european space agency

esa bulletin

agence spatiale européenne

number 74

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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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The ESA HEADQUARTERS are in Paris.

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

ESRIN, Frascati, Italy.

Chairman of the Council: Prof. F. Carassa

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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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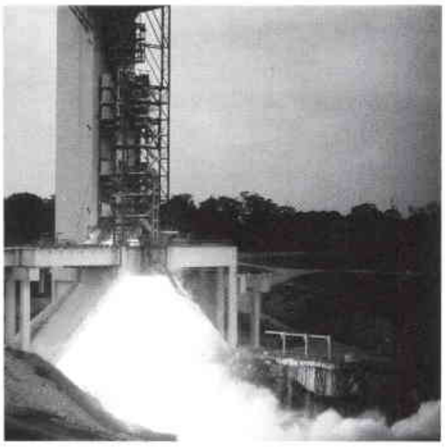

Cover: First test firing of an Ariane-5 P230 solid booster, on 16 February 1993, in Kourou, French Guiana

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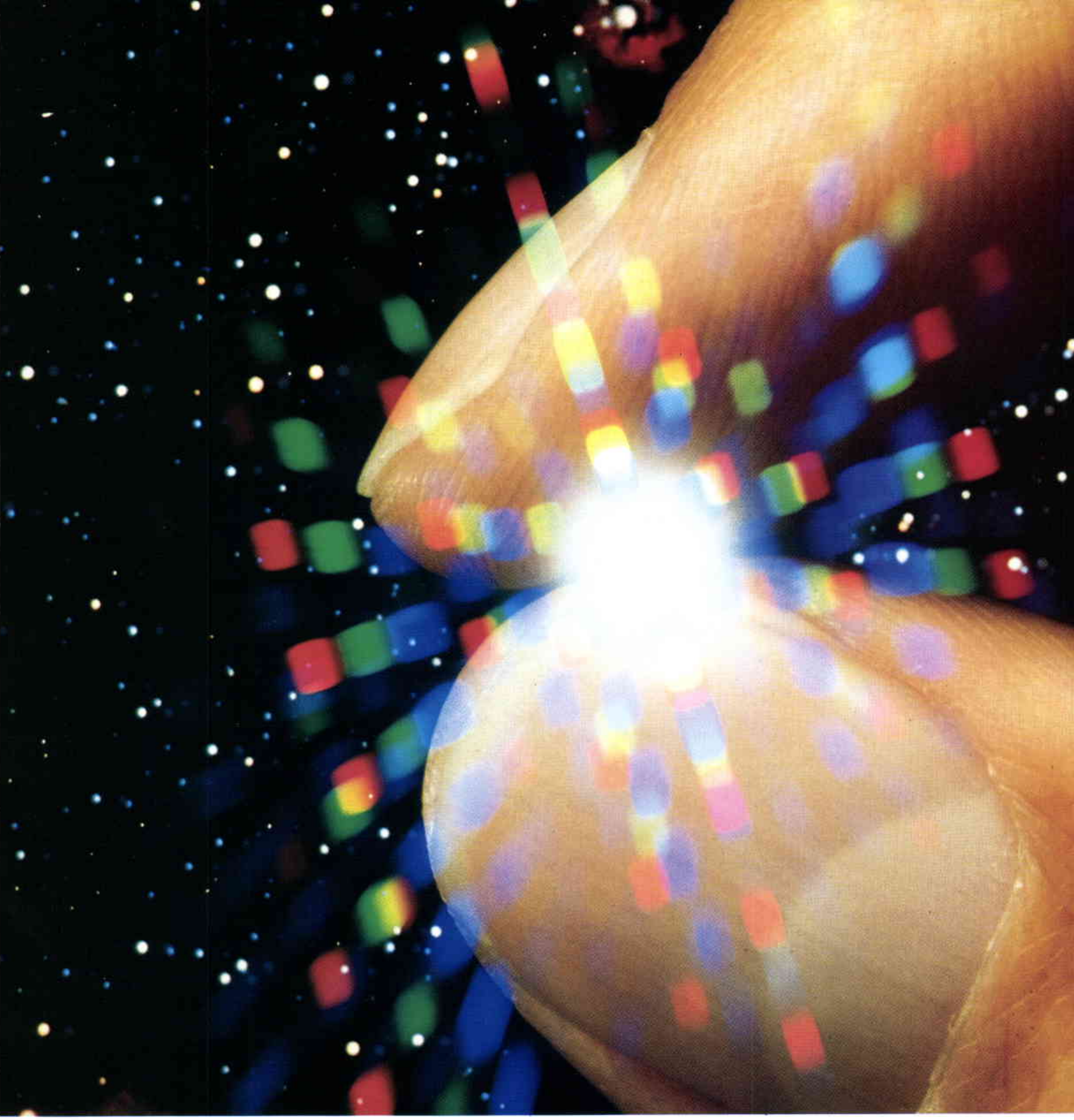

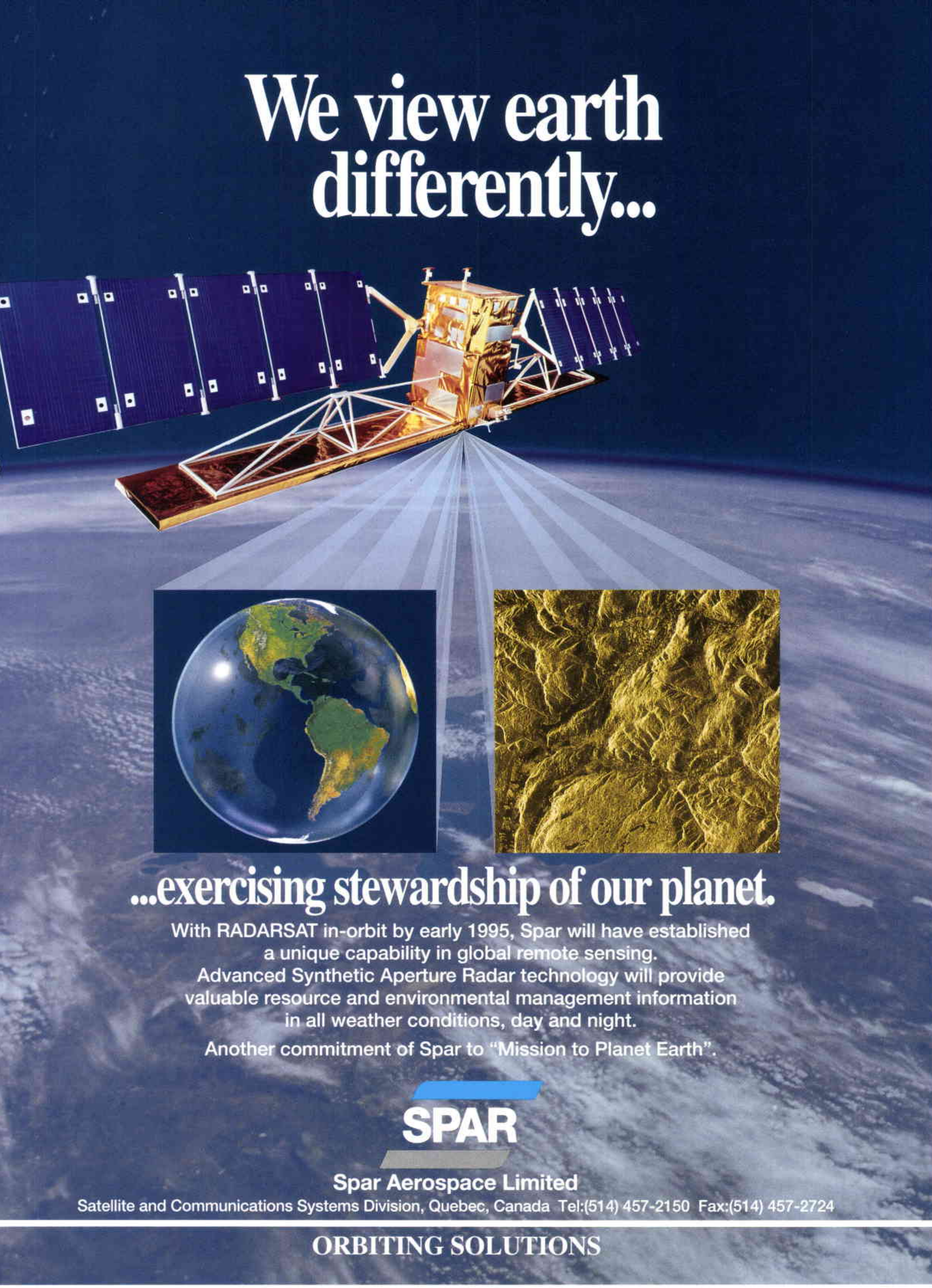

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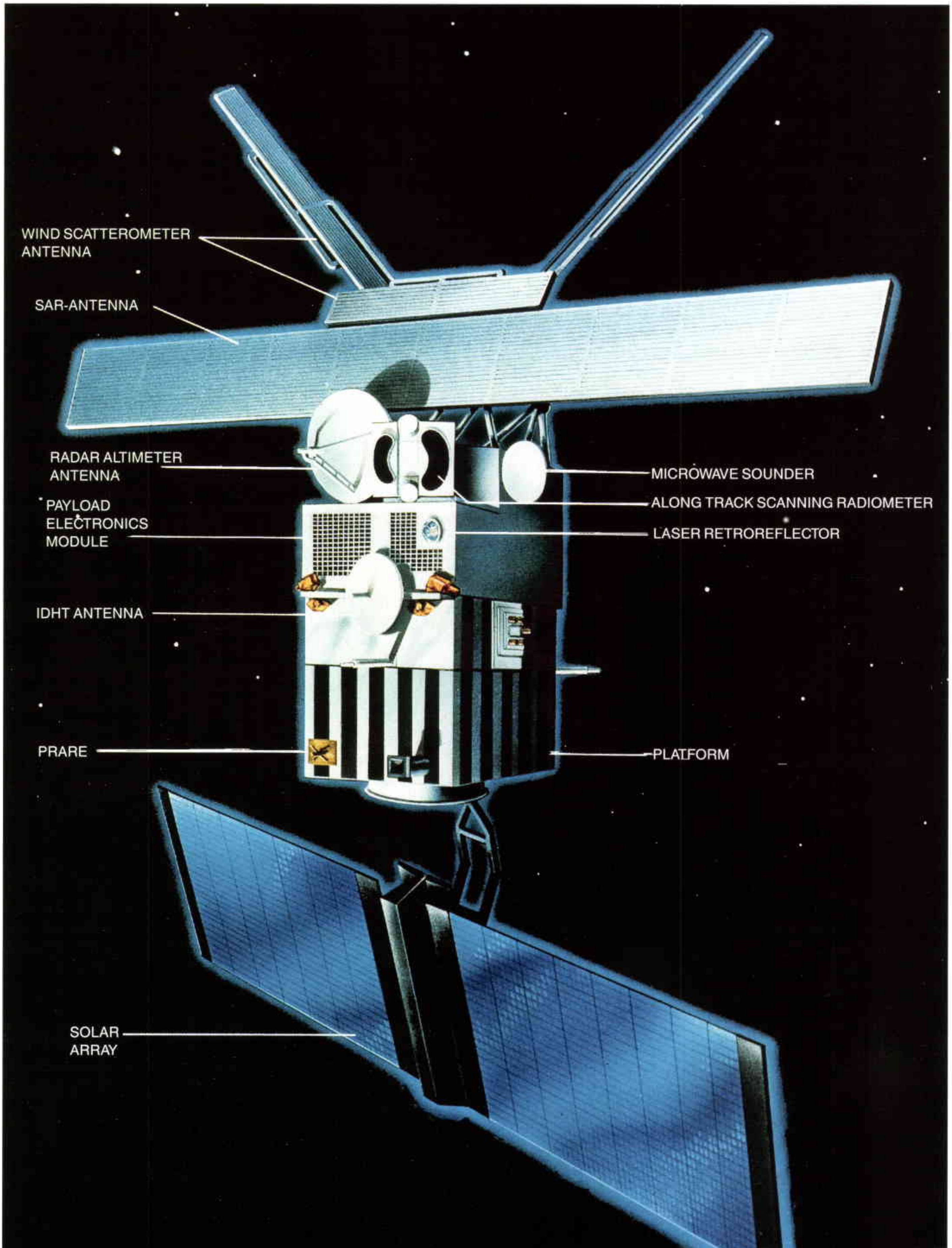


Figure 1. The ERS-1 satellite and its main components

The ERS-1 Satellite — Approaching Two Years in Orbit

J. Louet & R. Zobl
ESA Directorate for Observation of the Earth and Its Environment, ESTEC, Noordwijk, The Netherlands

After almost two years in orbit ERS-1, the most sophisticated Earth-observation satellite ever built in Europe, is delivering huge quantities of validated products to the scientific and applications communities. The need for absolute calibration of the onboard instrumentation and its continuous monitoring has been recognised by the user community and the Agency alike as an essential element in guaranteeing the best possible exploitation of ERS-1's substantial capabilities. The results of these continuous calibration and monitoring activities have served to confirm the outstanding and extremely stable performances of the ERS-1 instruments, which allow the user community to compare multi-temporal observations very precisely and thereby obtain a much better understanding of the dynamics of our environment.

Spacecraft performance

The main components of the ERS-1 satellite, namely the carrier spacecraft or 'platform' and the payload instrumentation, are highlighted in Figure 1. The platform has to provide all of the support services required by the satellite and therefore the status of the resources it is delivering is of major importance when analysing the satellite's overall health.

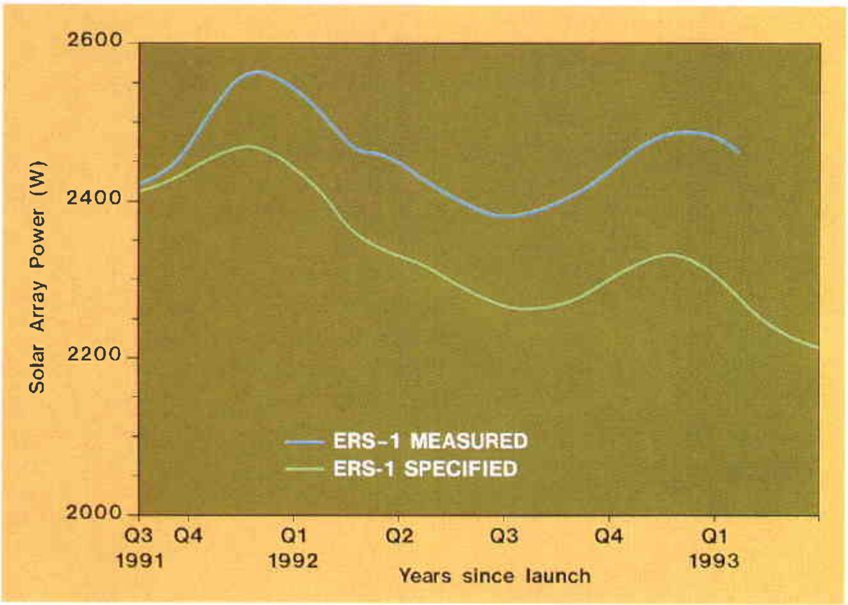


Figure 2. Evolution of solar-array power

The power system

The satellite's power is provided by a combination of a solar array and a battery compartment. ERS-1 makes one complete orbital revolution of the Earth every 100 min, 66 min of which are in sunlight, during which the solar array is used to power the whole spacecraft and to recharge the four batteries. The latter are then the sole source of power during the ensuing 34 min of eclipse.

The observed energy balance aboard ERS-1 remains excellent:

- The solar-array performances are significantly above predictions, due in particular to a lower degradation trend than expected (Fig. 2).
- The batteries are in a cold stable environment (−4°C), which helps to guarantee a potentially long lifetime. The payload operations induce a mean battery Depth Of Discharge (DOD) of around 20% per orbit, which is lower than the 24% anticipated, and modelled, before launch. This DOD is stable, due to the mission's rather constant operating profile: namely, global operation of the low-data-rate instrumentation with data recovery using the onboard tape recorder and a set of four playback stations, and regional operation of the AMI Synthetic Aperture Radar (SAR) for up to 12 min per orbit when in direct visibility of the ground stations.

  The observed battery end-of-discharge voltage (voltage of the platform power bus at end of eclipse) quickly stabilised at 27.5 V at the beginning of the mission and has been extremely stable ever since.

All in all, therefore, the spacecraft has a very healthy power system, which in turn allows the payload subsystem to be fully exploited.

The propulsion system

The satellite left the Kourou launch pad with

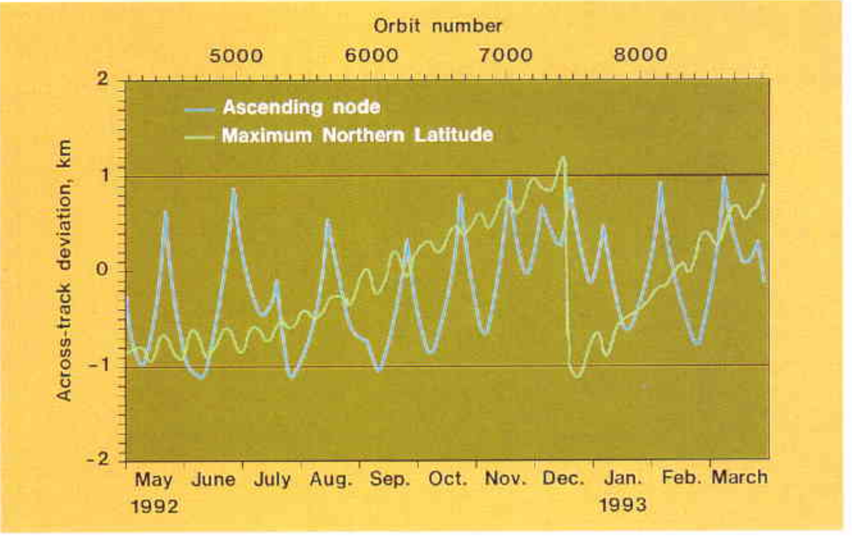
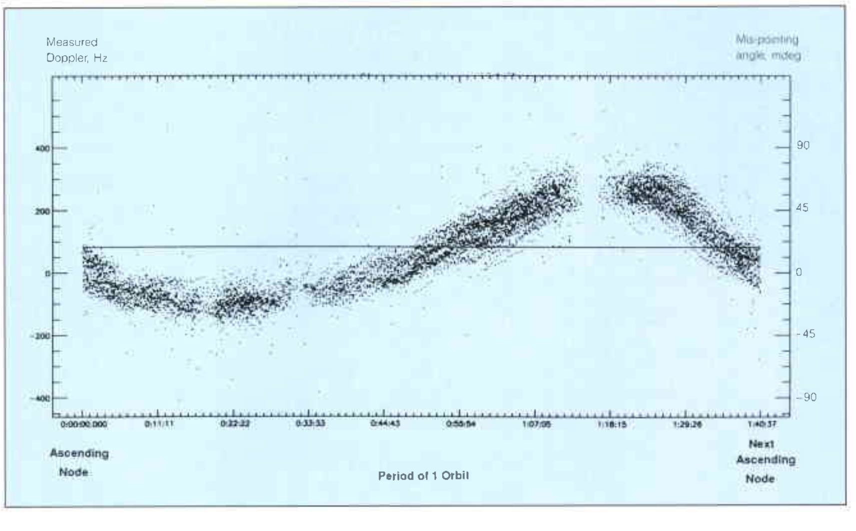


Figure 3. Orbit maintenance as a function of cross-track deadband for the multi-disciplinary phase orbit

a total of 317.6 kg of hydrazine in its four tanks. All of the orbit manoeuvres necessary to acquire first the commissioning-phase orbit, then by end-December 1991 the ice-phase orbit, and finally by early April 1992 the 35 day repeat cycle orbit of the multi-disciplinary phase (planned to be maintained until the end of 1993), have since been conducted. The same propulsion system is also used to maintain the satellite's regular orbit within a cross-track deadband of ±1 km defined with respect to an Earth-fixed pattern of 501 orbits for the 35 day repeat cycle.

As illustrated by Figure 3, the Mission Control Centre at ESOC in Darmstadt (D) has been very successful in keeping ERS-1 within this specified deadband. The very high solar activity at the beginning of the mission called for along-track corrections at intervals of 1 to 2 weeks to maintain the satellite within the specified deadband. Since April 1992, the interval between manoeuvres has been of the order of 1 month and will continue to increase as the prevailing solar activity decays.

Figure 4. De-pointing derived from SAR Doppler estimates for the period May to December 1992 (seven samples each of ten orbits over the period). A Doppler error of 45 Hz corresponds to a 10 mdeg antenna mis-pointing



Maintaining the deadband at the Earth's poles requires an out-of-plane manoeuvre twice per year, the last such manoeuvre having been performed in mid-December 1992. The next two are foreseen for April and December 1993.

An estimated total of 33.6 kg of hydrazine was consumed during the first eighteen months of ERS-1 operations. With 284 kg of hydrazine still available, therefore, the satellite currently has far more propellant available than is required for its originally planned operational lifetime of two years.

The attitude-control system

The performance of this system has been very closely monitored since launch because of its direct impact on overall payload performances. ERS-1's three-axis stabilisation is performed by a traditional system based on Earth sensors, Sun sensors, reaction wheels and magneto-torquers.

