAUNCH
▼ RETRIEVAL

Ulysse

Ulysse, qui est maintenant dans sa quatrième année d'exploitation, continue sa mission sans problème. La sonde a atteint une latitude solaire de 55° sud et va bientôt entamer son premier survol polaire. A compter du 26 juin, Ulysse va survoler pendant 132 jours au total les régions polaires sud du Soleil.

Depuis le dernier rapport, la seule anomalie de fonctionnement constatée a été la mise hors tension des éléments non essentiels de la charge utile (DNEL) le 27 novembre. Comme cela s'était déjà produit, le logiciel embarqué a coupé l'alimentation des instruments scientifiques et reconfiguré les sous-systèmes de la sonde, ce qui s'est traduit par une perte temporaire des données de télémesure. Trois jours après, la sonde et sa charge utile avaient retrouvé leur configuration nominale.

On dispose maintenant d'indices solides laissant à penser que les anomalies DNEL sont liées au fonctionnement des vannes à verrouillage lors de manoeuvres de routine. Leur cause la plus probable est un saut de courant survenant au niveau du détecteur de dépassement d'intensité du commutateur principal, dans le sous-système d'alimentation de la sonde. Dans ce cas, le seuil de déclenchement est atteint lorsque les vannes à verrouillage sont actionnées au moment où une autre pointe de courant se produit. Tout ce qui permet alors de réduire le courant au niveau du commutateur principal ou les phénomènes transitoires au niveau du bus principal diminuera les risques qu'une anomalie DNEL se reproduise. C'est ainsi, par exemple, que la sonde s'approchant du Soleil à mesure qu'elle se dirige vers ses régions polaires, les réchauffeurs des expériences peuvent être coupés. Il serait également possible de réduire la fréquence des opérations de commutation des vannes à verrouillage.

L'analyse des données scientifiques continue d'apporter de nouvelles informations passionnantes sur l'environnement solaire hors du plan de l'écliptique. Plus de 40 articles sur les résultats d'Ulysse ont été présentés à l'occasion de la réunion de décembre 1993 de l'American Geophysical Union. Deux revues scientifiques ont publié ces derniers mois des numéros spéciaux rassemblant des articles sur le survol de Jupiter.

L'année 1994 sera marquée par un atelier qui se tiendra à l'ESTEC à la mi-septembre (au moment où Ulysse atteindra sa latitude maximale vers le sud) au cours duquel les équipes scientifiques compareront leurs observations les plus récentes. Cet atelier s'achèvera par une journée consacrée à la presse.

Soho

Industrie

Le modèle d'identification (EM) du module de servitude (SVM) a été soumis aux essais système au cours de l'été et a été transféré sans problème sur la structure du modèle structurel (SM), disponible depuis la fin des essais système SM. L'EM du module de charge utile (PLM) avec toutes ses expériences avait été transféré de façon similaire un mois auparavant environ.

L'assemblage dans leur configuration finale des deux moitiés de l'EM du véhicule spatial a été mené à bien le 10 octobre, puis les essais fonctionnels intégrés de l'ensemble de l'EM du véhicule spatial ont eu lieu comme prévu et se sont prolongés jusqu'à la deuxième quinzaine de novembre.

Les essais de compatibilité électro-magnétique ont débuté et se

The Soho spacecraft under test at Matra Marconi Space

Le véhicule spatial Soho aux essais chez Matra Marconi Space

Ulysses

The Ulysses mission, now in its fourth year of operations, continues to go well. The spacecraft has climbed to 55° latitude in the southern solar hemisphere, and is rapidly approaching the start of its first polar pass. Starting on 26 June, Ulysses will spend a total of 132 days above the Sun's south polar regions.

During the reporting period, the only operational anomaly was a 'disconnect of non-essential loads' (DNEL) event on 27 November. As on previous occasions, the onboard logic switched off the scientific instruments and reconfigured the spacecraft subsystems, resulting in a temporary loss of telemetry. The spacecraft and its payload were returned to their nominal configuration within three days.

There are now rather firm indications that the DNEL events are related to latch-valve operations that take place during routine manoeuvres. The most probable cause is a current transient at the main-switch overcurrent detector in the spacecraft's power subsystem. The overcurrent threshold is triggered when a latch-valve pulse coincides with another current spike. In this case, anything that leads to a reduction in the main-switch current, or to the transients on the spacecraft main bus, will reduce the likelihood of a DNEL in the future. For example, the spacecraft is now getting closer to the Sun as it approaches the polar regions, and so experiment heaters can be switched off. In addition, it may be possible to reduce the frequency of latch-valve switching.

Analysis of the scientific data continues to reveal new and exciting results about the Sun's environment away from the plane of the ecliptic. At the December 1993 meeting of the American Geophysical Union, more than 40 papers were presented in which Ulysses results were discussed. Special issues of two scientific journals containing collections of papers addressing the Jupiter flyby have appeared in recent months.

Looking ahead, one of the highlights of 1994 will be a Workshop at ESTEC in mid-September (when Ulysses reaches its maximum southern latitude) at which the Science Teams will compare their latest observations. This event will be rounded off with a Press Day.

Soho

Industry

The Engineering Model (EM) of the Service Module (SVM) has undergone system testing during the summer, and has been moved without problem to the Structural Model (SM) structure, which became available at the end of the SM system tests. A similar transfer had been executed about a month earlier with the EM of the Payload Module (PLM) with all its EM experiments.

On 10 October, the two halves of the EM spacecraft were successfully mated in their final configurations and integrated functional testing of the whole EM spacecraft took place as planned, lasting until the second half of November.

Electromagnetic-compatibility tests have started and will continue until January 1994, with an interruption for a shock separation test with the Atlas-II-AS launch adaptor, which took place in mid-December.

The flight-model deliveries started with the PLM and SVM (with harness) structures, which took place on 27 September (Portsmouth) and 10 November (Toulouse), respectively. Other components (e.g. remote terminal unit, thermal hardware, harness for PLM) have been added to the structures to make the PLM ready to receive its first experiment on 16 December.

The flight models of the data-handling subsystem and of the communications subsystem were delivered by Saab (S) in the last week of November. Their integration started in parallel with the EM with a partial second set of EGSE equipment, which was commissioned in late November.

The Mission Critical Design Review (M-CDR) Board met in Noordwijk on 28 – 29 October, one month after the Spacecraft and Payload Critical Design Review. The CDR review cycle highlighted several points needing attention at mission constituent level (launcher, spacecraft/payload, operations) and at lower levels, and sanctioned the start of Assembly, Integration and Verification (AIV) activities on the flight model.

ESA – NASA cooperation

General Dynamics, the launch-vehicle manufacturer, has resolved the problem that had led to the failure of an Atlas launch on 25 March and have since successfully launched two more Atlas vehicles, in September and in late November. The first launch of the version to be used for Soho will take place on 14 December.

The tape recorders continued to exhibit problems in achieving the necessary performances and reliability, and in July two separate procurement actions were started for Soho and Cluster in order to have alternatives based on different technologies (semiconductor mass memories) ready in time for the planned launch dates. The first tape recorder flight-unit delivery (to Cluster) took place at the beginning of November.

Experiments

The second half of 1993 has seen all teams assembling the flight models of their experiments under severe schedule constraints. The first delivery took place on 6 December (SWAN) and a second (VIRGO) was planned for 15 December. The others will follow until March 1994.

Some experiments have been reporting difficulties in meeting the due dates, and two in particular (SUMER and UVCS) have decided to change both their detector designs and suppliers. For them, workaround solutions are being agreed to limit the impact on the overall Soho Programme.

Cluster

The proto-flight model spacecraft has been fully integrated and electronically tested at Dornier (D) and is now at IABG (D) for environmental testing. The first test in the series, the DC magnetic test, was successfully completed before Christmas and preparations are now underway for the thermal-balance/thermal-vacuum test due to commence in early February. The thermal-balance test represents the last remaining qualification test of the Cluster Programme; thereafter all tests will be conducted at flight-acceptance levels.

The second flight spacecraft (F2) is now fully integrated at Dornier and will commence full system electrical testing in January 1994. Flight model-3's (F3) *prolongeront jusqu'en janvier 1994; ils ont été interrompus à la mi-décembre afin de réaliser un essai de choc lors de la séparation avec l'adaptateur du lanceur Atlas II AS.*

Les livraisons des modèles de vol ont commencé: la structure du PLM a été livrée le 27 septembre (Portsmouth) et celle du SVM (avec câblage) le 10 novembre (Toulouse). D'autres éléments (comme l'unité terminale, le matériel thermique, le câblage du PLM) ont été ajoutés aux structures pour préparer le PLM à recevoir sa première expérience le 16 décembre.

Saab (S) a livré les modèles de vol du sous-système de traitement des données et du sous-système de télécommunications pendant la dernière semaine de novembre. Leur intégration a commencé, parallèlement à celle de l'EM, avec un deuxième jeu incomplet d'équipements EGSE mis en service fin novembre.

La Commission de revue critique de conception de la mission (MCDR) s'est réunie à Noordwijk les 28 et 29 octobre, un mois après la revue critique de conception du véhicule spatial et de la charge utile. Le cycle de revues CDR a attiré l'attention sur plusieurs points au niveau des grandes composantes de la mission (lanceur, véhicule spatial/charge utile, opérations) et à des niveaux inférieurs, et donné le feu vert aux activités d'assemblage, d'intégration et de vérification du modèle de vol.

Coopération ESA/NASA

General Dynamics, qui fabrique le lanceur, a résolu le problème qui avait entraîné l'échec du lancement d'un Atlas le 25 mars 1993 et a depuis mené à bien le lancement de deux véhicules, en septembre et à la fin de novembre. Le premier lancement de la version d'Atlas qui emportera Soho aura lieu le 14 décembre.

Les enregistreurs à bande continuent de ne pas présenter les caractéristiques de fonctionnement et la fiabilité nécessaires, aussi deux approvisionnements distincts ont-ils été lancés en juillet pour Soho et Cluster, de façon à disposer de solutions de rechange reposant sur des technologies différentes (mémoires de masse à semi-conducteur) qui soient disponibles à temps pour les dates de lancement prévues. Un premier enregistreur à bande aux normes de vol (pour Cluster) a été livré début novembre.

Expériences

Au cours du deuxième semestre 1993, toutes les équipes ont assemblé les modèles de vol de leurs expériences, dans des délais très serrés. La première expérience (SWAN) a été livrée le 6 décembre et la deuxième (VIRGO) devait l'être pour le 15 décembre. Les autres se succéderont jusqu'en mars 1994.

Les responsables de certaines expériences ont fait savoir qu'ils auraient du mal à respecter les délais. Pour deux expériences notamment (SUMER et UVCS), il a été décidé de changer de concepts de détecteurs et de fournisseurs. Des solutions sont mises au point pour limiter les incidences de ces modifications sur le programme d'ensemble Soho.

Cluster

Le prototype de vol du satellite a été entièrement intégré et son électronique soumise à essais chez Dornier (D); il a ensuite été transporté chez IABG pour y subir les essais en conditions ambiantes: on a commencé par les essais de compatibilité électromagnétique qui ont été menés à bon terme avant Noël; des préparatifs sont en cours pour les essais d'équilibrage thermique et les essais thermiques sous vide qui doivent commencer début février. Les essais d'équilibrage thermique marquent la fin de la procédure de qualification du programme Cluster. Tous les essais seront ensuite conduits au niveau de la procédure d'aptitude au vol.

L'intégration de la deuxième unité de vol (F2) est achevée chez Dornier. Le début des essais électriques au niveau système était prévu pour janvier 1994. British Aerospace (UK) a livré le système de commande à réaction (RCS) de la troisième unité de vol (F3) intégré au cylindre central; le RCS a ensuite été monté sur la plate-forme sur laquelle sont intégrés les sous-systèmes. La charge utile devait être livrée et intégrée début 1994.

La structure de la quatrième unité de vol a été livrée et l'intégration du RCS a commencé chez BAe.

Les unités de charge utile du F2 ont été entièrement intégrées et soumises à essais. Celles du F3 devaient être livrées début 1994. Dans leur majorité, les difficultés techniques rencontrées pendant la fabrication et les essais ont été surmontées.

Les travaux du secteur sol progressent conformément au calendrier; on a eu recours à des solutions de repli pour certains approvisionnements critiques. Les essais de validation 'système' de bout en bout devraient se dérouler début 1995.

