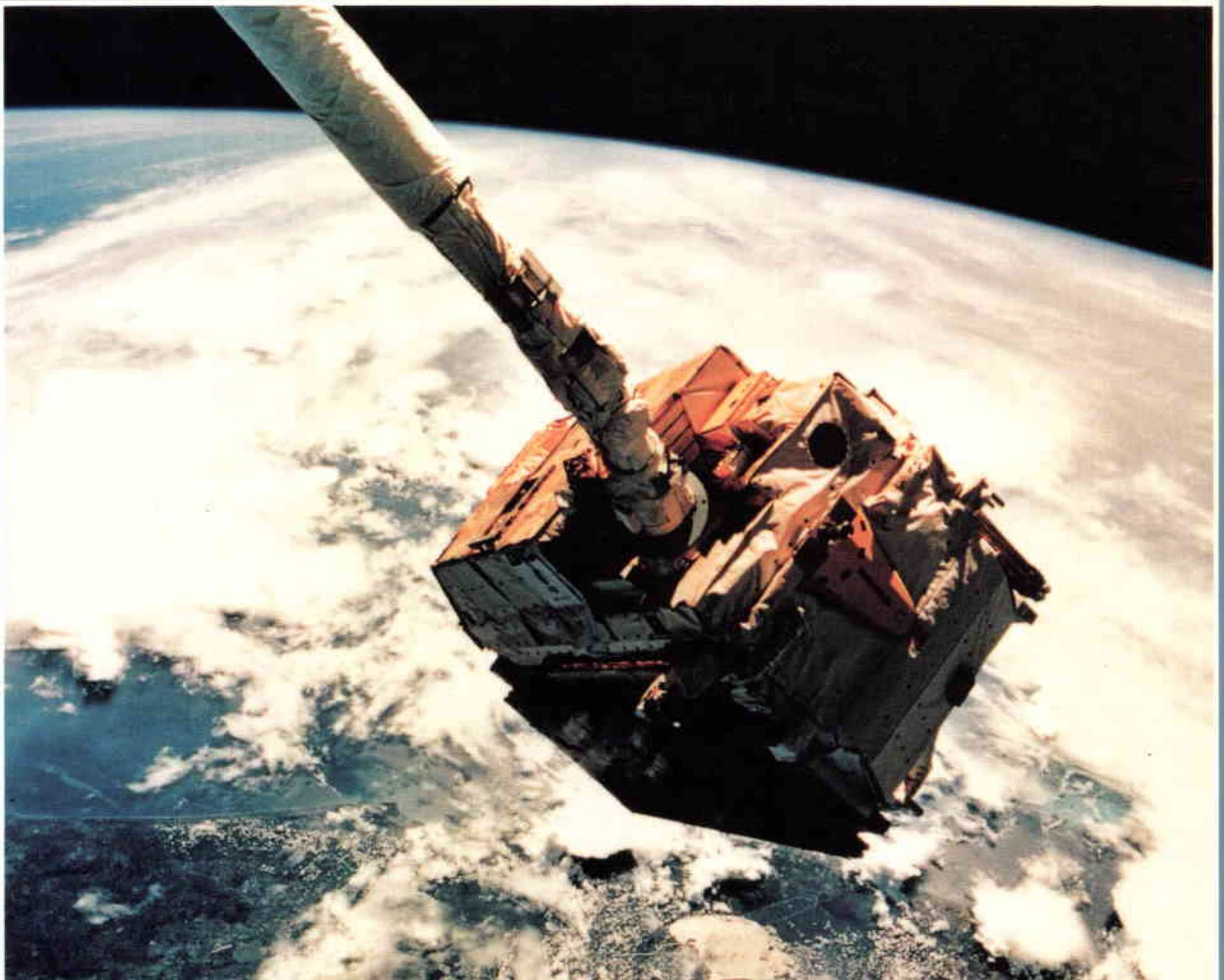
european space agency

esa bulletin

agence spatiale européenne



number 75

august 1993

european space agency

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

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

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agence spatiale européenne

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

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esa bulletin

no. 75 august 1993

contents/sommaire

Cover: Recovery of the 'Eureca' Retrievable Carrier; see page 108

Editorial/Circulation Office

ESA Publications Division
PO Box 299, Noordwijk
2200 AG The Netherlands

Publication Manager
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Bruce Battrick
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Layout
Carel Haakman

Graphics
Willem Versteeg

Montage
Keith Briddon
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Advertising
Brigitte Kaldeich

Printed in The Netherlands
ISSN 0376-4265

european space agency
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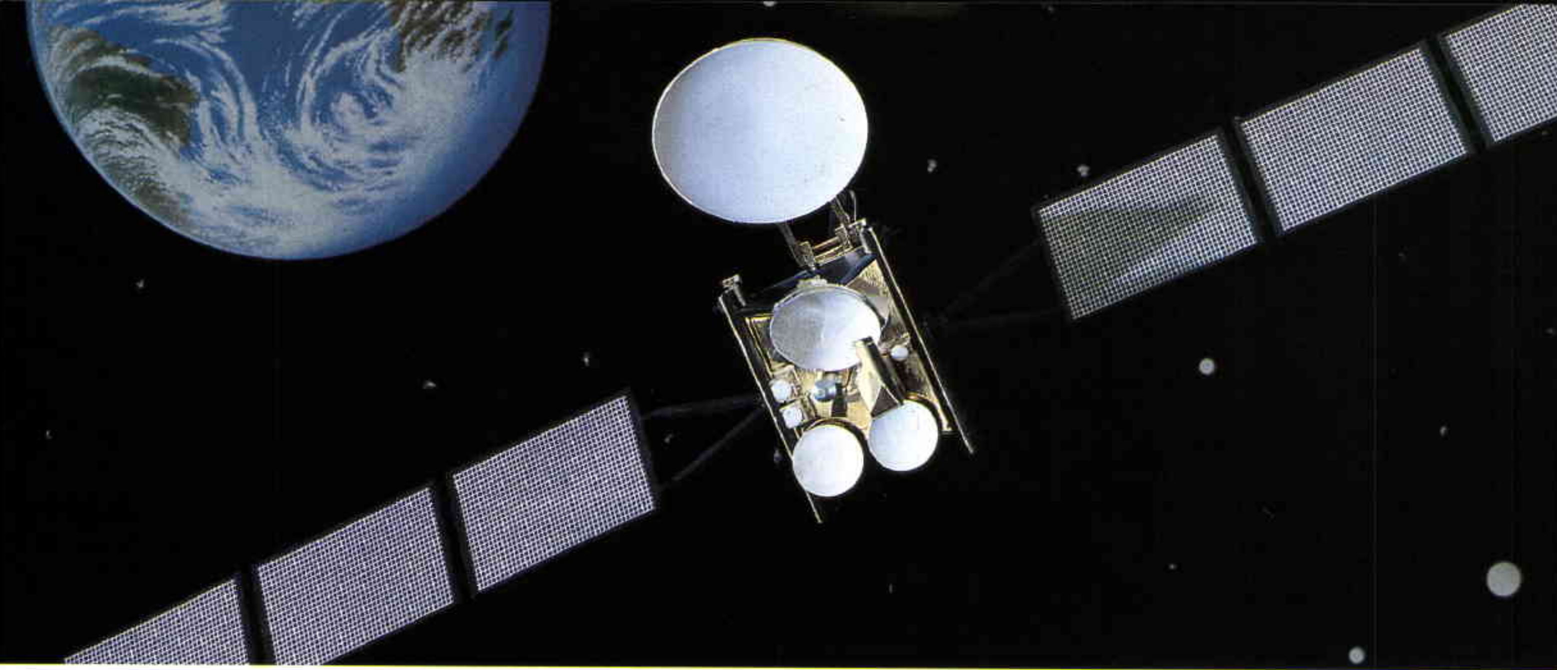


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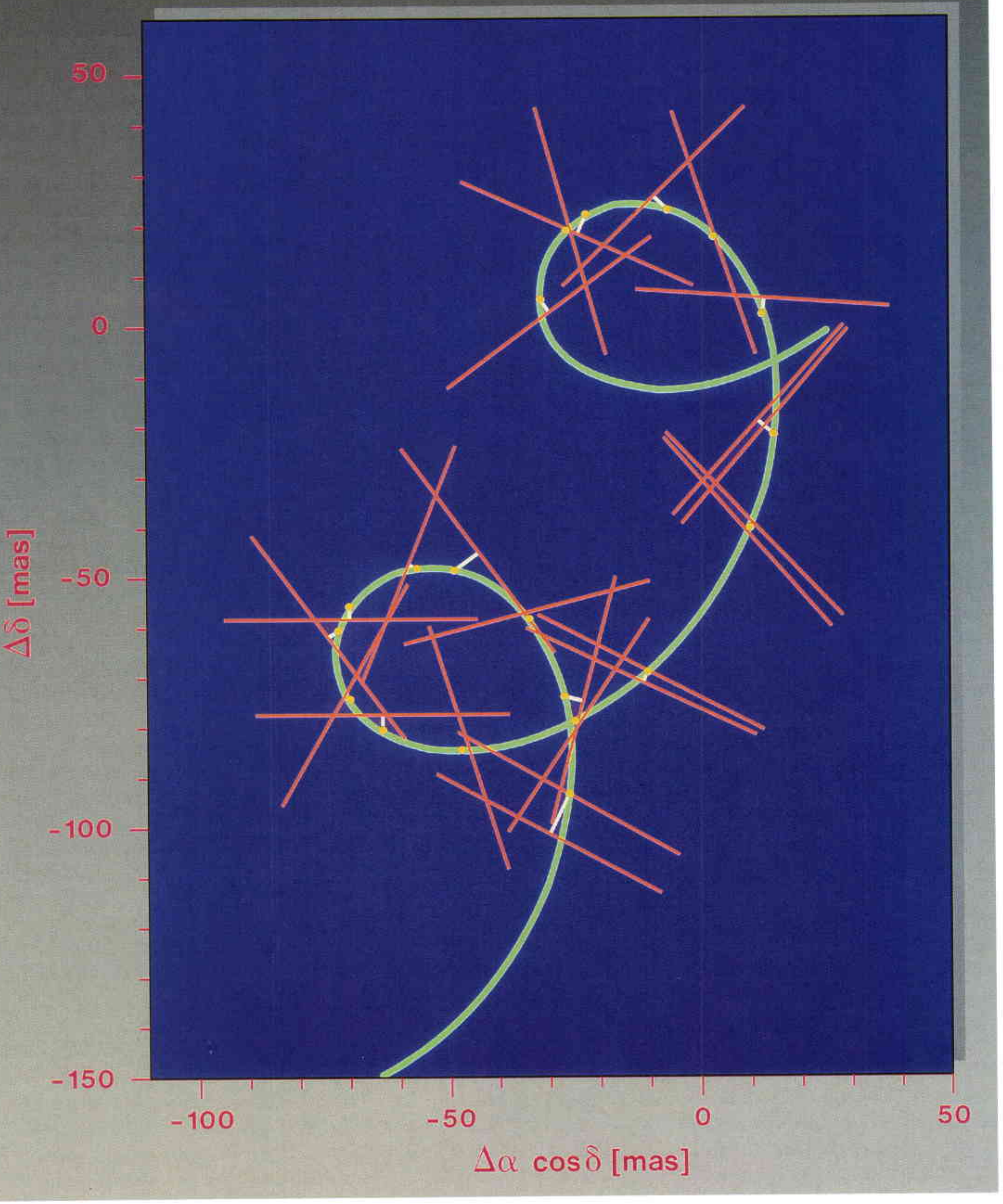
The motion across the sky of one of the 120 000 stars observed by the Hipparcos satellite during the first 19 monthsof the mission. The individual satellite measurements place the star somewhere along each of the long straight lines (in red) at a given time. The least-squares solution implies that the true motion of the star is then well-represented by the solid (green) curve, which shows the reconstructed combination of the linear proper motion and a sinusoidal parallax motion as the Earth moves in its orbit around the Sun. The latter reveals that the star's distance is 27.5 parsec, or 825 million million kilometres, or 5 million times further away than our own Sun (with an uncertainty of less than 4%). At this distance, and with the measured angular motion of about 8 arcsec per century, the star is moving at more than 300 million km per year, or just over 10 km/sec. This star is some 50 times fainter than the faintest star visible to the naked eye. The Hipparcos observations indicate a surface temperature of about 5000 K, and an intrinsic luminosity about a factor of 5 smaller than that of our own Sun (Courtesy of the Hipparcos NDAC Consortium, leader L. Lindegren)



The Hipparcos Mission – Four Years After Launch

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For Hipparcos, launched in August 1989, one setback – the failure of the apogee boost motor – threatened to obliterate the years of thorough scientific and technical preparations leading up to the launch. Now, following the redesign of the mission operations in 1989, and a continuous determination to maintain the flow of high-quality scientific observations, ESA's astrometry satellite has completely fulfilled its original mission objectives, and is close to reaching its fourth year in orbit. The vast on-ground data analysis effort, a collaboration of European scientists from some 30 institutes, is proceeding well and is providing information that is set to give a remarkable new perspective to our understanding of the structure, composition, and evolution of our Galaxy.

Introduction

Much of what we know about our Galaxy, and the Universe of which it is an all but insignificant part, is based upon the electromagnetic radiation (light, radio waves, X-rays, etc.) that reaches us from space. The last few decades have seen enormous advances in the quality, quantity and range of astronomical data that have been acquired. There has been, correspondingly, tremendous progress in theories that attempt to place these observations into some kind of natural order and which, at the same time, allow predictions about the nature of the Universe to be made.

It can now be guaranteed that the Hipparcos results will play an important role in the continuing development of scientific understanding of our Galaxy over the next few decades. This first space mission dedicated to the measurement of highly accurate stellar positions will provide distance estimates of 120 000 stars in the solar neighbourhood, and measurements of the velocity with which these stars are moving in their orbits through the Galaxy. The final results from Hipparcos (1–2 milli-arcsec in the positions, parallaxes and annual proper motions) will be at least as good as those targetted throughout the development programme, despite the unintended elliptical orbit in which the satellite was destined to carry out its measurements. In addition, the Tycho experiment, making use of the onboard star mappers, will yield a positional catalogue of more than a million stars.

Extending the mission operations

An intermediate report on the progress of the Hipparcos programme was made in ESA Bulletin No. 69, where some preliminary results of the first year of data processing were also included. By extrapolating these results, obtained by the NDAC and FAST data-analysis teams*, it was predicted that the original target mission accuracies would have been achieved with a data collection extending until mid- to end-1992.

With satellite resources (electrical power and attitude-control gas) likely to support mission operations until around mid-1994, the Hipparcos Science Team therefore submitted a proposal to the scientific advisory groups of ESA to extend the operations beyond the end-1992 date for which funding had already been approved, until the end of the satellite's useful scientific lifetime. This detailed proposal, setting out the scientific merit of an 18-month extension to the original three-year mission, was endorsed by ESA's Astronomy Working Group and Space Science Advisory Committee, and was thereafter approved by the ESA Science Programme Committee at its meeting in June 1992.

The Hipparcos Science Team had already made a careful evaluation of all the options available to it, including changing the observing programme, or attempting to place the satellite in 'hibernation' for a certain period of time, specifically in order to enhance the proper-motion estimates of

* NDAC = Northern Data-Analysis Consortium
FAST = Fundamental Astronomy by Space Techniques Consortium

the programme stars. Given the delicacy of the satellite's operations in its elliptical orbit, the hibernation option was not recommended, and neither was a change in the observing programme; it was considered more appropriate to continue improving the astrometric parameters of the 120 000 carefully selected programme stars by means of the mission extension.

By extending the measurement period, the positions and parallaxes (i.e. distance measurements) continue to improve, essentially by the square root of the overall observing time, while the proper motions improve by a further factor of the overall measurement duration. Photometric monitoring of each programme star, estimates of the double-star parameters, and observations of the minor planets, also benefit significantly from the extended measurement period, as does the general reliability of the global solution as a whole.

Satellite observations throughout 1992

Satellite operations continued smoothly until early August 1992. Figure 1 illustrates the continuity and efficiency of the data collection between the start of the scientific observations in November 1989 and August 1992, when a series of gyroscope anomalies affected the attitude control significantly and the satellite was triggered into its 'safe' Sun-pointing mode. The satellite was spun up to a rather stable configuration at about 0.4 rpm, while a series of investigations into the gyro anomalies, and full preparations for continuing the scientific operations under two-gyro control, were made. Scientific observations were resumed, at the nominal scanning inclination of 43° to the Sun, but using only two gyros, on 29 October 1992.

The 18-month sphere solution

Meanwhile, data analysis proceeded intensively throughout 1992, with both of the main data-analysis teams, NDAC and

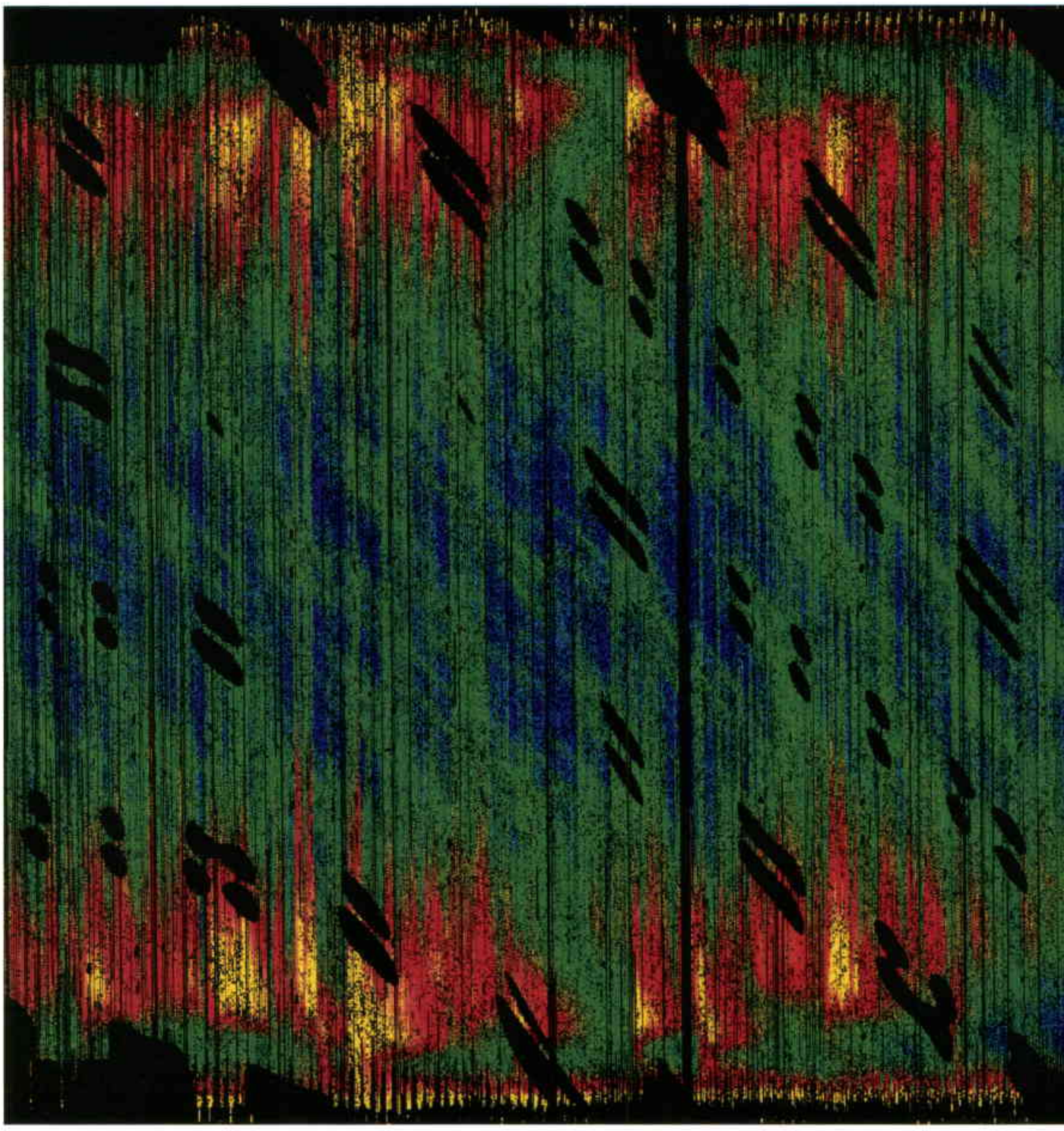


Figure 1. The star-mapper background derived from the first 2.5 years of the mission as part of the analysis by the Northern Data-Analysis Consortium (NDAC). A single 10.6-hour orbit is represented by a vertical line stretching from bottom to top of the figure, with orbits extending from November 1989 (left) to May 1992 (right). The perigee of each orbit lies at the top/bottom of the figure, with the apogee at the centre. The intensity of the background increases from blue (minimum), through green and red, to yellow (maximum). Black represents missing data.

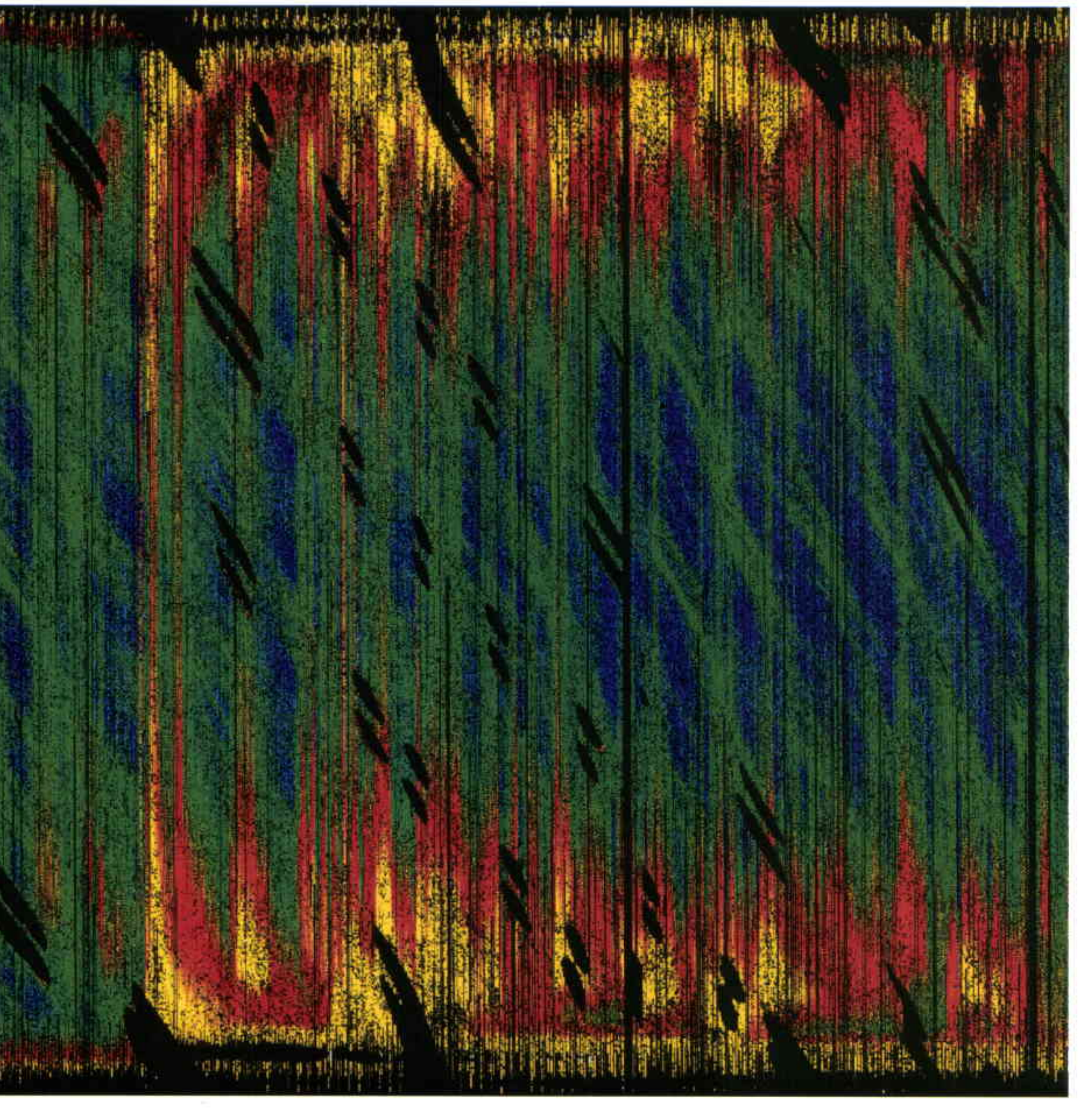
The figure illustrates many features of the mission, including: (a) the outer Van Allen radiation belts (the red/yellow regions near the top and bottom of the figure); (b) Earth occultations (the black elliptical regions, during which the viewing directions are obscured by the Earth); (c) zodiacal light and background originating from the galactic plane (the green stripes extending from top left to bottom right throughout the figure). Other black areas, indicating lost data, arise from the satellite's passages through perigee (top and bottom) or from ground-station outages or other satellite anomalies (vertical black lines) (Courtesy F. van Leeuwen, RGO Cambridge, NDAC Consortium)

FAST, reporting their global sphere solutions based on slightly more than the first 18 months of the mission data. The solutions are of a remarkable quality, with positions and parallaxes considerably improved with respect to the previous 12-month sphere solutions. For the first time, the full solution including the estimation of the two proper-motion components gave a clear improvement compared to the solution involving position and parallax only, i.e. the solution made by keeping the proper motions at their Input Catalogue (ground-based) values.

The data sets resulting from the 18-month 'sphere solution' contain over two million abscissa observations of the 118 000 programme stars observed on more than 1200 great circles. More than 80 000 stars were accepted as 'primary' stars (generally single stars that are well-behaved in the global solution), with an additional 20 000 'passive' stars, i.e. adjusted but not contributing to the definition of the positional system. In the end, data for more than 100 000 stars were retained in the 18-month sphere solution. Half of the resulting parallaxes have a formal error of better than 2 milli-arcsec, while 90% are better than 3 milli-arcsec. Examination of the distributions indicates that the formal errors agree quite well with the external (or 'true') errors, at least when they are less than 3 milli-arcsec.

The rms proper-motion update for the 18-month solution is about 11 milli-arcsec per year, both in right ascension and declination. 50% of the proper motions have formal standard errors in each component of better than 4 milli-arcsec per year, while 90% are better than 6 milli-arcsec per year. Again, these accuracies will continue to improve as more data are progressively combined into the global solution.

In parallel with the analysis of the main



mission data, the complex data processing that will eventually lead to the Tycho Catalogue, using data derived from the star mappers, also proceeded well. The production of the Revised Tycho Input Catalogue within the Tycho Data Analysis Consortium (TDAC) was completed – this contains just over 1 million stars with positions already better than 0.1 arcsec.

Some illustrations of the scientific results are shown in Figures 2–7.

Publication of the Hipparcos Input Catalogue

The 7-volume Hipparcos Input Catalogue, published as ESA SP-1136 in March 1992, represented one of the first major products of the mission, albeit comprising data compiled from existing sources, or from recent ground-based observations specially undertaken for the Hipparcos mission preparations. The main catalogue, a compilation of the best-available ground-based data used for the satellite attitude control and for the scientific observing programme, extends to five volumes, with an annex volume devoted to data on double and multiple star systems, and a further volume devoted to 'finding' charts of the fainter stars in the observing programme. The Input Catalogue is also being prepared for publication on CD-ROM.

For each of the main Hipparcos programme stars, this catalogue contains the most accurate and complete compilation of positions, motions, duplicity and variability data, spectral types, and cross-identifications to other astronomical catalogues. Independent analyses of the quality of the Hipparcos Input Catalogue have been undertaken using ground-based photometric data, or data from the preliminary satellite data analysis, and have confirmed the positional and photometric accuracies targetted, so important for the execution of the satellite observations.

Observations without gyroscopes

While the Hipparcos detectors continued to function flawlessly after nearly four years in orbit, problems with the gyroscope packages have challenged the creativity of the Hipparcos Project in devising and implementing new operational procedures to allow the scientific measurements to continue. The satellite was originally equipped with five gyros, two sensing rotation around the satellite's spin axis, and three sensing rotation around the axes perpendicular to the spin axis (with a total of two redundant units).

The Hipparcos 'real-time' attitude determination and control actually involves a rather precarious loop: star-mapper transits update the attitude knowledge, which is immediately used to point the main detector to the programme stars (with an accuracy of about 1 arcsec), and also to predict the time of the next star-mapper transit. It is the noise and time-dependent calibration terms (drift and scale factor) of the gyroscopes that make star-mapper updates necessary, and these have to be made typically every 10–20 s. If gyros were 'perfect', one initialisation would thereafter allow the instantaneous attitude

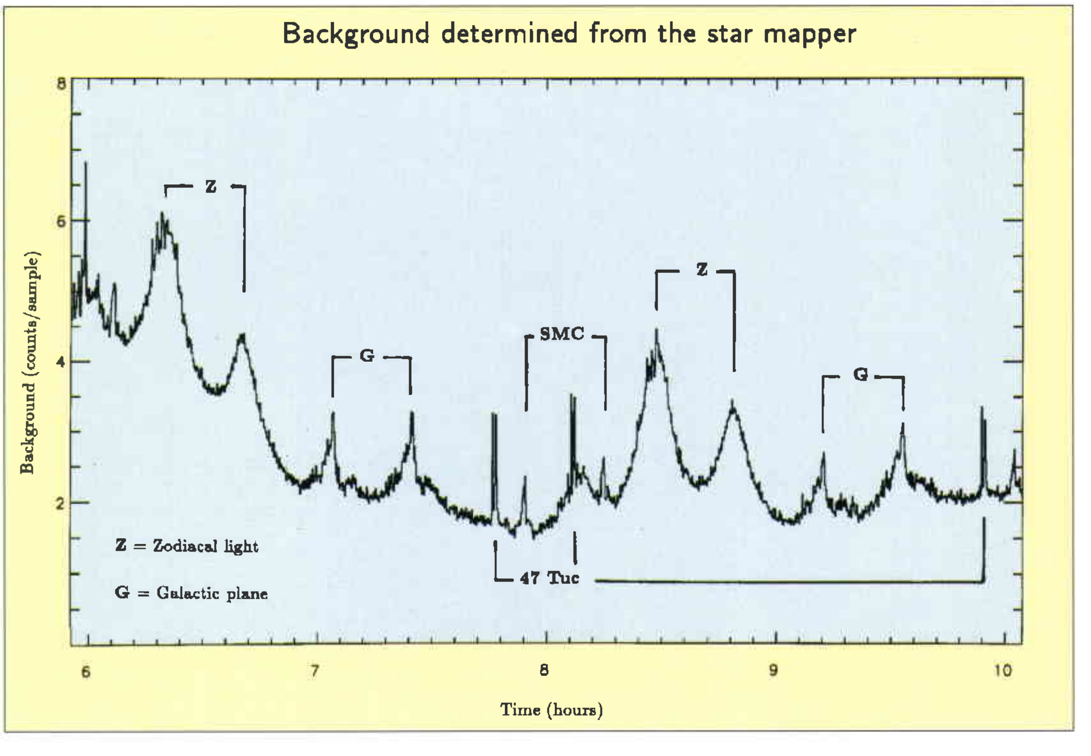


Figure 2. Star-mapper background for part of a single orbit, showing the main contributions from zodiacal light and galactic plane from both viewing directions. In this data interval, enhanced background originating from the Small Magellanic Cloud (SMC), and from the globular cluster 47 Tucanae, is also evident (Courtesy A. Wicenec, AIT Tübingen, TDAC Consortium)

knowledge to be maintained, irrespective of the external or internal perturbing torques acting on the satellite, or the gas-jet firings made to control the satellite's orientation and spin rates.

In practice, the star-mapper transits update the knowledge of both the satellite attitude and the gyro calibrations. In between the updates, the satellite's viewing directions, at a spin rate of 168 arcsec/s, have moved by some 2000–3000 arcsec, and the gyros are used to interpolate the attitude to the accuracy level required to pilot the main detector.

After the first gyro failure, rather early in the mission (in June 1990), preparations were made for a two-gyro operational solution. The solution, not at all obvious at the beginning of the studies, and which had to be implemented onboard in order to allow the real-time pointing requirements to be met (but with considerable ground-segment

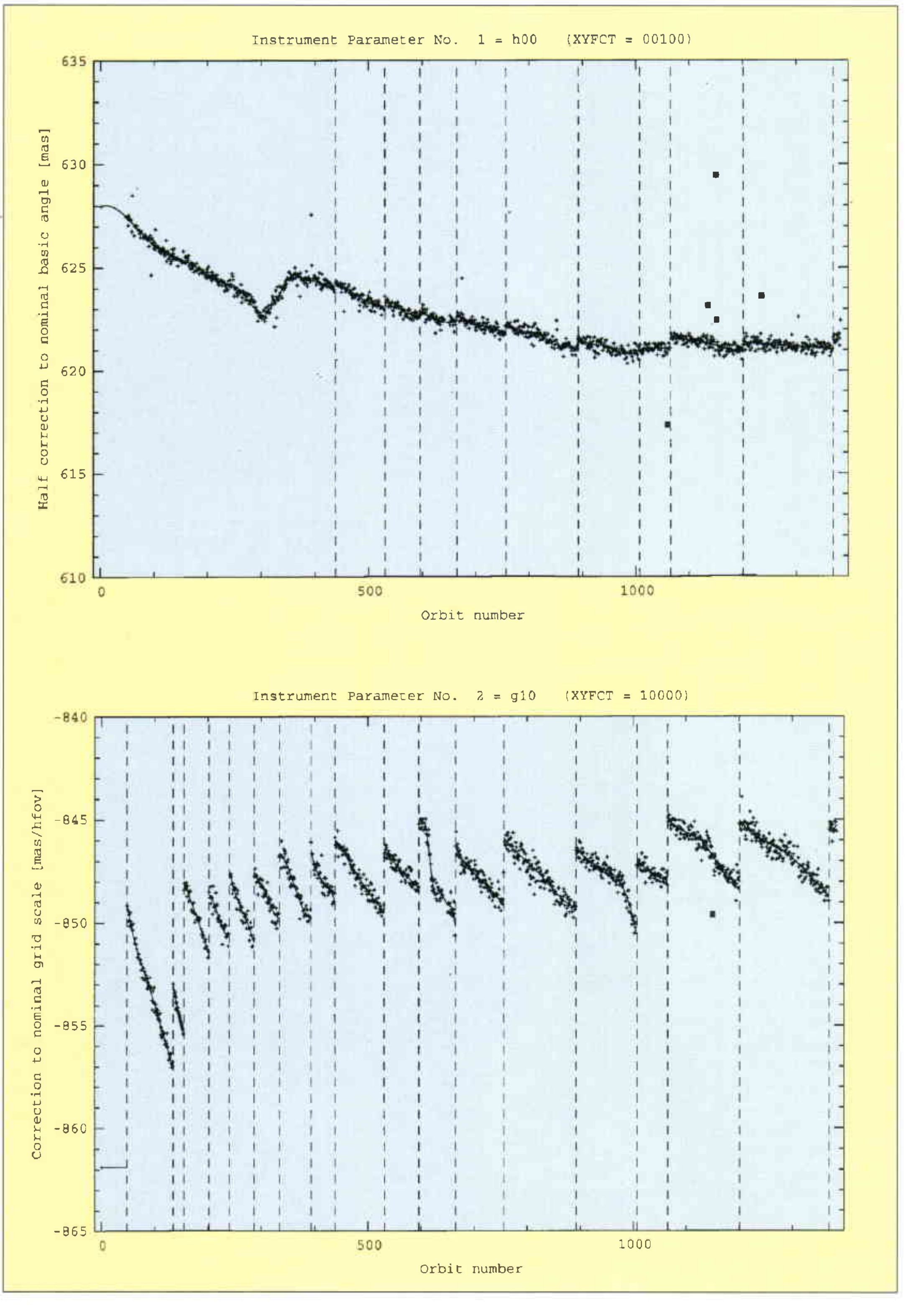


Figure 3. Geometrical terms in the great-circle reduction derived from the great-circle processing, for data from the first two years of satellite observations. The top figure illustrates the evolution of the 'basic angle' (the angle between the two viewing directions), while the lower figure illustrates the evolution of the grid scale. Each cross represents a value derived from the reduction of data from one satellite orbit, and the vertical dashed lines in the lower figure indicate when refocusing of the payload occurred. The payload evolution can be followed very precisely by means of the data analysis, and has allowed a physical model of these geometrical changes to be established (Courtesy C. Petersen, Copenhagen Observatory, NDAC Consortium)

support necessary!), differs fundamentally from the two-gyro operational procedures for the IUE spacecraft, where orientation information from the Sun aspect sensor is used. In the case of Hipparcos, in between the star-mapper updates, an onboard model of the predicted perturbing torques allows the along-scan attitude to be estimated in real time. Implementation has involved a careful calibration of the solar radiation pressure (the dominant external perturbation acting at apogee), as well as calibration of the internal gyro torques and thruster impulse torques, these being supplied and updated by the scientific consortia as an extension of their data-processing activities. The situation becomes more complex towards perigee, as gravity gradient, magnetic moment and eventually aerodynamic drag effects become significant.

The two-gyro control solution was eventually implemented in November 1992 following the third gyro failure (which left only two transverse gyros, and no spin-axis gyro, functioning). The two-gyro mode ran successfully, with no significant degradation in the resulting payload data quality, until mid-March 1993, when the fourth gyro ceased to function.

The satellite remained in 'hibernation' in Sun-pointing mode until 12 June, when a complete zero-gyro operational solution was finalised (a single gyro adding little to the possibility of attitude control). The problems to be surmounted were considerable, not only in the apogee operations (where the approach may be viewed as an extension to the two-gyro control), but more critically during perigee passages, and especially when eclipses occur at perigee. The complications were compounded by the solar-array degradation, making full payload operation impossible while the satellite is Sun-pointing, and exacerbated by long eclipses extending until mid-May.

Unfortunately, on payload re-activation after this hibernation phase, two of the four star-mapper detectors were found to be inoperable. Whilst this would not affect the main mission science, further ground software modifications had to be implemented in order to allow observations to continue. At the present time (mid-June), the possibility of continuing operations for several more months, without gyros, appears to be feasible, but by no means guaranteed.

It is appropriate to stress that the gyro packages employed in the Hipparcos satellite have had an excellent flight record. Ongoing investigations suggest that the factor-of-five enhancement in the radiation fluence in the non-intended elliptical transfer orbit may be responsible for their failure. In other words, if Hipparcos had been in its intended geostationary orbit, the failures may well not have occurred!

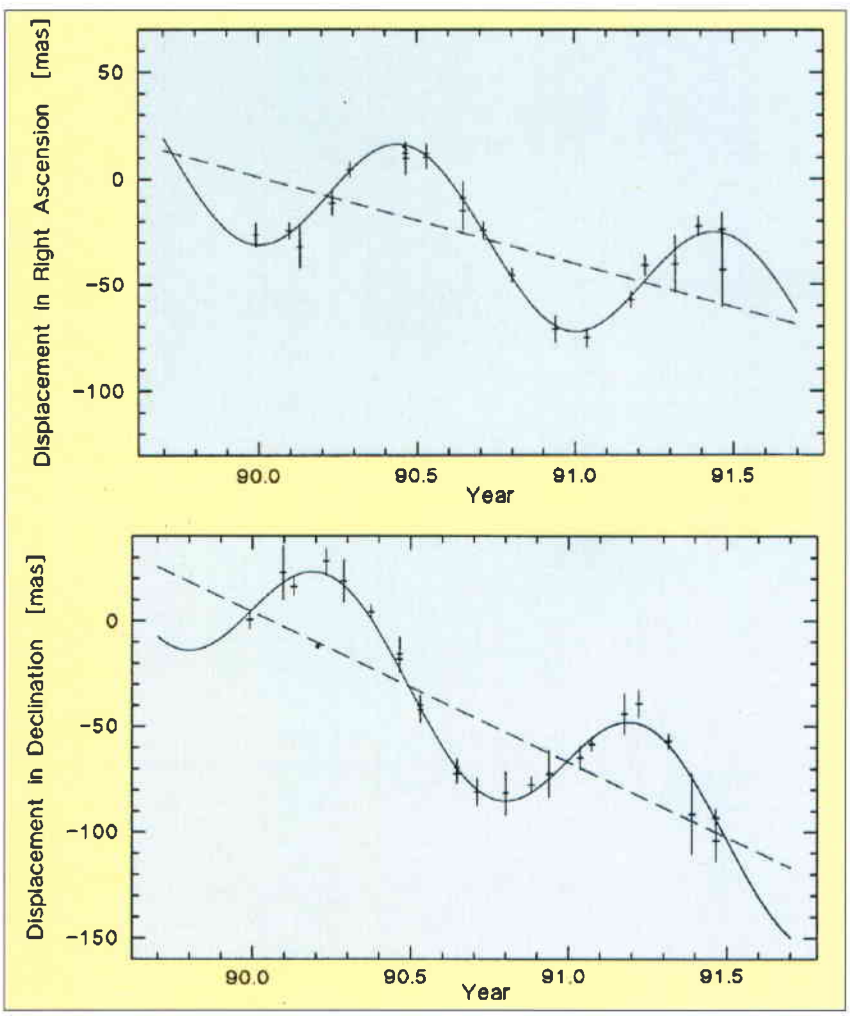


Figure 4. The principle of the sphere solution. After many observations on many reference great circles obtained throughout the mission, a star's proper motion and parallax is derived from the residuals of the one-dimensional great-circle measurements. The proper motion is revealed as a linear displacement of the star position with time, while the parallax is seen as a sinusoidal variation of the displacement with a period of one year (i.e. the orbital period of the Earth around the Sun). The parallax is larger the nearer the star is to our Sun. This star was observed in 24 reference great circles during the 19.5 months covered by the plot. The solution gave a proper motion of −41.1±2.7 milli-arcsec per year in right ascension (top), and −71.2±2.5 milli-arcsec per year in declination (bottom), with a parallax of 36.3±1.4 milli-arcsec. The resulting proper motion is in good agreement with the proper motion that had been derived from ground-based observations, although there had been no direct estimate of this star's distance made from the ground
(Courtesy L. Lindegren, Lund, NDAC Consortium)

The future schedule

Attitude-control gas is in principle available for operations, and hence scientific observations, to continue for another few months. With the completion of Hipparcos satellite operations therefore foreseen for the end of 1993 or early 1994 at the latest,

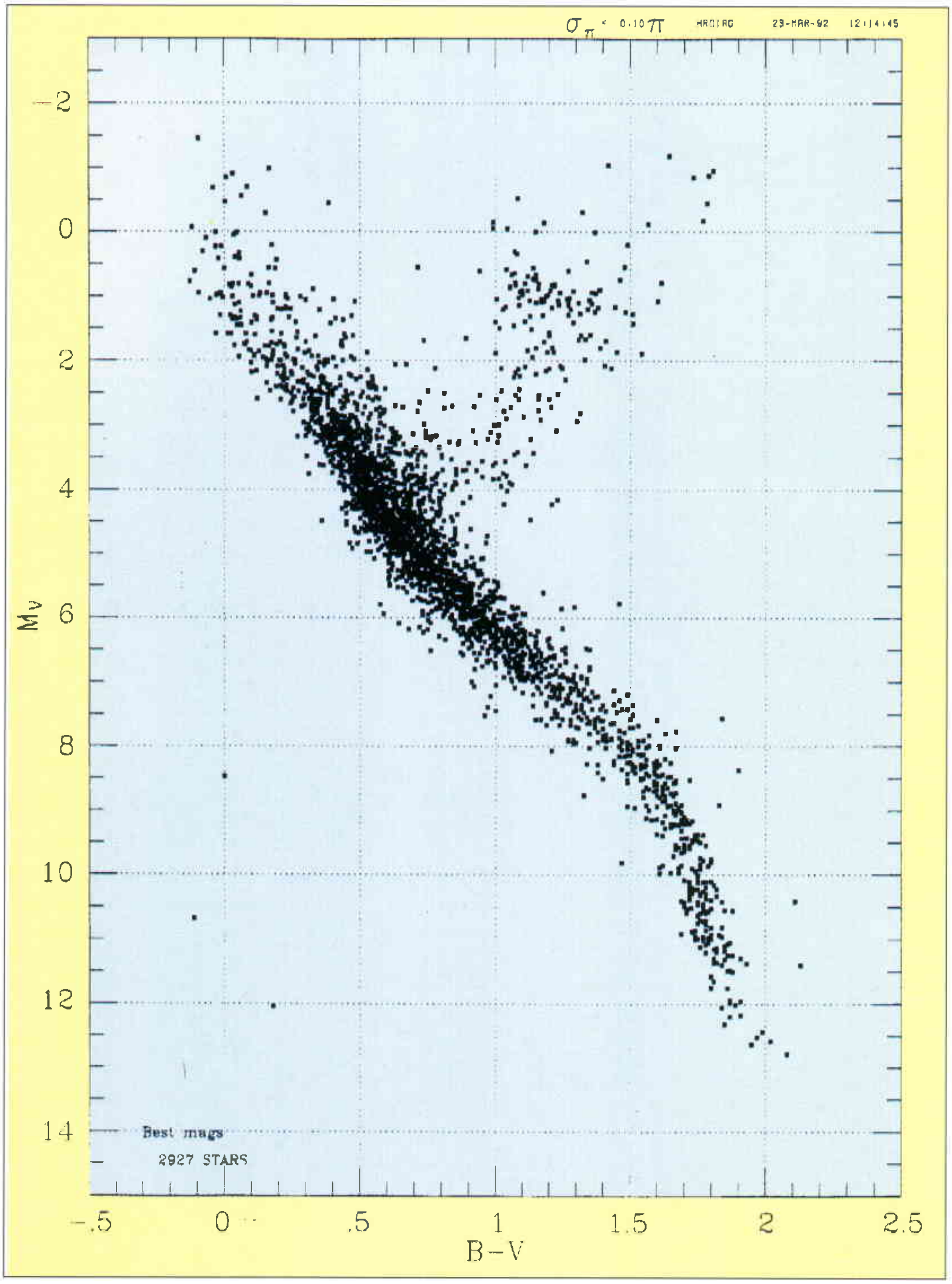
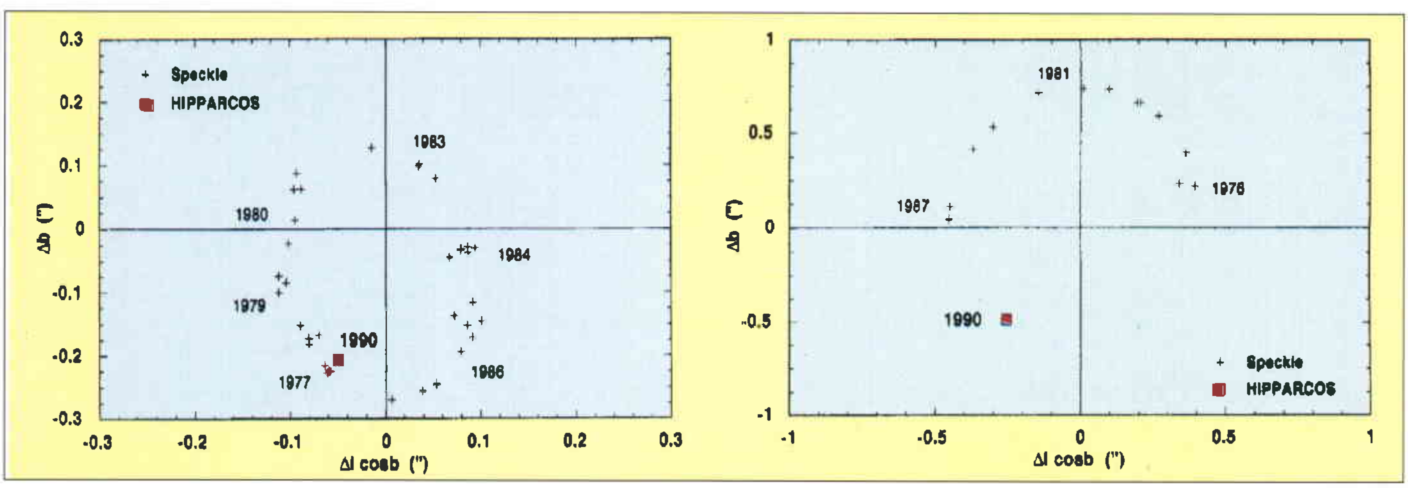


Figure 5. The Hertzsprung-Russell diagram from the first 12 months of the mission. The clustering of the stars in this figure, derived from the parallax and magnitude of each star, illustrates one of the most fundamental stellar relationships known. The dominant strip extending from top left (luminous blue stars) to bottom right (cool red stars) is the stellar main sequence, the region of this diagram where stars spend most of their evolutionary lifetime. Giants occupy the branch extending up to the top right of the figure, while the three objects at the bottom left of the diagram are white-dwarf stars.

The figure is a dramatic indication of the high quality of the Hipparcos parallaxes. The final Hipparcos Hertzsprung-Russell diagram will constitute a most powerful observational constraint on stellar evolutionary theories (Courtesy M.J. Penston, RGO Cambridge, NDAC Consortium)

Figure 6. Two examples of orbital double systems, for which the Hipparcos determination of positional separation at a given epoch (the square box) is in excellent agreement with determinations of the orbital elements made over many years from the ground by speckle interferometry (crosses). (Courtesy F. Mignard, CERGA Grasse, FAST Consortium)



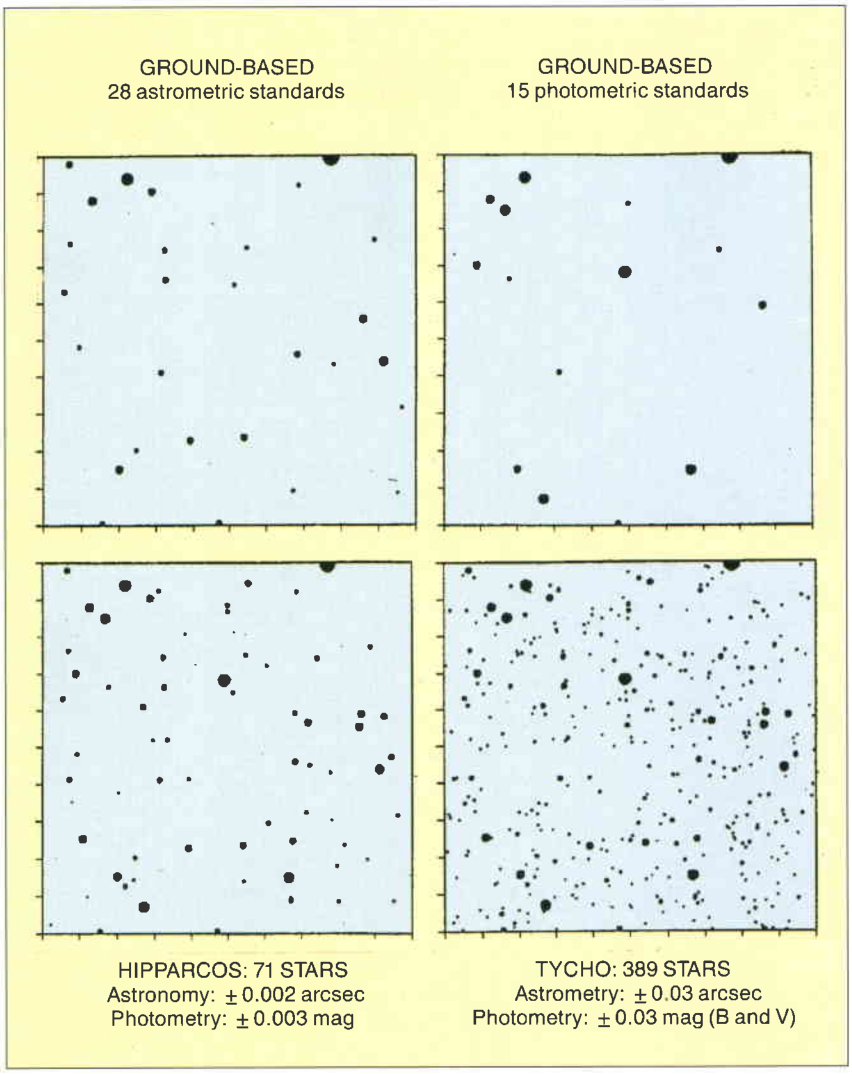


Figure 7. The expected products of the Hipparcos mission. The four figures cover the same 5° x 5° area of the sky in Ursa Major. The figures illustrate the availability of astrometric and photometric reference stars from ground-based observations (top left and top right, respectively), on the basis of the expected Hipparcos data (bottom left), and including the stars catalogued as part of the Tycho programme (bottom right). The numbers of stars with the expected astrometric and photometric accuracy are given in each case (Courtesy E. Høg, Copenhagen Observatory, TDAC Consortium)

the data-reduction teams are targetting the completion of their massive global data-analysis effort for two years after the end of operations, and the data-processing aspects of the Hipparcos project will therefore draw to a close in about three years from now. The Hipparcos Science Team, which advises ESA on all scientific aspects of the mission, is presently devoting some consideration to the question of the format and contents of the final mission products.

The global nature of the reductions means that, in principle, a re-analysis of the raw satellite data should never again be necessary. Given the size and complexity of the analysis, and the fact that the main mission data analysis is being carried out independently and in parallel by two separate scientific teams, any re-analysis is also considered highly unlikely.

More relevant, then, will be the final astrometric and photometric parameters of the two experiments: the data products derived from the main astrometric mission (the Hipparcos Output Catalogue), and the data products derived from the star mapper (the Tycho Catalogue). For the former, the data analysis will yield five astrometric parameters (the two position components, the two proper-motion components, and the parallax) for each of the 120 000 programme stars, an accurate broad-band magnitude at each of the 300 or so epochs of observation, information on the binary or multiple nature of the stars, and errors on these quantities. The summary of the astrometric, photometric and multiplicity data will yield some 50 data items per object. Astrometric errors will comprise 15 elements per object, and multiplicity data will run to some 100–200 parameters per system (including solutions derived on the basis of different assumptions, along with the corresponding error quantities). The photometric database will comprise calibrated magnitudes at each observational epoch, associated formal errors, and values of the background at each epoch.

The Tycho products will be more extensive, with the Tycho Catalogue now expected to contain more than a million stars. Each will yield five astrometric parameters, the corresponding error estimates, and two-colour photometry, again at each of the 300 or more epochs of observation.

Acknowledgements
We are pleased to acknowledge the efforts of the entire ESOC Operations Team, whose expertise, creativity, and dedication has kept the satellite operating efficiently since launch. This team has been ably assisted by many individuals from elsewhere in ESOC, in ESTEC, and from within Matra Marconi Space, the satellite prime contractor. Members of the Hipparcos scientific consortia (INCA*, NDAC, FAST and TDAC) have contributed significantly to the continued optimisation of the payload instrumentation, to the development of the two- and zero-gyro control procedures, and of course to the satellite data analysis, for which they have full responsibility.

The authors thank the members of the Hipparcos scientific consortia for permission to present their preliminary results here, and for the use of their illustrative material.

* INCA = Input Catalogue Consortium

Footnote added, in press, 15 August:

At the end of June, the satellite experienced some further difficulties in communications between the ground and the onboard computer, again attributable to radiation damage to certain components. Attempts to restart operations proved unsuccessful, and mission operations were terminated on 15 August, four years and one week after launch.

PRESS RELEASE 17 August 1993

Hipparcos: Mission Accomplished

After more than three years of efficient and successful operations, communications with ESA's scientific satellite Hipparcos were terminated on 15 August 1993. The Hipparcos satellite, a purely European undertaking, and the first space experiment dedicated to the highly accurate measurement of star positions, distances and space motions, was launched in August 1989. Targetted for an operational lifetime of two and a half years, more than three years of high-quality star measurements have eventually been accumulated, and all of the original scientific goals of the mission have been fully accomplished.

During the last few months of its life, as the high radiation environment to which the satellite was exposed took its toll on the on-board systems, Hipparcos was operated with only two of the three gyroscopes normally required for such a satellite, following an ambitious redesign of the on-board and on-ground systems. Plans were in hand to operate the satellite without gyroscopes at all, and the first such 'gyro-less' data had been acquired, when communication failure with the on-board computers on 24 June 1993 put an end to the relentless flow of 24 000 bits of data that have been sent down from the satellite every second, since launch. Further attempts to continue operations proved unsuccessful and, after a short series of subsystem tests, operations were terminated four years and one week after launch.

An enormous wealth of scientific data has been gathered by Hipparcos. Even though data analysis by the scientific teams involved in the programme is not yet completed, it is clear that the mission has been an overwhelming success. '*The ESA advisory bodies took a calculated risk in selecting this complex but fundamental programme*' said Dr. Roger Bonnet, ESA's Director of Scientific Programmes, '*and we are delighted to have been able to bring it to a highly successful conclusion, and to have contributed unique information that will occupy a prominent place in the history and development of astrophysics*'.

Extremely accurate positions of more than one hundred thousand stars, precise distance measurements (in most cases for the first time), and accurate determinations of the stars' velocity through space have been derived. The resulting Hipparcos Star Catalogue, expected to be completed in 1996, will be of unprecedented accuracy, achieving results some 10 to 100 times more accurate than those routinely determined from ground-based astronomical observatories. A further star catalogue, the Tycho Star Catalogue of more than a million stars, is being compiled from additional data accumulated by the satellite. These catalogues will be of enormous value in astronomers' attempts to understand and describe the properties and evolution of stars, and the dynamical motion of these stars within our Galaxy. In the process, Hipparcos has discovered many thousands of new binary star systems, measured the precise light variations of many hundreds of thousands of stars over its operational lifetime, and has provided an accurate and independent validation of the predictions of General Relativity.

Scientists working with ESA on the Hipparcos Programme, were at ESA's European Space Operations Centre (ESOC) on 13/14 July to review the progress of the data processing, and to examine whether any further efforts might allow the satellite to continue operating. '*All of us are sorry to see the end of this remarkable satellite*' said Dr. Michael Perryman, the ESA Project Scientist responsible for Hipparcos. '*On the other hand, we are delighted that it has delivered substantially more than it had been originally designed for. When our final results are published, some very interesting new insights into the nature of our Galaxy, its structure and its evolution will emerge*' he added.

A large team of scientists from the various ESA Member States is responsible for the analysis and interpretation of the vast amount of data that has been generated by the Hipparcos satellite, in what is considered to be the largest single data-processing challenge ever undertaken in astronomy. Working with ESA since the time of the mission acceptance in 1980, their immediate task will only end with the publication of the Hipparcos and Tycho Star Catalogues later this decade. Only then will an astrophysical exploitation of the results commence.

The Hipparcos results will represent a milestone in mankind's understanding of the structure and evolution of our Galaxy, and an invaluable legacy to future generations of astronomers.

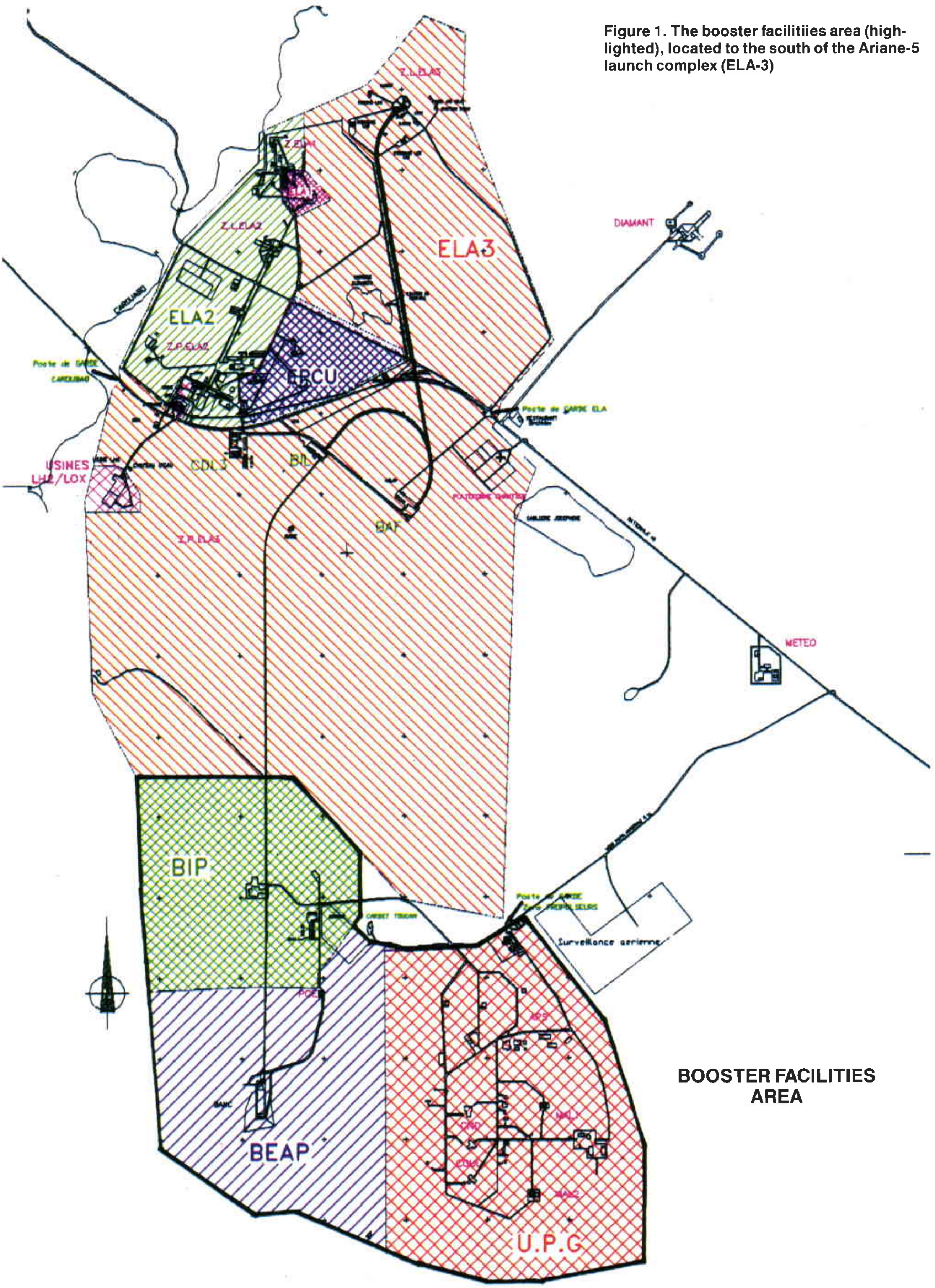


Figure 1. The booster facilitiies area (highlighted), located to the south of the Ariane-5 launch complex (ELA-3)

The Ariane-5 Booster Facilities

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Dedicated facilities for the manufacture, integration and testing of the Ariane-5 solid-propellant boosters have been installed at the Guiana Space Centre (CSG), in Kourou, French Guiana, near the ELA-3 launch complex (Fig. 1). During their design phase, major choices had to be made taking into account safety, reliability and economic factors. The successful test firings of the first two Ariane-5 solid-propellant boosters – known as 'B1' and 'M1' – took place on 16 February and 25 June 1993 at CSG, and the first two qualification flights of Ariane-5 are scheduled to take place in 1995 and 1996.

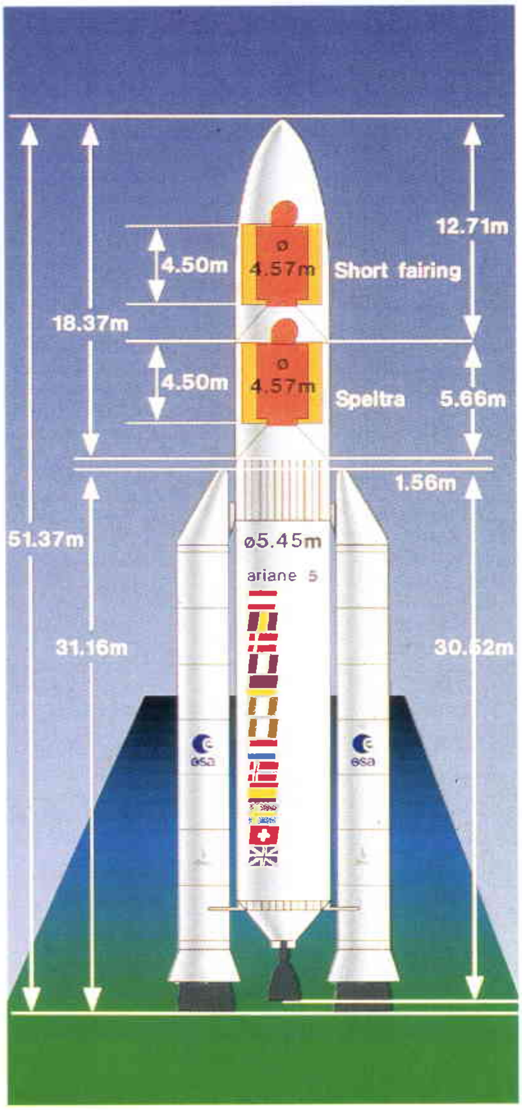


Figure 2. The positions of Ariane-5's two solid-propellant boosters, one on each side of the launcher

Introduction

The development of the Ariane-5 solid-propellant booster itself, in terms of its design, subassembly testing and the industrial infrastructure in Europe, was described in ESA Bulletin No. 69 (February 1992) by J. Gigou.