The satellite's payload permits direct verification of the attitude-control performance: the Radar Altimeter (RA) can precisely detect off-nadir pointing, while the Active Microwave Instrument (AMI), with its scatterometer and SAR (Synthetic Aperture Radar) antennas precisely aligned with respect to the satellite body, can be used to detect Doppler shifts with respect to the boresight azimuth direction in the respective antenna planes.

The SAR, when used in its so-called 'Imaging' and 'Wave' modes permits, as an inherent part of its data processing, a very precise estimate of the pointing direction of the azimuth antenna boresight by comparing the data-derived Doppler centroid with that expected for an ideally pointing antenna. This therefore gives a precise estimate of the combined yaw/pitch mis-pointing of the satellite.

A detailed analysis of the long-term monitoring of this SAR Doppler centroid information has confirmed that the combined yaw/pitch attitude performances are perfectly repetitive from orbit to orbit, and lead to an estimated combined yaw/pitch bias of 20 mdeg and an harmonic error, at orbital frequency, of ±30 mdeg, the residual noise error being of the order of 20 mdeg as shown in Figure 4.

An estimate of the off-nadir pointing of the Radar Altimeter, derived from a statistical analysis of the radar echo shape, confirms that the satellite's combined roll/pitch pointing error is less than 50 mdeg (Fig. 5).

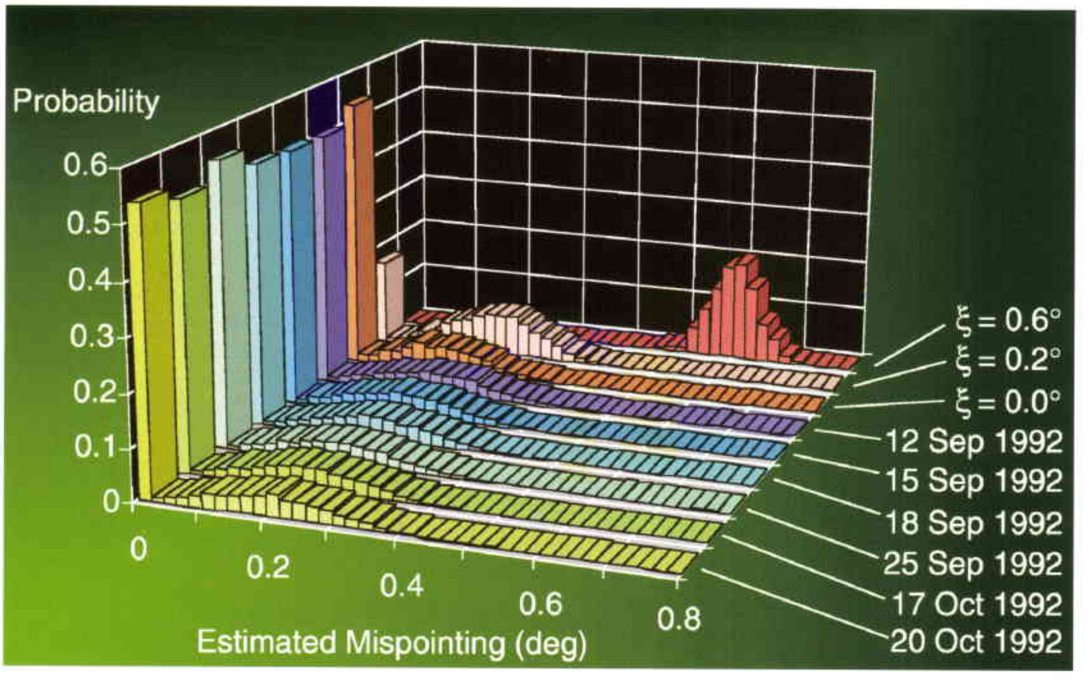


Figure 5. Radar Altimeter (RA) derived estimate of mis-pointing (off nadir). The RA return echo shape is compared with expected echo deformation as a function of off-nadir antenna de-pointing

The on-board computer

This computer controls not only the spacecraft platform, but also the ERS-1 payload, with time-tagged commands permitting about 24 hours of onboard operational autonomy. The only significant incident over the last few months has been an intermittent parity error, which caused repeated interruptions of payload operations last summer. The faulty memory module has since been identified and isolated, on 9 September 1992, allowing full operational stability to be recovered.

The satellite's master clock, used for the 'datatation' (time synchronisation) of all onboard events, including instrument-data time-tagging, has shown excellent stability (better than 10^{-7} per year). It is monitored at every pass over the Kiruna (S) ground station with a datation correlation accuracy of better than 30 μs with respect to Universal Time (UTC). It therefore permits payload product datation accuracy of better than the 1 ms accuracy specified for the Radar Altimeter in particular.

The above performances clearly demonstrate the excellent health of both the ERS-1 platform and its subsystems, which has permitted a cumulative in-orbit availability of more than 99% to be logged for the platform services.

The payload

Numerous publications in the literature, as well as the First ERS-1 Symposium held in Cannes (F) last November (which attracted more than 450 participants), have clearly confirmed the payload's outstanding performance from the users' viewpoint. In addition, the supporting performance-monitoring activities that have been conducted on a continuous basis by the project since the beginning of the mission are also providing an objective assessment of instrument performance stability.

For the Radar Altimeter and the Active Microwave Instrument, these performance-monitoring tasks are carried out by ESA itself, while for the Along-Track Scanning Radiometer and its associated Microwave Sounder, they are carried out by Rutherford Appleton Laboratory (RAL, UK) and Centre de Recherche en Physique de l'Environnement (CRPE, France), who are the respective instrument providers. We will concentrate here on the two instruments monitored by the Agency.

The AMI

Since early commissioning, the Active Microwave Instrument has been operated continuously in one of two modes:
- Imaging mode for a maximum of 12 min per orbit
- Wind–Wave interleaved mode for the remaining period of the orbit

which require separate external calibration verifications. The pure Wave mode, which is a snapshot operation of the SAR at 200 km intervals, benefits directly from the SAR Imaging-mode calibration and therefore does not require specific calibration operations.

For the SAR Imaging mode, the external calibration monitoring is primarily performed using three active transponders deployed in

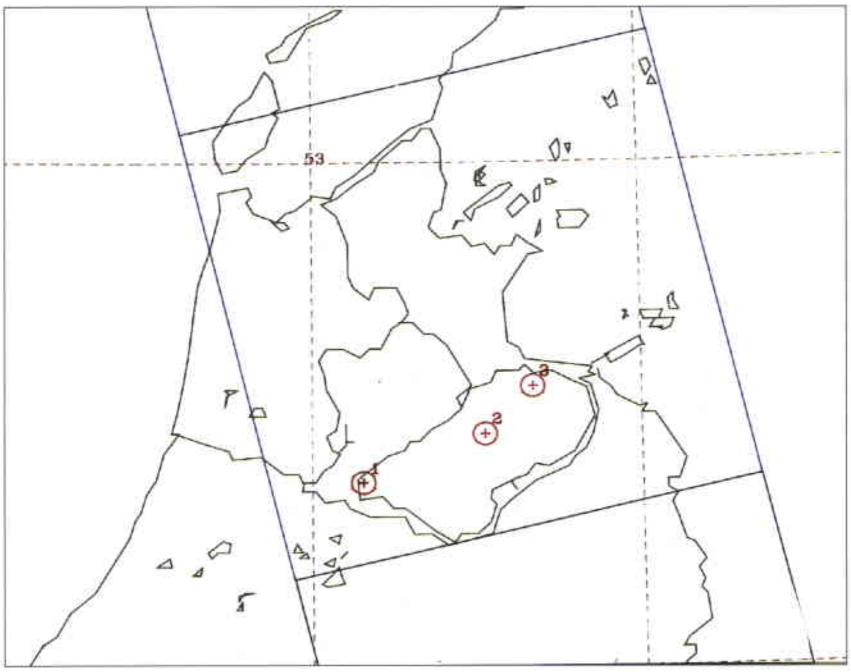


Figure 6. One of the three SAR transponders in Flevoland (The Netherlands)

the Flevoland area of The Netherlands, east of Amsterdam (Fig. 6). The satellite's 35-day orbit repeat cycle offers six opportunities to observe these transponders within the SAR swath. Three or four of these opportunities are exploited per repeat cycle and the transponders are remotely programmed from ESTEC in Noordwijk (NL) to be activated and pointed at the satellite at these times.

This suite of measurements has allowed the AMI's end-to-end stability to be verified continuously since launch. As Figure 7 clearly demonstrates, the absolute stability of the SAR chain has remained constant since launch, with a standard deviation of just 0.4 dB.

The SAR's stability can also be measured by analysing data acquired whilst overflying stable, homogeneous natural targets. SAR images taken over the Amazonian Rain Forest, selecting homogenous zones already identified by the Wind Scatterometer, allow the overall SAR processing-chain gain and antenna pattern to be verified.

The extreme radiometric stability that the SAR instrument has exhibited since launch permits users to exploit multi-temporal ERS-1 observations very efficiently and to make precise quantitative assessments of the changes that are taking place from image to image (Fig. 8). This same stability is also allowing 'SAR interferometry' to be performed, which is a new and very promising application of this type of instrument.

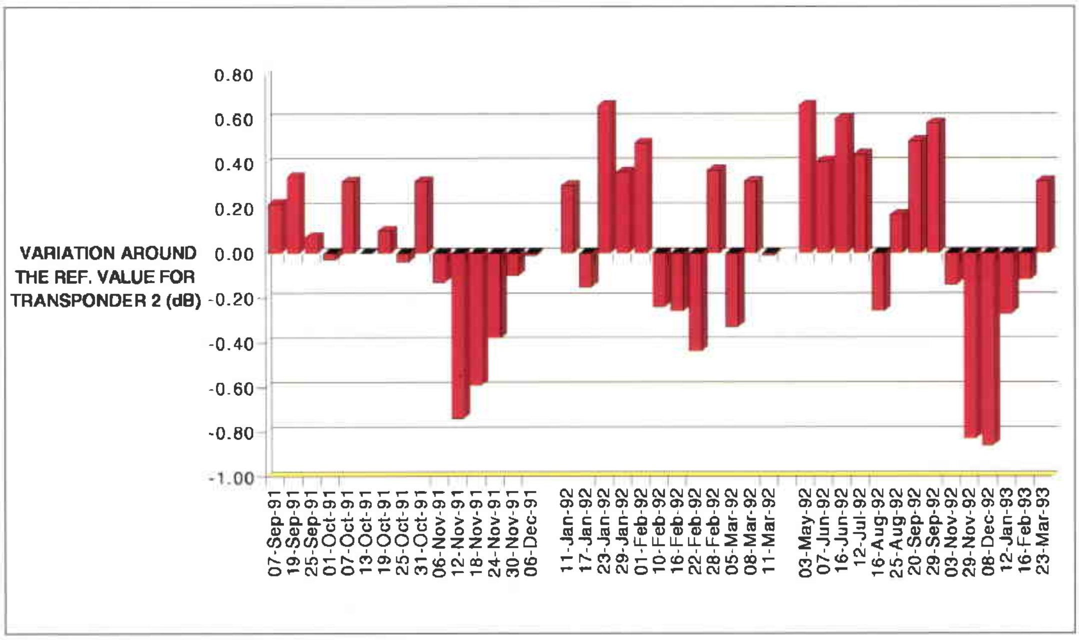


Figure 7. SAR end-to-end system stability verification via point-target analysis (transponder 2)

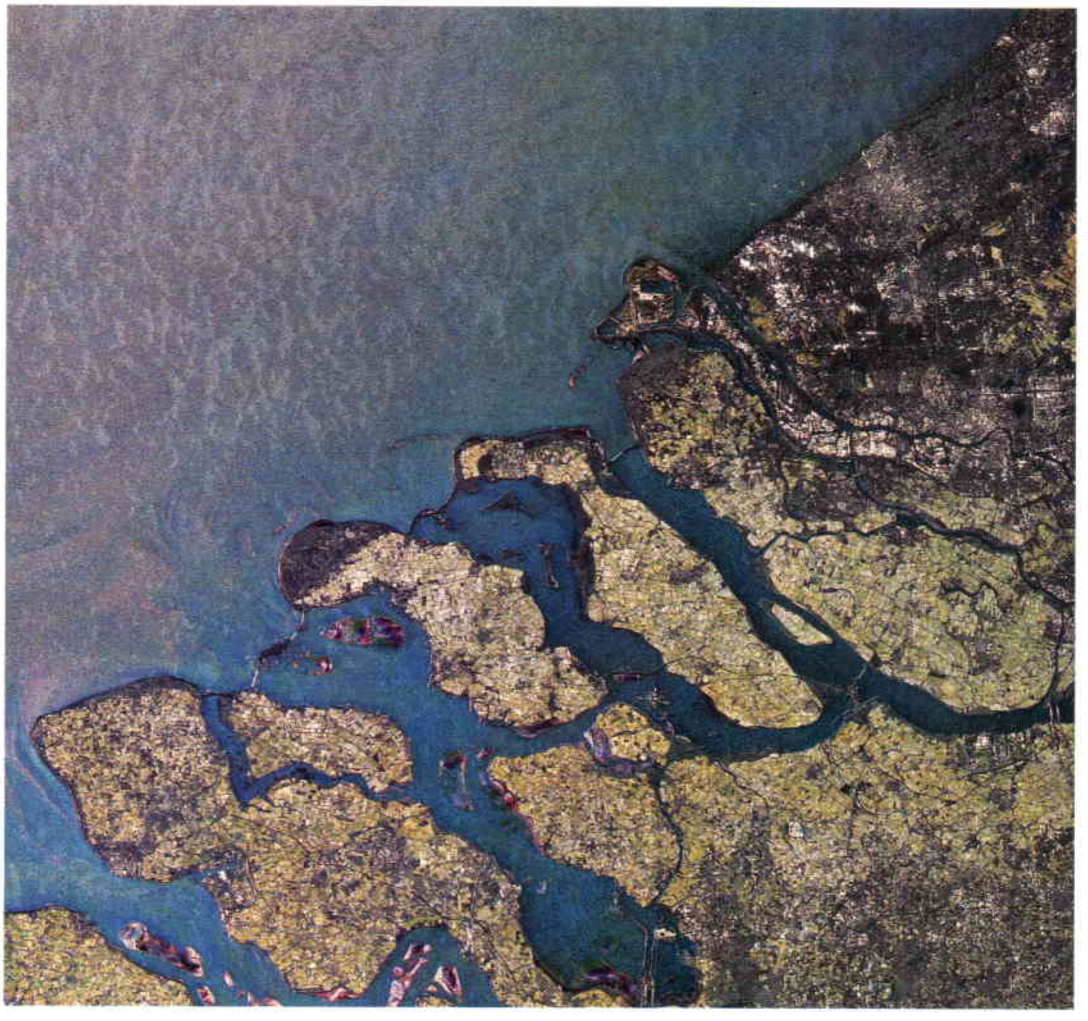


Figure 8. Multi-temporal image of Zeeland (The Netherlands), obtained by the superposition of six SAR fast-delivery images produced during the 'Ice Phase' of the mission: three images from the Kiruna station (S) for 1, 7 and 10 February 1992, and three images from the Fucino station (I) for 2, 5 and 14 March 1992. The colours resulting from three images are as follows:
- **7 February: red**
- **10 February: green**
- **2 March: blue.**

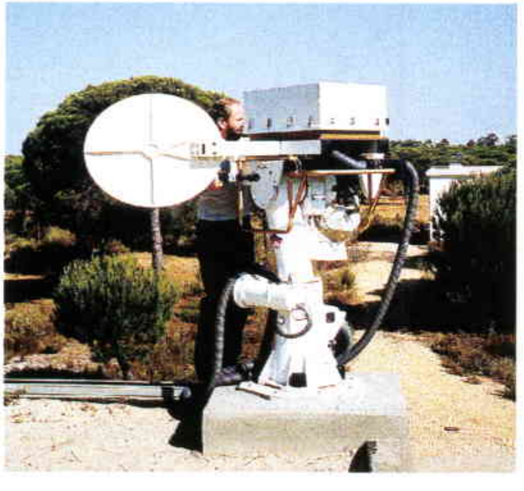
Zones with invariant backscatter over the observation period have remained grey.

(Image courtesy of the National Aerospace Laboratory (NLR), The Netherlands)

For the Wind Scatterometer mode, the external calibration monitoring has continued to be performed using three transponders deployed in Southern Spain (Fig. 9). The homogeneous targets of Amazonian Rain Forest identified during the commissioning phase have again been used as reference monitoring targets.

Thanks to the onboard recording of the Scatterometer data, the calibration monitoring over natural targets can be performed within a few hours of the data take by analysing the backscatter data contained in the fast-delivery wind products. Correlation of the measurements over time permits the stability of the instrument to be verified. The transponder processing allows absolute calibration to be guaranteed for the Wind Scatterometer also, as well as confirming the perfect stability of the instrument since the early commissioning phase.

Comparisons of observations over the selected natural targets confirm the transponder measurements in that the three Wind



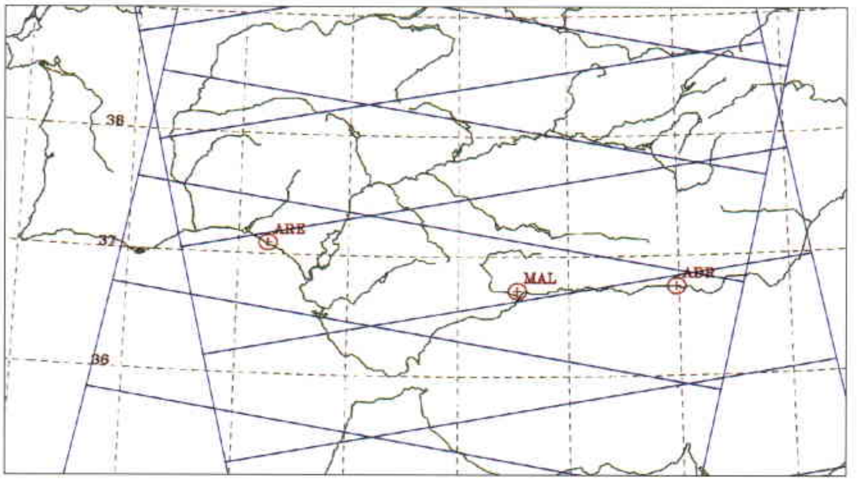


Figure 9. One of the three Wind Scatterometer transponders located in Southern Spain (in Arenasillo, Malaga and Adra)

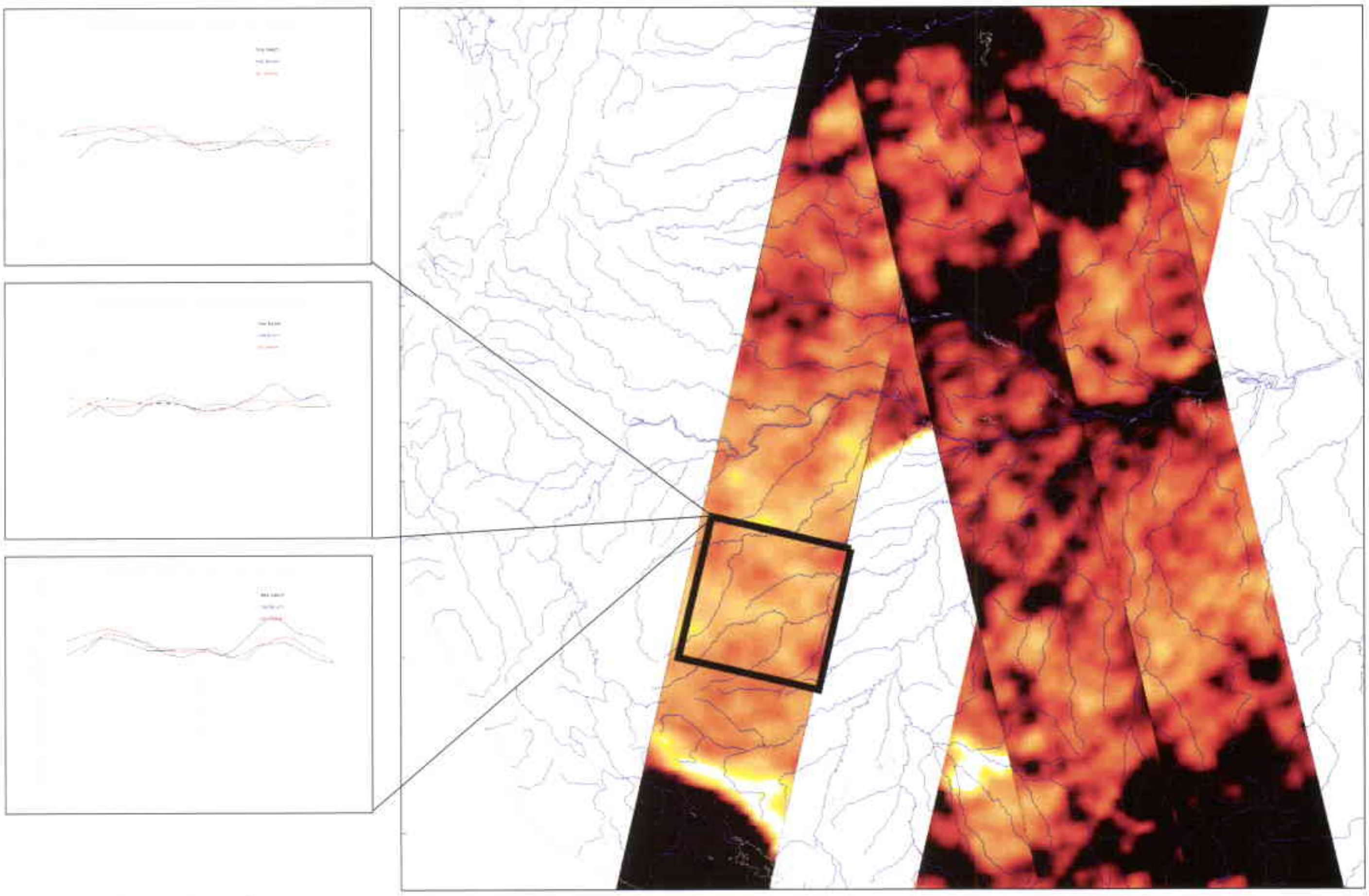


Figure 10. Correlation of the three Wind Scatterometer beam measurements over the full 500 km swath. Over this selected area of the Brazilian Rain Forest, the three beams are correlated to within 0.3 dB. The 0.2 dB backscatter increase observed in February 1993 is attributed to an annual cycle in the Rain Forest backscatter, which was also observed in 1992