Le système d'accès aux données scientifiques de Cluster (CSDS) est actuellement examiné dans le cadre de la Revue de définition architecturale au terme de laquelle les Centres de données participants seront connectés à temps pour le lancement de Cluster prévu fin 1995.

ISO

Instruments scientifiques

Les instruments scientifiques sont intégrés et soumis à essais sur le modèle de vol du satellite. Ceux du satellite de réserve subissent les derniers essais et leur livraison est prévue pour le début de l'année prochaine.

Modèle de vol du satellite

Les travaux sur le matériel du modèle de vol du satellite progressent; le module de charge utile est désormais équipé de son télescope et des unités au plan focal des instruments scientifiques. Le module est actuellement purgé et rempli d'hélium liquide avant que l'on procède aux essais du module intégré en janvier 1994. Les essais de lumière parasite sur les instruments scientifiques seront la prochaine opération délicate.

Le module de service a été livré à l'ESTEC en octobre. On a ensuite procédé aux essais en boucle fermée du logiciel des opérations de vol mis au point par l'ESOC. Ce module est stocké dans l'attente de l'arrivée, fin avril, du module de charge utile. L'intégration et les essais au niveau 'système' devraient alors commencer.

Pour rendre conformes aux spécifications les paramètres de pointage du suiveur stellaire, plusieurs actions sont menées en parallèle.

Reaction Control Subsystem (RCS), integrated onto the central cylinder, has been delivered from British Aerospace (UK) and mated with the platform on which the subsystems are being integrated. Payload delivery and integration are scheduled for early 1994.

The flight model-4 structure has been delivered and integration of the RCS has commenced at BAe.

The F2 payload units are fully integrated and tested; delivery of the F3 units is scheduled for early 1994. Most technical difficulties encountered during manufacture and testing have now been successfully overcome.

Progress with the ground segment remains on schedule, with work-around solutions in place for certain critical procurements. Full end-to-end system validation testing with the ground segment is scheduled for early 1995.

The Cluster Science Data System (CSDS) is currently undergoing its Architectural Design Review. Successful completion will enable the participating Data Centres to be on-stream in time for Cluster's scheduled launch in late 1995.

ISO

Scientific instruments

The flight-model scientific instrument units are now being integrated and tested on the satellite flight-model hardware. The spare-model scientific instrument units are in final testing and should be ready for delivery early next year.

Satellite

The satellite flight-model hardware continues to make good progress. The payload module has the telescope and scientific instrument focal-plane units installed. This module is now being evacuated and filled with liquid helium prior to conducting integrated module tests in January 1994. The next critical step will be the stray-light test with the scientific instruments.

The service module was delivered to ESTEC in October. Closed-loop tests with the spacecraft flight-operations system developed by ESOC were subsequently successfully completed. The service module is being stored pending the arrival of the payload module at the end of April, when system integration and testing should start.

Several parallel actions are being taken to bring the pointing performance of the star tracker within specification.

The satellite work is on schedule for the September 1995 launch.

Ground segment

Further actions are being taken to strengthen the science operations teams and to ensure timely completion of the development work.

An important milestone has been achieved with the successful completion of the system validation testing of the service module with ESOC's spacecraft flight-operations system. Other spacecraft operations developments are proceeding satisfactorily.

The ISO spacecraft

Véhicule spatial ISO

Huygens

The lengthy and demanding task of establishing and agreeing technical, financial and programmatic baselines for the Huygens Probe development phase culminated with agreement to the Phase-C/D prime contract. At a formal ceremony at ESA Headquarters in Paris on 20 September, the prime contract was signed by the Director General of ESA and the President of Aerospatiale, the Prime Contractor, giving the full go-ahead for all activities leading to delivery of the flight-model Probe to ESA in December 1996 for launch in October 1997.

Until the signature of the contract, development work in industry had been progressing under a preliminary authorisation to proceed, which had permitted the full level of activities, but for a period of just one year. The clearest signs of progress are the completion of Manufacturing Readiness Reviews for many of the Probe sub-systems and the start of mechanical qualification testing for certain units. As is usual at this stage in a project, a number of small problems have surfaced during the tests and corrective actions are being investigated and implemented. They are not expected to have any impact at Probe system level.

The development of the scientific instruments is generally proceeding on schedule, with just one experiment continuing to give cause for concern and warranting constant and detailed monitoring. Interfaces with NASA/JPL continue to be close and cooperative, with a quarterly technical and management meeting held in September, in Europe, further advancing agreement on formal documentation and interfaces.

ERS

ERS-1

The satellite's performance has remained extremely stable and its orbit has continued to be maintained within the ±1 km deadband. The satellite was maintained in the 35-day orbit repeat cycle until 20 December, when it was changed to a 3-day repeat cycle to give the high revisiting rate required for the Ice Arctic Winter campaigns planned for January to March 1994. By early April 1994, the

Les travaux respectent le calendrier de réalisation du satellite qui doit être lancé en septembre 1995.

Secteur sol

D'autres mesures sont prises pour renforcer les équipes chargées des opérations scientifiques et pour garantir que les travaux de développement seront achevés à la date voulue.

Une étape importante a été franchie lorsqu'ont pris fin les essais de validation 'Système' du module de servitude avec le logiciel des opérations en vol réalisé par l'ESOC. D'autres travaux de développement liés à l'exploitation d'ISO se poursuivent de manière satisfaisante.

Huygens

L'accord sur le contrat de maîtrise d'oeuvre pour la phase C/D a marqué la fin d'une longue et difficile période pendant laquelle on a défini et adopté les références techniques, financières et programmatiques de la phase de développement de la sonde Huygens. Ce contrat a été signé le 20 septembre 1993, lors d'une cérémonie officielle qui s'est déroulée au siège de l'ESA à Paris, par le Directeur général de l'Agence et par le Président d'Aérospatiale, maître d'oeuvre, qui peut ainsi lancer toutes les activités de réalisation de la sonde dont le modèle de vol doit être remis à l'ESA en décembre 1996 et lancé en octobre 1997.

Jusqu'à la signature du contrat, les travaux de développement en cours dans l'industrie ont été menés au titre d'une autorisation préliminaire d'engagement de travaux qui a permis aux activités d'atteindre leur plein régime mais pour une période ne dépassant pas un an. Les signes d'avancement les plus manifestes sont l'achèvement des revues d'aptitude à la fabrication pour de nombreux sous-systèmes de la sonde et le démarrage des essais de qualification mécanique de certaines unités. Comme cela arrive fréquemment à ce stade d'un projet, les essais ont permis de déceler quelques petits problèmes; on étudie les actions correctives à mettre en oeuvre ensuite. Ces difficultés ne devraient pas avoir d'incidences sur la sonde au niveau 'Système'.

De façon générale, les travaux de développement des instruments scientifiques se poursuivent selon le calendrier; une seule expérience demeure préoccupante et justifie un suivi constant et détaillé. Les relations avec la NASA/JPL se poursuivent de façon étroite et dans un esprit de coopération; la réunion trimestrielle 'technique et gestion' s'est déroulée en septembre, en Europe; elle a permis de faire avancer les discussions sur les accords relatifs à la documentation officielle et aux interfaces.

ERS

ERS-1

Le fonctionnement du satellite est resté extrêmement stable et son orbite a été maintenue à l'intérieur de sa bande de 1 km. Son cycle orbital de 35 jours a été maintenu jusqu'au 20 décembre, date à laquelle on est passé à un cycle de trois jours afin d'assurer le taux de répétitivité élevé exigé par les campagnes hivernales au dessus des glaces de l'Arctique, prévues de janvier à mars 1994. D'ici début avril 1994, le cycle orbital sera de nouveau modifié pour passer aux 168 jours de la phase géodésique, qu'il est actuellement prévu de conduire jusqu'au lancement d'ERS-2, à la fin de 1994.

Le deuxième symposium ERS-1, qui s'est tenu au Centre des Congrès de Hambourg du 11 au 14 octobre 1993 et au cours duquel ont été présentés les résultats obtenus à cette date par les chercheurs principaux et les responsables de projets pilotes sélectionnés par l'ESA, a accueilli plus de 700 scientifiques.

ERS-2

Le module charge utile ERS-2 a franchi une étape importante avec l'achèvement du bilan thermique et des essais thermiques sous vide dans le grand simulateur spatial de l'ESTEC. Aucun problème majeur n'a été rencontré, les modifications de la conception thermique de la charge utile ont été validées et l'intégrité fonctionnelle générale de la charge utile et des instruments a été démontrée.

Le prototype du nouvel instrument GOME, dont les essais étaient compris dans ceux de la charge utile, a fait la preuve de son bon fonctionnement, tant du point de vue de son comportement thermique que de sa fonctionnalité au niveau système.

La plate-forme ERS-2 est aujourd'hui pratiquement prête pour la livraison, avec l'achèvement des essais thermiques sous vide à Intespace, Toulouse (F).

Après l'approbation officielle par le Conseil directeur du programme d'observation de la Terre de la date de lancement de ERS-2, prévue au cours de la période décembre 1994 – février 1995, l'attention se concentrera au cours des prochains mois sur les préparatifs de mise en orbite et d'exploitation du nouveau satellite.

First image taken by Meteosat-6, on 29 November 1993

Première image de la Terre prise par Météosat-6 le 29 novembre 1993

orbit repeat cycle will be changed again to the 168-day Geodetic Phase, currently planned to be flown until the launch of ERS-2 at the end of 1994.

The Second ERS-1 Symposium, held at the Congress Centre Hamburg, from 11 to 14 October 1993, at which the results obtained to date by the ESA selected Principal Investigators and Pilot Project Managers were presented, attracted more than 700 participants.

ERS-2

The ERS-2 payload module has passed a major milestone with the completion of thermal-balance/thermal-vacuum testing in the Large Space Simulator facility at ESTEC (NL). No major problems were encountered and the modifications to the payload's thermal design were validated and the overall functional integrity of both payload and instruments was demonstrated.

The prototype model of the new GOME instrument which was included in the payload test demonstrated good performance in terms of both its thermal behaviour and system-level functionality.

The ERS-2 platform is now almost ready for delivery, with the completion of the thermal-vacuum testing at Intespace in Toulouse.

With the formal approval by the Earth Observation Programme Board of the ERS-2 launch date within the period December 1994 to February 1995, preparations for the launch and operation of the satellite will be the focus of attention in the coming months.

Earthnet

Data acquisition, archiving and product-generation activities for the Landsat and JERS-1 missions have been carried out at the Fucino (I) and Kiruna (S) ground stations.

Upgrading of the Landsat data-processing chain has been completed, thereby allowing generation of the new Thematic Mapper (TM) standard product applicable to mission data from Landsats 1 to 5. New product options (i.e. additional geometric and radiometric correction algorithms, calibrated reflectance, new media such as CD-ROM and exabyte tapes, as well as the digital three-band colour quick-look) will be available from January 1994.

Acquisition of MOS satellite data at the Maspalomas station (Canary Islands) was halted in October due to budget constraints. MOS data acquired prior to that date will, however, continue to be retrievable through the Earth Images catalogue.

Spot satellite data have been routinely acquired at the Maspalomas station.

The Fucino, Kiruna, Tromsø (N) and O'Higgins (Antarctica) stations have continued to acquire JERS data. Distribution of JERS-1 SAR and OPS payload data will commence in 1994 after finalisation of the ESA/NASDA Agreement. In the meantime, test SAR and OPS data products have been distributed to allow users to familiarise themselves with these new types of sensor data. In addition, installation of the new digital VNIR quick-look capability at ESRIN (I) has been completed.

The contract for the development of the SeaWiFS processing chain has been awarded, with delivery of the core system for the acquisition, processing and archiving activities foreseen for May 1994, in time for the spacecraft's planned launch in July 1994.

The acquisition of NOAA AVHRR HRPT data has continued throughout the Earthnet Tiros Coordinated Network.

In the first nine months of 1993, more than 16 000 products were distributed to users.

EOPP

Solid Earth

The proposed, revised Solid Earth programme strategy was approved by the Earth Observation Programme Board on 28 September. This authorised the Agency to prepare a potential, joint ESA/Russian precise time and position experiment and a proposal for a follow-on to the Aristoteles programme for launch in the year 2003.

A Phase-A study of the possible joint experiment was initiated with industry on 4 November and a meeting of interested representatives of the science community in the experiment was held in Paris on 10 November.

Meteosat Second Generation

In anticipation of final programme approval early in 1994, the Phase-B Invitation to Tender (ITT) was issued to Industry. Meanwhile, technology development work continues.