The Ariane-5 Development Programme is currently the largest ESA Programme. Overall responsibility for its execution, including the ground facilities, was entrusted to ESA in 1987 by a decision of the ESA Council, meeting at Ministerial Level, after a two-year preparatory programme phase. ESA subsequently delegated the technical and financial management of the programme – for the preparatory phase 1986–1987 and the current development phase 1988–96 to CNES, the French national space agency.

The major design choices

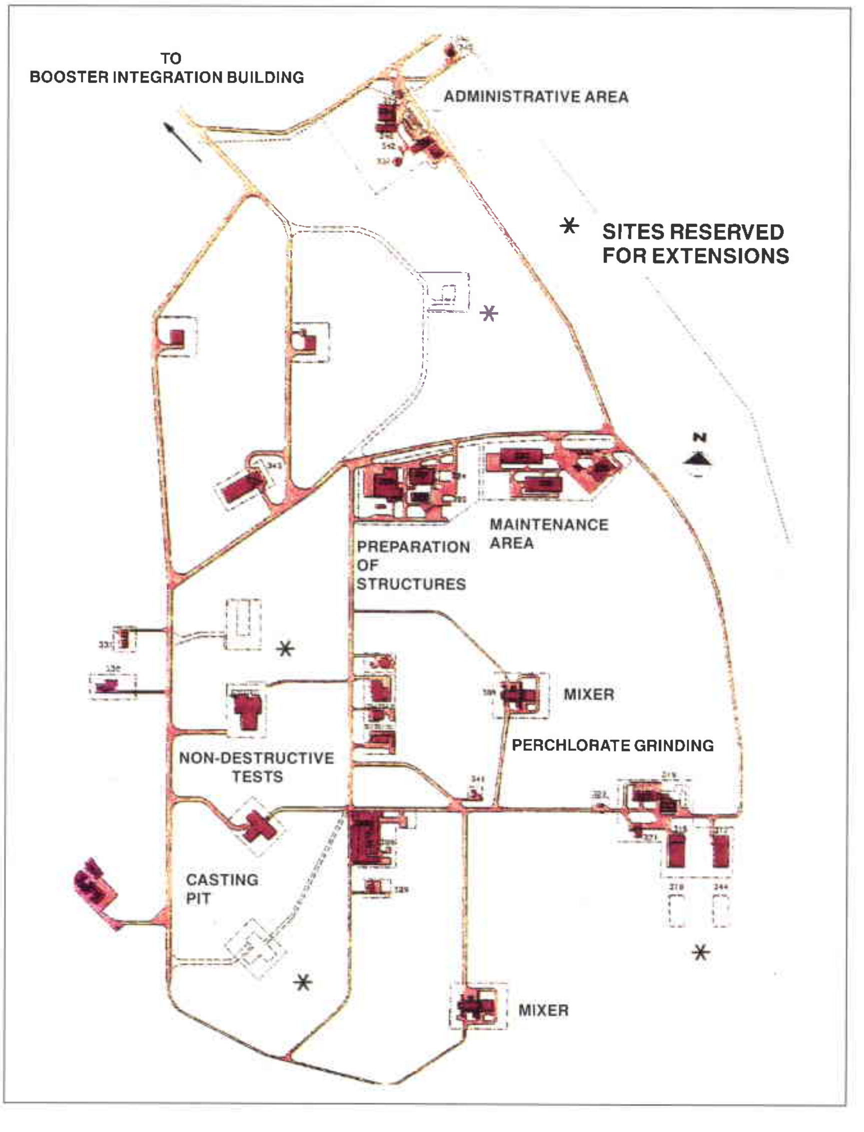
The two large solid boosters flank the Ariane launcher's central body (Fig. 2) and are the main providers of propulsion for the first two minutes of flight. The booster is about 30 m long and 3 m in diameter. It is made up of three segments: the forward segment weighs about 27 tons, the central segment about 116 tons, and the aft segment about 125 tons for the flight configuration. Each booster delivers 540 tons of thrust at the ground.

The manufacture of these boosters, each loaded with 230 tons of solid propellant, is one of the major challenges of the Ariane-5 Programme. A basic trade-off that had to be made in the early design phase of the Ariane-5 ground facilities involved the choice of location for propellant production and booster casting and testing activities, with Europe (close to the industrial suppliers) and French Guiana (close to the launch site) as the two primary options.

Cost, logistic and safety considerations led to the solid-propellant production being based in Kourou for the two large motor segments, and in Europe for the smaller segment. Following this choice, it was also decided to locate the booster integration and test facilities in Kourou and to design them for handling and testing in the vertical position.

The advantages of this solution are numerous:
- Local loading of the booster segments eliminates the risks of handling and transporting large pyrotechnic elements across Europe and through Atlantic sea ports. This also allows the manufacture of larger segments, thereby reducing the number of segments making up a stage to just three, with only two joints between them. This simplifies the design and increases the reliability of the booster.
- The test stand being close to the launch site offers climatic conditions that are identical to launch conditions. The choice of a vertical test stand, with the booster nozzle pointing downwards, offers test conditions most closely approximating to those of flight. Moreover, ambient temperatures in Kourou are stable and thus eliminate thermal shocks.
- The low population density of the region and the isolated location of the test stand mean that it is easier to arrange protection of populated areas during tests.
- The forward booster segment is smaller and lighter than the other two segments, being about 5 m long and 3 m in diameter. The fact that it is easily transportable by ship and road suggested that it should be manufactured completely in Italy by the process leader BPD (Fiat Group). A new plant was built and is now in operation at BPD in Colleferro, near Rome, where the metal structure of the segment arrives from MAN, in Germany, and is fitted with internal thermal protection prior to propellant casting.
- For the two larger segments, the metal structures are also sent from MAN to the BPD plant for fitting with their internal thermal protection, but they are then transported empty to French Guiana, where their propellant is manufactured and loaded.
- With the stage-integration, test and launch facilities at a single site, the same integration building can be used for both the development and the industrial production phases.
- An important choice for increasing safety was the vertical handling of segments throughout the production, inter-site transfer and testing phases, using air-cushion pallets wherever possible rather than cranes.

Figure 3. General layout of the Guiana Grain Plant (UPG)



The Guiana Grain Plant (UPG)

The UPG is dedicated to the manufacture, non-destructive testing and storage of solid propellant for the central and aft segments of the Ariane-5 boosters. Each segment is about 11 m long and 3 m in diameter. The UPG facilities are also used for the development work necessary for qualification of the manufacturing processes.

Based on experience gained from the existing solid-propellant plants in France and Italy, the UPG was designed for single-product manufacturing, but for larger product volumes. The quantity of raw materials mixed in each batch has been increased from three to twelve tons.

The plant is divided into three main areas (Fig. 3): an administrative area in the north, an 'inert' area in the centre, and a pyrotechnic area further south (down wind). The following functions are carried out, as shown

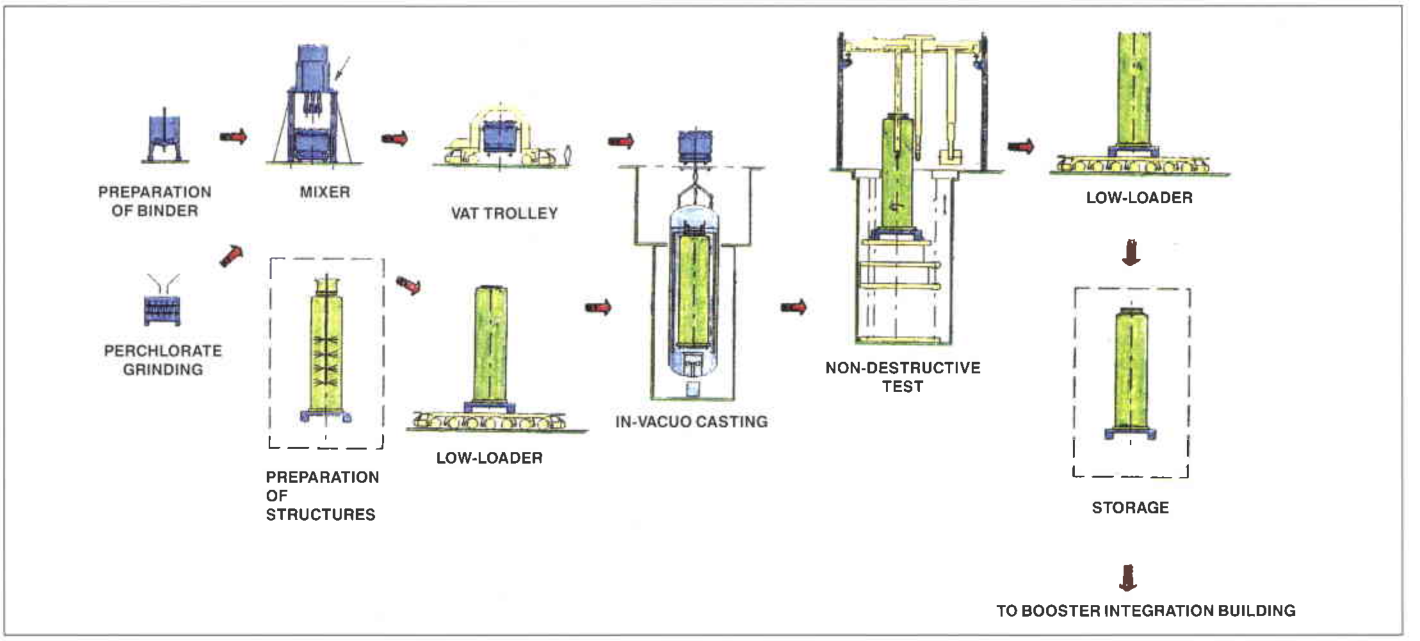


Figure 4. Simplified flowchart for the Guiana Grain Plant (UPG)

in the simplified flow chart in Figure 4:
- storage and conditioning of raw materials
- preparation of casings on arrival from Europe with an intermediate liner on the internal thermal protection, to ensure proper joining of the propellant
- pre-mixing of the binding material (HTPB polymer and 18% aluminium powder) and batch-mixing of propellant ingredients: binder plus solids (68 % ammonium perchlorate)
- checking of raw materials and products (mechanical and ballistic properties)
- loading of segments, which includes propellant casting in underground pits, and curing
- non-destructive testing of the loaded segments, using X-ray, ultrasound and three-dimensional video endoscopy.

The greatest importance has been attached to the safety, automation and quality control of the manufacturing process:
- buildings have been spread over a wide area (Fig. 5)
- automated control and command systems allow remote monitoring of hazardous operations like mixing, casting and non-destructive testing
- overall monitoring of the process and intermediate sampling and quality control of the propellant are also automated.

The project was started in late 1987 and construction work began in mid-1988. Since then, approximately 40 buildings spread over a surface area of 300 hectares, with the necessary supporting infrastructure and equipment, have been completed and

Figure 5. View of part of the UPG, with the Booster Integration Building and the top of the Test Stand in the background

qualified. About 80 contractors and sub-contractors from Belgium, France, Germany, Italy, the Netherlands and Spain have participated in the construction process.

The first buildings were handed over to the operator in late 1990. The facilities are owned by ESA, which has entrusted their operation to Regulus, a joint subsidiary of BPD Difesa e Spazio (I) and SNPE (F). Manufacture of the first segment model, with 105 tons of inert loading, was completed in July 1991. Final acceptance of the plant by ESA took place in December 1992, with the handover of the non-destructive-test building.

The success of the first booster test in February 1993 proved that the UPG is fully qualified for the manufacture of the Ariane-5 propellant.

The Regulus personnel are drawn from the two mother companies, plus an increasing number of locally recruited employees. The total staffing will rise progressively from about 50 in 1993 to more than 100 during the industrial production phase.

The UPG has been designed for a production rate of up to 24 segments per year, with growth potential to 32 segments per year, corresponding to the programme objective of 8 launches per year at a later stage.

The Booster Integration Building (BIP)

The BIP is located at a safe distance from the grain plant, the test stand and the launcher assembly building. Its construction was begun in 1988 and the building was commissioned by ESA in January 1992. The first test boosters (B1 and M1) have already been assembled and checked in this building.

The building has a surface area of 100 m by 63 m and a maximum height of 55 m. The air-conditioned volume is 130 000 m^3 (Fig. 6). The facilities, designed for a production rate of 16 boosters per year (8 launches), include:
- one airlock for unloading and decontainerisation of non-pyrotechnic equipment
- one airlock for reception and tilting of segments (Fig. 7)
- two bays for fitting segments with flight equipment
- one buffer bay able to store a maximum of six segments (two boosters)
- two bays for stage integration
- ten transport pallets (40 ton and 200 ton capacities)
- two air-cushioned transporters (40 ton and 200 ton capacities)
- three overhead cranes, each of 200 ton capacity.

Since the integration and functional testing of one booster takes more than one month, the building was designed, from the pyro-

Figure 6. The Booster Integration Building (BIP)

technic-safety standpoint, for simultaneous preparation of the boosters needed for two launches.

The safe handling of the segments, which are loaded with more than 100 tons of propellant, requires a high degree of reliability in both handling equipment and operating procedures to minimise the risk of an accident:
- automated tilting machine and crane controls to avoid shocks caused by manual handling
- using qualified operators, and minimising their number in the presence of a loaded segment or booster
- permanent monitoring of operations by the safety personnel, and control of access to the building.

The three segments that make up one booster are taken by road from the grain-plant storage area to the BIP on a specially designed platform trolley. The aft segment is mated with the nozzle, which arrives fully integrated from Europe, and then tilted into flight position. The segments are then fitted with the necessary auxiliary equipment: igniter, nozzle actuation unit, electrical and telemetry subsystems, stage recovery system, forward and aft skirts, forward and aft attachment and separation devices. The various segments then come together in the buffer bay before being assembled into the vertical position.

Functional tests include verification of the nozzle actuation system, leak testing, and verification of electrical and pyrotechnic subsystems. Each booster is integrated on a pallet in one of the two assembly bays, the doors of which open out onto a railway track. These tracks link the BIP to the test stand (1 km to the south) and to the launcher assembly building (3 km to the north).

A pallet carrying a fully assembled booster is moved along this track on a 'transporter', which is an 8 m x 8 m x 5 m mobile platform weighing 80 tons. Once in the launcher assembly building, the same pallet is used to roll the boosters onto the mobile launch platform, one on each side of the main cryogenic stage of Ariane-5.

When ESA commissioned the booster integration building in January 1992, it entrusted its operation for the initial development phase to Europropulsion, a joint venture between BPD Difesa e Spazio (I) and SEP (F). The integration of the first reinforced booster (called 'B1'), with bolted joints, was performed during the last quarter of 1992. Heavy-wall empty segments had been used previously in a preliminary validation campaign for all the major operations. Similar validations have also been performed with lighter flight-type mockups (loaded with inert propellant) before integration of the first flight-type booster ('M1') in March and April 1993.

The stage contractor Aerospatiale will take over the operation of the booster integration building from the stage qualification test (Q2) onwards and through the industrial production phase.

Figure 7. Airlock for the reception and tilting of the booster segments (in the BIP)

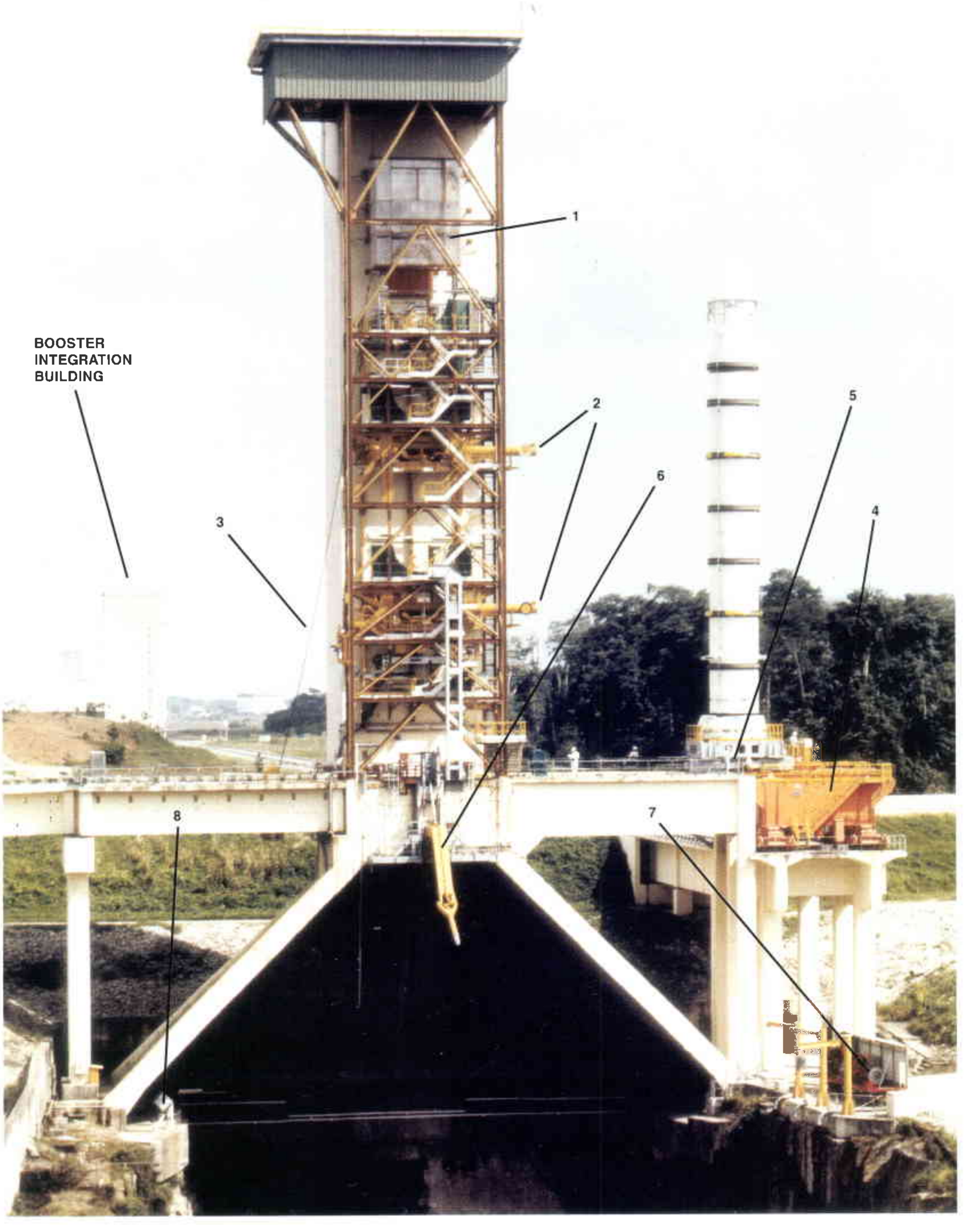
The Vertical Test Stand (BEAP)

A special test stand has been built for the development and qualification of the complete booster, and it could also be used for other tests during the subsequent production phase, if necessary (Fig. 8). The design criteria were to build a test stand, located close to the production and launch site, for test firing boosters mounted vertically, nozzle downwards, thus reproducing actual flight conditions as closely as possible.

Driven by safety concerns, the new test facilities were located at the extreme southwest of the Ariane-5 complex, which is down wind relative to the prevailing trade winds in French Guiana. The nearest populated areas in the down-wind direction are several tens of kilometres away. The main elements of the test stand are the servicing tower (62 m high), the flame trench cut out of the natural granite (60 m deep, 200 m long and 35 m wide), and the test control building located 600 m away in the up-wind direction.

Figure 8. The Vertical Test Stand

1. Thrust measuring device
2. Safety rings
3. Safety attachment cable
4. Platform trolley (pad of launch table) for moving booster on pallet between test stand and integration building
5. Pallet for moving booster between platform trolley and test stand
6. Nitrogen cooling arm
7. Pumping system for emptying water from flame trench before firing
8. One of many TV cameras



The reinforced-concrete tower is designed to resist more than twice the maximum thrust of one booster (600 tons). Its main function is to hold the booster and to measure its thrust during the test firing by means of a thrust measuring device located above the booster (Fig. 9). The same device is used to weigh the booster after firing.

The tower hosts a variety of equipment:

- mechanical: booster pallet roll-in railway and support; forward and aft booster attachments (with the same interfacing elements as with the main stage during flight); a metal structure with mobile platforms to access various levels of the booster; an overhead crane installed on the upper part for dis-assembling the booster after test;
- electrical: measurement conditioning rooms; transmission through optical fibres to the control building; instrumentation and control systems; firing lines; high-speed photograph and film cameras;
- fluid: hydraulic nozzle actuating unit; nitrogen system for cooling the boosters' interior on burn-out; water system for cooling the outside of the booster after testing;
- safety: two rings and one attachment cable, located at different levels of the tower, to prevent and limit the impact of

booster misbehaviour or take-off during combustion; emergency evacuation system for the operators.

The test control building also houses, besides an office area, the checkout equipment and the control room for monitoring test campaigns and countdowns. Over 600 parameters (such as temperatures and pressures at different locations) on the booster itself and in its close environment are transmitted to and recorded in the test control building.

Some of the parameters, such as pressure inside the booster or nozzle activation movements, can be monitored on-line during the 2 min of the firing. All of the others are available in elapsed time both in Kourou and in Europe. Automatic sequencing performs final checking and sends the commands to the various systems from 2 min before until 3 min after ignition. Permanent monitoring of hazardous operations is performed by the safety officer from the control room.

At the test stand, a campaign starts approximately seven working days before the test is due to take place, with the arrival of the booster and its pallet on the transporter, and ends approximately eight working days after the test with the departure of the booster. Configuration and validation of some systems, especially the patching through of the measurement links, has to be performed before the start of the campaign.

Construction of the BEAP began in 1988 and final commissioning took place in November 1992. The acceptance procedure included the satisfactory validation of the subsystems, as well as the safety and environmental-impact studies approved by the French Public Authorities.

Eight static test firings will be carried out before the first Ariane-5 flight planned for the end of 1995. An additional ninth test could be performed if needed. The first test (B1) was performed with a full-size heavy-structure engine. The second test (M1) was conducted with a flight-type booster. Four other 'M' tests (M2 through M5) are scheduled over the period to the end of 1994, and two 'qualification tests' (Q1 and Q2) in 1995.

Booster recovery and inspection

The Ariane-5 boosters are not designed to be reflown, but they will be recovered at sea and inspected on the ground. The specific booster recovery and inspection facilities will include:

- a tracking system
- a recovery ship
- handling facilities at Kourou's harbour
- equipment for disassembly and inspection of the booster.

Some elements, like the igniter or the nozzle, can then be shipped to Europe for further examination.

Organisation, cost and schedule

ESA, which is responsible for the overall management of the Ariane development programme, has delegated to CNES the technical and financial management of Ariane-5 ground facilities in French Guiana. ESA monitors the progress of work, costs

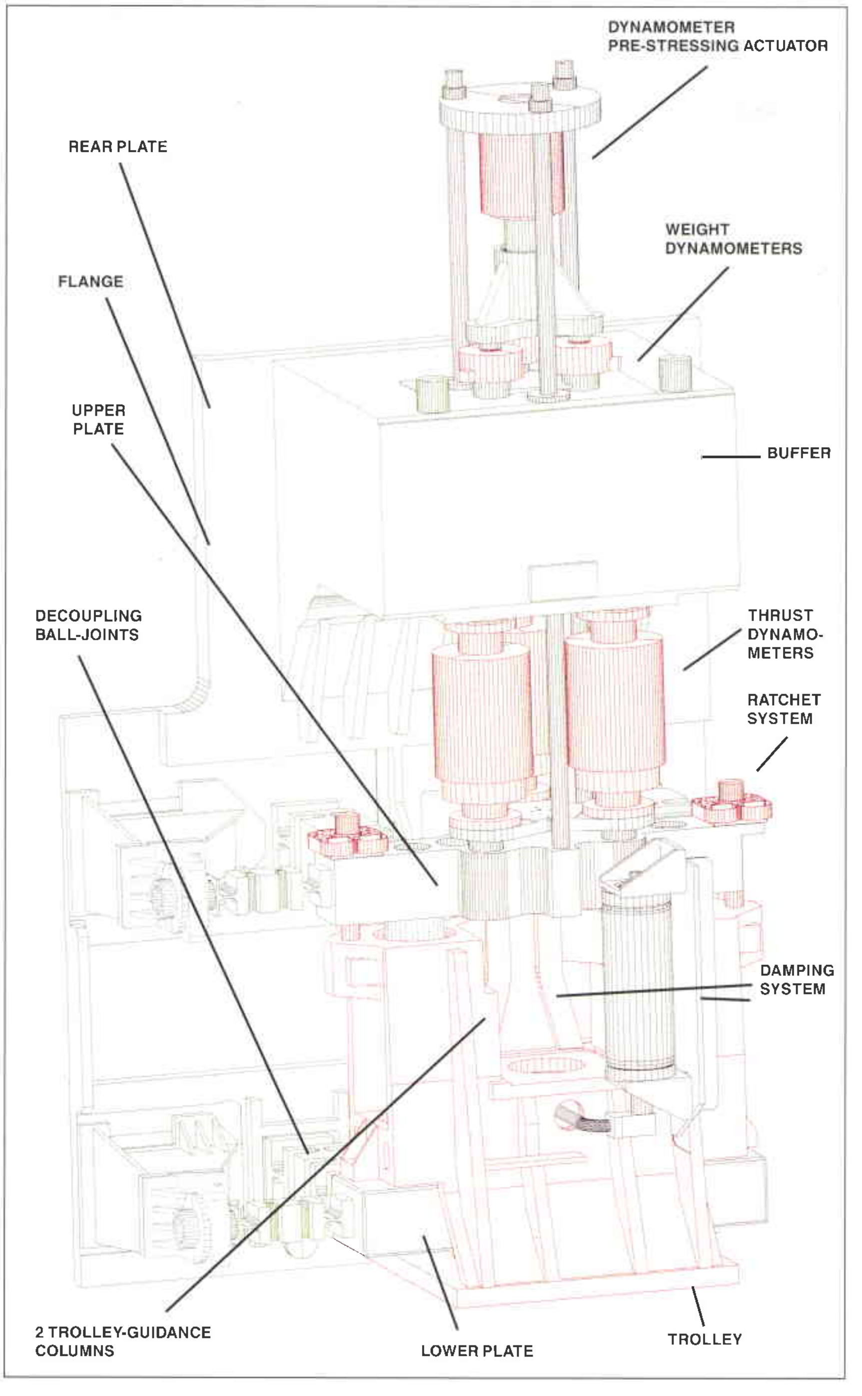


Figure 9. The thrust-measuring device

Figure 10. Vertical Test Stand during the successful first booster firing (on 16 February 1993)

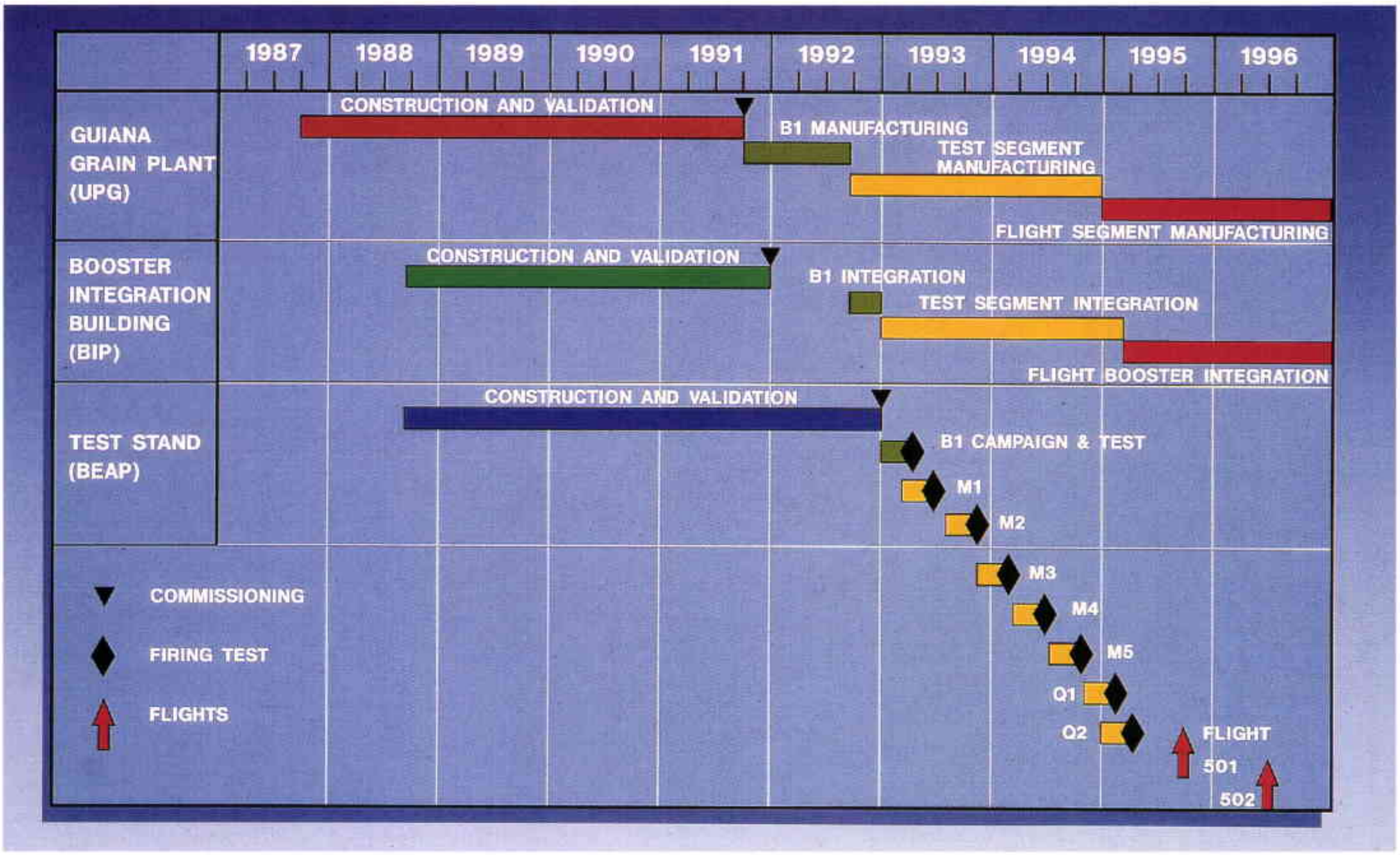


Figure 11. General timetable for booster development activities in French Guiana

and planning, and technical and operational development.

After construction and technical acceptance, ESA handed over exploitation to industrial contractors: Regulus for the grain plant; Europropulsion for the booster integration building, and CNES for operation of the test stand. All Ariane-5 ground facilities in Kourou remain ESA property, and the industrial contractors are contractually committed to maintain the elements entrusted to them at the requisite level of reliability, safety and efficiency.

Investment (at 1993 price levels) amounts to approximately 180 MAU (million accounting units) for the grain plant and 50 MAU for the test stand. The booster integration building cost approximately 40 MAU. The overall timetable for the booster development activities is shown in Figure 11.

The B1 test firing in February 1993 (Fig. 10) marked the end of the first phase of the booster-area facilities' history: four and half years of work and 270 MAU of investment in French Guiana. With the M1 test firing in June, the second phase started, covering the period 1993–1996 and involving production of the test-firing specimens and the flight boosters for the 501 and 502 development flights of Ariane-5.

At the end of the development programme, ESA will entrust Ariane-5 production to Arianespace, which will be in charge of marketing, manufacturing and launches during the operational lifetime of this new European launcher.

Conclusion

The 'booster area' has been the first of the Ariane-5 ground facilities at Europe's spaceport in French Guiana to be accepted for operation. The successful test firings of the first two solid-propellant boosters have shown that the facilities and, most importantly, the teams and procedures that are in place are capable of performing the complex task of building and operating a 230 ton booster, something which Europe had never previously attempted. This gives us every reason to trust in the success of the further challenging phases that lie ahead: the continued development of the solid-propellant booster until the second qualification flight of Ariane-5 in 1996, and the industrial production thereafter, which has to meet the highest reliability standards at competitive cost.

Acknowledgements

The authors wish to express their thanks to CNES, Europropulsion and Regulus for their support in the preparation of this article.

'GEWEX' – Requirements for Data from Spaceborne Instrumentation

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A quantitative understanding of the Earth's global energy and water cycle is still lacking despite the major advances that have been made in recent years in our knowledge of climatic processes. Reliable climate predictions will remain impossible whilst this gap in our knowledge persists. This realisation has prompted the launch of the 'Global Energy and Water Cycle Experiment' (GEWEX) within the framework of the World Climate Research Programme.

An ESA study has been conducted to consider the need for GEWEX of data from spaceborne instrumentation, the results and implications of which are discussed here.

Introduction

Concern over the potential impact of mankind's activities on our environment is now widespread, but in many areas there is no proper understanding of the actual processes involved or the way man can influence them. This is very unsatisfactory as it makes it impossible to predict future changes in the Earth's climate with any degree of confidence or to assess the impact of these activities on the Earth/atmosphere system. Examples of possible changes include changes in sea level, systematic shifts in weather patterns and increases in the risk of cancer or mutation (associated with the thinning of the ozone layer).

Responding to the general acceptance of the need to redress this balance and increase understanding of the Earth/atmosphere system, there have been several scientific initiatives, notable among which is the World Climate Research Programme (WCRP). This seeks to further our knowledge of the processes that effect climate in order to increase our ability to make predictions and hence to provide well-founded advice to policy makers.

Several very important programmes have already been launched within the context of the WCRP and together these are already making major contributions to advances in knowledge of climate and climate processes (Fig. 1). However, even if all of these programmes were to be one hundred percent successful in achieving their objectives, there would remain one major impediment to progress, namely the lack of a quantitative understanding of the Earth's global energy and water cycle (Fig. 2). Without this, reliable climate predictions will remain an impossibility.

Recognising this, a new initiative has been proposed, also within the auspices of the WCRP, to specifically address this deficiency. This is the so-called 'Global Energy and Water Cycle Experiment' (GEWEX). GEWEX is a major research initiative that poses major challenges, many of which are technical rather than scientific, as its data requirements are very exacting (Table 1). In addition to looking for the continuation of observations from established ground-based and space-borne observing systems, the satisfaction of the GEWEX data requirements will necessitate the provision of large new space-borne components. The development of many of these will be technically very demanding as well as expensive.

However, GEWEX is a programme of such fundamental importance that the satisfaction of its requirements must be a major consideration in formulating the Agency's long-term programme for Earth observation. It was therefore decided to initiate a study to clarify the specific requirements of GEWEX for space-borne data and, in particular, the role of the Agency. This article outlines the findings that have emerged from this study, amended in the light of recent evolutions. The aim is not, it must be stressed, to

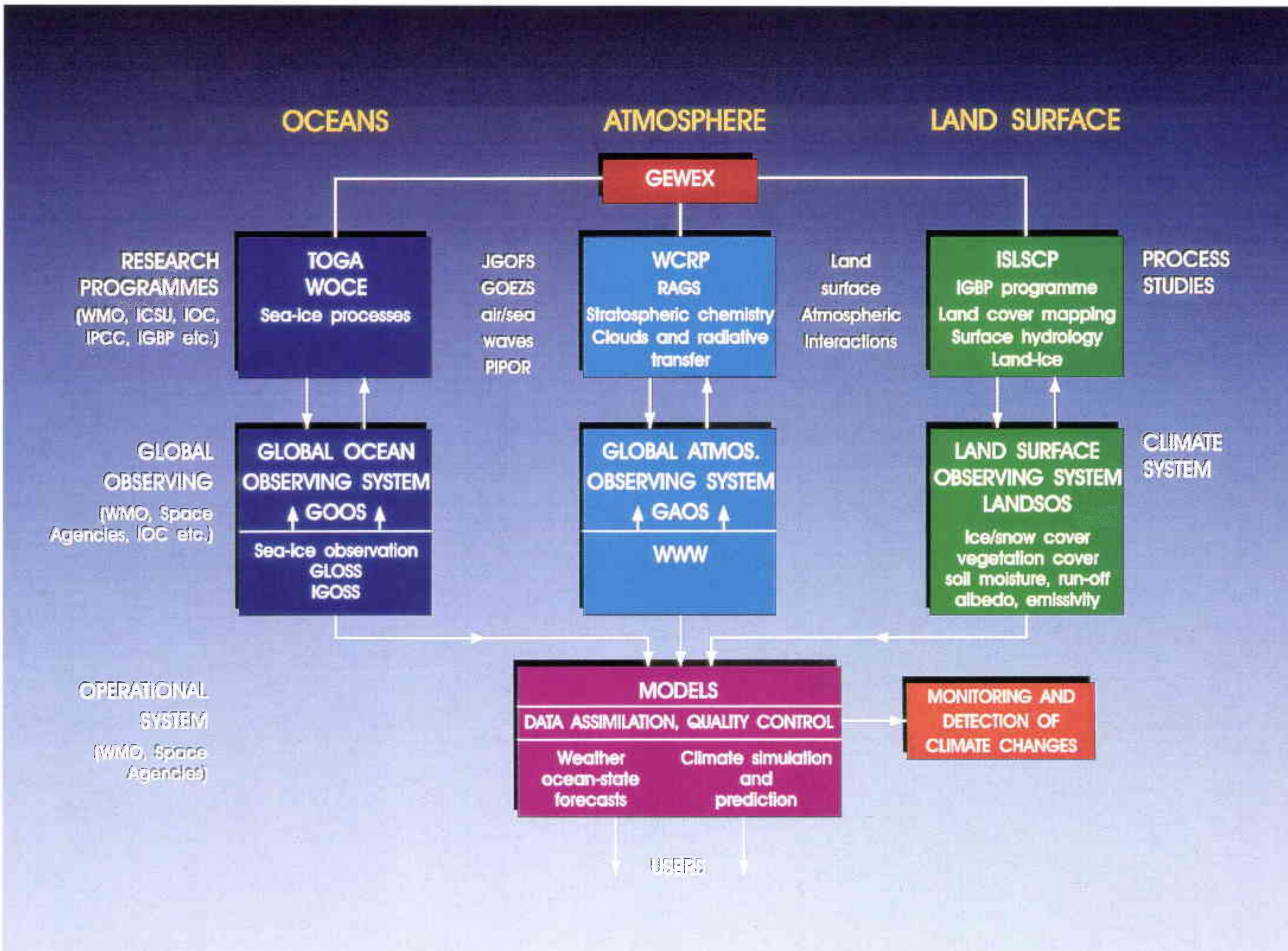


Figure 1. The Global Climate Monitoring and Prediction Programme

present a set of definitive proposals, but rather to encourage a wider debate on the role of the Agency in this very important programme.

The GEWEX experiment

In considering the motivation underlying GEWEX, it is important to recognise that the key to all climate problems is the redistribution of the Sun's radiated energy within the Earth's atmosphere and over its surface, and radiation transfers from the Earth's surface and its atmosphere to space. The presence of water, especially in the form of cloud, in all three of its physical phases, is of fundamental importance to these transfers of energy (latent heat plus radiative fluxes) and hence to climate. In fact, it is a unique factor of the environment.

Water is essential to the operation of the atmosphere heat engine, to the chemical moulding of the Earth's surface and, indeed, to life itself. Clouds control the planetary albedo and the amount of solar radiation reaching the surface. The inflow of fresh water at high latitudes is a major source of buoyancy, which modulates the deep-ocean

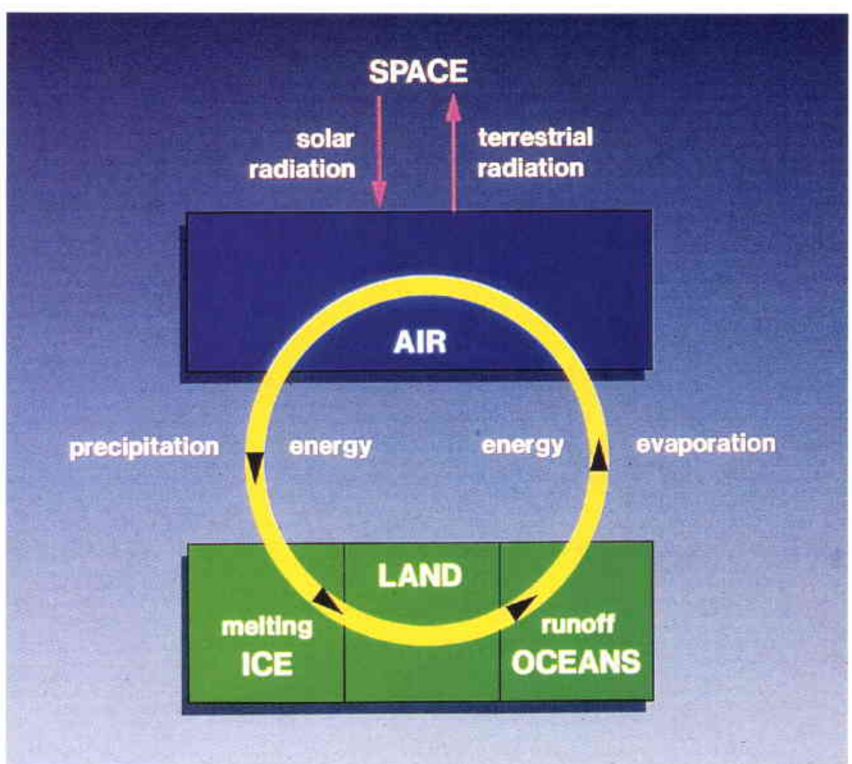


Figure 2. Schematic of the global energy and water cycles

circulation. The scavenging of chemicals by precipitation is a major cleansing process of the environment.

For these and many other reasons, a good understanding and a clear appreciation of precipitation and the availability of fresh water are of fundamental importance to the global environment. In fact, in terms of their impact on mankind, these are two of the most important elements of weather and climate.

At present, however, despite their importance, quantitative knowledge of global and regional water and energy budgets is limited. This is a matter of some concern as significant advances in these areas are basic to further progress in global weather and climate prediction. It is also an essential step in the study of global environmental changes.

*Table 1. The GEWEX data requirements**

1. Radiation and Clouds
- Solar irradiance
- Reflected solar flux at top of the atmosphere
- Emitted infrared flux at top of the atmosphere
- Incident solar flux at the surface
- Downward long-wave radiation flux at the surface
- Net flux at the surface
- Trace gases and aerosols (notably CO_2, N_2O, CH_4, CFCs, O_3, stratospheric water, aerosols)
- Cloud amount, type, heights of bases and tops

2. Standard Atmospheric Variables
- Surface meteorological observations (land, sea)
- Temperature profiles
- Tropospheric water vapour
- Upper air winds

3. Precipitation

4. Ocean Surface Variables
- Sea surface temperature and wind
- Ocean mixed layer thickness and heat storage
- Sea-ice extent, type and motion

5. Land Surface

(a) *Land-surface properties*
- o Surface albedo and roughness
- o Surface skin temperature
- o Surface emissivity
- o Vegetation index

(b) *Boundary layer variables*
- o Wind, temperature, water vapour content
- o Temperature and humidity profiles

(c) *Water storage*
- o Snow cover, depth and water content
- o Soil moisture

(d) *Surface hydrological parameters*
- o Precipitation and evaporation
- o Water run-off

* Report WCRP-5, 'The Concept of the Global Energy and Water Cycle Experiment', World Meteorological Organisation, Geneva, Switzerland.

Findings emerging from current programmes, such as TOGA (the Tropical Ocean Global Atmosphere), WOCE (the World Ocean Circulation Experiment) and the series of programmes concerned with the Earth's radiation balance, precipitation, land surface processes, etc., will not obviate this problem.

Thus, recognising the need to address this basic deficiency, the WCRP decided to launch a new initiative, namely GEWEX, to complement both existing and future programmes, exploiting the introduction of new and even more powerful computers and technological advances. It will combine the data from new observing systems (also those from existing ones) with global atmosphere/ocean/land/ice models. GEWEX embodies in a single programme all aspects relevant to the global energy and water cycles, ranging from model development and data assimilation to the deployment and operation of appropriate observing systems.

The aims of GEWEX have been summarised as follows:
- to determine the hydrological cycle and energy fluxes by means of global measurements of observable atmospheric and surface properties
- to model the global hydrological cycle and its impacts on the atmosphere and the ocean
- to develop an ability to predict the variations of global and regional hydrological processes and water resources and their responses to environmental change
- to foster the development of observing techniques and data management/assimilation systems suitable for operational application to long-range weather forecasting, hydrology and climate predictions.

These are enlarged upon in the report produced by the GEWEX study group*, but even from details given in this article it should be clear that the realisation of the GEWEX objectives poses major challenges, not least in the provision of the requisite data. The satisfaction of the data requirements outlined in Table 1 will be very difficult.

The ESA GEWEX Study

Given the importance of GEWEX and the potentially crucial importance of data from space-borne instrumentation to the realisation of its objectives, it was decided to fund a study to clarify aspects that could impinge on the long-term plans of the Agency for Earth observation. Specifically, this focused on part of the first of the GEWEX requirements, namely the provision of the data from space-borne instruments.

The specific aims of the study were:

- to review the data requirements for GEWEX and to identify the potential role of space-borne instrumentation
- to highlight deficiencies for GEWEX in the current plans for space-borne instrumenation
- to formulate a set of realistic strategies for satisfying the GEWEX requirements
- to assess the alternative strategies and identify critical areas where further work is required.

The study was wide ranging as, in addition to considering the role of space-borne instrumentation, the provision of platforms to support these instruments was also considered.

A fundamental part of the study was the review of data requirements, which was carried out by the Laboratoire de Meteorologie Dynamique (LMD), Palaiseau, France. This set the scene for the rest of the study by identifying, within the context of GEWEX, a set of specific scientific objectives to be met by the space-borne component.

The overall study was awarded to Aerospatiale (F), and in addition to LMD it involved Italspazio (I), Alcatel (F) and Macdonald Dettwiler (Can).

The objectives of the space-borne mission

The first step in formulating the data requirements for GEWEX is to consider the basic scientific objectives. Here, the LMD scientists highlighted three points:

(a) the fundamental importance of the tropical regions to the Earth's energy and water cycles because of the energy sources that are present in that part of the globe
(b) the need for continuity of observations in time as well as space to observe and monitor some of the processes basic to GEWEX
(c) the need to focus on the study of some specific processes that are central to GEWEX.

In its review, LMD identified three specific processes that are of fundamental importance to GEWEX, but which are not yet properly understood, namely:

(a) Interactions between precipitation and circulation in the tropics

On the global scale, energy deficits at high latitudes (notably in the winter) are corrected by energy transport from tropical to sub-tropical latitudes. A major component of this is via convective activity, which is driven by water convergence near the ground. Both latent heat, sensible heat and potential energy are transferred.

This is a complex process involving a wide spectrum of spatial and temporal scales, including both the Hadley and Walker cells, planetary waves and diurnal cycles. There are interactions with both the El Niño and monsoons. The picture is further complicated by significant inter-annual variability.

Of fundamental importance is precipitation and the links between precipitation and circulation. Many complex processes are involved which are not properly understood, and it is clear that specific studies will be required if knowledge is to advance to the point where significant progress can be made. In addition, it will be necessary to monitor the inter-annual variations.

(b) Cloud/radiation interactions

A major source of uncertainty in attempts to model the Earth's water and energy cycles (and hence climate) is cloud/radiation interactions. Many very complex processes are involved, which push our understanding of radiative transfer processes and cloud structure to its limits.

Global observations are needed to test our ability to model these interactions correctly and consolidate levels of understanding. A fundamental problem is the proper detection of the actual clouds, as some are notably difficult to observe (i.e. cirrus). In addition to internal characteristics, it will be necessary to measure the heights of both cloud tops and cloud base.

Again, both process studies and monitoring will be required on global scales.

(c) Water and energy exchanges through the surface

The planetary boundary layer couples energy and water fluxes from the surface to the bulk of the atmosphere. Many complex processes are involved which, particularly over irregular terrain, are not fully understood and so are difficult to model. Over the sea, a further complication arises where the fluxes of energy are locally determined by sea surface temperature, wind speed and air surface temperature/humidity. As a result, the determination of ocean surface fluxes lacks the self-correcting safety feature imposed on the land surface fluxes by the quasi-perfect mean energy balance over the ground (the net radiation largely determines the local energy balance).

The processes involved are sub-grid scale in all atmospheric models and, although parameterisations have been proposed, these have not been properly validated. In particular, it is necessary to validate the procedures for scaling point processes to regional and continental scales, especially over non-uniform surfaces. Most land-surface grid areas are inhomogeneous. The situation becomes particularly complex when cloud is present.

In this case, the principal requirement is continuous monitoring of some key boundary-layer parameters.

All three areas [(a)–(c)] are of fundamental importance to the Earth's global water and energy cycles and in all three cases there are fundamental gaps in our understanding. All are of fundamental importance to GEWEX.

In reviewing these requirements, three general time scales were identified, each linked with different types of scientific objective corresponding to:

(i) long-term processes monitoring
(ii) short-term process studies
(iii) long-term surveys.

Given the difficulty of implementing the first of these (high data rates over long periods, etc.), for the purposes of this study it was decided to concentrate on missions falling into the remaining two classes. The typical time scale assumed for a process study was two years, though it could be as short as three months.

Coupling these recommendations with an appreciation of the current state of knowledge and the potential contributions of ground-based and space-borne instrumentation, led LMD to propose eight specific GEWEX space missions. These are summarised in Table 2, grouped under the three general areas of interest. They should be viewed in the context of subsequent tables which indicate variables (and hence the instruments to be provided) that will have to be observed to meet these mission objectives. Many of these parameters cannot be measured directly, but will have to be derived indirectly from other variables.

Table 2. List of proposed GEWEX missions

Scientific Objective	Mission Description	Mission Type
I. Tropical Circulation Forcing	*Mission A:* Maintenance of tropical circulation by latent heat release	Short-Term Process Study
	Mission B: Tropical circulation monitoring	Long-Term Survey
	Mission C: Control of convection by humidity convergence	Short-Term Process Study
	Mission D: Convection monitoring	Long-Term Survey
II. Clouds Radiation Interaction	*Mission E:* Cloud life cycle and influence of cloud morphology	Short-Term Process Study
	Mission F: Albedo effect versus greenhouse effect	Long-Term Survey
III. Boundary Layer and Surface Fluxes	*Mission G:* Dynamics and atmospheric boundary layer structure	Long-Term Survey
	Mission H: Surface fluxes over land and sea	Long-Term Survey

Instrument requirements

These proposals serve to highlight requirements for specific instruments since, to realise the objectives of the eight missions, it will be essential to observe certain key parameters. These data requirements were analysed in terms of precision, resolution and sampling (space and time) and candidate space-borne instruments identified.

The findings are summarised in Table 3 which, for each of the eight missions, links key parameters to key instrument types, where the word 'key' presumes the availability of data from the 'standard' operational meteorological and other observing networks. The provision of several of the instruments referred to in this table poses major technical challenges.

In considering this list it is important to note that:

– To observe the vertical distribution of precipitation, a rain radar will be required (Fig. 3), coupled with a measurement package that includes a passive microwave radiometer (and an ultraviolet/visible imager such as AVHRR). In addition to providing complementary observations of total precipitation, the passive microwave radiometer (Fig. 4) could be used to put the radar data in context by indicating the overall distribution of rain areas.

Table 3. Key parameters and spaceborne instruments for GEWEX

Missions	Key Parameters	Key Instrument Types
Mission A	– Vertical distribution of precipitation – Wind profiles	0 Rain Radar and Microwave Radiometer 0 Wind Lidar and Scatterometer
Mission B	– Average precipitation rates – Wind profiles	0 Microwave Radiometer 0 Wind Lidar and Scatterometer
Mission C	– Vertical distribution of precipitation – Wind profiles – Humidity and temperature profiles	0 Rain Radar and Microwave Radiometer 0 Wind Lidar and Scatterometer 0 High Resolution Infrared Sounder
Mission D	– Average precipitation rates – Wind profiles – Humidity and temperature profiles	0 Microwave Radiometer 0 Wind Lidar and Scatterometer 0 High Resolution Infrared Sounder
Mission E	– Cloud cover, optical depth, top height and top temperature – Solar and long-wave radiation at the top of the atmosphere (and cloud properties) – Surface temperatures (over sea) – Humidity and temperature profiles	0 Medium Resolution Spectrometer, Cloud Radar and Backscatter Lidar 0 Earth Radiation Budget Instrument, Imaging Polarimeter, Cloud Radar and Backscatter Lidar 0 Infrared and Microwave Radiometers 0 High Resolution Infrared Sounder
Mission F	– Solar and long-wave radiation at the top of the atmosphere – Surface fluxes – Cloud optical depth, emissivity and top temperature	0 Earth Radiation Budget Instrument 0 See Mission H 0 Medium Resolution Spectrometer, Cloud Radar and Backscatter Lidar
Mission G	– ABL heights – Cloud cover – Low-level winds	0 Backscatter Lidar 0 None 0 Wind Scatterometer
Mission H	– Surface albedos – Sea surface winds – Sea surface temperatures – Surface spectral emissivity over the sea – Snow cover and sea ice	0 Earth Radiation Budget Instrument and Imaging Polarimeter 0 Wind Scatterometer 0 Infrared and Microwave Radiometers 0 Medium Resolution Spectrometer 0 Microwave Radiometer

Note: The availability of data from the current/planned operational meteorological and other observational networks is assumed.

- For wind profiles, a Doppler wind lidar (Fig. 5) will be essential as this is the only space-borne instrument that appears capable of observing wind profiles in clear air. Such a lidar will, however, not be able to penetrate thick cloud, so in many regions these data will not extend to the surface, but will be restricted to regions above clouds. It is also important to realise that coverage will be limited by swath, pulse rate, orbit, etc. It will therefore be essential to combine these data with other data (e.g. that from upper-air soundings and microwave scatterometers) to obtain the requisite wind fields.

- Realism points to the use of data from infrared and microwave sounders for the temperature- and humidity-profile

Figure 3. Operating schematic of a spaceborne Rain Radar

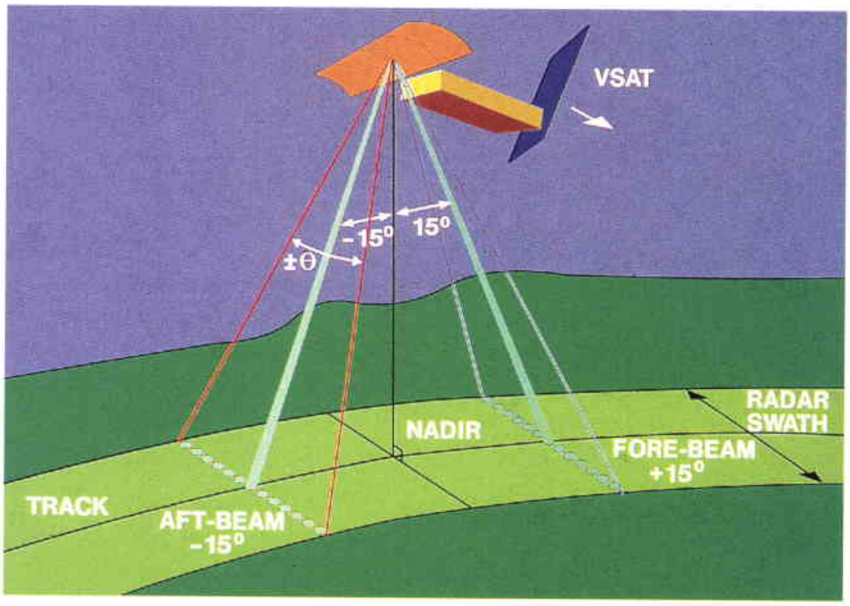


Figure 4. Operating schematic of the Multi-frequency Imaging Microwave Radiometer (MIMR)

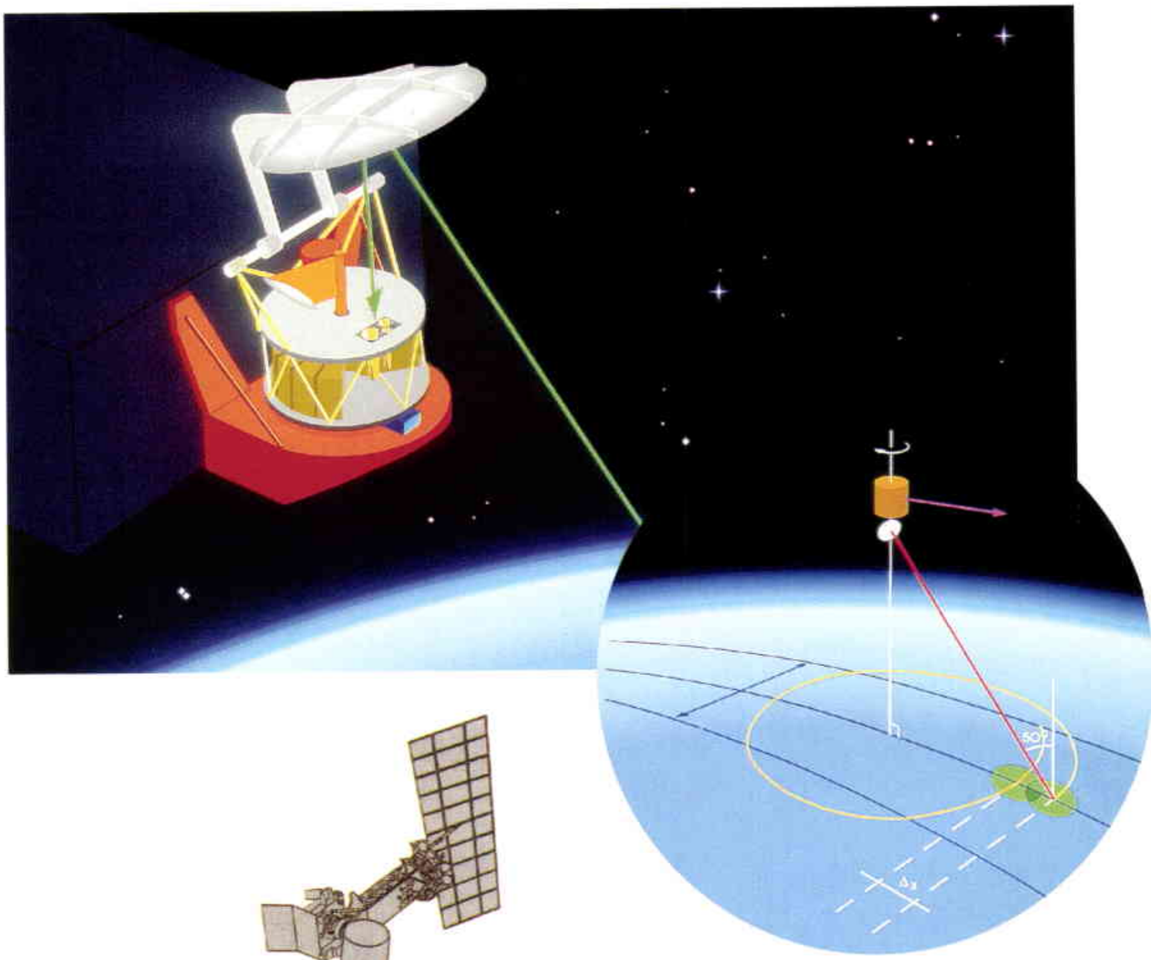
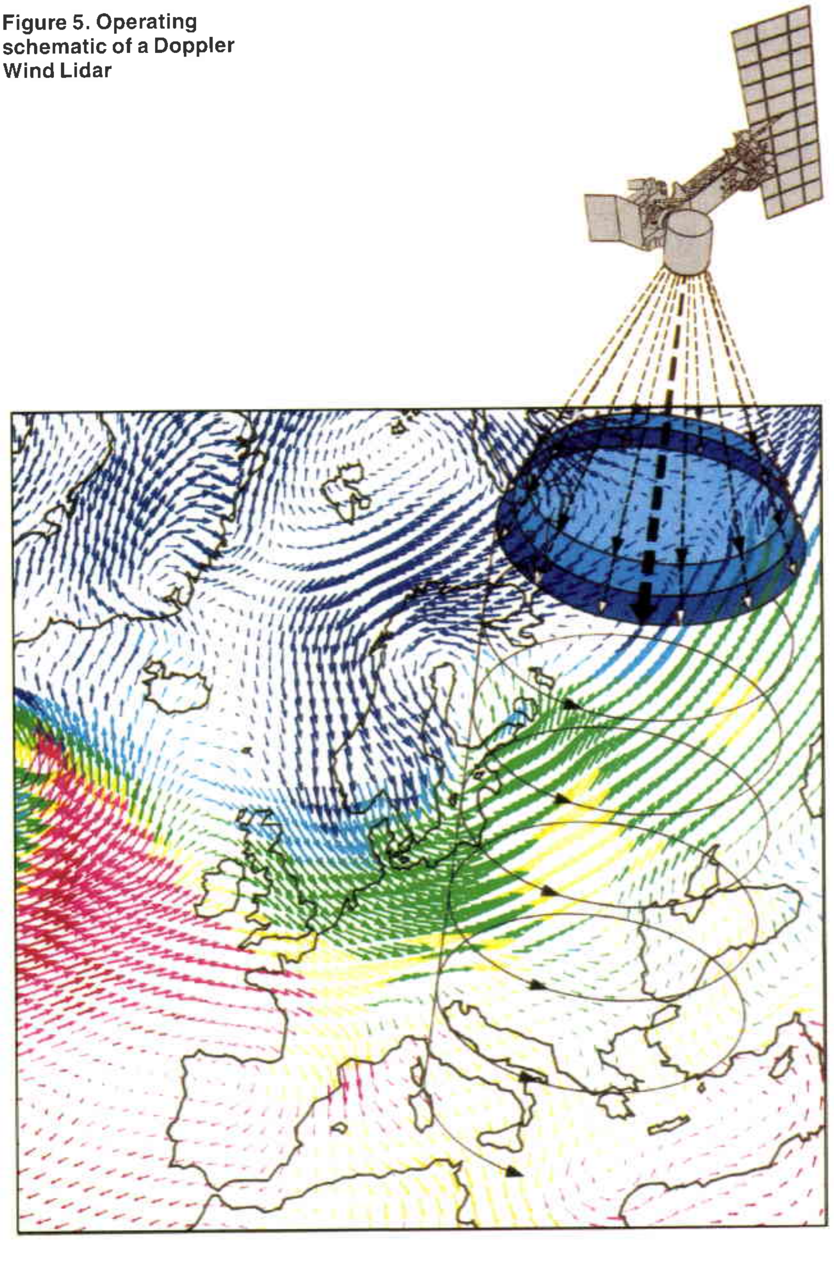


Figure 5. Operating schematic of a Doppler Wind Lidar



measurements, as DIAL lidars are unlikely to be available until well into the next century. To meet the GEWEX requirements, however, high-resolution infrared sounders (Fig. 6) are essential if the requisite vertical resolution is to be attained.

- Although the 'top of the atmosphere' radiative fluxes should be measured more or less satisfactorily by Earth radiation-budget instruments such as CERES and SCARAB, these data need to be allied with those from other instruments to obtain the requisite insights into cloud/radiation processes. Potential instruments include cloud radars, high-resolution imagers, imaging polarimeters, imaging spectrometers and backscatter lidars.

- A major challenge is the estimation of transfers in the atmospheric boundary layer. These cannot be measured directly and will have to be inferred from models. A vital parameter is the height of the boundary layer, and here a backscatter lidar would be invaluable. Another is surface wind, for which a wind scatterometer is essential.