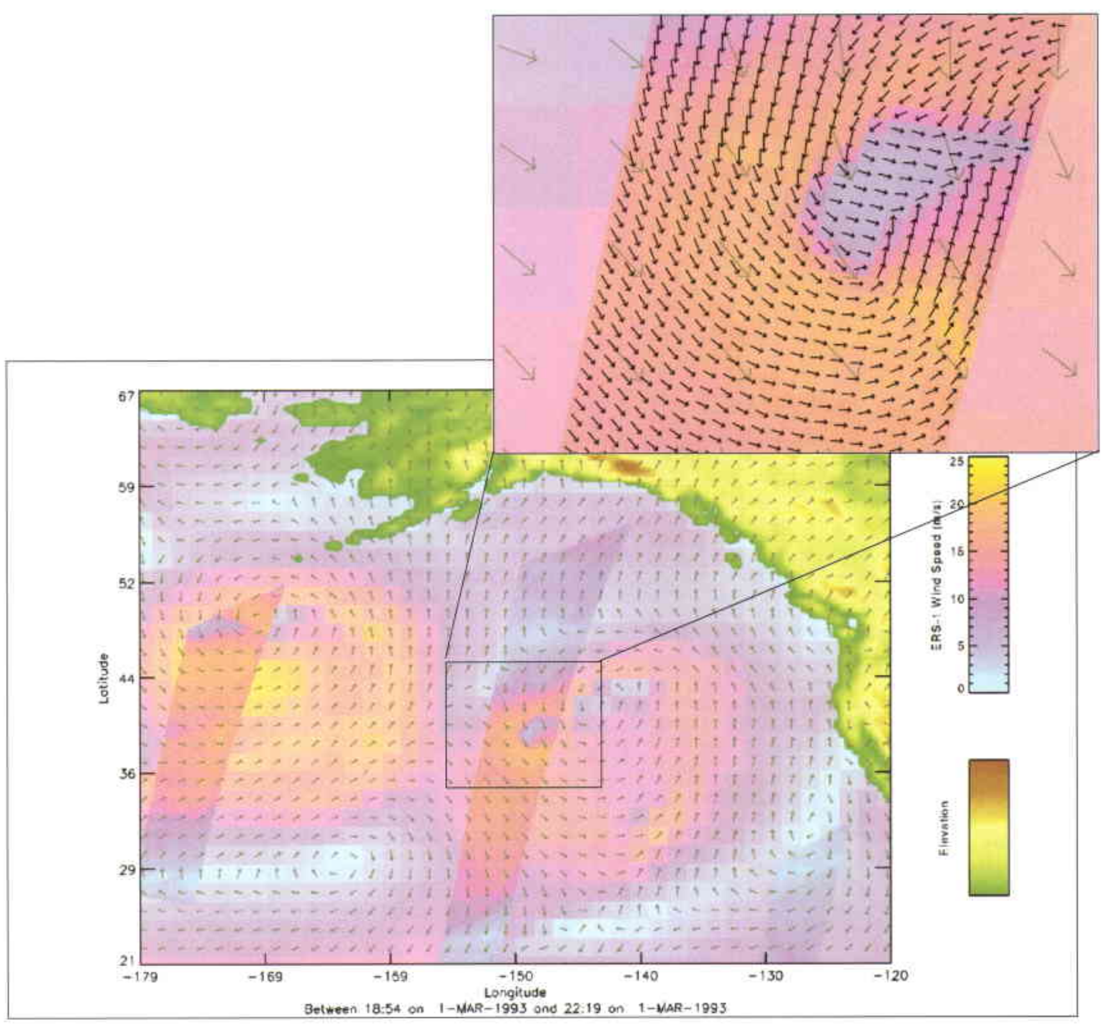


Figure 11. Comparison of the Wind Scatterometer wind field fast-delivery product with the background ECMWF wind prediction

Scatterometer antenna beams are within 0.3 dB over the complete swath (Fig. 10).

This combined use of transponders and selected natural targets allows very precise monitoring of the Wind Scatterometer's calibration with a fast turn-around time. The overall stability of the instrument since the commissioning phase was completed appears to be better than 0.2 dB peak-to-peak. This extremely high stability has permitted the validation of the wind retrieval model to be continued.

Using the recently installed CMOD 4 wind model, validated by the European Centre for Medium-Range Weather Forecast (ECMWF, Reading, UK), the wind retrieval performed as part of the fast-delivery processing gives wind speeds down to 0.5 m/s and has an extended validated range to 20 m/s or higher. It also permits greater quality in wind-field extraction.

An example of a recent fast-delivery product is shown in Figure 11. It demonstrates the wind-field 'smoothness' now being achieved in this product and the more detailed structure of the wind fields themselves compared with the global wind-prediction model provided by ECMWF (shown in the background).

The AMI wave mode is exhibiting the same performance stability as the SAR imaging mode. A major improvement over the last few months has been the implementation of an efficient image spectrum extraction algorithm, which is now operational in the fast-delivery processing chains. A sample of the results is provided in Figure 12. The latter clearly demonstrates the quality of the extracted spectra, which are presently being assimilated into a global wave model (WAM) as part of a joint ECMWF/Max-Planck Institute (Hamburg) project.

The overall availability of the AMI instrument has been excellent so far. The main source of service interruption has been arcing in the transmit power amplifier, almost a 100 such occurrences having been noted since launch. Two-thirds of them have been recovered automatically on board within

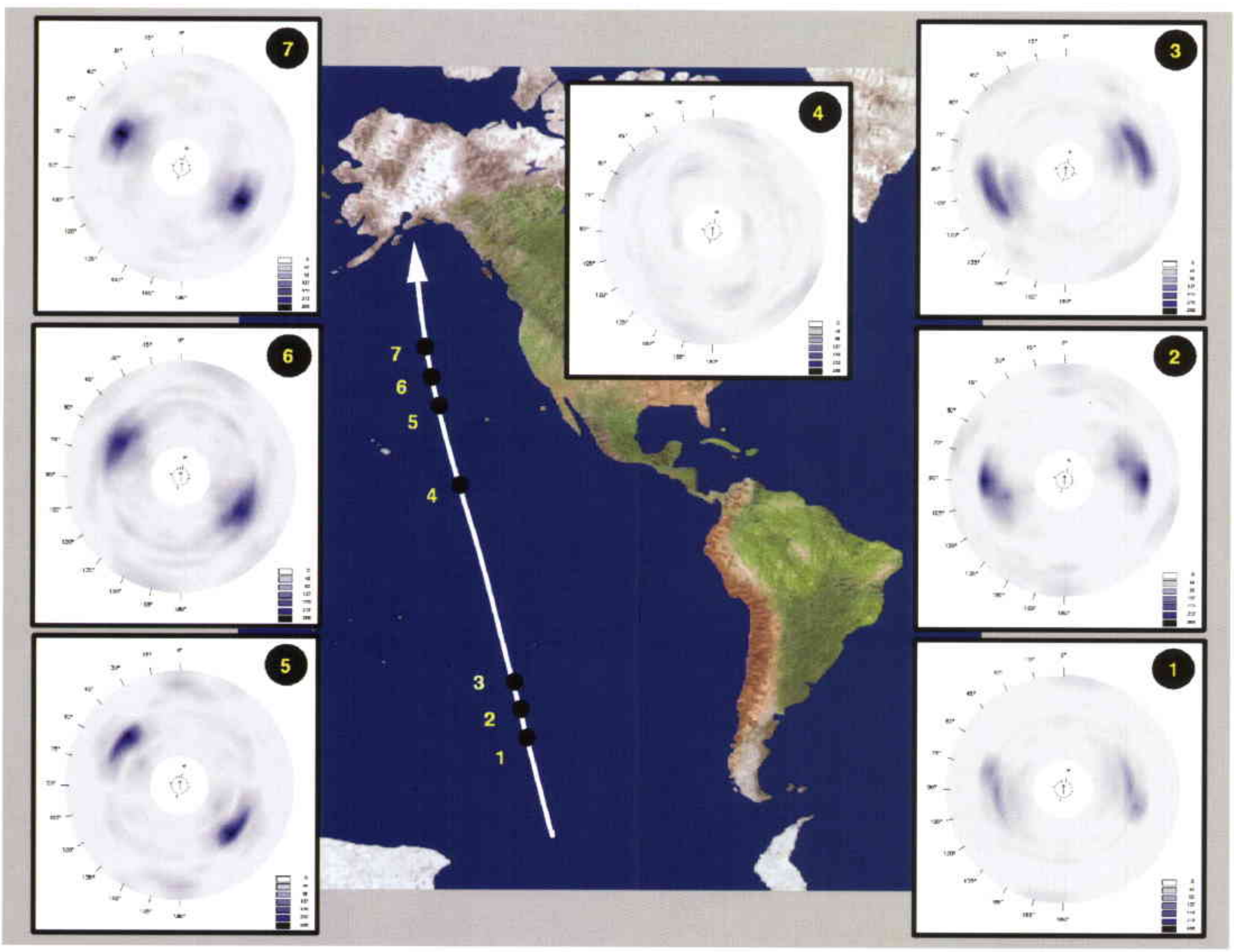


Figure 12. Evolution of Wave Mode image spectra observed over a Pacific ascending arc. Strong waves are observed in the southern latitudes (wavelengths close to 400 m in cells 1, 2 and 3), weak wave intensity and direction near the equator (cell 4), and strong waves at northen latitudes (about 300 m wavelengths in cells 5, 6 and 7)

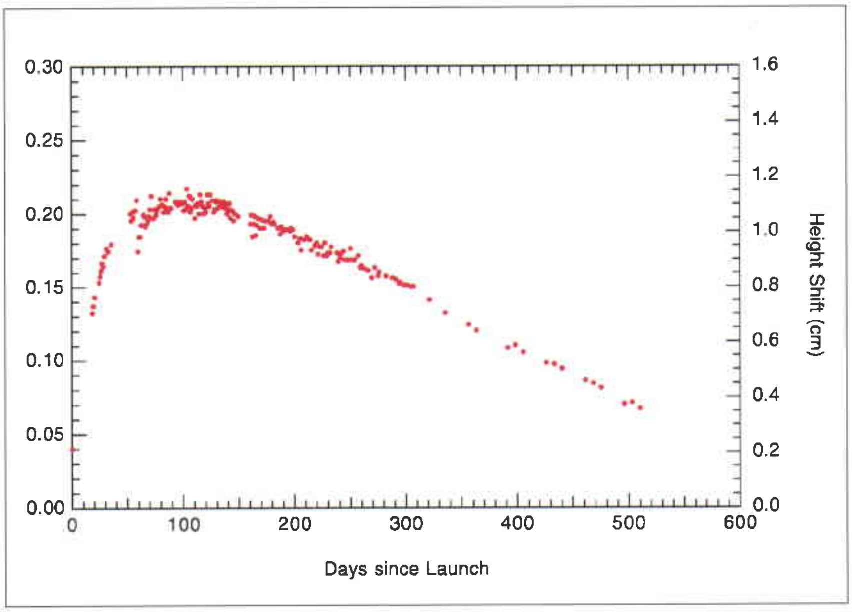


Figure 13. Radar Altimeter ultrastable-oscillator frequency monitoring, used to scale the RA round-trip time delay measured onboard ERS-1

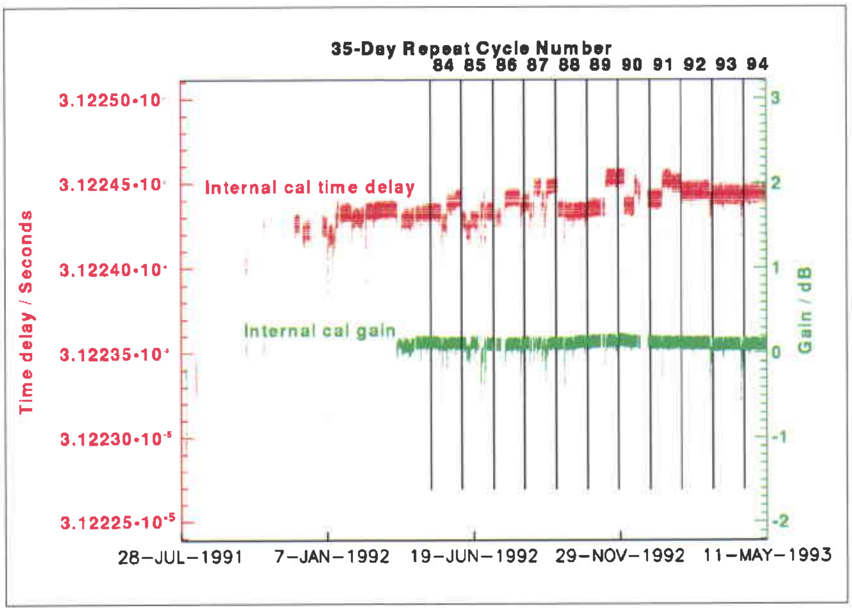
Figure 14. Radar Altimeter internal calibration loop stability monitoring (continuous monitoring onboard at 2 min intervals)

15 s, but the others have required a manual restart by the satellite controller at ESOC after detection of the anomally. The overall cumulative availability of the AMI is still above 98.5%, taking into account platform unavailability.

The RA

The Radar Altimeter's operational planning is based on continuous operation with time-tagged mode switching from ocean to ice mode according to a reference-zone-based scenario. This instrument's performance has also been monitored continuously since very early in the mission.

Detailed post-processing of data obtained during the 'Venice Height Calibration Campaign' during summer 1991 has confirmed that a 41.5 cm bias should be applied during height reference data processing. The observed peak-to-peak



variation in the ultrastable oscillator since the satellite's launch is equivalent to 1 cm in height (Fig. 13). The overall stability of the calibration loops also clearly confirms the excellent performance of the instrument (Fig. 14).

The tracking of the RA over the Earth's oceans has been very stable and robust since early commissioning. The optimisation of the tracking-loop performances over sea-ice has been more problematical, however, requiring several iterations in the optimisation of the onboard tracking-loop parameters. The performances achieved by the end of 1992 show a very significant improvement in the overall tracking performance over sea-ice, land and ice-covered surfaces (Fig. 15).

The quality of the RA tracking over Antarctica has allowed the three-dimensional image in Figure 16 to be constructed.

The wind-intensity and significant-wave-height products validated by the end of 1991 have continued to be delivered regularly as fast-delivery products.

The overall cumulated availability of the instrument is better than 98.5%. The main source of service interruption is an occasional computer hangup in the RA control unit/tracker, which requires a manual restart by the satellite controller. A 'software patch' is presently being prepared to overcome this problem.

The ATSR

The Along-Track Scanning Radiometer is also operated on a continuous basis around the orbit, with its two main components operating in parallel:
- the Infrared Radiometer
- the Microwave Radiometer.

Both radiometers are operating nominally, the Microwave Radiometer mainly providing the water-vapour correction applied to the Radar Altimeter height calculation.

The ATSR delivers surface-temperature maps at two resolutions: 1 km and 50 km. A failure in the 3.7 μm channel that occurred in May last year is not significantly affecting the instrument's performance, though it does reduce the accuracy of the corrections applied to the Sea Surface Temperature (SST) derivation during the eclipse part of the ERS-1 orbit.

The availability of the ATSR has nevertheless been excellent, at more than 98%.

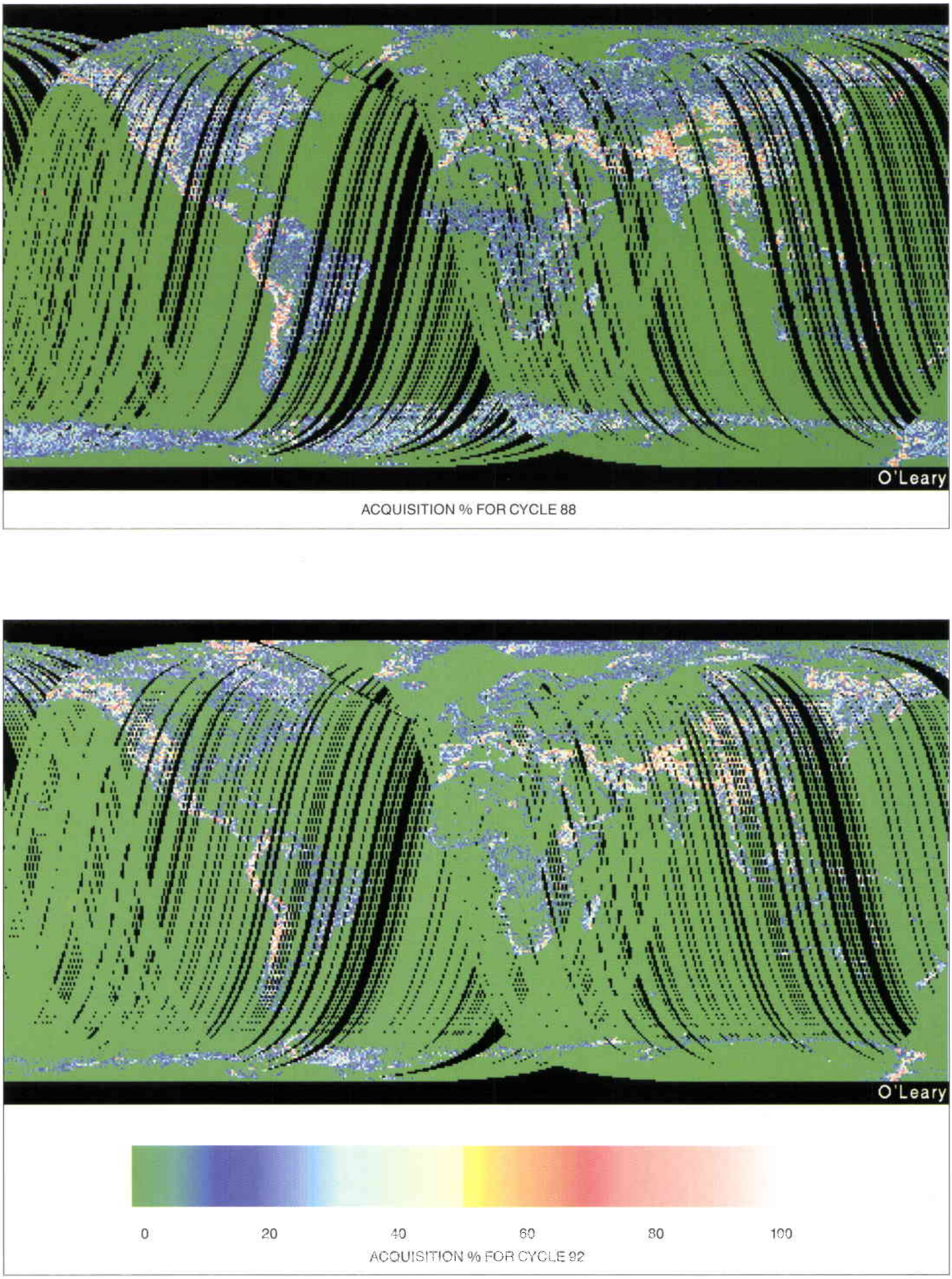


Figure 15. Comparison of Radar Altimeter tracking performances before and after fine tuning of the tracking-loop parameters

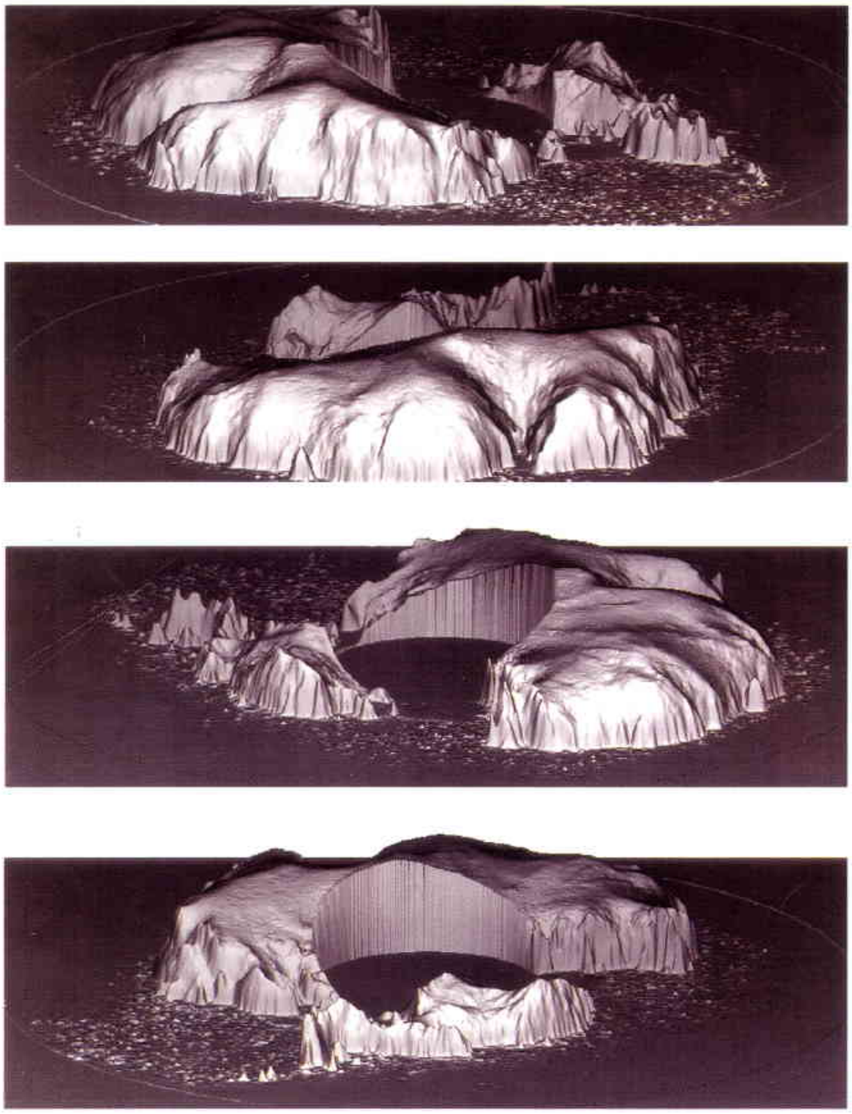


Figure 16. Map of Antarctica obtained with the Radar Altimeter's 35 day repeat cycle (Courtesy of UCL/MSSL, London)

Conclusion

The first twenty months of ERS-1's in-orbit operation have underlined both the very high availability and excellent stability of the satellite's instrumentation. Although ERS-1 was originally foreseen as an experimental/ pre-operational mission, in-orbit experience with this highly sophisticated satellite has demonstrated that the dual goals for the mission of both delivering reliably calibrated products to users and providing continuity of data sets implies operating procedures identical in large part to those required for a fully operational mission.