Metop-1

The Metop-1 Phase-A was initiated in industry in the second week of October. Metop-1 is intended to be the first in a series of European polar-orbiting satellites for operational meteorology and climate monitoring. The programme is planned to be carried out in cooperation with Eumetsat.

Earthnet

Des activités d'acquisition de données, d'archivage et d'élaboration de produits pour les missions Landsat et JERS-1 ont été menées à bien dans les stations sol de Fucino (I) et Kiruna (S).

La mise à niveau de la chaîne de traitement de données Landsat a été achevée, permettant ainsi d'élaborer le nouveau produit normalisé de cartographie thématique (TM), applicable aux données des missions Landsat-1, 2, 3, 4 et 5. Des options pour de nouveaux produits (algorithmes de correction géométrique et radiométrique supplémentaires, réflectance étalonnée, nouveaux supports tels que CD-ROM, bandes exabyte, ainsi que la visualisation rapide couleur trois bandes numérique) seront disponibles à partir du mois de janvier 1994.

L'acquisition des données du satellite MOS a été interrompue en octobre à la station de Maspalomas (Iles Canaries) en raison de contraintes budgétaires. Les données du MOS acquises avant cette date resteront toutefois disponibles par l'intermédiaire du catalogue des images de la Terre.

L'acquisition régulière des données du satellite Spot s'est poursuivie à la station de Maspalomas.

Les stations de Fucino, Kiruna, Tromsø (N) et O'Higgins (Antarctique) ont continué d'acquérir les données JERS. La diffusion des données des charges utiles JERS-1, SAR et OPS débutera en 1994, après mise au point finale de l'accord ESA/NASDA. Parallèlement, des produits expérimentaux, élaborés à partir des données des charges utiles SAR et OPS, ont été distribués aux utilisateurs pour leur permettre de se familiariser avec ce nouveau type de données de détection. En outre, l'installation à l'ESRIN du nouveau dispositif de visualisation rapide d'images numériques VNIR a été achevée.

Le contrat de développement de la chaîne de traitement SeaWifs a été attribué. La livraison du système central d'acquisition, de traitement et d'archivage doit avoir lieu en mai 1994, à temps pour le lancement du satellite prévu pour le mois de juillet prochain.

L'acquisition des données AVHRR HRPT des satellites NOAA s'est poursuivie via le réseau Tiros coordonné par Earthnet.

Plus de 16 000 produits ont été distribués aux utilisateurs au cours des neuf premiers mois de 1993.

EOPP

Solide terrestre

La proposition de stratégie révisée pour un programme d'étude du solide terrestre a été approuvée le 28 septembre par le Conseil directeur du programme d'observation de la Terre. L'Agence est ainsi autorisée à préparer une possible expérience de détermination spatio-temporelle précise ESA/Russie, et une proposition pour une suite au programme Aristoteles à lancer en 2003.

Une étude de phase A de cette possible expérience commune a été lancée avec l'industrie le 4 novembre et une réunion des représentants de la communauté scientifique intéressés par l'expérience s'est tenue à Paris le 10 novembre.

Météosat de deuxième génération

Par anticipation de l'approbation du programme final début 1994, l'appel d'offres relatif à la phase B a été adressé à l'industrie. Parallèlement, le travail de développement technologique se poursuit.

Métop-1

La phase A de Métop-1 a été lancée dans l'industrie au cours de la seconde semaine d'octobre. Métop-1 doit être le premier d'une série de satellites européens sur orbite polaire pour la météorologie opérationnelle et la surveillance du climat. Ce programme est conçu pour être mené en coopération avec Eumetsat.

Campagnes

La campagne EMAC 1994 a été réorganisée pour tenir compte de l'indisponibilité des instruments EARSEC du JRC avant le milieu de l'année. La campagne 1994 poursuit cinq objectifs principaux; d'autres sont prévus pour 1995.

Une seconde campagne sera organisée pour coïncider avec l'emport de l'expérience américaine LITE (expérience de technologie Lidar) à bord de la Navette spatiale en septembre 1994.

Plate-forme polaire

A la suite de la revue de consolidation de la Plate-forme polaire destinée à la mission Envisat-1, un certain nombre de réductions et de simplifications ont été apportées à la configuration de base. Les spécifications et les plans du niveau

Polar Platform Service Module under structural testing at CASA, in Spain

Le module de service de la Plate-forme polaire aux essais de structure chez CASA (Espagne)

Campaigns

The EMAC campaign for 1994 has been replanned to cope with the unavailability of the JRC EARSEC instruments before mid-year. The 1994 campaign covers five main objectives; others will be scheduled for 1995.

A second campaign will be aimed to coincide with the flight on the Space Shuttle in September 1994 of the US Lidar Technology Experiment (LITE).

Polar Platform

Following consolidation of the Polar Platform for the Envisat-1 mission, a number of design descoping and simplification changes have been implemented in the baseline. Top-level specifications and plans have been updated to reflect these changes.

Preparatory work has been initiated together with the Envisat Project, both in the Agency and in Industry, for the Envisat-1 System Preliminary Design Review, planned for early 1994.

Two major Preliminary Design Reviews have been completed for the Payload Equipment Bay and the Payload Module Structure.

Manufacture of the Service Module Structural Model has been completed and static testing has been started and is due to be completed early in 1994. Manufacture of engineering models is well in hand, while several MGSE items have already been delivered. Several breadboarding activities have basically been completed for the Solar Array Drive Mechanism (SADM) and the Ka-band subsystem (antenna pointing mechanism, travelling-wave-tube amplifier).

Interface definition between the Polar Platform and Ariane-5 has advanced with the start of the preliminary Launch Coupled Dynamic Analysis for Envisat-1 and Ariane-5.

Final negotiations have been completed for the majority of the Service Module and Payload Module subcontractors, the objective being to place the Phase-C/D contract early in 1994.

The Polar Platform Programme Declaration has not yet entered into force due in part to an insufficient level of subscriptions. Matters are in hand to resolve this deficit.

Envisat-1

Following a period of intense consultation between ESA and the Envisat Industrial Consortium, which identified several areas for cost savings and at the same time provided a solid technical baseline for the programme, a consolidated proposal was submitted by the mission Prime Contractor, Dornier (D), in early November.

Following review by the Tender Evaluation Panels, the Tender Evaluation Board endorsed the overall positive assessment. Assuming confirmation of the levels of subscription by the end of 1993, good progress has been made towards a fully fledged Phase-C/D.

On the technical side, the majority of the critical breadboarding activities are now nearing completion and the detailed definition of all interfaces is currently in the final stages of refinement. The principal documents for the Envisat/Polar Platform interface are in the final review cycle prior to signature.

The first Instrument Preliminary Design Review (IPDR) for the Radar Altimeter has been successfully completed. The IPDRs for the other instruments are planned for late 1993/early 1994.

The precise content and scope of the Envisat-1 Ground Segment is currently being defined and the corresponding Ground Segment Consolidation Phase is planned to be initiated by early 1994.

Metop-1 Preparatory Programme

The activities to develop an Advanced Scatterometer (ASCAT) technology-demonstrator were kicked off early in November. A proposal for the corresponding activities for MIMR is expected in January 1994.

Metop-1 spacecraft Phase-B activities are planned to start in the second half of 1994, following completion of the Phase-A activities begun in October 1993.

Meteosat

Meteosat-6 (MOP-3) was successfully launched aboard Ariane flight V61 on 20 November, together with the Mexican communications satellite 'Solidaridad'. Meteosat's Apogee Boost Motor was fired on the fourth apogee and all pyrotechnics in the payload were successfully fired a few days later at the start of the radiometer's commissioning. The first image was obtained, as scheduled, nine days after lift-off, with the infrared and water-vapour images becoming available two days later, after the detectors had reached their correct operating temperature (90 K). A complete end-to-end test, in which the satellite's performance as part of the complete Meteosat system is to be assessed is now underway.

Microgravity

The need to provide the scientific community with regular flight opportunities for basic microgravity research is recognised in ESA's Long-Term Plan and was endorsed by the ESA Council meeting at Ministerial Level in Granada in November 1992.

In response, the Microgravity Programme Board approved the conversion of the ongoing Microgravity Programme Phase-2 into a first slice of a new programme known as the European Microgravity Research Programme (EMIR-1). At the same time, France has increased its subscription to this programme from 10 to 12%, and Switzerland has also increased its contribution slightly.

The EMIR-1 Programme will cover flight opportunities for microgravity multi-user facilities on the Shuttle and Spacelab, and on Russian spacecraft like the unmanned Foton carrier and the Mir space station. It also includes a sounding-rocket programme and parabolic flights. Microgravity payloads for the Space Station are to be supérieur ont été remis à jour pour tenir compte de ces modifications.

Des travaux préparatoires ont été lancés conjointement avec le projet Envisat, au sein de l'Agence comme dans l'industrie, pour la revue de définition préliminaire du système Envisat-1, prévue pour le début de 1994.

Deux importantes revues de définition préliminaire ont été menées à bien, pour la case à équipements et la structure du module charge utile.

La fabrication du modèle structurel du module de servitude a été achevée. Les essais statiques ont été entamés et devraient s'achever début 1994. La fabrication des modèles d'identification est bien lancée, et plusieurs équipements MGSE ont déjà été livrés. Plusieurs montages table, relatifs au mécanisme d'entraînement du réseau solaire (SADM) et au sous-système en bande Ka (mécanisme de pointage de l'antenne, amplificateur du tube à ondes progressives), ont été pratiquement réalisés.

La définition des interfaces entre la Plate-forme polaire et Ariane-5 a progressé, avec le début de l'analyse dynamique préliminaire des conditions de lancement du couple Envisat-1/Ariane-5.

Les négociations finales ont été menées à bien avec la majorité des sous-contractants concernés par le module de servitude et par le module charge utile, l'objectif étant de passer les contrats de phase C/D début 1994.

La déclaration relative au programme de Plate-forme polaire n'est pas encore entrée en vigueur, en raison notamment du niveau insuffisant des souscriptions. Des démarches sont en cours pour réduire ce déficit.

Envisat-1

A la suite d'une période de consultation intense entre l'ESA et le consortium industriel Envisat, qui a permis de cerner certains domaines où des économies pouvaient être faites tout en fournissant une base technique solide au programme, une proposition consolidée a été soumise début novembre par le maître d'oeuvre de la mission, Dornier (D).

La Commission d'évaluation des offres a entériné l'estimation positive globale après examen par les groupes d'évaluation. Si l'on tient pour acquis que les niveaux de souscription seront confirmés d'ici la fin de 1993, on peut considérer que des progrès satisfaisants ont été accomplis vers une phase C/D complète.

Sur le plan technique, la majorité des activités critiques de montage sur table sont sur le point de s'achever et la définition détaillée de toutes les interfaces en est actuellement au stade de mise au point finale. Les principaux documents relatifs à l'interface Envisat/Plate-forme polaire en sont au stade de l'examen final avant signature.

La première revue de définition préliminaire (IPDR) de l'altimètre radar a été effectuée avec succès. Les IPDR des autres instruments sont prévues fin 1993/ début 1994.

La composition et l'étendue précise du Secteur sol d'Envisat-1 est actuellement en cours de définition et la phase de consolidation correspondante devrait être lancée d'ici le début 1994.

Programme préparatoire Metop-1

La réalisation du modèle de démonstration technologique d'un diffusiomètre de pointe (ASCAT) a été lancée début novembre. Une proposition pour réaliser le modèle de démonstration technologique d'un MIMR (imageur hyperfréquences multibande) est attendue en janvier.

Les activités de phase B du satellite Metop-1 devraient débuter au cours du second semestre de 1994, après achèvement des activités de phase A qui ont débuté en octobre 1993.

Météosat

Météosat-6 (MOP-3) a été lancé avec succès le 20 novembre dernier, en compagnie du satellite de télécommunications mexicain 'Solidaridad', à l'occasion du vol V61 d'Ariane. Le moteur d'apogée du satellite a été mis en route lors du quatrième apogée et l'ensemble de la chaîne pyrotechnique de la charge utile a été mis à feu avec succès quelques jours plus tard, lors de l'entrée en service du radiomètre. La première image a été obtenue, comme prévu, neuf jours après le lancement, les images dans les bandes infrarouge et vapeur d'eau étant disponibles deux jours plus tard, après que les détecteurs eurent atteint leur température correcte de fonctionnement (90 K). Un essai complet de bout en bout est actuellement en cours afin d'évaluer le fonctionnement du satellite en tant qu'élément du système complet Météosat.