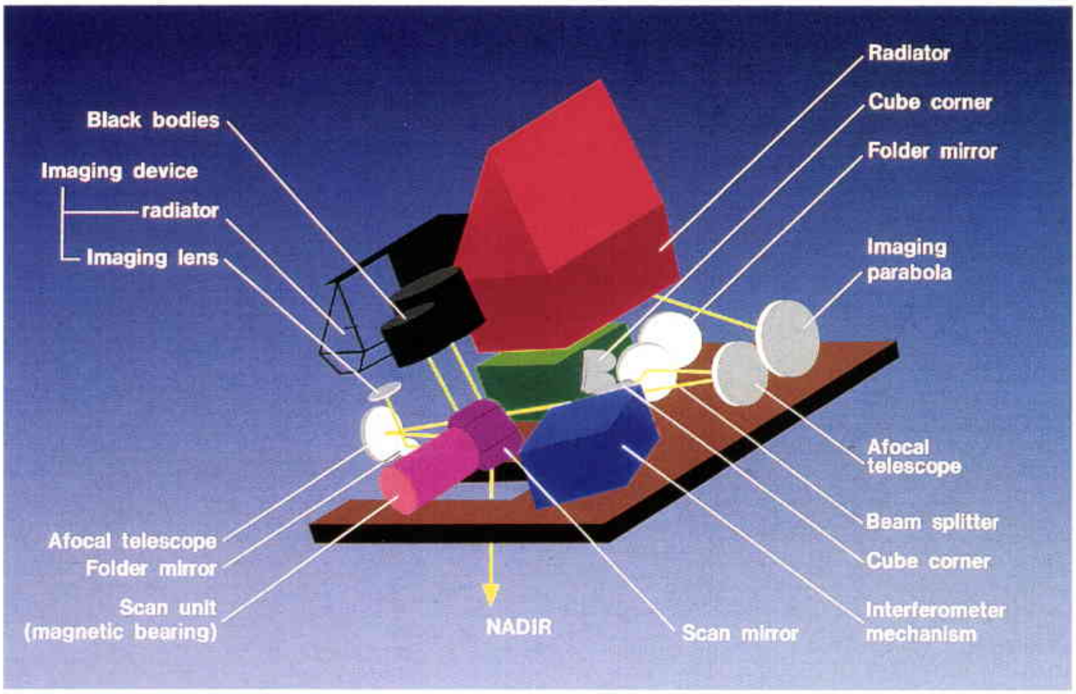


Figure 6. Instrument layout of a High-Resolution Infrared Sounder (IASI) (Courtesy of ASI and CNES)

Bearing these (and other) points in mind, Aerospatiale performed a very detailed review of existing and planned space instruments to assess their suitability for the proposed missions. Selection of specific instrument types took account not only of their likely performances, but also their likely availabilities within the GEWEX time frame.

Table 4 summarises the key new instruments required for the GEWEX missions that emerge from this exercise. It includes an indication of the likely time scales for the provision of individual instruments. Note that, although technically the bulk of the instruments listed could be made available for GEWEX (assuming adequate funding), there are particular problems with the wind lidar. Given its fundametal importance to the realisation of the aims of GEWEX, this is a matter of some concern.

Possible scenarios

Having identified the potential instruments, the data requirements corresponding to the proposed missions were analysed taking account of the capabilities of the various instruments. In many cases these proved to be very exacting, both in terms of the variables that have to be measured and in terms of the sampling requirements (space and time).

Quite apart from the problem of actually measuring many of the variables (as discussed in the previous section), it is clear that to satisfy the coverage requirements, with the appropriate time and space sampling,

Table 4. The availability of the key GEWEX instrument types

Instrument Type	Candidate Instruments	Availability
Rain Radar[1]	TRMM Rain Radar Advanced Rain Radar	1996 Not before 2000
Microwave Radiometer	MIMR SSM/I	2000 Available
High Resolution Infrared Sounder	AIRS IASI	2000 2000
Earth Radiation Budget Instrument	SCARAB CERES	Available 1998
Cloud Radar[1]	None	Not before 2000?
Imaging Polarimeter[2]	POLDER	1996
Backscatter Lidar[3]	ATLID	2003
Infrared Radiometer	ATSR AATSR	Available 1994
Medium Resolution Spectrometer	MODIS-N MERIS	1998 1998
Doppler Wind Lidar	LAWS ALADIN	Not before 2000 Not before 2000
Wind Scatterometer	AMI NSCAT ASCAT	Available 1996 2000

1 There are no firm flight opportunities for the BEST (or any other more advanced) Rain Radar, a Cloud Radar or a Doppler Wind Lidar. However, a follow-on TRMM mission is being proposed.

2 To cover the GEWEX time scale, a further flight opportunity would be required for POLDER.

3 Currently the flight opportunity for ATLID is 2003 (on a European Polar Platform, i.e. ENVISAT-2).

observations will have to be made from various orbits – namely geostationary, polar and low-inclination (tropical LEO) orbits.

Furthermore, the choice of a scenario to realise the GEWEX mission requirements cannot be carried out in isolation. It must take full account of the likely availability of data from other planned missions. GEWEX must make maximum use of existing or planned missions within the GEWEX time frame.

Another point of note is the need to take full account of commonalities that exist between the data requirements of the eight proposed GEWEX missions. In this context it is clear that the requirements for Missions A and B are covered by Missions C and D, respectively, making it possible to define two grouped missions:

- A + C: 'Tropical Circulation Forcing Process Study'
- B + D: 'Tropical Circulation Long-Term Survey'.

In both cases, the key difference betweeen Mission A and Mission C and Mission B and Mission D is the requirement for high-resolution humidity and temperature profiles. However, the instrument meeting this requirement (i.e. AIRS or IASI) is unlikely to be on the critical path for either mission. Other missions have overlapping requirements, but none actually totally subsumes another.

Assuming the availability of data from the operational meteorological satellites, the schedule constraints on the two composite missions and the four other missions follow directly from the data on instrument availabilities given in Table 4:

Mission A + C (short term)
The earliest opportunity for the proper realisation of this mission depends critically on the development of a Doppler wind lidar, which is unlikely to be available before the turn of the century.

The development of a rain radar is already technically feasible (viz. TRMM) and the proposed TRMM follow-on is of great relevance to this mission. However, a more advanced rain radar is really required to meet its requirements properly.

Data from a wind scatterometer and a microwave radiometer are already available and, assuming existing plans materialise (notably the European and other polar platform missions), these data should continue to be available for GEWEX. The first of the missions that include a high-resolution infrared sounder should be launched around the year 2000.

However, as it is not clear when the first of the Doppler wind instruments will be available to fly, a serious question mark hangs over the realisation of this mission within the GEWEX time scale, although even without a Doppler wind lidar significant progress should be possible. This must be further investigated.

Mission B + D (long term)
The situation is simiiar to that for the composite Mission A + C, though there is no requirement for rain radar data. It could be viewed as a continuation of Mission A + D.

Mission E (short term)
Two key instruments must be considered here, namely the backscatter lidar and the cloud radar. Neither is currently expected to be available before the year 2000, although technically it might be possible to produce a backscatter lidar by then. The problem is one of time scale as the ESA backscatter lidar, Atlid, is not scheduled to fly before the year 2003 (on Envisat-2). The cloud radar is another matter, as technically it is not clear when one could become available. This is the subject of current studies.

However, even without these two instruments, it might be worth proceeding in 2000 (at least as a first stage of the mission) as data from the remaining instruments could make significant progress possible. For this, a further flight opportunity may also be required for an imaging polarimeter, i.e. Polder.

Mission F (long term)
The situation is similar to that for Mission E, though there is no requirement for an imaging polarimeter. However, the logic of proceeding with this experiment without the full complement of instruments would have to be reviewed. Without these instruments, the study could in principle be initiated in the year 2000.

Mission G (long term)
The critical requirement is a backscatter lidar and so unless plans change this mission will not be feasible before the year 2003. Wind-scatterometer data should already be available.

*Table 5. GEWEX space-mission scenario**

	New Missions / Flight Opportunities		Planned Missions / Flight Opportunities	
	Instruments	Orbit	Relevant Instruments	Mission
Mission A+C	Rain Radar+MIMR+AVHRR	Tropical	MIMR+IASI+ASCATT	METOP (polar)
			MIMR+AIRS	EOS-PM (polar)
	Doppler Wind Lidar	Tropical	Rain Radar+SSM/I+AVHRR	TRMM/2 (tropical)
Mission B+D	Doppler Wind Lidar	Polar	MIMR+IASI+ASCATT	METOP (polar)
			MIMR+AIRS	EOS-PM (polar)
Mission E	ATLID+POLDER+Cloud Radar	Polar	MIMR+IASI+SCARAB+ AATSR	METOP (polar)
			MERIS+AATSR	ENVISAT (polar)
			CERES+AIRS+MIMR	EOS-PM (polar)
			CERES+MODIS	EOS-AM (polar)
Mission F	ATLID+Cloud Radar	Polar	As for Mission H	
Mission G	ATLID	Polar	ASCATT	ENVISAT (polar)
Mission H	POLDER	Polar	MERIS+ASCATT+AATSR+ SCARAB	ENVISAT (polar)
			MIMR+AATSR	METOP (polar)
			CERES+MIMR+AIRS	EOS-PM (polar)
			CERES+MODIS	EOS-AM (polar)

* Notes: (a) Assuming that data from the operational meteorological instruments is available;
(b) The listed 'planned missions/flight opportunities' are illustrative; others may also be planned;
(c) The TRMM/2 (i.e. TRMM Follow-on) is only a partial substitute for a GEWEX precipitation mission.

Mission H (long term)
This could be fully initiated in the GEWEX time frame, provided a further flight opportunity were to be provided for Polder.

The overall scenario that emerges is summarised in Table 5, which not only identifies the importance of data from currently planned missions, but also lists three specific GEWEX missions, plus a further flight(s) opportunity for Polder, namely:

(a) A *Doppler Wind Lidar Mission* – for Mission A + C and Mission B + D.

(b) A *Precipitation Mission* (rain radar plus microwave radiometer plus ultraviolet/ visible imager) – for Mission A + C and Mission B + D, though for the latter the rain radar is not required. A possibility is a TRMM follow-on, although this will not fully meet the requirements unless a Doppler wind lidar is also available.

(c) A *Cloud Characteristics Mission* (cloud radar and backscatter lidar plus imaging polarimeter) – would be relevant to all remaining missions, though only Mission E needs all three instruments. It may prove possible to include this package on Envisat-2.

This must be viewed as a minimum requirement as the conclusions are dependent on a detailed assessment of sampling requirements (in time and space). Several of the key instruments can only provide limited coverage and the impact of this on the mission objectives needs to be carefully assessed. This might reveal a need for further missions. Questions of data assimilation and synergism would also have to be addressed in depth.

Concluding remarks
This study has been very useful as it has served to highlight some specific GEWEX requirements for data from space-borne instruments. Six specific GEWEX studies are proposed, which are intended to serve as the basis for discussion and would provide

data additional to those provided routinely from established observing systems.

At the same time, it is clear that instrument technology development is on the critical path for obtaining the proper implementation of these experiments in the year 2000 to 2005 time frame. Here special mention must be made of the Doppler wind lidar and a cloud radar; the former poses the major challenge.

Furthermore, even assuming that the technical problems are overcome, additional complications arise when flight opportunities for the instruments are considered. Several of these can be solved by ensuring the continuity of data from instruments such the wind scatterometer and the passive microwave radiometer, including a backscatter lidar and cloud radar on Envisat-2 and by the TRMM follow-on mission. However, an additional flight opportunity will be required for the Doppler wind lidar (when available).

In addition, it will be necessary to study the space/time requirements of the six experiments to ensure that their minimum data requirements can be met without the provision of missions over and above those planned. It will also be necessary to investigate the implications of not having Doppler wind-lidar data available on the GEWEX time scale.

Furthermore, pending clarification of the sampling requirements for the six GEWEX missions, the exact nature of these flight opportunities must remain open. However, the starting point must be agreement on the GEWEX space missions. Until these are agreed, it will be difficult to proceed further, though the need for a dedicated precipitation mission, a successor to TRMM, over the GEWEX time frame seems clear. It is also clear that the provision of a Doppler wind lidar is on the critical path for GEWEX.

Acknowledgements
The authors would like to express their thanks to their colleagues for their assistance in what has proved to be a very exacting study.

Special thanks are due to T. Banos, P. Basseler and P. Kamoun of Aerospatiale, and A. Chedin, P. Flamant and R. Kandel of LMD.

VAS: A New Infrastructure in ESRIN's Data-Dissemination Network

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Value-Added Services (VAS) include those communication functions that go beyond the pure transport services normally provided by networks. A new communication infrastructure providing VAS based on Open System Interconnection (OSI) standards has been developed at ESRIN to serve the user communities accessing its data handling and distribution systems.

Introduction

ESRIN is responsible for providing user communities, mainly external to the Agency, with data handling and distribution services, such as information retrieval from databases, access to remote-sensing catalogues, and delivering earth-observation images and scientific-payload data. All users of the above services have, as a common requirement, the need to exchange documents, files and images among themselves and with their service providers at ESRIN (i.e. the persons responsible for interfacing with the user communities for each specific service).

The Data Dissemination Network (DDN) VAS infrastructure provides an answer to their communications needs. It provides them with all the facilities required to interoperate directly as well as to interact, through appropriate mail and file-transfer gateways , with services made available by external networks.

User requirements

The users' communications needs include:
- exchange of messages and documents
- exchange of files, images, programs
- participation in electronic conferences and debates, and access to bulletin boards.

In terms of computer services, these needs imply:
- electronic-mail and file-transfer services, to allow the exchange of information (messages, documents, files, programs), according to one-to-one (from one originator to one recipient) or one-to-many (from one originator to many recipients) communication schemes ('interpersonal communication')
- electronic bulletin boards/newsletters/ conferences, to provide groups of users with the possibility to collect and share information of common interest; this kind of communication can be considered 'group communication' and follows a many-to-many (from many originators to many recipients) communication scheme.

Additional services are required to support the above, although their need is not always explicitly recognised by users:
- gateways for mail, to allow the use of a unique mailbox for exchanging mail with all correspondents (also those connected to heterogeneous mail services), and to send messages to correspondents accessible only via conventional facilities, such as telex and fax
- gateways for file transfer, to allow users to send/receive files to/from correspondents provided with heterogeneous file-transfer services
- directory service, allowing users to easily identify people they want to communicate with (e.g. their electronic-mail address, postal coordinates, etc.).

Technical approach

The DDN-VAS implementation was approached with two prime goals as a basis:
- provision of Value-Added Services based on OSI standards
- provision and interconnection of gateways for mail and file transfer in order to interoperate with non-OSI services.

The OSI approach guarantees worldwide connectivity via public carriers (PTTs) and pan-European research networks, such as 'Cosine' and 'Y-Net'.

The provision of gateways and the interconnection to existing gateways guarantee the possibility of exchanging information between OSI and non-OSI environments. Consequently, users will no longer need to consult many different mailboxes searching for mail received from different mailing systems. They can adopt a unique mail service and a unique file-transfer service for exchanging information with correspondents provided with heterogeneous services.

Accessing the DDN-VAS infrastructure

An important consideration was the type of access offered to users. The need to afford access to users with a minimum of equipment was fulfilled by implementing a character-oriented interface. It is in fact

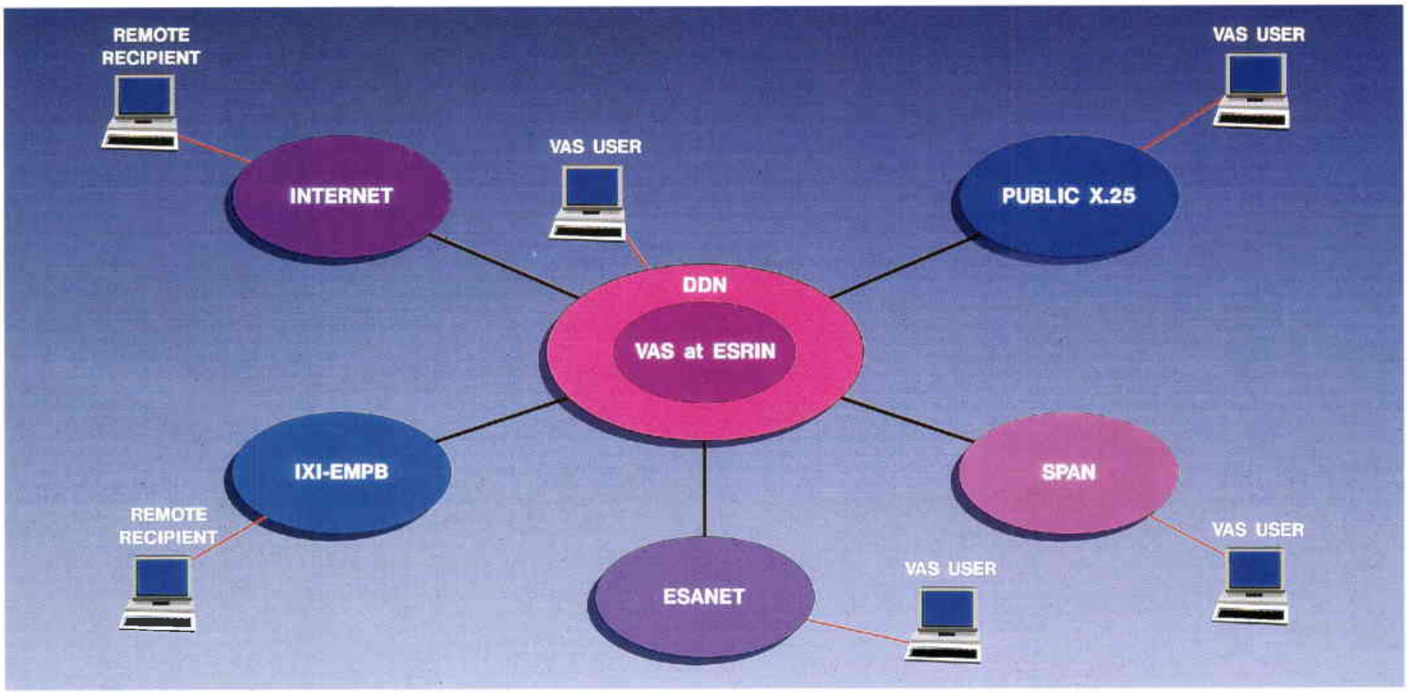


Figure 1. User access to the DDN Value-Added Services (VAS).

possible to access the VAS infrastructure using a simple terminal (TTY/VT100), or an emulation package, connected via X.25 networks. Access via Internet (Telnet) and SPAN is also possible (Fig. 1).

VAS services are also accessible to users of such information systems as the Earthnet ERS-1 Central Facility (EECF) or the ESA Information Retrieval Service (IRS), with the help of an access function integrated into their application environment. ERS-1 users, for instance, can suspend their catalogue consultation, access the VAS infrastructure through the EECF system in order to send mail, and then come back to the previous session.

Special attention has been paid to the user-friendliness of the interface. Access to all

ESA DDN Value Added Services

Type QUIT at any prompt to interrupt the current operation or ? for help.
Please select a sevice and press < CR >

M Mail
D Directory
T File Transfer
F File Management
P Change Password
U User Set-up
X Exit (leave the ESA DDN VAS)

Option?

Figure 2. User DDN VAS screen

services is driven through a series of menus with online help available for every function (Fig. 2). The possibility of using powerful Graphical User Interfaces (GUIs) has also been taken into account. Application Programming Interfaces (APIs) are available to allow the easy development of GUIs in the integrated application environment.

Services offered

The services provided by the VAS infrastructure are as follows:

- electronic mail, based on X.400
- directory, based on X.500
- file transfer, based on FTAM and extended to industry and public-domain protocols, such as FTP (Internet), Copy (DECnet), Kermit and transparent up/downloading

- bulletin boards, newsletters and conferencing, integrated with all of the above.

Mail

The mail service offered is based on the CCITT X.400 standard, which guarantees worldwide interconnection via multiple connections to the public X.400 services offered by PTTs, through the Italian Administration Management Domain (ADMD), Master400 managed by Saritel, as well as to pan-European research networks Cosine and Y-Net (Fig. 3).

It is both a very powerful and a flexible mail service, offereing a large number of options. It is possible to deliver texts, binary content through the appropriate gateway facilities made available by the PTTs.

Directory

The directory service, necessary to support the mail service, follows the standards for user directories. In preparing a message, users need to be able to:

- consult the directory easily to identify the correct information to be inserted in the mail recipient's address field
- address the message to a list of recipients, simply by indicating the name of the list
- address the message using friendly names instead of machine-oriented X.400 addresses.

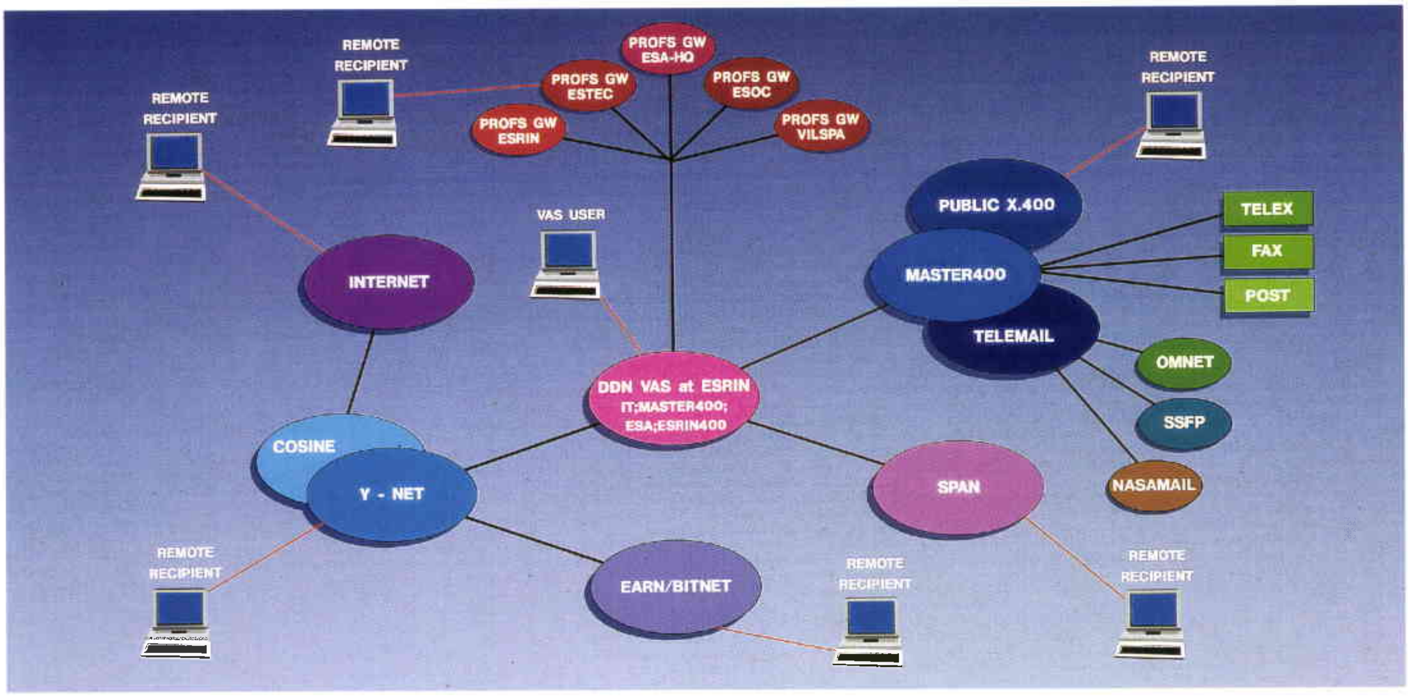


Figure 3. Mail interoperation via DDN VAS

parts, or any combination of the two. Users can access the mail service interactively, or prepare mail 'offline' on their workstation and then send it in batch mode.

The management of aliases and distribution lists is also provided, in order to allow easy definition of new addresses, mailing lists, and the possibility to address recipients through friendly names and lists of names. This key feature is made possible by the careful integration of the mail and directory services.

Due to the interconnection with the various mail gateways, users of the ESRIN VAS infrastructure can exchange mail with correspondents on Internet, SPAN, EARN/Bitnet and ESA-PROFS, as well as send messages to telex, fax and postal-service subscribers, if duly authorised.

Users may also need to access more general information about people, such as:

- surname and first name
- phone number
- fax/telex number
- postal address, etc.

The ESRIN directory service answers such needs by both supporting the mail service and providing access to more general user information via the same man/machine interface as the mail service.

Based on the CCITT X.500 family standards, it is designed to be integrated with the worldwide directory through interconnection with other emerging X.500 directories, managed by PTTs and research network operators.

File transfer
The file-transfer service offers the possibility to exchange text and binary files between user workstations and the VAS infrastructure, as well as between the latter and remote systems. File-transfer protocols supported include:
- FTAM (OSI)
- FTP (Internet)
- Copy (DECnet)
- Kermit
- transparent up/downloading (without error correction).

A number of file-transfer gateways are also provided to allow interoperation between the following networks:
- Internet (FTP)
- SPAN (Copy DECnet)
- EARN/Bitnet (NJE)
- OSI networks (FTAM).

As an example, a user on SPAN can exchange files with Internet, EARN/Bitnet or FTAM correspondents by using the Copy function available within SPAN and activating the appropriate gateway to the required recipient network.

Bulletin board, newsletters and conferences
In general terms, bulletin boards, newsletters and conferences are variations of a single concept: the electronic forum, in which defined groups of users can read and provide information related to specific topics. Each forum requires a manager responsible for defining the list of authorised users, allocating user access rights (read and/or write), and structuring the information.

These services are integrated with the mail and directory services to allow users to reply to the author of a bulletin-board advertisement or to forward a conference contribution to another user from within the same man/machine interface. The integration with the directory service allows the manager to authorise access or allocate access rights to lists of users compiled with the help of the directory service.

The bulletin board is a collection of 'advertisements' of interest to a user group and is the electronic equivalent of the office notice board. Each advertisement contains: an author name (the person who inserted it), date of submission, subject and text.

A 'warning' service is provided for those users who wish to be automatically informed that a new advertisement has been inserted in a specific bulletin board.

In a similar way, the newsletter service allows electronic distribution of newsletters to specific groups of users. Only the newsletter manager is allowed to write new contributions, all other users having read access only.

A newsletter is composed of a number of sections, each of which contains: date of submission, subject and text. In addition to the warning service, a 'delivery service' is provided that automatically sends any new sections of a newsletter to authorised subscribers.

Finally, a conference is a collection of information about a specific subject. It is composed of two kinds of contributions: topics and replies (contributions associated with a specific topic). Each contribution contains: author name (the person who inserted it), date of submission, subject, type (i.e. topic or reply) and text.

The warning service is provided to authorised users.

Automatic registration and filtering methods
Automatic registration functions and filtering mechanisms are provided by the VAS infrastructure in order to perform:
- automatic registration of users, taking advantage of their previous registration in the different systems currently providing ESRIN services; for this purpose, the VAS infrastructure is able to process specific files originated by the above systems containing all the required user information
- automatic registration of users as subscribers of gateway functions the first time they send or receive messages through the gateway
- filtering of messages on the basis of the originator/destination combination; as an example, an originator can be prevented from sending messages to telex or fax correspondents.

Architecture
As mentioned above, a fundamental design guideline was conformity to international standards: OSI standards were therefore taken as the basis of the hardware/software architecture. Nevertheless, the need for interconnecting important existing scientific networks was also a fundamental consideration. The resulting architecture includes standard functions wherever applicable, and gateway functions designed to allow interoperability with the relevant scientific networks.

To avoid unnecessary duplication, care has been taken to exploit the capabilities of the existing mail gateways made available by research networks, such as Cosine and Y-net, and by the PTTs. The impact on the architecture is that functionalities rely not only on ESRIN-provided systems, but also on a number of external gateways.

Hardware platform

The VAS infrastructure is currently based on two hardware platforms:

- the Central Server, which implements standard OSI services, and
- the Gateway, which provides users with conversion facilities between OSI and non-OSI environments.

From a hardware point of view, the two platforms are quite similar: both are based on a dual-host VAX configuration (Fig. 4), chosen to provide a reasonable compromise between cost and performance. In practice, the dual-host solution gives the possibility of load sharing between two processing units, which share a common mass storage. This configuration also achieves a degree of robustness in the case of hardware faults.

The Central Server is based on a dual-host VAX 4300, with 2 Gbyte of storage. The Gateway machine is based on a dual-host VAX 3400, with 1.2 Gbyte of storage. The two platforms share a single ethernet Local Area Network (LAN), which is connected to a couple of DEC routers, acting as the interface between the VAX machines and the wide-area X.25 network, for both user access and communication with other systems.

Software architecture

From a software point of view, the Central Server and the Gateway use the same DEC operating system (VMS Version 5.4), which has proved to be both reliable and robust in the past and is very suitable for the development of communications applications.

The two systems differ substantially, however, in terms of their software implementation. The architecture of the Central Server is based on standard OSI portable products from Marben Produit. These products perform the services foreseen by the international standards for the intermediate and top layers of OSI architecture (transport, session, presentation and application layers), while access to level-3 (X.25) is via the standard DEC PSI package. Mail, directory and file-transfer applications are built on top of the Marben products (Fig. 5).

The bulletin-board, newsletter and conference features are based on the DEC VAX Notes package, which maintains the necessary common data structures; a specific applic-
ation handles man/machine interface aspects and is also responsible for interfacing mail and directory entities for integrated services, such as reply via mail to the author of a bulletin board, allocation of access rights to lists of users, etc.

The software architecture of the Gateway has been designed to allow the implementation of two main functions:

- mail gateway between X.400 and VMSmail, the mail service available on SPAN

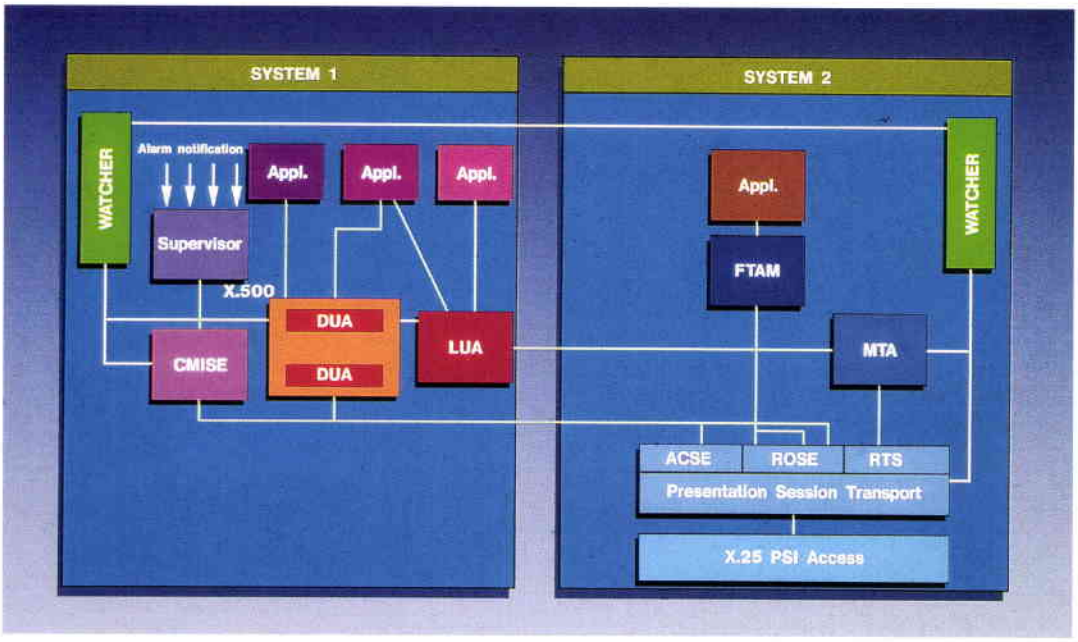


Figure 4. Central Server architecture based on dual-host VAX configuration

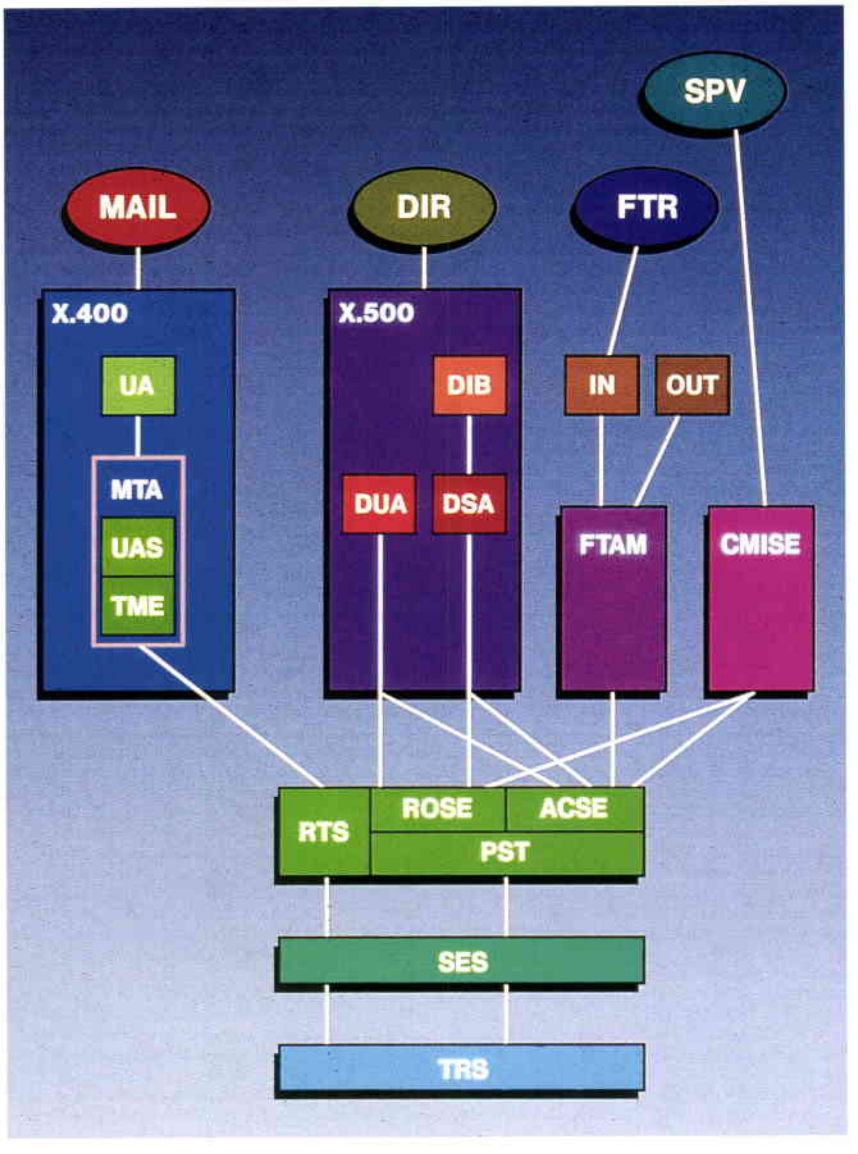


Figure 5. Software architecture of the VAS infrastructure

- file-transfer gateways between Internet, SPAN, EARN/Bitnet and OSI networks.

For the mail gateway functionality, the software architecture is based on the DEC Mailbus concept, whereby different mail packages can be interconnected by means of a 'software bus' that is actually a common message format known to all packages.

For file-transfer gateway functionalities, the implementation is based on a number of file-transfer packages (such as FTP, FTAM, etc.) installed on the Gateway machine, allowing the exchange of files with each of the networks concerned (Internet, SPAN, EARN/Bitnet, OSI).

Interconnections

Within the VAS infrastructure, the Central Server and the Gateway are interconnected for the exchange of mail and files; moreover, the Central Server acts as an X.400 router for the whole VAS infrastructure towards the external world.

In particular, through the Central Server, users of the VAS infrastructure are able to exchange mail with correspondents on:

- the public X.400 service managed by Saritel in Italy and the worldwide X.400 services managed by the PTTs
- the Cosine and Y-net research networks
- Internet, through the X.400—Internet gateways made available by Cosine and Y-net
- EARN/Bitnet, through the X.400—EARN/Bitnet gateways made available by Cosine and Y-net
- ESA-PROFS, through the X.400—PROFS gateways, available in all ESA establishments.

Ongoing activities are aimed at interconnecting the ESRIN-provided directory to the worldwide directory through the services offered by PTTs and research-network operators.

Conclusion

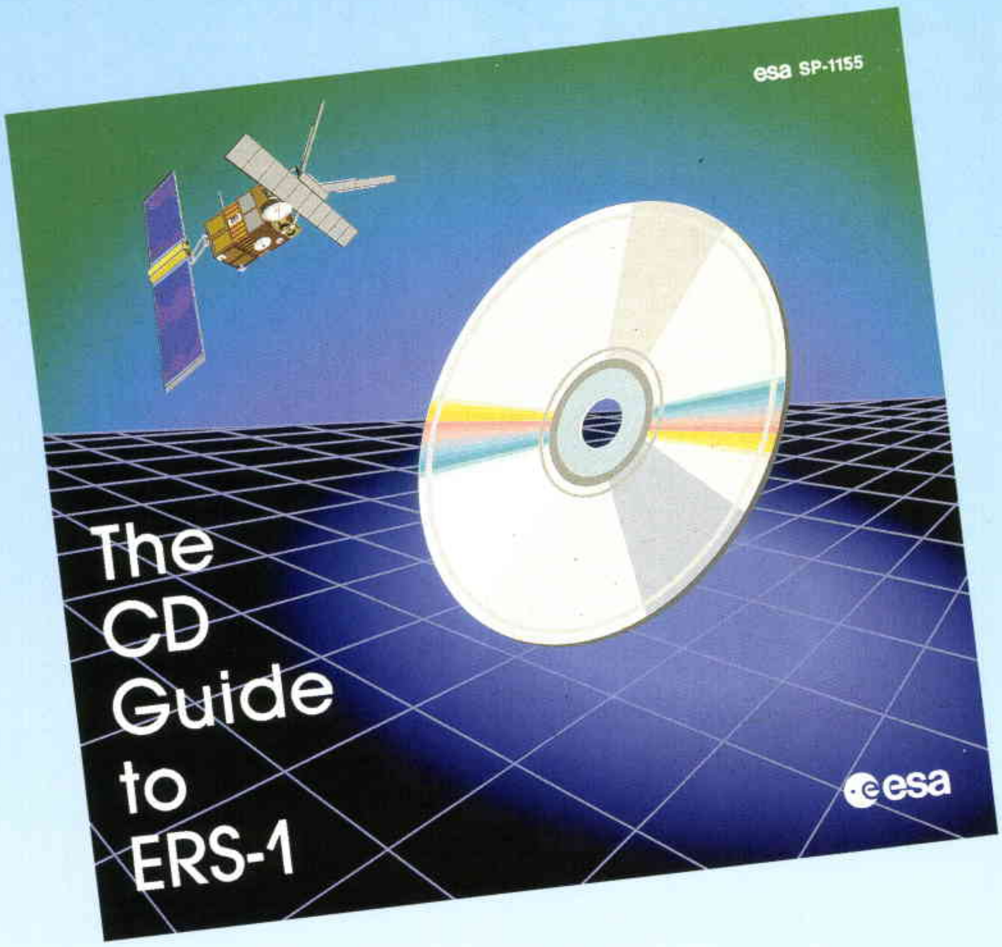
An integrated set of facilities has been put into operation within the ESRIN VAS infrastructure aimed at satisfying today's communications needs of the space-interested user communities. Worldwide mail connectivity is provided via public PTT services, as well as through pan-European research networks.

Additional significant steps planned for the near future include:

- development of GUIs in order to provide users with more powerful interfaces for accessing all of the above-described functionalities
- integration of the ESRIN directory within the worldwide directory, through interconnection with directory services provided by PTTs and research network operators
- use of the VAS infrastructure for Electronic Data Interchange (EDI) applications, in support of the ESA Science Directorate requirements.

The approach undertaken in the implementation of the project, in terms of software architectural design and standards adopted, makes the VAS infrastructure a solid basis, well-suited for supporting all planned future evolutions.

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

An example of D2-MAC data broadcasting. Earth-observation images and related data are forwarded from ESRIN to a transmit facility, from which they are up-linked to the satellite for broadcasting within Europe.

Satellite Data Broadcasting – A European Solution

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ESTEC, Noordwijk, The Netherlands

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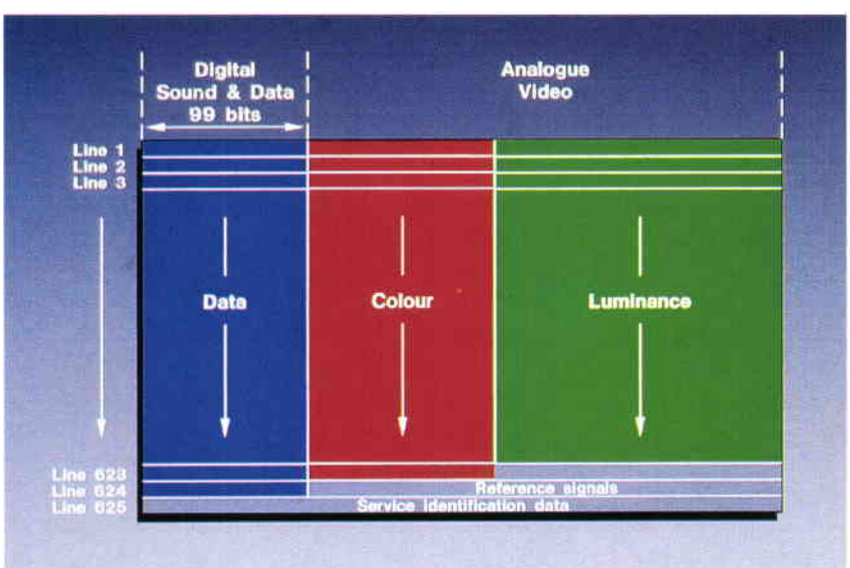
Introduction

D2-MAC data broadcasting is now entering the commercialisation phase. A first value-added service provider is already offering the service on a commercial basis and the system, with its unique possibilities, is expected to become very popular in the near future. At the same time, it constitutes a first step towards a data broadcasting system based on a future fully digital television standard.

A satellite data broadcasting system has been developed based on the digital element of the D2-MAC television standard. Trials have been made with applications ranging from news dissemination to the broadcasting of weather-forecast information. One particularly promising application is the dissemination of Earth-observation images and related data. Extended trials are presently in progress at ESRIN with the goal of applying D2-MAC (Multiplexed Analogue Component) data broadcasting for the ESRIN Data Dissemination Network (DDN).

Figure 1. A D2-MAC television signal, with the digital sound and data components time-multiplexed with the analogue video component



The D2-MAC television standard was established as a European approach to high-definition television. It was designed for Direct Satellite Broadcasting (DBS) and was introduced in 1989 on several satellites, including ESA's own Olympus.

In addition to its wide-screen capability and enhanced picture quality, the D2-MAC TV system offers a high-speed digital component. The digital sound and data component is multiplexed with the analogue video component as shown in Figure 1.

Four digital channels each with a capacity of 384 kbit/s are available in a D2-MAC television signal. Channels may be used as mono sound channels, as compact-disc-like quality stereo sound channels, or for general-purpose data transmission. Capacity for data transmission is thus available in multiples of 384 kbit/s, depending on how many of the four digital channels are used for sound. The option to use the full digital channel capacity of the D2-MAC system exists, providing a maximum data capacity of about 10 Mbit/s.

Unlike other television standards, D2-MAC has a conditional access system incorporated (such as the 'Eurocrypt' system), which can be used to restrict the availability of certain television or data services to particular viewers or user groups. The General-Purpose Data (GPD) standard, as defined by the European Broadcasting Union (EBU), provides the protocol for supporting data services on the digital channel. A wide range of data services can thereby be defined.

The high-speed digital data component in the D2-MAC signal, together with the features offered by the GPD protocol, allows a new and versatile method of data broadcasting, surpassing by far the possibilities of existing data broadcasting systems.

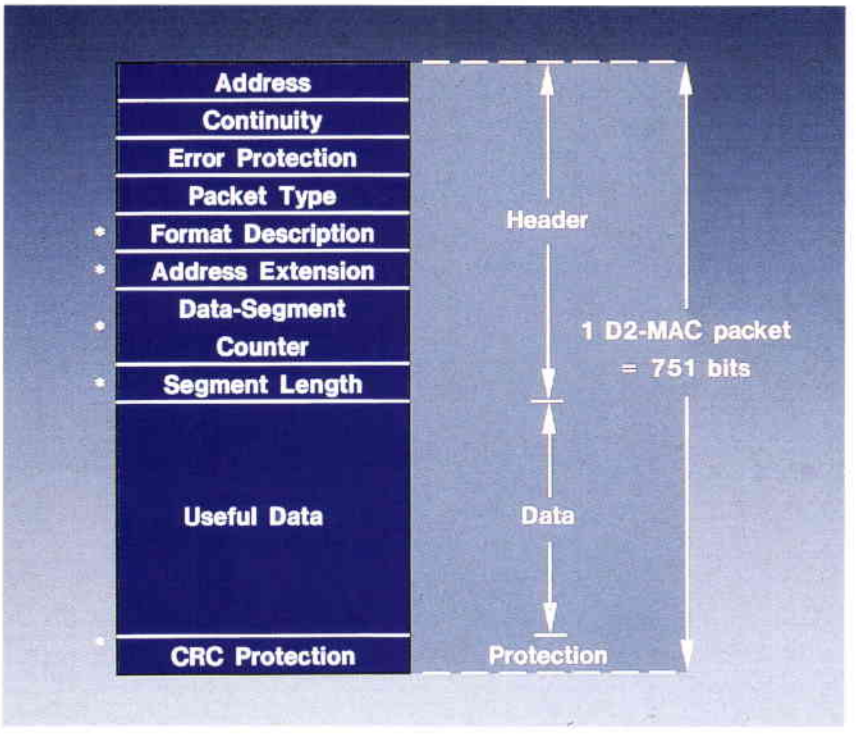


Figure 2. Structure of a D2-MAC signal packet
(* indicates optional)

The GPD protocol
Within the D2-MAC standard, a special protocol for GPD services is defined which allows the simultaneous broadcasting of different data services characterised by a multitude of associated parameters, such as conditional access through data encryption, data protection and correction, addressing schemes, and data rate. The information 'packet' structure, as defined in the GPD protocol, is shown in Figure 2. The packets have a constant length of 751 bits and are divided into a header, a useful data part, and a protection segment.

The address field within the header is used for the distinction of various data services, each of which is allocated a unique address code. It is used in the receiver to identify and select the packets of the appropriate data services. The extended address field may be used to address individual users or user groups, or alternatively to define sub-classes within a certain data service.

Another important feature is conditional access, the principles of which are shown in Figure 3. Prior to transmission, the signal is rendered unreadable by combining it with a time-variant pseudo-random code word. This code word is encrypted and sent together with the scrambled data through the D2-MAC data channel. It can be decrypted by authorised users equipped with a corresponding decoder card. The Data Broadcast Service providers give access rights for certain data services in the form of digitised entitlement messages. These are also encrypted, transmitted through the D2-MAC data channel, and decrypted by the receivers, enabling them to decrypt the code words and to descramble the data.

Development of data receive terminals
Following standardisation work in cooperation with the European Broadcasting Union and initial feasibility studies, ESA began the development in 1989 of a prototype data receive terminal based on the D2-MAC standard and exploiting the GPD protocol. Three parallel contracts were awarded: to Tandberg Telecom AS (N), Nokia Research Center (SF), and SAIT Systems (B).

The D2-MAC data receive terminal that has been developed consists, as shown in Figures 4a,b, of the following elements:
- a small dish antenna for reception of the satellite signal followed by a low-noise down-converter for frequency conversion
- a tuner/demodulator for tuning-in to the satellite channel and demodulating
- a standard personal computer equipped with a dedicated interface board for processing the D2-MAC signal based on commercially available decoder chip sets.

The first three elements are low-cost standard equipment items as used for satellite TV reception. The last element, the data receive interface board, was specially developed by each of the three contractor companies. Its basic functions are to:

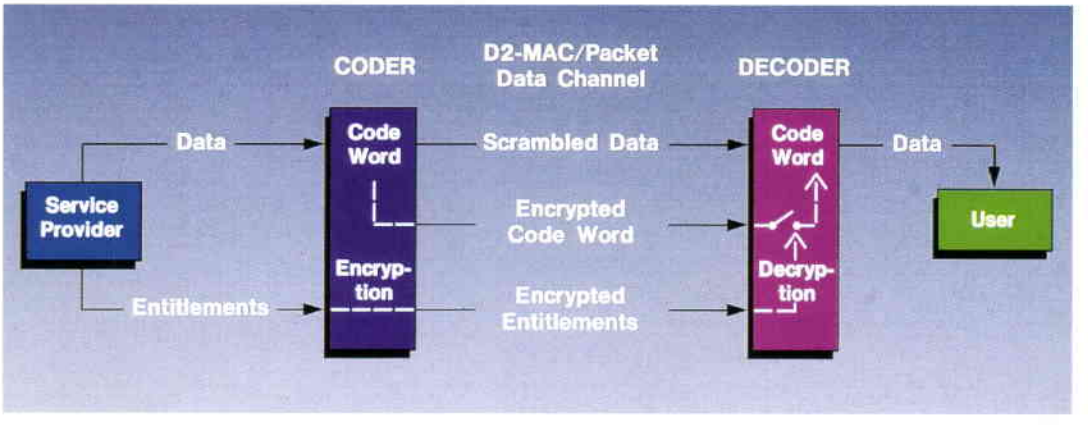


Figure 3. Principle of conditional access applied to data broadcasting

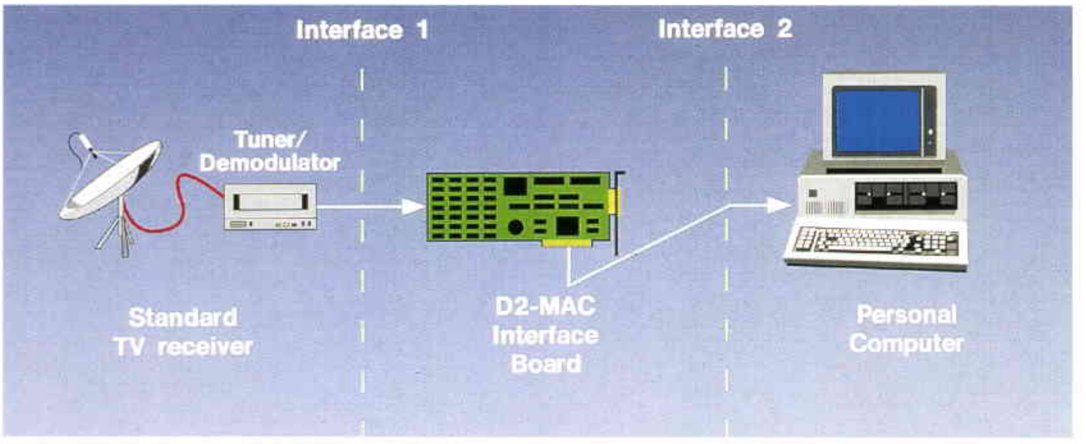


Figure 4a. Components of a D2-MAC data receive terminal

Figure 4b. A D2-MAC data receive terminal implementation. (In some implementations, the tuner/demodulator is integrated into the interface board). (Courtesy of Nokia Research Center, Finland)

- command the tuning-in to a satellite channel and receive the baseband D2-MAC signal
- process the D2-MAC signal, including selection of the desired data services
- descramble the signal if access rights are granted
- perform decoding and continuity checking if required
- buffer the data and interface it to the personal computer, thereby making the data available to the user's application software.

Definition of a data broadcast facility

The next step towards an operational data broadcasting system was the definition of the infrastructure required for data transmission. Based on initial market studies, the basic requirements for a data broadcast facility were identified and an architecture was defined.

The resulting transmit infrastructure is shown in Figure 5. The data provider's interface to the transmit facility is the transmit front-end, which is installed at his own premises. From here, data files are transferred to the data-broadcast facility via terrestrial lines, such as dial-up lines, the Public Switched Telephone Network (PSTN), the Public Switched Packet Data Network (PSPDN), or the Integrated Service Digital Network (ISDN), where available.

The data files are received from the different data providers by the data services front-end in the data broadcast facility. They are subsequently processed depending on the control parameters of the different data services chosen and are formatted into packets according to the D2-MAC GPD protocol.

Depending on the characteristics of the service requested, the data is sent to the D2-MAC encoder either:

- in real time
- in a store-and-forward mode, i.e. as soon as capacity is available, or
- in a scheduled mode, i.e. at pre-defined times.

The configuration and control unit contains knowledge of all data services and defines the transmission parameters of the D2-MAC encoder according to the data services requested.

The D2-MAC encoder multiplexes all data packets together with the television and sound signals. The output is the baseband D2-MAC TV signal, which is modulated and up-linked to the satellite.

Field trials and pre-operational phase

With the development of the prototype data receive terminals and a preliminary implementation of a transmit facility in 1991, the technical viability of a D2-MAC-based data broadcasting system was demonstrated by transmission and reception of D2-MAC data signals via satellite.

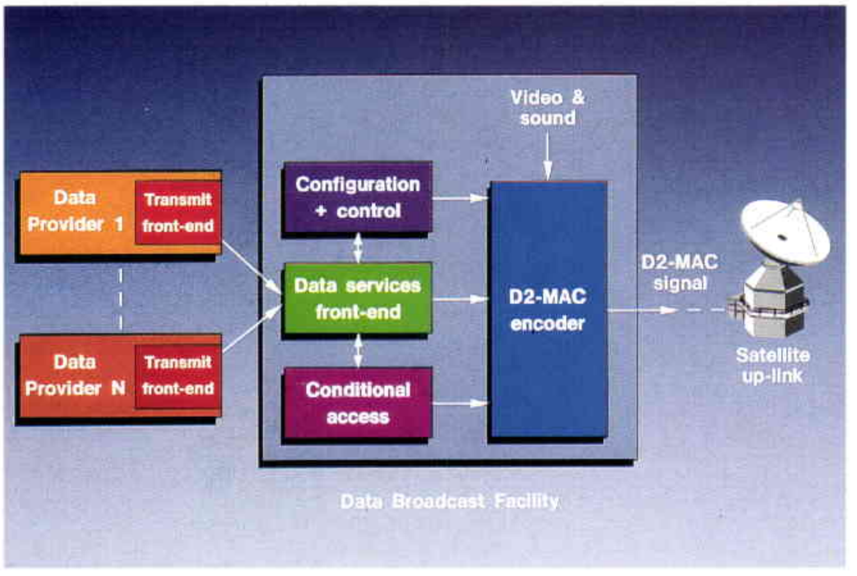


Figure 5. Structure of the D2-MAC data broadcast facility

The next step has been to validate the end-to-end system performance in a field-trials set-up as a basis for a future operational scenario. Therefore ESA has supported the field trials and will continue to do so up to the point where it becomes feasible for interested operators and service providers to engage in operational activities.

Various field trials were set up by Nokia Research Center and SAIT Systems and demonstrations of the overall data broadcasting systems started in March 1993.

Data broadcast facilities were built for the field trials and batches of 20 data receive terminals were produced. Typical applications were identified with communication requirements such as:

- fast delivery time
- broadcast topology
- high data volume.

The applications being supported in the field trials are:

- dissemination of Earth-observation images and related data from ESRIN
- news dissemination for ESMERK, a world-wide news and information-services company
- dissemination of tender information for the EEC
- updating of a medical images database for the University of Essen (D)
- dissemination of weather-forecast information for the Norwegian Meteorological Institute.

The field trials for the last application were initiated outside the ESA activities by Tandberg Telecom AS.

The ESRIN field-trial configuration can be considered to be the most complete and most intensively tested.

Dissemination of Earth-observation data: the ESRIN trials

In view of the growing demand for user network resources for data broadcasting, ESRIN has been evaluating the possibility of integrating VSAT technology into the general concept of its Data Dissemination Network (DDN). The new networking component was expected to serve broadcasting applications primarily originating from ESRIN, and had to cope with the dissemination of files of different types – text, images, binary – and originating from different missions, to a large European user community. An important requirement was to serve Earth-observation missions, with their demanding dissemination requirements in terms of high data volumes and short delivery times.

As part of its evaluation, ESRIN participates in the D2-MAC trials and defined an extended trial configuration. The ESRIN-specific development focused on the integration of data broadcast facilities and the PC-based data receive terminals into the DDN infrastructure. At the data-provider end at ESRIN, transmit front-end facilities were developed, acting as a server for interfacing the local data sources with the data transmit facilities via Wide Area Networks (WANs). At the receiving end, enhanced interface functions at the data receive terminal were implemented, together with an integration into the local computing infrastructure allowing the data to be received directly on a user work station (Fig. 6).

During the trials, ESRIN operates the local transmit front-end server for correct scheduling and forwarding of transmission requests originating from local data sources to two different data broadcast facilities, located in Belgium and the Netherlands (Figs. 7,8). From both transmit facilities, the D2-MAC signals have been up-linked to the same satellite, Eutelsat II at 16°E, but using different 11 GHz transponders.

Four stations located at ESRIN (I) and two in Brussels (B), with antenna diameters ranging from 90 to 120 cm, serve as receiving terminals.

Special attention was paid in the tests to dissemination requirements for emerging Earth-observation applications, particularly batch and on-demand dissemination of images of reduced resolution and related

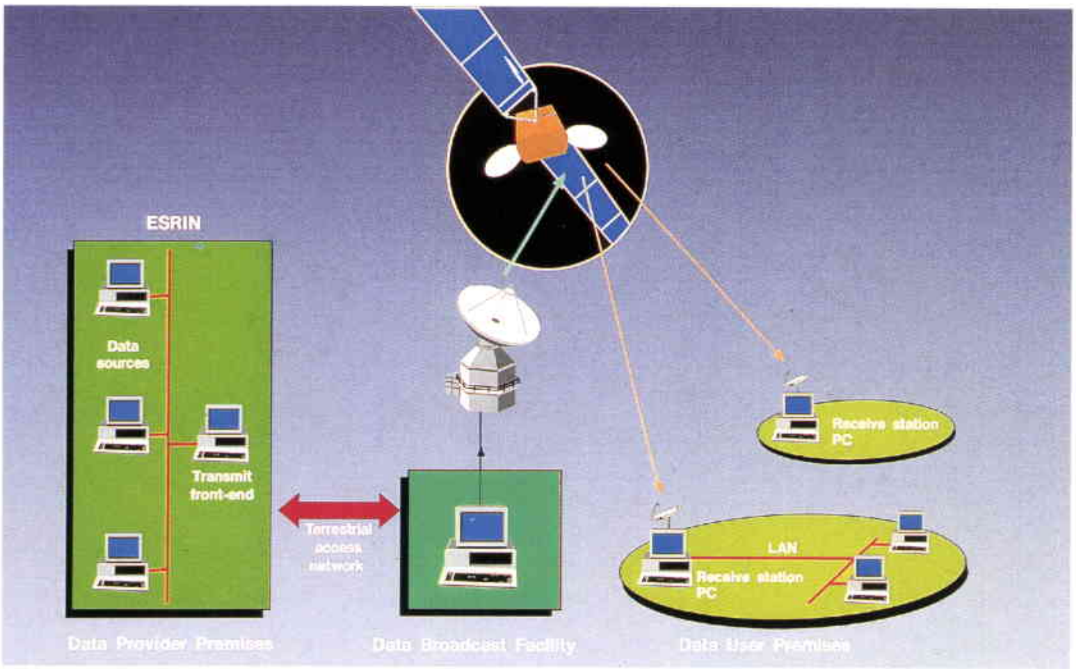


Figure 6. Schematic of the ESRIN field-trial configuration

data. Such applications typically require the broadcasting of between a few Mbytes and several hundred Mbytes of data per day to multiple user groups throughout Europe. Delivery-time requirements range from a few hours (fast delivery) to one or more days after acquisition by the satellite. User groups can also have overlapping data-broadcast applications, i.e. groups can be involved with more than one application at a time.

Examples of possible applications are:

- *Browse Ordering*, for the batched broadcasting (i.e. scheduled; typically daily) of Earth-observation satellite images at reduced resolution to assist in the pre-selection of full-resolution data for further analysis. Image data sets covering, for example, a particular user-defined geographical region can be made available in this way on a routine basis at the customer's premises for local browsing and the identification of images of specific interest. The appropriate full-resolution data product can then be ordered for delivery by separate means, such as a dedicated network.

- *Quick-Look Applications*: reduced-resolution images can be transferred to customers and used immediately for less-demanding analysis. Such data can be used, for example, by ships to monitor ice movements in the polar regions. Other applications include the monitoring of certain agricultural patterns.

During the field trials, the following features have been sucessfully tested:

- *Data transmission rates*
  A receiving rate of 150 kbit/s was achieved when the data was streamed to a local receiving terminal's hard disk. The maximum net data rate achieved by streaming to a terminal internal chip memory was around 250 kbit/s. This limit is presently set by the encoding speed of the data broadcast facility, which could potentially be upgraded to support 750 kbit/s.

- *Cyclic redundancy checking in combination with retransmissions*
  Trial broadcasts showed the potential for improving the reliability of the uni-directional transmission by identifying lost packets and by filling them in during a pre-configured number of retransmissions of the files.

- *Group addressing*
  Two different receiving terminals configured for different communities requiring different services proved the system's capacity to distribute data to closed user groups.

- *Simultaneous reception of different services*
  Trials have also been performed with simultaneous reception of two different services. A 64 kbit/s scheduled service, i.e. a service executed at the data broad-cast transmit facility during pre-defined time slots, and a 9.6 kbit/s real-time service, i.e. a service offering immediate broadcasting, have been received simultaneously at the same terminal.

Figure 7. Example of a D2-MAC encoder as used during the field trials (Courtesy of SAIT Systems, Belgium)

- *Volume of data broadcast*
  A daily satellite time slot of 1 h has been used to disseminate batches of approximately ten files of Earth-observation images. Individual file sizes have varied from a few bytes to 1 Mbyte.
- *Periodic broadcasting*
  Periodic transmissions of a data-broadcast facility news channel and an ESRIN news channel have been performed at 1 minute intervals. Such a service can be used for providing online information to the user community, information regarding for instance maintenance intervention, or any kind of message that relates to the operational procedures at the transmit front-end, the data broadcast facility or the receiving terminals.
- *Tele-maintenance*
  Software updates for the system have been disseminated from the data broadcast facility to the receiving terminals. This could offer the future possibility of tele-maintenance for the receiving-terminal software.

The results of the field trials have exceeded expectations and it has been demonstrated conclusively that network requirements for the applications tested at ESRIN can be matched with the D2-MAC data broadcasting system.

Commercialisation phase

After the successful demonstration of the technological feasibility and the positive results of the field trials, marketing efforts are being intensified and the focus is now on the commercialisation of the system. Currently, the systems developed are being refined taking into account the first results from the trials.

Another factor in the start-up of the commercial phase is the space-segment availability and associated cost. Three options are conceivable:

- A Data Broadcast Service (DBS) provider piggybacks with a D2-MAC TV broadcaster and uses his spare capacity based on a commercial agreement.

Figure 8. One of the Control Centres used during the field trials to up-link the D2-MAC signal to Eutelsat-II (Courtesy of PTT Telecom, Hilversum, Netherlands)

- A DBS provider rents his own satellite transponder and uses the television channel for business television, such as training videos or advertisement clips for very specific user groups. The spare data capacity could then be used for data broadcasting. This combination of services is attractive due both to their complementary nature and the sharing of space-segment and operations costs.

- A DBS provider could also use the whole transponder in the full digital mode for data broadcasting only.

The availability of the D2-MAC TV channels that can form the basis for such a piggyback arrangement is assured for the next three years. The final condition for the commercialisation of the service is the commitment of a service provider to engage in the business. A number of service providers are emerging in the marketplace and the company SAIT-Videohouse (B) is already offering a value-added D2-MAC data broadcast service.

Those offering such a service must consider:
- guaranteed availability of the space segment
- guaranteed service-level agreements
- operation of the data broadcast transmit facility
- operation of the satellite up-link
- set-up and maintenance of receiver stations
- operation of the terrestrial access lines to the data broadcast facility.