The ERS-1 satellite is exhibiting such excellent reliability and stability of performance at the present time that an extension to its originally planned two-year operational lifetime can be confidently predicted. Both the platform and the instrumentation that it carries have considerable built-in redundancy at both unit and subsystem level as a design ground rule. In practice, this redundancy has not yet needed to be invoked.

Based on the extremely encouraging in-orbit experience to date, the current mission baseline scenario therefore assumes that ERS-1 will continue to be operated to bridge the gap until the ERS-2 mission is launched, nominally in early 1995, and commissioned. A primary goal in this respect is to serve the user community as effectively as possible by providing continuity of data services whilst paving the way for the Envisat and Metop missions that are to follow.

Acknowledgement

The authors would like to take this opportunity to thank their colleagues at ESTEC (NL), ESOC (D) and ESRIN (I) who are supporting the ERS-1 mission operations and have provided much of the material presented in this article. We would also like to express our appreciation to the scientific institutes and meteorological organisations who, in close cooperation with the Agency, have been instrumental in the product-validation activities and are still supporting the necessary product quality monitoring as well as the further enhancement of ERS-1 derived products.

Extended Atlantic Weather Coverage Provided by Meteosat-3

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The third European geostationary weather satellite Meteosat-3 began operating at a position of 50°W on 1 August 1991. This choice of location both extended the European capability to monitor mid-latitude storm tracks, and assisted the US National Oceanic and Atmospheric Administration (NOAA) in surveying the Atlantic Basin and coastal areas. Another factor in the initial choice of the 50°W location was that the satellite and its missions were to be controlled from the Meteosat Operations Control Centre at ESOC in Darmstadt (D).

Based on the early success of the mission, a relay station has now been built at NOAA's Wallops Island facilities, which, in combination with a commercial satellite link with the Darmstadt Control Centre, now allows Meteosat-3 to be operated at an even more westerly position. The satellite was therefore relocated to 75°W on 27 January 1993 and routine operations from this new position began on 20 February.

Introduction

The European Space Agency has been operating the Meteosat family of satellites for the last fifteen years. Operations started in 1977 with the launch of Meteosat-1 as the basis of a pre-operational programme. This led to the birth of a fully fledged operational programme, called the 'Meteosat Operational Programme' or 'MOP', in November 1983.

The pre-operational programme was a great success and continued until 2 December 1991, when Meteosat-2 was re-orbited by increasing its altitude by approximately 500 km to free the geostationary position that it had been occupying. This satellite was launched on 19 June 1981 and had taken close to 300 000 images of the Earth. After more than ten years in orbit, it was still in perfect condition, but was running short of the hydrazine fuel used to control its orbit.

The third satellite of the original design is still in use, namely Meteosat-3. This satellite (an old prototype) was launched on the first Ariane-4 launcher in June 1988 and was originally intended to bridge the gap between the end of the pre-operational programme and the launch of the first satellite in the operational series.

Soon after its launch, Meteosat-3 assumed a key role in the operational programme. Originally used as the prime European operational meteorological satellite positioned at 0° longitude, it was later repositioned to 50°W following the successful launch and commissioning of the first of the operational series of satellites, Meteosat-4, during the summer of 1991. From its new geostationary position, Meteosat-3 provided additional coverage of the Atlantic Ocean, and was subsequently referred to as the Atlantic Data Coverage (ADC) mission.

The new coverage scheme served two major applications. Firstly, it extended westward the European capability for monitoring the mid-latitude storm tracks. Secondly, it enhanced the ability of the US National Oceanic and Atmospheric Administration (NOAA) to survey the Atlantic Basin and coastal areas, which proved particularly useful during the hurricane season, not least for the observation of Hurricane Andrew (see Fig. 1, and ESA Bulletin No. 73, pp. 15–20).

To provide more effective coverage of the weather over the western hemisphere for the benefit of NOAA, ESA, Eumetsat and the global meteorological community, it was decided to move Meteosat-3 even further westward. The ground-segment extensions that have now been carried out allow Meteosat to be operated at any position between 50°W and 115°W. This new mission is referred to as the 'Extended Atlantic Data Coverage' or 'XADC' mission.

The XADC concept

The original ADC/XADC position was selected to be 50°W because at that location the satellite was still within the field of view of the Meteosat ground station at Rehbach, about 40 km southeast of Darmstadt, in

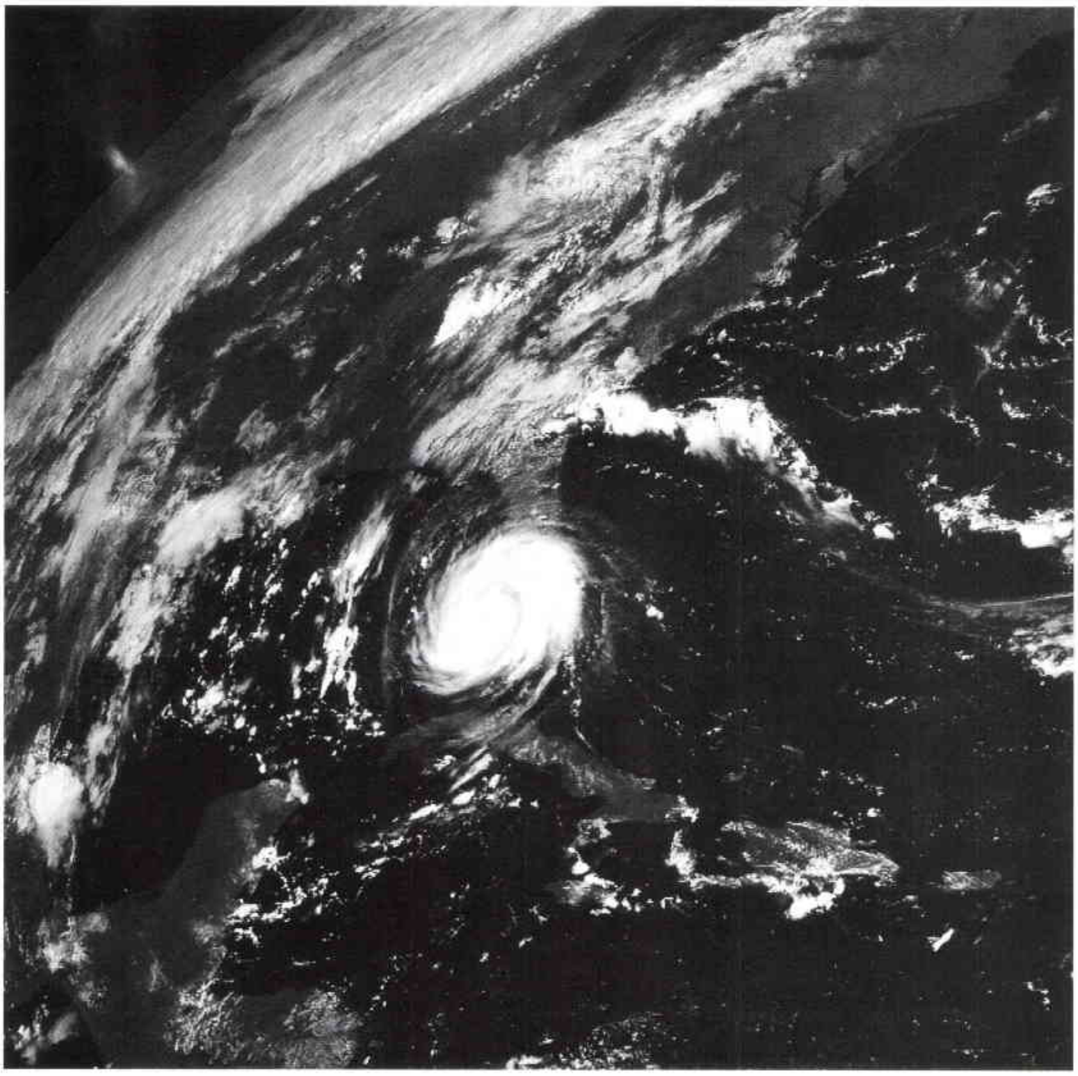

Figure 1. Hurricane Andrew as observed by the ADC Meteosat satellite on 22 August 1992

Germany. With the decision to improve the mission return still further by placing the satellite in a more westerly position, the immediate problem was that an additional ground station would be required.

It was logical to locate the new ground-segment element at the NOAA Wallops Island facility, but unfortunately the existing Wallops baseband equipment was not Meteosat-compatible. A new concept had therefore to be developed and with just 14 months available for the new mission's implementation, this could only be achieved by reusing the Meteosat Rehbach station design to the maximum extent possible.

A feature of the Rehbach station is that it is completely remotely controlled from the Meteosat Operations Control Centre (MOCC) at ESOC. The station computer, which provides more than four thousand engineering parameters to the ground-segment controller at ESOC, is the key element in the remote-control concept. The system allows for remote switching to redundant equipment should a failure appear in one of the prime units, and permits reconfiguration of all ground-station chains from the MOCC. Antenna pointing is normally effected by closed-loop control from the station (auto-tracking), monitored from the MOCC. It can also be effected by downloading the pointing parameters from ESOC (programmed tracking).

Use of this same concept for the new Wallops-located ground segment called for a highly reliable communications link between Darmstadt and Wallops Island. For this, NOAA selected a commercial satellite link providing 4 x 64 kbit/s for transmission of the received raw imagery data from Wallops to the MOCC and for dissemination of the processed image data in the other direction. In addition, a single 64 kbit/s link is used for telemetry, telecommand, ranging, station monitoring and control, auxiliary data and voice data. The latter satellite link is backed-up by a 64 kbit/s channel provided through a Trans-Atlantic Trunk (TAT-9), enabling reconfiguration of the satellite into a safe mode should the high-capacity trans-Atlantic satellite link fail.

In the extreme case of both trans-Atlantic links failing simultaneously, the spacecraft control operations can still be conducted under voice control using a standard telephone line. A subsystem known as the 'Backup MOCC' has been installed at both the NOAA and NASA Wallops sites for this purpose. This backup system allows the acquisition and readout of the satellite's telemetry data and the uplinking of telecommands.

A remote diagnostic unit, also installed at the Wallops site, permits remote software maintenance and the installation of software upgrades from Europe.

The overall result is a highly cost-effective operational concept.

Contractual arrangements

The XADC endeavour work is covered by a tri-partite Agreement negotiated in October 1991 between NOAA, ESA and Eumetsat. Under this Agreement, ESA assumed responsibility for the development and implementation of the Wallops station baseband equipment, the extended control facilities required in the MOCC at ESOC, and the provision of ranging equipment to be installed at the Agency's Kourou facility in French Guiana.

In addition, backup satellite-control facilities had to be installed both at the NASA Wallops station and the NOAA site. These backup facilities allow the satellite to be put into a safe operating mode if a failure should occur in either the prime system (MOCC or trans-Atlantic communication system), or the Wallops relay-station infrastructure. Furthermore, ESA assumed responsibility for the development of the necessary operational procedures and training of the NOAA personnel at the Wallops facilities.

The contract called for the provisional handover of the complete integrated system from ESA to NOAA on 21 December 1992. ESOC assigned prime contract responsibility to Dornier/Deutsche Aerospace (D). However, ESOC supplied certain items directly, such as the communications equipment, the MOCC back-up systems and the Land-Based Transponder (LBT).

NOAA assumed responsibility for the radio-frequency front-end systems, the provision of the trans-Atlantic satellite and the inter-site (NOAA-NASA) communication links, as well as for the TAT-9 backup link.

The tri-partite contract defines several operational phases, the first lasting for ten months with the satellite initially positioned at 50°W and later at 75°W. Further options allow for a continuation of these operations, with the satellite at any position between 50° and 115°W, for periods of one year. The last of these periods ends on 30 November 1995, which is the end of the European Meteosat Operational Programme and at the same time marks the end of ESA's involvement in the operation of the European geostationary meteorological satellites.

Preparatory phases

Validation phase

All equipment, except for the LBT subsystem, was first delivered to ESA's Rehbach station. The advantage of this approach was that system tests could be performed before shipment to the USA. The baseband equipment for the Wallops relay station was directly interfaced with the Rehbach station's antenna systems and with the MOCC via specially procured terrestrial data links. The LBT and the ranging baseband equipment (delivered by ATNE) were located at the SNEC premises in Normandy (F) and interfaced with the rest of the system via the standard operational links. Finally, the satellite was included in the test loop so that the complete system could be pre-validated.

Following successful completion of these system tests in October 1992, the equipment was delivered to both the Wallops site for integration with the existing front-end (RF) systems and to ESA's Kourou facility. Full validation testing was then performed which included the trans-Atlantic data link.

Transition phase

The XADC hardware and software were declared ready for handover to NOAA on 17 December 1992, about a week earlier than specified. The ensuing 'transition phase' lasted until 3 January 1993, its prime objective being to 'soak' the equipment and to familiarise the operations teams both at ESOC and at Wallops with the XADC environment.

Throughout this period the Wallops-MOCC and Rehbach-MOCC downlink chains were operated in parallel, enabling direct comparison of the accuracies achieved in the image processing chain. The uplink systems were also exercised, first by transmitting the dissemination formats and commands to Wallops and later, after confidence had been built up, by uplinking through the Wallops facility directly to the satellite, so completing

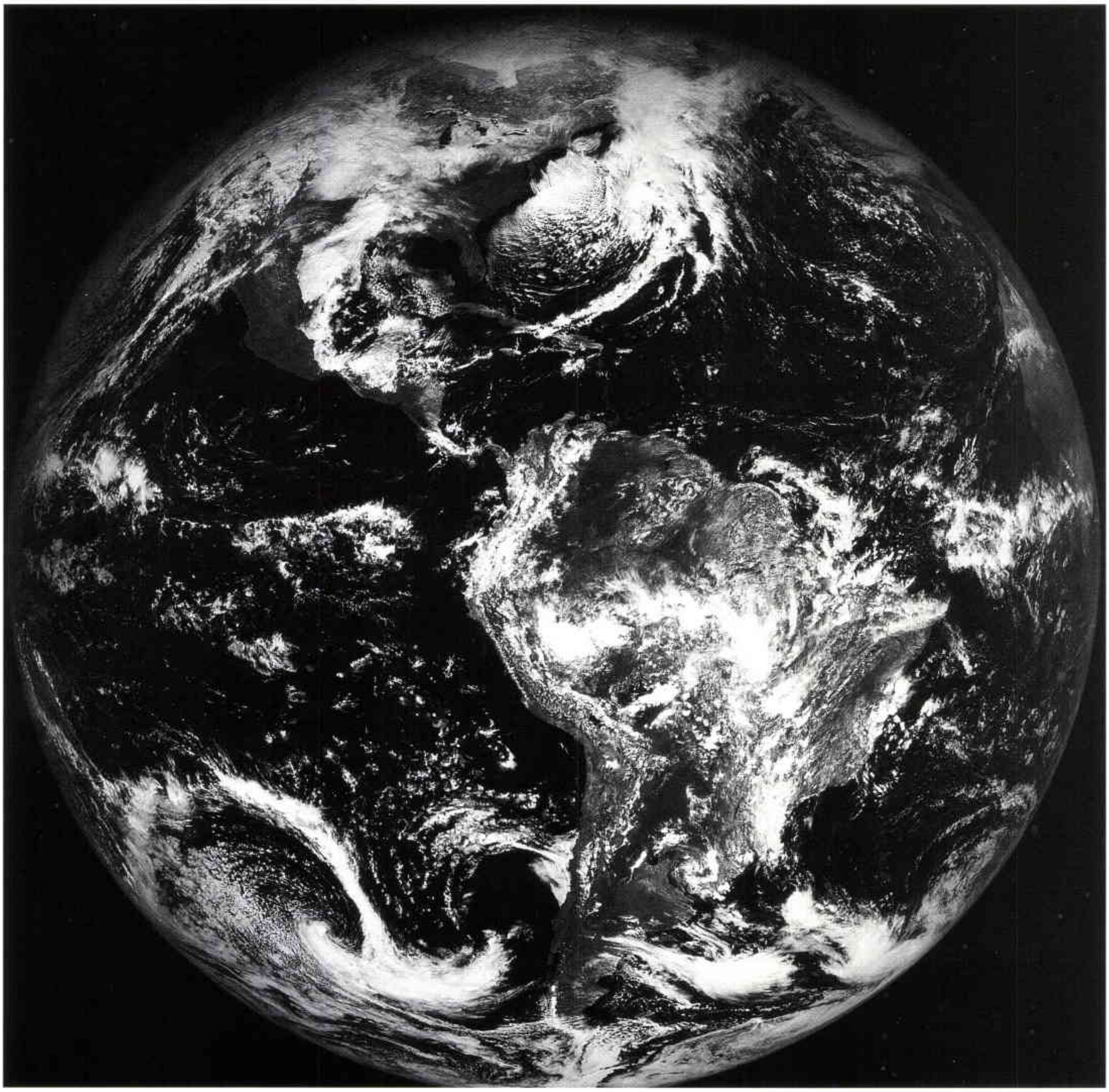

Figure 2. View of the Earth from the new XADC Meteosat position of 75°W

the loop by transmitting disseminated data to the users.

Running-in phase
The so-called 'running-in phase', which began on 4 January, was characterised by an 'overlap' in the working periods of the day staff at the MOCC in Europe and the Wallops site. Towards the end of this phase, the full mission was being controlled from the Darmstadt-based MOCC through the Wallops facilities on a continuous basis, allowing the associated operational procedures to be validated also. The existence of the parallel downlink proved extremely useful during this phase as it enabled full performance verification of the new elements against the proven Rehbach station-MOCC chain. The system was declared fully operational on 27 January 1993.

Drift phase
The drift manoeuvre taking the satellite to its new XADC position at 75°W was initiated that same day (27 January). The drift rate selected was about 1°/day, and so after approximately one week the satellite left the Rehbach station's field of view. From then onwards, all operations were conducted solely through the Wallops relay station, with a fully trained operations team at both sites.

Image data was received at the MOCC throughout this phase and was geometrically corrected against intermediate longitudinal positions until the satellite arrived at 75°W, on 20 February 1993. Subsequently, all imagery data were rectified for the new XADC location and fully quality-controlled (Fig. 2).

Figure 3 shows the 'combined view' from Meteosat-4 (at 0°) and Meteosat-3 (at 75°W) on 18 February 1993 at the beginning of the XADC programme.

the raw image data via the high-rate data link ('Commet', 4 x 64 kbit/s) to the front-end processor of the MOCC. An additional route is provided for the auxiliary data via a raw-image extraction unit at Wallops connected with the MOCC via the ISS link. Consequently, full visibility of the satellite's on-board health is available even if the high-rate data link is non-operational.