Recherche en microgravité

Le Plan à long terme de l'ESA, entériné par le Conseil réuni au niveau ministériel à Grenade en novembre 1992, reconnaît qu'il est nécessaire de fournir à la communauté scientifique des occasions de vol régulières pour la recherche fondamentale en microgravité.

Pour répondre à ce besoin, le Conseil directeur du programme de recherche en microgravité a approuvé la transformation de la phase 2 du programme de recherche en microgravité actuellement en cours en une première tranche d'un nouveau programme dénommé Programme européen de recherche en microgravité (EMIR-1). La France a parallèlement porté de 10 à 12% sa contribution à ce programme et la Suisse a également légèrement accru sa participation.

Le programme EMIR-1 comprendra les occasions de vol des installations à utilisateurs multiples sur les navettes et le Spacelab, ainsi que sur les satellites russes comme le porte-instruments automatique Photon et à bord de la station spatiale MIR. Il comprendra également des campagnes de fusées-sondes et de vols paraboliques. Les charges utiles pour des recherches en microgravité à bord de la Station spatiale internationale seront réalisées dans le cadre d'un programme séparé.

developed by means of a separate programme.

The preparations for flight of the four ESA payloads – Biorack; Bubble, Drop and Particle Unit; Critical-Point Facility; and Advanced Protein Crystallisation Facility – on a Spacelab mission (International Microgravity Laboratory 2: IML-2), planned for launch in July 1994, are proceeding well.

For the ESA Mir mission in 1994 (EuroMir 94), 25 experiments in the area of life sciences – mainly in the field of physiology – and 5 experiments in the area of materials science were selected. These experiments will mainly use equipment already onboard Mir, with the exception of a freezer, a high-speed centrifuge and a transport container, which will be provided by ESA.

Experiment selection for the 1995 ESA Mir mission (EuroMir 95) is currently in progress. There is great interest in the user community in participating in this flight opportunity. ESA is currently developing two major multi-user facilities for it: a Respiratory Monitoring System for human physiological research, and an Incubator for biological investigations.

Two sounding rockets carrying microgravity experiments have been successfully launched from Esrange in Sweden in recent weeks. One of them, Maser-6, managed by the Swedish Space Corporation, was launched on 4 November and the other, Texus-31, managed by ERNO/DASA, on 26 November.

A parabolic-flight campaign was carried out from 16 to 18 November 1993 aboard a Caravelle aircraft. This campaign, dedicated solely to microgravity experiments (three material-science/fluid-physics and eight life-science experiments), was the seventeenth organised by ESA. Ninety-three parabolas, each providing approximately 20 sec of microgravity conditions, were flown from the Centre d'Essais en Vols (French test flight centre) in Brétigny.

Work on further microgravity multi-user facilities is in progress, the most important of which are:

- an advanced Glove Box for handling materials in a controlled environment, for the USML-2 Spacehab mission (mid-1995)
- an Advanced Gradient Heating Facility for the processing of materials samples with high temperature accuracy on either a Spacehab or the MSL-1 Spacelab mission in 1997
- a Torque Velocity Dynamometer, which is a device for measuring muscle forces in the elbow and ankle joints of astronauts during spaceflight, foreseen to be flown on the MSL-1 mission in 1997
- a Fluid-Physics Facility for flight on the Russian unmanned 'Foton' carrier in 1996
- the development of a neuroscience payload (neurobiology, sensory motor systems), to be flown on the SLS-4 Spacelab Life Science mission at the end of 1997.

Columbus Programme

International Space Station

After discussions between, and some joint studies by, the United States and Russia, and discussions between the US and the International Partners in Space Station 'Freedom', Russia has been formerly invited to join the Space Station project and a new programme has been elaborated.

This programme, leading to a 'global space station' (to be named at a later date), is composed of several phases. It will be preceded by a so-called 'Phase 1', covering US missions to the Mir station with joint technology demonstrations. On the ESA side, the missions to Mir will be performed during this same period. The programme itself is composed of two phases:

- Phase 2: first phase of assembling a 'global space station' in a 51.6°-inclination orbit, leading to a Human Tended Configuration with eight to ten assembly flights by the Shuttle for US elements and Russian expendable launchers for Russian elements. It will be composed essentially of US and Russian elements, with potential contributions from the European and other partners.
- Phase 3: addition of further US and Russian elements, and of the other International Partners' elements, to the Phase-2 configuration, in order to complete the 'global' station complex. Launch of the Columbus Laboratory is planned for the year 2000 in the new manifest, but this date will not be feasible on the ESA side due to the limited budget available in the coming years.

The Envisat-1 spacecraft

Le véhicule Envisat-1

Les préparatifs pour l'emport des quatre charges utiles de l'ESA (le biorack; le dispositif bulles, gouttes et particules; le dispositif point critique et l'installation de cristallisation des protéines de pointe) lors d'une mission Spacelab (Laboratoire international de microgravité: IML-2) dont le lancement est prévu en juillet 1994, progressent d'une manière satisfaisante.

25 expériences dans le domaine des sciences de la vie – et notamment en physiologie – et 5 expériences dans le domaine de la science des matériaux ont été sélectionnées pour la mission de l'ESA à bord de MIR en 1994 (EuroMIR 94). Ces expériences utiliseront surtout les équipements déjà installés à bord de la station russe, à l'exception d'un congélateur, d'une centrifugeuse à grande vitesse et d'un conteneur de transport qui seront fournis par l'ESA.

La sélection des expériences pour la mission ESA à bord de MIR en 1995 (EuroMIR 95) est actuellement en cours. Les utilisateurs manifestent un grand intérêt pour cette occasion de vol. Dans cette perspective l'ESA réalise actuellement deux importantes installations à utilisateurs multiples: un système de contrôle respiratoire pour des recherches en physiologie humaine, et un incubateur pour des expériences biologiques.

Deux fusées-sondes, emportant des expériences en microgravité, ont été lancées au cours des dernières semaines à Esrange, en Suède. L'une d'entre elles, Maser-6, a été lancée le 4 novembre sous la responsabilité de la Swedish Space Corporation et l'autre, Texus-31, a été lancée le 26 novembre sous la responsabilité d'ERNO/DASA.

Une campagne de vols paraboliques a été menée du 16 au 18 novembre 1993 à bord d'une Caravelle. Cette campagne, entièrement consacrée à des expériences de recherche en microgravité (3 expériences en science des matériaux et en physique des fluides et 8 expériences en sciences de la vie), est la 17ème organisée par l'ESA. 93 trajectoires paraboliques, permettant chacune d'obtenir une vingtaine de seconde en conditions de quasi impesanteur, ont été réalisées au centre français d'essais en vol de Brétigny.

Des travaux sont en cours pour développer d'autres installations de recherche en microgravité à utilisateurs multiples. Les plus importantes d'entre elles sont:

- *Une boîte à gants perfectionnée permettant des manipulations de matériaux dans un environnement contrôlé, destinée à la mission Spacehab USML-2 (mi-1995).*
- *Un four à gradient de haute technologie pour le traitement d'échantillons de matériaux avec une grande précision thermique, destiné à une mission Spacehab ou à la mission Spacelab MSL-1 en 1997.*
- *Un dynamomètre de mesure du couple force-vitesse, qui doit être utilisé lors de la mission MSL-1 en 1997. Il s'agit d'un appareil qui permet de mesurer la force musculaire des astronautes au niveau des articulations de la cheville et du coude au cours d'un vol spatial.*
- *Une installation de physique des fluides qui devrait être embarquée à bord du porte-instruments automatique russe 'Photon'.*
- *Une charge utile consacrée aux disciplines neurologiques (neurobiologie, étude des systèmes sensori-moteurs) et destinée à embarquer lors de la mission Spacelab SLS-4 sur les sciences de la vie, prévue pour fin 1997.*

Programme Columbus

Station spatiale internationale

Après des discussions et la réalisation d'un certain nombre d'études communes entre les Etats-Unis et la Russie, et des consultations entre les Etats-Unis et les partenaires internationaux de la Station spatiale 'Freedom', la Russie a été officiellement invitée à se joindre au projet de Station spatiale internationale et un nouveau programme a été élaboré.

Ce programme, devant conduire à la réalisation d'une 'Station spatiale mondiale' (dont le nom sera choisi plus tard), comporte plusieurs phases. Il sera précédé par ce qu'il est convenu d'appeler la phase 1, qui comprendra les missions américaines vers la station MIR, avec démonstration de technologies communes. L'ESA conduira ses propres missions à destination de MIR au cours de la même période. Le programme proprement dit comporte deux phases:

- *La phase 2: Ce sera la première phase d'assemblage de la Station spatiale mondiale sur une orbite inclinée à 51,6°, permettant d'aboutir à une configuration visitable par l'homme (HTC). La Navette américaine, pour les éléments d'origine américaine, et des lanceurs russes non-réutilisables, pour les éléments d'origine russe, effectueront de 8 à 10 vols d'assemblage. Cette phase comprendra essentiellement la mise en place d'éléments américains et russes, avec contribution potentielle des européens et d'autres partenaires.*

- *La phase 3: Elle permettra de compléter la configuration de phase 2 par l'adjonction d'éléments fournis par les Américains, les Russes et les autres partenaires internationaux, en vue d'achever le complexe de Station spatiale mondiale. Le lancement du laboratoire Columbus est prévu en l'an 2000 dans le nouveau manifeste, mais cette date ne pourra être respectée par l'ESA en raisons des budgets limités dont on disposera au cours des prochaines années.*

Programme Columbus révisé

Le programme Columbus a été révisé au cours des derniers mois pour refléter la nouvelle conception de référence de la Station spatiale, la stratégie proposée par l'ESA pour les éléments du programme d'infrastructures habitées, et pour tenir compte de l'évolution prévisible des capacités financières des Etats membres participants.

Le programme Columbus se compose à présent de deux éléments:

- *Contribution à la Station spatiale avec le laboratoire Columbus et contributions soumises à sélection à la phase 2 (avant le lancement du laboratoire de l'ESA) sous forme de sous-systèmes ou d'équipements.*
- *Vols précurseurs.*

L'élément 'Etudes pour une station future' a été supprimé. Les activités prévues dans le cadre de cet élément et qui seraient toujours utiles au nouveau programme Columbus sont incluses dans l'élément 'Contribution à la Station spatiale'.

Revised Columbus Programme

The Columbus Programme has been revised during the last months to reflect the new Space Station baseline, the ESA-proposed strategy for the manned infrastructure programme elements, and to take into account the changes in the anticipated financial capabilities of the participating Member States.

The Columbus Programme is now composed of two elements:
- Contribution to the Space Station with the Columbus Laboratory and selected contributions to Phase-2 (before the launch of the ESA Laboratory) with subsystems or equipment
- Precursor Flights.

The 'Studies for a Future Station' element has been deleted. The activities that had been planned for this element and that would be still useful for the new Columbus Programme are included in the element 'Contribution to the Space Station'.

At the last session of its 111 th Meeting on 15 February, the Council adopted an 'Act in Council' giving the definitive go-ahead for the Columbus and Manned Space Transportation Programmes covering activities for the next two years. It confirmed the establishment of a unified structure for managing these two programmes, resulting in the creation of a combined programme 'Space Activities Related to Manned Spaceflight' in March 1994.

'Contribution to the Space Station'

This element is still being defined in detail. Because activities will initially be decided upon for the next two years only, and will mainly be of a study or early development nature, activities in Industry will be further reduced in the coming years, and a rundown has been started to achieve a lower spending rate, compatible with the budget available and the corresponding activities.

'Precursor Flights'

Progress has been made in the selection of Euromir 95 payloads, and preparations for the EuroMir 94 and 95 missions are progressing normally.

A reflight of the Eureca retrievable carrier is still under study, together with a shared flight of Spacelab.