The chances of D2-MAC DBS providers establishing themselves in the market are good, as there are currently no other high-bandwidth broadcasting systems that could offer a comparable multitude of features. Moreover, the D2-MAC service has all the potential needed to be able to offer competitive pricing.

Hence, the D2-MAC Data Broadcast Service is expected to thrive, becoming more and more popular once the first commercial services are introduced. It has many potential applications, particularly for:
- news and information agencies
- environmental data networks
- the automobile sector
- the computer industry
- multi-national companies and organisations
- banking.

One of the first applications using a commercial D2-MAC DBS could be the dissemination of Earth-observation data as an extension of ESRIN's Data Dissemination Network (DDN).

Advantages of D2-MAC data broadcasting

- High data capacities are available in the D2-MAC signals.
- Data broadcasting can piggyback within the available space capacity of a D2-MAC TV transmission and thus share the same transponder and associated costs.
- Conditional access is supported.
- Individual users or user groups can be addressed.
- Inside the data broadcasting channel, various data services can be supported simultaneously.
- High service quality due to coding and re-transmission schemes.
- Upgrading to a future digital TV standard is possible.

Beyond D2-MAC

The work at ESTEC and ESRIN to date has shown that the D2-MAC system offers a technically valid and commercially attractive solution for high-speed data broadcasting for the coming years. At the same time, it constitutes a step towards the future, as it provides a foretaste of the data broadcasting possibilities that a future, fully digital TV system might offer.

When a fully digital TV standard becomes available, data broadcasting will be possible in a manner very similar way to that with the D2-MAC system, provided the necessary developments in terms of data receiver and data broadcast transmit facilities are pursued.

Efforts will be undertaken by ESA to develop a successor to D2-MAC data broadcasting compatible with a future fully digital television standard, so that the D2-MAC Data Broadcast Services launched today can be migrated to the new standard when necessary.

Focus Earth

Nimes and The Camargue

This ERS-1 image shows The Camargue, a large plain in Southern France, as well as the Cevennes foothills, which are part of the Massif Central. Towns and villages appear white. The city of Nimes is located in the top centre of the image and Arles is situated beside the River Rhone on the right-hand side. The Camargue, lying between the branches of the Rhone Delta, is a flat area with marshes and ponds. The fields, in which wheat and corn are cultivated, are generally small and delineated by ditches or dirt roads.

The dates of the three ERS-1 acquisitions were selected to coincide with the rice-growing season. The rice paddies appear purple, enabling a rapid estimate to made of potential rice production. The purple colour (a combination of red and blue, no green) shows that the backscattering level of the rice fields was high in mid-August (red channel) and at the end of October (blue channel), but low in mid-June (green channel).The large increase in backscattering between June and August is due to differences in the rice's phenological stage and to the presence of water in the paddy fields. In mid-June, the rice plants are at an early stage in their growth cycle (0 to 30 cm high, water surface partially covered by the rice canopy) whereas by mid-August they are in the final stages of growth (more than 60 cm high, completely covering the water surface). The fields are harvested before October and the high backscattering level in the end-October image is probably due to their roughness (no more water).

The contrast is high between the large fields in the plain and the vineyards and forests covering the valleys and hills in the top left of the image. The forests and shrubs on the hills appear grey because they exhibited similar radar backscattering levels on the three imaging dates.

Montpellier airport is visible in the bottom left and that of Nimes in the centre of the image. Airports are always easily identifiable in

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

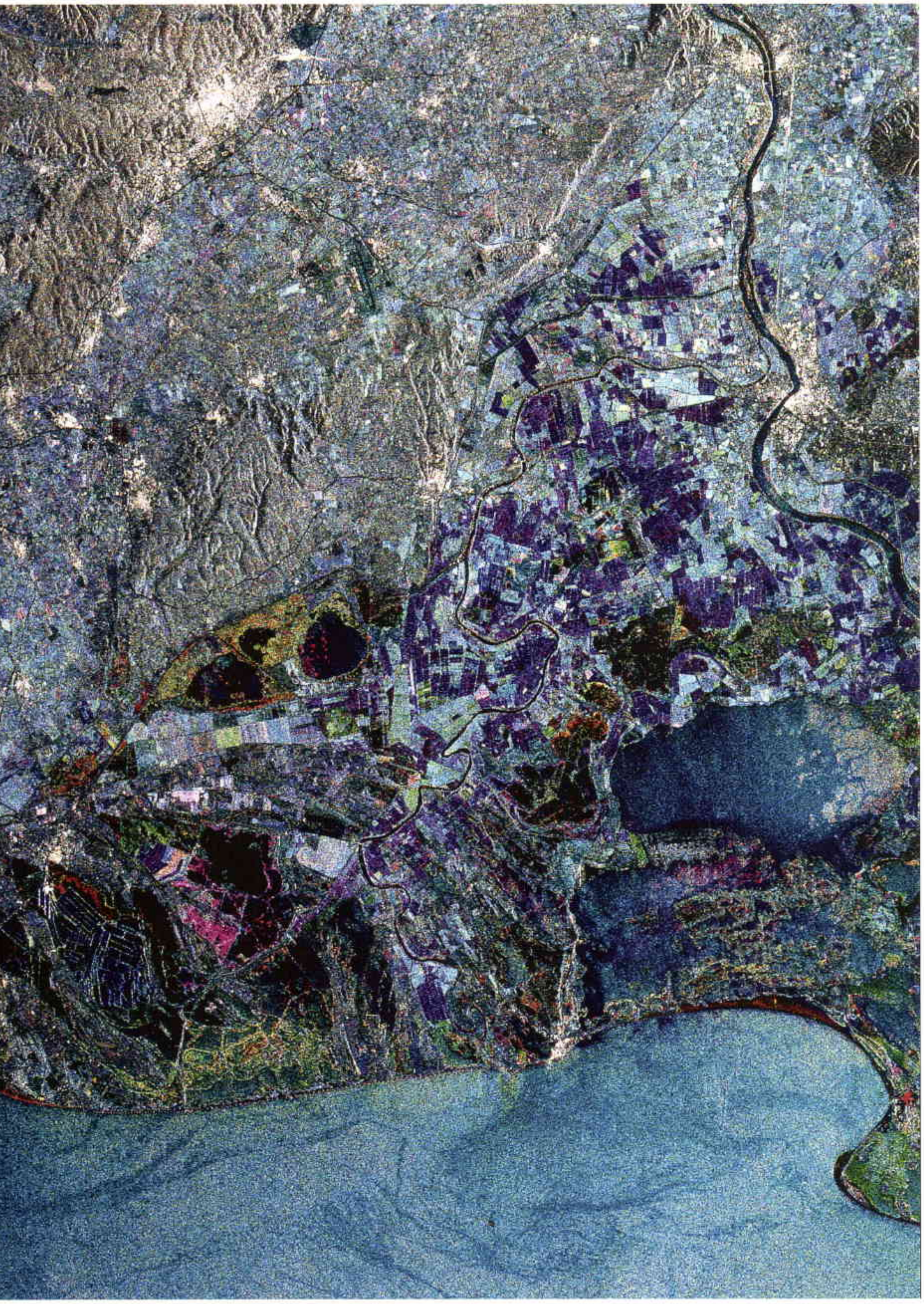
Eurimage ERS-1
Order Desk
ESRIN
CP 64
I-00044 Frascati, Italy

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

ERS-1 SAR images because the runways are smooth surfaces that appear as short black lines.

The sea appears blue because it was rougher on 31 October (date of blue-channel imaging) than on the two previous imaging dates.

Image characteristics
- Produced with Fast-Delivery Products acquired at the Fucino Ground Station (I)
- Processed by ESA/ESRIN
- Area covered 60 km x 60 km
- Dates of imaging: 13 June 1992, green channel; 22 August red channel; 31 October blue channel



Straits of Messina and Mount Etna

This JERS-1 image of the Straits of Messina and the Mount Etna volcano (Southern Italy) was acquired at the Fucino Ground Station (I) on 22 June 1992 and processed by ESA/ESRIN, Frascati (I).

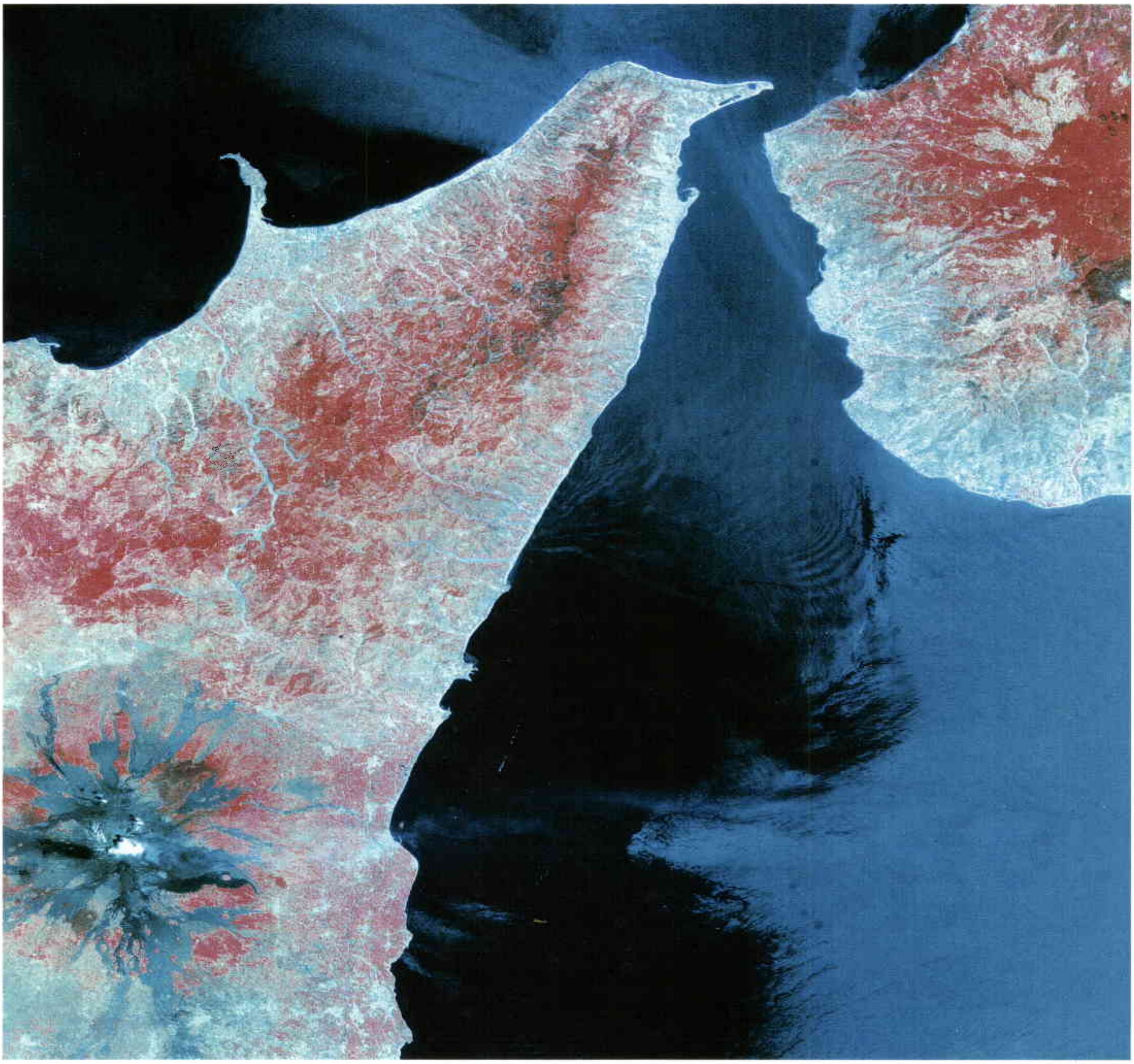
Japan's Earth Resources Satellite 1, launched by NASDA on 11 February 1992, carries a Synthetic Aperture Radar (SAR) and Optical Sensor (OPS) instrumentation. The latter is a high-resolution radiometer that measures solar radiation reflected by the Earth's surface in the visible, near-infrared, and short-wavelength infrared.

ESA has access to JERS-1 data via the Ground Stations at Fucino in Italy (OPS and SAR acquisition), Kiruna in Sweden (OPS only), Tromso in Norway and DLR's O'Higgins Station in Antarctica (SAR only).

Further information about the JERS-1 payload, available products and data-acquisition requests and planning is available from:

Third-Party Missions Service
Earth Observation Exploitation Division
ESRIN, 00044 Frascati, Italy

Tel. 39-6-94180371
Fax. 39-6-94180361



Very-Low-Temperature Cryogenics and Related Space Applications

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Future scientific instruments for space applications will require improved performances. This can sometimes be achieved by making such instruments last longer or physically bigger. The highest gains in performance, however, are often achieved when a new detection technique is introduced. In-house work at ESTEC is concentrating on developing such a new detection technique using superconducting technology, which requires cooling to temperatures a few tenths of a degree above absolute zero.

Introduction

Cryogenics is defined as 'the production and maintenance of very low temperatures, and the study of phenomena at these temperatures'. In the late 19th century, this would have been interpreted as the quest to liquefy oxygen at 90 K (90° above absolute zero or −183 °C). Nowadays, in research laboratories on Earth temperatures of 10^{-3} K (one thousandth of a degree above absolute zero) can be maintained for significant periods, while nuclear spin temperatures down to the nanokelvin range (10^{-9} K) have been briefly investigated. It is therefore not surprising that cryogenics has developed to serve a range of applications that stretches from the more mundane industrial cooling/freezing applications to rather more exotic applications which only manifest themselves at temperatures close to absolute zero.

As well as the cooling techniques necessary to achieve such temperatures, it is these more exotic applications that are of interest for this article and in particular their use in powerful new-generation spaceborne detectors. Before describing these applications and their potential cryogenic cooling methods in space, it is perhaps informative to briefly outline 'what goes on' at temperatures close to absolute zero.

'Quantum phenomena' near absolute zero

Most people would not expect physics to be any different at −270°C (3.0 K) by comparison with our everyday experience at temperatures of +270°C. In fact 3.0 K is two orders of magnitude lower than room temperature and should be compared with a temperature two orders of magnitude higher than room temperature, i.e 27 000 K! Here, intuitively one would wonder whether everyday classical physics is adequate to describe what is 'going on'. While not attempting to answer this question for 27 000 K, it is indeed the case that classical physics with its description of vibrating atoms is inadequate at 3.0 K, where phenomena associated with quantum-mechanical behaviour can be seen on a macroscopic scale.

So what is meant by quantum mechanical behaviour and why is it so strange? It is in effect only strange in that such behaviour is outside our realm of everyday experience. For instance, quantum mechanics predicts that an electron with an energy E_1 has a certain probability (sometimes quite high) of tunnelling through an energy barrier E_2, where E_1 is less than E_2. Or, in other words, on a macroscopic scale, this leads to the prediction that if somebody ran at a wall he would have a certain probability (fortunately infinitely small) of passing through that wall (i.e not feeling any resistance) and coming out on the other side! Such effects are not circus tricks and are entirely consistent with modern physics. In fact, they stem from a description of matter as a probability wave where, due to Heisenberg's Uncertainty Principle, the position and momentum of a particle can never be simultaneously known to a level of less than 6.63×10^{-34} Joule.s (Planck's constant).

Normally, such effects need only be considered at atomic or sub-atomic level in particle accelerators, for instance. By a quirk of nature, however, the pursuit of low temperatures has led to the discovery of superfluidity and superconductivity, which are both spectacular manifestations of quantum effects existing on a macroscopic scale. Superfluidity can loosely be described as a viscousless flow of liquid, and superconductivity as the flow of electrons (or electric current) without any resistance whatsoever.

Both phenomena relate to the fact that bound particles can only exist in certain well-defined energy levels, and at low temperatures most of the particles are in the lowest energy level (or ground state) where, to interact with the rest of the of the 'universe', they need to receive a precise amount of energy.

Such quantum phenomena have commercial applications (e.g. high-magnetic-field superconducting magnets for medical scanners), but are also fundamental to a new generation of powerful scientific detectors.

Detectors requiring very low temperatures

The most important application of Very Low Temperature Cryogenics (VLTC) in space is certainly that associated with the utilisation of cryogenic detectors, where one of the main benefits is simply noise reduction. If, for instance, we are interested in detecting very weak signals such as electromagnetic waves in the infrared, generated by the emission of only a few photons (the smallest indivisible packet of electromagnetic energy), then we have to be able to read above the noise level, which is often of the order of 1 eV.

Here it should be noted that the energy of a 1 eV photon corresponds to 10^{-19} Joules, or in other words to only one millionth of the energy required to lift one millionth of a gram for one hundredth of a millimetre! So it is obvious that in order to do this we are obliged to minimise all possible sources of noise, including the contributions of the detector and associated readout electronics. This can only be done by reducing the temperature, which lowers the wideband noise that is always present due to atomic vibrations. Typical astrophysical applications involve the detection of single photons randomly emitted by weak and distant sources. This therefore eliminates the possibility of adopting special noise-reduction techniques associated with periodic events.

However, the noise problem is not the only reason to work at very low temperatures, since many of the detectors exploit the 'quantum phenomena' which are only available at very low temperatures and which allow detectors not only to detect photons, but also to provide precise information on their energy content. The cryogenic detectors that are of interest for space applications are mainly electromagnetic-wave or nuclear-particle detectors and can be divided into five main sub-groups:

(i) Micro-calorimeters

Crudely speaking, a micro-calorimeter or bolometer is an extremely sensitive thermometer. It converts the energy absorbed by photons or nuclear particles into a temperature rise and then an electrical signal. Such detectors have been successfully exploited for the detection of infrared sources onboard the COBE (Cosmic Background Explorer, 1989) satellite, while excellent results have recently been obtained using bolometers as X-ray detectors in the 1–10 keV range where an extremely high resolution of the order of 0.1 % has been demonstrated. Typical operating temperatures for these types of devices range from 2.0 K down to 0.1 K, with the sensitivity improving as $T^{-5/2}$.

(ii) Photoconductive detectors

Photoconductive detectors have already been used aboard such satellites as IRAS (Infrared Astronomical Satellite, 1983) and will be used by ESA's Infrared Space Observatory (ISO), due to be launched in 1995. The most commonly used detectors are doped germanium crystals (Ge:Ga, Ge:Sb, Ge:Be), where at low temperatures and low photon fluxes the electrical resistance of these crystals is very high. Infrared photons of sufficiently high energy can ionise the doping atoms (impurities), generating charged particles (electrons or vacancies) and thereby enhancing the conductivity. The change in electrical conductivity is a measure of the photon flux, where the choice of the doping element controls the cut-off frequency of the detector. Typical operating temperatures are in the range 1.5–3.5 K.

(iii) Transition edge detectors

These are conceptually similar to bolometers, giving a drastic and very fast change in resistance on absorption of energy (photons or nuclear particles). Since the recovery time can be as fast as 10^{-9} s, these devices are of interest for high-speed applications and operate at temperatures of less than 1.5 K.

(iv) Superconducting Tunnel Junction Detectors (STJD)

These detectors consist of two superconducting films separated by a very thin insulating barrier (typically a few atomic layers thick), which favours quantum-mechanical tunnelling. The devices detect excess electrical charge, or 'quasi-particles', which are generated by the absorption of energy (e.g. photons, phonons, nuclear particles) via tunnelling through the thin insulating barrier. STJDs have enormous potential for X-ray and even optical/UV spectroscopy, due to their intrinsically high energy resolution (of the order of 0.07 % at 6 keV).

The STJs can also be used as mixers for sub-millimetre wave detection in heterodyne receivers following a process similar to that often used in a radio receiver. They feature very high sensitivities up to 500–1000 GHz, and several laboratories have demonstrated the advantages of these devices in comparison with traditional Schottky (semiconductor) diode instruments. ESA is actively working on developing such detectors for satellites like FIRST (Far-Infrared Space Telescope), which is one of the 'Cornerstone' missions of the Agency's Space Science: Horizon 2000 Programme. However, although the mixers can tolerate the relatively high temperature of 4 K, aluminium-based STJDs developed for X-ray or optical applications would need to operate at temperatures as low as 0.1 K (Table 1).

(v) Superconducting Quantum Interference Device (SQUID)
A DC-SQUID consists of a ring of superconducting material with two tunnel junctions in parallel. By proper biasing, when a magnetic field is applied a voltage change can be detected across the device with extremely high sensitivity. Fluxes as low as a few millionths of one quantum flux (2.07×10^{-15} Weber) can be detected. To give an idea of the sensitivity involved, such devices are used to detect the magnetic-field changes set up in the human body when a glass of water is being drunk.

Table 1

Detector	Temperature, K
Nb SQUID	4.2
Photoconductor	1.5–3.0
Nb SIS sub-mm	2
Transition edge	< 1.5
Nb STJ X-ray	1
Al SIS sub-mm	0.5
Nb STJ optical	0.3
Al STJ X-ray	0.2
Al STJ optical	0.1
X-ray bolometer	0.05

Scientific applications are innumerable and temperatures significantly below the superconducting transition temperature (less than 4 K) are required for operation.

In-house detector development activites
Within the Astrophysics Division of ESA Space Science Department at ESTEC, R&D activities are currently concentrating on the development of high-energy-resolution photon detectors based on Nb–Al–AlOx–Nb superconducting tunnel junctions. This programme has the goal of developing a new generation of high-resolution sensors with both spectroscopic and imaging capabilities from the X-ray band to the infrared. The choice of niobium as a superconducting material has been dictated by the availability of a relatively mature technology for the fabrication of niobium STJs, by the high critical temperature (T_c = 9.25 K), and by the resistance of Nb devices to thermal cycling.

Each detector is the final result of a complex fabrication route, which starts with the deposition (by sputtering in an ultra-high-vacuum system) of the base Nb film onto a sapphire substrate. The fabrication procedure continues with a further deposition of Al, followed by an oxidation phase (in a controlled oxygen atmosphere) responsible for the barrier formation. Finally, a top Nb film is sputtered over the AlOx barrrier. Once this original 'tri-layer' structure is formed, standard photolithographic procedures (patterning and etching) are applied, with the final aim being to shape the junctions properly and create the necessary contact leads.

Figure 1 shows a scanning-electron-microscope image of one of these detectors, which are typically 10 microns square and have film thicknesses of the order of 0.1 microns. At present, there are two main areas of activity: one is concentrating on the improvement of the spectroscopic performance of these devices, while the other is studying the possibility of developing imaging detectors based on arrays of single STJs.

The extension of the sensitivity window for STJ devices into the ultraviolet and optical range is also being studied. Figure 2 shows the response of a niobium STJ at 0.3 K pulsed with light at different wavelengths. These very recent experiments conducted at ESTEC have demonstrated that niobium STJDs are sensitive to the ultraviolet, optical and even near-infrared parts of the electromagnetic spectrum, and open up the way

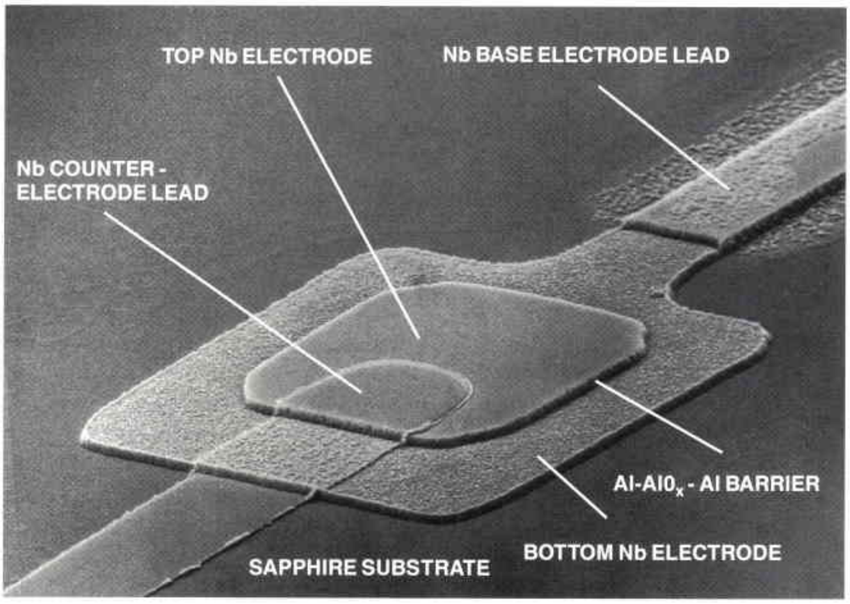

Figure 1. A Scanning Electron Microscope (SEM) image of an Nb junction (magnification x1000)

to new applications for superconducting tunnel junctions.

Future activities will involve new detector geometries with a view to achieving the theoretical spectroscopic capability. Further improvements in sensitivity and performance (particularly in the optical waveband) will be tackled through the introduction of new superconducting materials. The ultimate aim is to fabricate a camera based on superconducting devices.

Therefore, although not comprehensive, this list of applications already indicates the future importance of VLTC in space, and the extremely high scientific return possible at very low cryogenic temperatures. There are other potential applications needing VLTC in space, such as digital superconducting electronics, microwave components, high-intensity magnetic fields and superconducting motors, but these cannot be addressed here.

Potential very-low-temperature cryogenic cooling methods

While some of the applications mentioned above can function at temperatures close to 2 K and hence would benefit from present-day space cryogenic technology (see ESA Bulletin No. 57, February 1989), it is the new technology associated with the need for sub-1 K cooling that will stretch the ingenuity of future technology development engineers. We will briefly outline some of the terrestrial methods for obtaining such temperatures, before concentrating on ESA's present activities in this field.

Table 2 summarises the different methods normally used for obtaining sub-1 K temperatures on Earth. Unfortunately, it is impossible in such a short article to explain every method in detail and an extremely short summary of each could lead to confusion or, worse still, inaccuracies. Therefore we will concentrate on what we consider to be the two most promising methods for space applications.

The ^{3}He refrigerator

The most frequently used method for obtaining low temperatures is the evaporation of low-boiling-point liquids. ^{4}He cryostats can reach temperatures down to 1 K, while temperatures of 0.3 K are achievable on pumping a bath of liquid ^{3}He. Why is this?

The helium atom is spherically symmetrical and smaller than that of any other element. The only binding forces in the liquid are the Van der Waals forces, which stem from fluctuating polarisation charges induced in the electronic shells of adjacent atoms. These forces are weaker than in all other substances and so the critical and boiling points of helium are the lowest of all known elements. A pure quantum effect, so-called 'zero-point energy', leads to helium being the only element that remains liquid in a stable phase down to absolute zero. The ^{3}He atom, having an odd number of elementary particles, is a so-called 'fermion', in contrast to ^{4}He, which has an even number of elementary particles and is called a 'boson'.

The two different quantum statistics applicable to these atoms cause fundamental differences in their behaviours at low

Table 2

	Mechanical coolers		Helium refrigerators			Paramagnetic salt
	Stirling	Joule-Thomson	3He refrigerator	3He–4He dilution refrigerator	Vortex refrigerator	Adiabatic demagnetisation refrigerator
Temperature range	80 K–20 K	4 K–2.5 K	2 K–0.3 K	0.8 K–2 mK	1.8 K–0.7 K	20 K–2 mK
Cooling cycle	Continuous	Continuous	Intermittent	Continuous	Continuous	Intermittent

temperatures (see below), although their chemical structures and individual atomic sizes are exactly the same. In fact, the ^{3}He isotope has a higher zero-point energy than the ^{4}He isotope, which means that a ^{3}He atom in the liquid phase occupies a larger volume than a ^{4}He atom. One consequence of this is that at all temperatures the density of ^{3}He liquid is significantly less than of ^{4}He liquid. Hence, because the distance between neighbouring atoms is higher, the ^{3}He atom is less tightly bonded in its liquid phase than a ^{4}He atom, leading to a much higher saturated vapour pressure than for ^{4}He at the same temperature. This higher saturated vapour pressure means that, for a fixed pumping speed, lower temperatures can be reached with ^{3}He than with ^{4}He.

Unfortunately, the idea of flying a cryostat full of ^{3}He is out of the question, as all commercially available ^{3}He is obtained through the radio-active decay of tritium and costs approximately $100 per stp gas litre; in other words, 150 million US$ for a 2200 l ISO-like charge of helium, which also happens to be about half of the world's current stock! Therefore, all developments of ^{3}He technology for space (and even Earth) applications concentrate on closed-cycle methods, i.e methods that re-cycle the ^{3}He.

The ^{3}He–^{4}He dilution refrigerator

In 1962 a new proposal for continous refrigeration with liquid helium to temperatures lower than 0.3 K was published by H. London et al. In contrast to the helium refrigerators discussed above, where the latent heat of evaporation is used for cooling, it was proposed to use the heat of mixing of the two helium isotopes to obtain low temperatures. Das, De Bruyn-Ouboter and Taconis from the University of Leiden (the same University that discovered superfluidity and superconductivity) built the first refrigerator based on this principle in 1965 and achieved a temperature of 0.22 K. Such refrigerators are called ^{3}He–^{4}He dilution refrigerators, and the minimum temperature achieved by this method is about 2 mK, in 1977, by Frossati et al., formerly at Grenoble and now at the University of Leiden.

The fundamental principles are as follows. It is possible to dilute ^{3}He atoms into an almost pure ^{4}He liquid phase down to $T = 0$ K, because the binding energy of a ^{3}He atom in a dilute ^{3}He–^{4}He liquid phase is higher than in a pure ^{3}He liquid phase. Also, the difference in enthalpy between a concentrated ^{3}He–^{4}He mixture and a dilute ^{3}He–^{4}He mixture provides a cooling mechanism almost down to $T = 0$ K. This result stems from quantum-mechanical effects, namely the different zero-point motions of the two isotopes and the different statistics that have to be applied to understand their properties.

As already noted above, the isotope ^{4}He is a boson with a nuclear spin $I = 0$ and therefore it obeys Bose statisitics. Such a Bose liquid undergoes a so-called 'Bose condensation' in momentum space when its temperature is reduced, and for liquid ^{4}He this corresponds to its transition to the superfluid state. At $T < 0.5$ K, liquid ^{4}He is almost totally condensed into its quantum-mechanical ground state, where there are essentially no excitations (phonons, rotons) left. Its viscosity, entropy and specific heat go to zero. The rare and lighter isotope ^{3}He with its nuclear spin $I = 1/2$ is a Fermi particle and obeys Fermi statistics. In a helium mixture, the ^{4}He component acts as an inert superfluid background, which contributes to the volume of the liquid and to the effective mass of the dissolved isotope ^{3}He. In this description of the helium mixture, ^{3}He is treated as an interacting quasi-paticle Fermi gas with a pressure equal to the osmotic pressure of ^{3}He in ^{4}He. The calculated enthalpy of ^{3}He in the dilute phase is larger than in the concentrated phase. Thus, when ^{3}He atoms are transferred from the concentrated phase into the dilute phase of a phase-separated mixture, cooling will result according to the enthalpy difference of the two phases.

Although commonly used in low-temperature laboratories on the ground, a version

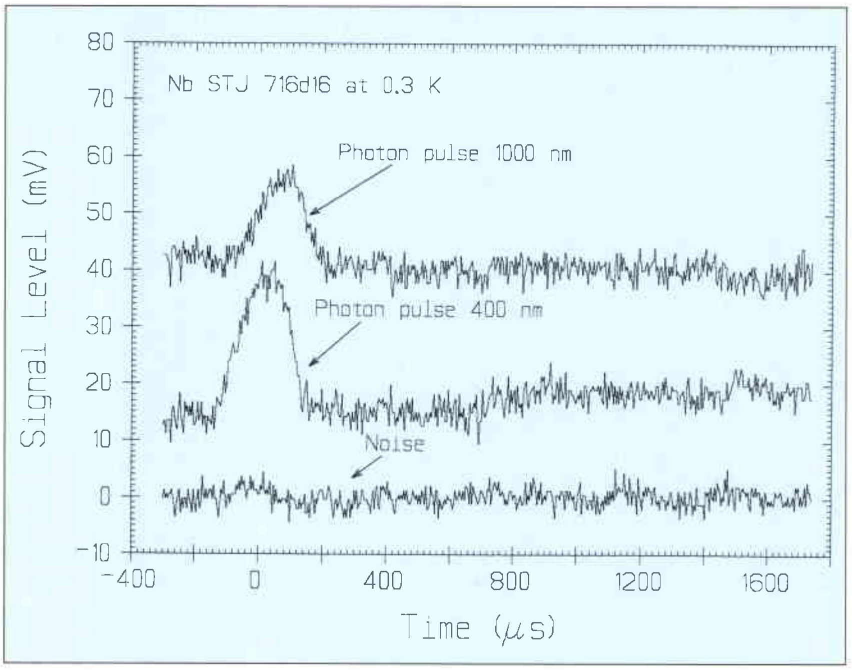

Figure 2. Response of an Nb Superconducting Tunnel Junction (STJ) to light pulses of 1 μs duration ranging from the ultraviolet to the infrared

compatible with use in space has suffered from the major problem associated with the separation of the ^3He-rich and ^4He-rich phases in microgravity. A promising idea for overcoming this problem (from Benoit et al., Grenoble) is under consideration. Therefore the possibility of fulfilling even the most demanding cooling requirements of the new generation of scientific detectors could soon be realised.

Very-low-temperature cooling developments at ESA

Since the background temperature of space is only 3° above absolute zero, it is strange that cryogenic cooling in space should cause any problems at all. In fact, as outlined in more detail in a previous Bulletin article (see ESA Bulletin No. 62, May 1990), the satellite is normally kept at around room temperature, and this leads to the same requirements with respect to thermal isolation. However, survival of the launch environment normally entails the design of a mechanical support that is far from thermally optimal, and constraints on mass and power make the task even more complex.

Since the early 1970s, liquid cryogen cooling has been the favoured choice for low-temperature cooling in space, but by its very nature it is an extremely 'heavy' solution. Therefore, since 1986 the ESTEC Thermal Control and Heat Rejection Section has concentrated on developing alternative cooling options, known as 'cryocoolers'. Cryocoolers are somewhat like the household refrigerator, converting electrical power into cooling. A development programme with Rutherford Appleton Laboratory (RAL, UK) and British Aerospace has recently seen space-prototype cryocoolers operating at 2.6 K, and work aimed at achieving temperatures as low as 0.4 K with a cryocooler has been initiated within ESTEC. While it should be mentioned that ^3He refrigerators for balloon, sounding-rocket and space applications have been built elsewhere, the work at ESTEC is based on the more difficult problem of developing such a cooling mechanism attached to a cryocooler. This leads to the potential of cooling to 0.4 K for an 'affordable' system-level cost in terms of both mass and power over several years of operation.

The ^3He refrigerator is built up from an adsorption pump and an evaporator, connected via a heat exchanger by two thin-walled pumping tubes and two bellows, which accommodate thermal contraction on cool-down (Fig. 3). The refrigerator is charged with 2 l of ^3He gas at room temperature, at a pressure of 67 bar, and permanently sealed. It is operated from two cold heat-sinks using two gas heat switches and one heater.

Operation begins by cooling the pump and the evaporator to 4 K and 1.5 K, respectively. At this moment all the ^3He is adsorbed by the pump adsorbent. Then the refrigeration cycle starts by heating the pump to about 35 K. The ^3He gas is driven out of the pump chamber and pre-cooled in the 4 K heat exchanger before it condenses into the 1.5 K evaporator. After condensation is complete, the pump is cooled to 4 K and therefore starts to pump the ^3He gas. The evaporator temperature drops to around 0.4 K and refrigeration is produced until all the liquid is evaporated, at which time the refrigerator has to be recycled.

In designing this ^3He refrigerator for space applications, one of the principal technical problems is the containment of the liquid. Containment alone, however, is not the whole problem. The confinement system must also allow for condensation of the ^3He vapour, with close thermal contact between the system to be cooled and the condensed ^3He liquid, which is very important for effective evaporative cooling. One solution to these problems is the use of surface tension in adsorbing a liquid into the voids of a porous medium. Although surface-tension methods have been used for controlling fluids in space, the low temperatures and low surface tension of ^3He require special considerations. The main concerns with capillary confinement are whether the vapour can be condensed into the porous matrix without leaving large voids, and whether the liquid can be evaporated from the sponge without forming bubbles that would expel liquid. Any expelled liquid would reduce the quantity of liquid available for cooling, and hence useful operating time.

Another problem is that of structural requirements. There is a trade-off to be made between minimising the heat input through the structure and sizing this structure to survive the static and dynamic launch loads. Furthermore, the use of copper, one of the favourite materials in the design of terrestrial ^3He refrigerators, is severely restricted because of its high density and very poor mechanical properties. Aluminium has some excellent thermal/mechanical properties, but below a temperature of 1.17 K it becomes superconducting, with the associated phenomena of magnetic-flux trapping that can affect very sensitive detectors. Lowcarbon-content stainless steel offers excellent mechanical properties at low temperatures, together with a very low thermal conductivity, and can therefore be used for structural support. As a result of this qualitative discussion, the refrigerator is designed with a pump and a heat exchanger in copper, an evaporator porous matrix in copper, a radiation heat shield in aluminium, and all pumping tubes and structural elements are in stainless steel. Some other design parameters of the ^{3}He refrigerator are outlined in Table 3.

At present, the new ^{3}He refrigerator design is being manufactured at ESTEC and testing is due to start by the end of this year, with the goal of having a running 0.4 K cryocooler by the end of 1994. A prototype version of this cooler is shown in Figure 4.

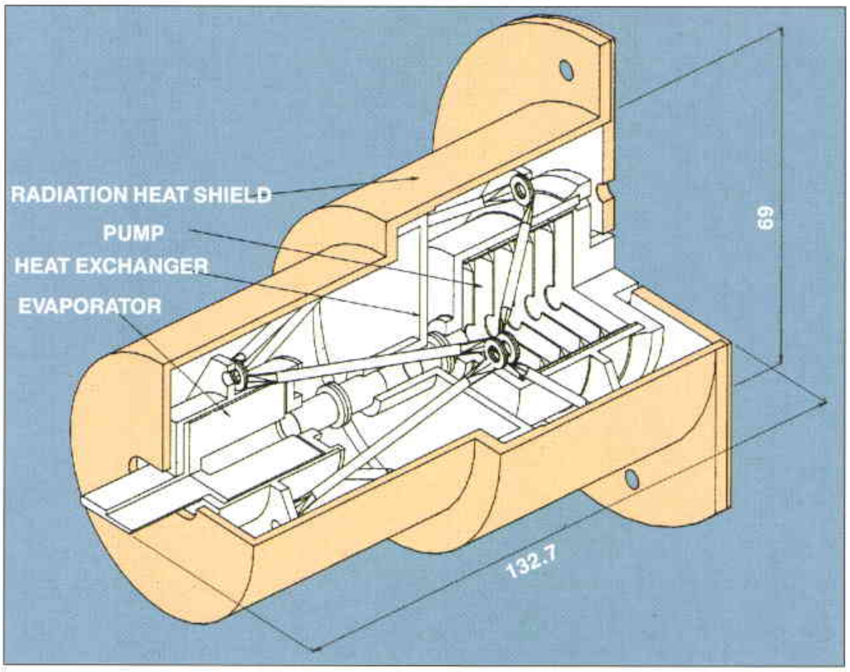

Figure 3. The ESTEC ^{3}He refrigerator

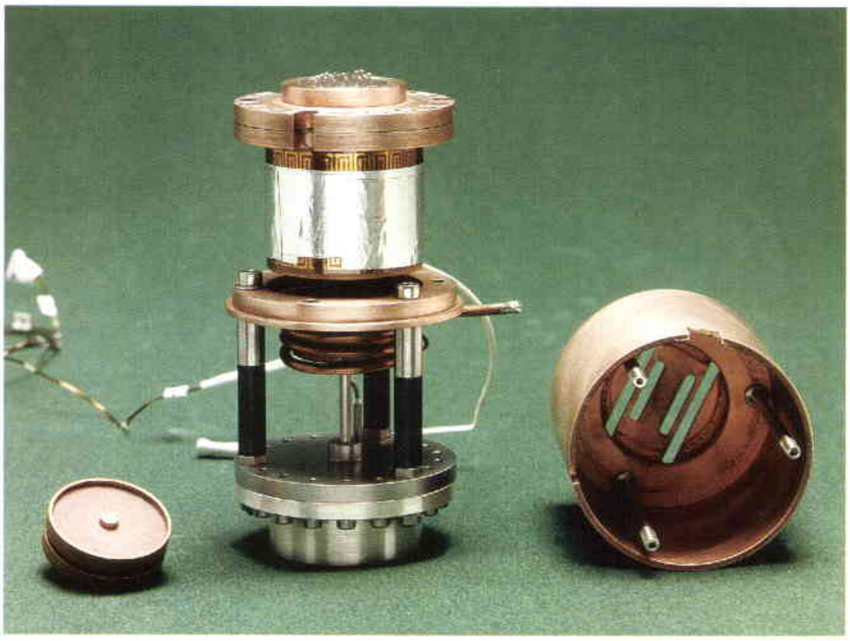

Figure 4. Prototype of the ^{3}He refrigerator

Table 3

3He charge at 273 K	2 litre STP (0.27 mg)
Filling pressure at 273 K	67 bar
Adsorbent	7 g of activated charcoal
Pump volume	27 cc
Pumping tube volume	1.5 cc
Evaporator volume	3.5 cc
Size, diameter × length:	69 mm × 132.7 mm
Total mass	< 550 g
Pumping tubes	diameter 6 mm thickness 100 µm
Structural tubes	diameter 2 mm thickness 100 µm
First resonant frequency	466 Hz

Conclusion

When considering the cost to the satellite system, cryogenic cooling is to be avoided whenever possible. However, it seems clear that many future scientific detectors will need such cooling with temperature requirements that push the present-day temperature limit of 1.6 K in space down to approximately 0.1 K. In fact, it is considered that many excellent proposals have never been submitted because of the known lack of cooling technology at such low temperatures in space.

Both the detector and cooling requirements are extremely demanding and imply that the development of the detectors and cooling mechanism must go somewhat 'hand in hand' with a good appreciation of each other's problems, e.g. cryocooler microphonics and its effect on detector system noise. At present, this is being achieved at ESTEC where work is being done within both the Astrophysics Division and the Thermal Control and Heat Rejection Section.

Acknowledgements

Although it is impossible to personally thank everybody involved in the above development effort, we would particularly like to mention: the ESTEC Workshop and Design Office, the laboratory staff in both the Astrophysics Division and the Mechanical Systems Laboratory at ESTEC, and Oxford Instruments (UK).

Membrane Technology for Gas-Water Separation: Applications and Concepts

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On Earth, the separation of mixtures of gas and water is usually very easy: gravity and the large difference in density ensure that, after sufficient time, all water collects at the bottom of a vessel while the gas rises to the top. Such gravity assistance does not exist in space and therefore special devices must be applied for phase separation. One concept, membrane technology, which is rapidly being developed for terrestrial purposes, offers great potential in microgravity. A two-membrane filter, which is used in medicine, was recently tested on a parabolic flight and it is expected that its development for space purposes will continue.

Gas-water separation in space systems
On Earth, the separation of mixtures of gas and water is usually very easy: gravity and the large difference in density ensure that, after sufficient time, all water collects at the bottom of a vessel while the gas rises to the top. Such assistance from gravity does not exist in space. In spacecraft, there are two categories of gas-water mixtures, divided according to the different appliances used for their separation:

— Relatively small amounts of water carried along in an air stream can be found, for instance, in the condensate outlet of a condensing heat exchanger or in waste water collection devices. Different types of water separators collect the water in a storage tank and return the water-free air to the cabin of the spacecraft. Condensate and waste water separators are standard components in life support systems for crewed spacecraft.

— At the other extreme, undesired gas bubbles can occur in the water lines of, for example, cooling systems or at the outlet of fuel cells. Gas traps ensure that these gas bubbles do not enter narrow passages which they might block, and they protect sensitive components like water pumps whose performance deteriorates when gas bubbles become caught in them.

Gas traps are needed in the water cooling loops of space suits and space stations. When wearing a space suit, the astronaut is cooled by a liquid cooling garment which consists of many metres of flexible plastic tubing. Gas can permeate the tubing and therefore regular removal of gas bubbles is required. In a space station, gas bubbles in the water loop are created by slow chemical processes. They can also be introduced during servicing of the water loops, for example, during the exchange of life-limited components.

Experiments performed in microgravity also have both types of requirement for gas-water separation. For example, a gas trap must be included in the water cooling loop of the Zone Melting Furnace experiment that ESA is presently developing. The experiment is being designed to operate over long periods in a space station. The exchange of components required during servicing will lead to the introduction of undesired gas bubbles that have to be removed before the loop can enter into operation again. A gas trap also proved to be necessary in another experiment, an electrophoresis experiment that was to be flown on a sounding rocket. During electropheresis, the production of gas electrolytically cannot be avoided. The absence of gravity would leave the generated gas bubbles dispersed within the liquid phase where they would cause intolerable disturbances to the separation processes.

Concepts for gas-water separation in microgravity
There are two basic principles for achieving a separation of gas and water in space: artificial gravity and selective processes.

Artificial gravity separators
At present, artificial gravity is widely applied in centrifugal waste and condensate water separators: the air-water mixture enters a rotating drum and the centrifugal forces push

the water toward the drum's circumference. Due to the static and dynamic pressure of the water, a tube extending into the rotating water layer can collect and remove the water, placing it in a storage tank. The principle behind a centrifugal water separator is shown in Figure 1.

The advantages of a centrifugal water separator are that a very high water-removal efficiency can be achieved and the separator delivers the water already under pressure, without requiring additional pumps. Centrifugal water separators are usually integrated with a fan, which is necessary to provide an air flow. The drawbacks of such a separator are its power consumption, limitations on its life time and the induced vibration levels of the rotating machinery, as well as the contamination sensitivity, especially of the small-bore water collection tube.

The vortex separator, another type of separator based on the artificial gravity principle, does not have any moving parts but exhibits a lower separation efficiency. This principle is applied in the gas trap of the Russian Orlan DMA space suit. The gas trap collects the gas bubbles which must be vented to the ambient air through a manually activated valve before the space suit is used.

Selective process separators
The principle of selective processes has been applied in the form of various hydrophilic (water-attracting) and hydrophobic (water-repelling) screens, plugs and membranes. They do not have any moving parts but they all require a pressure differential or a pumping action for operation. In addition, chemical and microbial contamination have to be controlled.

A hydrophilic material is easily wetted by water. Such material can therefore be used to collect and separate water while it retains gases. This method is used in the gas trap in the U.S. space suit. It, however, has a drawback: the gas bubbles retained on the hydrophilic screen have to be removed by a water-bleed stream, and another gas-water separation step is then required. The gas-water stream from the gas trap in fact constitutes a significant load on the water separator.

Hydrophilic material is used in another way in the Russian Orlan DMA space suit. A porous, hydrophilic plug is placed at the outlet of the condensing heat exchanger. The air flow is deflected in such a way that water droplets being carried along in the air flow will come into contact with the plug. The hydrophilic plug absorbs the water. The water collected is then drawn into a sublimator and is used to reject heat from the space suit. The space vacuum, to which the external surface of the sublimator is exposed, provides the pressure differential necessary to remove and transport water through the plug. While the hydrophylic plug is compact and has no moving parts, it can only operate when the astronaut is in a vacuum. Condensate removal during operations in a pressurised environment, for example, in the airlock during preparations for Extra-Vehicular Activities (EVA), requires additional absorbers.

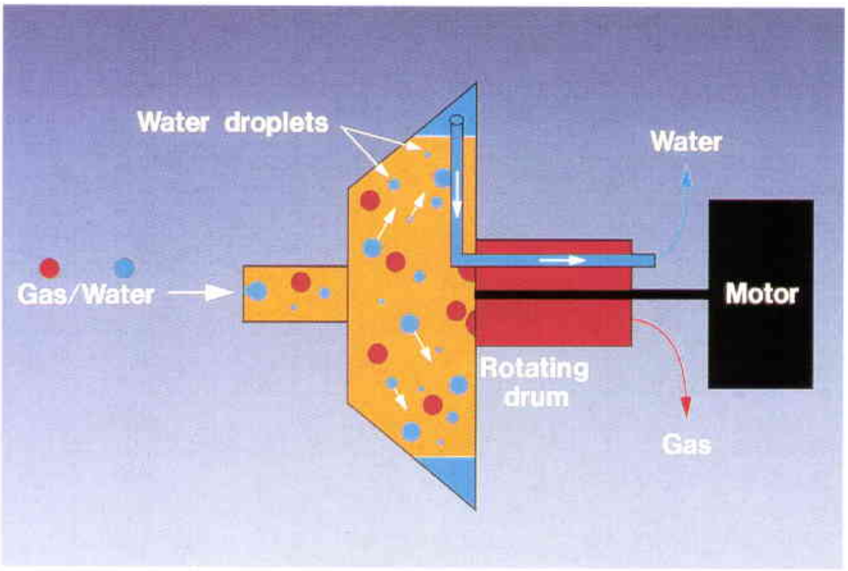


Figure 1. Principle behind a centrifugal water separator

Hydrophobic membranes, such as GoreTex which is widely used in protective clothing, are not wetted by water. They retain liquid water while allowing gases to pass through. Hydrophobic membranes have been applied in the form of hollow fibres to remove gas bubbles from liquids. This technology is available in Europe and is being used, for example, in the previously mentioned electrophoresis experiment that is flying on sounding rockets.

The principle underlying a gas trap based on a hydrophobic membrane is shown in Figure 2. The water-gas mixture passes over a bundle of hydrophobic hollow fibres. Due to a pressure differential, the gas passes through the membrane and is rejected to the ambient air, while the degassed water re-enters the water loop. An apparent disadvantage of hollow fibre bundles is their rather high water-flow resistance.

Two-membrane gas-water separator
An interesting concept for gas-water separation by a membrane device is to use a

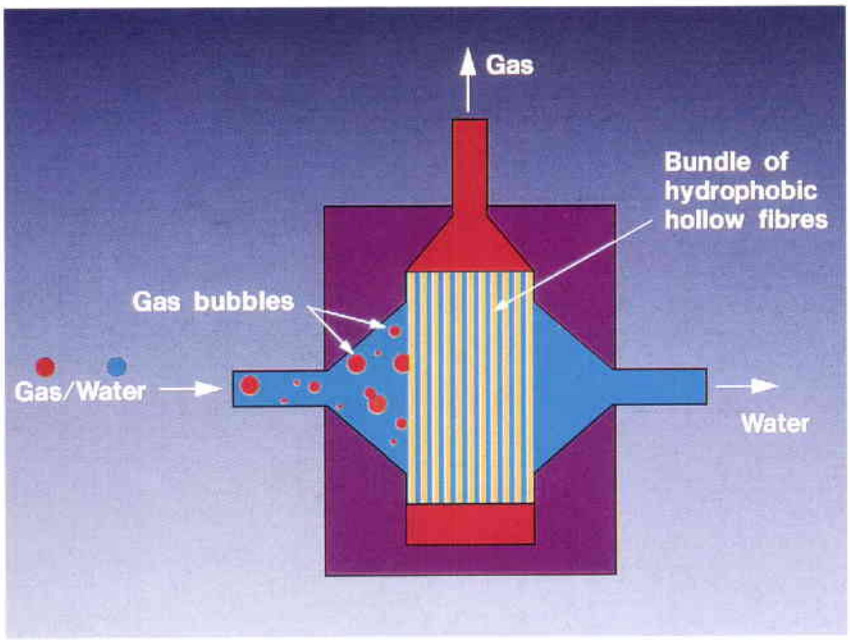
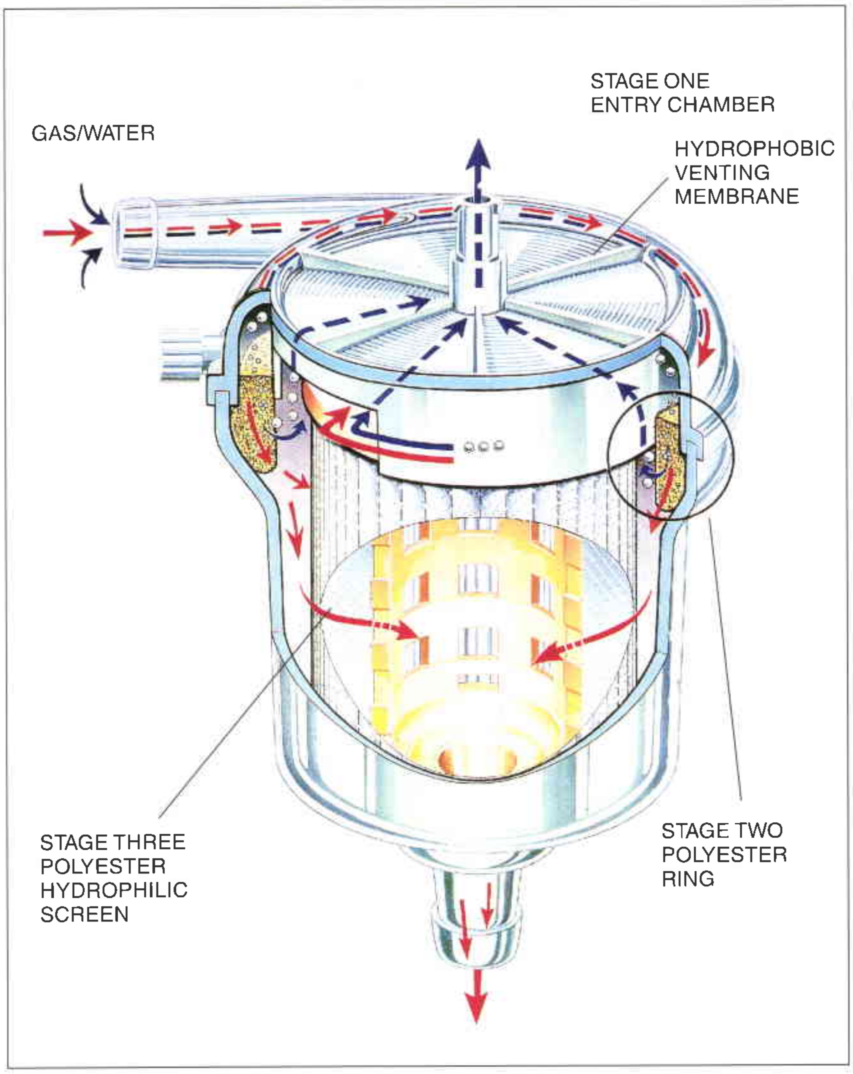


Figure 2. Principle behind a hollow-fibre gas trap

Figure 3. Principle behind a two-membrane gas-water separator
Photo: Pall (D)



combination of a hydrophilic and a hydrophobic screen. The hydrophilic screen retains gas and lets water pass while the hydrophobic membrane allows gas to escape to the ambient air without water carryover. With such a device, a secondary gas-water separation is no longer required.

Such devices are already being used in heart surgery, where they prevent gas emboli from entering the blood circulation of a patient connected to a heart lung machine. Figure 3 shows the principle behind such a device. The gas-water separation process occurs in three stages:

— In the first stage, the gas-liquid mixture enters the entry chamber of the filter tangentially, where centrifugal forces separate it into gas and liquid. These forces push the air bubbles toward the middle of the entry chamber where the hydrophobic venting membrane is located. Gas bubbles that come into contact with the membrane are released towards the ambient air. As a driving force, a differential pressure over the membrane of approximately 200 hPa is required.

— Some small gas bubbles remain in the water flow. The water flows through a hydrophilic foam ring (Stage two). The ring helps to coalesce the gas bubbles and retains them in the upper part of the filter.

— However, the tiniest bubbles, with a diameter of only a few microns, can also pass through this ring. They are then trapped by a hydrophilic screen (Stage three). The water flows through the screen and leaves the filter through the bottom of the trap.

On the ground, gravity will drive the gas bubbles toward the hydrophobic venting membrane located at the top of the filter. In microgravity, the retention capability of the hydrophilic screen becomes more important. It must be able to eventually retain bigger gas bubbles and allow them to grow large enough to come into contact with the hydrophobic venting membrane, in order for them to be released toward the ambient air.

A gas trap based on the two-membrane principle is presently being developed for the water cooling system on the Space Station 'Freedom'.

Parabolic flight test of two-membrane separator

In the existing design of the two-membrane separator, gravity assists in directing the gas bubbles toward the hydrophobic membrane through which they are vented to the ambient air. Since gravity assistance is not available in space, it was necessary to test whether the centrifugal pre-separation and the retention capability of the hydrophilic screen would be sufficient to ensure that the separator also operates successfully in microgravity. The test would clarify if a fundamental redesign would be necessary or whether the existing design could be used with only minor modifications.

It was decided to test the filter that is currently being used in heart surgery on a parabolic flight. This would allow the filter to be tested under many different conditions at a low cost. A typical ESA parabolic flight campaign consists of three flights with 30 parabolas each and with breaks between the parabolas to allow experimental parameters to be adjusted. Each parabola provides about 20 seconds of microgravity. An external contractor built a small test rig just in time for an ESA-sponsored parabolic flight campaign in Bretigny (F) in March/April 1992. The test rig (Fig. 4 and 5) allows the filters (Fig. 6) to be tested at different water-flow rates, pressures and gas/water mixing ratios, and to detect gas bubbles breaking through the hydrophilic screen into the water outlet. During the parabolic flight campaign, the parameters were varied to test the gas trap scenario as well as the water separator scenario, although the gas trap was not optimised for the latter application. Two gas traps with hydrophilic screens of different pore size and different resistance against gas breakthrough into the water outlet were tested.

The test results for the filter with the denser hydrophilic screen are summarised in Figure 7. The combinations of air flow (injected into the circulating water) and relative pressure (toward the ambient air) at which tests were conducted are indicated. The probability of a gas breakthrough increased with a higher air-flow rate and lower differential pressure: low relative pressures will not be sufficient to drive a high gas flow through the hydrophobic venting membrane so that gas will be pushed into the lower part of the filter, toward the hydrophilic screen. Gas bubbles could block the passage of water through part of the screen, resulting in an increased differential pressure over the hydrophilic screen. Once a

Figure 4. The gas trap during testing on a parabolic flight

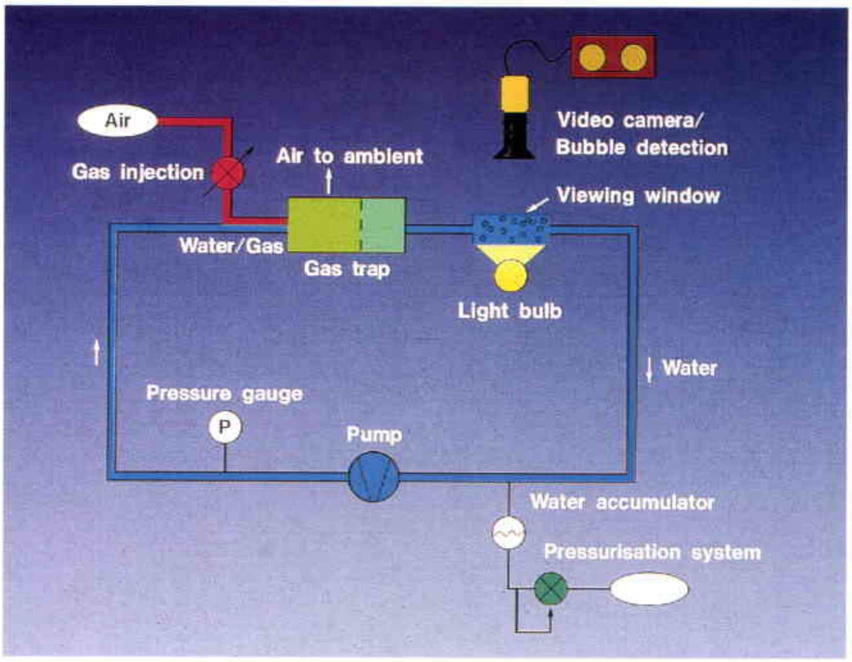


Figure 5. Fluid schematic of the gas trap used during testing on parabolic flights

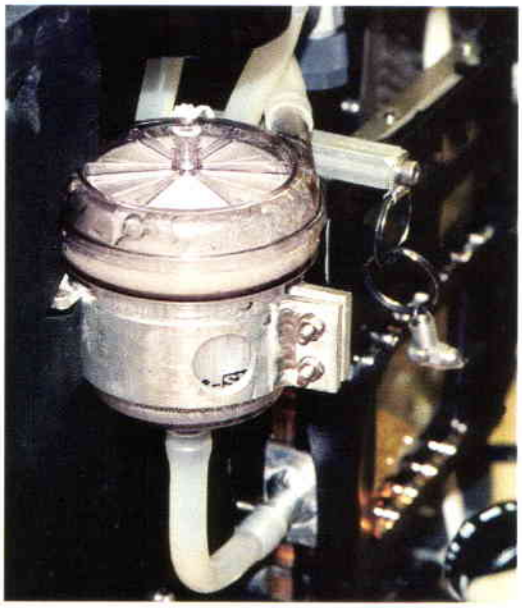


Figure 6. The two-membrane filter during testing. The viewing window is on the bottom right. The ring is a simple zero-gravity indicator: it floats in the absence of gravity.

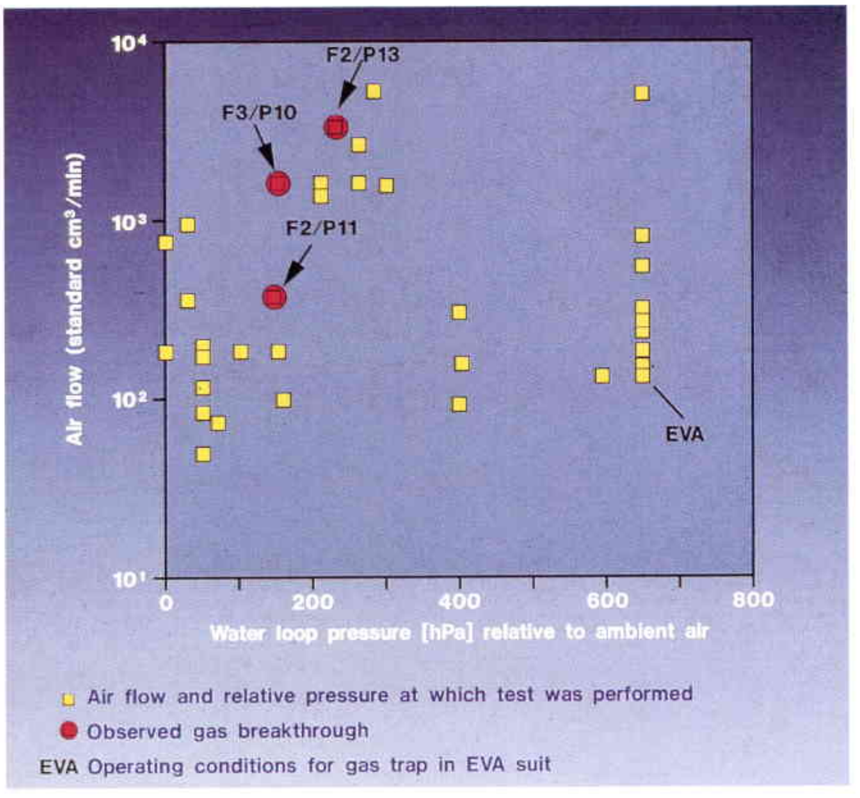


Figure 7. Results of the functional test of a two-membrane filter in microgravity

critical pressure is exceeded, gas breakthrough into the water outlet will occur. The water-flow rate had also been varied during the test but was found to be of minor influence.

In total, 45 tests were carried out on this filter and only three significant gas breakthroughs were observed. The breakthroughs occurred at relatively high air flows (more than 0.5 l/min) and low differential pressures. These conditions are comparable to those in the water separator application: a gas trap would operate under conditions of higher relative pressure and lower gas-flow rates. As an example, the gas trap used in the European space suit is supposed to handle gas flows of less than 0.1 l/min at a differential pressure of 650 hPa. Eleven tests at these conditions did not result in a significant gas breakthrough. Only a few gas bubbles were released during the first flight; they are thought to have been caused by gas trapped in the filter during filling. For the filter with the less dense hydrophilic screen, gas breakthroughs occurred more often and at a lower air-flow rate and a higher differential pressure.