Raw image data
Second priority is assigned to the transmission of the raw image data to the MOCC via

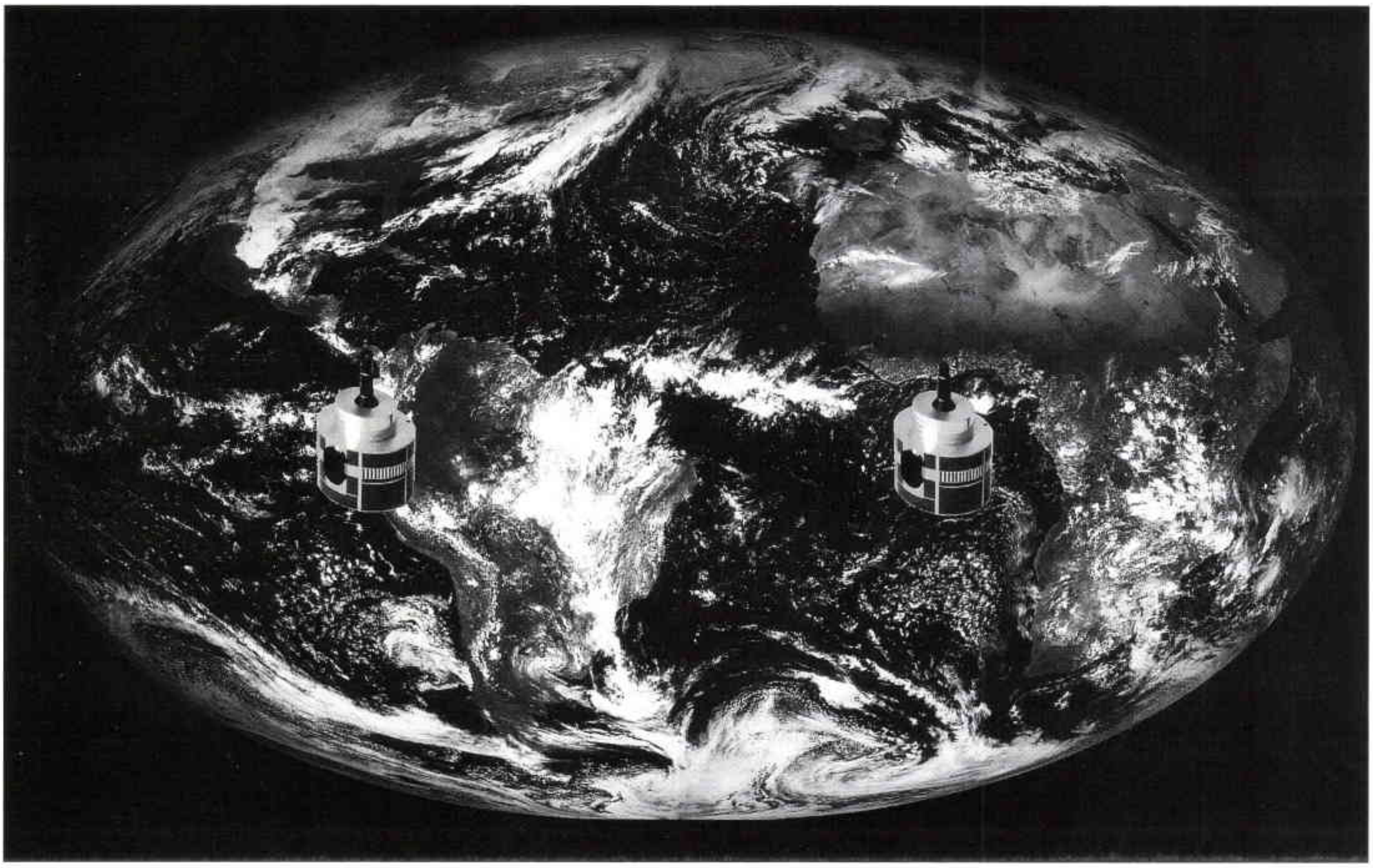

Figure 3. The Earth as seen on 18 February 1993 from Meteosat-3 as it approached its new position of 75°W and Meteosat-4 positioned at 0° (so-called 'combined view')

the high-rate data link. All image lines of the Earth scan must be received to perform the image processing successfully, which means that any re-configuration of the ground segment and/or the satellite is normally performed during the radiometer retrace and standby period (i.e. during the movement of the radiometer's optical axis from the position reached at the end of the forward scan to its most southerly starting position).

Operational concept

Figure 4 shows the main elements of the operational XADC system and the remote-control concept used for existing Meteosat operations, with all operational tasks being performed, and their execution controlled, from the Meteosat facilities in Darmstadt.

Spacecraft control data
The system assigns highest priority to the spacecraft control data, consisting of the spacecraft telemetry data and auxiliary payload control data. Both of these data streams are processed in real time. The telemetry data is normally routed through the Wallops housekeeping chain (HK) and the trans-Atlantic low-rate channel (ISS, 1 x 64 kbit/s) via Panamsat to the MOCC. The auxiliary data is normally routed with

Disseminated data/Mission products
Third priority is assigned to the dissemination of the processed image data to the USA, which starts about 6 min after the end of the forward scan. All of the data to be disseminated, and its specific formats, are defined in the XADC dissemination schedule.

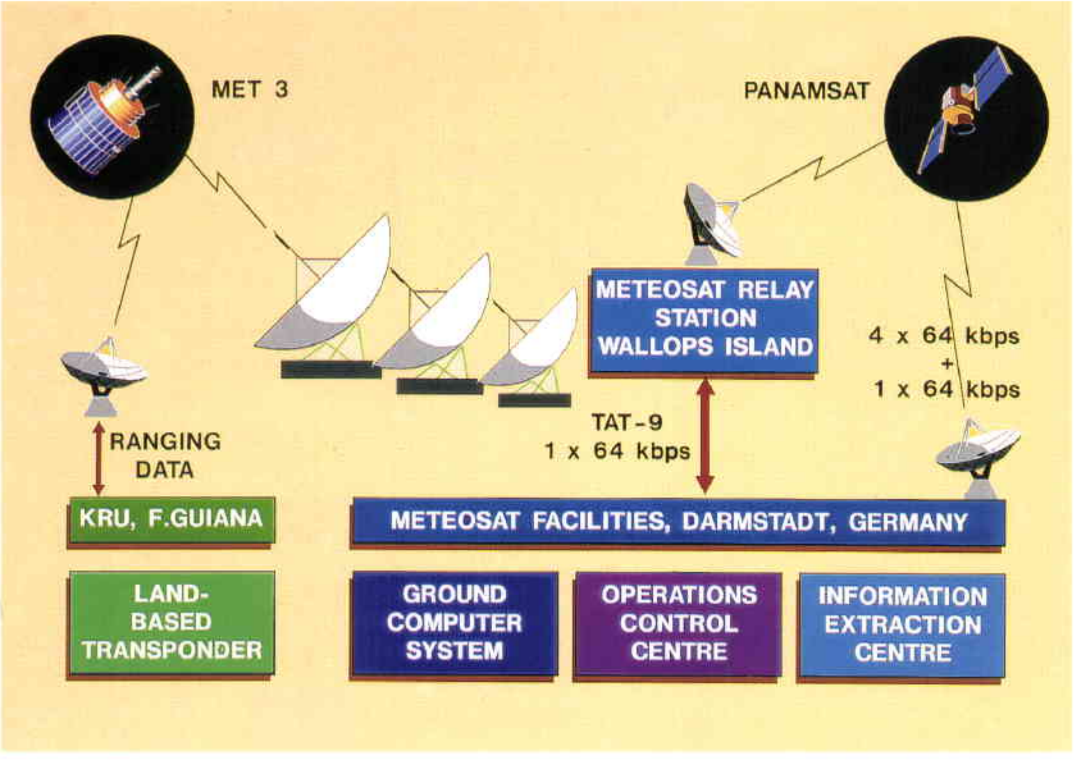

Figure 4. Configuration of the operational XADC system

Data processing

The raw image received is not of perfect quality. For example, for instrumental and orbital reasons, a given image element, referred to as a 'pixel', may not be positioned at its geometrically correct place, and may not be exactly representative of the radiance value in the scene. These imperfections must be corrected before the data can be used for quantitative scientific applications.

Based on the need to distribute the geometrically corrected image data in quasi-real-time, the necessary corrections must be *predicted* based on the corrections applied to the last few images.

Raw-image acceptance

The image data processing onboard the satellite is limited to an absolute minimum, which means that the data being received on the ground can be considered as representative 'raw' image data output from the onboard radiometer chain (Fig. 5). This data stream is relayed via the trans-Atlantic Commet link to the MOCC, where the image data enters a front-end processor working in real time, just as if the data were being received from the Rehbach station (one image line processed every 0.6 s).

Each line of data contains interleaved visible, infrared and water-vapour data. After thorough quality control (via checking of synchronisation words, identification bits, etc.), the data is decomposed into separate data streams containing the infrared, visible and water-vapour data, respectively. These data are then forwarded to the mainframe computer for further processing on a channel-by-channel basis.

Main-frame processing

Unfortunately, the received signal is not absolutely perfect. 'Static' distortions which are small and can be considered linear are caused by imperfections in the optical system, the detector response, electrical bandwidth limitations, and by the analogue-to-digital conversion. Periodic noise, introduced by electrical cross-talk, and white noise inherent in the system also affects the quality of the data. All of these effects can, however, be computer-modelled and their impact analysed and compensated for.

Compensation methods

When a satellite is carefully designed, its optical system has a performance superior to that of the subsequent components in the data chain. We must, however, compensate for the fact that the detectors are not located on the telescope's optical axis (misregistration). Secondly, as the telescope is of the Ritchey-Crétien type, with a small 45° on-axis folding mirror in a Coudé-Cassegrain arrangement, a small rotation of the image occurs in the focal plane of the instrument which has to be counteracted. Fortunately, this rotation is limited to the scan angle of the telescope, and is therefore restricted to ±9°. Therefore, the process can be linearised.

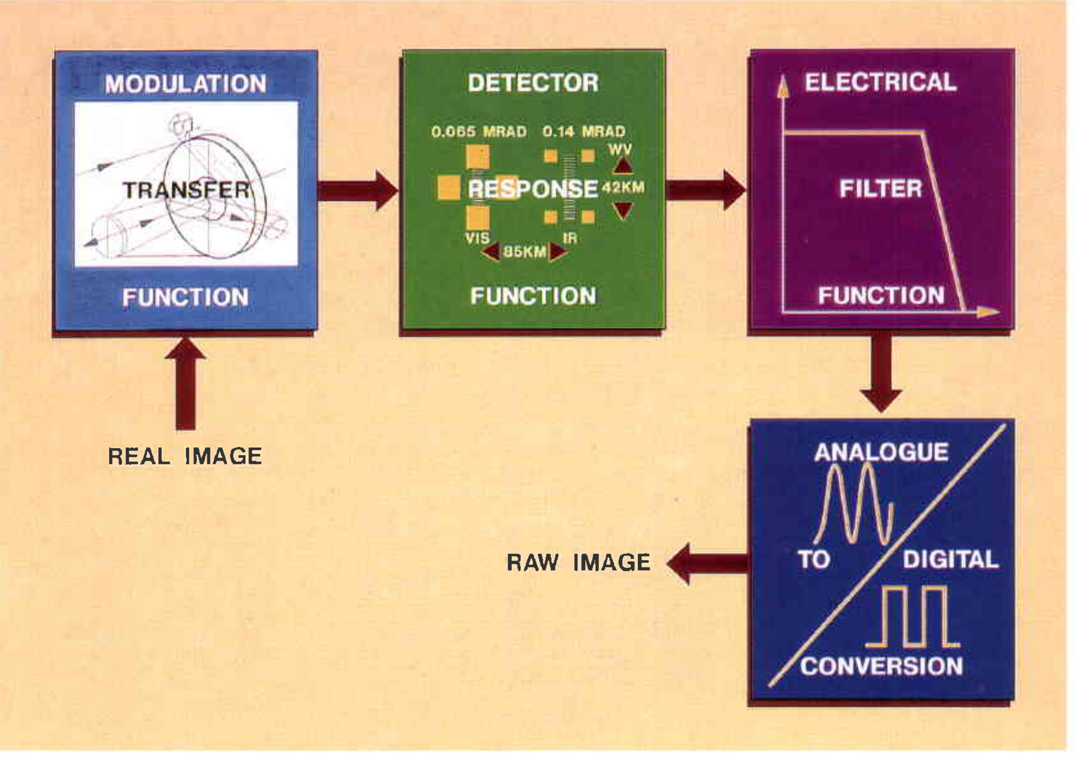

Figure 5. The on-board image chain of the Meteosat radiometer

These 'mechanical' corrections, computed for a number of grid points (26 x 26 pixels), are made during the rectification process. Corrections for the detector response function, on the other hand, can be applied during the general calibration process.

The grid points for which the mis-registration parameters are computed coincide with those defined for the rectification process. The final compensation can therefore be done in one single step by adding the registration factors to the computed deformation matrix elements, before the image corrections are made.

Rectification

Rectification is the process by which an image is located in terms of Earth coordinates. The problem stems from the fact that no geostationary satellite stays in an absolutely fixed position with respect to the Earth's surface beneath. In practice, the satellite's orbital position, attitude, spin rate and scan-line start deviate, time dependently, from their ideal values. As a result, the actual images taken are deformed with respect to a reference image taken under ideal conditions.

The use of a mathematical model describing the orbital variations of the satellite and statistical analysis of the deformations computed for the last series of images taken enable, together with measurements made on the first couple of lines of the incoming image, a set of deformation factors to be calculated in near-real-time from which the 'true' geographical locations of the image pixels can be determined. The deformation matrix also takes into account corrections required to compensate for sensor mis-registration and for image rotation caused by the radiometer mirror's south-to-north scanning, as mentioned above.

All of the above-mentioned processing tasks are performed at the MOCC in Darmstadt immediately after reception of the raw image data and prior to the dissemination process.

Outlook

The accuracy of the rectification process is currently limited because of computer capacity limitations. However, a newly developed transputer-augmented workstation has proved to be able to handle the rectification tasks, using sophisticated re-sampling techniques, in real-time. It is the intention to implement this technique as soon as possible for the XADC mission. The advantages will be substantial not only in terms of better image quality, but the derived products will also be of improved quality.

The XADC mission has already led to close collaboration between the Meteosat Exploitation Project (MEP) experts at ESOC and the NOAA specialists at the Wallops Station. In addition, close collaboration has also been developed between the MEP scientists and their counterparts in the Space Science & Engineering Center (SSEC) of the Cooperative Institute for Meteorological

Satellite Studies (CIMSS), at the University of Wisconsin (USA). It is hoped that this collaboration will be further extended in the future.

A point worthy of note is the fact that these days ground software and computer hardware are better standardised, so that software developed in Europe can be directly used in the USA, and vice versa. This was already evident with Upper Tropospheric Humidity extraction software developed at ESOC, which could be installed at CIMSS in Wisconsin without any problem.

Satellites, on the other hand, are still a result of custom-tailored design efforts, requiring specific ground-segment systems and operating procedures. This is why the additional investments in the Wallops relay station were necessary and why more than a year elapsed before the system could be made operational. If an agreement could be reached on a world-wide meteorological satellite standard, backup operations could be provided in the future on a world-wide basis much more quickly and at much lower cost.

It is to be hoped, therefore, that we have all learned a valuable lesson from the XADC mission.

Acknowledgement
A task of the magnitude of the XADC mission's implementation and operation requires the cooperation of many hands and minds. I would like to thank my ESOC colleagues for their tireless devotion to this project. Their ingenious ideas and the many hours spend in bringing them to fruition made this project a success. Thanks are also due to the many colleagues from European industry involved in the programme. Last, but not least, I would like to extend my thanks to the NOAA staff who did so well in obviating procedural barriers and in providing such an excellent infrastructure at their Wallops station.

Concept of a Moon rover with manipulation arm, currently being studied in France (CNES)

Technologies for Automatic Lunar Exploration Missions

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Why back to the Moon?

The Moon, as our closest planetary neighbour, is the best known object in the solar system, with the obvious exception of the Earth. Many of us remember the spectacular successes of the lunar space programmes of the USA (the Apollo programme) and of the former USSR (the Lunokhod lunar rover) in the 1970s. Although successful in themselves, these programmes left unanswered major questions concerning the origin and characteristics of the Moon, as recently confirmed by the findings of an ESA-convened study group of European experts, known as the Lunar Study Steering Group (LSSG)**.

ESA's Lunar Study Steering Group (LSSG) recently stressed the unique scientific and strategic assets of the Moon. Utilisation of the Moon offers a wide range of possibilities, including a better understanding of the history of the solar system, improved potential return for astronomy, as well as a useful environment for life-sciences activities and research into artificial ecosystems. ESTEC is already examining the technology needs and the exploitation of currently available technology for the possible next steps in a lunar exploration scenario. A range of missions involving lunar polar-orbiter and lander-spacecraft concepts are examined.

Beyond the purely scientific interest, the possible future exploitation of the Moon's resources has also stimulated interest in a return to the Moon. In the longer term, it might be possible and attractive, from both an economic and an environmental point of view, to expand human endeavours into outer space. Some potential applications for the very long-term future include:
- using oxygen extracted from the lunar regolith for the propulsion of crewed spaceships to Mars
- producing the structural elements needed for the deployment of very large space-based power systems from lunar material
- extracting and transporting to Earth sufficient quantities of helium-3 for the generation of electricity in large quantities by advanced fusion reactors
- archiving underground and near the lunar poles, records of the evolution of life on Earth and of the development of human existence and culture (which might otherwise be destroyed by unfavourable environmental circumstances, or deliberate human actions or wars).

Which, if any, of these scenarios may finally be realised is still a matter of conjecture. Should we invest in a crewed 'return to the Moon' now if major benefits are to be expected only in the longer term? Small, uncrewed precursor missions, which could be conducted in the late 1990s, would help us to pinpoint the most attractive and realistic options for the not-too-distant future. The scientific knowledge acquired through these missions would make it possible to identify reasonable objectives for participation in future crewed lunar exploration programmes leading, step-by-step, to eventual full-scale exploitation of the Moon's resources in the next century.

Options for uncrewed missions

Three categories of possible scientific activity, identified by the Lunar Study Steering Group, drive the technology needs for uncrewed lunar missions:

1. Science of the Moon: which includes:
   - complete physical, chemical, and high-resolution topological mapping of the lunar surface by remote sensing, with emphasis on global coverage including coverage of the polar regions
   - in-situ determination of the internal structure of the Moon, and the chemical and mineralogical composition of selected sites
   - return of lunar samples from the highlands and the far side of the Moon for further investigation on Earth; and
   - perhaps later, an outpost base for field geologists and for the refurbishment of surface stations and rovers.

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** ESA Special Publication SP-1150, Mission to the Moon, provides more details (available from ESA Publications Division).

2. **Science on the Moon:** which deals with questions relating to human activities in space, especially the development of artificial ecosystems with a view to preparing for a crewed base. This would include studies of human physiology under conditions of reduced gravity, and radiation protection.

3. **Science from the Moon:** which includes specific areas in astronomy that can possibly be better studied from the Moon rather than from satellites or the Earth, such as ultraviolet to submillimetre interferometric imaging, very-low-frequency (VLF) radio astronomy, and solar physics. For VLF radio astronomy, for example, the deployment of large arrays on the far side of the Moon is seen as the only means of avoiding the interference effects caused by electromagnetic pollution on Earth.

   Moreover, the lunar surface and subsurface layers provide a unique record of the history of such radiations as the solar wind, solar-flare particles, and galactic cosmic rays, covering the last two to four billion years. Clearly, investigations such as these, while ultimately addressing non-lunar phenomena, rely on many of the elements that would be developed in the context of 'Science of the Moon', such as sample collection, sample analysis, and sample return.

Based on the recommendations made by the ESA Lunar Study Steering Group, the technological challenges of a set of uncrewed lunar mission concepts involving an orbiter, a lander, a rover, a network of small surface stations, and a sample-return spacecraft are currently being assessed. The set of missions includes:
- A **Lunar Polar Orbiter** weighing 1300 or 2100 kg for seleno-graphical mapping, seleno-chemical surveying, and making seleno-physical measurements. It could also be used as part of a lunar communications network.
- A **Lunar Lander** of either 1100 or 2400 kg landed net mass, the former being equipped with chemical- and physical-analysis equipment, manipulators of various dexterities, or with a deep-drilling device for probing the regolith base, the latter having both biological- and material-processing facilities. Deployment of three identical surface stations, each weighing about 250 kg and especially intended for building up a seismographic network, might be an alternative.
- A **Roving Lunar Explorer**, as a special payload of a lander spacecraft, primarily equipped with manipulators and basic soil-analysis instruments in order to extend the area explored by the lander.
- A **Lunar Sample-Return Mission** providing for the return of some 50 kg of soil samples or drill cores from pre-selected areas of the Moon, or 1–2 kg of biological samples in a freezer.

Table 1 provides an overview of the major scientific goals and how they might be distributed among the different types of mission elements. For the Orbiter, the areas that need or would at least benefit from having a relay satellite in a lunar orbit, are indicated by 'communication'.