European Manned Space Transportation Programme (MSTP)

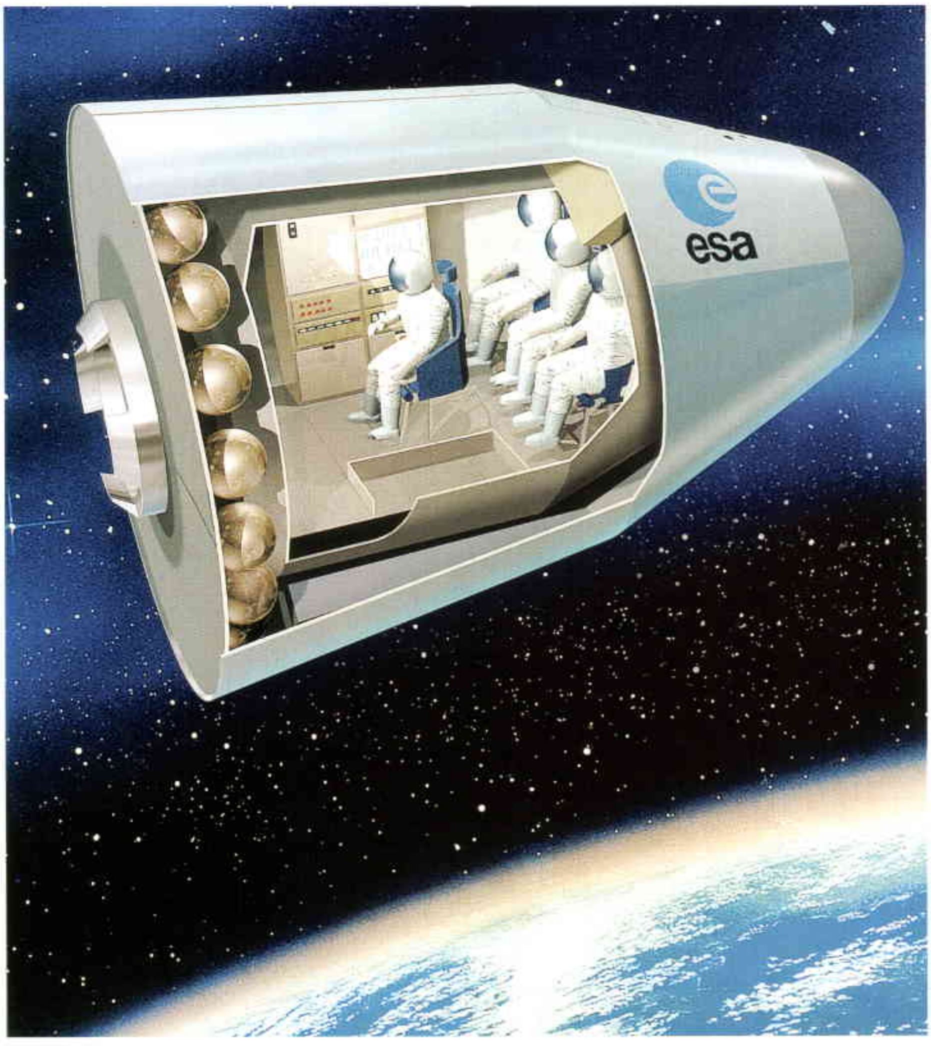
A revised Programme Proposal and Declaration have been established and presented to the ESA Council. The main elements of the European MSTP resulting from the re-orientation of the Hermes Programme are a Crew Transport Vehicle, the Servicing Elements and a Technology Programme. The proposal covers the definition and interface studies for these elements for the period 1994/5 in preparation for decisions regarding their definite development.

The Technology Programme has been adjusted to limit the continuation of activities from the previous programme to a rundown, and to cover the new requirements of the non-winged re-entry vehicles.

The system concept studies performed on winged and non-winged re-entry vehicles have been completed. The results have enabled the definition of the Crew Transport Vehicle (CTV) programme element. Other system studies in progress deal with the operation and utilisation of the MSTP and the determination of environmental constraints.

Two parallel CTV Phase-0 studies have started in Industry. They will permit conclusions to be drawn by mid-1994 on the type of vehicle and system to be maintained for further analysis. The vehicles presently being considered for crew transport include simple capsules as well as advanced shaped vehicles, with integrated propulsion or alternatively with transfer provided by an Automated Transfer Vehicle (ATV).

The results from the Phase-A studies on an ACRV (Assured Crew Return Vehicle)



Artist's impression of the Assured Crew Return Vehicle (ACRV)

Vue conceptuelle de véhicule de secours pour le retour de l'équipage (ACRV)

Lors de la dernière session de sa 111ème réunion le 15 février, le Conseil a adopté un 'Acte en Conseil' permettant le démarrage effectif des programmes Columbus et MSTP (programme de moyens de transport spatiale habités). Je confirme d'autre part la mise en place d'une structure unique de gestion de ces programmes qui devrait aboutir à la constitution d'un programme global d'activités spatials concernant les vols habités à partir de mars 1994.

Contribution à la Station spatiale

Les détails de cet élément sont toujours en cours de définition. Les activités ne seront en effet décidées au départ que pour les deux prochaines années et consisteront principalement en études ou développements préliminaires. Les activités dans le domaine industriel seront en conséquence encore réduites au cours des années à venir, et une révision à la baisse a été entreprise pour diminuer les dépenses afin de les rendre compatibles avec le budget disponible et les activités correspondantes.

Vols précurseurs

Des progrès ont été accomplis dans la sélection des charges utiles pour EuroMIR 95, et la préparation des missions EuroMIR 94 et EuroMIR 95 progresse normalement.

Un réemport du porte-instruments récupérable Eureca est toujours à l'étude, de même qu'un vol en utilisation partagée du Spacelab.

Programme MSTP

Une proposition de programme et une déclaration révisées ont été établies et présentées au Conseil de l'ESA. Les principaux éléments qui composent le programme européen de moyens de transport spatial habités (MSTP), après réorientation du programme Hermes, sont un véhicule de transport d'équipages, des éléments de desserte et un programme de soutien technologique. La proposition concerne la définition et les études d'interfaces relatives à ces éléments au cours de la période 1994–1995, en préparation des décisions à prendre quant à leur développement définitif.

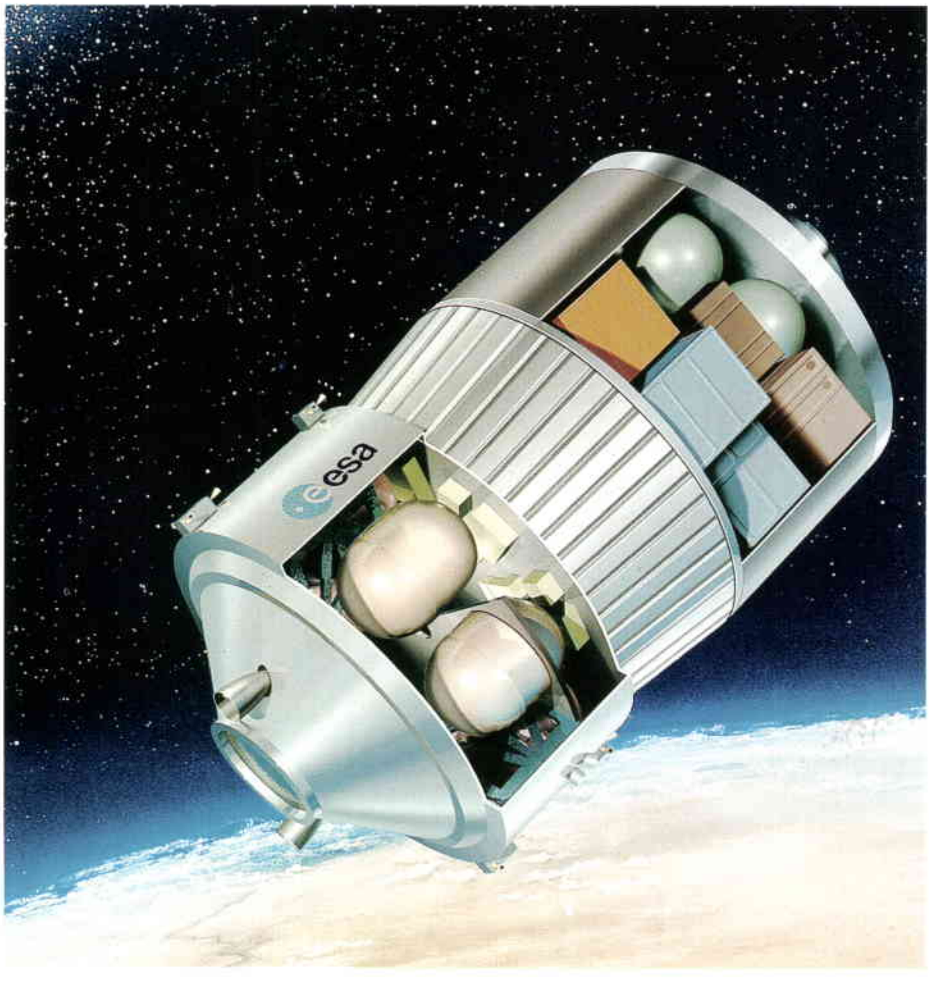
Le programme de soutien technologique a été réajusté de façon à limiter la poursuite des activités du programme précédent, et afin qu'il puisse répondre aux impératifs posés par le choix d'un véhicule de rentrée atmosphérique sans voilure.

Les études de concept système des véhicules de rentrée atmosphérique avec ou sans voilure ont été achevées. Leurs résultats ont permis de définir l'élément de programme relatif à un véhicule de transport d'équipages (CTV). D'autres études système, portant sur l'utilisation et l'exploitation des éléments du MSTP et sur les contraintes liées à l'environnement, sont actuellement en cours.

Deux études de phase 0 concernant le CTV ont été lancées en parallèle dans l'industrie. Elles permettront d'ici la mi-94 d'obtenir des conclusions relatives au type de véhicule et de système devant faire l'objet d'une analyse plus poussée. Les véhicules actuellement envisagés pour le transport des équipages vont de la simple capsule aux véhicules de forme complexe, avec système de propulsion intégré ou transfert par véhicule de transfert automatique (ATV).

Les résultats des études de phase A relatives à un ACRV (véhicule de secours pour le retour de l'équipage) ont été évalués en commun avec la NASA. L'analyse des problèmes critiques se poursuit dans l'industrie, et en particulier la comparaison des exigences du CTV et de l'ACRV.

Les travaux techniques et les préparatifs pour la première partie du développement des éléments ERA/EVA (activités extra-véhiculaires) ont progressé de manière satisfaisante. L'utilisation possible des éléments ERA/EVA à bord de MIR-2, étudiée en coopération avec la Russie, a confirmé l'intérêt qu'il y aurait de voir ces éléments disponibles à temps pour la construction de cette station. Par contre, aucun accord n'a encore été conclu avec le partenaire américain concernant l'utilisation de ces matériels à bord de la Station mondiale.



Artist's impression of the Automated Transfer Vehicle (ATV)

Vue conceptuelle du véhicule de transfert automatique (ATV) have been jointly evaluated with NASA. Industry continues to further analyse critical issues, including a requirements comparison between a CTV and an ACRV.

The technical work and the preparations for the Part-1 development of ERA/EVA have progressed well. The utilisation of ERA/EVA for the Mir-2 station, studied in cooperation with Russia, has confirmed interest in having these elements available in time for the construction of Mir-2, but agreements with the American partners concerning their utilisation for the global station still need to be established.

Analysis of the launch configuration of the Astropas/Minispas composite for ARC (Automated Rendezvous and Capture) has provided a mathematical model for the simulation of the launch configuration. Tests performed with real software and hardware for the rendezvous sensors have demonstrated good performance over a wide range of distances.

The ATV configuration review has been completed. The industrial team continues to process the review issues and assess the changes in the design reference missions resulting from the implementation of the global space station.

Ariane-5

The following two events have taken system work a significant step forward:
- the first lower composite – P230 boosters and H155 stage – has been integrated on the launch table without incident and the table and composite assembly transferred to the launch zone;
- dynamic testing on the equipment bay, the L9 stage and the Speltra has been completed with highly satisfactory results.

Full analysis of the second test on the P230 stage with a flight-type structure shows the booster's general performance to be in line with predictions and similar to the first test (test B1).

The third test, scheduled for November, has been postponed owing to heterogeneity problems with the composition of the propellant in two segments of the M2 booster. The next test is planned for June 1994 using the M3 booster. The development plan has been rearranged in such a way that this incident does not affect the overall programme timetable.

The rear skirt underwent qualification testing in November and the results were in line with predictions.

Integration of the H155 battleship stage test stand is continuing in French Guiana with the equipped thrust frame and the Vulcain engine. The first hot tests on this stage are planned for June 1994.

On the European side, development work is proceeding normally, a main area of activity at present being proof pressure testing of the tank for flight 501.

Production of the flight 501 and qualification thrust frames is well under way.