From the parabolic flight tests, it can be concluded that the filter configuration that was tested is suitable for the gas trap application in microgravity without any major modifications. The test results for the water separator application (high airflow, low differential pressure) are promising but an optimisation of the membranes and filter configuration is necessary: a denser hydrophilic screen with a better resistance against gas breakthrough and a bigger hydrophobic membrane to cope with the high gas flows, should make it possible to build a two-membrane water separator. Laboratory tests on ground confirmed that pressure drops and the operational lifetime of the membranes did not prohibit the use of this technology in space systems.

Conclusions

Membrane technology is under rapid development for many terrestrial applications and its use in biotechnology, medicine, environmental technology and physico-chemical process engineering is rapidly increasing.

Due to the promising results obtained with a filter not originally intended to be used in microgravity and because it offers the advantages of having no moving parts, no induced vibrations and no power consumption, it is expected that development of the two-membrane concept for space applications will continue. This new area of application may lead eventually to a fruitful cross-fertilisation of both terrestrial and space technology.

EGSE: A Validation Tool for Satellite Simulators?

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Satellite simulators are used at the European Space Operations Centre (ESOC) to test and validate the Operations Control Centre (OCC) facilities and flight-operations procedures, as well as to train the flight-control personnel. Their validation (the verification of the degree of realism with which they represent the behaviour of the actual satellites) requires the involvement of operations staff and is usually performed in a manual fashion. The Electrical Ground Support Equipment (EGSE) used as main test tool in all satellite Assembly Integration and Verification (AIV) programmes could, in principle, be used to overcome the shortcomings of the current validation process, by providing an operations-independent and largely automated test environment for satellite simulators.

Introduction

Simulators represent an essential tool for testing and validating ground-segment facilities for satellite operations. At ESOC, they are used extensively before and after launch in support of the following activities:
- verification and validation of satellite control facilities and interface to ground stations
- verification and validation of flight-control procedures
- training of flight-operations personnel
- mission-readiness rehearsals.

In order to satisfy the requirements originating from these various activities, simulators need to model accurately and in real-time the in-orbit status of the satellite and to react realistically to any type of telecommand.

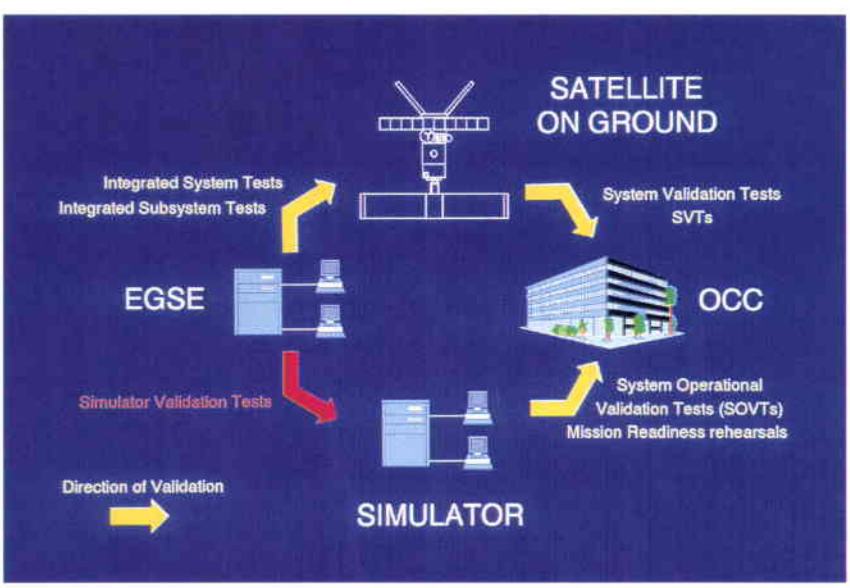
The increase in on-board autonomy and 'intelligence' over recent years has resulted in a dramatic growth in the complexity of simulators. This is noticeable in particular in the modelling of the Attitude and Orbit Control Subsystem (AOCS) and of the On-Board Data Handling Subsystem (OBDHS). A few hundred telemetry parameters used to be sufficient to represent the status of a satellite ten years ago, but now several thousands are required. The same holds for the number of telecommands.

As the complexity of simulators grew, their validation became more and more a time-consuming and critical process. A simulator developer used to be able, from his terminal, to exercise the effects of the various tele-commands and to verify that the modelling accuracy satisfied the requirements. Complex scenarios are now necessary, which require all the power of the satellite control facilities to be run and the expertise of the flight-control personnel to be interpreted.

The involvement of operations personnel in the final stages of simulator validation has obvious drawbacks. Furthermore, the Control Centre facilities that are supposed to be validated using the simulator, are themselves used in the process of simulator validation (e.g. for command generation, telemetry display, etc.), thus possibly leading to unreliable results.

One way of overcoming some of these limitations and at the same time improving

Figure 1. The EGSE as a potential simulator-validation tool in the overall mission-validation process



Satellite Simulator

The satellite simulators in use at ESOC are closed-loop simulators capable of receiving and executing all telecommands that can be sent to the real satellite and of generating realistic telemetry. They run in real-time, which implies that events occur at the same time as they would on-board the real satellite under the same conditions. Finally, they are dynamic in the sense that effects of interactions between the satellite and its environment or between the various satellite subsystems are fully modelled.

A typical simulator has four major components (Fig. 2):
- a satellite model, which closely reflects the standard breakdown of a satellite into subsystems (each subsystem is modelled)
- an orbit and environment model, which provides the position of the satellite with respect to the Earth and the other main celestial bodies (e.g. Sun, Moon)
- a simulator monitoring and control interface, which enables the operator to enter simulator commands and to display the status of any of the simulator variables
- a ground-station model, which simulates the telemetry and telecommand equipment of a standard ground station.

Among the various simulator commands available, the 'special effect' command is particularly relevant for the EGSE/simulator test as it allows the operator to trigger a special event or sequence of events within the simulator (e.g. special sensor illumination condition, sensor failure, etc.).

Satellite EGSE

The Electrical Ground Support Equipment (EGSE, also known as the Check-out System) encompasses a wide range of computer-based facilities required to perform satellite electrical testing at unit, subsystem and system level. It represents the main verification and testing tool used in support of the satellite Assembly, Integration and Verification (AIV) programme.

During the AIV programme, test procedures written by test engineers in a dedicated test language, are implemented and executed using the standard facilities provided by the EGSE. The purpose of these test procedures is to achieve a high level of automation and repeatability, as certain tests will be repeated at different sites in several tests configurations throughout the AIV programme. Their execution is monitored, together with the status of the satellite, and any anomalies detected during a test run (e.g. unexpected interference between different satellite subsystems, incorrect satellite status, etc.) are recorded for subsequent analysis.

The tests run during a satellite AIV programme can be divided into two main categories:
- Integrated Subsystem Tests (ISSTs) aimed at performing a complete and detailed functional test of each satellite subsystem, while the other subsystems are in a quiescent or switched-off mode.
- Integrated System Tests (ISTs) aimed at taking the complete satellite through a sequence of all possible operational modes, including the pre-launch, launch, initial and early-orbit, commissioning and on-station modes.

A typical EGSE configuration (Fig. 3) involves the following equipment:
- telemetry and telecommand front-end processors providing the interface to the satellite
- test processor workstation in charge of all activities related to the test execution and monitoring and to the recording of test results
- workstations providing the man/machine interface for the test engineers to operate the tests
- Special Check-out Equipment (SCOE) used for satellite stimulation (in order to recreate its operational environment) and acquisition of measurement information. The SCOE is controlled by the test processor workstation (e.g. specific commands inserted in the test procedures)
- a local area network for transport and distribution of information between the various EGSE components.

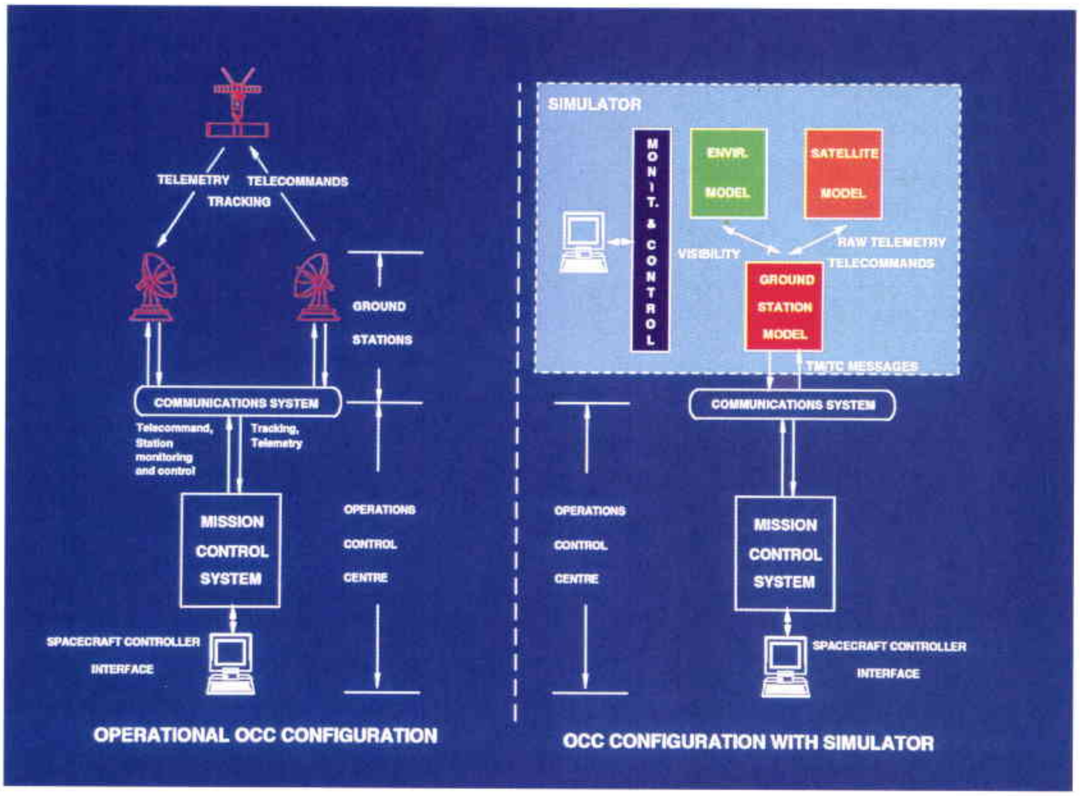


Figure 2. The simulator models the satellite, its environment and the ground stations

the effectiveness of the simulator validation process, would be to use the EGSE as test tool, applying the actual satellite test procedures to the simulator (Fig. 1).

In order to assess the technical feasibility of this approach, a series of tests have been performed involving a satellite simulator running on a computer located at ESOC, and the corresponding satellite check-out software (part of the EGSE) running on a computer located at ESTEC (systems interconnected via ESAPAC X.25 wide-area network).

The major characteristics of satellite simulators and EGSEs are summarised in the accompanying panels.

EGSE/Simulator testing

Configuration

It was decided to use Hipparcos as a representative example to assess the feasibility and the effectiveness of the proposed validation. Actually, the Hipparcos mission can be considered as fairly representative of the scientific missions currently supported by ESA and the Hipparcos simulator is very similar in structure and functionality to most of the simulators in use at ESOC. In addition, an operational simulator of Hipparcos was available at ESOC and the check-out database and test procedures of Hipparcos were made available and could be executed

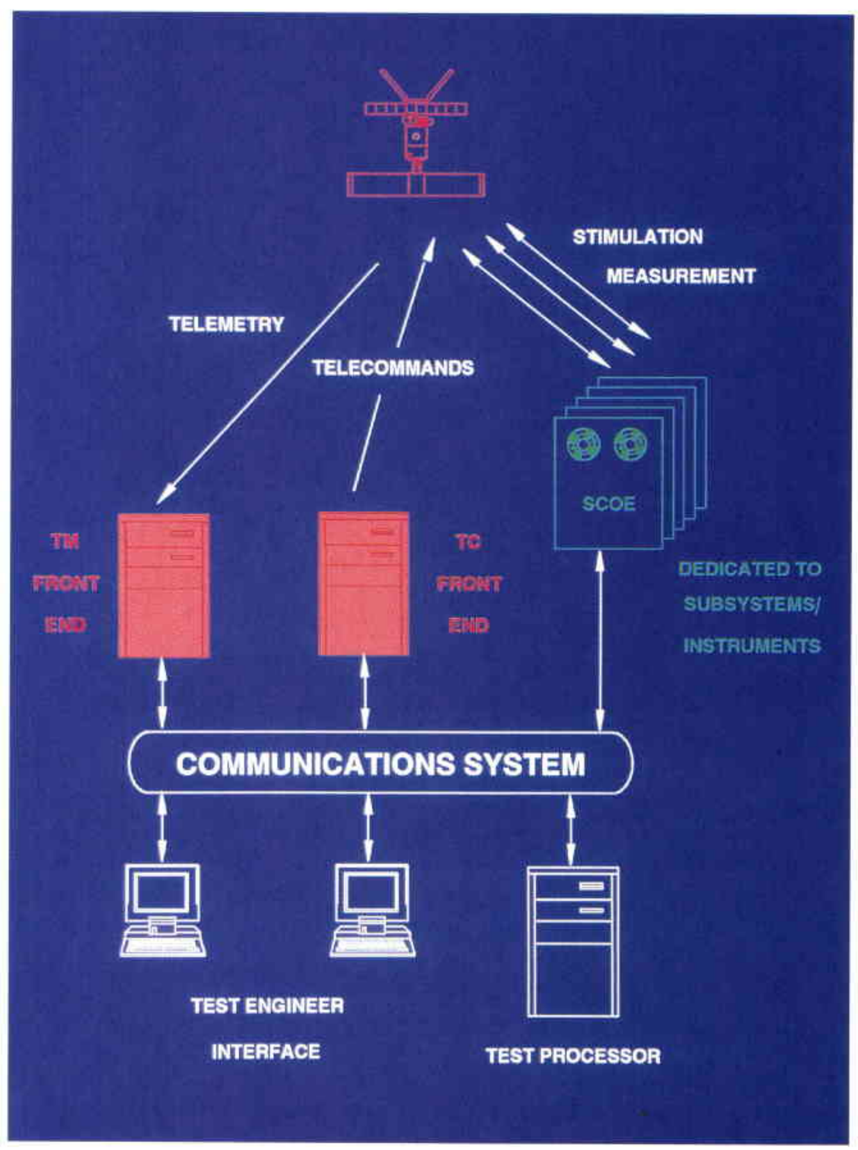


Figure 3. A typical EGSE configuration showing its major elements

on the EGSE reference facilities at ESTEC. This geographical separation of simulator and EGSE added further realism as the EGSE usually follows the satellite from one integration and test facility to another, and would therefore not normally be available for use in the same location as the simulator.

The test configuration was defined with the prime objective of minimising the modifications to existing systems (EGSE and/or simulator) and maximising the reuse of existing and validated Integrated Subsystem and System Test (ISST and IST) procedures (Fig. 4). It consisted of:

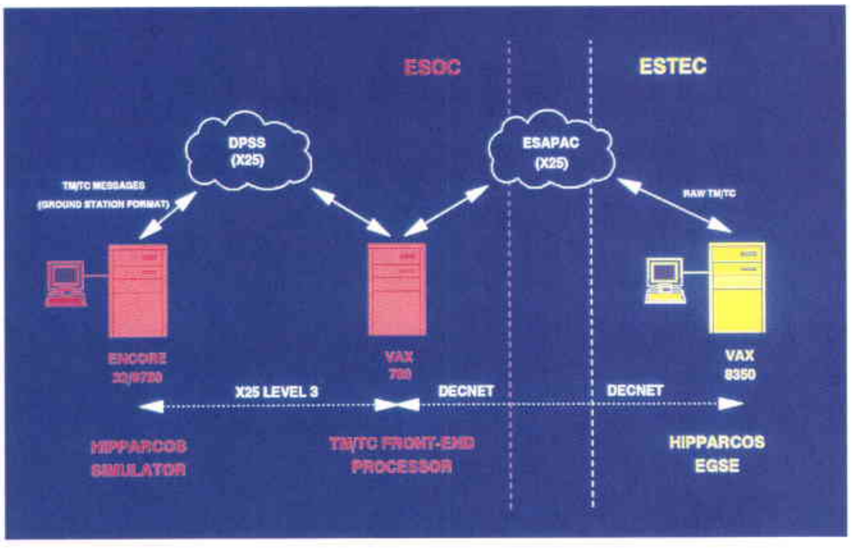


Figure 4. The EGSE and Simulator test configuration

- Hipparcos check-out software running on a VAX 8350 at ESTEC
- Hipparcos simulator running on an Encore 32/9780 at ESOC
- ESAPAC, the ESA X.25 wide-area network for communication between ESTEC and ESOC
- DPSS, ESOC's operational X.25 wide-area network for access to the simulator
- Network Services Processor (NSP), a VAX 780 located at ESOC and operating as a gateway between ESAPAC (running the Decnet protocol) and DPSS (running the X.25 standard protocol).

The decision to use the NSP was a direct consequence of the requirement to minimise the modifications to the existing systems. All the additions to the original facilities were concentrated into a single third node, without the need to affect either the simulator or the EGSE (e.g. the simulator could maintain its X.25 OCC interface, and the EGSE could continue to operate with the Decnet protocol). The interlinking VAX system thus provided the necessary protocol conversions, as well as some minor changes to the telemetry and telecommand data formats.

A further interface between the EGSE and the simulator (not represented on the diagram in Fig. 4) is a connection (RS 232) which was set-up to enable the test operator to interact with the simulator remotely (i.e. from the EGSE location) via a dedicated console.

As the SCOE could not be part of the test configuration, it was necessary to modify the test procedures by replacing the SCOE commands for setting up the test environment and generating satellite stimuli with equivalent 'special effects' commands already supported by (or easily implementable within) the Hipparcos simulator.

Tests

A subset of Integrated Subsystem Tests and Integrated System Tests from the Hipparcos Protoflight model AIV programme were selected for evaluation and possible execution on the test configuration. Due to the limited amount of time available to prepare and execute the demonstration, the selection had to be restricted to tests involving low-rate telemetry only. The tests involving high-rate telemetry would have necessitated the implementation of a faster link between the EGSE and the simulator. This, however, would not have significantly increased the meaning of the experiment.

Integrated Subsystem Tests

The selected subsystem tests related to the Electrical Power Subsystem (EPSS), the Attitude and Orbit Control Subsystem (AOCS), the Data Handling Subsystem (DHSS) and the Telecommunications Subsystem (TCMS).

The complete Hipparcos EPSS ISST procedure was evaluated. Of its 21 tests, 12 were found relevant and were fully executed on the simulator. Four further tests were relevant but would have required modifications to the test procedures or to the simulator (or both). Five tests were found not relevant as they were dealing with manual operations to be performed on either the satellite or the SCOE.

A subset of the tests related to DHSS mechanisms control was selected for partial execution. Some steps of the procedure were selected with the aim of verifying telemetry, telecommands and telecommand authorisation within the simulator.

Some steps of the TCMS test procedure were also selected for execution on the Hipparcos simulator, again with the objective of telemetry and telecommand verification.

Integrated System Tests
A series of tests of the thermal-control activation sequence (heater switch-on) and of the solar-array and fill-in-antenna deployment were evaluated and selected. For each of them, the related telemetry and telecommands were to be verified.

Test results
All of the selected tests were executed on the test configuration. Thanks in part to careful setting up of the overall test environment, no technical problems were encountered and all procedures ran automatically from start to finish. A few 'anomalies', which were traced back to inconsistencies between the status of the spacecraft on-ground expected by the test procedures and the status in-orbit as modelled by the simulator, were flagged immediately; this applied in particular to thermal parameters.

It is interesting to note that, although the simulator had undergone final validation and had been used in support of an intensive pre-launch simulation programme, a few modelling errors were revealed by the EGSE procedures, in particular in the area of AOCS reconfigurations.

Despite the short time (one month) and reduced manpower (about one man-month) dedicated to carrying out the exercise, the technical feasibility of the proposed concept has been verified and the following aspects have been highlighted:
- It is possible to reuse existing EGSE facilities, and in particular the ISST and IST procedures, to validate an ESOC-type satellite simulator in an automated fashion.
- The procedures can be used as originally designed to test the real satellite, or would require only minor modifications to the code.
- A systematic execution of all applicable AIV procedures (validated on the electrical model of the satellite) represents an independent method of validating the simulator implicitly against the real satellite.
- The additions and interface adaptation between the two systems can be easily implemented (software-wise) on a third node or anyhow as a separate process running on one of the two machines.
- The SCOE commands can be handled by implementing, whenever required, additional 'special effect' modules in the simulator.
- There is no requirement for the EGSE and the simulator to be co-located. Wide-area networks (e.g. X.25) can be used to communicate simulator-generated telemetry and EGSE-originated telecommands reliably over great distances, thereby making it possible to execute the simulator testing and validation even from remote locations (e.g. different countries).

Although the demonstration of the the technical feasibility of the EGSE/Simulator validation concept represents an important step in the proposed verification exercise, it is not sufficient to make a definite statement of suitability for future projects. Other relevant aspects need to be taken into account, in particular those related to the actual availability of the facilities (i.e. simulator and test-procedure development time-scales).

Figure 5. Simulator Workshop in progress at ESTEC

Schedule considerations
The tests involving the Hipparcos EGSE and simulator have been performed several years after launch, when both systems were available and a set of validated ISST and IST procedures already existed. How would the situation have looked like a few years before launch?

A retroactive analysis of the actual implementation schedules for the Hipparcos simulator and the Hipparcos EGSE procedures (Fig. 6) shows that:
- ISST procedures for the most critical subsystems, validated on the Engineering Model (EM), would have been available between six and three months before the start of the implementation of the corresponding simulator models.
- IST procedures, also validated on the EM, would have been available six months before the start of the simulator system validation tests.

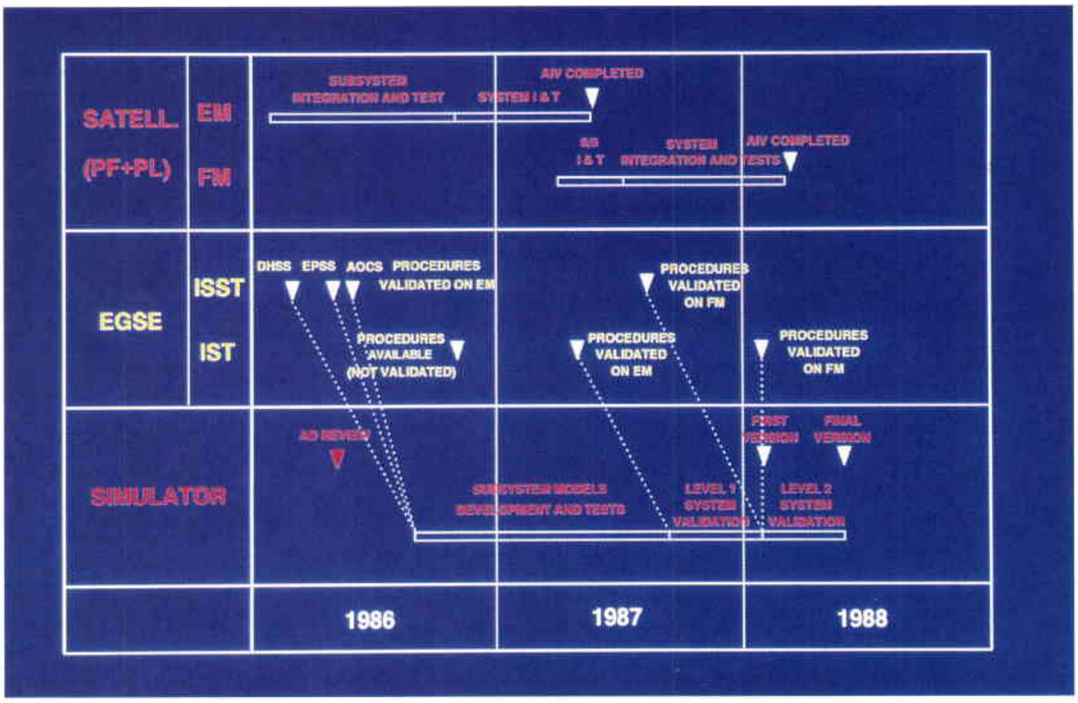


Figure 6. The Hipparcos example shows compatibility between availability of the IST and ISST procedures and the simulator development/ validation schedule

- IST procedures validated on the Flight Model (FM) would have been available four months prior to the final delivery of the simulator, one year prior to launch.

Assuming that the Hipparcos case is representative as far as development of the simulator is concerned, and also satisfies the test-procedure development needs of other missions, it can be concluded that EM- and FM-validated test procedures will generally be available early enough to be used in the simulator validation process, both at subsystem and system levels.

The Hipparcos scenario also shows that simulator validation tests would have been performed at the same time as a the FM integration and testing. This, unfortunately, is also representative of a typical scientific mission. Access to the EGSE is therefore a critical issue that needs to be addressed on a case-by-case basis. Possible solutions could be to:

- use the backup/second EGSE, if available (not always the case)
- share the access to the EGSE used for FM integration with AIV users (technically feasible but not very practical)
- use a copy of the check-out software, database and procedures on a reduced EGSE configuration (no SCOE needed), which could even be co-located with the simulator development facilities.

The last solution (which was also used for the Hipparcos technical-feasibility demonstration) is particularly attractive if the check-out software runs on a standard off-the-shelf computer or workstation.

Conclusion

The experiment that has been described here showed that it is technically feasible to use the EGSE to run the test procedures required to validate the simulator. This approach has the advantage of being an independent method of validating the simulator against the real satellite. It could be adopted to increase the quality of the first-level test and as such it would provide a higher degree of confidence in the simulator's representativity at an earlier stage. The effect would be a reduced need for second-level testing, to be run by the operations staff, and an easier simulator maintenance phase.

It can also be concluded that there would be no major problems in following this procedure, provided the EGSE is available. Moreover, as all of this is achieved by simply reusing existing and available facilities, a worthwhile increase in cost-effectiveness is to be expected.

Acknowledgement

The authors would like to thank Messrs G. De Bernardi (Alenia), K. Booty (Cray Systems) and F. Smith (CRI) for the considerable support they provided during the preparation, execution and evaluation of the various tests described.

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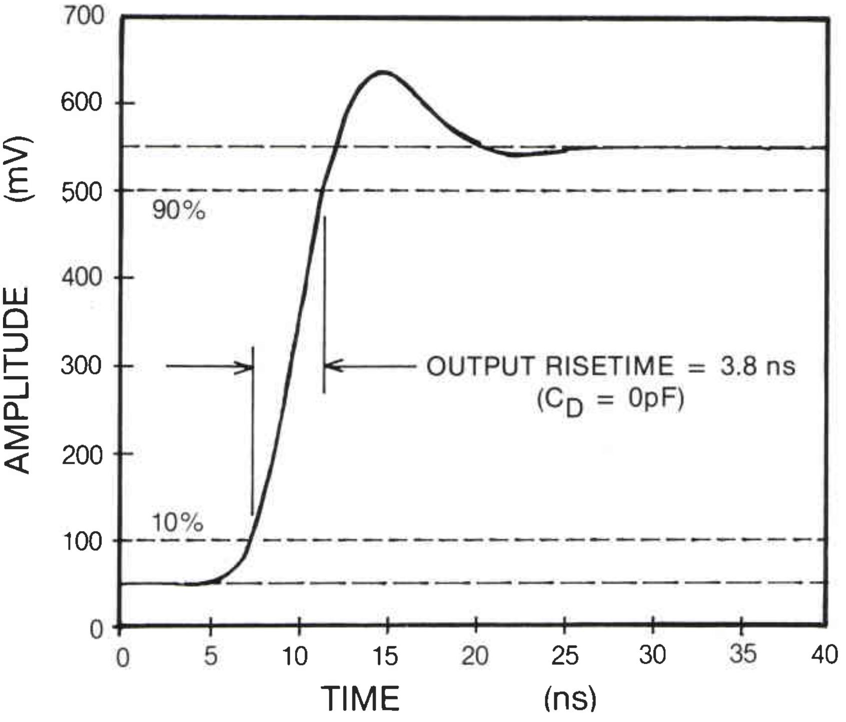

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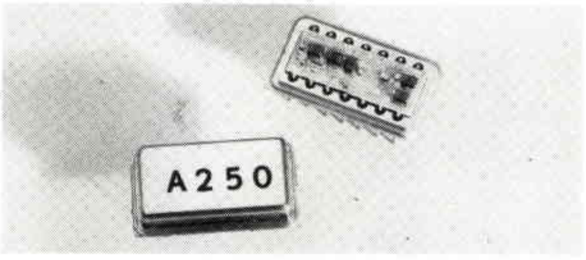

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ESOC's Support to the Lageos-2 Mission

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ESOC's extensive ground facilities for spacecraft control are frequently called upon to support non-ESA missions. A recent example is the support given to the Italian Space Agency's Lageos-2 spacecraft, launched from Space Shuttle 'Columbia' on 22 October last year. It serves as a good illustration of the way in which international cooperation can contribute to the efficient use of facilities in supporting space missions.

Figure 1. The Lageos-2 spacecraft (Courtesy of ASI)

The Lageos-2 mission

Scientific objectives

The Laser Geodynamical Satellite Lageos-2 is a joint mission by the Italian Space Agency (Agenzia Spaziale Italiana, ASI) and NASA. The surface of the 405 kg, 60 cm-diameter satellite, dedicated exclusively to passive laser ranging, is covered with 426 equally-spaced cube-corner reflectors (CCRs), giving it the appearance of a large golf ball (Fig. 1). The CCRs reflect a laser beam back in the same direction as it is received from a transmitting ground station.

Comparison of the round-trip delays measured by researchers in 30 different countries from both Lageos-2, and its identical predecessor Lageos-1, will enable geologists to monitor the Earth's crustal-plate movements, measure the wobble in the Earth's axis of rotation, enhance their knowledge of ocean tides, and observe geopotential changes. This information will be used to monitor regional fault movement in areas subject to earthquakes, such as California and the Mediterranean Basin.

With Lageos-2 at 5900 km altitude and 52° inclination, and Lageos-1 at the same altitude but 110° inclination (Fig. 2), the accuracies of geodetic measurements are expected to be improved by a factor of two.

Mission operations

For launch, the passive Lageos-2 satellite was attached to the Lageos Apogee Stage (LAS) equipped with a solid-propellant motor (Fig. 3). These two were attached in turn to the Italian Interim Stage (IRIS), a solid spinning booster stage for use with the NASA Space Transportation System (STS).

As shown in Figure 4, after release of the Lageos-2/LAS/IRIS composite from the Space Shuttle at a height of approximately 296 km, the IRIS Perigee Kick Motor (PKM) injected Lageos-2/LAS into a transfer orbit with an apogee of 5900 km and an inclination of 41°. Subsequently, the LAS motor was fired to circularise the orbit at 5900 km altitude with a 52° inclination.

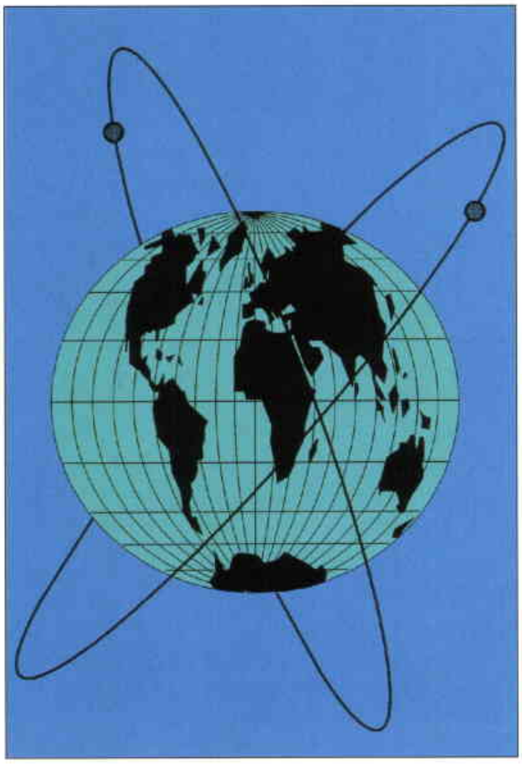


Figure 2. The Lageos-1 and Lageos-2 orbits

Lageos-2 was tracked extensively during its first 30 days of life in order to calculate its orbit accurately before the satellite's scientific mission could start. Following the satellite's deployment from the Shuttle, ASI required IRIS and LAS tracking and the reception of telemetry data, in particular during the critical periods of PKM and AKM firing. Both ESA and NASA ground stations were used for this purpose.

The ESA stations at Malindi (Kenya), Kourou (French Guiana) and Perth (Australia) were potentially able to provide support. A pass of nearly 10 min over the Malindi station, coinciding with the IRIS PKM firing, was of particular interest. The AKM firing was to be tracked by the NASA Hawaii and Goldstone stations.

Mission-support requirements

Negotiations between ASI and ESA for the support of Lageos-2 began in 1985. The use of the three ESA network stations was initially considered – Malindi, Kourou and Perth – the intention being to provide good coverage for the reception of IRIS PKM burn and LAS AKM burn telemetry. Real-time telemetry readout at the stations and post-pass transmission of the data to the Payload Operations Control Center (POCC) at Johnson Space Centre (JSC) in Houston (USA) was called for. No commanding was required, but transmission of antenna pointing angles to the POCC, as soon as possible after the pass, was necessary.

Two ESA station options were considered. Option 1 was for IRIS and Lageos telemetry reception at Malindi, while Option 2 was for IRIS and Lageos telemetry reception at Kourou, and Lageos apogee telemetry reception at Perth.

Early negotiations were based on a Lageos-2 launch in November 1988, before the accident to Space Shuttle 'Challenger'. Negotiations also started at a time when the ESA S-band facilities in Australia were located at Carnarvon. (The station was moved to Perth during 1988 and became operational in September that year).

Production of the mission-implementation plan

Based on the initial support requirements, a Mission Implementation Requirements Document (MIRD) was produced for discussion with ESA. The MIRD and its response, the Mission Implementation Plan (MIP), formed the technical part of a contract between ASI and ESA. During discussions on these documents, the Option 2 requirement was deleted as a result of refinements in the mission profile. The dual (IRIS and Lageos) telemetry support from Malindi was reduced to IRIS support following an analysis of the cost of the

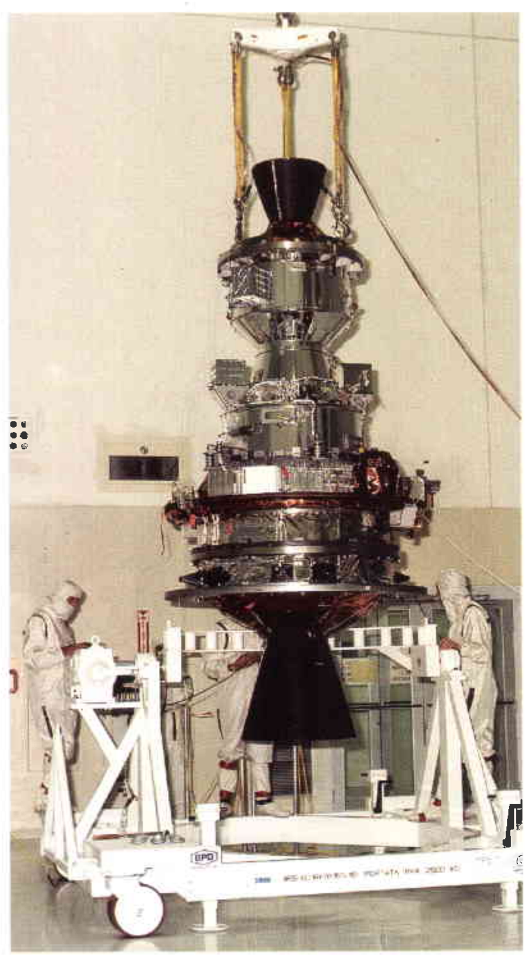


Figure 3. The IRIS/Lageos-2 composite (Courtesy of ASI)

changes that would be necessary to the station configuration.

The resulting support requirements and implementation plan were incorporated in a contract between ESA and ASI signed in November 1991. The contractual launch date with NASA by this time was September 1992.

Ground-station specifications

Lageos was designed for telemetry transmission at S-band in accordance with ESA standards. The Malindi ground station supports missions using S-band frequencies in accordance with those standards, and therefore the Lageos-2 requirement did not result in any changes to the radio-frequency reception facilities there.

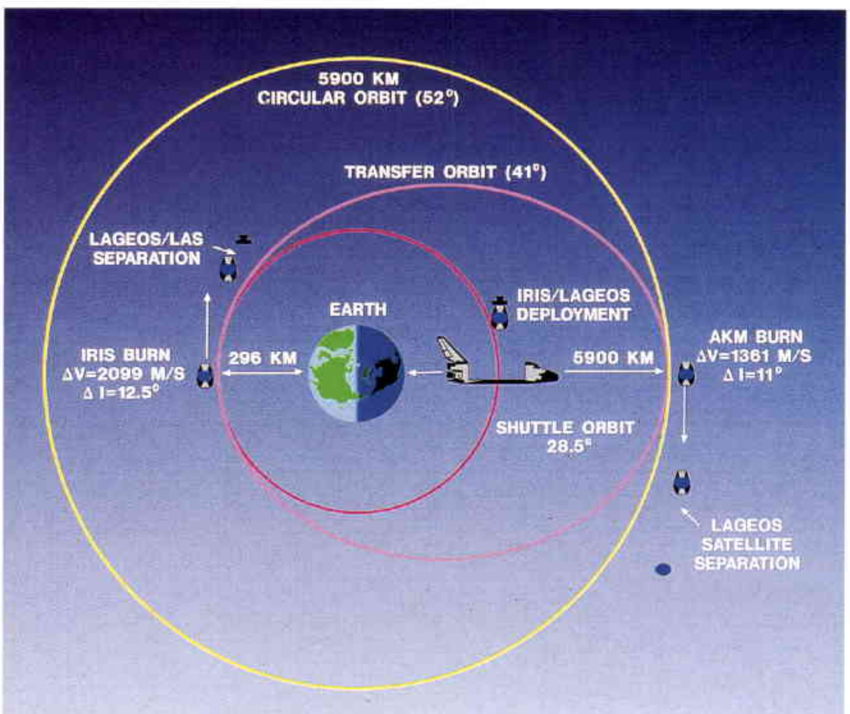


Figure 4. Milestones in the Lageos-2 mission scenario

Data reception and recording

The Lageos requirement was to receive the data during the pass, store it at the station, and transmit it to the POCC at JSC as soon as possible after loss of signal. Storage at the station ensured that loss of external data links would not result in the loss of Lageos data.

In addition to the reception and recording requirements, ASI needed a quick indication of the perigee motor's firing start and duration. This was available as a reading of solid-rocket motor pressure, a telemetry parameter. It was therefore agreed that this parameter would be read from the station computer display in real time and passed by voice to the POCC.

Data transmission to JSC

The Lageos requirement was for a single short pass over Malindi. ASI required that the data received be transmitted to the POCC within 1 h of loss of signal. In these circumstances, it was agreed that dedicated data lines between Malindi and JSC could not be financially justified, but for preparation and control of the operation it was necessary to establish links between ESOC and Malindi in the conventional way (two dedicated voice/data lines).

A solution was therefore agreed in which the data was passed over these links to ESOC and then, via already established data-transmission networks, to the POCC.

Support implementation

Examination of the Lageos-2 nominal orbit with respect to the Malindi station coordinates yielded the maximum slant range to be supported and the azimuth and elevation ranges. With a horizon mask at Malindi always below 2°, this resulted in an estimated pass duration of 10 min. The maximum slant range was used to compute the link budgets, which showed margins of the order of 20 dB.

To ensure the earliest possible acquisition of data at Malindi, it was necessary to provide ESOC with up-to-date Shuttle state vectors and a predicted IRIS state vector after deployment. These would be converted at ESOC to antenna-pointing elements and transmitted to the station.

Ground-station compatibility

The Lageos-2/IRIS/LAS telecommunications equipment was specified and designed according to both NASA and ESA standards so as to be able to communicate with both Agencies' ground stations.

As for all ESA missions, a Radio-Frequency Compatibility Test (RFCT) was carried out to demonstrate compatibility between the spacecraft telecommunications equipment and the earth station. This test required that the satellite TTC qualification model (representative of the flight model) be shipped to ESOC and installed in an electromagnetically clean Faraday cage. There it was connected to the ESOC Test and Reference Station, which has the technical characteristics of an Estrack ground station.

A complete series of tests involving all of the subsystems required in the space-to-ground communications, with the exception of the

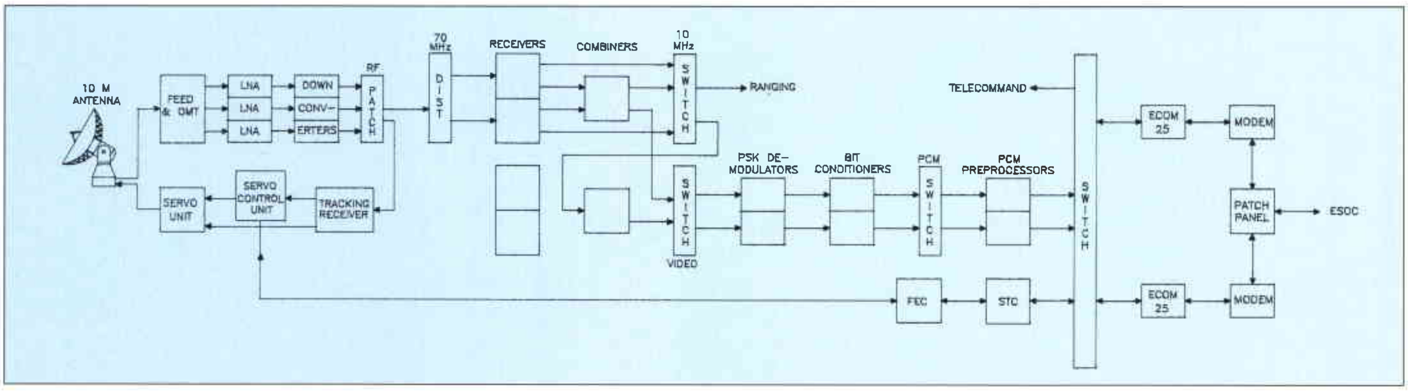


Figure 5. Functionality of the Malindi ground station

antennas, was then performed with the twofold aim of demonstrating compatibility and determining the optimum equipment setup and end-to-end performance. No problems were experienced. The measured end-to-end performance was used to refine the link budgets, and the relevant equipment setup was used in implementing the Malindi configuration (Fig. 5).

Data handling and ground communications

The Malindi station is equipped with two hot-redundant telemetry chains compatible with the Lageos-2 specifications. In order to meet the ASI requirement for having telemetry data at the POCC within 1 h after loss of signal, it was decided to use an OPSNET link between Malindi and ESOC and send the telemetry frames to ESOC in real time (prime mode). The Malindi—ESOC line capacity of 4.8 kbit/s was more than adequate for the Lageos-2 2 kbit/s telemetry.

For the ESA/JSC (POCC) link, many different solutions were proposed by both ESOC and NASA, including a dedicated line which required the use of the NASCOM protocol (thereby requiring ESA/NASA protocol converters) and inter-NASA links to JSC, and the simple use of a dial-up modem and telephone lines. In the end, taking due account of the short mission duration (one 10 min pass over Malindi) and the low telemetry data rate, and of the security aspects involved, it was agreed to make use of the ESANET and the NPSS, two non-operational ESA and NASA networks, respectively, connected together by various gateways (Fig. 6).

Early testing showed that the concept worked, that the ESOC—JSC link was reliable, and that an average throughput of about 4 kbit/s could be obtained. It was therefore decided that the link could also be used to receive Shuttle state vectors from the JSC Customer Support Room (CSR), should the fax connection between JSC and ESOC prove unreliable.

Operations preparation

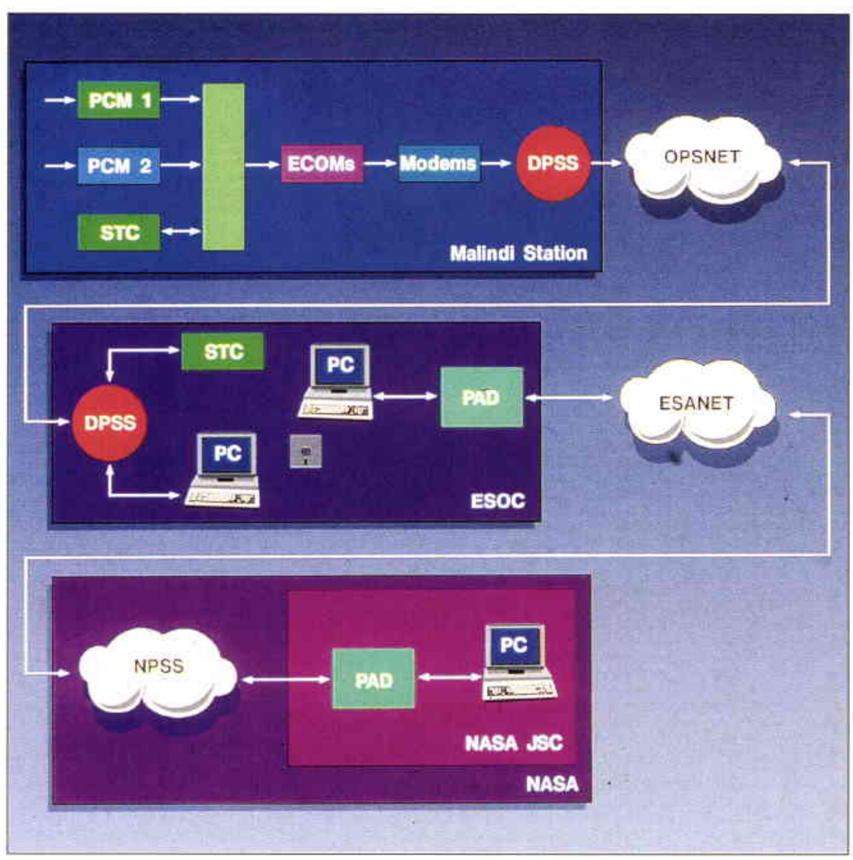
ESOC's support team

In the usual manner, a support team was assembled at ESOC, consisting of the necessary experts from the engineering, flight-dynamics and operations areas.

Ground-station configuration

Although the Malindi station is equipped for S-band communications, it is not used for continuous mission support. Therefore, for each mission it is necessary to conduct performance testing and to configure the station for the characteristics of the spacecraft to be supported and to satisfy the data-handling requirements. This work was completed for Lageos-2 prior to the connection of the communications link between the station and ESOC.

Figure 6. The Malindi–ESOC–JSC links



Mission-readiness testing

When the station had been declared operational in terms of configuration and performance, and the communications lines had been connected and tested, a series of mission-readiness tests commenced. These tests, which covered all operational activities in both prime and back-up configurations, continued until shortly before launch.

The results showed that the mission could be reliably supported and that the 1 h requirement for the Lageos-2 data to be at JSC would be met with ample margins.

Training and simulations

To ensure the readiness of all team members, training and simulation sessions were held. A Portable Satellite Simulator (PSS) was used as a data source, realistic configurations were set up, and all procedures practised. In particular, due to the non-standard approach adopted for the ESOC/JSC file transfer, a number of data flow tests were carried out. None failed, demonstrating the reliability of the link. The throughput was found to be traffic-dependent and varied between 2 and 4.9 kbit/s, with both ESOC and NASA 9.6 kbit/s modems. It was always sufficient to meet the 1 h maximum delay requirement.

The procedures for the transmission of state vectors to ESOC, the calculation of antenna-pointing data for Malindi, and the reporting of pointing data to the POCC were also practised. ESOC successfully participated in Joint Integrated Simulations requested by NASA, with Lageos-2 passes over Malindi simulated by the PSS.

Real-time operations

In the event, the Space Shuttle launch (STS-52) took place as planned, with a delay of just some 2 h due to wind conditions at Kennedy Space Center, at 17:09:39 GMT on 22 October. An ESOC—JSC file-transfer test was carried out at 20:40:00 GMT, which confirmed the good status of the link in both directions. The Shuttle state vectors were sent to ESOC, where the antenna-pointing elements for the Malindi antenna were computed and sent to the station.

Given the good status of both the Shuttle and Lageos-2, contingency deployment opportunities were deemed unnecessary, and NASA/ASI confirmed that the nominal deployment would take place the day after the launch.

A final JSC—ESOC data flow test was successfully carried out on 23 October at 11:50:00 GMT. Data flow tests between Malindi and ESOC were also performed on a regular basis.

Lageos-2's deployment from the Shuttle was confirmed at 13:57:04 GMT, with a nominal pass over ESA's Malindi station predicted for 14:38 GMT. ESOC was linked to the Malindi telemetry chain awaiting real-time telemetry frames. As long feared, the Malindi lines that had stayed in good shape from the day before, went down 10 min before acquisition-of-signal but came back 5 min later, only to go down again shortly thereafter. Fortunately, the link was restored 3 min before signal acquisition.

Acquisition-of-signal occurred as predicted, and the lines remained operational throughout the 10 min pass. The Malindi acquisition took place at 14:38:00 GMT and the PKM fired between 14:42 and 14:43 GMT. At loss-of-signal (14:48:00 GMT), examination of the telemetry file recorded at ESOC revealed that no frames had been lost. The back-up procedure was therefore not necessary.
The file was transferred (on diskette) to a PC connected into Esanet for transmission to JSC. Simultaneously, the antenna-pointing data were retrieved at ESOC and faxed to JSC.

By 16 min after loss-of-signal, all of ESOC's tasks had been successfully completed, and the ESOC Support Team had therefore fulfilled its brief very successfully and well within the scheduled time window. NASA subsequently reported that the satellite had been placed into the correct orbit and that its stations were able to predict the satellite's passes to within 200 ms, which was well within the Lageos-2 accuracy requirements.

SCOS II: ESA's New Generation of Mission-Control System

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New mission-control infrastructure software is currently being developed by ESOC which will constitute the second generation of the Spacecraft Control Operations System (SCOS II). The reasons behind the production of the new system and how it will address a number of important future mission-control issues are discussed in this article.

Why do we need a new infrastructure?
Before embarking on a major development such as SCOS II it is important to have a good overview of the reasons and aims for the investment of such large amounts of money and manpower. These can be broadly categorised as follows:

– Financial
The development and maintenance of mission-control systems based on the current generation of infrastructure software (SCOS I) has become costly. This is due, at least in part, to the inflexibility of the SCOS I system structure and the resulting difficulty of customising SCOS I software to a mission and of adding mission-specific software to the basic system.

– Functional
The increasing complexity of missions requires a corresponding increase in the capabilities of the control systems. For the same reason, the effort involved in preparing for mission operations is increasing. The SCOS II infrastructure will improve the support provided to the operations staff in both mission operations and mission preparation. Improved support is also expected to help reduce operations costs.

– Strategic
The cost of computer hardware for previous systems has been an item for concern. This is partly due to the centralised architecture of current systems which, together with the mounting performance requirements and complexity of processing required, has led to the need for large and powerful host computers to support the systems. This has resulted in dependence on the operating system and basic software provided by vendors of the particular host computers chosen, thus effectively tying the Agency to these vendors. To avoid this in the future, the SCOS II infrastructure is required to operate in a hardware and basic software environment that is vendor-independent.

What is mission control?
In general terms, 'mission control' embraces the tasks of preparing, planning, executing and subsequently reporting on the operations of a spacecraft mission.

– Mission preparation
A vast amount of information (mainly in the form of documents) is produced during the manufacture of a spacecraft. A portion of this information is essential to the operations of the spacecraft. The corresponding documents must be isolated, collected and then used as a basis for defining operations in terms of procedures, each procedure having a specific operational goal.

SCOS II-based control systems will provide facilities for electronic storage and review of documents in many common formats and for the creation of links between documents to allow easier correlation of information.

– Mission planning
For reasons of both safety and efficiency, it is normal practice to pre-plan and automate

operations as far as possible. This pre-planning can be done in the form of manual procedures prepared before launch. In general, however, not all operations can be defined and scheduled before launch. For payloads in particular, operations schedules may be prepared just several days, or even one day, in advance. These schedules must attempt to achieve a set of goals (e.g. satisfy requests for payload utilisation from end users) subject to any applicable constraints (e.g. onboard power, available ground-station contacts, payload instrument conflicts, etc.). To date, mission planning has been conducted on a 'special-to-project' basis.

ESOC is currently studying the possibilities of providing generic support for the planning process. Once identified, such generic support can be included in a future release of the SCOS II infrastructure.

The result of mission planning is a detailed schedule of activities or high-level operations. Whatever the nature of the planning process, SCOS II will be able to translate the operations timeline or schedule into a specific set of spacecraft commands.

– Mission execution
The schedules resulting from the planning will result in operations that will, in general, affect both the ground facilities ('ground segment') and the spacecraft ('space segment'). The resulting behaviour must be monitored. Discrepancies between the expected behaviour (as contained in the schedule) and the actual behaviour must be identified and corrective action taken.

Systems based on the SCOS II infrastructure will provide major improvements in the support for mission execution. We hope to reduce the time spent by operations staff on mechanical or repetitive activities by providing a system that automates many of these functions. We also hope to achieve a better match between the user's view of the mission and the one embedded in the control system.

Space-segment monitoring and control activities are often complicated by the limitations on the access to the spacecraft, e.g. due to limited data rates on telemetry and telecommand links, periods in which the ground station is out of contact with the spacecraft, etc. It follows that an area of particular interest is to try to compensate for limitations in access to the spacecraft, thereby allowing the operations engineers to concentrate more on the end object (the spacecraft) and less on the methods used to access it (telemetry parameters, network links, telecommands, etc.).

– Mission reporting
In order to determine whether the mission goals are being achieved, the long-term behaviour of the spacecraft and the ground segment must be evaluated and reports provided to mission management. This is also commonly referred to as 'Spacecraft Performance Evaluation'.

Future SCOS II-based systems will contain integrated support for analysis and summary work, as opposed to the loosely coupled and independently implemented service provided to date. We plan to take advantage of commercial analysis and visualisation packages (e.g. PV-WAVE™) rather than rely exclusively on purpose-built software.

Despite the apparently sequential nature of the activities described above, each usually continues in some form for the duration of the mission. For example, feedback from the reporting often affects the planning of subsequent operations, procedures may be updated as a result of execution anomalies, and replanning takes place at fairly short intervals to optimise resource usage or to correct deviations from the overall mission goals. Mission preparation may need to be done during a mission if a major anomaly occurs, necessitating adjustment to new mission assumptions or goals.

Each of these activities has its own special challenges for both the users and the providers of Mission Control Systems; the SCOS II infrastructure system will become the foundation of a coordinated set of tools which will meet these challenges, providing a Mission Control Infrastructure that, for the first time, covers all of these activities.

How can we approach these issues?
We will now examine some of the more interesting facets of SCOS II and show their application to some of the mission-control activities summarised earlier. Most of the material covered here arises from proposed improvements to the execution-phase software, the area in which most of the original thought has been invested. The improvements to the support for the other phases will depend on integration of a carefully chosen set of commercial tools (for example, in the area of mission preparation, publishing software with hypertext-link capabilities and, in the area of reporting, statistical or visual data-analysis packages).

Modelling as an aid to monitoring

Previous control systems have approached the monitoring and control task in a manner that is closely linked to the way in which they have been forced to access the spacecraft – as a collection of telemetry parameters and telecommands. The functions of the systems have been centred around monitoring the values of the telemetry parameters and issuing telecommands. Considerable effort has been invested over the years in ad-hoc attempts to derive actual and desired spacecraft status from this collection of isolated measurement and control items and a certain level of sophistication has been reached, but at a considerable cost.

The SCOS II design team has recognised that it is necessary to make a concerted effort to improve the situation. To this end, the approach to the fundamental database of information used to drive the control-system software has been completely changed in order to allow the user to concentrate more on the characteristics of the subsystems or devices being controlled (e.g. attitude and orbit control subsystem, thrusters, batteries, etc.) and less on the transport mechanisms used to view these devices (packets, frames, parameters, sampling rates, command frames, etc.).

It is not sufficient to provide a description of the devices; the system must also be able to make appropriate use of this information! Traditionally, a single model or processing technique has been applied to the whole spacecraft. Thus, telemetry parameters are described in tables, including, for example, limits on their values. Equally, telecommands are described in tables which include, among other information, the expected effects on telemetry values. These tables may be administered via a database system. A single data-processing 'engine' scans each entry to carry out certain prescribed checks (e.g. limits).

SCOS II will allow (although not require) each item described in the database to provide its own engine to interpret its database, telemetry and telecommand data in its particular way. These engines may be shared; it is possible, for example, that all heaters on a particular spacecraft will have the same behaviour and will differ only in the specific details of their telemetry and telecommand data.

As a result of all these modifications, the monitoring functions of a SCOS II system are best seen as a collection of independent models of various parts of the spacecraft, which act in concert to maintain a view of the spacecraft (as opposed merely to a list of the current values of the telemetry parameters) using specially chosen methods appropriate to each model. These models form a sort of 'ghost' copy of the spacecraft communicating with the real spacecraft using the telemetry and telecommand links.

Model the ground systems too

A mission-control system must not only monitor and control the spacecraft, but also

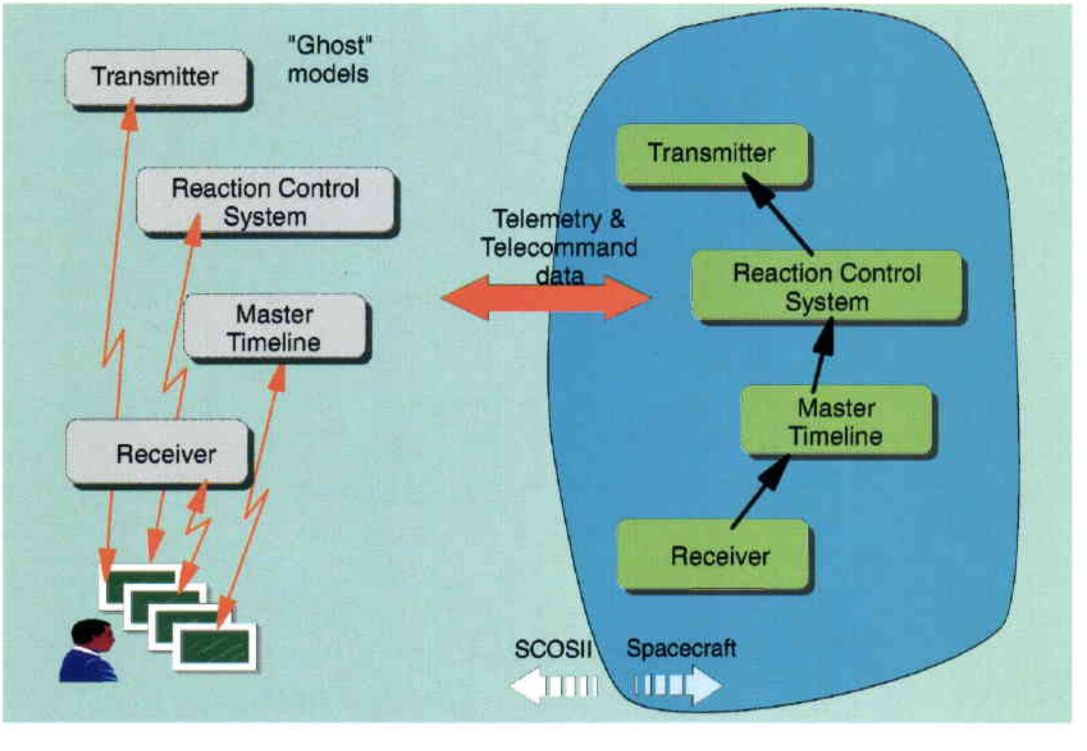

Figure 1. SCOS II systems contain model elements representing spacecraft items

the ground segment. Previously this has been done by a collection of specific utility programs, which have been only loosely integrated with each other and with the spacecraft monitoring and control facilities. This was identified as an area for improvement, given that many aspects of operations require a close coordination of ground facilities with spacecraft operations (e.g. ranging operations or command uplink acquisition).

To do this, we can take advantage of the removal of the restrictions imposed by the need to be completely data-driven and interpretable by a single engine. Thus we can employ the same modelling techniques for ground-segment monitoring and control as for the spacecraft, the ground-segment facilities being represented by additional models. Thus in a typical SCOS II-based system there could be items in the database representing such things as the station communications network, the telecommand and telemetry equipment at each of the ground stations, the station antenna and even the various components of the SCOS II system itself. Each of these models will monitor and control the item that it represents, using an appropriate access channel.

One of the major advantages of such an integrated database is that all of the functions foreseen for spacecraft control can be used for ground-segment control. Future SCOS II-based systems will contain automated procedures that cover more than just spacecraft operations. An example would be the acquisition of the telemetry and telecommand links at the start of a pass. Today this requires a carefully orchestrated sequence of operations involving several systems and several independent operations staff, thereby affording many possibilities for human error.

In a similar way, the data-display and analysis tools originally conceived for spacecraft-related use can be applied to ground-segment data as well. A typical monitoring window might contain station-related items (e.g. transmitter mode and power, received signal strength and noise levels) together with the related spacecraft data and would provide an integrated 'up- and down-link' monitoring capability.

Building blocks for models

As the full use of the SCOS II infrastructure requires extensive creation of models of various elements of the space and ground segments, some effort must be made to ease the task of preparing a system for use for a particular mission. It is obviously not feasible to expect each mission team to prepare from scratch all of the models required.

SCOS II will therefore provide a library of 'building blocks', which can be combined in various ways to produce the overall spacecraft and ground-system model. To allow this to be done easily, object-oriented software-engineering technology has been updated for analysis and implementation of SCOS II. Specifically, the Coad/Yourdan method and the C++ programming language have been chosen. Correctly used, this technology and its supporting

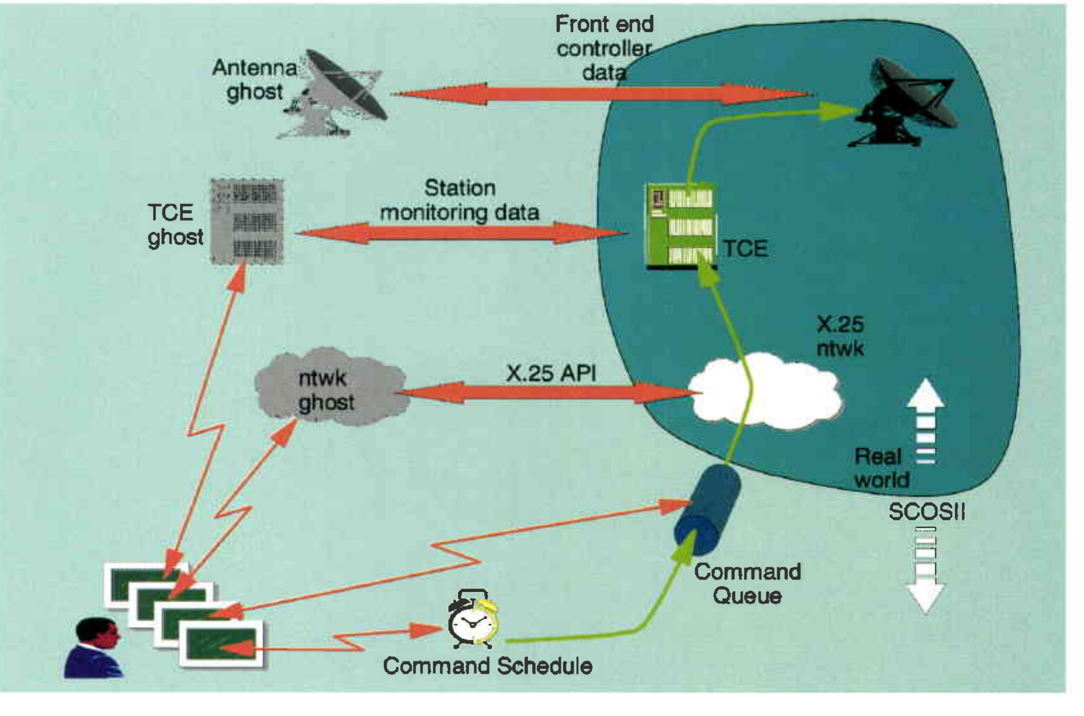

Figure 2. The ground segment can also be modelled in a SCOS II system

tools should ensure the clarity of interface definition and flexibility of implementation essential for a building-block approach.