Instrument technologies for the Lunar Polar Orbiter mission

Ideally, a polar orbiter should have a visible/infrared/imaging spectrometer (VIMS) type of payload. VIMS provides high-resolution, bi-dimensional images and spectrograms of the surface composition. However, for earlier topological mapping by a small orbiter satellite, a high-resolution, multi-spectral stereo camera can be envisaged, with a solid-state 1 Gbit memory, real data compression, and a maximum resolution of about 5 m from a 100 km orbit. To map selected sites in greater detail, it should be possible to go into an elliptical orbit with a periselenum (lowest altitude above the Moon's surface) of some 50 km, thereby improving the resolution to some 2 m.

The chemical composition of the surface material, including its water content, could be determined by two instruments: a gamma-ray spectrometer/neutron detector, together with the multi-spectral stereo camera described above, could be employed. It would be able to determine the elemental composition of the surface (H, O, Mg, Al, Si, S, Cl, K, Ca, Fe, Th, U) with a spatial resolution of the same order as the orbital height (around 100 km). In addition, it could detect water by registering neutrons with a plastic scintillator.

A gradiometer, an altimeter, and a magneto-meter could be used for better determination of the core properties and distribution of mascons and palaeo-magnetism, for example. The candidate gradiometer for this instrument package is based on the Gradio instrument being developed for the Aristoteles mission, by Alenia (I). It consists of four accelerometers (Fig. 1) accommodated on a 1 m-square platform. The accelero-meters are of the capacitive pick-off type,

Table 1. Overview of scientific issues and possible methods of addressing them through future uncrewed Moon precursor mission elements

Scientific issue	Orbiting Spacecraft	Lander Spacecraft	Rover Vehicle	Sample-Return Capsule
• *Selenophysics*				
— crust/core dimensions	communication	seismometer		
— crust properties		heat-flow conductometer	sample collection	drill core return
— magnetism	magnetometer	magnetometer		
— paleomagnetism		drill core analysis	sampe collection	drill core return
— gradiometry	gradiometer, altimeter			
• *Selenochemistry*				
— crust composition	multispectral camera	drill core analysis α- and X-ray spectrometer gamma-ray spectrometer	sample collection	drill core return
— water contents	neutron detector	neutron detector		drill core return
— interaction with solar wind, rays		drill core analysis		drill core return
• *Selenography*				
— topology	high-resolution stereo camera	stereo camera	stereo camera	
• *Solar physics*				
— current activity		monitor		
— historic evolution				drill core return
— pointing reference		sun telescope		
— ageing of optics		sun telescope		
• *Radio astronomy*				
— VLF/VLBI	communication	VLF telescope	antenna deployment	
• *Interferometry*				
— VIS 1 – 4 m telescope	communication	telescope		
— interferometer	communication	interferometer		
• *Life science*				
— radiation protection		dosimeter		dosimeter
— solar flare alert		dosimeter		
— closed life support system		biopackage		biopackage return
• *Exploitation*				
— environmental monitoring	spectrometer			
— prospecting	multispectral camera		sample collection	drill core return
— exploitation technology		drill analysis processing		
— infrastructure	communication			material return
• *Archive*		delivery	deployment	

with a proof mass suspended between three pairs of electrodes. A displacement of the proof mass by external acceleration is measured as a capacity variance between the electrodes. Recent test results have confirmed that the accelerometers could measure a signal in the pico-g (10^{-12}g) range. Due to the lack of airdrag in an orbit around the Moon, a calibration device may not be necessary.

A laser altimeter that can achieve a vertical resolution of 2 m and has recently been developed within ESA's Technology Programme, would also seem to be applicable for the Lunar Polar Orbiter mission.

Magnetometers from previous deep-space missions could be reused. Alternatively, the magnetometer package could be derived from the Aristoteles experiment. It consists of two separate sensors in order to avoid a blind zone caused by the directional sensitivity of the optical sensor.

Instrument technologies for the Lunar Lander mission

To analyse the composition of selected sites and to provide the ground truth for the remotely-sensed seleno-chemical data, a set of instruments for soil analysis and selenophysical measurements could be carried on the first Lunar Lander mission. The

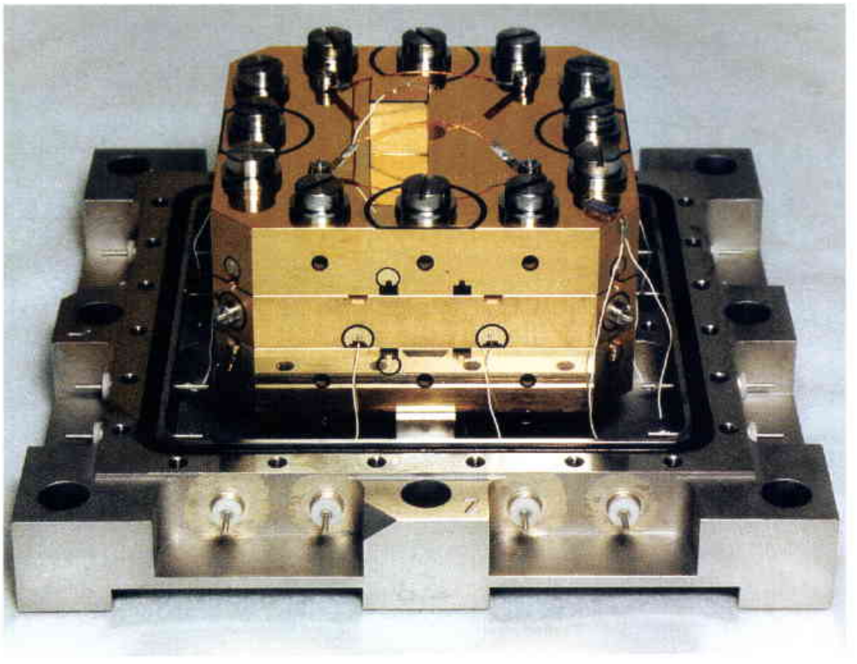


Figure 1. Mechanical assembly of an accelerometer developed for another gradiometer mission (Aristoteles mission)

instruments could include:

- a three-axis seismometer with an inertial mass and a leaf spring sized for lunar gravity
- a TV camera that provides high-resolution multispectral (four-band) images; if necessary, a simple black-and-white CCD camera (video camera) with a 40° field-of-view could also be carried for exact manoeuvring at the landing site
- a magnetometer that measures the local static and fluctuating magnetic fields, and the paleo-magnetic signature in the rocks around the landing site
- a heat-flow probe that determines the variations with time of surface temperatures and the thermal properties of the soil, consisting of two thermal sensors in contact with the soil
- a conductometer that provides information about the soil's electrical properties.

For the determination of all major and most minor constituents, including the lighter elements carbon, nitrogen and oxygen, the combination of an α-backscatter and an XRF-spectrometer is advantageous, as both rocks and soil can then be analysed by moving the detector head to the sample. The sensors must be able to view a sample with a diameter of some 5 cm at a distance of 4 cm. This can be achieved by moving the sensor head towards the sample using a simple mechanical arm. An additional Mössbauer spectrometer might be useful for characterising the mineralogy and maturity of lunar soil. Current ESA studies that are addressing missions to Mars and asteroids (the Marsnet and Rosetta missions) have also defined surface instruments that could be considered to be strong candidates for a Lunar Lander mission.

Further Lander-related missions

In the life-science area, several Lander missions are required. The ultimate goal may be to develop a system using lunar soil to cultivate bacteria, weeds or other simple organisms for at least two weeks (the duration of a Moon day), in order to observe the impact on the growth process of living organisms.

The principal experiment with living organisms can be conducted in two ways: either as a batch culture, or continuously run. In the former, dehydrated or frozen micro-organisms are added to a given amount of water and nutrient substances, and they live until the subsistence resources are consumed. The products and the organisms are then analysed. The advantage of a batch culture is the ease of controlling the experiment, and the amount of water and nutrients can be tailored so that the culture lives exactly for the two weeks of daylight, thereby eliminating the need for space-consuming tanks for the storage of consumables and products.

Later in the programme, when the infrastructure allows continuous operations, it would be necessary to switch to continuously sustained cultures, where water and subsistence resources are added and byproducts and organisms are extracted from the reactor in an open loop. This would not only require large tanks for the substances being supplied and extracted, but also a much more complex control system which, in fact, would be one of the development goals of these missions.

Since none of the above-described experiments has yet been done in space, nor are any of the required elements being developed at the moment, no mass, power or other figures can be given with certainty for this equipment. It can, however, already be said that the mass of the system would be quite high even for batch cultures, and in some cases, when performing continuous experiments, not the mass but the volume of the tanks might become a problem.

Instrument technologies for the Roving Lunar Explorer mission

The instruments carried by a roving vehicle would be very much like those described for landers and for small surface stations. The prime goals of early rover missions would be the determination of soil composition and the wider exploration of surface features.

The experiments carried might include TV cameras, a manipulator system with tools (see introductory figure), a magnetometer for paleomagnetism studies and spectrometers for sample analysis. Small autonomous packages containing, for example, seismometers and other instruments, rather like the Apollo Lunar Surface Experiment Package (ALSEP), could be deployed by a rover. Later on, large rovers could carry drilling devices (Fig. 2).

Given the short signal round-trip time between the Earth and the Moon, almost real-time control over the vehicle and the manipulator operations on the near side is feasible. This has been demonstrated with both the Lunokhod vehicles and the Surveyor landers. It considerably reduces the degree of on-board autonomy required.

One major constraint that has to be considered, however, is that, no radio-isotope thermal generators are available in Europe. The rover's power would have to be generated by solar arrays. In order to minimise their size, a restriction could be imposed on the rover and payload operating simultaneously, i.e. the payload could only operate with the vehicle at rest. This should be acceptable for most instruments, but exceptions might be the magnetometer or the cameras.

Instrument technologies for the Lunar Sample-Return mission

The payload for this mission could consist of a small return capsule and a small drilling device, a surface sampler, and a robotic manipulator arm to insert the unbiased samples into the capsule. Such a configuration has been studied recently for ESA's Rosetta mission (Fig. 3) Other small instrument packages, comparable to those of the ALSEP Programme, might be attached to the lower part of the lander which remains on the lunar surface.

Transportation to the Moon

Orbiter missions to the Moon pose less severe problems, generally speaking, than other interplanetary missions. Communication delay times are shorter, the solar boundary conditions (power and thermal control) are Earth-orbit-like, and launch windows are much more frequent. Landing on the Moon is easier than on planets with an atmosphere because there are no uncertainties about the weather and wind conditions at the landing site. Also the degree of autonomy required for near-side missions at least is far less, since the signal round-trip time of two seconds allows intervention by ground controllers both for normal payload operation and in the event of unforeseen anomalies. The same would also be true for the far side of the Moon, if a suitable data-relay system was available.

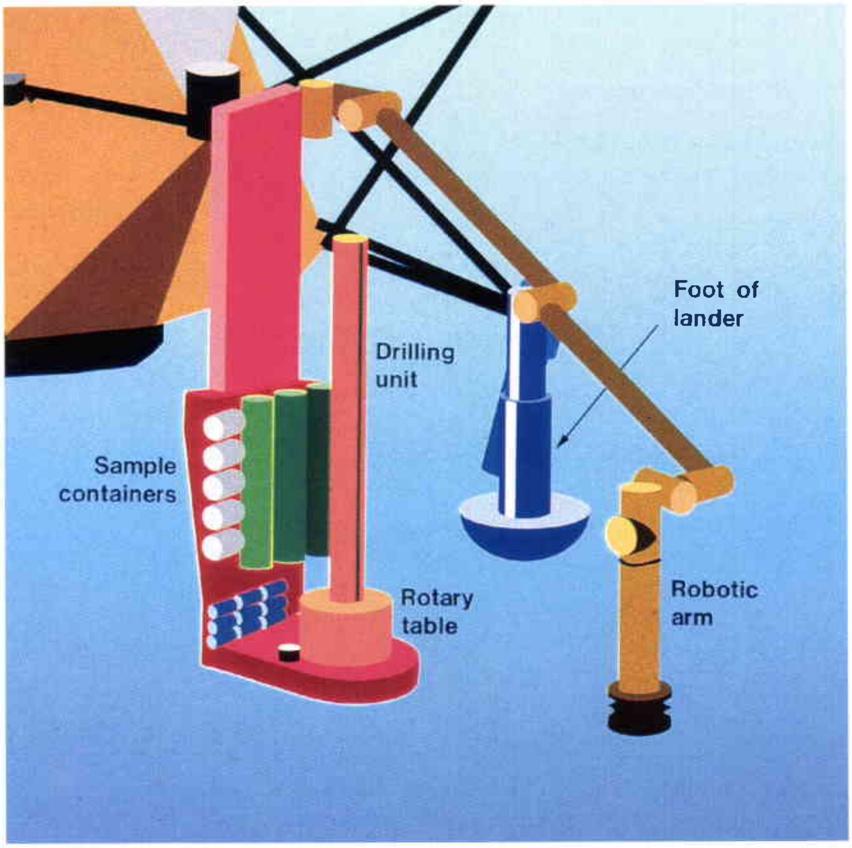


Figure 2. A surface sampling device served by a robotic manipulator arm

Given an Ariane-5 launch into Geostationary Transfer Orbit (GTO), an Apollo-type transfer to the Moon and an inclination change (at the aposelenum) could be selected as the standard flight-path for all missions that have been discussed here. Lander missions would also involve the descent to the lunar surface and, in the case of a sample-return capsule, the relaunch towards the Earth. Table 2 shows the manoeuvres and velocity steps on the way to the Moon.

Table 2. Manoeuvres and velocity steps on the way to the Moon

Description of manoeuvre	Δv[m/s]
Injection from GTO into lunar transfer orbit	650
Capture into High Elliptical Lunar Orbit (HELO) from lunar transfer orbit	150
Inclination change of 90°	106
Circularisation of HELO to Low Lunar Orbit (LLO) (100 km)	650
Landing on lunar surface	2250
Relaunch towards Earth	2900

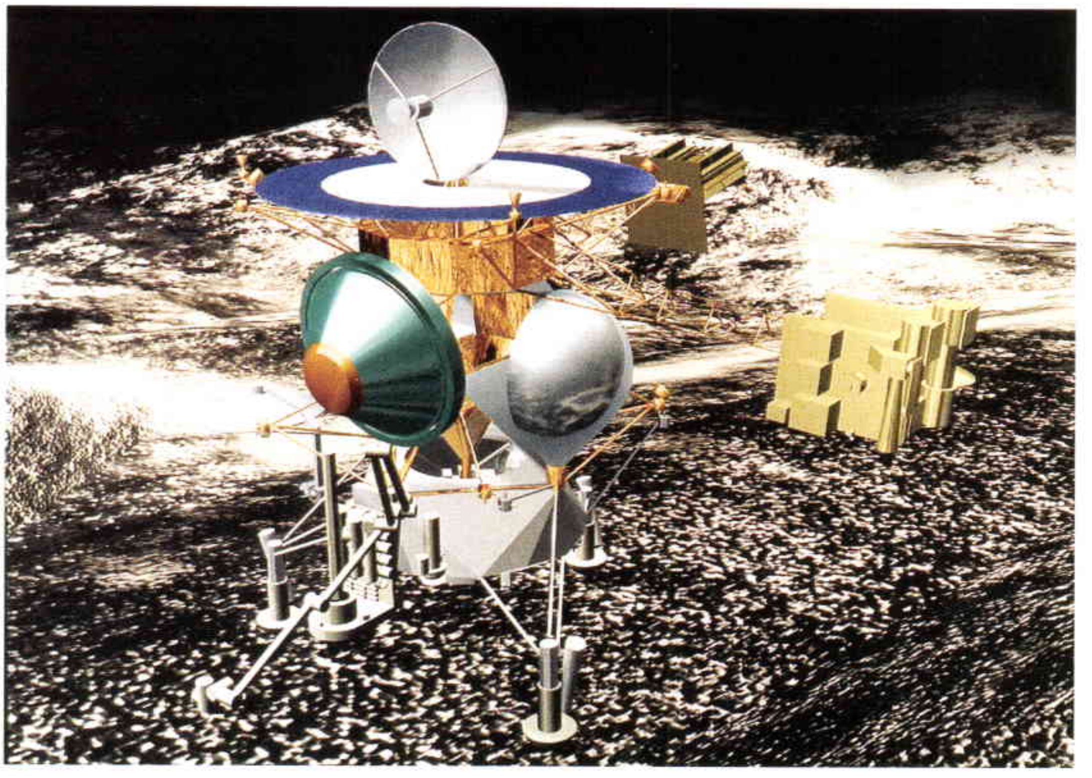


Figure 3. Concept of a spacecraft (Rosetta) designed for the return of samples to Earth. Consists of a lander (grey), an orbital transfer stage (gold) and a sample-return capsule (turquoise)

For the main orbit manoeuvres, a large, restartable bipropellant engine is needed. The GTO-to-lunar transfer and the high-to-low lunar orbit manoeuvres in particular require a rather high thrust in order to keep the burn time down. Europe has a suitable technology available in the upper stage of Ariane-5, whose bipropellant engine delivers 27.5 kN of thrust and a specific impulse of 316 s. This engine can also be restarted several times. The use of a range of bipropellant engines that are either currently available or under development in Europe – with thrust levels between 400 N and 20 kN – would simplify the transfer strategies or increase the maximum available spacecraft mass considerably.

In addition, although currently not being considered for Ariane-5, a cryogenic upper stage based on the Ariane-4 HM-7B engine, with a thrust of 62 kN and a specific impulse of 445 s, could potentially increase the maximum payload mass for the sample-return mission. All of the necessary technology for this is available and space-qualified, except for the engine's restartability.

Although they would vary with the transfer-stage concept selected, typical maximum spacecraft masses would be 2000–3000 kg for a lunar orbiter spacecraft after launch as a second passenger to GTO on an Ariane-5, and 6000–8000 kg for a lunar lander spacecraft carrying either a rover or sample-return capsule.

Enabling technologies

In order to reduce the development risks and times for the critical technologies to an acceptable level, some basic technological research is needed in the near future. Several technologies are considered strong candidates in this respect.

For the Orbiter mission, only partially developed payload technology is currently available. An additional effort is needed to develop the gradiometer and laser-altimeter instruments suitable for very low lunar orbits.

A rover is considered one of the key elements of a lunar infrastructure, and is indispensable for any manipulation and handling of material and experiments that is done without a human's presence. It would therefore be necessary to develop small rovers equipped with dextrous manipulators, that can be carried by a lander. These would widen the ground area being investigated and enable the deployment of self-standing surface stations or larger, lightweight structures, such as antennas for VLF radio telescopes. The Lunar Archive, one of the possible future lunar applications, would also require such a vehicle for the manipulation, storage and retrieval of its contents.

Unfortunately, ESA has little experience with roving vehicles, and there have not been any associated studies or technology programmes of note. However, some ESA

Member States are now undertaking studies or technology-development programmes, and conducting ground demonstrations of Mars rovers. Except for a suitable adaptation of these technologies to the conditions of the Moon, it might be beneficial to concentrate initially on the development of auxiliary tools, such as manipulators that can work under lunar-surface environmental conditions and a deep-drilling device able to reach a depth of 15–25 m.

Any lunar programme will sooner or later lead to the exploration and exploitation of the far side of the Moon. Reliable and almost permanent communication links will then be needed between ground control and the far side of the planet. In the early stages, i.e. as long as the mission frequency is low, this can be achieved most economically by sending a data-relay payload package with some of the later orbiters. For longer and more frequent missions, however, a permanently installed and mission-independent lunar communication system and/or a high degree of automation would be needed.

The payload capability of the Ariane-5 launcher is still a handicap in the planning of lunar sample-return missions. The planning would have a much greater flexibility if the cryogenic propulsion technology employed for Ariane-4's upper stage could be adopted.