Where the Vulcain engine is concerned, a total of 155 hot tests have been carried out, the cumulative burn time amounting to 33 700 seconds.

The first L9 stage has just been delivered to Lampoldshausen (D) and testing is planned to begin in January 1994.

The second in-vacuo separation test on the fairing took place in November 1993. The separation system functioned just as predicted.

L'analyse de la configuration de lancement du composite Astropas/ Minispas du système ARC (rendez-vous et capture automatiques) a fourni un modèle mathématique pour la simulation de la configuration de lancement. Les essais réalisés avec les logiciels et les matériels effectivement prévus pour les dispositifs de rendez-vous ont permis d'obtenir de bons résultats à des distances très différentes.

La revue de configuration de l'ATV a été achevée. L'équipe industrielle poursuit l'examen des éléments de cette revue et évalue les modifications à apporter au concept de référence des missions, dans l'optique de la réalisation de la Station spatiale mondiale.

Ariane-5

Deux événements significatifs de l'état d'avancement des travaux au niveau système doivent être signalés:
- l'intégration sur la table de lancement du premier composite inférieur, boosters P230 et étage H155, s'est parfaitement déroulée et l'ensemble table plus composite a été transféré sur la zone de lancement;
- les essais dynamiques de la case à équipement, de l'étage L9 et de la Speltra se sont terminés avec des résultats très satisfasaints.

L'exploitation complète du deuxième essai de l'étage P230 avec une structure de type vol, montre un comportement général du propulseur conforme aux prévisions et voisin du premier essai B1.

Le troisième essai qui était prévu en novembre a été suspendu suite à la présence d'hétérogénéité dans la constitution du propergol de deux segments du propulseur M2. Le prochain essai est prévu avec le propulseur M3 en juin 1994. Grâce à une réorganisation du plan de développement, cet incident n'affecte pas le planning général du programme.

Les essais de qualification de la jupe arrière se sont déroulés en novembre conformément aux prévisions.

L'intégration du banc d'essai de l'étage lourd H155 se poursuit en Guyane avec le bâti moteur équipé et le moteur Vulcain. Les premiers essais à feu de cet étage sont prévus en juin 1994.

En Europe, le développement de l'étage se poursuit normalement avec notamment le timbrage du réservoir destiné au vol 501.

Par ailleurs la fabrication des bâtis-moteurs 501 et de qualification est bien engagée.

Le moteur Vulcain quant à lui a accompli 155 essais à feu cumulant plus de 33 700 secondes de fonctionnement.

Le premier étage L9 vient d'être livré à Lampoldhausen et les premiers essais sont prévus en janvier 1994.

Le deuxième essai de séparation sous vide de la coiffe s'est déroulé en novembre 1993. Le système de séparation a fonctionné conformément aux prévisions.

Ariane-5 lower composite mounted on launch table

Ariane-5: composite inférieur monté sur table de lancement

In Brief

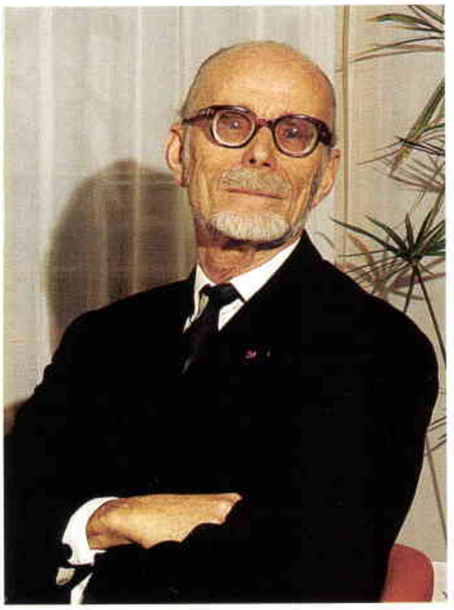
Pioneer in European Space Research Passes Away

Pierre Auger, one of the leaders in the organisation of space research in Europe and a founder of one of the organisations that later formed ESA, died in Paris on 24 December.

In the late 1950s, as space was becoming a high priority for many countries, Auger, a successful research physicist and initiator of several international scientific collaborations, including the European Laboratory for Particle Physics (CERN) in Geneva, turned his interests to space.

He set up a national committee for space research in France and, in 1959, was elected president of that newly-created Comité des recherches spatiales. He subsequently served as the first president of France's Centre national d'études spatiales (CNES), between 1961 and 1962.

During those periods, he strove, with a group of other scientists, to establish cooperation between scientists and engineers working in the different national space centres within Europe. Through their efforts, COPERS, a 'preparatory commission to study the possibilities of European collaboration in the field of space research', was established and Auger was named the Executive Secretary of the group in 1962.



Pierre Auger, the Executive Secretary of COPERS and the first Director General of the European Space Research Organisation

As a result of COPERS' work, the European Space Research Organisation (ESRO) was established and Auger became its first Director General in 1964, a position that he held until stepping down in 1967. That agency later merged with the European Launcher Development Organisation (ELDO) to form ESA.

DICE Systems Installed in Russia for EuroMir Project

In December, ESA completed an important step in its preparation for the EuroMir-94 and EuroMir-95 missions. Part of the satellite videoconferencing network that will be used to support those missions was implemented — two stations were installed near Moscow and one in Cologne, Germany — after three weeks of intense activity. Four ESA astronauts are currently training in Russia in preparation for the EuroMir missions (see the article 'ESA Astronauts Prepare for EuroMir' in this issue). The first mission, EuroMir-94, will last 30 days and will take place in September 1994, while the

Installing the DICE system that will support the EuroMir missions, on the roof of the building housing the ESA office at ZPK in Russia second one, EuroMir-95 will last up to 135 days and will begin in August 1995.

A communication link between centres
This satellite videoconferencing system will be used as the main means of communication between the ESA astronauts training at the Yuri Gagarin Cosmonaut Training Centre (known as ZPK) in Star City near Moscow, Russia, and the supporting centres at various locations in Europe and Russia. Communication links will be established with the European Astronauts Centre in Cologne, Germany; the EuroMir project team at ESTEC in The Netherlands; the Russian Mission Control Centre in Kalingrad near Moscow (known as ZUP); and the System for Control of Operations of Payload for EuroMir (SCOPE) Centre in Toulouse, France.

The system is based on the Direct Inter-establishment Communications Experiment (DICE) system developed by Matra Marconi Space (UK) and Joanneum Research Institute (Austria) under an ESA contract.

The videoconferencing terminals allow simultaneous voice and video communications between four selected sites. For instance, during the mission preparation phase, the system will provide the astronauts training at ZPK and their supporting team with reliable audio/video communications with the EuroMir supporting teams at EAC or ESTEC. The astronauts will also be able to use the system to maintain contact with their families in order to minimise the effects of a long separation from home.

During each mission, the network will also be used to relay realtime or playback video images from the Mir space station, via ZUP, to the EuroMir mission support centres at SCOPE, EAC or ESTEC.

The system
The video images are encoded at each terminal using digital techniques, and are then ready for transmission to the satellite at a rate of 384 kbps. This rate provides a balance between hardware complexity, space segment costs and picture quality.

Three terminals consist of an 8 W Ku-band VSAT (Very Small Aperture Terminal) transceiver coupled to an antenna with a diameter of 2.4 metres, while the fourth terminal, located at ZUP, is a 75 W Ku-band VSAT transceiver. The four terminals are aligned on the Eutelsat II-F4 satellite orbiting at seven degrees East.

Cross-site cables connect the outdoor unit to the indoor equipment rack that houses the modems and ancillary equipment. A fibre optic link is used in turn to connect the rack to the video coding/decoding (codec) equipment which is located in the videoconferencing studio along with the camera, monitors and associated units.

The installation
Due to the amount of work that had to be performed outdoors, the team intended to install the equipment before the harsh Russian winter began. However, because of delays in the procurement and delivery processes, the installation was finally undertaken in temperatures around −16°C and in often strong winds.

While this activity was taking place in Russia, a similar installation was being performed at EAC in Cologne. Some four-point videoconference test sessions were then carried out successfully using ESTEC or Matra Marconi Space in the UK as the fourth partner.

The next step
The next step in the preparation of the ground infrastructure will be the installation of the fourth terminal at the SCOPE Centre in Toulouse in March 1994.

The DICE installation at ZUP in Russia

ESA Signs 10 000th Industrial Contract

On 4 October 1993, ESA signed its 10 000th contract with industry. In order to carry out its research and development programmes, ESA spends the majority of its budget on industrial activities. Through this policy, each of ESA's Member States receives, in exchange for its investment, industrial contracts and benefits from the technological spin-offs.

ESA awarded the contract to Alenia Spazio (Italy) for the development and building of the Artemis telecommunications and data relay satellite. Artemis is scheduled to be launched in 1996 on Ariane-5.

As prime contractor for the satellite, Alenia Spazio will lead an industrial group of more than 70 highly-skilled European companies.

ESA's Director General, Jean-Marie Luton (left), the Italian Minister of Universities and Scientific and Technological Research, Umberto Colombo (centre), and the Chief Executive Officer of the Italian company Alenia Spazio, Andrea Pucci (right), at the signing of the 10 000th ESA industrial contract

Artemis Satellite to Introduce Space Communications by Laser

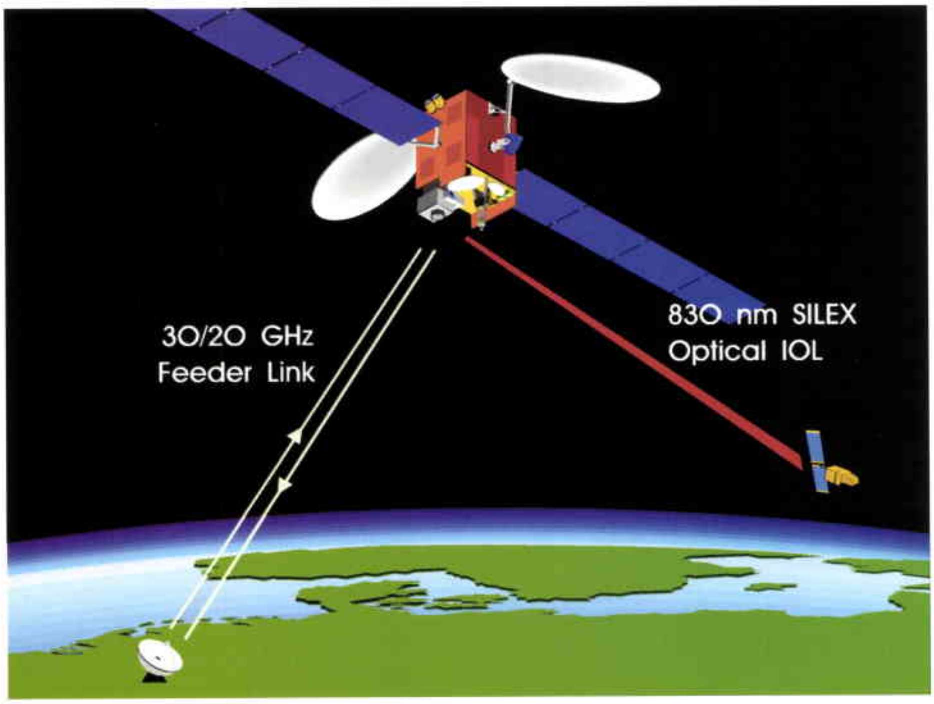
Fibre optics is a well-established technology on the ground, and now ESA is developing the technology for space optical communications. Using lasers, data will be able to be transmitted directly from one satellite to another. The first demonstration of such a link will take place in 1997.

In 1996, ESA will launch its Artemis satellite, an advanced satellite for testing and operating new telecommunications techniques. It will carry a Satellite Inter-orbit Laser Experiment (SILEX) optical terminal which will enable Artemis to exchange data with other satellites or with ground stations, by sending or receiving a laser beam.

The French SPOT-4 Earth-observation satellite, to be launched in early 1997, will be the first satellite to make use of Artemis' laser communications capabilities. Using existing technology, SPOT-4 would not be able to send its image data from its low-Earth orbit 700 km above the ground to any one ground station for more than 10 minutes. Data sent to ground stations overseas would often have to be transported over long distances for processing and distribution to users.

Using the SILEX optical terminal, SPOT-4 can have an uninterrupted link with the SPOT operations centre in Toulouse, France, whenever the satellite is in sight of Artemis on its geostationary orbit 36 000 km above Europe. In practice, SPOT-4 will therefore be able to provide observational data on more than half of the Earth's land mass using an Artemis data-relay link. The SILEX's data rate is 50 Mbit per second.