Extension of systems by specialising building blocks

Not all missions are the same which, as remarked earlier, led to high costs on some earlier infrastructure systems. In many cases it will be necessary to make modifications to the library building blocks to be used in a specific mission. The object-oriented approach to the system has an advantage in this area as well.

Using an object-oriented technique known as 'inheritance', it will be possible to provide a customised building block for, say, the batteries of a given mission by specifying (and implementing) only the differences between the batteries and those represented by the generic building block. This avoids a proliferation of similar, but subtly different, models and the resulting software and operational configuration-control issues which would consequently arise. It should also save manpower by avoiding such multiple implementations.

Finally, the use of models that differ only where absolutely necessary should promote the use of similar, if not identical, operational procedures. This should help to reduce the cost of preparing operations and should also contribute to the safety of mission operations by ensuring that new (and potentially faulty) procedures are only created when strictly required rather than in all cases, as at present.

Separation of user interfaces from implementation machinery

Each of the models discussed above will provide an interface to a human operator. These interfaces may be grouped into 'windows', which will be located and managed on a 'desktop' following well-established Graphical User Interface (GUI) techniques.

In contrast to current implementations in which applications and interfaces are inextricably linked, the choice of grouping and the layout of these windows will be separated from the models themselves and will be easily modifiable by the users of a specific mission. This means that it will be quite possible to have, say, network-status information in the window of the manual commanding interface for mission X, and to replace or augment it with spacecraft power-status information for mission Y.

What kind of hardware and software does this imply?

Distributed systems

The demands placed on the computing environment by such a flexible and ambitious set of system functions will be considerable. The hardware concept for SCOS II must be flexible enough to provide configurations to deal with the differing demands of the specific mission-control systems, whilst not requiring software modifications to cope with them.

In view of this, and in view the strategic objective of vendor-independence discussed earlier, the SCOS II system will be hosted on a Local Area Network (LAN) of Unix workstations. Each operational user will be

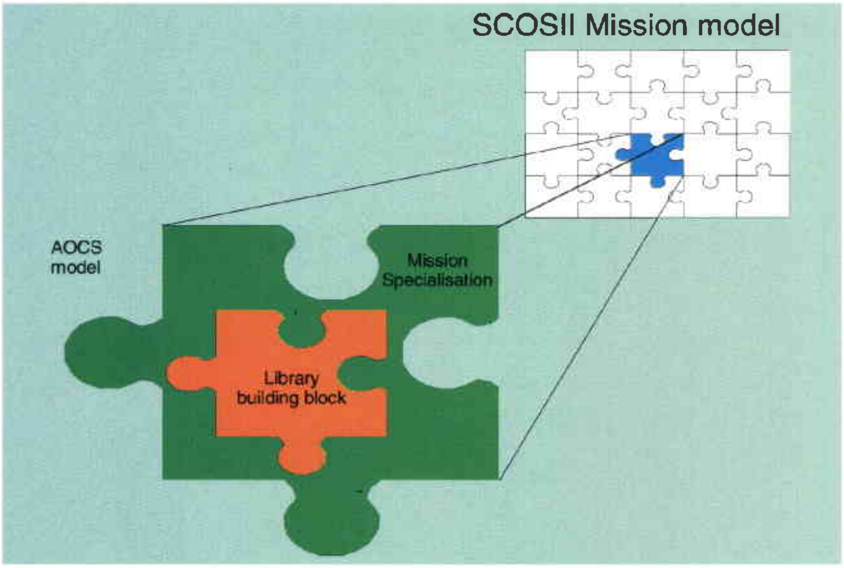

Figure 3. Building blocks used to create the SCOS II mission model can include mission-specific specialisation whilst maintaining the same interface

provided with at least one processor at their workstation to cope with the user-interface processing load. A set of overall coordination functions will be embedded within the SCOS II system software to ensure consistency between the spacecraft models located on these workstations and to provide a relocation service allowing system functions to be distributed over the physical hardware as mission needs require.

Some services of the system will be provided by 'server' processors, which are not dedicated to any particular user, but which provide a service to the system as a whole. A typical example of such a server would be a database server, containing the basic representation of each of the models used for a particular mission and which would be copied to each active workstation required to monitor the item in question. Such use of centralised services by applications software is commonly referred to as the 'client-server' concept.

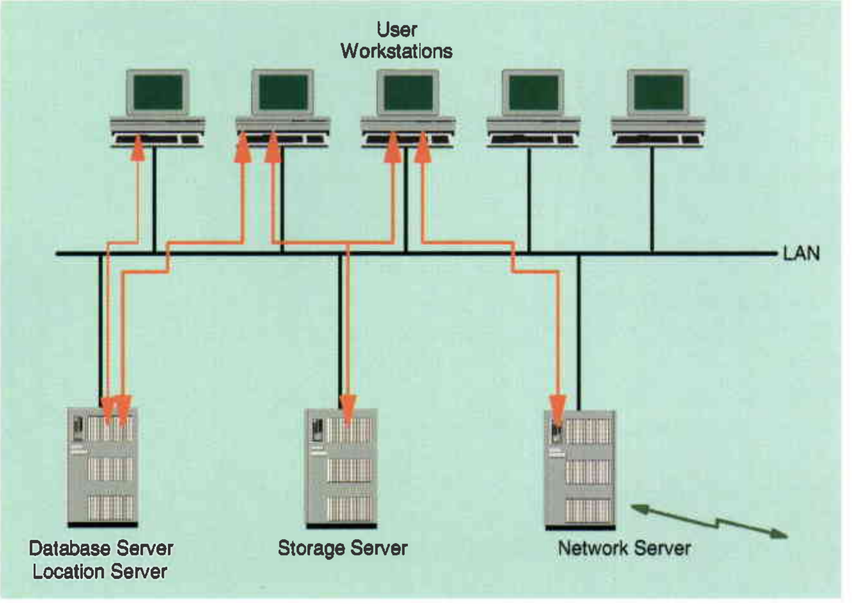

Figure 4. A simple SCOS II configuration with example 'client-server conversations'

It is also planned that a minimum SCOS II system should be capable of running on a single workstation should it be necessary to install mission-control facilities at remote sites (typically in ground stations). In this case, the servers and their clients would be physically located on the same processor.

The use of such a distributed system also offers advantages in terms of system availability and failure tolerance. By careful planning and design (particularly of redundant servers), we expect to achieve resilience of SCOS II-based systems to most failures (although a user may be required to move to an alternate workstation in some cases).

Performance goals

As SCOS II is intended to be the basis for systems until the early part of the next century, we have adopted some fairly ambitious performance goals; these include real-time data rates (for spacecraft housekeeping data) of 2–3 Mbits, display update rates exceeding 10 per second (particularly during retrieval of non-real-time data, a problem of existing systems), and user communities of up to 50 workstations. The first release of SCOS II is not required to achieve such levels of performance. Despite this, we are paying great attention to performance factors in the design of the system rather than merely relying on the ever-increasing performance of workstation hardware and software.

Adaptive processing

In typical mission-control systems, there are two basic usage scenarios that must be supported: the 'normal operations' case and the 'critical operations' case. A normal case scenario is characterised by a small number of users at any one time, and by limited and fairly repetitive user activities. A critical-operations scenario usually involves a larger number of users and a more varied set of activities. The critical-operations case is the more difficult one to support, but it has a number of peculiarities that can be used to advantage when designing the system:

- The users will be working with a relatively small amount of data; this will be related to the procedures being executed at the time of the anomaly. The SCOS II infrastructure should allow adaptation to this situation at the cost of degraded response for those requiring other data (i.e. not involved in critical operations).
- A particular user will only be looking at only some subset of the full data set within the time window.

In order to take proper advantage of these two characteristics, each user workstation will be provided with a local 'cache store', where telemetry and model data is stored and retrieved without affecting other users of the system. The algorithms that determine which data is to be kept in the cache and which will have to be retrieved from the system server can be tuned as usage patterns for the system become more obvious. An initial version of the system will apply a simple 'most recently used' approach, combined with a filtering to eliminate types of data not required by that user.

Status and future plans

The User Requirements for the first major release of SCOS II are currently under review; together with this, the matching Object-Oriented Analysis model has been produced and documented in a Software Requirements Document. This will be reviewed as soon as the User Requirements review has been completed. In addition, proof-of-concept prototyping of the technology was carried out in 1992, and considerable prototyping has been done in support of the user-requirements definition.

An initial delivery of Release 1 is foreseen for early 1994. It will contain basic functions of the system and will provide equivalent capability to that of existing SCOS I-based systems.

Acknowledgements

The authors would like to acknowledge the enormous effort and enthusiasm of all of the ESOC SCOS II team members, past and present; many of the concepts mentioned here are directly attributable to their efforts, vision and dedication.

Protecting ESA's Computer Operations

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Why protect computer operations?
The demands of space research have resulted in the use of sophisticated computer technology that supports, both directly and indirectly, sensitive or mission-critical functions and allows the storage of vast amounts of data.

The Agency's policy on the protection of its computer operations can be simply stated:

'Computer and data-communication systems and the data contained within and transmitted through these systems are fundamental assets of the Agency. It is the responsibility or all Agency employees, contractors, and other persons using or working in connection with Agency computer and data-communication systems, to maintain the confidentiality, integrity and availability of these assets'.

However, policy alone is not sufficient. Behind that broad statement there must be a supporting infrastructure – in other words a data security programme. How is the policy to be achieved? In particular, how are people expected to meet their responsibilities?

The ESA data-processing function is supported by a large, complex and widely distributed computer and data-communication environment. The data-processing resources are managed on a decentralised basis throughout Europe and include mainframe computers, mini-computers, micro-computers and an array of networks. The scope of the Agency's data processing ranges from administrative applications, through scientific/engineering computing and information-retrieval systems, to real-time satellite control.

The ESA computing facilities do not exist solely for the Agency, but are made available worldwide to large elements of the scientific and industrial communities. Neither is it possible to ignore the interfaces that ESA has with other international organisations such as NASA. Such interfaces impose an obligation on the Agency to contribute and conform to certain accepted practices. The loss of availability, integrity or confidentiality of any of the Agency's systems could result not only in embarrassment to the Agency, but could jeopardise major missions and, ultimately, even pose a threat to individuals' lives.

Providing protection in such a scenario involves a continuing management process, balancing user needs for ready-access to applications and information with the sometimes conflicting requirement to control such access and preserve the confidentiality, integrity and availability of the systems. Security always makes additional demands upon people – it is inevitably an overhead. Since a chain is only as strong as its weakest link, data security relies upon every person working in connection with Agency data-processing and data-communication systems taking a positive approach and accepting various responsibilities.

In recent years, much publicity has been given to the threats to which computers can be exposed, for example:

- software attacks (e.g. viruses, worms, trojan horses)
- unauthorised access (e.g. hacking)
- fire and natural disasters
- industrial espionage, including electronic eavesdropping and scavenging (trashing)
- fraudulent use
- malicious damage and terrorist attack.

Some of these problems can be expected to become more technically complex and more widespread with the continuing advances in computer and telecommunications technologies.

In addition to the above, it should not be forgotten that good old-fashioned human error still accounts for the majority of adverse incidents.

Elements of a data security programme
A data security programme consists of several elements that, when taken as a whole, provide an appropriate level of protection to data-processing- and data-communication-related assets.

System/network classification and registration
All computer systems and data-communication networks need to be uniquely identified and registered along with a data security profile. This profile will determine the data security requirements and will primarily be based upon the sensitivity/criticality of the applications being processed.

Risk management
Computer risk management involves the identification of threats, determination of risk, assessment of potential impact and the recommendation of appropriate countermeasures to reduce the exposure to an acceptable level.

Policies and procedures
Policies and procedures define the requirements for a data security programme and the means by which it can be implemented and sustained.

Roles and responsibilities
Policies and procedures will not implement themselves; there need to be defined roles and associated responsibilities. These roles can be divided into four main categories and in most cases simply augment an individual's existing function:

- user roles
- technical roles
- security roles
- management roles.

Awareness programme
For a data security programme to be effective, individuals need to have an appreciation of what is involved and why. They need to understand their particular role and responsibilities.

Compliance and waivers
To meet the objectives of a policy, certain procedures need to be complied with. There are inevitably situations where this is simply not possible and some form of waiver is necessary. These are usually cases where protective measures can not be applied retrospectively to existing systems.

Data-security incident response
A data security violation is:

'any incident that results directly in the loss of availability, integrity or confidentiality of a data-processing- or data-communication-related resource, or any incident that causes a financial loss as a direct result of the misuse of data-processing or data-communication resources'.

It is necessary to have appropriate responses to apparent data security violations, both to assess any 'damage' and to feed back any procedural enhancements into the data security programme.

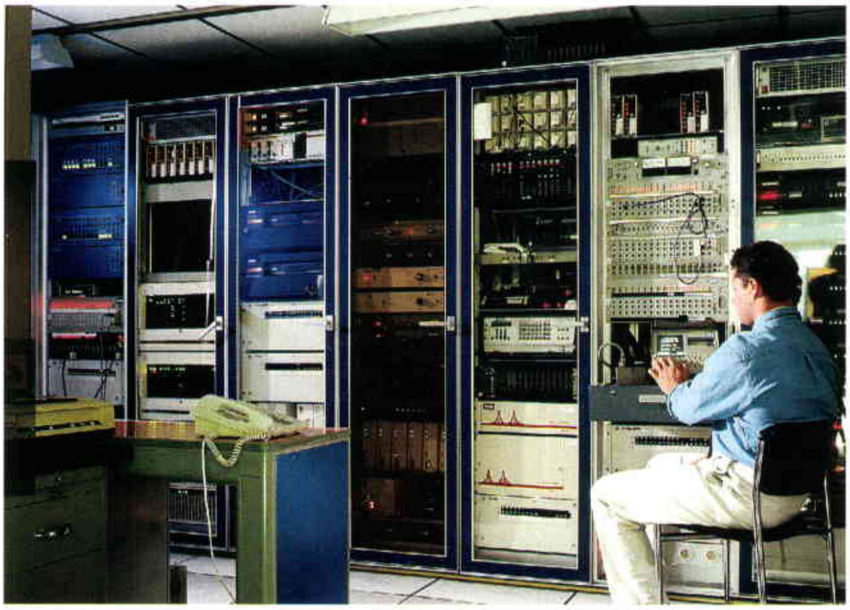

Figure 1. Computer facilities at ESTEC (NL)

Areas addressed by the ESA data-security programme
Personnel
The most important asset of any organisation is its staff. Equally, the major source of data-security violations is people. Without preventative intervention, computer systems tend to become more at risk the more people use them. If data-processing and data-communication operations are to be safeguarded, we need to be aware that security is fundamentally a people issue. Considerations in the area of personnel include:

- thorough selection procedures
- vocational training to ensure that staff are competent in the functions that they are expected to perform
- security awareness training
- regular counselling
- clear job descriptions
- adequate segregation of duties
- enforcing the taking of leave entitlement.

At ESA, these issues fall under the responsibility of the Personnel Department in the Directorate of Administration.

Physical security

The purpose of physical security is to protect computer systems, including the software and data, from loss or damage by physical means. This covers a wide spectrum of threats, e.g. fire, flood, sabotage, theft, and loss of power. Without appropriate physical security, other protective measures (e.g. logical access controls) can be undermined by very simple accidents or physical attacks upon the computer facility.

The Agency's main computer facilities contain hardware and software of high monetary value. When this value is combined with the high degree of operational reliance placed on these facilities, physical security is clearly of major importance.

Figure 2. Computer facilities at ESRIN (I)

Physical security is equally important for smaller systems, although the risks and countermeasures may differ in some respects from those relating to large systems. When a personal computer is stolen, so is the software and, often more importantly, the data.

At ESA, physical security is generally the responsibility of the local Site Services department. The site safety and security function of the Risk Management Office regularly liaises with those involved, particularly in the areas of standards and the carrying out of reviews. When planning new computer facilities, security should be one of the fundamental considerations.

Logical access control

Logical access is the means whereby a person gains access to data-processing resources via a communications device (e.g. a terminal) or by running a program. The purpose of logical-access control is to enable the Agency to restrict access to system resources to authorised persons for authorised purposes.

Logical access to a system is usually a three-stage process. Using a traffic light as an analogy:

- *RED*: The system asks you for **identification**, normally by means of a 'user ID'. If the system recognises the user ID, then
- *AMBER*: The system asks you for **authentication**, typically by requesting a password, to prove that it is your user ID.
- *GREEN*: The system allows you access. This **authorisation** may restrict you to certain system resources.

There are various products that can be used to implement logical access control. At ESA Headquarters and at ESRIN, IBM's Resource Access Control Facility (RACF) is used. At ESOC, ACF2 is installed. Both work on the 'traffic-light' principle, but have much more sophisticated functionality available, such as confining certain user IDs to certain terminals or times of day. Equally important, they allow security to be flexible and auditable.

Logical access controls are not solely to prevent malicious system activity by unauthorised people. By ensuring that a user is confined to specific authorised system resources, it helps to prevent accidental damage to other resources on the system.

Application/system development

Application/system development is the process by which user requirements are defined and converted into an operational computerised function. Aspects of this requirement will always involve integrity, usually availability, and often confidentiality.

Development standards such as those specified in the Agency's Software Engineering Standards document (PSS-O5), including documentation standards, are a fundamental part of the process by which data security is achieved. PSS-O5 requires that a 'target' data-security profile for the application/system be determined, so that individuals responsible for the various stages of the development 'life cycle' can then ensure that appropriate security is incorporated. Once a system has been implemented, it is often the case that such issues cannot easily be addressed.

Technical support and system software

System software is installed, customised and maintained by technical support staff. Effective control and auditability of systems-software and technical-support activities is essential since, to a large extent, these two aspects determine the operational environment within which applications will run.

Because of the nature of the technical-support function, it is sometimes difficult to restrict the access of technical-support personnel to certain system resources whilst at the same time allowing them to perform their tasks effectively. It is important, therefore, to provide effective audit controls to log such activity and in particular any changes made to the systems.

Operations

Operations activities generally include supervision and management of computer hardware, application processing, back-up and recovery, control of output and the media library.

Operations personnel are custodians of data belonging to data owners. As such, they are responsible for physically safeguarding the data in their care. In conjunction with technical-support personnel, they also carry the primary responsibility for ensuring that systems remain available for use.

The ESA Computer and Network Operations Department (ECNOD) is responsible for a large amount of the Agency's data-processing and data-communication infrastructure. In common with some 'user-controlled' areas, it has Operations Manuals covering procedures necessary for the secure operation of the systems under its control. The computer-security function of the Risk Management Office works with ECNOD and others to assist in the identification and resolution of potential security exposures.

Contingency planning/Disaster recovery

A disaster can be defined as:

'a total or partial loss of system functionality which results in utilisation falling below an acceptable level for an unacceptable period of time'.

Disasters often result in problems that increase in proportion to the duration of the outage. The consequences can be mitigated by having adequate disaster recovery arrangements. ESA has such a plan for its financial system 'EFSY'. This plan, which is tested annually, basically involves transferring the system to a back-up site.

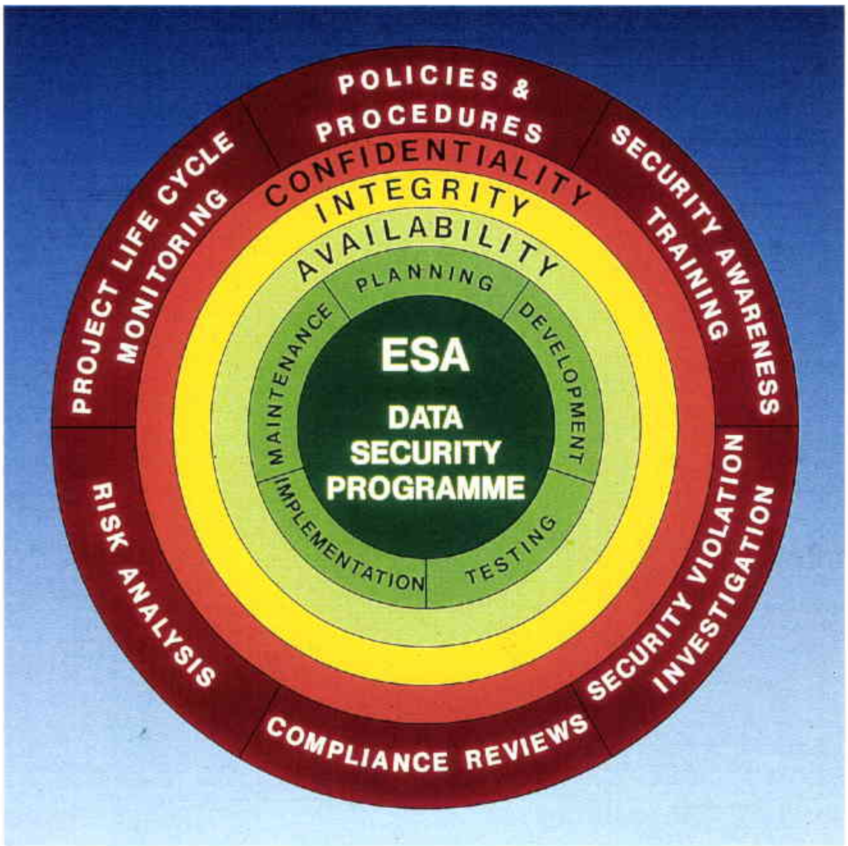

Figure 3. Relationship between data-security functions and the computer system life-cycle caption

It should not be forgotten that there are many other areas that need to be considered in contingency planning. Merely providing back-up computer capability may not be sufficient.

Micro-computer security

In a mainframe or mini-computer environment, the security of the computers and data is generally capable of being well-controlled. However, in a micro-computer environment there are usually fewer controls inherent in the system. The other significant difference is that micro-computers are often single-user systems. As such, a user, who is often not a computer specialist or aware of security considerations, has default responsibility for security.

One specific threat to the integrity and availability of micro-computer systems is the computer 'virus'. One definition of a computer virus is:

'computer program code that is self-replicating within an active processing environment'.

A computer virus is therefore a computer program which, without direct human involvement, can utilise the resources of a computer system to make copies of itself. This self-replication is not, of itself, the cause for concern, except in a few cases where the purpose of the virus is specifically to utilise so much of the system resources that there are none available for normal processing. The main problem is that most viruses carry a 'payload' which, when 'triggered', can have undesirable consequences for the system, and hence for the user. These range from relatively harmless, if somewhat irritating, effects such as playing tunes over the system speaker, to re-formatting the hard disk with the consequent loss of all data. The trigger is typically a date (e.g. Friday 13th), but can be any one of a number of things.

Figure 4. Computer facilities at ESOC (D)

One of the most common ways of spreading viruses is the copying of software, particularly games. You could have a virus for a considerable time and not be aware of it, since they often give themselves plenty of time to spread before 'announcing their presence'. By their very existence, they force prudent organisations to devote time and money to virus prevention, detection and response. Wasted time due to the direct effects of the virus, the reconstruction (if possible) of any lost data or programs, the inability to trust data and programs, to say nothing of any direct financial or even life-threatening consequences, are all reasons for concern.

It should not be forgotten in this respect that ESA is not an 'island'. We continually interact with large numbers of organisations throughout the world, both in industry and elsewhere. Failure to act responsibly could easily result in the spread of a virus from a low-risk area in the Agency to a high-risk area somewhere else.

Anti-virus software has been made freely available within the Agency and the incidences of virus 'attack', mostly from the FORM and Cascade 1701 viruses, have been reduced dramatically over the last six months.

There are other issues that the micro-computer user must address. For instance, it is up to the users themselves to ensure that regular copies of the data on their system are made in case the original gets lost or damaged.

Networks

Network services is one of the fastest growing and most rapidly changing areas in computing. It is also, in many ways, one of the most difficult to control. The risk from 'hacking' and other abuses of Agency computer systems increases with inter-connection to non-Agency systems. To enable genuine, authorised users to have unhindered access without exposing the Agency and those same users to a significant level of risk is a major concern.

Persons responsible for the security of systems connected to networks must realise that, for now, any security features incorp-orated into networks simply augment controls on the system – they do not replace them. If you don't want people to enter your house without your knowledge, don't leave the door open; give them a key or make them knock first!

Conclusion

Data security is first and foremost a management issue. Good management will often compensate for inadequate technology, but good technology rarely compensates for inadequate management. Installing the most sophisticated security mechanisms in the world will be ineffective if those responsible for them do not understand them, or if their implementation and use are not adequately supervised. If the management of an organisation is not committed to data security, one cannot expect others to take it seriously.

Secondly, everyone connected with ESA's data-processing and data-communication facilities, including the users, has a part to play, however small. Bypassing what you may think of as an inconvenience could lead to serious problems for someone else further down the line.

Cooperation with Russia in the Framework of the Columbus Precursor Flights

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The two planned missions to Mir by ESA astronauts in September 1994 and August 1995 will represent an important step in the intensification of cooperation between ESA and the Russian Federation in the field of manned space flight. They will not only benefit the European user community by providing long-duration experiment possibilities, but will also offer flight opportunities to ESA astronauts in the near term, thus helping to prepare Europe for the exploitation of a future manned space infrastructure in an international context.

Introduction

To widen and strengthen international cooperation, thereby taking into account the dramatic geopolitical evolution that has recently taken place, was one of the major objectives reflected in the Resolutions adopted by the ESA Council Meeting at Ministerial Level in Granada (E) on 10 November 1992. Particular emphasis was laid on greater cooperation with the Russian Federation. Consequently, ESA has intensified its contacts with the Russian Space Agency (RKA) to elaborate an Agreement on cooperation on manned space infrastructure and space transportation systems in the 1993–95 time frame.

In this context, the Columbus Programme is preparing for the missions of two ESA astronauts aboard the Russian space station 'Mir', as part of the Columbus Precursor Flights programme. The latter represent an integral element of the Columbus Programme and include, in addition to the two Mir flights, one Spacelab mission, and storage of the European Retrievable Carrier (Eureca) for a further mission.

Objectives

The major objectives of the Columbus Precursor Flights are to:

- prepare the European space user community, ESA, and the Participating States, for the Space Station/Columbus era
- provide the user community with continuing flight opportunities as a transition to the utilisation of Columbus
- provide in-flight validation of design concepts for Columbus payloads (e.g. serviceability, tele-science) and to introduce, as far as feasible, the operations concepts foreseen to support experimentation onboard Columbus
- develop and maintain a core of ESA astronauts and to provide them with flight opportunities in order to improve European experience in crew-operated space systems.

The Mir station

The Mir space station circles the Earth at an altitude of between 350 and 400 km in an orbit with an inclination of 51.6°. In its present configuration, Mir consists of four main modules: the Mir core module and the scientific modules known as 'Kvant', 'Kvant-2' and 'Kristall'.

The Mir core module, which was launched in February 1986, has a mass of approximately 21 tons, a length of about 13.1 m and a maximum diameter of 4.2 m. It consists primarily of a passage area with five docking ports, a working area housing the command station, living/eating and hygiene facilities, and a propulsion section through which a tunnel allows access to the Kvant module.

Kvant, an astrophysics module that accommodates instruments from several countries, was docked to the Mir core module in April 1987. It is about 5.8 m long, has a maximum diameter of 4.15 m, and a mass of about 11 tons.

Kvant-2, a module housing scientific and technological experiment equipment, a shower facility and an airlock supporting extra-vehicular activities (EVA) by the crew, was docked to the station in December 1989. It has a mass of about 19.5 tons, a length of 11.9 m, and a maximum diameter of 4.35 m.

The Kristall module joined the station in June 1990. It is mainly dedicated to technological research, such as semiconductor and biological experiments. It also houses Earth-observation instruments. The mass and dimensions of Kristall are similar to those of Kvant-2.

Figure 1. The Mir space station

In August 1992, a thruster package, known as 'Sofora', was installed on a 14 m mast mounted on top of the Kvant module. These thrusters allow efficient and propellant-saving attitude control of the station.

Two further modules are planned to be added to Mir. The 'Priroda' module, mainly dedicated to Earth-observation tasks such as ocean surface-temperature measurement and studies of ocean/atmosphere interactions, and the 'Spectr' module, supporting studies of the Earth's atmosphere.

Logistical resupply of Mir is provided by the unmanned Progress system, with a payload capacity in the order of 2.5 tons. The crew is transported to and from the station with the Soyuz-TM vehicle, which can accommodate three astronauts/cosmonauts per trip. Both the Soyuz-TM and Progress are expendable systems and are launched by the Soyuz launch vehicle.

The results of the experiments, including samples, film, etc., are usually returned to Earth by the astronaut/cosmonaut on-board the Soyuz-TM capsule. A special unmanned re-entry capsule enhances these return capacities.

Mission definition and payload composition

The cooperative programme provides for two Mir missions in the 1994–96 time frame, called EuroMir-94 and EuroMir-95. The EuroMir-94 mission is planned to be launched in September 1994 and will have a duration of about 30 days. The activities of the European astronaut will be concentrated mainly on conducting physiological and some materials experiments. The EuroMir-95 mission, to be launched in August 1995, will last up to 135 days. On this trip, the European astronaut will not only perform experiments, but will also be trained and qualified as a flight engineer, with defined responsibilities for Mir station operations. During this mission the ESA astronaut will also undertake EVA sorties outside the station.

This approach, conceived with the rationale of implementing steps of increased duration in-orbit, will enhance ESA's experience of crew behaviour in space from both the life-sciences and orbital-operations points of view.

The flights will follow the typical sequence of key activities described below:
- launch of an unmanned Progress vehicle, accommodating most of the ESA payload, to the Mir station approximately one to two months prior to the launch of the ESA astronaut
- launch of the European astronaut and two cosmonauts, together with the remainder of the ESA payload, with a Soyuz-TM
- rendezvous and docking of the Soyuz-TM with Mir about two days after launch

- station hand-over activities from the outgoing crew to the newly arrived crew, including the ESA astronaut (nominal duration about 1 week for EuroMir-95; extended duration of about 1 month for EuroMir-94), and start of the experimental programme
- return to Earth of the outgoing crew (for EuroMir-94, together with the ESA astronaut and the ESA experiment results) with the Soyuz-TM
- for EuroMir-95, continuation of the experimental and operational programme by the ESA astronaut and the cosmonauts
- return to Earth of the ESA astronaut, the two cosmonauts and the ESA experiment results by Soyuz-TM, after hand-over of the station to the new crew.

The ESA astronaut will perform experiments in the space-science, material-science, life-science, fluid-science, and basic physics and technology domains. The Earth-observation opportunities offered by the high inclination of the station's orbit will also be considered.

For the EuroMir-94 mission, a payload of 100 kg is foreseen to be taken up by Progress, and one of 10 kg in the Soyuz-TM. The second mission will feature a significantly higher payload of about 200 kg on Progress and 10 kg on Soyuz.

The identification of ESA experiments and facilities for the two missions is based on three sets of experiment proposals, namely:
(a) experiment proposals received within the context of the Announcement of Opportunity issued for the Columbus Precursor Flights
(b) experiment proposals for the re-flight of experiments already carried out in the context of earlier national Mir missions involving ESA Member States, and
(c) new experiment proposals specifically for the EuroMir-95 mission.

The selection of the experiments and corresponding instrumentation for the EuroMir-94 mission took place in May 1993. By far the majority of the experiment proposals for this first mission were in the field of human physiology, with a few additional experiments in the material-sciences domain. Most of the scientific investigations will use existing instrumentation already onboard of the Mir station, but it will be operated by the ESA astronaut. In fact, the European astronaut will himself be an essential part of the life-sciences experiments.

For the second mission, in 1995, it is planned to follow a more conventional approach for the selection of the experiments and instruments from the microgravity, space-science, Earth-observation and technology-demonstration disciplines. Here, the definition of the experiment programme is currently nearing completion.

Astronaut training

In August 1993, four ESA astronauts will begin training at the Yuri Gagarin Cosmonaut Training Centre near Moscow, known as 'Star City' (see earlier article on astronaut

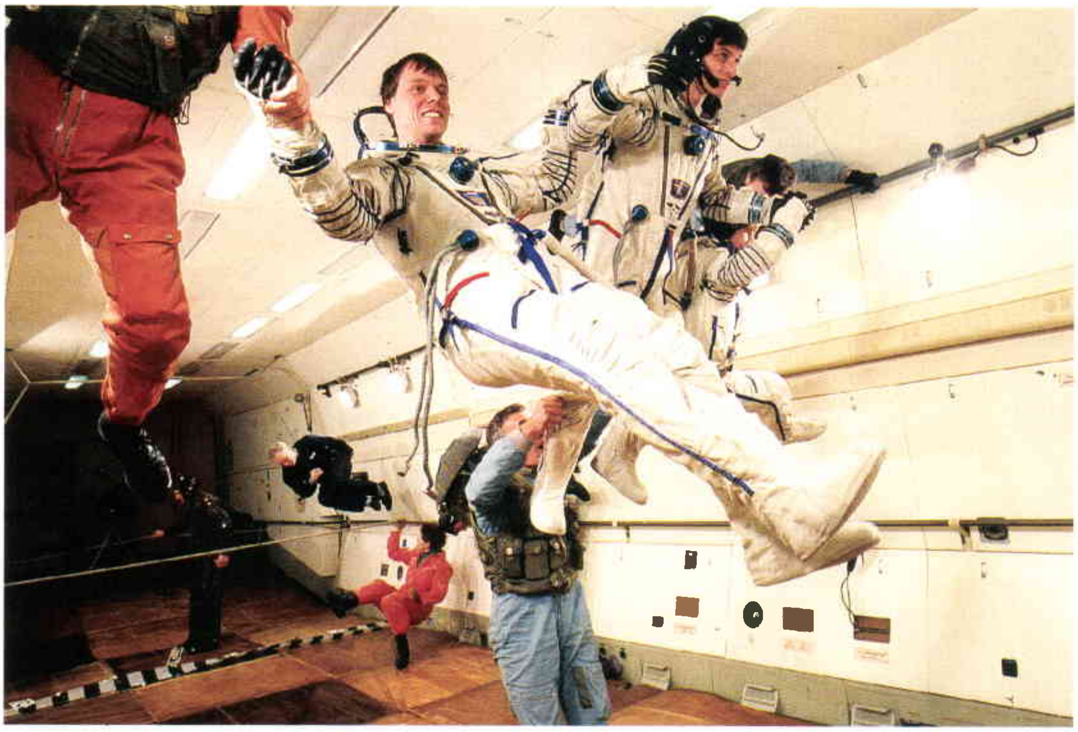

Figure 2. ESA candidate astronauts during parabolic flights from Star City

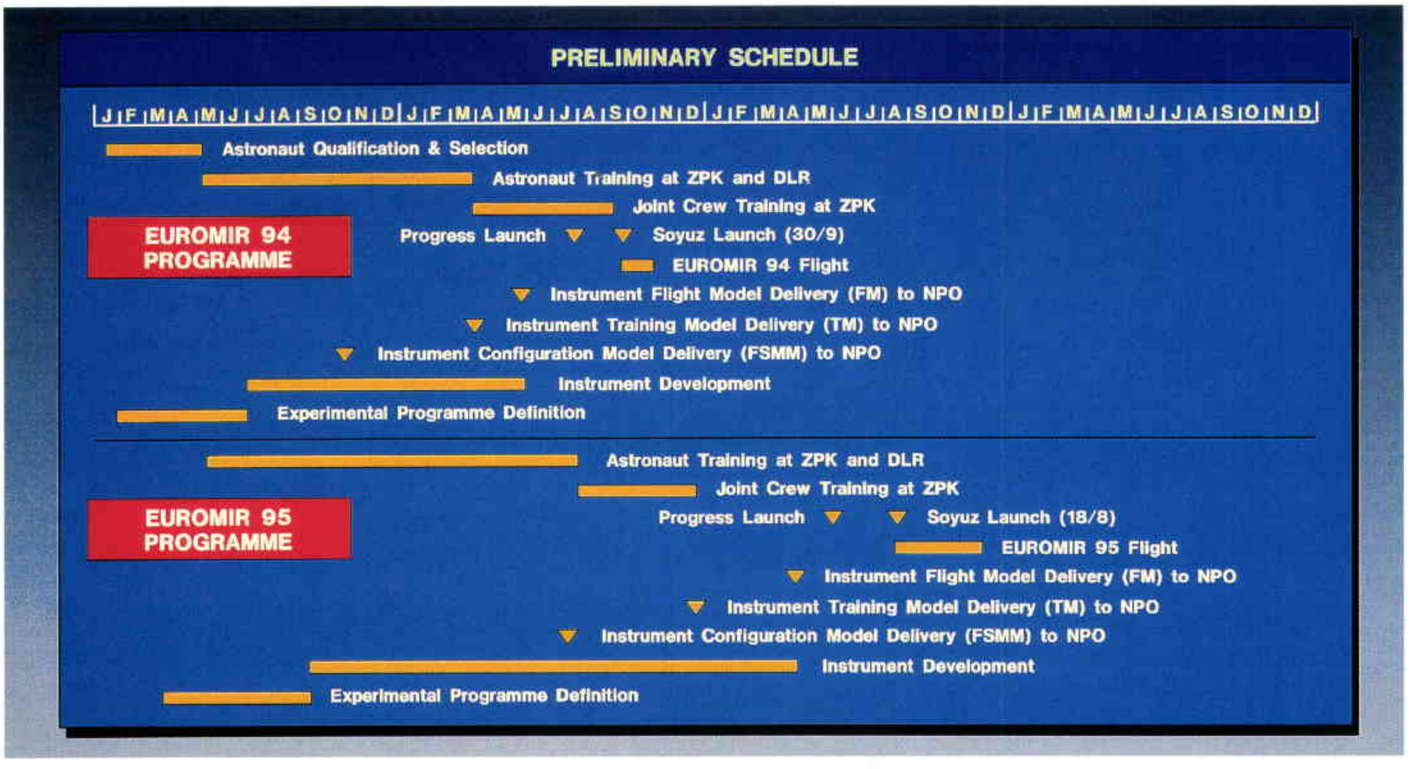

Figure 3. Overall schedule for the EuroMir-94 and EuroMir-95 missions

training in the CIS in ESA Bulletin No. 73, February 1993). For each mission, there will be one nominal astronaut and one back-up, both of whom will follow the same training programme. The medical certification of the ESA astronauts, performed in cooperation with Russian medical experts, was completed in April 1993.

The astronauts have followed ESA basic training and intensive Russian language courses at the European Astronauts Centre (EAC) near Cologne, Germany, to prepare themselves both for the training sessions at Star City and the subsequent onboard mission operations, which are all conducted in Russian. A one-month stay at Star City in November 1992 allowed them to familiarise themselves a little with the facilities and the environment of the training centre.

The training in Russia will consist of two major elements: common 'Basic Training' and specific 'Mission Training' for Euro-Mir-94 and EuroMir-95, respectively. The common Basic Training will last about four months and includes such topics as the theory of manned space vehicles, manned space vehicle control systems, fundamentals of space navigation, Soyuz-TM systems, an overview of the scientific experiments and research conducted on Mir, general EVA training and biomedical training, as well as lessons to maintain proficiency in the Russian language.

The subsequent Mission Training will include technical training, biomedical training, Russian language proficiency maintenance, and crew training in the Soyuz-TM and Mir simulators. The Mission Training for Euro-Mir-95 will feature significantly enhanced training time on Mir systems and operations, and special EVA training sessions, mainly in the neutral-buoyancy facility at Star City.

A substantial part of the ESA payload training is planned to be performed in Western Europe.

Schedule

Following first contacts with the Russian partner during the course of 1992, the actual preparation effort for the two Mir flights started in early 1993. The missions will be implemented within the framework of a Cooperation Agreement between ESA and the Russian Space Agency (RKA) through the placement of an industrial contract with the company NPO-Energia.

A summary schedule for the preparations for and the undertaking of both missions is shown in Figure 3.

The Mir-95 post-mission activities are expected to be completed in early 1996.

The HYDRA Multi-Axis Shaker

– A New Vibration Testing Facility at ESTEC

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HYDRA will be a very powerful and safe tool for the qualification and acceptance testing of space structures, permitting the application of standard as well as advanced test methods. It will reduce the operational effort involved in, and permit the shortening of, test campaigns, which will have a positive impact on overall user programme schedules and costs.

Introduction

ESA has developed and maintains major environmental test facilities at its European Space Research and Technology Centre (ESTEC) at Noordwijk. These facilities are at the disposal of industry, scientific institutes, and projects to support space programmes, in particular those of ESA and its Member States. The performance characteristics of the test facilities are regularly reviewed and adapted to the needs of future Agency programmes. In this context, ESA has decided to add a six-degree-of-freedom hydraulic shaker (HYDRA), in order to make the ESTEC Test Centre fully compliant with the system test requirements for future Ariane-4 and Ariane-5 payloads.

As shown in Figure 1, the main facilities co-located within one building complex consist of the:

- Large Space Simulator (LSS)
- Electrodynamic Vibration Systems
- Compact Payload Test Range (CPTR)
- Acoustic Facility (LEAF), and
- six-degree-of-freedom Hydraulic Shaker (HYDRA).

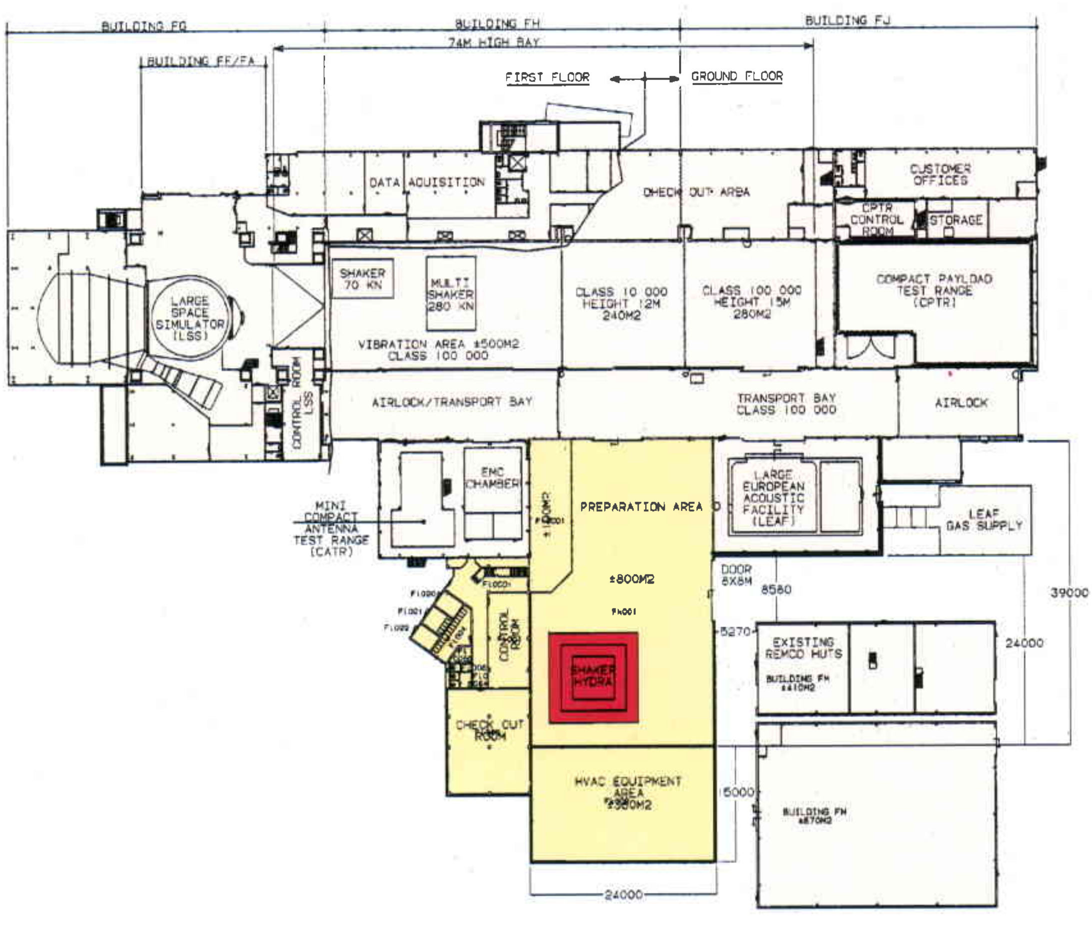


Figure 1.Plan view of the ESTEC test centre showing the HYDRA shaker test area

The co-location of facilities with transportation links within one building is a pre-requisite for efficient spacecraft testing campaigns.

Tool for structural qualification

Considerable effort has been expended during the last decade in studying the possibilities for dynamic structure qualification and system acceptance of Ariane-4 and Ariane-5 payloads. These investigations have fed through into the concept for and design of the HYDRA hydraulic shaker (6 DOF), which is distinguished by the following main features compared with conventional electrodynamic shakers:

(a) extended shaker forces and stroke
(b) active control of orthogonal motions
(c) extended frequency range below 5 Hz
(e) realistic flight-load representation by 6-DOF transient excitation
(f) improved test operations and safety.

Dynamic performance

Some of the main dynamic characteristics of the HYDRA facility are shown in the accompanying performance diagrams (Figs. 2,3), which indicate the test-table excitation limits for different payload masses.

The Ariane-5 qualification levels for sinusoidal vibration tests are indicated in the diagrams and demonstrate that adequate margins exist even for very heavy payloads. Also, low-level excitation at 0.05 g up to 15 Hz and 0.1 g up to 100 Hz is possible with adequate accuracy. An important improvement is the active control in all axes, which avoids undue cross-axis excitations.

Realistic flight-load simulation (transient testing)

The introduction of a test method that reflects a more realistic representation of the space flight environment has been a major objective of the above-mentioned studies. It has been concluded that the simulation of the multi-directional transients at the interface of launcher and spacecraft produces the most realistic structural responses, unlike traditional sine or random tests, which lead to unrealistic responses and therefore involve an inherent risk of over- or under-testing.

Multi-degree-of-freedom hydraulic shakers designed for earthquake simulation have been used in the past to demonstrate that the reproduction of transients representative

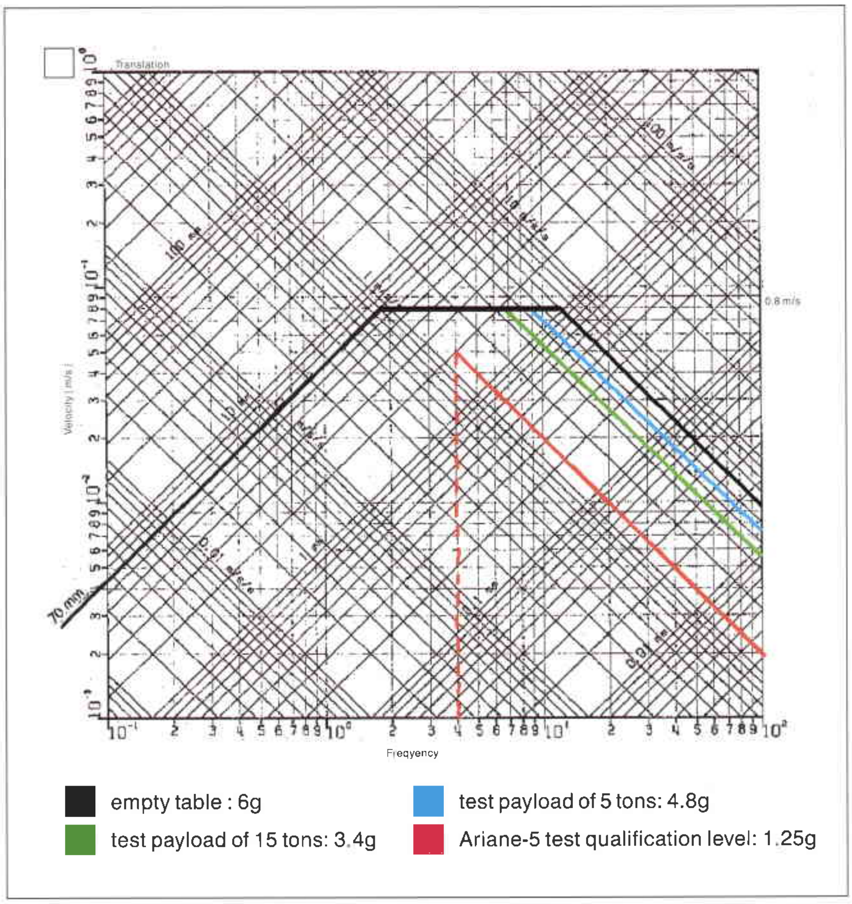


Figure 2. Performance of HYDRA in vertical sine test mode

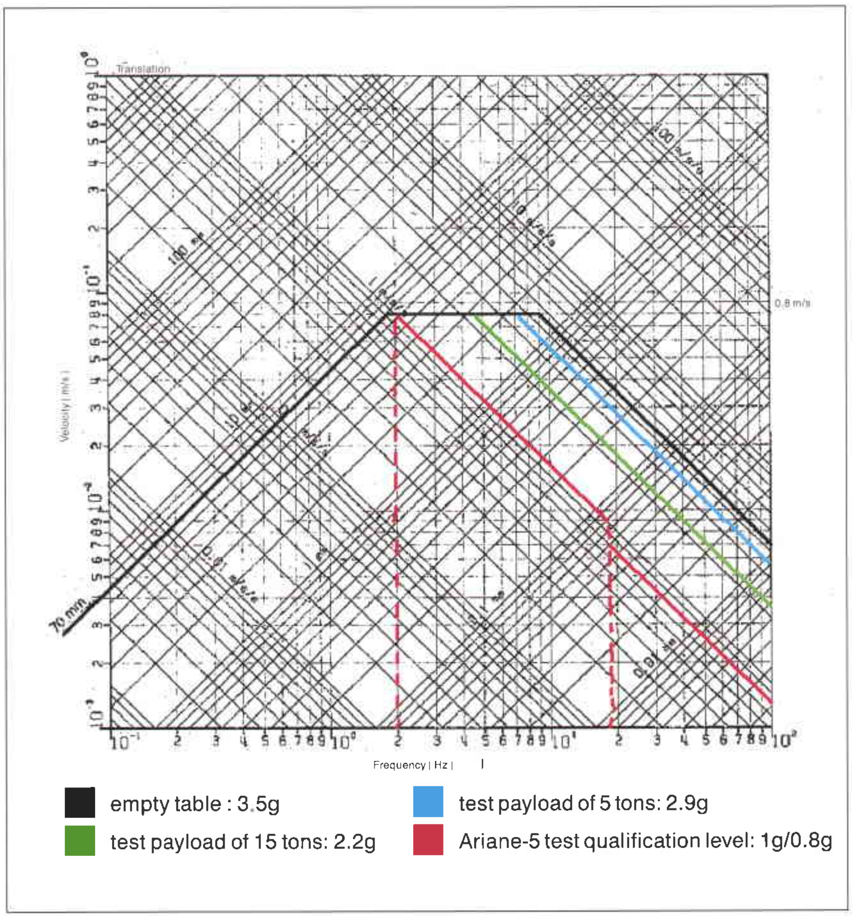


Figure 3. Performance of HYDRA in horizontal sine test mode

of the Ariane and Space Shuttle environments is feasible after several iterations. The progress in computer technology in recent years has facilitated the specific design of a control system that permits the simulation of transients at the payload interface in six degrees of freedom without an iteration process (patent of Mannesmann-Rexroth and AGE pending). This capability will make it feasible to apply the transient test method for spacecraft-structure qualification in future (Fig. 5).

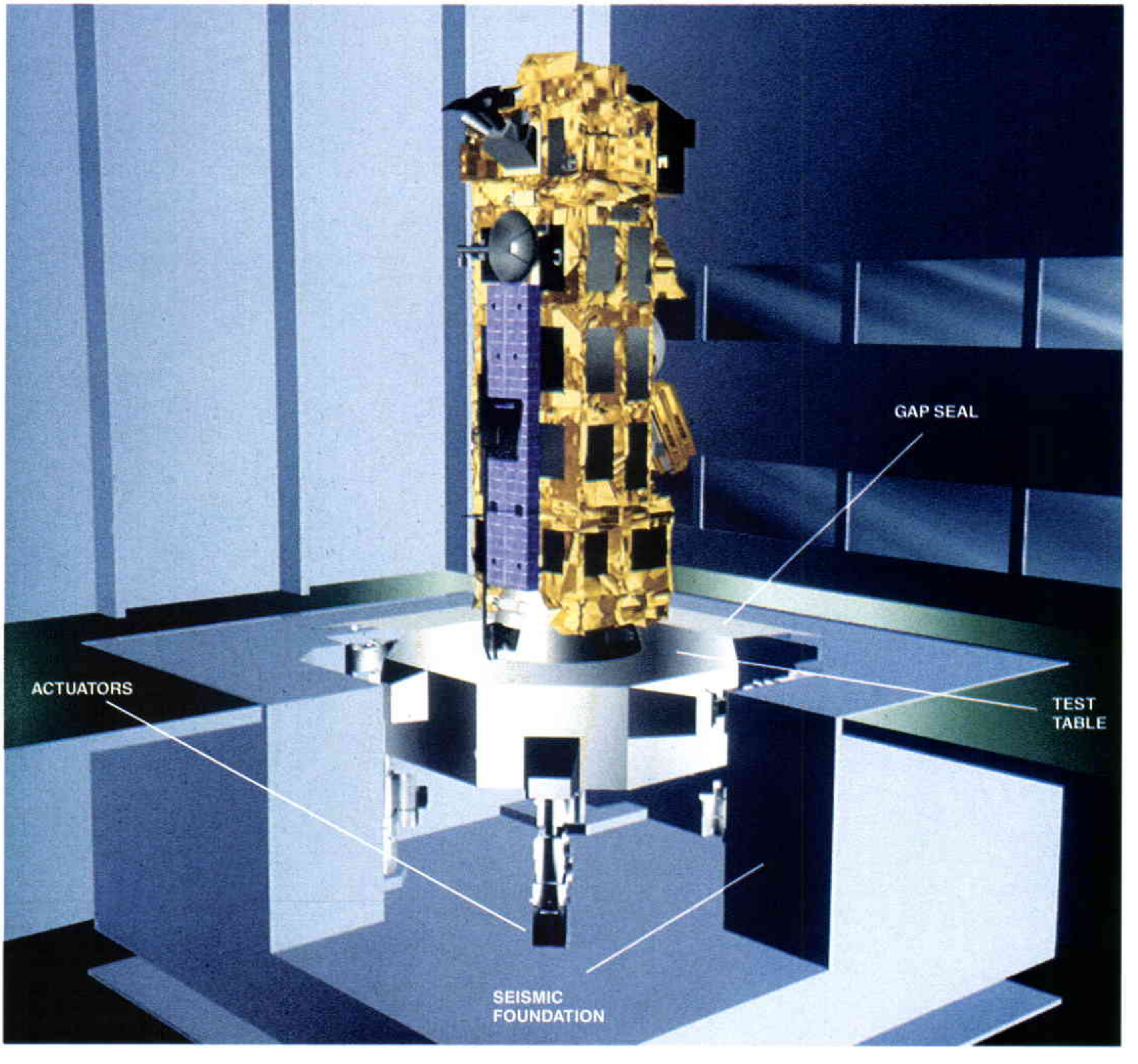
Consequently, HYDRA has been designed to perform sinusoidal testing as well as to generate 6-DOF transients. The latter test mode can be implemented as soon as satellite programmes are ready to apply this new test method.

Operational aspects

The 6-DOF hydraulic shaker allows the specimen to be tested along both the vertical and the lateral axes with a single test setup. It is therefore no longer necessary to dismount, re-locate, and re-instrument the payload for the different excitation directions. This not only reduces the effort involved in handling and in instrumentation, with consequent reductions in test durations and risk, but it also provides flexibility in the sequencing of tests. In particular, *x*-, *y*- and *z*-signature tests can be performed without particular effort before and after each single-axis test run.

The aspects of the HYDRA configuration of particular interest to the 'customer' are illustrated in Figure 4. The large octagonal

Figure 4. Artist's impression of the operational configuration



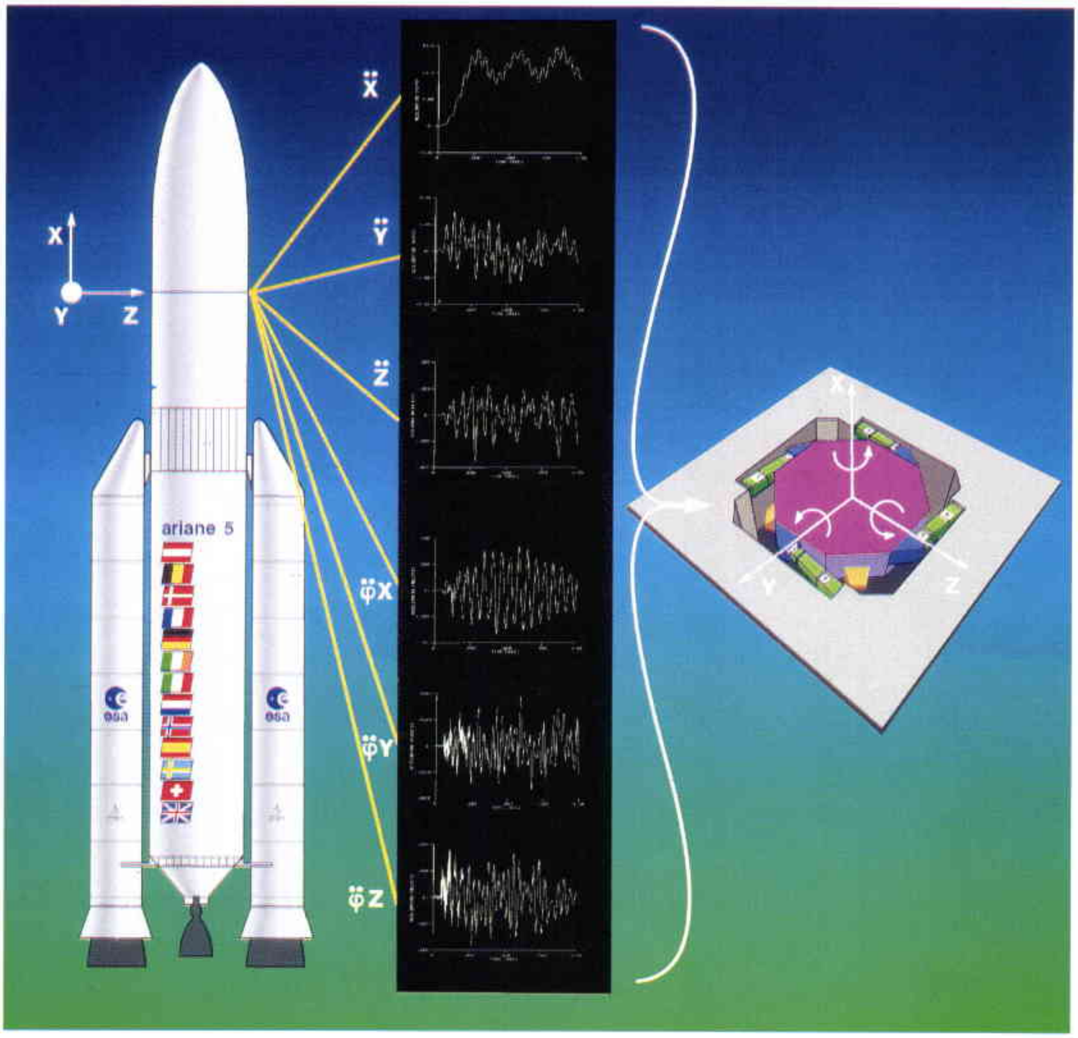


Figure 5. Illustration showing a typical transient at the payload interface of Ariane-5 in six degrees-of-freedom

test table has a span of 5.5 m and is flush with the test floor. It facilitates the mounting of heavy and/or geometrically large specimens (e.g. appendages such as solar arrays). The complexity and mass of test-specific mechanical support equipment and adaptors can be reduced with this configuration.

The shaker is located adjacent to both the control room and the area for the customer's satellite check-out equipment, which fosters good communication and working links between the user teams and the test operations staff. All shaker equipment and supplies are located in the basement of the building, mechanically isolated from the clean test area (class 100.000 Fed. Std. 209).

Cleanliness and safety

Detailed product-assurance analyses during HYDRA's design have led to a well thought out strategy for providing optimum protection for the test item against contamination and overtesting. The safety system is of the utmost importance, due to the presence of moving masses with high inertias and the large installed hydraulic power. The control system protects the specimen against all potential failures identified in various safety analyses, by initiating a 'soft facility shutdown'.

The gap between the aluminium test table and the test floor is closed by a flexible seal. This provides mechanical separation of the clean test area from the hydraulic equipment (actuators, bearings, valves, etc.) located below the table (Fig 4).

Implementation schedule

A detailed design and engineering phase for HYDRA and the associated building has been performed during 1992/1993. Construction of the building will start before the end of the year. HYDRA will then be operational during the last quarter of 1996. The Envisat flight model will be the first user of the new hydraulic vibration facility, based on current planning.

Integral Selected as ESA's Next Scientific Mission

In Brief

ESA's Science Programme Committee (SPC), meeting at ESTEC in Noordwijk (NL) on 3 and 4 June 1993, accepted the recommendations of the Agency's Space Science Advisory Committee (SSAC) and confirmed the International Gamma-Ray Astrophysics Laboratory – 'Integral' – as the second 'Medium-sized Mission' (M2) within the framework of the ESA Long-Term Programme 'Space Science: Horizon 2000'.

Integral is a gamma-ray observatory to be developed in cooperation with the USA and Russia. The instruments that it will carry, which are 10 to 50 times more sensitive than those previously flown on other spacecraft of this kind, will allow it to push the limits of gamma-ray astronomy very considerably.

The mission

Integral's primary mission will be to observe the Galactic Plane and Galactic Centre, but it will also be looking in other directions to search for extragalactic gamma-ray sources such as nuclei of active galaxies, or clusters of galaxies. Another observing priority will be the study of compact objects (neutron stars, black holes) as well as supernovae and novae. Most of the observing time (75%) will be made available to the worldwide astronomy community via a 'Guest Observer Programme',
for which Calls for Proposals will be issued. The remainder of the time will be reserved for the research institutes that will develop the payload instruments and the data-processing facilities.

As a cost-reducing measure, the Integral satellite will re-use a platform (a so-called spacecraft 'bus') identical to that currently being developed for the ESA X-ray Multi-Mirror Mission (XMM).

ESA will have overall responsibility for the Integral spacecraft and mission design, instrument integration and testing, spacecraft operations and data acquisition. The payload instruments will be provided largely by the European scientific community. NASA will supply one or two ground stations and is expected to be involved in the development of certain instruments, such as the Spectrometer. Russia may provide a Proton launcher free of charge in exchange for observing time.