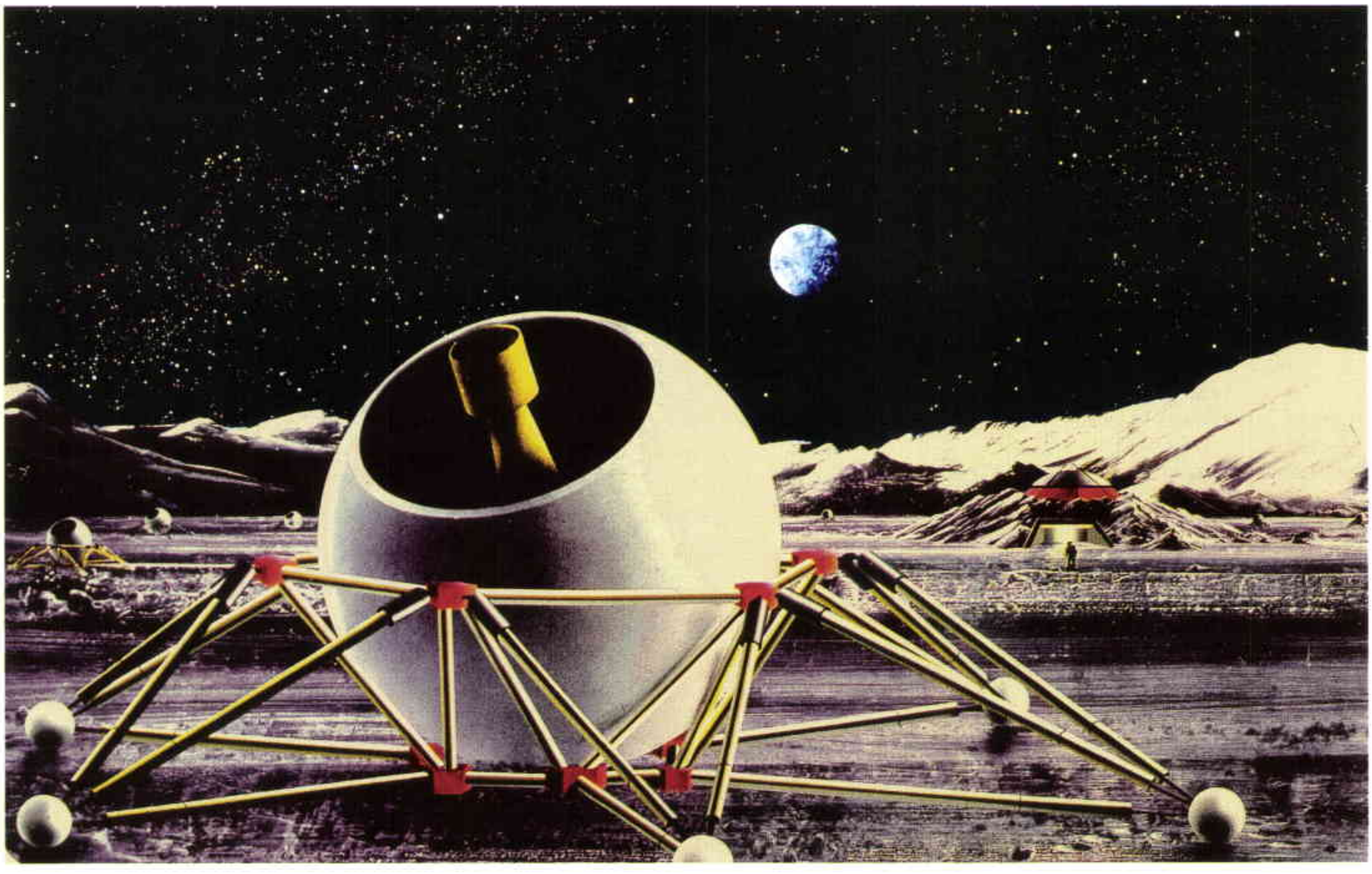
In an advanced stage of an uncrewed lunar exploration programme, it will be important to be able to return soil or biological samples from the Moon to Earth; this will become even more important as soon as pre-industrial activities relating to the possible exploitation of Moon resources start. Re-entry capsules in which to return material to Earth are therefore also a necessity.

Conclusion

A range of uncrewed lunar exploration missions with orbiters, landers, surface-station networks and rovers, and sample-return missions can be projected before the turn of the century. These missions would expand our knowledge of the Moon, would provide basic data needed for placing scientific instruments on the lunar surface, and would provide a more reliable overview of lunar exploitation opportunities. Finally, these short and comparatively cheap missions could lay the ground work for future crewed expeditions to the Moon.

The various types of spacecraft needed for these uncrewed missions can be built to a large extent using technology that is already available in Europe. Some technological development will be required for the payload instruments to be carried and for the sample-handling and sample-return devices.

Science from the Moon: very-long-baseline optical interferometers deployed on the lunar surface



The Critical Point Facility and the IML-2 Mission

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ESA's Critical Point Facility (CPF) offers investigators the opportunity to conduct research on critical point phenomena in the Spacelab's microgravity environment. This facility provides the highly precise and extremely stable temperatures that are required for the study of critical point phenomena. It was designed primarily for the optical investigation of transparent fluids. The CPF was flown on the first International Microgravity Laboratory (IML-1) mission in January 1992, with great success. It will be flown again on the second IML (IML-2) mission scheduled for launch in July 1994.

Scientific objectives

Pure fluids near their critical point and binary mixtures near their consolute point undergo a phase transition. This transition is characterised by a coexistence (or miscibility) curve, which exhibits the general features shown in Figure 1. At high temperatures, the system is formed as a single phase. When the temperature is lowered and the coexistence curve is reached, instability sets in: a phase separation is initiated under the form of density fluctuations, until two distinct equilibrium phases are formed, which are located on the coexistence curve. The peak of this curve is the critical point.

When nearing the critical point, a pure fluid acquires very unusual properties, which are independent of the molecular species. For example, the isothermal compressibility diverges. Because of this extreme compressibility, fluid areas arise with high and low densities: these are the density fluctuations mentioned above. In turn, these fluctuations strongly alter some of the fluid's other properties, including its thermal qualities. For example, adding a very minute amount of energy locally to the fluid has a great effect on the local temperature and on the density throughout the whole sample. In practice, this means that the temperature of the fluid must be controlled with very high precision and stability. This also means that non-perturbing diagnostic techniques, such as the use of optical means and thermistors at low-energy levels ($\leq 10\ \mu W$), must be used when determining a fluid's critical point and its behaviour around that point.

ESA's Critical Point Facility (CPF), which is flown in the Spacelab research module, has been designed to submit transparent fluids to an adequate, user-defined temperature scenario (with a precision of 0.0001 K), and to monitor the fluid's behaviour using thermal, pressure and different optical means. For example, if a fluid is nearing its critical point, the density fluctuations mentioned above can produce scattered light; the CPF can monitor that scattering using two of its diagnostics. In addition, variations in their index of refraction, which

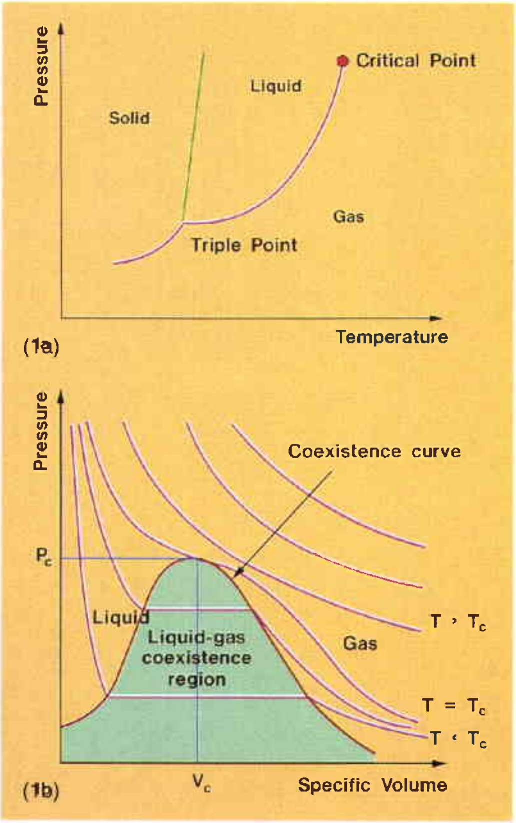


Figure 1. Thermodynamic phase diagrams showing the critical point

A. The critical point (T_c, P_c, V_c) is the highest temperature at which the gas and liquid phases can still be distinguished

B. In the area below the critical temperature (T_c) isotherm, the fluid separates into two phases. The density of each phase is determined by where the temperature line meets the coexistence curve.

Figure 2. ESA astronaut, Ulf Merbold, with the CPF. The display panel, keypad and power switches are on the electronic drawer (bottom). The cable issuing from it is only used on the ground, to enable monitoring and commanding. The experiment drawer (top) holds the thermostat (bronze-coloured, with the cover removed) and the camera (left, protected by a bracket).

are related to temperature or density inhomogeneities, can be analysed with an interferometer.

The study of critical phenomena in fluids requires low gravity conditions because gravity strongly affects the phenomena. Firstly, fluids at the critical point become compressed under their own weight because of their diverging compressibility. As a consequence, fluids cannot be maintained in a critical state under gravity conditions but immediately undergo a phase separation, neither phase being at the critical point. Secondly, the role played by gravity in the formation of interfaces between distinct phases is not clearly understood. Hence, the low-gravity environment of Spacelab is very suitable for this type of experiment.

Another aspect of this phenomenon is the time that it takes for a system to reach equilibrium: the time required approaches infinity as the system approaches the critical point. Hence, to reach the critical point and to be able to study the equilibration process requires experiments of very long duration (40–65 hours, for instance). The length of Spacelab missions permits such long experiment times.

The applications of this research extend beyond the fluids and binary mixtures investigated in the CPF, to all pure fluids and to other physical systems where critical phenomena are also observed, such as magnetic transition at the Curie point. The understanding of critical point behaviour (heat and mass transport, equilibration timescales, nucleation and growth) can be useful to both everday and industrial processes involving phase separation, and in particular to heat exchangers. It can also contribute to a better understanding of the behaviour of fluids in rocket and spacecraft thruster reservoirs, which can approach the critical point during the functioning of the thrusters. Critical point phenomena are described in terms of universal laws, which are independent of the fluid's molecular nature and are valid within a range of more than 100°C in many systems. Hence, the implications of this basic research are wide and extend to the supercritical fluids which are simultaneously dense and compressible. A growing number of technological applications are using these fluids.

Description of the CPF

The CPF is composed of two interconnected drawers: the electronic and the experiment drawers (Fig. 2 and Fig. 3). The bottom one, the electronic drawer, houses the CPF's power supply, control electronics and data handling capabilities. In the experiment drawer above it, there is a chamber in which exchangeable thermostats are placed, and surrounding it, the complete optical diagnostic system. A thermostat (Fig. 4) houses experiment-specific elements, namely one or two test cells that contain the fluid that is being investigated, and possibly stimuli/diagnostic elements such as a pressure sensor. During a mission, the crew members place a thermostat in the chamber in the experiment drawer and, when the experiments have been completed, they remove the thermostat and replace it with another one. The thermostat also provides interfaces for the stimuli (such as heating and

Figure 3. ESA astronaut, Ulf Merbold, and the CPF (above his head) during the IML-1 mission

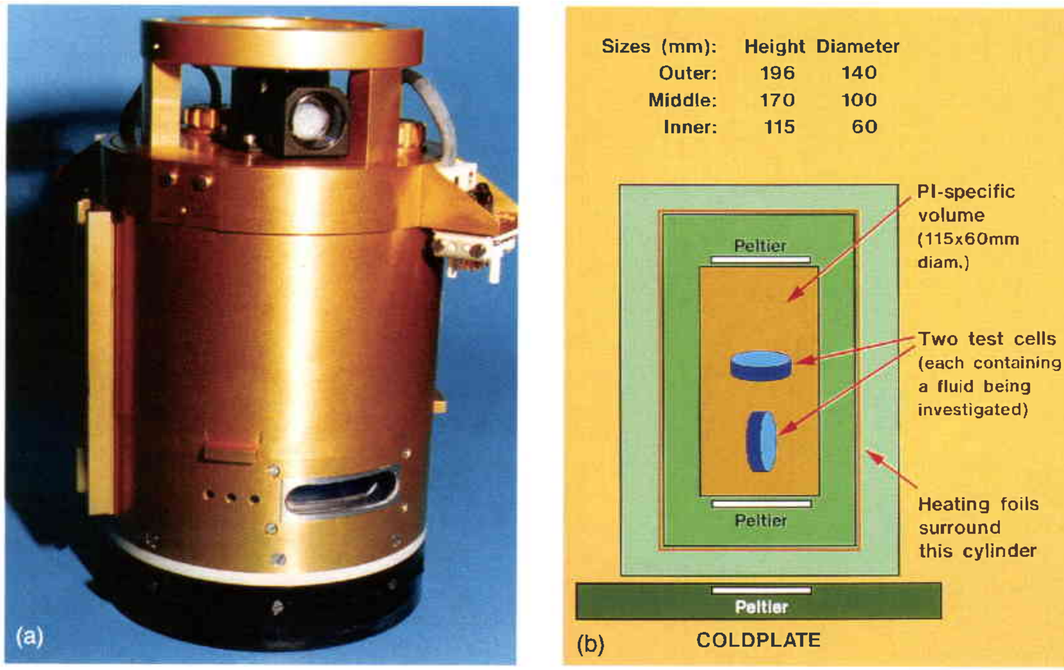


Figure 4A. CPF thermostat and B. a simplified cross-section of the thermostat attached to the coldplate

mixing stimuli) and for the diagnostic devices (thermal and pressure sensors, and optical means).

The CPF is an automatic facility. It runs experiments according to a pre-programmed timeline that has been defined by the corresponding Principal Investigator (PI) and loaded into the CPF's memory. This timeline can be modified in real-time from the ground during the experiment's run, when requested by the PI. This method, which requires minimum crew involvement, is particularly adapted to the very long durations that are typical of experiments involving critical point phenomena.

Hardware

The CPF also has a keypad and a display panel (Fig. 5), located on the front of the electronic drawer, that the crew uses to interact with the CPF.

The thermostat provides excellent thermal control of the test fluid, with an accuracy of one ten-thousandth of a degree (0.0001°C). This accuracy is achieved by using three co-axial cylinders (Fig. 4B), the middle one being surrounded by Joule heating foils, with torus-shaped Peltier elements on the top and bottom. The thermostat is mechanically attached to a 'coldplate' in the CPF and is positioned with great accuracy. To allow the highly-accurate temperature control that the thermostat requires, two elements are temperature-controlled: the coldplate and part of the thermostat control electronics. In addition to providing thermal control, each thermostat has optical and electrical interfaces to enable stimuli and diagnostics to interact with the test fluid. Each thermostat has a built-in identification number that ensures that the fluid will be processed in conjunction with the proper, pre-recorded timeline. This process can be overruled in the case of a malfunction.

Stimuli

Three types of stimuli can be used: thermal, mixing and electrical.

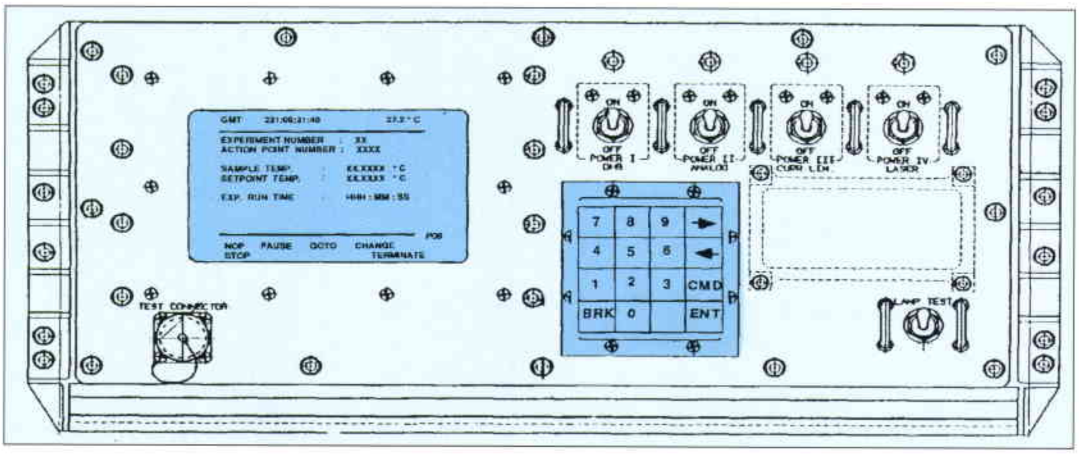


Figure 5. Front of the electronic drawer, with the display panel (left) and keypad (right) that the crew uses to interact with the CPF. Shown in the nominal operation mode.

Thermal stimulus
The thermostat provides the following thermal capabilities at the level of the test cells:
- temperature controlled between 30° and 70°C
- accuracy and heating/cooling step size: 0.1 mK
- minimum speed of heating/cooling ramps: 0.3 mK/min
- maximum heating rate: 36 K/hr
- maximum cooling rate (loss to ambient): 10 K/hr
- temperature stability: 0.05 mK/hr
- temperature gradients within fluid: ~ 0.1 mK/cm
- quenching rate: 25 mK/s or better
- quenching step size (downward and upward): 0.1 mK below 1 mK, 1 mK for 1 mK to 100 mK.

Mixing as a stimulus
Fluids can be mixed in four ways:
1. An acoustic mixer at 1.7 MHz that eliminates concentration inhomogeneities above the critical temperature (T_c), and emulsifies the fluid phases below T_c, in a binary system.
2. A coil-driven magnetic bar inside the fluid that eliminates remaining density inhomogeneities above T_c, but creates temperature gradients.
3. A system that is similar to the one described in 2. and affects the fluid in the same way, but is activated by a motor-driven magnet located outside the fluid.
4. A strong, crew-activated magnet, placed in front of the CPF, that moves a magnet located in the fluid, without any heating effect.

The first three methods generate heat and are therefore used only when uncontrolled temperature changes are acceptable, i.e., when the test fluid is not near T_c.

Electrical stimulus
A voltage source of 0 to 500 V and a current source of 0 to 1 Amp are other stimuli that can be used. Some of their possible applications are local heating (as opposed to homogeneous heating) in the sample fluid, and the investigation of critical fluids under an electrostatic field.

Diagnostics
The test fluid's temperature is monitored with a precision of 0.1 mK relative to the T_c. The T_c is determined beforehand and can be updated during the experiment on board Spacelab. Several thermistors and thermocouples are located next to the fluid sample and at different locations within the thermostat. Their output is available to the scientists on the ground. Instead of being used for automatic temperature control, some thermistors are used for temperature determination and possibly for local heating. The PI determines their precise location.

The optical diagnostic methods used are:
- direct visualisation (transmission of diffuse light)
- beam attenuation in transmission (turbidity)
- interferometry (Twyman-Green type)
- Small Angle Light Scattering (SALS) at angles between 0° and 30°
- Wide Angle Light Scattering (WALS) at angles between −38° and 90°
- monitoring of the intensity of the input laser beam, with an accuracy of 0.05%
- microscopy (integrated in the interferometer channel by adapting the thermostat optics).

The performance of most of these methods is described in detail in Table 1, and their geometry with respect to the thermostat is shown in Figure 6. A video (CCD) camera and/or a photocamera acquire the images from either the direct visualisation or the interferometer channel, as selected by the automatic timeline program running the CPF.

In the SALS diagnostic, the PI selects at any time the number of scans that the linear camera will make, with an average calculated based on 1 to 256 scans. The PI also selects the scan frequency, from 13.3 to 1.66 kHz. The WALS measurement is the integration of the photomultiplier signal over the time that it is exposed to a fibre output, i.e. 250 ms.

A pressure gauge is also part of the CPF. Its measurements (12 bits resulting in an accuracy of 13 mbar) are acquired and downlinked at a rate of either one or 147 measurements per second, as selected by the PI.

The automatic timeline program
All the timelines are pre-defined by the PIs and are stored in the CPF's memory, along with a back-up, before the launch. As soon as the crew has inserted a thermostat in the CPF and initiated the corresponding experiment, the CPF runs automatically according to that timeline. This automatic timeline program is called the Experiment Parameter Table (EPT). Each experiment has an EPT. Each EPT consists of a header, which specifies information such as the value of T_c and the duration of the experiment, and up to 1024 sequential steps called action

Table 1. CPF Optical diagnostic methods

CPF optical diagnostics	Visualisation	Attenuation	Interferometry (Twyman-Green)	Small angle light scattering (SALS)	Wide angle light scattering (WALS)
Light source	LED light	He-Ne Laser 1 mW—0.6 mm diam.	He-Ne laser 0.06 mW	He-Ne Laser 1 mW—0.6 mm diam.	He-Ne Laser 1 mW—0.6 mm diam.
Field of view (at object)	12 mm diam.	0.63 mm diam.	12 mm diam.	—	—
Detection					
• Detector	CCD camera Photocamera	20 first pixels of SALS CCD	CCD camera Photocamera	Linear CCD (Peltier-cooled, 512 pixels)	Photomultiplier (1 angle at a time)
• Angles	—	—	—	0°—30°	—22, —30, —38, 66, 74, 82, 90°, laser input reference, dark signal
• Sensitivity		10^{-3}—10^{-7} W/pixel		10^{-6}—10^{-10} W/pixel	10^{-8}—10^{-12} W
• Intensity resolution	6 bits/pixel (CCD digital downlink)	16 bits linear (≈0.2%)	6 bits/pixel (CCD digital downlink)	8 bits (logarithmic) (≈5.5%)	12 bits (logarithmic) (≈0.35%)
• Acquisition	30 fps	1 Hz or averaged	30 fps	1 Hz or averaged	Average over 300 ms per angle, 7 cycles/min
• Downlink rate	30 fps & 1/6 Hz	1 Hz	30 fps & 16 Hz	1 Hz	7 cycles/min
Resolution (at object)	40 μm (CCD) 20 μm (photoc.)	— —	Fringe density: 25 mm^{-1} (photoc.) 10 mm^{-1} (CCD)	0.25°	2°

Note: the SALS data are averaged over sets of four pixels before downlink

points. Each action point defines the time that the action will last and up to four commands that control the stimuli/diagnostics, for example:
— Setpoint temperature to 45.6789°C
— Take a photo
— Change the LDC scan frequency to 1.66 kHz.

Figure 7 shows an EPT for a sample experiment being created.