A one-metre telescope, financed by the German Space Agency DARA, will be deployed on Tenerife, Canary Islands, to receive laser signals from satellites. It will be installed in 1995.



An artist's impression of the Artemis telecommunications and data-relay satellite, and its SILEX optical terminal

Meteosat-6 Successfully Launched

The third, and last, of the meteorological satellites built under ESA's Meteosat Operational Programme was successfully launched on 20 November on Ariane Flight V61.

This was a double launch with the Mexican communication satellite Solaridad as upper passenger on the Ariane 42 LP launcher.

Meteosat-6
The Meteosat-6 satellite will ensure that weather forecasters in Europe and abroad continue to receive until the turn of the century the vital meteorological data that enables them to provide increasingly more reliable weather information.

The Meteosat-6 satellite was developed by ESA on behalf of Eumetsat, the European Organisation for the Exploitation of Meteorological Satellites. ESA currently operates all Meteosat satellites for Eumetsat and the US weather service NOAA. At the end of 1995, Eumetsat will take over the operation of the Meteosat satellites.

The launch
After an uninterrupted countdown, the launcher lifted off at the opening of the launch window. The injection into the geostationary transfer orbit was extremely precise: the orbit was within 4 km of the targeted apogee of 35 894 km.

As scheduled, on the fourth apogee 36 hours after lift-off, the apogee boost motor was fired and yielded an increase in velocity of 1521 m/s compared to the predicted 1523 m/s, confirming once again the good performance of the solid propellant motor. The motor burned for 30 seconds and was ejected within six minutes, in accordance with the flight plan.

ESA's space operations centre, ESOC, in Darmstadt, Germany, took control of the spacecraft immediately after separation from the Ariane third stage, and started the commissioning activities shortly after the apogee boost motor had placed the spacecraft into geostationary orbit.

The commissioning found all subsystems working according to specifications with the exception of the radiometer. The radiometer is a special telescope that produces images of the Earth in three bands, visible, infrared and water vapour. It was found that the grey levels for the infrared and water-vapour channels were intermittently showing a variation of around 8%. This anomaly is currently under investigation.

The very-precise orbit injection achieved saved much on-board fuel and will allow orbital station-keeping for seven years (until March 2001), two years more that the design goal of five years.

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An Unsuccessful Ariane Launch ...

After seven launches in 1993, all of which were successful, the first Ariane launch of 1994 has failed.

Flight V63, using a 44 LP launcher, lifted off on 24 January from ESA's launch site in Kourou, French Guiana. After a nominal take-off and a normal performance of the first and second stages, the third stage engine shut down prematurely. Telemetry data showed that an abnormal heating of the engine's liquid oxygen pump bearing about 52 seconds after it started to operate, caused the engine to stop immediately.

This interruption subsequently led to the loss of the launcher and its two-satellite payload: Eutelsat 2-F5 for the European Telecommunications Satellite (Eutelsat) Organisation of Paris, and Turksat 2 for the Turkish telecommunications agency.

A Technical Inquiry Board, appointed by Arianespace, ESA and CNES, has investigated the failure. Although the Board could not establish a proven cause for the bearing overheating, it appears that the cause is 'a cooling defect resulting from the delayed pre-cooling (the cause of which has not yet been determined) combined with possible aggravating factors ... and high axial force'. In addition, 'the possible unsymmetrical thermal distribution along the pump's shaft might have impaired its sliding in its grooves, which could have drastically increased the axial force on the bearing'.

The Board has also made 15 recommendations, which are intended to reduce the risk of such an event re-occurring, and which should make the bearing less sensitive to changes in its operating conditions.

Arianespace is already implementing two of the recommended corrective actions and expects the changes to be qualified in May. The company plans to then resume launches at the end of May.

1. Integration of Meteosat-6 into the launcher

2. The Ariane launcher on the launch pad, carrying the Mexican Solaridad satellite (at the top, with blue circle) and Meteosat-6 below it (with blue rectangle)

.... A Successful Ariane Launch

The last Ariane launch of 1993 was successfully executed on the night between 17 and 18 December (at 02:27 CET).

Using the Ariane 44 L launch vehicle, Flight V62 placed two satellites in geostationary transfer orbit: DBS-1 (previously named DirecTV), the first commercial American direct broadcasting satellite, for Hughes Communications of the U.S.; and THAICOM 1, the first Thai telecommunications satellite, for the Shinawatra Satellite Corporation Ltd. of Thailand.

Ariane V62 lifts off from ESA's launch site in Kourou, French Guiana

ESA Astronaut, Claude Nicollier, who operated the remote arm during the HST Servicing Mission, explains the manoeuvres required, at a press conference at ESA Headquarters in Paris

Crew of First HST Servicing Mission Visit ESA Establishments

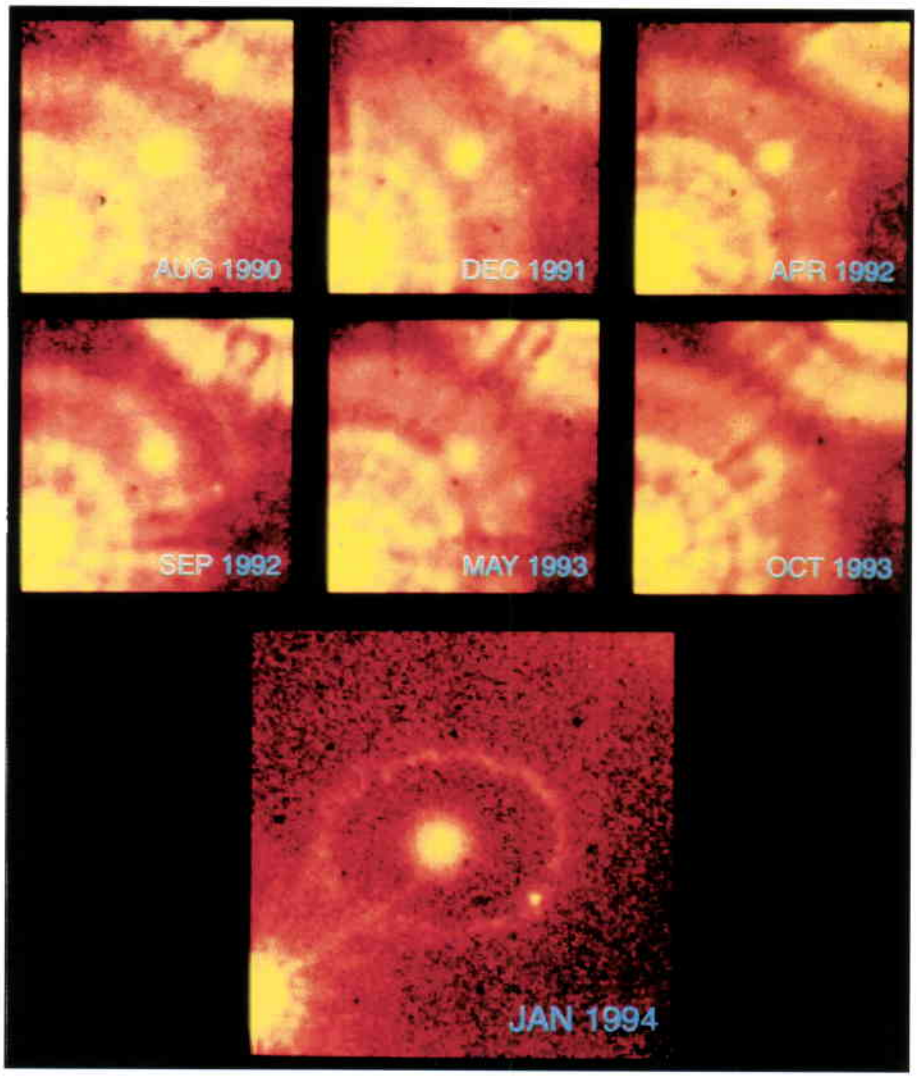
The crew of the First Hubble Space Telescope (HST) Servicing Mission visited two ESA establishments, ESA Headquarters in Paris and ESTEC in The Netherlands, in February as part of their tour of Europe to share their experience with the European space community and the press. The seven-member crew included ESA Astronaut Claude Nicollier who operated the remote arm during the Space Shuttle's rendezvous and docking with the Telescope and during the astronauts' five 'space walks'.

ESA provided the new solar arrays for the Servicing Mission. It also originally provided the Faint Object Camera for the Telescope.

During their visit, the astronauts participated in a press conference with the French press while at ESA Headquarters, and later while at ESTEC, with the Dutch and Belgian press. They also spoke to ESA staff about their Mission.

The Director of ESTEC, Marius Le Fèvre, introduces the crew of the First HST Servicing Mission to the press. From left to right Story Musgrave (payload commander); Tom Akers, Kathy Thornton, Jeffrey Hoffman and Claude Nicollier (mission specialists); Richard Covey (mission commander) and Ken Bowersox (pilot)

HST Provides Clearest View Yet of Supernova



This series of images of Supernova 1987A was taken with ESA's Faint Object Camera (FOC) aboard the Hubble Space Telescope, before (the top six images) and after (Jan 1994) the HST Servicing Mission.

They demonstrate the dramatic improvement in the HST's capabilities following the installation of the Corrective Optics Space Telescope Axial Replacement (COSTAR), which compensates for spherical aberration in HST's primary mirror. The new picture provides the most detailed, close-up view ever obtained of the supernova, its circumstellar ring and the surroundings.

Since this supernova first appeared in the southern sky in 1987, the outer envelope of the exploding star has been expanding into space at many kilometres per second. To follow the evolution of the ejecta, astronomers have observed SN1987A with the FOC six times, from just after the launch of HST in 1990 to just before the First Servicing Mission in December 1993.

The top six images were taken in ultraviolet light, which reveals the faint but fastest moving outer parts of the envelope. The last of these six images, taken in October 1993, shows that the supernova was barely visible, superposed on the spherical aberration halo of a nearby companion star.

The detailed images that are now possible with the COSTAR-corrected FOC will allow SN1987A to be closely monitored for years to come.

ESA Signs Cooperation Agreement with Poland

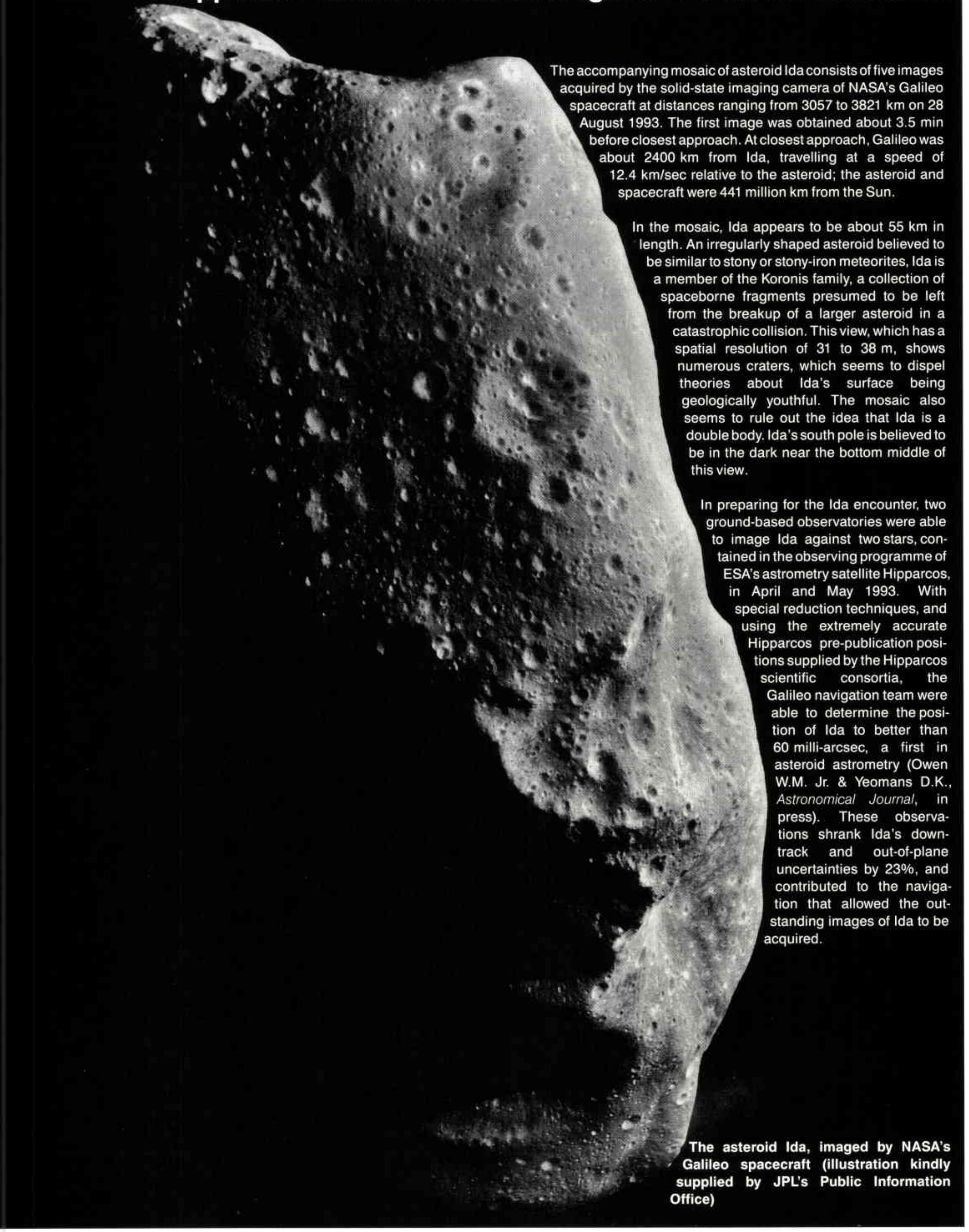
On 28 January, ESA and the Republic of Poland signed an agreement at ESA Headquarters in Paris, covering cooperation on the exploration and use of outer space for peaceful purposes.