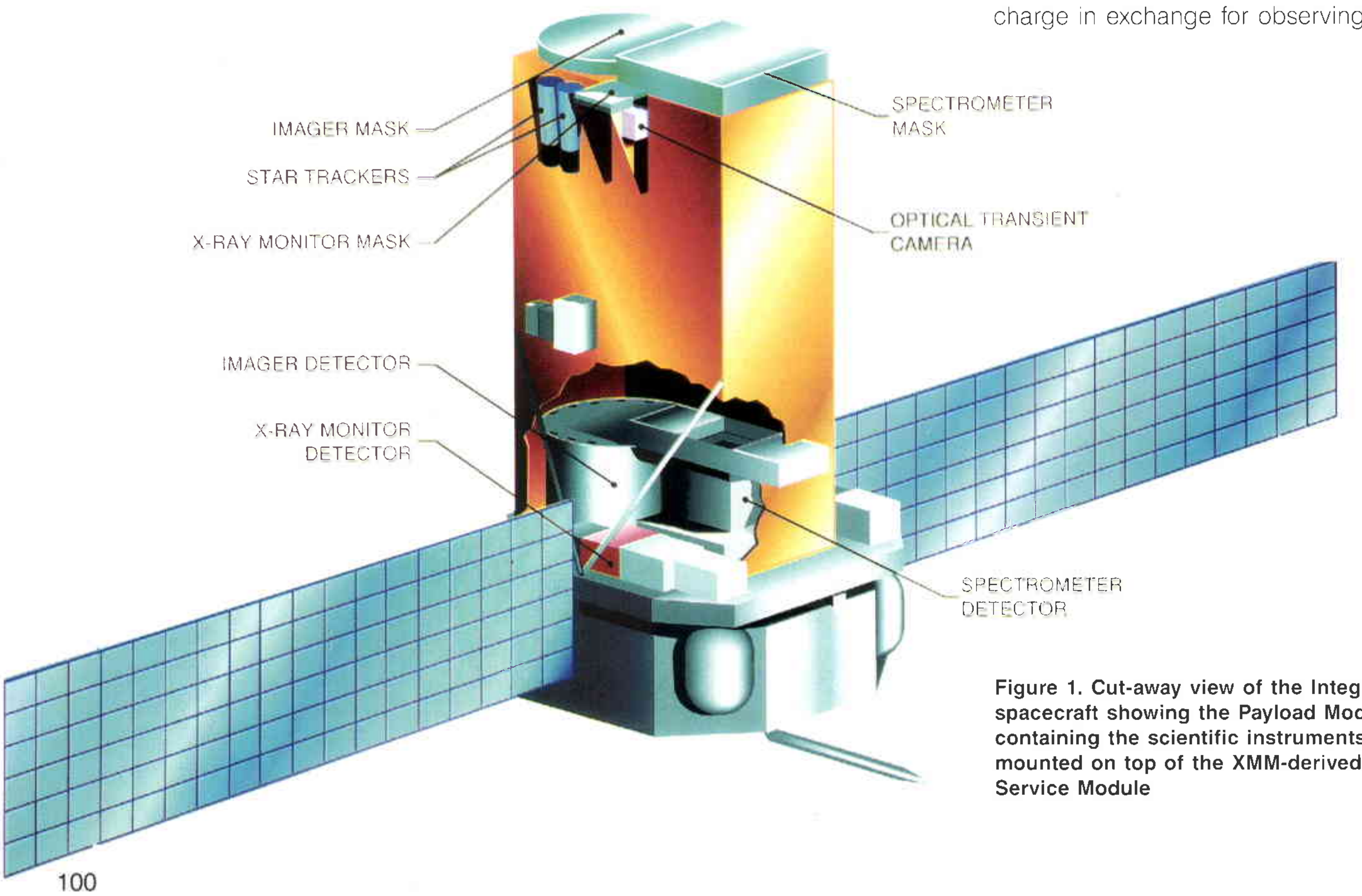


Figure 1. Cut-away view of the Integral spacecraft showing the Payload Module, containing the scientific instruments, mounted on top of the XMM-derived Service Module

A parallel option with an Ariane-5 launcher is also being considered.

The launch of the 3.6 ton Integral spacecraft is planned for early 2001. The Proton launcher would deliver Integral into a 72 h orbit with a high perigee of 48 000 km and a 115 000 km apogee, at 51.6° inclination, while an Ariane-5 launch would inject the spacecraft into a 24 h orbit with a 4000 km perigee and 68 000 km apogee at 65° inclination. Both launch vehicles would thus make it possible for the satellite to avoid the disturbances caused by high-energy particles trapped in the Earth's radiation belts, which actually permit observations to be carried out only from altitudes above 40 000 km.

The Integral mission is expected to last two years, but could be extended to up to five years.

The science

In common with most of the components of the electromagnetic spectrum, gamma rays do not reach the Earth's surface, because they are intercepted by our planet's atmosphere. They can therefore only be observed from space, despite the fact that they have the highest energies of any form of electromagnetic radiation known to man. In space, gamma-ray photons have been detected with energies more than 10^{12} times that of visible photons. Because of these extreme energies, gamma rays reach the Earth's atmosphere from the furthest corners of the Universe, carrying information from objects almost as old as the Universe itself.

Gamma rays also carry information from much closer regions, such as the centre of our own Galaxy, which are shrouded in dense molecular clouds and gases that are opaque at most other wavelengths. Black holes are just one example of the violent and exotic objects in the Universe that emit much of their radiation in the gamma-ray range.

The spectroscopic study of atomic and molecular lines in the infrared, visible and ultraviolet regions of the electromagnetic spectrum has been responsible for most of our current knowledge of the physics of 'normal'

ESA Space Science Advisory Committee

Recommendation on the Choice of the Next Scientific Project (M2)

The Space Science Advisory Committee (SSAC), at its meeting on 29 April 1993, considered the recommendations of the Solar System, Astronomy and Ad-hoc Fundamental Physics Working Groups and unanimously recommends that: the Integral (International Gamma-Ray Astrophysics Laboratory) mission be accepted as the next scientific project.

The Recommendation is based on the scientific goals, which address fundamental and outstanding problems in galactic and extragalactic astrophysics. These include compact objects such as neutron stars and black holes, nucleo-synthesis, active galactic nuclei and gamma-ray bursts. The Integral payload is based on the combination of fine imaging, high-resolution spectroscopy and also polarimetry. Integral is an observatory-type mission and is timely because it is the next logical step in gamma-ray astronomy, utilises existing technology, and incorporates the advantages offered by using commonality of the hardware development for the XMM bus.

The SSAC was also impressed by the quality of the other Phase-A studies presented. The STEP mission is evidence of a new and original capability in Europe in the use of space for fundamental physics. The mission had been expanded during the Phase-A study beyond the original focus on the Equivalence Principle to include, amongst others, a test of the inverse square law of gravitation, a measurement of the value of the gravitational constant, and questions of general relativity and particle physics. It also had the capability to provide major information in geodesy with unprecedented accuracy, which could make a significant contribution to research on climate.

The intensive study of Mars is widely accepted as the next logical goal in the exploration of the Solar System. The similarities and differences between Mars and Earth give the study special and continued importance. Marsnet showed the European capability to perform meteorological, geochemical, geophysical and geological investigations of the Red Planet. For the Marsnet mission to be successfully implemented, the Agency would require a full commitment from an international partner, which is not currently available.

The Committee recognised stellar seismology as was proposed in Prisma to be an area of active research in Europe providing new and important insights into basic questions in astrophysics, such as stellar structure and evolution, and regarded this area of research as one where there would be a continued need for space studies in the coming years.

stars. Spectral lines are also produced in the gamma-ray region, but by different physical processes, including radioactivity, nuclear excitation, electron-positron pair annihilation, and cyclotron absorption. These lines can therefore serve as powerful diagnostics for the high-energy processes taking place in some of the most violent objects in our Universe.

The first ESA satellite to observe gamma rays was Cos-B, launched in 1975. It was initially designed for a two-year mission, but in the event it remained operational for six and a half years. Cos-B was the second satellite dedicated to observing at this end of the electromagnetic spectrum, following the American SAS-2 satellite (Small Astronomical Satellite) which had been launched in 1972.

On the strength of these early successes, the Europeans and Americans began working on satellites for future missions. In 1989, the Soviets launched their Granat satellite, carrying a French gamma-ray telescope (Sigma). In April 1991, the United States launched the Compton Gamma-Ray Observatory (CGRO). Granat is now nearing the end of its mission, while CGRO continues to explore the skies for gamma-ray sources.

As the next logical step in gamma-ray astronomy, Integral will fly a payload consisting of two main instruments, a caesium-iodide Imager and germanium Spectrometer, and two monitoring instruments, a CCD Optical Transient Camera (OTC) and a coded-mask*

* In gamma-ray astronomy one cannot use mirrors to concentrate photon fluxes; instead, Integral's Spectrometer, Imager and X-Ray Monitor will use so-called 'coded masks' to image photon sources. Images of the sources observed will be deduced from the shadow cast by the mask on the detectors. This technique, which provides 'statistical images', has been used for some 15 years in gamma-ray telescopes flown on balloons, as well as in the French Sigma telescope.

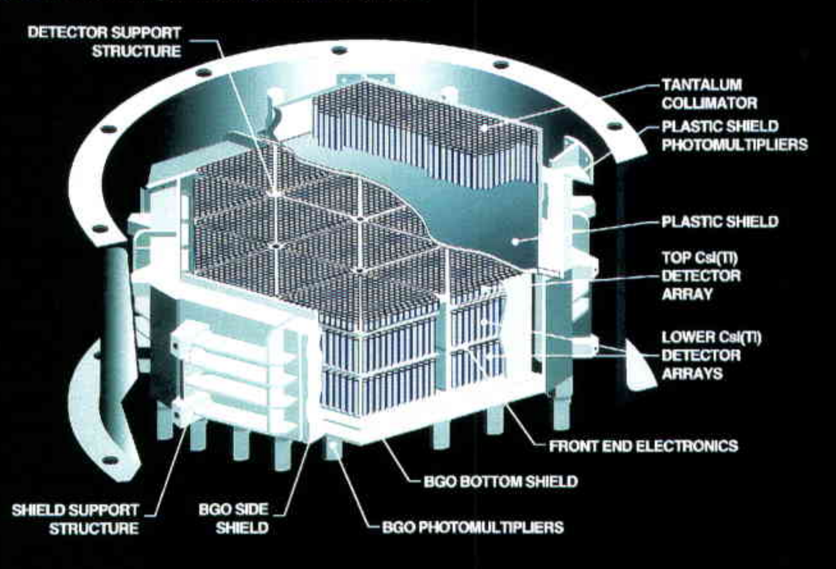
On Integral, each of the masks will be tailored to the type of observation to be carried out by the particular instrument concerned. The mask for the main Integral Imager, which will consist of over 2000 elements, will also be rotatable, in order to eliminate any background noise likely to blur the images obtained.

Table 1. Main features of the Integral mission

Objectives	Gamma-Ray Astronomy 15 keV – 10 MeV using High-Resolution Spectroscopy and Fine Imaging. Concurrent Monitoring in X-Ray and Optical Bands International Collaborations: ESA, NASA, Russia
Payload	Main Instruments: Germanium Spectrometer Caesium-Iodide Imager Monitors: X-Ray Monitor (XRM) Optical Transient Camera (OTC)
Field of View (fully coded)	3.2° to 5.6° (main instruments)
Field of View (part. coded)	13° to 22° (main instruments)
Angular Resolution	< 20′ to > 10° (main instruments, according to mode)
Spectral Resolution	$E/\Delta E \sim 500$ at 1 MeV
Source Location (20 σ source)	1′
Continuum Sensitivity (3 σ)	3×10^{-8} ph cm^{-2} s^{-1} keV^{-1} in 10^6 s at 1 MeV
Narrow Line Sensitivity (3 σ)	1.5×10^{-6} ph cm^{-2} s^{-1} in 10^6 s at 1 MeV
Polarisation Sensitivity (3 σ)	~10 mCrab in 10^6 s, $\phi\sim$ degrees
Highly Eccentric Orbit (HEO)*	Period: 72 h / 24 h Inclination: 51.6 / 65° Perigee: 48 000 km / 4000 km Apogee: 115 000 km / 68 000 km
Ground Stations	Villafranca, Canberra and/or Goldstone
Spacecraft	Three-axis-stabilised bus, common with XMM
Absolute Pointing Error	≤ 15′ (95%)
Launch Mass	3643 kg
Science Instrument Mass	1942 kg
Total Payload Mass	2314 kg
Total Payload Power	568 W
Total Spacecraft Power	1268 W
Telemetry	40 kbps science data
Payload Dimensions	Diameter: 3 m Height: 4 m
Operational Mode	Observatory
Nominal Mission Lifetime	2 years
Design Lifetime	5 years

* Parameters for Proton/Ariane launch options

Figure 2. The Imager focal-plane instrument



X-Ray Monitor (XRM). All instruments are co-aligned and will simultaneously observe the same region of the sky. The four instruments have been carefully chosen to complement each other, and their measurements will be made available as a single comprehensive data set for each target studied.

The two main instruments will bring major improvements in both the spectral and angular resolution of gamma-ray observations (cf. Table 1).

With its germanium detectors – which have a much better spectral resolution and are more sensitive than detectors used so far – Integral's **Spectrometer** will be able to study typical radiation from violent processes in the 15 keV to 10 MeV region; these processes include nuclear excitation, positron annihilation and cyclotron emission.

The main task of Integral's **Imager** will be observation and mapping of sources with a much improved spatial accuracy and sensitivity.

The **X-Ray Monitor** instrument aboard Integral will observe the same part of the sky as the main instruments, but in a somewhat less energetic band of the spectrum.

Integral's **Optical Transient Camera** (OTC) will hopefully make it possible to associate a gamma-ray burst source with a visible object for the first time.

C. Winkler
ESA Space Science Department

Detailed descriptions of the four missions that were in contention for selection as ESA's next scientific project (M2) – Integral, STEP, Marsnet and Prisma – can be found in the September issue of the **ESA Journal** (Vol. 17, No. 3), complimentary copies of which are available from ESA Publications Division.

Figure 3. The Spectrometer focal-plane instrument

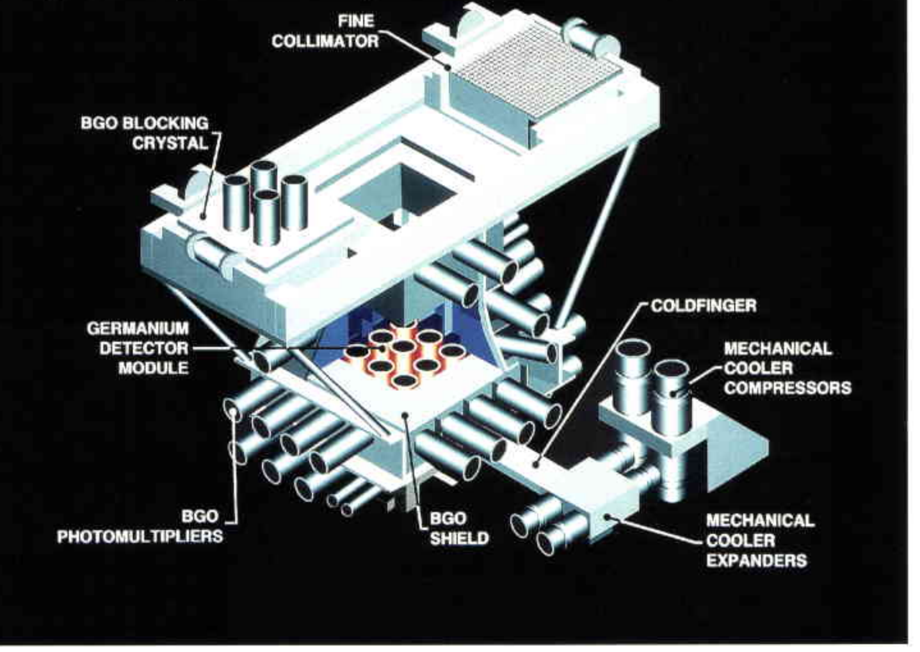


Figure 4. The X-Ray Monitor focal plane instrument

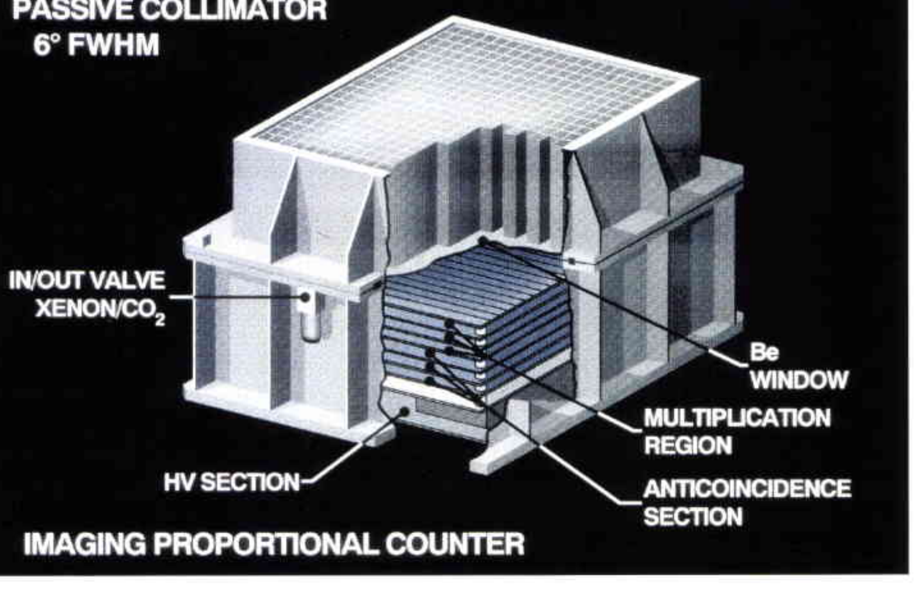
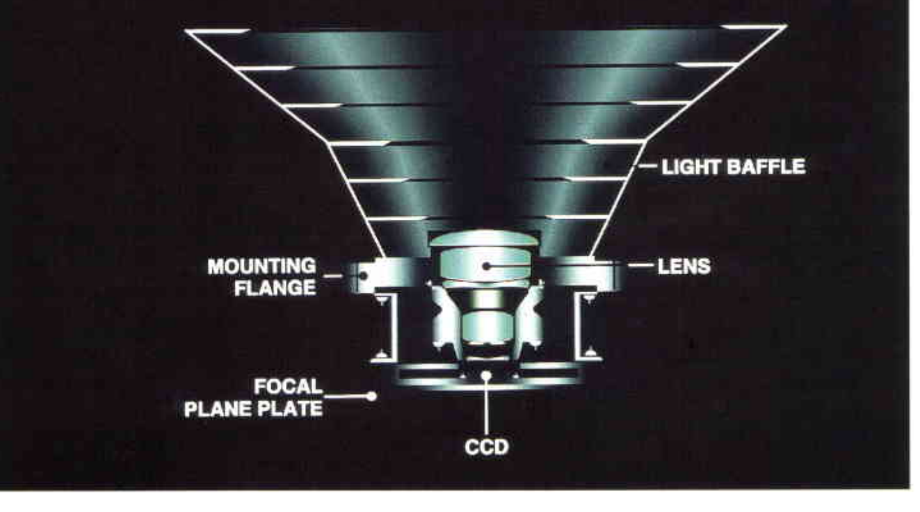


Figure 5. The Optical Transient Camera



New Chairman of ESA Council Elected

At its 109 th Meeting on 23–24 June, the ESA Council unanimously elected a new Chairman, Mr Pieter Gaele Winters, of The Netherlands. He will replace the current Chairman, Prof. Francesco Carassa, of Italy, and will hold the position for the next two years.

Mr Winters is the Head of The Netherlands' Delegation to the ESA Council. He is also the Deputy Director General for Industry in the Dutch Ministry of Economic Affairs.

Mr P.G. Winters, the new Chairman of the ESA Council

New ESA Director for Observation of the Earth and its Environment

The ESA Council has appointed Mr Lanfranco Emiliani as the new Director for Observation of the Earth and Its Environment, to succeed Mr Philip Goldsmith, with effect from 1 September.

Mr Emiliani, of Italian nationality, joined one of ESA's forerunners, the European Launcher Development Organisation (ELDO), in 1967 as a senior engineer. He was subsequently appointed Deputy Director of ELDO's Equatorial Launch Base in French Guiana (1969–1971) and later ELDO Director of Flight Trials and Launching Facilities (1971–1973).

In 1973, he was appointed Head of ESRO's Spacelab Project Operations Division and in 1976 became ESA's Deputy Project Manager for Spacelab. In 1980, Mr Emiliani was appointed Project Manager for the Agency's Hipparcos Project.

Since 1986, he has been the Head of the Columbus Programme Department, and has been responsible for ensuring coordination between Columbus and the other elements of the European space infrastructure. In addition, since January 1992 he has served as the Head of the Microgravity and Columbus Utilisation Department.

Mr Lanfranco Emiliani, ESA's new Director for Observation of the Earth and Its Environment

New Associate Director for Strategic Planning and International Policy Appointed

The Agency's Director General has appointed Mr Jean Jacques Dordain as ESA's Associate Director for Strategic Planning and International Policy, with effect from 1 July.

Mr Dordain, of French nationality, was previously Head of the Microgravity and Columbus Utilisation Department in the ESA Directorate for Space Station and Microgravity.

In this new position, he will monitor the execution of the Agency's approved programmes, assess changing priorities and resources, propose areas of international cooperation, and draw all of these aspects together in order to propose a coherent strategy for the Agency's activities and programmes as a whole.

Mr Jean Jacques Dordain, ESA's new Associate Director for Strategic Planning and International Policy, at work at the Le Bourget Air Show

ESA Signs Contract for Mir Precursor Flights

On 7 July, ESA signed a Contract with the Russian company NPO-Energia agreeing that ESA astronauts will undertake two missions on board the Russian Mir space station in 1994 and 1995. The Contract was signed by Yuri Semenov, Director General of NPO-Energia, and Frederik Engström, Director of ESA's Space Station and Microgravity Programmes.

This contractual agreement represents the first major milestone in the cooperation between ESA and Russia in the field of crewed spaceflight (see related article elsewhere in this issue). The contract has a value of 45 million ECU and covers all activities necessary to prepare and conduct the two flights, as well as all post-flight activities.

The first mission will last 30 days and will take place in September 1994, while the second one will last up to 135 days and will begin in August 1995. During the flights, a comprehensive programme of scientific and technological experiments will be performed.

Four ESA astronauts, Ulf Merbold, Pedro Duque, Christer Fugelsang, and Thomas Reiter, begin training for the missions at Star City, near Moscow, in August.

ESA and EPO-Energia signing the Contract, in Moscow, under which ESA astronauts will participate in future Mir flights.
From left to right: Y. Semenov, Director General, NPO-Energia; W. Nellesen, Head of ESA's Columbus System and Projects Department; and H. Arend, Precursor Flights Programme Officer, ESA Directorate for Space Station and Microgravity.

SPC Meeting Held at ESTEC

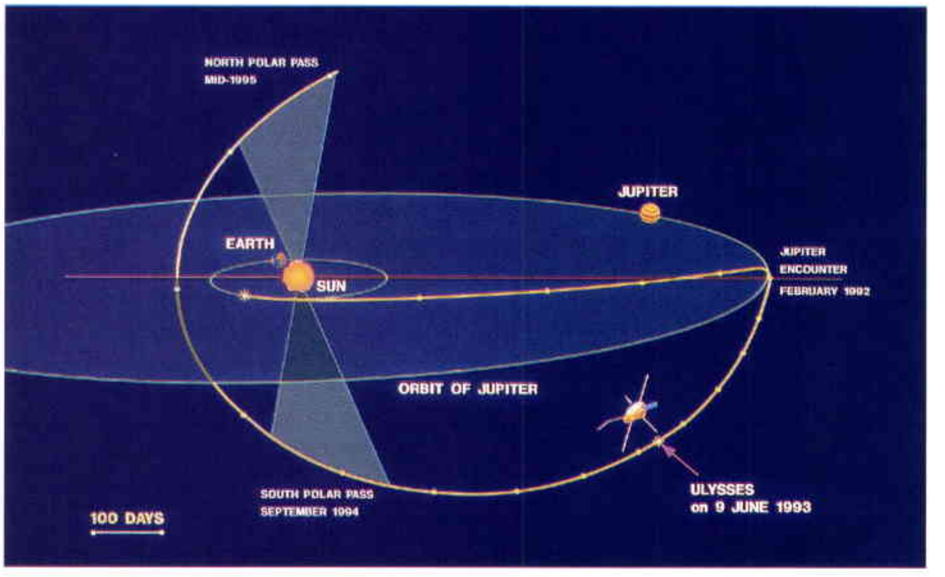
ESA's Science Programme Committee (SPC), the Delegate Body in charge of the Science Programme, held its 67th Meeting at ESTEC, in Noordwijk (NL) on 3 and 4 June.

The SPC usually meets at ESA's Headquarters in Paris. However, because the SPC's current Chairman, Dr J.A.M. Bleeker, Director of the Dutch Space Research Organisation (SRON), was retiring after three years in office, the 67th Meeting was held in The Netherlands in his honour.

Prof. D. Southwood (UK) will replace Dr Bleeker as SPC Chairman.

Members of the SPC during their recent meeting at ESTEC in Noordwijk (NL)

Ulysses Breaks Latitude Record



The Ulysses orbit, showing the position of the spacecraft on 9 July 1993 (32.2° southern solar latitude)

On 9 June, Ulysses became the first spacecraft to reach a latitude of more than 32° relative to the Sun's equator. In so doing, the European-built space probe broke the existing record held by NASA's Voyager-1, which is currently exploring the depths of space beyond the Solar System.

Ulysses, launched by the Space Shuttle 'Discovery' in October 1990, is undertaking the first systematic exploration of the heliosphere at all latitudes from the solar equator to the poles.

Ulysses underwent a gravity-assist manoeuvre at Jupiter (the so-called Jupiter fly-by) in February 1992. It is now in a highly inclined solar orbit that will bring it over the Sun's south pole in September 1994. At that time, Ulysses will establish a new record as it climbs to its maximum latitude of just over 80°.

With the Jupiter fly-by safely accomplished, the scientific focus is now directed toward phenomena related to the spacecraft's increasing latitude. There is already strong evidence that Ulysses has crossed into a region that is dominated by the magnetic field and solar wind outflow of the south pole. Near the Sun's equatorial regions, the interplanetary magnetic field alternately points towards and away from the Sun during a single solar rotation, which gives rise to so-called 'magnetic sectors'.

The existence of these sectors is interpreted as the effect of a boundary (the 'current sheet') that is tilted with respect to the Sun's rotation axis, and which separates oppositely-directed magnetic fields from the north and south polar caps. The recent Ulysses magnetic field observations reveal a single polarity, i.e. the disappearance of magnetic sectors. This implies that Ulysses is now above the current sheet. The polarity of the observed fields corresponds to that of the Sun's south polar cap, as would be expected.

Concurrent with the disappearance of the magnetic sector, the Ulysses solar-wind plasma instrument has observed a persistently faster solar wind flow than at lower latitudes. High-speed solar wind is thought to issue from coronal holes, i.e. regions of reduced X-ray brightness and density in the Sun's corona. It is also known that extended coronal holes cover each of the polar caps at this phase of the solar cycle. The Ulysses observations are interpreted as indicating that the spacecraft has now entered a region dominated by the southern polar coronal hole.

After its flight over the Sun's southern pole, Ulysses' orbit will bring the space probe swinging back towards the equatorial regions, heading for its second high-latitude excursion in mid-1995, this time above the northern polar regions.

JCB Celebrates 100th Meeting

Participants in the 100th JCB Meeting, including several past Board Chairmen and previous directors of ESA's Telecommunications Programme

The Joint Board on Communication Satellite Programmes (JCB) held its 100th Meeting on 29/30 June at ESA Headquarters in Paris. The Board held its first meeting in August 1975 following the decision to merge the European Communications Satellite (ECS) and the Maritime Satellite programmes. Those programmes had previously had separate Programme Boards. The JCB subsequently also took over the responsibility for the Aerosat programme.

Over the past 18 years, the JCB has overseen the launch of 11 communications satellites, namely two OTS, five ECS, three Marecs spacecraft, and Olympus.

Members of the Microgravity Programme Board en route to the 35 th Meeting aboard MS Blümlisalp, sailing on Lake Thun under the ESA flag

First Workshop on Intellectual Property Rights in Outer Space

The European Centre for Space Law (ECSL) and the Spanish Centre for Space Law jointly organised the first workshop on intellectual property rights on inventions made in outer space, held at the Diplomatic School in Madrid on 26 May. This Workshop represented an important step in a study initiated by ECSL in 1992 to analyse the legal framework for microgravity issues in view of the expected increase in experiments in the microgravity environment in the near future. As more experiments are performed in microgravity, more inventions made in outer space are expected.

The Workshop was attended by about 60 experts in the field of intellectual property rights. Its aim was to gather the opinion of participants on the future steps that the study should take and the possible need for harmonisation in this area of the law. The major issues were discussed from both the technical and legal points of view.

The Workshop concluded by focussing on the great need for harmonisation of regulations regarding legal rights in Europe and the rest of the world, and on the importance of continuing the ECSL study to this end, in coordination with the institutions and individuals active in this field.

The ECSL is a forum established under the auspices of ESA for all those active in the field of law of space activities (see ESA Bulletin No. 73, February 1993).

ECSL/CEDE Workshop. From left to right: A. Farand, ESA; J.J. Dordain, ESA; J.A. Pastor Ridruejo, Spanish Centre for Space Law; D.R. Armengod, Diplomatic School, Madrid; A. Tramposch, World Intellectual Property Organisation; M. Oehm, ERNO-Gmbh; G. Ghidini, University of Milan.

Basic European Microgravity Research Programme Established

The 35th Meeting of ESA's Microgravity Programme Board took place in Thun, Switzerland, on 27–28 May, at the invitation of J.P. Ruder who was chairing the Board for the last time before stepping down. A major item on the agenda was the establishment of a basic European Microgravity Research (EMIR-1) programme.

In June 1992, the Board had adopted a Resolution on the future structure of the Microgravity Programme. That Resolution requested that, in the future, the Agency's microgravity activities be split into two financially-independent elements:

- a basic European Microgravity Research (EMIR) Programme, and
- a programme to develop the facilities required for microgravity experiments to be performed in the Columbus Attached Laboratory, to be called the Microgravity Facilities for Columbus (MFC) programme.

That Resolution was adopted by the ESA Council in July 1992, and by the Council at Ministerial Level in Granada, Spain on 9–10 November 1992. At the meeting in Thun, the Draft Declaration for the transformation of the existing Microgravity Research Programme into the two new elements of the EMIR-1 Programme was tabled and is in the process of being ratified by the participating Member States.

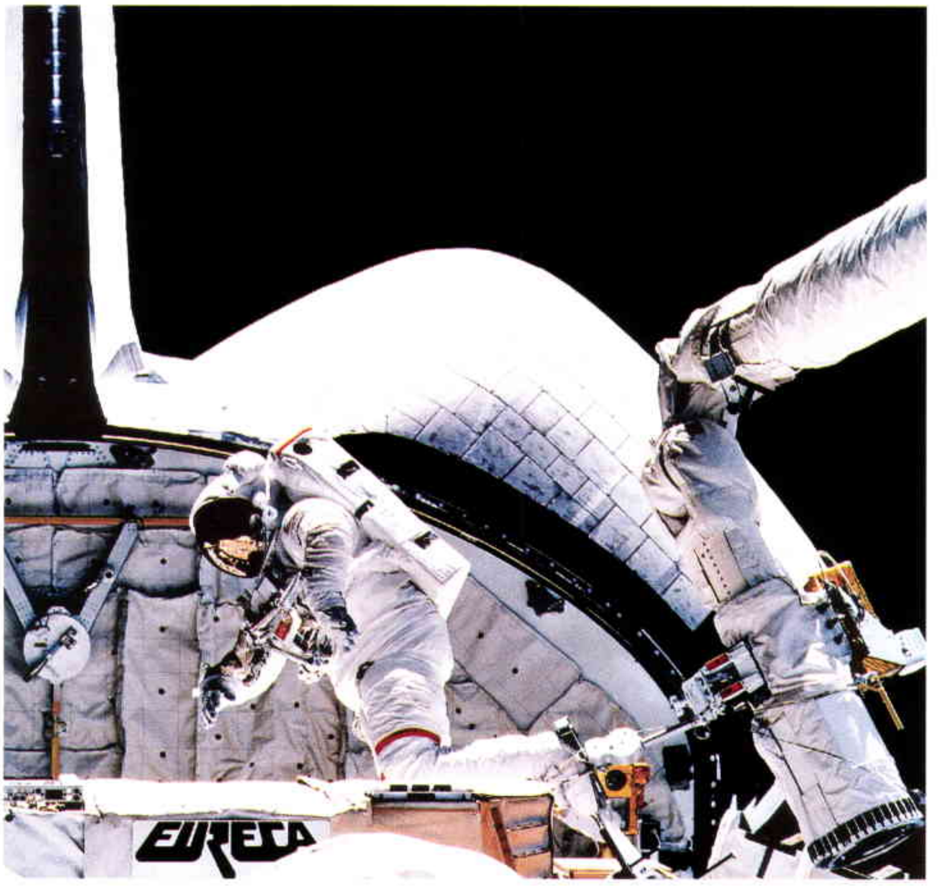
By establishing such a basic research programme, the Member States are attempting to ensure a modest but assured funding for basic microgravity research activities independent of any future changes in related programmes.

Eureca Retrieved

The European Retrievable Carrier (Eureca) was brought safely back to Earth aboard the Space Shuttle 'Endeavour' at the end of June, after nearly 11 months in orbit.

Endeavour successfully rendezvoused with Eureca in its 474 km high retrieval orbit on 24 June and grappled the platform using the Shuttle's Remote Manipulator System (RMS arm) without a hitch. There was a brief period of concern, however, when telemetry data indicated that Eureca's two antennas, which had been folded ready for the platform's retrieval, were not latched into position. The next day, during an EVA sortie, one of the Shuttle astronauts pushed the antennas into place whilst the latching command was re-sent from the ground, and this proved effective.

Space Shuttle 'Endeavour' landed at Kennedy Space Center on 1 July and Eureca's experiments and samples were subsequently removed and returned to their respective investigators for analysis.



Eureca safely berthed in the Shuttle's cargo bay

ESA and the Ukraine Establish Contact

During the NeoCom'93 Conference and Exhibition on telecommunications in Kiev (Ukraine) on 11–13 May, ESA established preliminary contact with the Ukraine, which is a promising environment for space communications.

During the Conference, ESA's Director of Telecommunications Programmes, Dr. René Collette, held a first meeting with the Director General of the Ukrainian Space Agency, V. Gorbulin. An ESA delegation is now expected to visit the Ukraine to discuss in more detail the exchange of information and possible co-operative projects in fields such as Earth observation and telecommunications.

The ESA stand at the Conference featured demonstrations of satellite communications with mobile receivers, and high-volume data transmission via Very Small Aperture Terminals (VSATs). Many professional visitors from Ukranian industry and research institutes expressed great interest in using such advanced systems on Ukranian territory.

A Successful Olympus Utilisation Conference

On 20–22 April, 300 delegates from 25 countries gathered at the Olympus Utilisation Conference in Seville, Spain, to review the many and diverse ways in which this ESA satellite is being used, and to report on the achievements of the Utilisation Programme since the Olympus launch in 1989.

Olympus is a large and complex technology satellite with payloads operating in all of the major frequency bands, and a wide range of special features such as dynamic on-board switching, steerable spot beams and 20/30 GHz transponders.

The Olympus Utilisation Programme provides the framework for industry, science and academia to develop and test new techniques and applications in satellite communications. This essentially free satellite capacity on Olympus was timely, since it came at a time when the regulatory environment in Europe is being liberalised and many new possibilities are becoming available.

Strong demand for the use of Olympus capacity continues even though the satellite is now in its last phase of operation (until July 1994).

The Conference was opened by a series of addresses from a panel of speakers, including Mr E. Triana from Spain's Ministry for Industry, Mr J.-M. Luton, ESA's Director General, Prof. F. Carassa, Chairman of the ESA Council, and Dr R. Collette, ESA's Director for Telecommunications Programmes. The first Plenary Session consisted of an introduction to the Olympus Utilisation Programme and a televised presentation from Ottawa, Canada, by Mr Jacques Lyrette of the Canadian Space Agency. This live transmission was carried across the Atlantic via the Olympus 30/20 GHz payload, just one example of the regular broadcasts made to Europe from Canada via Olympus.

The 130 papers presented in the four themes of the Conference – Small Terminal Systems, Educational Matters, Broadcasting & In-Orbit Communications, and Propagation – covered the results of the Olympus utilisations to date.

Small terminal systems
Several papers demonstrated that the higher 30/20 GHz (Ka-band) frequencies can now readily support small terminal systems operating at the user's site, and that the momentum for development in that area should be maintained. Much of the development carried out at Ka-band is also applicable in other frequency bands. For example, the CODE VSAT system, developed within the Olympus Ka-band programme, which is currently being used to deliver lectures to university classes in Spain via Olympus, is migrating to operational systems on the Ku-band Spanish satellite Hispasat and on a Eutelsat satellite. This multimedia application was demonstrated daily at the Conference, with live lectures presented from Madrid.

The DICE video-conferencing system, which was also demonstrated daily at the Conference, is another example of a service migrating from the demonstration environment of Olympus to an operational service. In this case, the service is being offered by Matra Marconi Space (F/UK) and Joanneum Research (A).

Conference sessions were not only dedicated to the development of new applications and services, but also to the technology developments behind those services. Such presentations from prominent industrialists provided an interesting insight into the development of a wide range of subsystems and software. Several new operating organisations were represented, which have established gateways into the space segment for new application areas. These will provide strong competition to the existing telecommunications operators in specialised areas, taking advantage of the new and more liberal European broadcasting environment.

Broadcasting and in-orbit communications
In the field of satellite broadcasting, several papers dealt with the development of the Italian RAISAT channel and the Enterprise Channel, which later led to the BBC World Service. Speakers also addressed the recent technological drive towards digital (high-definition) television and audio broadcasting via satellite, and detailed some of the most recent experimentation in these fields using Olympus.

From the resulting discussions, it was clear that whereas a great deal of broadcasting was performed using Olympus and new programmes were developed, the next technological push will be in narrow-band digital transmissions for both video and sound broadcasting. The most recent wave of Olympus experiments, which are still in progress, are directed toward these techniques. Narrow-band technology was also widely advocated for the distance-learning field, particularly where it could be coupled with the interactivity needed to provide true educational rapport between teacher and pupil.

In the field of inter-orbit communications, the results of the very successful, first European data-relay experiments were presented. In those campaigns, the Olympus 20/30 GHz payload was used to relay high-speed data to and from a communications package onboard ESA's low-Earth-orbiting space platform 'Eureca', via the Agency's Maspalomas earth-station facility in the Canary Islands. The transmissions were also directly received at several other research centres in Europe.

The opening session of the Olympus Utilisation Conference. From left to right: Mr E. Triana, Spain's Secretary General of Industrial Promotion and Technology; Mr J.-M. Luton, Director General of ESA; Prof. F. Carassa, Chairman of the ESA Council; Dr R. Collette, ESA's Director for Telecommunications Programmes; and Mr C. Hughes, Conference Chairman.

Educational and training applications
Olympus is also being used for many educational and training purposes. The Eurostep organisation, with its 100 members in 12 countries, provided much of the interest and many of the papers for the educational theme.

Several initiatives from universities are also now becoming fully commercial applications. For example, through its partnership with local industry, Plymouth University (UK) has assisted in the establishment of corporate training, banking, and cattle-auction businesses that are based on the use of Olympus.

Propagation research
In the more scientific field of propagation research, many papers dealt with fade countermeasure techniques. This was in addition to the more traditional measurement and analysis of attenuation and cross-polarisation caused by the Earth's atmosphere. In this area, the results produced by modelling cross-polar effects at 20 GHz were found to be of particular value, since the Olympus results represented the bulk of the data of this type that is currently available.

The future
In his closing remarks, the Conference Chairman looked forward to further benefits from Olympus' remaining lifetime and future satellites beyond. He was encouraged by the mood of the Conference delegates, who argued for an ESA policy increasingly focussed towards utilisation and applications based on the provision of satellite capacity for development purposes.

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1. *The ESA Pavilion at Le Bourget, with Envisat-1 prominent in relief on its facade (upper right)*

2. *Eager visitors to the ESA Pavilion*

3. *The ESA Pavilion prior to opening, spanned by the antennas of the first European Remote-Sensing Satellite, ERS-1*

Photographer: Anneke van der Geest

3

ESA on Display at the 40th Paris Air Show

Visitors to ESA's Pavilion at this year's Le Bourget Air Show on the outskirts of Paris on 10–20 June were treated to an exceptional presentation of European space expertise, with **Man, Earth and Space** as the pervading theme.

Man and his role in space was represented by a unique opportunity for the public to watch 'astronauts' at work 'in space'. The microgravity environment in which astronauts must work in orbit was simulated with the help of a giant octagonal aquarium containing a structure representing the Columbus Attached Laboratory. The divers performed both training exercises and actual tests in the tank throughout the week, giving both the media and the public a spectacular insight into the difficulties faced by space crews in conducting tasks that would be comparatively routine on Earth.

Study of the **Earth** itself is high on the list of the Agency's foremost interests. Several ESA programmes are already helping substantially to improve our knowledge of our home planet and our environment, including ERS-1 and Meteosat, soon to be joined by the new Polar-Platform-based environmental mission 'Envisat'. All three of these missions were prominently displayed in Le Bourget.

4. *Ariane-5 (scale 1:10 model) launcher, together with a panel showing the new Vulcain engine, and a one-quarter scale half-fairing housing two model satellites*

5. *The ESA Pavilion prior to opening, with the large diving tank on the right and the Ariane family of launchers in the background*

6. *The Le Bourget divers in front of the large aquarium containing the structure representing the Columbus Attached Laboratory. The diving team was a mixture of ESA staff and professional divers provided by the company Comex SA(F). On the right is Mr Peter Colson of ESA, who coordinated activities*

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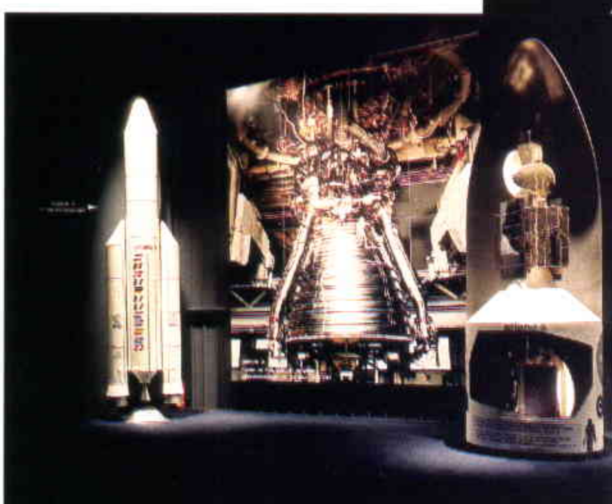

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The conquest and exploitation of **Space** are, as ever, prime ESA activities, made possible in large part by the Ariane Programme. Ariane-4, which has put Europe at the forefront of the World launcher market in recent years, was on display. So too was the next in this impressive launcher family, Ariane-5, the maiden flight of which is scheduled for Autumn 1995.

Science, which has been the backbone of ESA's activities over the years, was represented by full-scale mock-ups of the ISO and SOHO spacecraft that are currently under development. ISO, the infrared space observatory, is due to be launched in 1995, and so too is SOHO, which will make detailed observations of the Sun over a long time scale.

7

7. ESA's Philip Willekens hosts a quiz designed to test the younger public's knowledge of space. ESA is inviting five winners, aged between 14 and 17, to spend a weekend at the European Space Camp in Belgium

8. Members of the World's Press attending a briefing at the ESA Pavilion

9. Mr Jean-Marie Luton (left), ESA's Director General, welcomes France's President François Mitterand, in the company of Mr Serge Dassault (centre), Chairman of GIFAS, the organiser of Le Bourget, to the ESA Pavilion

The Agency's telecommunications interests were represented by a model of the Advanced Relay and Technology Mission spacecraft 'Artemis', to be launched in 1996.

In addition to the considerable amount of space hardware on display, there were a variety of audio-visual presentations designed to stimulate public-awareness of space and the many possibilities and benefits that it offers for our future.

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10. Mr Jean-Marie Luton (centre), ESA's Director General, and ESA Astronaut Wubbo Ockels (right) explain the diving activities in the large aquarium to President François Mitterand

11. Mr Jean-Marie Luton (left), ESA's Director General, and Mr Jörg Feustel-Büechl (right), ESA's Director of Space Transportation Systems, explain one of the ESA displays to Mr Paul Krüger, the German Minister for Research and Technology

12

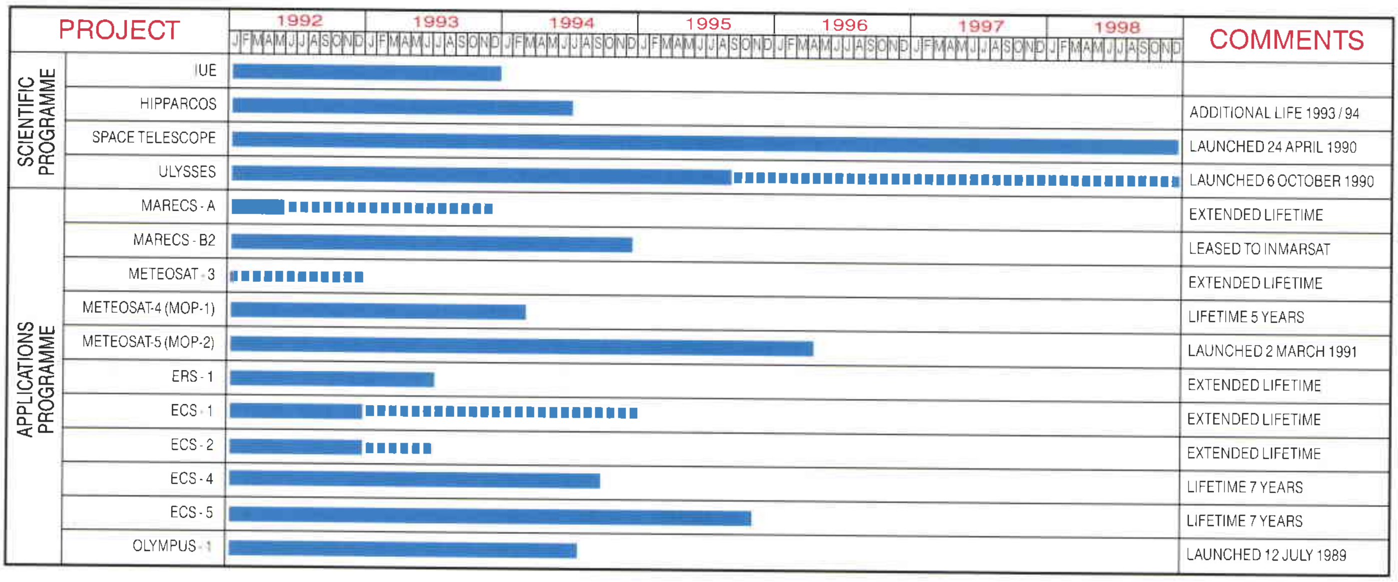
12. Visit by the Prime Minister of Sweden to the ESA Pavilion. From left to right: Mr Fredrik Engström, ESA Director for Space Station and Microgravity; Mr Karl Reuter, ESA's Head of Cabinet; Mr Jean-Marie Luton, ESA's Director General; and Prime Minister Carl Bildt of Sweden

13. Signature during the Air Show of the Meteosat-7 Development Contract between ESA, acting on behalf of Eumetsat, and Aerospatiale of France, the industrial Prime Contractor. From left to right: Mr Louis Gallois, President and Chief Executive Officer of Aerospatiale; Mr Philip Goldsmith, ESA's Director of Observation of the Earth and Its Environment; and Mr John Morgan, Director of Eumetsat

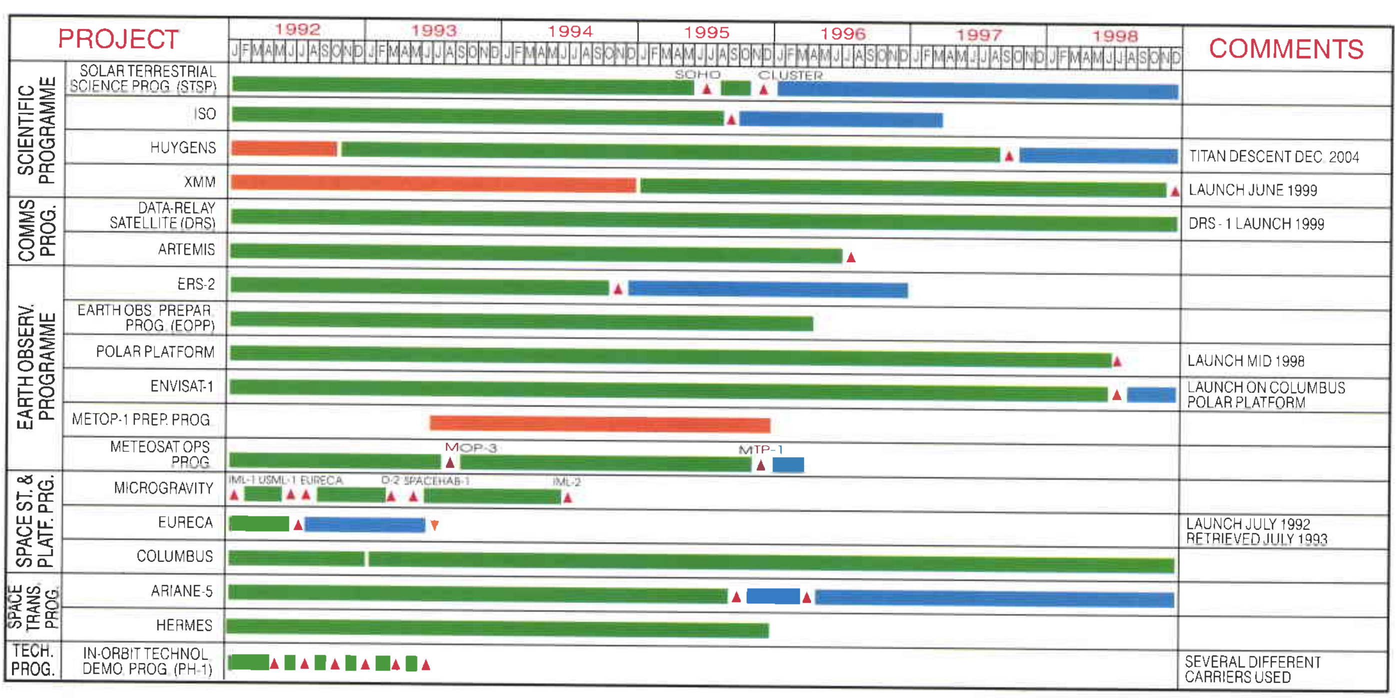
13

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

Au cours des derniers mois la mission Ulysse a été marquée par quelques faits nouveaux importants. Sur le plan programmatique, le Comité du programme scientifique (SPC) de l'ESA a approuvé lors de sa réunion de juin un ensemble de mesures financières dans lequel figurait le soutien de l'archivage des données d'Ulysse à l'ESA, et a entériné à l'unanimité la prolongation de la mission pour une deuxième révolution autour du Soleil.

L'accord définitif du SPC sur la prolongation des opérations du 1er octobre 1995 au 31 décembre 2001 est subordonné à la poursuite de la participation de la NASA, selon le partage actuel des responsabilités: à l'ESA l'exploitation en orbite du véhicule spatial, tandis que la NASA fournit les services de poursuite et d'acquisition des données de son réseau pour l'espace lointain (DSN) et assure le traitement et la distribution des données scientifiques.

L'intérêt scientifique de poursuivre la mission réside dans le fait que la période orbitale de 6,2 ans amènera Ulysse au-dessus des pôles du Soleil lors de la phase du cycle solaire opposée à celle des survols polaires de la mission de base, opérés en période d'activité minimale du Soleil. L'étude des régions situées sous les hautes latitudes solaires dans ces conditions très contrastées enrichira sensiblement les résultats scientifiques attendus de l'ensemble de la mission.

Si l'approbation de l'ESA a été sollicitée dès maintenant pour cette prolongation de la mission, c'est essentiellement dans le souci de faire clairement comprendre à la NASA que l'Europe est déterminée à apporter son soutien aux recherches scientifiques nouvelles, uniques en leur genre, que cette prolongation de la mission Ulysse permettra de conduire à bon compte.

Le véhicule spatial et ses instruments scientifiques sont en excellent état et la couverture des données continue d'atteindre régulièrement près de 100% grâce aux efforts qu'y consacrent l'équipe commune ESA-NASA chargée des opérations de la mission ainsi que le réseau DSN de la NASA.

Soho

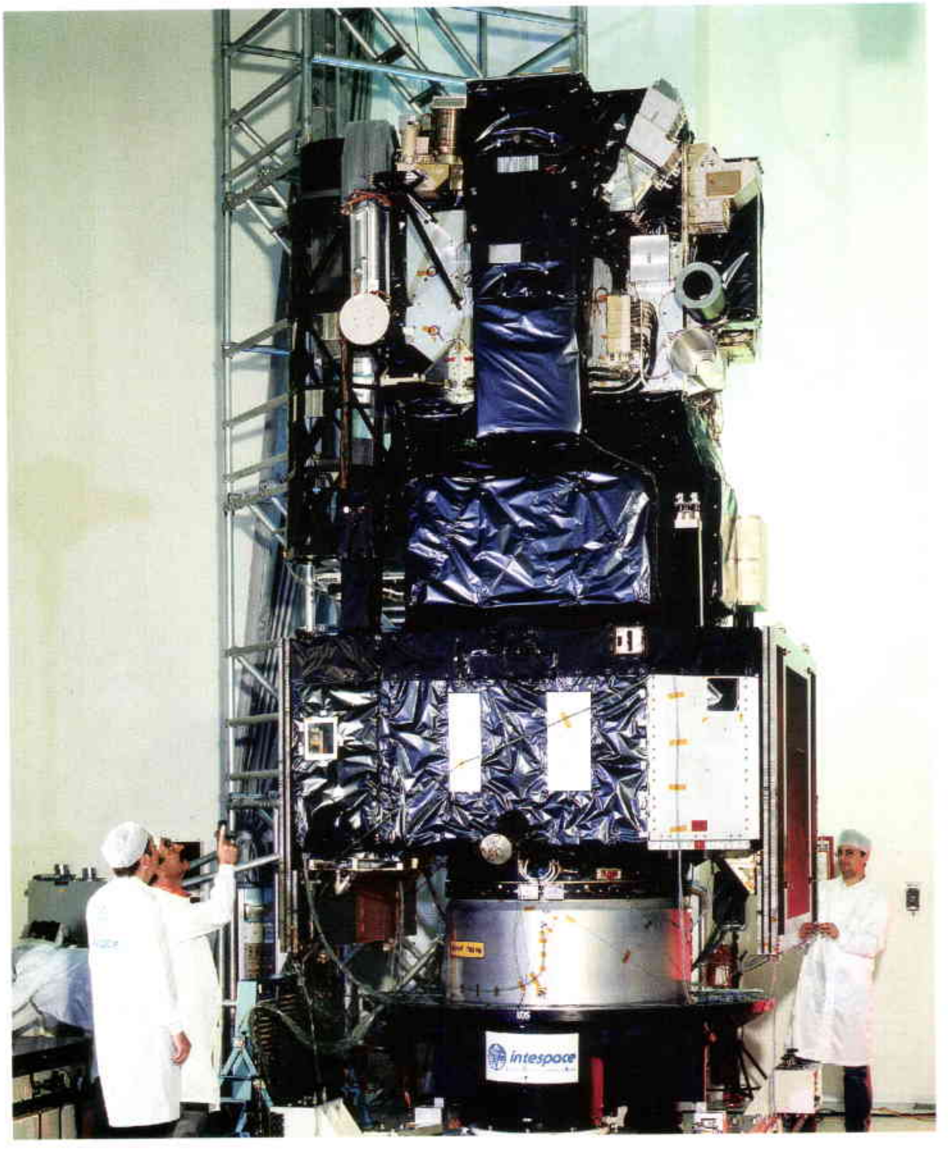
Industrie

Le modèle structurel (SM) complet du véhicule spatial Soho en est actuellement (en juin) aux derniers stades de son programme d'essais. Les essais de qualification acoustiques ont été achevés et les essais de vibrations sinusoïdales se déroulent actuellement chez Intespace (Toulouse, F), à l'aide des prévisions d'analyse de charges couplées fournies par la NASA.

Début juillet, lorsque les essais du modèle structurel seront terminés, les unités, maquettes et câblages qui entrent dans sa composition seront démontés et la structure du véhicule spatial sera utilisée comme prévu pour la deuxième phase des essais du modèle d'identification (EM) actuellement conduits sur des maquettes des structures.

Le modèle d'identification du module de charge utile (PLM) a été équipé des modèles d'identification de toutes les expériences, qui ont subi des essais spécifiques destinés à vérifier leurs interfaces. Les essais fonctionnels au niveau système, au cours desquels toutes les fonctionnalités du PLM seront testées conjointement, dans le cadre de séquences opérationnelles représentatives, auront lieu durant la première quinzaine de juillet.

Le modèle d'identification du module de servitude (SVM) a été équipé de tous



The Soho spacecraft

Le véhicule Soho

Ulysses

Some significant developments have taken place in the Ulysses mission during the last few months. At the programmatic level, ESA's Science Programme Committee (SPC), at its meeting in June, approved a financial package that included support for the archiving of Ulysses data in ESA, and unanimously endorsed the extension of the mission for a second solar orbit.

Final SPC authorisation for extension of operations from 1 October 1995 until 31 December 2001 is contingent upon the continued participation by NASA, assuming the same share of responsibilities as at present. ESA's responsibilities include the in-orbit operation of the spacecraft, while NASA provides tracking and data acquisition via the Deep Space Network (DSN), and processes and distributes the scientific data.

The scientific rationale for continuing the mission lies in the fact that the orbital period of 6.2 years will bring Ulysses over the poles of the Sun at the opposite phase of the solar cycle to the polar passes of the prime mission, which occur at solar minimum. By studying the high-latitude regions under widely varying conditions, the scientific return of the mission as a whole will be greatly enhanced.

The main reason for seeking an early ESA approval of the extended mission was to send a clear sign to NASA of Europe's determination to support the new, unique and cost-effective science that a Ulysses extended mission will provide.

The spacecraft and its scientific instruments are in excellent condition, and the data coverage continues to be consistently close to 100%, thanks to the dedicated efforts of the joint ESA – NASA Mission Operations Team and NASA's DSN.

Soho

Industry

The complete Structural Model (SM) of the Soho spacecraft is currently undergoing (in June) the last steps in its test programme. The acoustic qualification test has been completed and the sine vibration tests are in progress at Intespace (Toulouse, F), using the coupled-load-analysis predictions delivered by NASA.

At the beginning of July, on completion of the SM tests, the SM units, mockups and harnesses will be dismounted and the SM spacecraft structure will be used, as planned, for the second phase of the Engineering Model (EM) tests, presently performed on mockup structures.

The EM Payload Module (PLM) has received all the EM Experiments, which have undergone specific tests to verify their interfaces. The system functional test, in which all the PLM functionality will be tested together, with representative operational sequences, will take place in the first half of July.

The EM Service Module (SVM) has received all subsystems whose integration is complete. Functional tests of increasing complexity are now planned on the Service Module until its installation on the SM structure.

The procurement of flight hardware is very advanced, with units and assemblies undergoing tests at various stages. Subsystem Critical Design Reviews have taken place as planned.

The Mission Critical Design Review (M-CDR) planning has been refined with sub-reviews (mission and operation, payload and spacecraft) taking place between July and September. The M-CDR Final Board will be held at the end of October.

ESA – NASA cooperation

All flight-model high-power amplifiers have been delivered except one, which is being reworked to eliminate a problem found during testing.

Delivery of the flight models of the fine-pointing Sun sensors is expected soon.

The Soho tape recorder (EM2) has been delivered for integration on the EM Service Module. The extensive testing that it has undergone in the last months gives reason to believe that the problems associated with low operating temperatures and recording rates may have been fixed. The next models planned for delivery to both Cluster and Soho will need to confirm the effectiveness and reliability of the modifications.

A Ground-Segment Design Review in late July at NASA/GSFC will be the next milestone in this sector of the overall Soho programme. Preliminary reviews of dedicated resources and facilities are taking place with ESA involvement.

Payload

After having delivered the agreed development models (engineering and structural) until the first quarter of 1993, and having supported the system-level tests, particularly those of the EM Payload Module, the Soho experiment teams have concentrated their efforts on manufacturing and assembling their flight instruments. Activities are continuing with deliveries scheduled for the last quarter of 1993.

A Science Working Team meeting will discuss status and relevant plans in the first week of July.

ISO

Scientific instruments

Most of the flight hardware for the scientific instruments has been delivered. The focal-plane unit of the short-wavelength spectrometer is being fitted with new high-performance detectors. The other focal-plane units are awaiting installation on the flight-model telescope when it is delivered. Flight-spare hardware for all scientific instruments is in the final testing and calibration phase.

Satellite

The flight-model Payload Module (PLM) has been fitted with a dummy telescope and liquid-helium test valves as a temporary measure to permit continuation of PLM testing until September, when the flight-model telescope and liquid-helium valves should be ready for installation. The PLM has successfully passed its cryogenic testing and is being prepared for vibration testing.

The flight-model Service Module (SVM) integration and testing is also proceeding satisfactorily. Almost all attitude-control subsystem units have been integrated in the SVM and subsequent test results *les sous-systèmes dont l'intégration est achevée. Des essais fonctionnels de complexité croissante sont maintenant prévus sur le module de servitude jusqu'à son installation sur la structure du modèle structurel.*

L'approvisionnement du matériel de vol est très avancé, les unités et ensembles se trouvant actuellement à différents stades des essais. Des revues critiques de la conception des sous-systèmes se sont déroulées conformément aux plans.

La planification de la revue critique de la conception de la mission (M-CDR) a été affinée, avec la conduite de revues fragmentées (mission et exploitation, charge utile et véhicule spatiale) entre juillet et septembre. La commission chargée de la revue finale M-CDR se réunira fin octobre.

Coopération entre l'ESA et la NASA

Tous les modèles de vol des amplificateurs haute puissance ont été livrés à une exception près, en cours de réfection pour éliminer un problème apparu au cours des essais.

La livraison des modèles de vol des détecteurs à référence solaire et pointage fin est attendue sous peu. L'enregistreur sur bande (EM2) de Soho a été livré en vue de son intégration sur le modèle d'identification du module de servitude. On a de bonnes raisons de croire après les essais poussés auxquels il a été soumis ces derniers mois que les problèmes associés aux basses températures de fonctionnement et aux faibles vitesses d'enregistrement ont probablement été réglés. Les nouveaux modèles dont la livraison est prévue pour Cluster et pour Soho devront confirmer l'efficacité et la fiabilité des modifications.

Une revue de la conception du secteur sol fin juillet, au GSFC/NASA, sera la prochaine étape de ce volet du programme Soho d'ensemble. Des revues préliminaires des ressources et installations spécialisées se déroulent actuellement avec la participation de l'ESA.

Charge utile

Après avoir livré les modèles de développement dont il avait été convenu (modèles d'identification et structurels) jusqu'au premier trimestre 1993 et apporté leur soutien aux essais du niveau système, en particulier sur le modèle d'identification du module de charge utile, les équipes responsables des expériences de Soho ont concentré leurs efforts sur la fabrication et l'assemblage des modèles de vol de leurs instruments. Les activités se poursuivent avec les livraisons qui sont programmées pour le dernier trimestre de cette année.

Le groupe de travail scientifique doit se réunir pour débattre de l'état d'avancement des activités et des plans connexes au cours de la première semaine de juillet.

ISO

Instruments scientifiques

La plupart des matériels de vol des instruments scientifiques ont été livrés. L'unité du plan focal du spectromètre ondes courtes est actuellement équipée de nouveaux détecteurs à hautes performances. Les autres unités du plan focal attendent l'installation du modèle de vol du télescope, lorsqu'il aura été livré. Les rechanges de vol de tous les instruments scientifiques ont atteint la phase finale des essais et de l'étalonnage.

Satellite

Le modèle de vol du module de charge utile (PLM) a été équipé à titre provisoire d'un télescope factice et de vannes expérimentales à hélium liquide pour que ses essais puissent se poursuivre jusqu'en septembre, date à laquelle les modèles de vol du télescope et des vannes devraient être prêts à être montés. Après les essais cryogéniques qu'il a subis avec succès, on prépare le PLM aux essais vibratoires.

L'intégration et les essais du modèle de vol du module de servitude (SVM) se poursuivent également de façon satisfaisante. Les unités des sous-systèmes de commande d'orientation ont presque toutes été intégrées au SVM et les essais menés ensuite ont donné de bons résultats. Les essais de qualification du suiveur d'étoiles ont été interrompus dans l'attente d'une enquête sur le comportement anormal du détecteur pendant l'étalonnage.

Les travaux relatifs au satellite sont en accord avec le calendrier d'un lancement en septembre 1995.

Secteur sol

Les activités préparatoires avancent de façon satisfaisante pour les opérations en vol du véhicule spatial. On s'attache plus particulièrement à simplifier la mise au point des opérations scientifiques.

De nouveaux progrès ont été faits sur la voie d'un accord sur les principes selon lesquels la NASA pourrait fournir la deuxième station sol. Le détail des modalités de l'accord avec la NASA et avec le Japon pour le soutien de la prolongation des opérations en vol journalières est en cours d'élaboration.

Huygens

La proposition de contrat relative aux activités relevant du contrat principal de réalisation (phase C/D) de Huygens ayant reçu l'accord du Comité de la Politique industrielle (IPC) de l'ESA lors de sa réunion de mars, l'autorisation officielle d'engager les travaux à plein régime a été donnée à l'industrie, en principe pour une année d'activités en attendant que soit arrêté le détail des spécifications des sous-systèmes, de la doctrine en matière de modèles, des calendriers et, bien entendu, des prix. Les négociations et les accords avancent conformément à ce qui avait été initialement envisagé, ouvrant la voie pour un accord complet avec l'industrie d'ici la fin de l'été.