The agreement is an expression of ESA's political will to cooperate with the countries of Central and Eastern Europe, as was reaffirmed at the ESA Council meeting at ministerial level in Granada, Spain, in November 1992. It encourages regular exchanges of information with Polish scientists, mutual access to databases and laboratories, awarding of fellowships, joint symposia, and studies on joint projects in fields of mutual interest.

This is the third such agreement that ESA has concluded with a Central or Eastern European country. The first one was signed with Hungary in 1991 and the second one with Romania in 1992.

J. Lukaszewski, Ambassador of Poland to France (left), and J.-M. Luton, Director General of ESA (right), sign the cooperation agreement between ESA and Poland, at ESA Headquarters in Paris

Hipparcos Assists Galileo's Navigation for the Ida Encounter



The accompanying mosaic of asteroid Ida consists of five images acquired by the solid-state imaging camera of NASA's Galileo spacecraft at distances ranging from 3057 to 3821 km on 28 August 1993. The first image was obtained about 3.5 min before closest approach. At closest approach, Galileo was about 2400 km from Ida, travelling at a speed of 12.4 km/sec relative to the asteroid; the asteroid and spacecraft were 441 million km from the Sun.

In the mosaic, Ida appears to be about 55 km in length. An irregularly shaped asteroid believed to be similar to stony or stony-iron meteorites, Ida is a member of the Koronis family, a collection of spaceborne fragments presumed to be left from the breakup of a larger asteroid in a catastrophic collision. This view, which has a spatial resolution of 31 to 38 m, shows numerous craters, which seems to dispel theories about Ida's surface being geologically youthful. The mosaic also seems to rule out the idea that Ida is a double body. Ida's south pole is believed to be in the dark near the bottom middle of this view.

In preparing for the Ida encounter, two ground-based observatories were able to image Ida against two stars, contained in the observing programme of ESA's astrometry satellite Hipparcos, in April and May 1993. With special reduction techniques, and using the extremely accurate Hipparcos pre-publication positions supplied by the Hipparcos scientific consortia, the Galileo navigation team were able to determine the position of Ida to better than 60 milli-arcsec, a first in asteroid astrometry (Owen W.M. Jr. & Yeomans D.K., *Astronomical Journal*, in press). These observations shrank Ida's down-track and out-of-plane uncertainties by 23%, and contributed to the navigation that allowed the outstanding images of Ida to be acquired.

The asteroid Ida, imaged by NASA's Galileo spacecraft (illustration kindly supplied by JPL's Public Information Office)

SECOND ANNOUNCEMENT

Workshop on Space Launch Systems

COST, RISK REDUCTION AND ECONOMICS

Organised by the
European Space Report and TransCostSystems (Dr. Koelle)

Munich, Germany, 16 – 17 June 1994

Lectures will include:

- Risk assessment
- Cost of introducing new technologies into space programmes
- Launch insurance
- Cost as design criteria
- Cost-efficient ground operations
- Risk reduction of future launch vehicle design and development
- Cost analysis of future launch systems
- New development strategies
- Assessment of future US launch requirements and missions

Location and Accommodation

Munich Penta Hotel, Hochstrasse 3, 81669 Munich, Germany. Tel: (+49 89) 480-30

The organisers have made a block booking of rooms at the Penta Hotel at a special rate of 198.- DM (approximately $118) per night for a single room, and 298.- DM (approximately $178) for a double room; includes tax and breakfast.

The hotel is located on the main subway line and can be reached directly from the airport within 40 minutes and from the main train station within 15 minutes.

Deadline for Abstracts is Monday 5 April 1994

For more information on the Space Launch Systems Workshop, complete and fax the attached form. Please print clearly:

First name .... Family Name ....

Position .... Company ....

Address ....

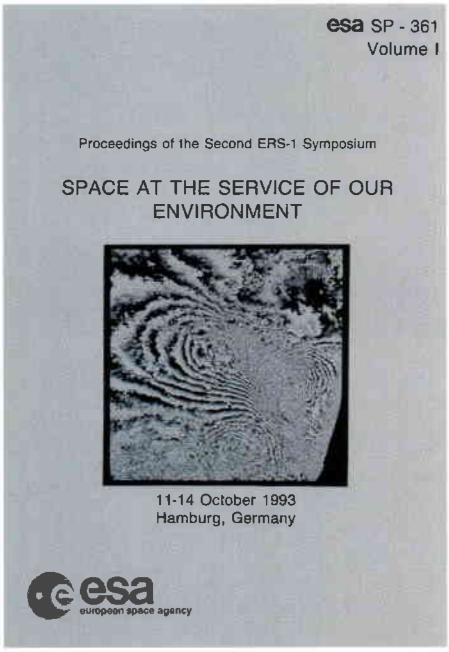
City/Country ....

Telephone No. .... Fax: ....

Contact Person: Sierra Edmonds, European Space Report, P.O. Box 140 280, 80452 Munich.
Tel. (+49 89) 834-3051. Fax (+49 89) 834-6061.

Publications

The documents listed here have been issued since the last publications announcement in the ESA Bulletin. Requests for copies should be made in accordance with the table on the second last page of this issue, and using the Order Form on the last page.



ESA Journal

The following papers were published in ESA Journal Vol. 17, No. 3:

INTEGRAL — THE INTERNATIONAL GAMMA-RAY ASTROPHYSICS LABORATORY
C. WINKLER ET AL.

MARSNET — A NETWORK OF STATIONS ON THE SURFACE OF MARS
A. CHICARRO ET AL.

PRISMA — THE FIRST SPACE MISSION TO SEE INSIDE THE STARS
T. APPOURCHAUX ET AL.

STEP — A SATELLITE TEST OF THE EQUIVALENCE PRINCIPLE
R. REINHARD ET AL.

The following papers were published in ESA Journal Vol. 17, No. 4:

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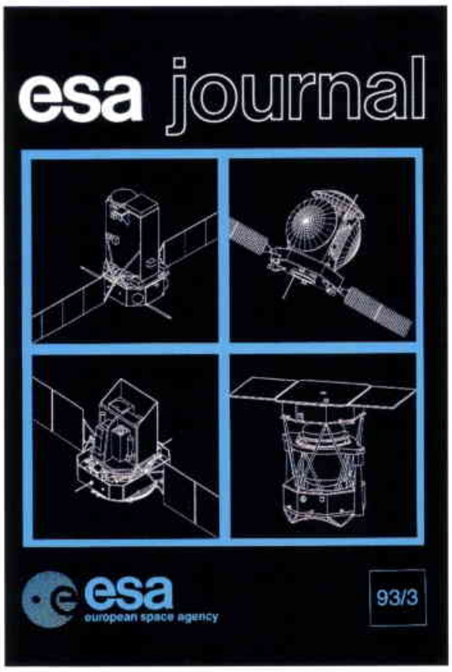

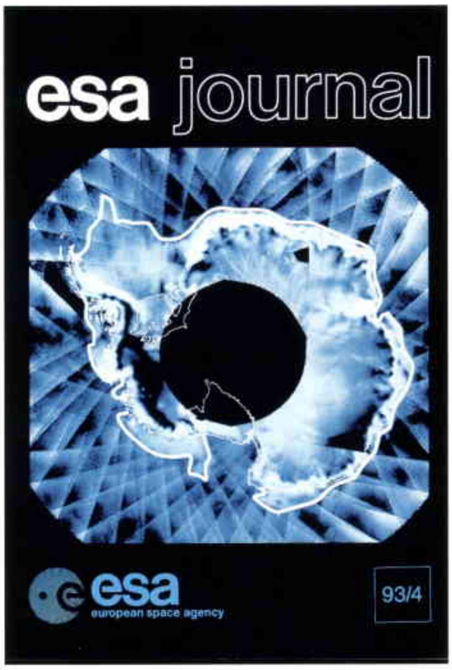

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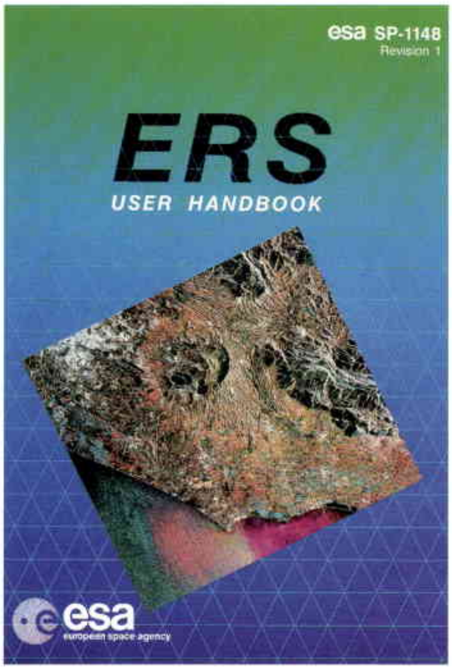

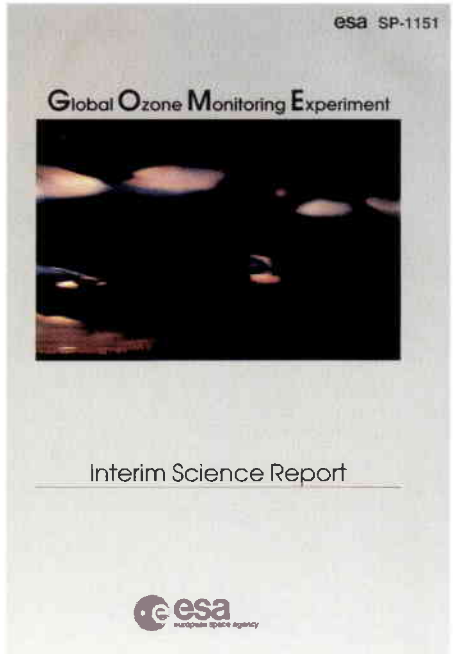

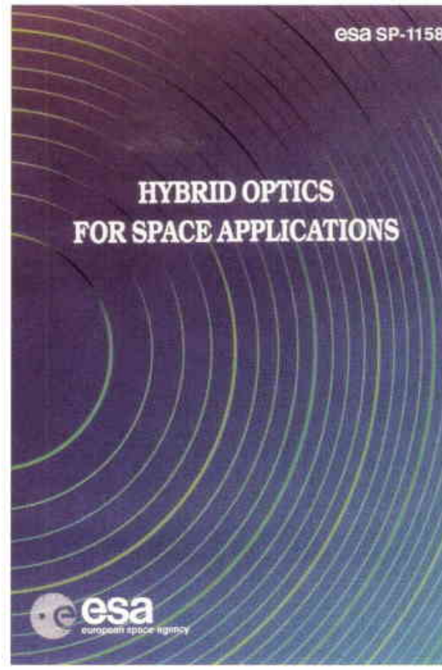

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