Un certain nombre de réunions ont été organisées avec le Jet Propulsion Laboratory (JPL) de la NASA sur la conception et les interfaces des véhicules spatiaux Huygens et Cassini ainsi que sur les interfaces scientifiques et expérimentales de part et d'autre, débouchant sur des résultats en général positifs. De nombreux documents de contrôle d'interfaces ont été officiellement approuvés et les secteurs présentant des points d'incertitude ou des problèmes potentiels qui ont été recensés font l'objet d'études intensives.

La première revue de sécurité conduite avec l'autorité responsable du lancement n'a pas fait apparaître d'insuffisance notable.

were good. Qualification testing of the star tracker has been stopped pending investigation of anomalous sensor behaviour during calibration.

The satellite work is on schedule for the target launch date of September 1995.

Ground segment
Preparations for spacecraft flight operations are proceeding satisfactorily. Special efforts are being made to simplify the science operations development.

Further progress has been made in agreeing the principles whereby NASA could provide the second ground station for ISO. Details of the agreement with NASA and with Japan to support the extended daily flight operations are being worked out.

Huygens

The contract proposal for the Huygens main development activities (Phase-C/D) was approved by ESA's Industrial Policy Committee (IPC) at its meeting in March. Subsequently, formal authorisation to proceed at full speed with the work has been granted to industry, notionally for one year's activities pending agreement on the details of subsystem specifications, model philosophy, schedules, and of course, prices. The progress with the negotiations and agreements is in accordance with the scheme originally envisaged, paving the way for achieving full agreement with industry by late summer.

A number of meetings have been held with NASA/Jet Propulsion Laboratory (JPL) on Huygens Probe/Cassini spacecraft designs and interfaces, as well as scientific and experiment interfaces on both sides, resulting generally in a positive outcome. Numerous interface control documents have been formally agreed and areas with elements of uncertainty or with potential problems have been identified and are under intensive investigation.

The first safety review with the launching authority has been accomplished without significant shortcomings being unearthed during the process.

ERS

ERS-1
The satellite's performance has remained stable over the reporting period, with a platform availability of 100% and instrument operations above 99%. The cumulative instrument availability since launch amounts to 96% for the AMI, 96% for the RA, and 97% for the ATSR, including unavailabilities induced by the platform and the onboard data-recording/data-transmission subsystems. Analysis of the instrument performances over the 21 months of the mission shows extremely good correlation between early commissioning results and the current performances.

The satellite orbit continued to be maintained within its ±1 km deadband, with an orbit-inclination correction manoeuvre being successfully performed in early May 1993. The satellite is to be maintained in the current 35-day orbit repeat cycle until the end of 1993.

The Low Bit Rate (LBR) global data mission has continued to be performed nominally, together with its associated fast-delivery service and offline archiving and processing.

As a result of the continued improvement of the wind and wave fast-delivery products and the very encouraging evaluation results obtained over the past months, several meteorological entities have initiated assimilation of these data products into their models. The UK Meteorological Office and the European Centre for Medium-Range Weather Forecasts are particularly active in these evaluations.

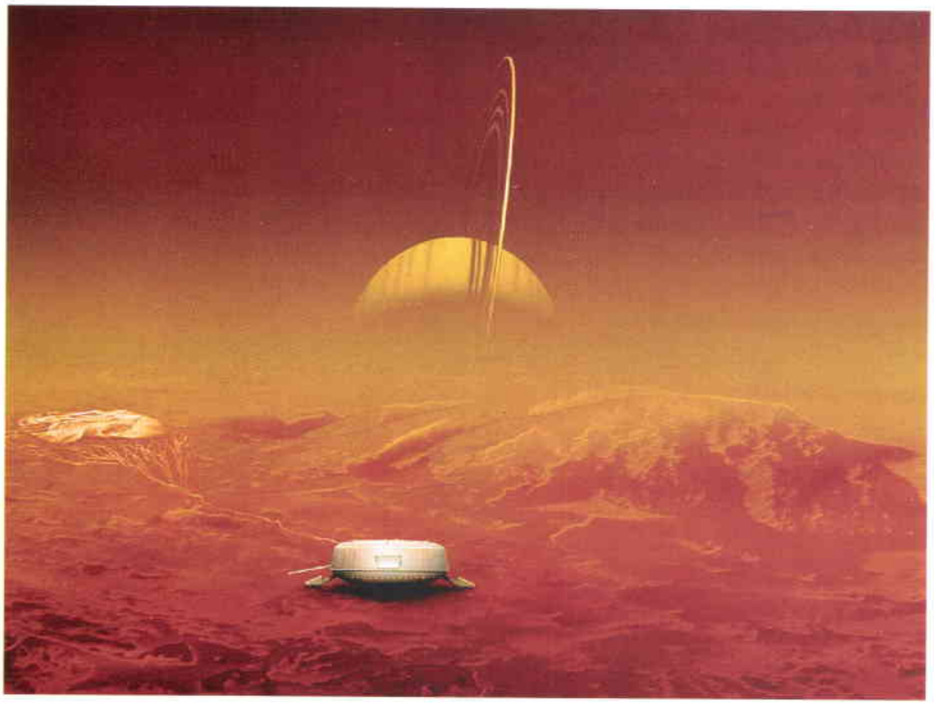
The European Synthetic-Aperture Radar (SAR) fast-delivery service supported several ice campaigns in Northern Europe during the winter season.

SAR data acquisition has continued to be performed by the network of ESA, national and foreign stations, along with the associated data-processing and fast-delivery service at the ESA stations. In addition, testing of the Saudi Arabia and Taiwan ground stations was supported, as well as the pre-operational activities of the Bangkok station.

Offline SAR and LBR standard products have also continued to be generated and distributed. Radar Altimeter and Wind Scatterometer FD data up to early 1993 and RA level-2 data for the initial 35-day cycles have been distributed to selected Principal Investigators (PIs).

Out of a total of 1300 SAR products delivered from ESA facilities in the three-month reporting period, nearly 1000 went to Principal Investigators and Pilot

Artist's impression of the descent of the Huygens probe to Titan's surface
Vue conceptuelle de la descente de la sonde Huygens sur Titan



ERS

ERS-1

Le fonctionnement du satellite est resté stable depuis le dernier rapport, avec un taux de disponibilité de 100% pour la plate-forme et de plus de 99% pour les opérations des instruments. La disponibilité totale des instruments depuis le lancement s'établit à 96% pour le détecteur actif à hyperfréquence (AMI), 96% pour l'altimètre radar (RA) et 97% pour le radiomètre à balayage le long de la trace (ATSR), compte tenu des temps de non-disponibilité dus à la plate-forme et aux sous-systèmes embarqués d'enregistrement et de transmission des données. L'analyse des caractéristiques de fonctionnement des instruments sur les 21 mois de la mission fait apparaître une corrélation extrêmement bonne entre les premiers résultats de la phase de recette et les performances actuelles.

L'orbite du satellite s'est maintenue à l'intérieur de sa bande de ±1 km, avec une correction de son inclinaison menée à bien début mai 1993. Le rythme actuel de répétition de l'orbite tous les 35 jours sera conservé jusqu'à fin 1993.

La mission de recueil de données à faible débit (LBR) à l'échelle du globe s'est poursuivie de façon nominale, ainsi que le service de livraison rapide et les activités de traitement et d'archivage correspondants.

Devant l'amélioration continue des produits 'vents' et 'vagues' à livraison rapide et les résultats très encourageants des évaluations faites au cours des mois écoulés, plusieurs entités météorologiques ont entrepris l'assimilation de ces produits de données dans leurs modèles. Les services météorologiques britanniques et le Centre européen pour les prévisions météorologiques à moyen terme sont particulièrement actifs en ce qui concerne ces évaluations.

Le service de livraison rapide des données du radar à synthèse d'ouverture (SAR) européen a participé à plusieurs campagnes d'observation des glaces conduites en Europe septentrionale durant la saison d'hiver.

L'acquisition des données du SAR s'est poursuivie dans le réseau de stations ESA, nationales et étrangères, en même temps que le service correspondant de traitement des données et de livraison rapide dans les stations ESA. Un soutien a en outre été apporté aux essais des stations sol d'Arabie saoudite et de Taïwan ainsi qu'aux activités pré-opérationnelles de la station de Bangkok.

L'élaboration et la distribution de produits SAR et LBR standard en différé s'est également poursuivie. Les données à livraison rapide de l'altimètre radar et du diffusiomètre vent, jusqu'au début de 1993, ainsi que les données RA de niveau 2 des cycles de 35 jours initiaux, ont été distribuées à des chercheurs principaux (PI) sélectionnés.

Sur 1300 produits SAR livrés au total par les installations de l'ESA durant les trois mois faisant l'objet du présent rapport, près de 1000 ont été distribués aux chercheurs principaux et aux projets pilotes et plus de 150 aux utilisateurs commerciaux, le reste étant destiné aux activités d'étalonnage et de validation de l'ESA, aux évaluations de qualité et à d'autres fins.

Une réunion de projets pilotes couronnée de succès a été organisée à l'ESRIN début mai. Avec la participation de quelque 80 chefs de projets pilotes des premier et deuxième groupes, cette réunion s'est située à un niveau véritablement mondial. Des résultats préliminaires très prometteurs ont été présentés et des améliorations possibles portant sur le service fourni aux chercheurs principaux et sur la coordination d'ensemble ont été répertoriées.

Le deuxième symposium ERS-1 organisé pour la présentation des résultats obtenus par les chercheurs principaux et les chefs de projets pilotes sélectionnés par l'ESA se tiendra du 11 au 14 octobre 1993 au centre des congrès de Hambourg.

Devant la réussite d'ERS-1, la phase d'exploitation est prolongée d'un an et demi.

(photo MBB)

The Meteosat MTP spacecraft

Le satellite du programme de transition Météosat

Projects, over 150 to commercial users, and the remainder were delivered for ESA calibration/validation activities, quality assessments and other purposes.

A successful Pilot Project Meeting was held at ESRIN at the beginning of May. The presence of some 80 Pilot Project leaders, from the first and second Pilot Project groups, ensured truly worldwide participation. Very promising early results were presented and possible improvements in the service to PIs and in overall coordination were identified.

The Second ERS-1 Symposium, organised to present the results obtained by the ESA selected Principal Investigators and Pilot Project Managers, will be held at the Hamburg Congress Centre on 11–14 October 1993.

As a result of the success of ERS-1, the exploitation phase is being extended for a further year and a half.

ERS-2

Integration of the main instruments into the payload has been completed for the AMI, RA and IDHT. The ATSR integration is currently in progress. Preparations for the payload thermal-balance/thermal-vacuum testing in the Large Space Simulator facility at ESTEC (NL) have started.

The first prototype of the Global Ozone Monitoring Experiment (GOME) has been delivered and has demonstrated very good performance, closely meeting expectations. Fit checks with the ATSR and electrical ground-support equipment were carried out prior to starting a calibration and characterisation campaign with the instrument. The Critical Design Review for the instrument is being prepared and should confirm the validity of the flight-model design.

Platform integration has continued. The PRARE instrument has been delivered and successfully integrated. The thruster problem has now been diagnosed and a recovery-action plan is being implemented.

The technical preparations for the ERS-2 launch (scheduled for December 1994) and operations have been started with Arianespace and ESOC/ESRIN. Scenarios for possible parallel operations of ERS-1 and ERS-2 have been analysed and will be presented to Delegations for consideration.

Meteosat

Meteosat-3 and -4 continue as operational units at 75°W and 0°, respectively, both spacecraft being operated from ESOC in Darmstadt on behalf of Eumetsat.

MOP-3 is undergoing final testing in preparation for a launch towards the end of the year. The test programme is running according to schedule.

The spacecraft being built under the Meteosat Transition Programme (MTP), funded by Eumetsat, is taking shape. The schedule calls for delivery in time for a launch in December 1995.

Earthnet

MOS (Marine Observation Satellite) and Spot data have continued to be acquired routinely at Maspalomas.

The Earthnet Coordinated Tiros Network has also continued to provide a regular data flow from the NOAA-11 (afternoon) and NOAA-12 (morning) missions, with data being acquired at all ground stations, including Scanzano (I), which has recently been integrated into the network.

Within the NASA/NOAA/ESA '1 km Global Land AVHRR Data Set' Project, the various facilities around the world have been operationally involved in the data collection, which is planned to last for 18 months. Over 15 000 passes have so far been acquired within Phase-1 (data collection and archiving), the progress of which was successfully illustrated at the third 1 km Project Meeting held in Maspalomas. A copy of the worldwide data set is being archived at ESRIN, to serve the European Scientific User Community in general, and the main AVHRR Projects such as TREES, OSS, FAO, etc.

The cooperation already established in the past between the European Commission (CEC DG/VIII) and ESRIN to archive Tiros AVHRR data acquired at the Niamey, Nairobi and La Reunion stations in Africa, is likely to be extended through 1994.

Preparations for the operational activities at the Manila AVHRR station have continued with formal training of the personnel, which is expected to continue until the end of June.

In the absence as yet of an agreement with NASDA, dissemination of data from JERS-1 will start with the supply of raw and precision products to the Principal Investigators (PIs) only.

The development of Coastal-Zone Colour Scanner (CZCS) Level-3 products for the Ocean Colour European Archive Network (OCEAN) Project has started at JRC, Ispra (I), and products have been sent to ESRIN. In parallel, the distribution of Level-1 and 2 products has continued.

The Asean Project activities have progressed and the ERS-1 SAR acquisition campaign has started with successful acquisition of a few passes. Delivery of the SAR processing chain is foreseen by the end of 1993.

EOPP

Solid Earth

A revised Solid Earth programme-strategy proposal has been prepared for the Earth-Observation Programme Board. One element is a possible cooperative activity with the Russian Space Agency, and this is the subject of ongoing technical and scientific discussions.

Meteosat Second Generation

Discussions have continued with Eumetsat to agree both on the details of the Cooperative Agreement that will be the basis of the joint programme, and on the technical requirements for the satellite system.

The Potential Participants have met on three occasions, with a fourth meeting planned for mid-June. Meanwhile both Phase-A and Phase-A/B bridging activities are proceeding in industry.

Low Earth Orbit (LEO) missions

Definition of the Metop-1 Phase-A

ERS-2

L'intégration des principaux instruments dans la charge utile a été achevée en ce qui concerne l'AMI, le RA et l'IDHT. Celle de l'ATSR est en cours. La préparation des essais thermiques sous vide et de bilan thermique de la charge utile à conduire dans le grand simulateur spatial de l'ESTEC (NL) a commencé.

Le premier prototype de l'expérience de surveillance de l'ozone à l'échelle du globe (GOME) a été livré et démonstration a été faite de son très bon fonctionnement, répondant de très près aux attentes. Des essais de compatibilité avec l'ATSR et l'équipement électrique de soutien au sol ont été exécutés préalablement au lancement d'une campagne d'étalonnage et de caractérisation de l'instrument. La revue critique de conception de l'instrument en cours de préparation devrait confirmer la validité de la conception du modèle de vol.

L'intégration de la plate-forme s'est poursuivie. L'instrument PRARE a été livré et son intégration menée à bien. Un diagnostic a maintenant été établi en ce qui concerne le problème de propulseur; un plan de retour à la normale est mis en oeuvre.

Les préparatifs techniques du lancement d'ERS-2 (programmé pour décembre 1994) et de ses opérations ont été mis en route chez Arianespace et à l'ESOC/ESRIN. Des scénarios d'exploitation parallèle possible d'ERS-1 et d'ERS-2 ont été analysés et seront soumis à l'examen des Délégations.

Météosat

Les satellites Météosat-3 et -4 sont toujours en service à 75° ouest et 0° respectivement, la conduite des opérations des deux satellites étant commandée de l'ESOC, à Darmstadt, pour le compte d'Eumetsat.

MOP-3 subit ses derniers essais en vue de son lancement vers la fin de l'année. Le programme des essais se déroule conformément au calendrier.

Le satellite en cours de construction dans le cadre du programme de transition Météosat (MTP) que finance Eumetsat prend forme. Le calendrier prévoit sa livraison en temps utile pour un lancement en décembre 1995.

Earthnet

L'acquisition régulière des données des satellites MOS (satellite d'observation des mers) et Spot s'est poursuivie à Maspalomas.

Le réseau Tiros coordonné par Earthnet a également continué à fournir un flux régulier de données des missions NOAA-11 (après-midi) et NOAA-12 (matin), captées par toutes les stations sol, y compris celle de Scanzano (I) récemment intégrée au réseau.

Dans le cadre du projet NASA/NOAA/ESA qui vise la production d'un ensemble de données AVHRR sur les terres à l'échelle du globe offrant une résolution de 1 km, les différents centres du monde entier ont participé à la collecte opérationnelle des données qui doit durer dix-huit mois. Les données de plus de 15 000 passages ont été ainsi recueillies à ce jour dans le cadre de la phase 1 (collecte et archivage des données), dont l'avancement a été illustré lors de la troisième réunion sur ce projet tenue à Maspalomas. Une copie de l'ensemble de données à l'échelle du globe est en cours d'archivage à l'ESRIN, pour les besoins des utilisateurs scientifiques européens en général et pour les principaux projets AVHRR tels que TREES, OSS, FAO, etc.

La coopération déjà instaurée dans le passé entre la Commission européenne (CEC DG/VIII) et l'ESRIN pour l'archivage des données AVHRR Tiros reçues par les stations de Niamey, de Nairobi et de La Réunion dans la zone africaine se poursuivra probablement en 1994.

La préparation des activités opérationnelles de la station AVHRR de Manille s'est poursuivie avec la formation officielle du personnel qui devrait se prolonger jusqu'à fin juin.

En l'absence pour le moment d'un accord avec la NASDA, les données de JERS-1 ne seront distribuées pour commencer que sous la forme de données brutes et de produits de précision délivrés aux seuls chercheurs principaux (PI).

L'élaboration de produits de niveau 3 de l'analyseur 'couleurs de la mer' pour zones côtières (CZCS) destinés au réseau européen d'archivage des données sur la couleur des océans (OCEAN) a été mise en route au JRC, Ispra (I) et des produits ont été envoyés à l'ESRIN. La distribution des produits des niveaux 1 et 2 s'est poursuivie en parallèle.

Les activités du projet Asean ont avancé et la campagne d'acquisition des données SAR d'ERS-1 a commencé par l'acquisition réussie des données de quelques passages. La livraison de la chaîne de traitement des données SAR est prévue pour fin 1993.

EOPP

Solide terrestre

Une proposition de stratégie révisée pour un programme d'étude du solide terrestre a été élaborée à l'intention du Conseil directeur du programme d'observation de la Terre. L'une des composantes en est une coopération possible avec l'Agence spatiale russe, qui fait actuellement l'objet de discussions d'ordre technique et scientifique.

Météosat de deuxième génération

Les discussions se sont poursuivies avec Eumetsat en vue d'arrêter les modalités de l'accord de coopération qui constituera la base du programme conjoint ainsi que les impératifs techniques auxquels devra répondre le système satellite.

Les participants potentiels se sont réunis à trois reprises, avec une quatrième réunion prévue pour la mi-juin. Pendant ce temps les activités de phase A et les activités de phase relais A/B suivent leur cours dans l'industrie.

Missions sur orbite terrestre basse (LEO)

La définition des impératifs relatifs aux études industrielles de phase A de Métop-1 a été menée à terme. L'appel d'offres correspondant doit être lancé en juillet.

La définition des études et technologies nécessaires pour les instruments futurs des missions qui feront suite à Envisat-1 s'est poursuivie.

industrial study requirements has been completed. The corresponding Invitation to Tender (ITT) is to be issued in July.

The definition of studies and technology requirements for future instruments for follow-on missions to Envisat-1 has continued.

Campaigns

Preparation work has continued on the definition of a multi-sensor campaign planned to be jointly organised with the JRC and NASA, entitled 'EMAC-94/95'. Over one hundred proposals were received in response to the Announcement of Opportunity.

Polar Platform

The re-orientation of the Polar Platform (PPF) design and development to the Envisat-1 mission has basically been completed. The Envisat-1 instrument accommodation on the PPF has been finalised in conjunction with the Envisat-1 mission prime contractor. The Polar Platform basic requirements have been frozen and the design updated in a number of areas. A design consolidation review with industry is foreseen for June/July.

In parallel, subsystem development has continued with adaptations, where necessary, due to the Envisat re-orientation design simplifications.

A number of Preliminary Design Reviews have been completed (solar array, Ka-band DRS terminal, etc.).

Manufacture of the Service Module structural model is almost complete and manufacture of some of their engineering models has started.

Activities have been initiated to finalise subcontracts for the Payload Equipment Bay and the Service Module, which are the responsibilities of Dornier and Matra, respectively.

The overall Polar-Platform Phase-C/D contract should be finalised before the end of 1993.

Artist's impression of Envisat
Vue conceptuelle d'Envisat

POEM-1

System and instrument Phase-B studies

These studies are now complete. Test results from ASAR transmit/receive modules and antenna radiation panels are now being used in the Envisat-1 Phase-C/D design work.

ASCAT and MIMR instrument Phase-B studies

Both riders to the Phase-B studies of these instruments have been successfully completed. The further activities are part of the Metop-1 Preparatory Programme.

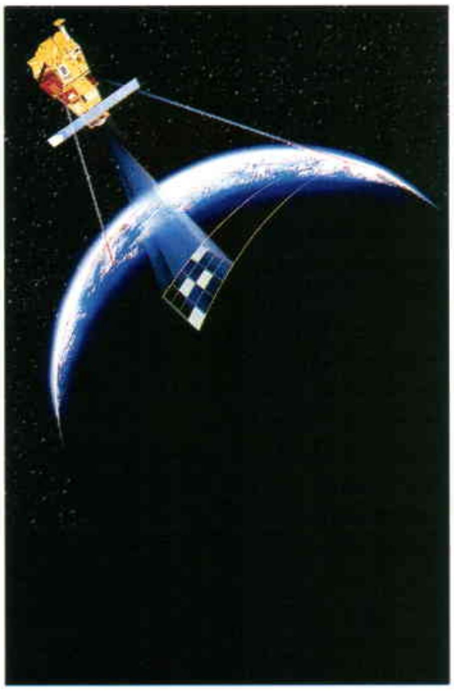
Ground-segment Phase-B

The final presentation is planned for September.

Envisat

The updated Phase-C/D proposal for the ESA-developed instruments (ASAR, MERIS, MIPAS, GOMOS, RA-2 and MWR) was submitted by Industry on 23 April. Following a review by ESA, a request for clarification of a number of points was sent to the mission prime and instrument contractors. All open points are expected to be resolved at joint meetings planned for June–July.

Preliminary design reviews for all Envisat-1 instruments are planned for the second half of 1993.



A proposal has been made to ESA's Industrial Policy Committee (IPC) regarding the industrial composition of Mission Prime Consortium. The preliminary authorisation to proceed already granted to the Consortium has been extended.

Metop-1

Initial activities have been started to develop ASCAT and MIMR to the level of technology demonstrators in preparation for the Metop-1 Programme. A Phase-B study for the Metop-1 space and ground systems is also planned as part of the Preparatory Programme.

Eureca

The Eureca platform continued to provide scientific data to the ground on a daily basis, except for the occasions when orbital manoeuvres were required. The principal experiments operating over the last few weeks were the Solar instruments, the WATCH survey of x-ray bursts, the use of the Inter-Orbit Communications equipment to transmit data to user facilities in Copenhagen (DK), and further tests with ORA, SFA and ASGA.

Orbital manoeuvres were made in May and June to position the spacecraft in the retrieval orbit at 474 km altitude. Once this orbit had been achieved, Eureca was ready to support rendezvous on a date determined by the Shuttle programme.

On 20 June, the Orbiter 'Endeavour' was successfully launched from Kennedy Space Center (KSC) and on the fourth day of its mission rendezvous with and grappling of Eureca was achieved as planned. The only anomaly encountered was a failure of the two antenna booms to latch closed. On day five of the mission, during a planned EVA, an astronaut held the boom in the closed position while ESOC sent the latch commands, which successfully achieved positive latching.

This whole operation of rendezvous with Eureca and stowing it safely in the

Campagnes

On a continué de travailler à la définition d'une campagne à détecteurs multiples qu'il est projeté d'organiser en commun avec le JRC et la NASA, intitulée EMAC-94/95. Plus d'une centaine de proposition sont répondu à l'avis d'offre de participation.

Plate-forme polaire

La réorientation de la conception et de la réalisation de la plate-forme polaire (PPF) en fonction de la mission Envisat-1 est achevée pour l'essentiel. L'installation des instruments d'Envisat-1 sur la PPF a été définitivement mise au point en liaison avec le maître d'oeuvre de la mission Envisat-1. Les impératifs de la plate-forme polaire ont été figés et la conception a été actualisée dans un certain nombre de secteurs. Une revue portant sur la consolidation de la conception avec l'industrie est prévue pour juin-juillet.

Le développement des sous-systèmes s'est poursuivi en parallèle, avec les adaptations éventuellement, demandées par les simplifications de conception résultant de la réorientation en fonction d'Envisat.

Un certain nombre de revues de conception préliminaires ont été menées à terme (réseau solaire, terminal DRS en bande Ka, etc.).

La fabrication du modèle structurel du module de servitude est presque achevée et la fabrication de certains des modèles d'identification a été mise en route.

Les activités ont démarré pour la mise au point définitive des sous-contrats relatifs au compartiment des équipements de charge utile et au module de servitude dont la responsabilité incombe respectivement à Dornier et à Matra.

Le contrat de phase C/D pour l'ensemble de la plate-forme polaire devrait être définitivement mis au point avant la fin de 1993.

POEM-1

Etudes de phase B au niveau système et instruments

Ces études sont aujourd'hui achevées. On utilise maintenant les résultats des essais des modules d'émission-réception de l'ASAR et des éléments rayonnants des antennes pour les travaux de conception de phase C/D d'Envisat-1.

Etudes de phase B des instruments ASCAT et MIMR

Les deux avenants aux études de phase B de ces instruments ont été menés à bien. Les activités ultérieures font partie du programme préparatoire Métop-1.

Phase B du secteur sol

La présentation finale aura lieu en septembre.

Envisat

La proposition actualisée de phase C/D relative aux instruments réalisés par l'ESA (ASAR, MERIS, MIPAS, GOMOS, RA-2 et MWR) a été remise par l'industrie le 23 avril. Après examen, l'Exécutif a été amené à demander un certain nombre de clarifications au maître d'oeuvre mission et aux contractants responsables des instruments. Tous les points en suspens devraient normalement être réglés dans le cadre de réunions conjointes prévues pour juin-juillet.

Pour tous les instruments d'Envisat-1, les revues de conception préliminaires sont programmées pour le deuxième semestre de 1993.

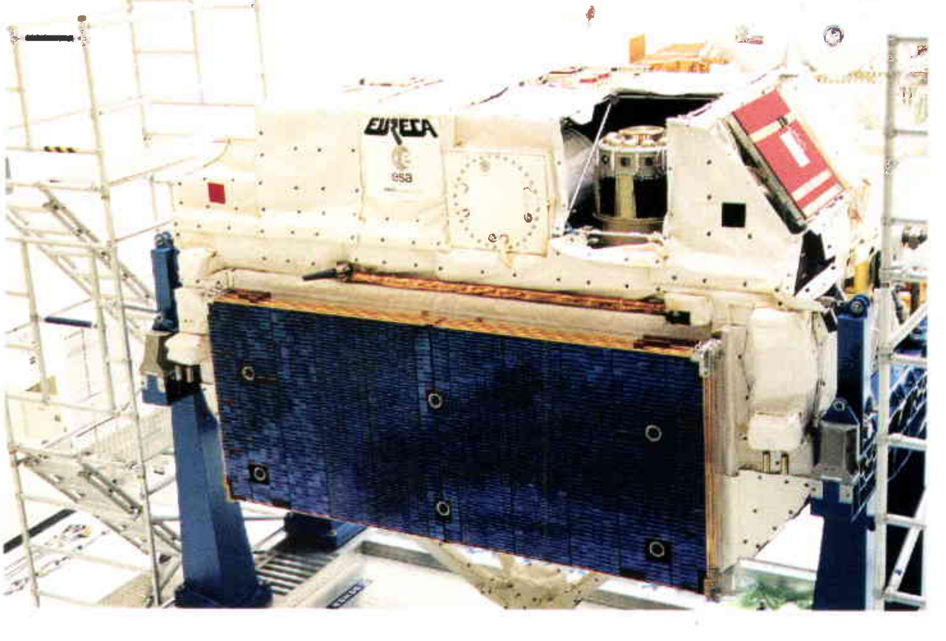
Une proposition relative à la structure industrielle du consortium du maître d'oeuvre mission a été présentée au Comité de la politique industrielle (IPC) de l'ESA. L'autorisation préliminaire d'engagement des travaux précédemment accordée au consortium a été prolongée.

Metop-1

Des activités initiales ont été mises en route en vue de pousser le développement des instruments ASCAT et MIMR jusqu'au stade des modèles de démonstration technologique, en préparation du programme Métop-1. Une étude de phase B relative aux systèmes, spatial et sol, de Métop-1 est également prévue dans le cadre du programme préparatoire.

Eureca

La plate-forme Eureca a continué à transmettre des données scientifiques au sol tous les jours, sauf lorsque des manoeuvres orbitales devaient être exécutées. Les principales expériences fonctionnant au cours des dernières semaines ont été les suivantes: instruments solaires, surveillance WATCH des bouffées de rayons gamma, utilisation de l'équipement de télécommunications interorbitales pour transmettre les données aux installations utilisatrices de



Eureca after its return to Earth

Eureca à son retour sur terre

Shuttle Orbiter involved very close co-operation between ESOC and Mission Control at Johnson Space Center (JSC).

The Orbiter 'Endeavour' landed at KSC on 1 July, completing nearly eleven months of a very successful first mission for Eureca.

Following its removal from the Orbiter, Eureca will be moved to a commercial facility near Kennedy Space Center and the remaining hydrazine fuel removed. Instruments and their samples will be removed and delivered to the investigators. In addition, an investigation will commence of the micrometeoroid and debris damage sustained by the spacecraft, including a survey of any deterioration of the materials used on Eureca. Failure investigations will commence, paying particular attention to the partial loss of solar-array power, gyro anomalies, and the antenna latching problem. These investigations will provide important information for the design of future spacecraft.

Space Station 'Freedom'/Columbus

NASA, at the request of the American President, has initiated a redesign activity for the 'Freedom' Programme, the aim being to drastically reduce the cost of building and operating the Space Station. The International Partners – Europe, Japan, Canada and Italy – have been involved in these redesign activities, where they have presented their positions and expressed their concerns regarding some of the proposed designs.

At the end of the redesign period, at the beginning of June, a report was presented to President Clinton by the specially appointed team of experts ('Blue Ribbon Panel'). This report includes the assessments of the International Partners.

Three options have been studied, known as A (with sub-options A1 and A2), B and C. Options A and B build on the 'Freedom' concept, while Option C is based on a very large pressurised vehicle launched with the Shuttle boosters.

On 17 June, President Clinton called *'for the US to work with our International Partners to develop a reduced-cost, scaled-down version of the original Space Station Freedom....[and] seek to enhance and expand the opportunities for international participation in the Space Station project'.* He is also *'directing NASA to implement personnel reductions and major management changes to cut costs, reduce bureaucracy, and improve efficiency'.*

ESA will analyse, together with the other International Partners involved, the impacts on the Attached Laboratory Programme.

Attached Laboratory

Whilst the programme was being reviewed in the USA, the industrial activities have continued at a reduced pace in order to be able to accommodate potential changes in the design, but maintaining the minimum pace necessary to ensure the planned launch date and resume normal activities and continuation of the programme as planned, if so decided. A 'bridging phase' extending from March to October 1993 has been implemented with industry for this purpose.

Work has progressed regularly on ground-segment activities and the preparations for utilisation.

Precursor flights

Following discussions in the Columbus Programme Board, and given the funding limitations that now exist, the programme will be implemented in several steps, each depending on new commitments by Delegations for covering the budget.

THe first step includes two Mir flights in 1994 (30 days) and 1995 (135 days), the negotiations for which are in progress, and the candidate astronauts already in training in Russia. This first step also includes the storage of Eureca after its recent retrieval.

The second step covers the Spacelab-E1 flight (1996–97 if the decision is made before the end of 1993), while the third step is a reflight of Eureca.

Future European Station

The work with NPO Energia to define the cooperation between Europe and Russia has continued and some results are expected this summer.

Ariane-5

P230 solid-booster stage

Full analysis of the results of the first test on the P230 stage in battleship configuration show that, overall, the booster's performance was as predicted. Integration of the first P230 stage of the M1 flight type went smoothly and the M1 test took place on 25 June in French Guiana. In addition, the two main segments of the M2 stage have been cast and are undergoing inspection. Meanwhile, the qualification tests on the stage's rear skirt have started, as have the first tests on the separation rockets.

H155 stage

Development work on the H155 cryogenic stage is continuing on schedule, with the forward-skirt qualification tests, proof pressure testing of the qualification tank, and manufacture of the liquid-oxygen tank for the first flight unit now complete. The Vulcain engine has undergone 138 tests in all, amounting to a cumulative burn time of over 27 000 sec.

L9 stage

Testing of the L9 stage flight-control mockup has been completed, with all of those involved satisfied with the results. The vibration mockup has been delivered. In addition, integration of the first stage of the flight type has started on schedule with a view to ground testing.

Upper composite

Many tests have been conducted on this part of the launcher, including
- the fairing-separation test, with an empty chamber, and
- the separation test involving the upper composite and H155 stage.

All of these latest events show that development of the Ariane-5 launcher is well under control.

Hermes

Close-out of the Hermes Baseline

The close-out of the earlier Hermes Development Phase activities has continued and only a few items remain to be completed. Following an overall

Copenhague (DK), nouvelles activités expérimentales au moyen des équipements ORA, SFA et ASGA.

Des manoeuvres orbitales ont été exécutées aux mois de mai et juin en vue d'amener le véhicule spatial sur son orbite de récupération, à 474 km d'altitude. Une fois placée sur cet orbite, la plate-forme Eureca s'est tenue prête à exécuter les opérations de rendez-vous à la date fixée dans le cadre du programme de la navette.

Quatre jours après son lancement réussi, le 20 juin, du Centre spatial Kennedy (KSC), la navette Endeavour a procédé aux manoeuvres de rendez-vous et de récupération d'Eureca conformément aux plans. Seule anomalie: les deux mâts d'antenne ont refusé de se verrouiller en position repliée. Le cinquième jour de la mission, au cours d'activités extra-véhiculaires (EVA) qui avaient été prévues, un astronaute a maintenu le mât en position repliée pendant que l'ESOC envoyait l'ordre de verrouillage, qui a alors été correctement exécuté.

L'ensemble de l'opération de rendez-vous avec la mise en sécurité d'Eureca dans la navette a donné lieu à la coopération la plus étroite entre l'ESOC et les services de contrôle de la mission au Centre spatial Johnson (JSC).

Le 1er juillet Endeavour atterrissait au KSC, marquant l'achèvement de près de onze mois d'une première mission Eureca couronnée du plus grand succès.

Après son extraction de la navette, la plate-forme Eureca sera transportée vers des installations commerciales proches du KSC où elle sera vidée de ses dernières réserves d'hydrazine. Les instruments et leurs échantillons seront retirés et remis aux chercheurs. L'étude des dommages causés au véhicule spatial par les micrométéorites et les débris spatiaux sera en outre entreprise, avec le relevé de toute détérioration des matériaux utilisés sur Eureca. Les enquêtes sur les défaillances enregistrées commenceront, en s'attachant plus particulièrement aux pertes partielles de puissance des réseaux solaires, aux anomalies présentées par les gyroscopes et au problème de verrouillage des antennes. On en attend des enseignements précieux pour la conception de satellites futurs.

Station spatiale Freedom/Columbus

La NASA, à la demande du Président des Etats-Unis, a lancé une opération de redéfinition de la station Freedom visant à réduire de façon draconienne les coûts de construction et d'exploitation de la station spatiale. Les partenaires internationaux – Europe, Japon, Canada et Italie – ont été associés à ces activités, au sujet desquelles ils ont fait connaître leur position et exprimé les préoccupations que suscitaient pour eux certaines des conceptions proposées.

A l'issue de la période assignée à cette opération, début juin, l'équipe d'experts spécialement désignée (Blue Ribbon Panel) a remis son rapport au Président Clinton. Il y est fait état des évaluations des partenaires internationaux.

Trois options, A (avec sous-options A1 et A2), B et C, ont été étudiées. Les options A et B partent du concept Freedom, tandis que l'option C repose sur un très grand véhicule pressurisé lancé au moyen des fusées d'appoint de la navette.

Le 17 juin, le Président Clinton en a appelé aux Etats-Unis 'pour collaborer avec (leurs) partenaires internationaux à la réalisation d'une version d'échelle réduite, de moindre coût, de la station spatiale Freedom d'origine.... (en s'attachant également) à renforcer et élargir les possibilités de participation internationale au projet de station spatiale'. *Il donnera en outre* 'des instructions à la NASA pour qu'elle procède à des réductions de personnel et remanie sa gestion en profondeur en vue d'abaisser les coûts, de réduire la bureaucratie et d'améliorer l'efficacité'.

Avec les autres partenaires internationaux intéressés, l'ESA analysera les incidences qui en résultent pour le programme de laboratoire raccordé.

Laboratoire raccordé

Pendant que le programme était réexaminé aux Etats-Unis, les activités industrielles se sont poursuivies au ralenti, de facon à permettre de prendre en compte les modifications qui pourraient être apportées à la conception, tout en maintenant le rythme minimal nécessaire pour pouvoir respecter la date de lancement prévue et reprendre les activités normales et le déroulement du programme conformément aux plans s'il en est décidé ainsi. Une phase relais allant de mars à octobre 1993 a été organisée avec l'industrie à cet effet.

Les travaux ont avancé de façon régulière en ce qui concerne le secteur sol et la préparation de l'utilisation.

Vols précurseurs

Après débat au sein du Conseil directeur du programme Columbus, compte tenu des limitations de financement qui existent désormais, la mise en oeuvre du programme se fera en plusieurs étapes dont chacune sera subordonnée à de nouveaux engagements budgétaires des Délégations.

La première étape comprend deux vols Mir en 1994 (30 jours) et 1995 (135 jours), pour lesquels les négociations sont en cours et les candidats astronautes se forment d'ores et déjà en Russie. Dans cette première étape figure également l'entreposage d'Eureca après sa récente récupération.

La deuxième étape couvre le vol Spacelab-E1 (1996–1997 s'il est décidé avant la fin de 1993), tandis que la troisième porte sur un nouveau vol d'Eureca.

Future station européenne

Les travaux de définition de la coopération entre l'Europe et la Russie se sont poursuivis avec NPO Energia; des résultats sont attendus pour cet été.

Ariane-5

Etage à poudre P230

L'exploitation complète du premier essai de l'étage P230, en version lourde, montre un comportement général du propulseur conforme aux prévisions. L'intégration du premier étage P230 de type vol M1 s'est déroulée sans incident et l'essai M1 a eu lieu le 25 juin en Guyane. Par ailleurs les deux segments principaux de l'étage M2 ont été coulés et sont en cours d'inspection. Il faut noter le début des essais de qualification de la jupe arrière de cet étage et les premiers essais des fusées d'éloignement.

definition status assessment, the work performed by the contractors on vehicle functions has been reviewed and found to be generally satisfactory. The close-out documentation has been further completed.

Technology and system technology

The Hermes Technology Programme slice evolved from the development activities of the previous programme. A smooth transition was assured by covering the most important tasks to continue by the extension of the Hermes Development Phase 1. In this way, the industrial work is not interrupted and the preparation of the technical and contractual requirements, the preparation of the offers by industry, and their evaluation can be completed during the first half of this year.

The main elements covered by the Technology Programme are: aerothermodynamics, thermal protection structure materials, spaçe-debris protection, power generation and storage, propulsion, avionics and test facilities.

The ESA/RKA technology working team has reviewed the many areas for cooperation and has prepared the selection of the most beneficial ones.

System concepts

The internal effort to investigate alternative scenarios for crew and cargo transportation has continued. Industrial support contracts have been initiated to cover the non-winged and winged re-entry vehicle as well as launcher-composite aspects.

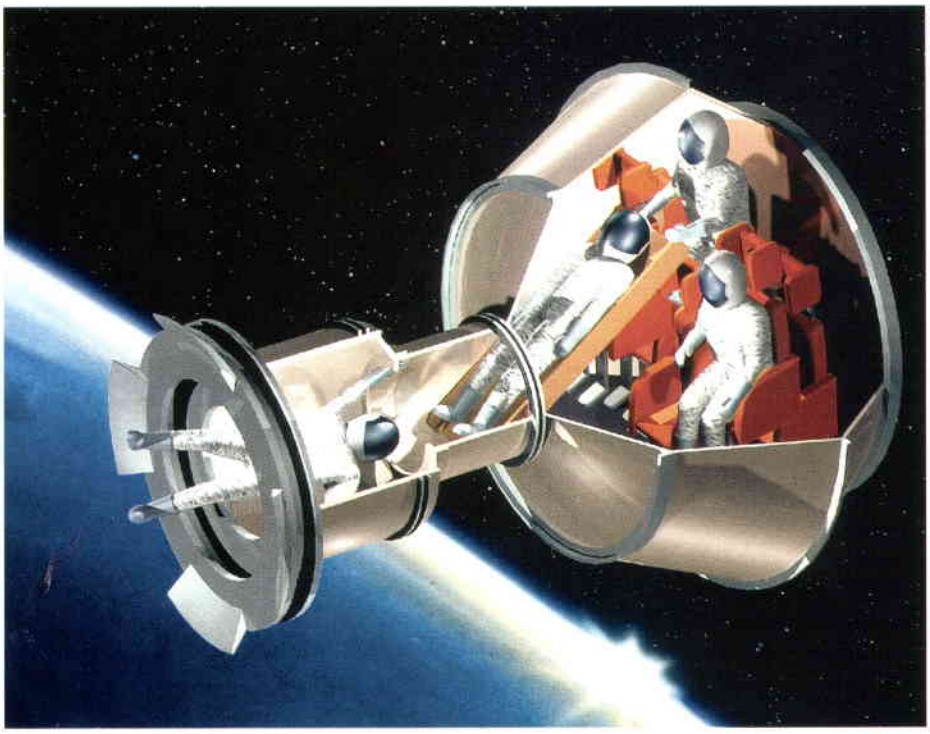
The trend for non-winged re-entry is to converge to either an advanced reusable capsule, or a very simple one, and for the winged re-entry to investigate a small automatic vehicle for crew and/or cargo transport.

Other system studies cover the support of the ESA/RKA working teams for space transportation and servicing missions.

The cornerstones of the infrastructure assumed for the studies of these cooperative scenarios are Space Station 'Freedom' and Mir-2.

Assured Crew Return Vehicle (ACRV)

The two parallel Phase-A studies for the ACRV have accomplished good agreement concerning overall feasibility, the design-driving parameters, and the life-cycle cost. The requirement to maintain immediate operational availability of the vehicle over many years of in-orbit storage represents a special challenge.



Artist's impression of the Assured Crew Return Vehicle (ACRV)

Vue conceptuelle de l'ACRV

The preparations for the Phase-B study have also been completed. The cooperative endeavour with NASA has made good progress in this area.

Servicing elements

ATV (Automated Transfer Vehicle)

With the completion of the Phase-A studies, the two industrial teams continue to work on special aspects of the transfer vehicle and its interfaces, in preparation for the Phase-B study, which is planned to start by the end of 1993. A configuration review is in preparation.

ARC (Automated Rendezvous and Capture)

The Phase-C/D proposal request has been prepared and presented to industry. The interfaces and agreements with NASA have been further advanced. The agreed launch date is end-1997.

ERA (External Robotic Arm)

The cooperation with RKA has started to become an important factor for the further development of the arm, due to the request to use it for the assembly of the Mir-2 station. A full-size demonstrator arm is presently being used to test the hardware and software capabilities for performing the required manipulations. The Phase-C/D request for proposal has been completed.

EVA

With EVA 2000 already being a joint development effort, its need for Mir-2 has made the development of the suit a confirmed objective.

The possibility of meeting the early need dates for both ERA and EVA is under evaluation.

Management

In line with the revised ground rules for the ESA/CNES cooperation, the Hermes Programme management-team structure has been modified; a matrix and multiple-project structure has been adopted to cope more effectively with the new programme objectives. The work of the prime contractor, Euro-Hermespace, will be phased out by mid-1993.

Etage H155

Le développement de l'étage cryotechnique H155 se poursuit conformément aux prévisions notamment avec la fin des essais de qualification de la jupe avant, le timbrage du réservoir de qualification et la fabrication du réservoir d'oxygène liquide du premier exemplaire de vol. Le moteur Vulcain, quant à lui, en est à 138 essais cumulant plus de 27 000 secondes de fonctionnement.

Etage L9

Les essais de la maquette de pilotage de l'étage L9 sont terminés à la satisfaction de tous les intervenants et la maquette de vibration est livrée. Par ailleurs l'intégration du premier étage de type vol, pour essais au sol, a commencé conformément au planning.

Composite supérieur

De nombreux essais concernant cette partie du lanceur ont eu lieu, parmi lesquels on peut citer:

- *l'essai de séparation de la coiffe, en chambre à vide*
- *l'essai de séparation entre le composite supérieur et l'étage H155.*

L'ensemble de ces éléments récents montrent que le développement du lanceur Ariane-5 est bien maîtrisé.

Hermes

Clôture des activités relatives au programme de référence Hermes

La clôture des activités de la phase initiale de développement Hermes s'est poursuivie, seuls quelques éléments restant à compléter. Après l'évaluation de la situation d'ensemble de la définition, les travaux exécutés par les contractants sur les fonctions du véhicule ont été passés en revue et jugés de façon générale satisfaisants. L'établissement de la documentation de clôture a été parachevé.

Technologie et technologie système

La tranche du programme de technologie Hermes a pris la suite des activités de développement du programme précédent. La transition s'est faite en douceur avec la couverture des tâches les plus importantes qui se sont poursuivies dans le cadre de la prolongation de la phase 1 de développement Hermes. En évitant de la sorte une rupture de charge dans l'industrie, l'élaboration des impératifs techniques et contractuels, la préparation des offres par l'industrie et leur évaluation peuvent être menées à bien durant le premier semestre de cette année.

Les principaux éléments couverts par le programme de technologie sont les suivants: aérothermodynamique, matériaux pour structures de protection thermique, protection contre les débris spatiaux, génération et stockage d'énergie, propulsion, avionique et moyens d'essai.

Après avoir passé en revue les nombreux domaines de coopération possibles, le groupe de travail ESA/RKA sur la technologie a préparé la sélection de ceux qui semblent les plus intéressants.

Concepts système

Les activités internes de recherche de scénarios de remplacement pour le transport d'équipages et de cargaisons se sont poursuivies. Des contrats de soutien ont été lancés pour couvrir les questions relatives aux véhicules de rentrée avec et sans voilure et à l'ensemble lanceur-composite.

La tendance qui se dessine serait de concentrer les efforts, pour les véhicules sans voilure, sur une capsule réutilisable soit de technologie avancée soit très simple, et pour les véhicules à voilure, sur l'étude d'un petit véhicule automatique de transport de personnel et/ou de fret.

D'autres études système couvrent le soutien des groupes de travail ESA/RKA dans le domaine des missions de desserte et de transport spatial.

Les pierres angulaires de l'infrastructure prise pour hypothèse des études relatives à ces scénarios de coopération sont la station spatiale Freedom et Mir-2.

Véhicule de secours pour le retour de l'équipage

Les deux études parallèles de phase A faites pour l'ACRV ont réussi à bien concilier la faisabilité globale, les paramètres déterminants de la conception et le coût du cycle de vie. Le fait que le véhicule doit pouvoir rester prêt en orbite à être utilisé à tout instant pendant de nombreuses années représente un défi particulier.

La préparation de l'étude de phase B a également été menée à terme. La coopération avec la NASA a bien progressé dans ce domaine.

Eléments de desserte

ATV (Véhicule de transfert automatique)
Avec l'achèvement des études de phase A, les deux équipes industrielles poursuivent les travaux sur des aspects particuliers du véhicule de transfert et de ses interfaces, en préparation de l'étude de phase B dont le démarrage est prévu fin 1993. On prépare une revue de configuration.

ARC (Rendez-vous et capture automatiques)
La demande de proposition de phase C/D a été élaborée et présentée à l'industrie. On a continué d'avancer en ce qui concerne les interfaces et les accords avec la NASA. Il a été convenu d'une date de lancement fin 1997.

ERA (Bras télémanipulateur extérieur)
La coopération avec la RKA commence à devenir une composante importante de la suite des travaux de développement du bras, dont l'utilisation a été demandée pour l'assemblage de la station Mir-2. Un modèle de démonstration en vraie grandeur sert actuellement à vérifier si matériel et logiciel sont capables d'exécuter les manipulations voulues. La demande de proposition de phase C/D a été achevée.

Activités extra-véhiculaires (EVA)
Le développement de la combinaison EVA 2000 correspondait déjà à un effort conjoint; le besoin de cet équipement pour Mir-2 en a fait un objectif confirmé.

On évalue actuellement s'il serait possible de disposer des deux équipements ERA et EVA pour les dates rapprochées où ils seraient nécessaires.

Gestion

En accord avec les principes révisés de la coopération entre l'ESA et le CNES, la structure de l'équipe de gestion du programme Hermes a été modifiée. Une structure matricielle et multiprojet a été adoptée pour mieux faire face aux nouveaux objectifs du programme. Il sera progressivement mis fin d'ici la mi-1993 aux travaux du maître d'oeuvre EuroHermespace.

Publications

The documents listed here have been issued since the last publications announcement in the ESA Bulletin. Requests for copies should be made in accordance with the Table and using the Order Form inside the back cover of this issue.

ESA Journal

The following papers have been published in ESA Journal Vol. 17, No. 2:

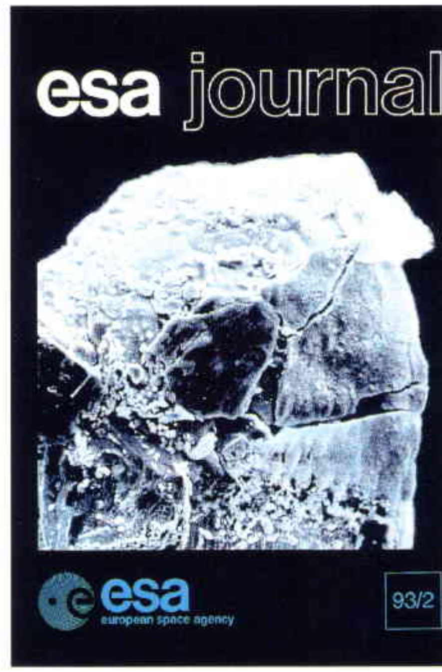
MOLECULAR COMPOSITES: POTENTIAL THIRD-GENERATION POLYMERS FOR AEROSPACE APPLICATIONS
S. PALSULE

OPERATION OF LIQUID-METAL FIELD ION EMITTERS UNDER MICROGRAVITY
F.G. RÜDENAUER ET AL.

AUTONOMOUS PROXIMITY MANOEUVRING USING ARTIFICIAL POTENTAIL FUNCTIONS
C.R. McINNES

SYNSIM: A SOFTWARE TOOL FOR THE RETRIEVAL OF SEA-SURFACE AND ATMOSPHERIC PARAMETERS FROM ACTIVE AND PASSIVE MICROWAVE MEASUREMENTS
P. SOBIESKI & A. GUISSARD

A NEW STAR-CONSTELLATION MATCHING ALGORITHM FOR SATELLITE ATTITUDE DETERMINATION
D. BALDINI ET AL.



ESA Special Publications

ESA SP-334 // PRICE 90 DFL
PROC. FIFTH EUROPEAN SPACE MECHANISMS & TRIBOLOGY SYMPOSIUM
(ED. W.R. BURKE)

ESA SP-351 // PRICE 90 DFL
PROC. 4TH INT. CONFERENCE ON PLASMA PHYSICS & CONTROLLED NUCLEAR FUSION
(EDS. T.D. GUYENNE & J.J. HUNT)

ESA SP-359 (2 VOLS) // PRICE 150 DFL
PROC. FIRST ERS-1 SYMPOSIUM – SPACE IN THE SERVICE OF OUR ENVIRONMENT
(ED. B. KALDEICH)

ESA SP-1157 // PRICE 50 DFL
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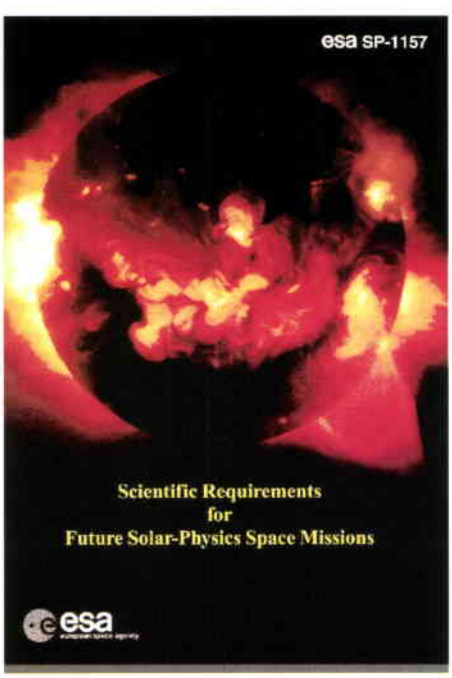
CLUSTER: MISSION, PAYLOAD AND SUPPORTING ACTIVITIES
(ED. W.R. BURKE)

ESA SP -1161 // PRICE 75 DFL
REPORT ON THE ACTIVITIES OF SPACE SCIENCE DEPARTMENT 1990-MID 1992
(ED. M.A. PERRY)



ESA Brochures

ESA BR-80 // NO CHARGE
LOOKING AT SCIENCE ON BOARD EURECA
(ED. S. HEERD)

ESA BR-93 // NO CHARGE
GIOTTO'S SECOND ENCOUNTER – THE MISSION TO GRIGG-SKJELLERUP
(ED. B. BATTRICK)

ESA BR-94 // NO CHARGE
ECSL – BIENNIAL REPORT 1991-1993
(ED. T.D. GUYENNE)

ESA HSR-8 // NO CHARGE
EUROPE IN SPACE: THE AUGER YEARS (1959-1967)
(ED. J. KRIGE)

ESA HSR-9 // NO CHARGE
THE EARLY DEVELOPMENT OF THE TELECOMMUNICATIONS SATELLITE PROGRAMME IN ESRO (1965-1971)
(ED. A. RUSSO)

ESA Newsletters

EARTH OBSERVATION QUARTERLY – No. 41, JULY 1993 (ENGLISH)
(NO CHARGE)
(EDS. N. LONGDON & T-D. GUYENNE)

COLUMBUS LOGBOOK – No. 19, MAY 1993
(NO CHARGE)
(ED. N. LONGDON)

REACHING FOR THE SKIES – No. 8, JUNE 1993
(NO CHARGE)
(EDS. N. LONGDON & T-D. GUYENNE)

MICROGRAVITY NEWS FROM ESA – VOL. 6 No. 1, JUNE 1993
(NO CHARGE)
(ED. B. KALDEICH)

NEWS & VIEWS – VOL. 18 No. 1, JUNE 1993
(NO CHARGE)
(ED. N. LONGDON)

PREPARING FOR THE FUTURE, VOL. 3, NO. 2, JUNE 1993
(NO CHARGE)
(EDS. N. LONGDON & S. HEERD)

ESA Procedures, Standards and Specifications

ESA PSS-02-10 VOL 1 // 35 DFL
POWER STANDARD
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ESA PSS-02-10 VOL 2 // 35 DFL
RATIONALE FOR THE POWER STANDARD
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Association for the Advancement of Space Science and Technology

SERIES OF INFORMATION SCIENTIFIC-TECHNOLOGICAL WORKSHOPS 1994 WINTER/SPRING SESSION

January, 17-21 ❶ **Russian Space Communication And Navigation Systems**

★ Current state and outlook of the new communication and positioning systems;
★ Main consumer performance of the systems being at the final stage of designing;
★ Cooperation in designing and operating.

January, 24-28 ❷ **Exploration of the Earth and ecological monitoring: space-based facilities and methods.**

★ Operational and future space systems for exploration of the Earth and ecological monitoring.
★ Methods and technical facilities for obtaining, transmitting, receiving, processing and distributing space information about the Earth
★ Results of scientific research and design work in the area of methods and technical facilities for remote sensing
★ Information about scientific, industrial and commercial organizations of the Russian space sector specialized in remote sensing and ecological monitoring.

February, 15-18 ❸ **The aerodynamics of hypersonic flight vehicles and the physics of hypersonic flows.**

★ The TsAGI hypersonic experimental basis;
★ Aerodynamics studies for hypersonic flight vehicles;
★ Heat-mass transfer on hypersonic flight vehicles;
★ Studies of physical phenomena accompanying the hypersonic flows and flight of hypersonic flight vehicles, including the ionization and emission irregularity phenomenon.

February, 21-25 ❹ **Spacecraft systems and elements**

★ Onboard attitude and stabilization systems.
★ Optical sensors to control S/C position.
★ Onboard computers.
★ Power supply systems elements and units.
★ Structure and antenna/feeder devices.

March, 14-18 ❺ **Small spacecraft and launchers**

★ Small spacecraft projects.
★ Existing capabilities to launch them as additional payload.
★ New launching facilities.
★ Spin-off rockets.

March, 21-25 ❻ **Experimental basis of Russia Space Companies**

The workshop is for making acquaintance with test installations belonging to the following space oriented companies:
★ Central scientific research institute of machine engineering (TsNIIMash, Kaliningrad);
★ Scientific-industrial Ass. "Mashinostroenie" (NPOMash, Reutov);
★ Scientific research institute of chemical engineering (NIIKHIMash, Sergiev-Posad);
★ Energia Scientific-industrial Ass. (NPO Energia, Kaliningrad);
★ Molnia Scientific-industrial Ass. (NPO Molnia, Moscow); and others

See other side...

SHORT DESCRIPTION

- The workshops are aimed at scientists and engineers, managers and businessmen, involved in aerospace business and interested in the latest Russian achievements in science and technology.
- The workshops are carried out by leading scientists and engineers from Russian space companies. The program of each workshop includes a visit to one or several space-oriented companies or institutes.
- Working language of the workshops is English.
- Social and entertainment program will be offered to all the workshop participants. Accompanying persons can participate with special guest registration.
- Registration fee covers organizational and technical expenses, transport, meeting at the airport and seeing-off, translation, coffee/tea breaks, banquets, social program.
- Each participant will be provided with quality and not expensive hotel accommodation and all meals at the workshop site. The cost of hotel services will be included in more detailed information.

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Please forward your applications, proposals, recommendations and questions to the following address:

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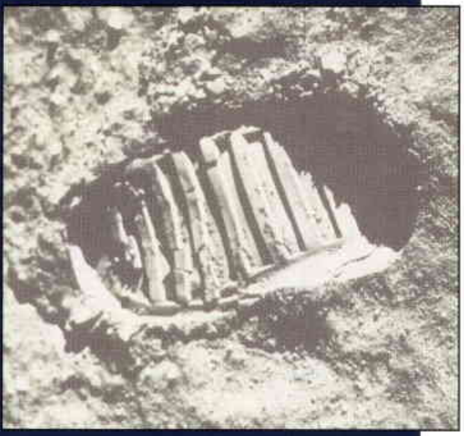

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International Colloquium

on

The Implementation of the ESA Convention Lessons From the Past

25 – 26 October 1993, Florence, Italy

A Colloquium, organised by the European Space Agency, the European Centre for Space Law and the European University Institute will take place in Florence, on 25 – 26 October 1993, on the Implementation of the ESA Convention. This colloquium will present the main issues raised by the Convention both from a historical and a prospective point of view. After an introduction given by Professor Reimar Lüst, the developments will be divided into four sessions: The Birth and The Evolution of the ESA Convention, chaired by Mr. Roy Gibson; Geographical Return, chaired by Dr. George Van Reeth; Commercialisation (From Independence to Integration), chaired by Professor Massimo Trella; The Agency and the Evolution of the International Environment, chaired by Mr. Henrik Grage. The aim of this colloquium is to permit an exchange of views among speakers and participants on all these issues.

You may obtain information from Mrs. E. Vermeer, ESA, Paris, 33.1.42.73.71.61., or from Miss B. de Hartogh, EUI, Florence, 39.55.509.23.79.

Second ECSL Practitioners' Forum

10 November 1993, ESA, Paris

Following the resounding success of the First Practitioners' Forum held last November, the European Centre for Space Law (ECSL) decided to continue with this initiative. The aim of this Forum is to discuss the specific legal problems that lawyers encounter in their day-to-day practice when dealing with space activities. ECSL has, again this year, been able to attract a number of outstanding specialists who will bring the participants up to date on the current legal issues surrounding space activities.

The Forum will be divided into two panels. The morning panel will deal mostly with the actual space law developments. It will be chaired by *Professor K.H. Böckstiegel.*

Presentations will be given on Satellite Communications, by *Mr. Phillip Dann, Bird & Bird London;* on Intellectual Property Issues, by *Mr. Sa'id Mosteshar, Mosteshar London;* on Regulatory and Policy Developments in the European Community, by *Dr. Tim Howell, Deputy Head Space Telecommunications Policy Unit, European Commmission, DGXIII;* on A Broadcaster's Point of View on these EC Developments, by *Dr. Mareni Pichler, Legal Adviser CLT Multimedia, Luxembourg.*

The afternoon panel will deal with Issues in space contracts. It will be chaired by *Dr. Ralph Kröner, Trenite van Doorne, Rotterdam.* Presentations will be given on ESA Contracts by *Dr. Winfried Thoma, Head Contracts Department ESA;* on Public Procurement by *Dr. Steven Kahn, Head of Rules and Procedures, Contracts Department ESTEC;* on Liability by *Dr. Curt Dombek, Bryan Cave London;* and on Insurance, by *Mr. Dhabi, Faugère et Jutheau, Paris.* Each presentation will be followed by a discussion.

Admittance to the Forum is free of charge but we can only welcome a limited number of participants. For more information on the Practitioners' Forum, contact Valérie Kayser, ECSL Secretary, 8-10 rue Mario Nikis, 75738 Paris Cedex 15, Phone: 33.1.42.73.76.05, Fax: 33.1.42.73.75.60.

Publications Available from ESA Publications Division

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Periodicals				
ESA Bulletin	4	ESA's primary magazine	Free of charge	ESA Publications Division, ESTEC, 2200 AG Noordwijk, The Netherlands
ESA Journal	4	ESA's learned journal	,,	
Earth Observation Quarterly (English or French)	4	Remote-sensing newspaper	,,	,,
ECSL News	4	Newspaper of the European Centre for Space Law (under the auspices of ESA)	,,	,,
Reaching for the Skies	4	Space Transportation Systems newspaper	,,	,,
Columbus Logbook	4	Space Station/Columbus newspaper	,,	,,
Microgravity News (English with French summaries)	3	Microgravity Programme newspaper	,,	,,
Preparing for the Future	4	Technology Programme newspaper	,,	,,
News & Views	4	ESA Information Retrieval Service's newspaper	,,	ESRIN, Via Galileo Galilei, CP64, 00044 Frascati, Italy
Monographs	**Code**			
Conference Proceedings	(SP-xxx)	Volumes of specific Conference papers	Prices below	ESA Publications Division, ESTEC, 2200 AG Noordwijk, The Netherlands
Scientific/Technical Monographs	(SP-xxxx)	Specific/detailed information on graduate-level subjects	,,	
ESA Brochures	(BR-xxx)	Summaries of less than 50 pages on a specific subject	,,	,,
ESA Folders	(F-xxx)	'Folders' giving short descriptions of subjects for the space-interested layman	Free of charge	,,
Scientific & Technical Reports	(STR-xxx)	Graduate level — reflecting ESA's position on a given subject	Prices below	,,
Scientific & Technical Memoranda	(STM-xxx)	Graduate level — latest but not finalised thinking on a given subject	,,	,,
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