Operations

During the time that CPF experiments are running on board Spacelab, the PI receives telemetry data on the ground to monitor the execution of the experiment and can

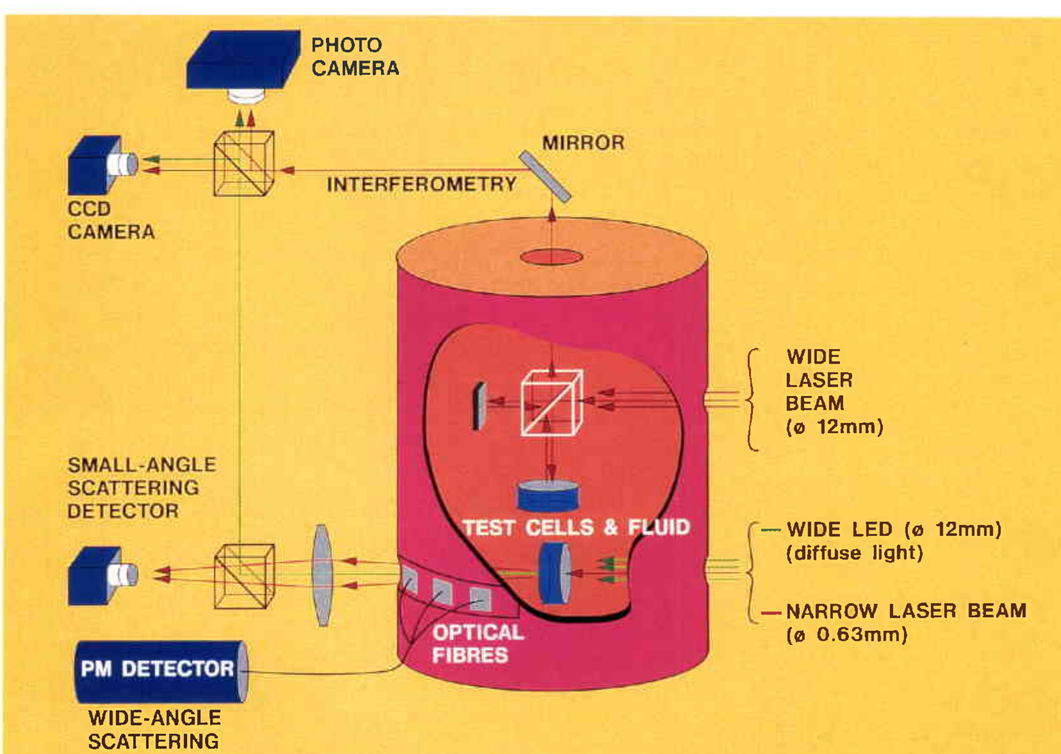


Figure 6. CPF thermostat and its optical diagnostic methods. The output of the interferometric channel is on top, the output of the Small-Angle Scattering is on the bottom, with three holes on the side that are used for the Wide-Angle Scattering.

influence the way that the experiment runs:

- All the scientific and housekeeping data generated by the CPF are displayed in real-time (or re-played after every period of loss of contact with Spacelab).
- The video images from the CPF are displayed in real-time, at the television rate (30 frames per second) during short, pre-selected periods, and continuously at a reduced rate of one image every six seconds.
- Voice contact with the crew can be established while the crew is executing CPF-related tasks.
- The PI can also modify the automatic program running the experiment by issuing commands from a dedicated microcomputer, part of the CPF command Electrical Ground Support Equipment (EGSE).

All data sent to the ground is recorded and made available to the PI after the mission, together with the pictures taken by the camera (100 photographs per thermostat).

Interacting with the CPF

Although the CPF runs automatically according to a PI-predefined program, the PI can also interact with the CPF during an experiment on the ground or during the mission, to modify the way that the experiment is running and in particular to modify the predefined program. This feature of the CPF has proven to be absolutely essential for reaching the scientific objectives, and was used extensively during the IML-1 mission.

There are two ways to interact with the CPF: using the CPF keypad and display, or from the CPF command microcomputer on the ground. During the mission, this command PC is located at the Payload Operations Control Center (POCC) at NASA's Marshall Space Flight Center (MSFC) in Huntsville, Alabama, along with the other elements of the CPF EGSE (Fig. 8). A CPF engineer operates the PC, based on input from the PI concerned.

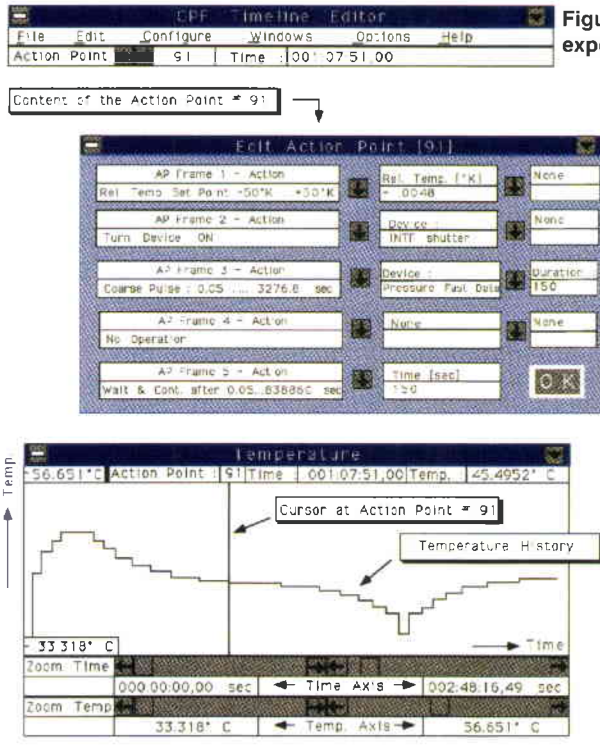


Figure 7. Creating a CPF experiment parameter table

A menu describes the basic operational states in which the CPF can be set, using the keypad. The CPF display corresponding to each operational state is shown in Figure 9. Some of the software's characteristics are:

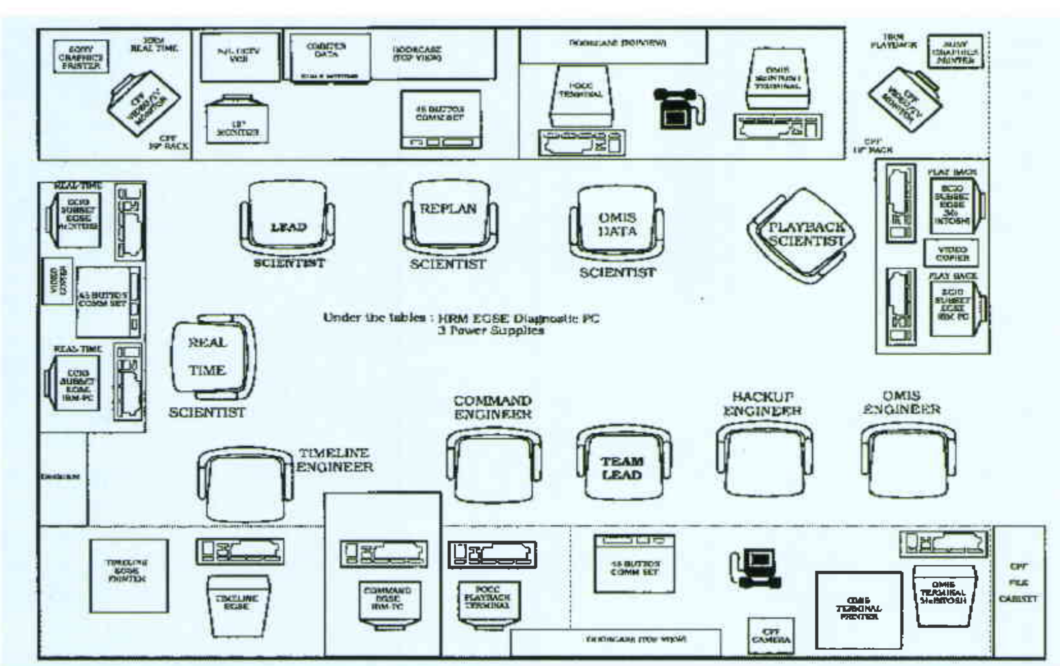
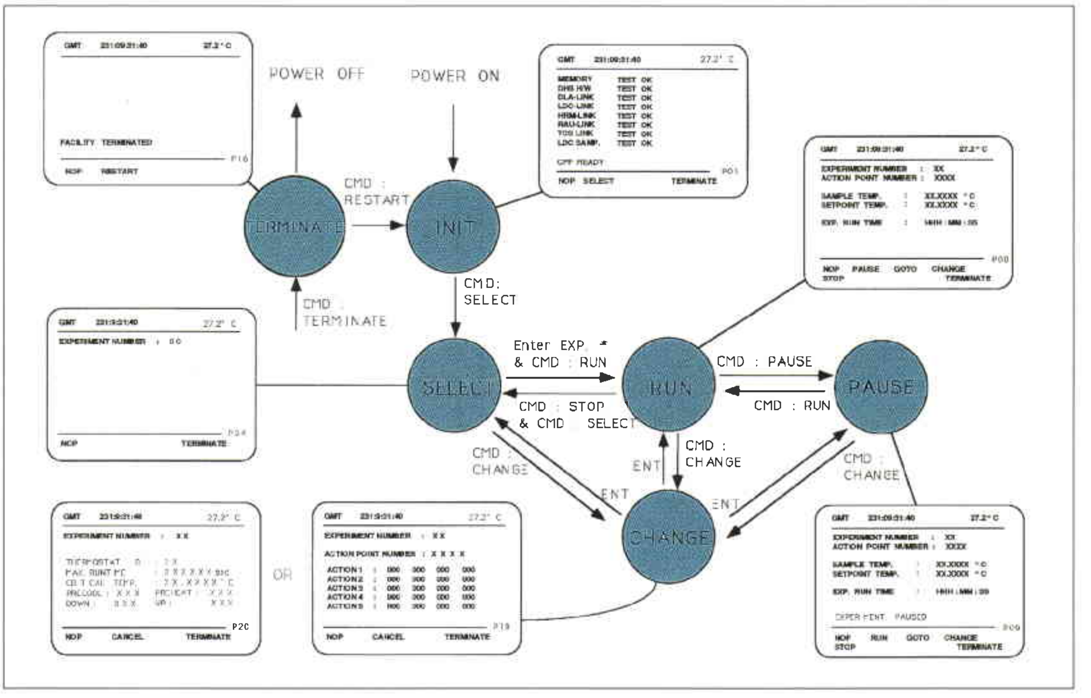


Figure 8. Layout of the CPF area at the Payload Operations Control Center (at NASA-MSFC) during the IML-1 mission. The same layout will be used during the IML-2 mission.

Figure 9. CPF's operational states (circles), with corresponding screen displays



— The Terminate state can be reached from any state.
— Any change between two states requires two key strokes or more (this minimises the risk of an error).
— A GOTO command exists, which enables the execution of the experiment to go to another of the automatic program's action points.
— The Change function enables the user to modify the automatic program's header and its sequence.
— In the PAUSE state, the CPF maintains its existing situation and does not proceed to the next step in the automatic program.

The IML-1 mission

The CPF was first flown on the first International Microgravity Laboratory (IML-1) mission, in the bay of the Spacelab, in January 1992. This mission was considered to be very successful.

CPF description

For the IML-1 mission, some features of the CPF were changed, as follows:
— Optics:
No advanced SALS/WALS averaging system (not available at that time)
Reduced dynamic range for the SALS and WALS
Reduced spatial resolution of the LED channel
— Thermal control system:
Accuracy reduced to 1 mK
No heating/cooling ramps included
Lowest temperature: 40°C
No heating quench
— Data handling:
Displays and commanding slightly less advanced
SALS data compressed by the CPF and decompressed on the ground
— Other:
No current or voltage source
No pressure gauge.

Mission summary

The IML-1 mission was extended from the originally planned seven days to eight days, allowing the CPF to be run for an extra day.

Four scientific experiments were performed using the CPF:
— Study of density correlations and density distributions at the critical point of SF_6 (Dr. A.-C. Michels, van der Waals Laboratory, University of Amsterdam, The Netherlands)
— Study of phase separation phenomena and of the relation to two-phase equilibria in cyclohexane-methanol mixtures (Dr. D. Beysens, SPEC, Commissariat à l'Energie Atomique (CEA), Saclay, France)
— Study of equilibration in a gas-liquid system (Dr. D. Beysens, SPEC, CEA, Saclay, France)
— Investigation of the thermal equilibrium dynamics of SF_6 (Dr. A. Wilkinson, NASA Lewis Research Center, Cleveland, USA).

Besides the CPF itself, all teams and hardware involved in this successful mission performed perfectly. In particular, the continuous data/video downlink and commanding systems performed flawlessly, providing great hope for the telescience approach recommended for the future Space Station.

Technical highlights of the mission

The downlink of data and video images in real-time operated successfully throughout the mission. This was a major achievement because, for the first time, the scientists were able to see their fluid reaching the critical point without being affected by gravity. In addition, during the last 24 hours of the mission, the CPF was given an exceptionally large amount of real-time video downlink time since the CPF was then one of the only users of that resource.

The downlink of the digital video images (at a rate of one image every six seconds) also operated perfectly throughout the mission. This low-rate video system is an original feature of the CPF. It was installed because the scientists need to be constantly informed about their sample fluid and able to 'feed back' to the experiment but Spacelab's real-time video downlink is not continuously available to the CPF because it is shared by all facilities within the Spacelab. In fact, the low-rate video is appropriate for the CPF since the dynamics of fluids around the critical point are usually slow, as was confirmed during the mission.

The scientists also used the CPF commanding capability continuously, with some 1100 commands being sent to the CPF during the mission. The CPF properly executed all of the commands; it confirmed each one by sending an acknowledgement message which was received on the ground console seven seconds after the command was sent. The scientists used the commands to provide feedback on their experiment and also to adapt it to any externally-imposed change such as the shift of an acquisition of signal (AOS) period or the extension of the experiment beyond the nominal duration.

The CPF was originally foreseen to run for about 150 hours, however, with the extra day added to the mission, the CPF was able to run for an additional 24 hours. Also, the CPF was allowed to run 10 hours after the nominal CPF shutdown time: the crew actually shut the CPF off as part of the shutdown of the full Spacelab system before leaving the Spacelab to prepare for landing. This total of 34 additional experiment hours was a great benefit for the CPF scientists because they could then take advantage of the scientific results acquired during the previous days.

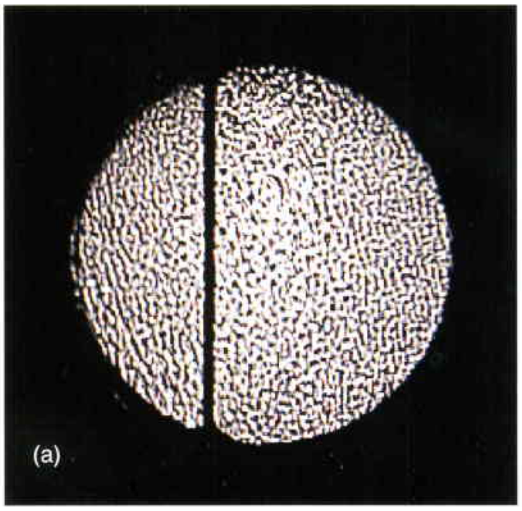
A commercial camera was mounted on the CPF to acquire high-resolution images of interferometric patterns. It performed perfectly in the different modes in which it was set. The films were delivered to ESA 25 hours after the landing. They provided 500 high-quality photographs, which allow accurate and quantitative evaluation of the phenomena. Two examples are shown in Figure 10.

The CPF team

Each facility within the Spacelab had a team located at the POCC at NASA-MSFC (Fig. 8 and Fig. 11). The 32-member CPF team was divided into two shifts to allow around-the-clock operations. Each shift consisted of four scientists and five engineers, one of whom was responsible for the commanding.

The scientists used highly sophisticated equipment to perform their activities:

- A computer-based system that provided both scientific and housekeeping data.
- A computer-based system that provided light-scattering data.



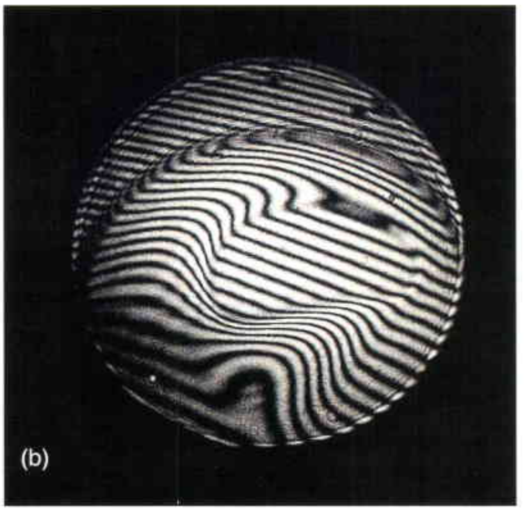


Figure 10. Two images from the CPF taken during the IML-1 mission

A. Vapour droplets two hours after the onset of thermal quench to the two-phase region. The areas are not uniform because of the presence of a laser beam at the beginning of the process. Its influence is still not well understood.

B. Density-related interference pattern from an SF_6 sample in the two-phase region at 60 mK below T_c. The central part is in the vapour phase; the more densely spaced, parallel fringes at the bottom are in the liquid phase. In between, there is a transition region in which the density varies (+0.6% to −0.3%). In gravity conditions, vapour and liquid separate into two homogeneous regions. In microgravity, the phase separation redistributes locally, enabling the phenomenon to be studied in detail. The sample shown has in fact been in this stable state for more than 10 minutes.

— A computer-based system that displayed low-rate video images (digitally downlinked at 1/6 Hz) on a monitor.
— A monitor that displayed the CPF video images (at 30 frames per second).

Each of these systems was duplicated to allow the processing and display of both real-time and playback data, and each system was equipped with the capability to store the data received. In addition, the Spacelab orbit information was provided on a monitor, to foresee the periods of contact and loss of contact with the Spacelab. The scientists' main activity was to monitor the screens, to evaluate the scientific data and to feed back any changes to their experiment by requesting that the engineers issue specific commands to the CPF.

Figure 11. CPF scientists and engineers at the POCC during the IML-1 mission

The engineering team was responsible for the correct, continuous operation of the CPF, including the monitoring of the crew activities on the CPF and of the CPF data/video communication. The engineers also provided specific support to the scientists, for example, through commanding. The engineering team was in permanent contact with the NASA team responsible for managing the mission through a set of approximately 30 voice communication loops, including two crew voice loops. The NASA team was responsible for the real-time and replanning activities.

The CPF team, which was composed of people of eight different nationalities, speaking a variety of languages, provides an excellent example of a very successful international cooperative effort.

The IML-2 mission
The IML-2 mission is expected to be launched in July 1994, and it is intended to last for up to 15 days (13 nominal days and 2 extra days if Spacelab's resources allow it).

Four experiments using five thermostats are foreseen for the CPF, with a total experiment duration of 260 hours. All of the experiments will use the fluid, sulfur hexafluoride (SF_6, $T_c \approx 45°C$, $P_c \approx 40$ bars). The experiments will be:
— Heat transport and density fluctuations in the critical fluids under microgavity conditions
(Dr. A.-C. Michels, van der Waals-Zeeman Laboratory, University of Amsterdam, The Netherlands)
— The piston effect in supercritical SF_6
(Dr. D. Beysens, SPEC, CEA, Saclay, France)
— Density equilibration timescale (DET)
(Dr. H. Klein, WB-RS, DLR, Germany)
— Thermal equilibration in a one-component fluid
(Prof. R. A. Ferrell, University of Maryland, USA) (This experiment will use two thermostats: an Adiabatic Fast Equilibration (AFEQ) and a Thermal Equilibration (TEQB) thermostat.)

In order to investigate the effect of reduced gravity on critical fluids, it is foreseen that the Shuttle will rotate around each of its three axis, at a rate of one degree per second, during the 'piston effect' experiment.

As was the case on IML-1, and in order to fully interpret the data gathered, the scientists will receive the Spacelab acceleration data measured during the mission after the mission has been completed.

The CPF was developed by DASA/ERNO Raumfahrttechniek GmbH (D) with OIP (B), Vd Waals-Zeeman Laboratory (University of Amsterdam, NL) and Battelle-Institut. (D) as subcontractors. An engineering model of the CPF for crew training will be located at the Payload Crew Training Center, NASA-MSFC. The flight model for the IML-2 mission will be integrated into the Spacelab at NASA's Kennedy Space Center during the summer of 1993.

Return from Space – ESA's Technology Transfer Programme

ESA Technology Transfer Group

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Technology transfer is the process of taking innovations from one domain and applying them to another. In the last twenty years, industrial companies have realised that they can – and must – improve the efficiency with which they introduce new technology into their products. By actively managing technology transfer, companies reduce the delay in introducing new technology, leading to more competitive products. Instead of a remote research laboratory taking years over basic research, innovation takes place near the factory where equipment is produced, introducing simple ideas as soon as possible into commerce. These techniques give an enormous competitive advantage to the companies that can understand and manage technology transfer correctly.

Introduction

ESA has started a Technology Transfer Programme to take space technology and move it into Europe's non-space industry (Fig. 1). Many preliminary actions have already been started; for example, a catalogue of transferable technology has been distributed throughout Europe. At each ESA site, a focal point has been established to handle technology-transfer issues, and within each ESA Programme a local liaison person will handle links for, say, the Space Science Department or the Columbus Programme. A contract has been placed with 'Spacelink', a consortium of 'technology broker' companies which promotes transfers and arranges agreements between the buyer and seller of the technology. Some transfers resulting directly from the Agency's Technology Transfer Programme will have been completed by the time this article is published.

Obviously, technology transfer is not ESA's main business, but there are several reasons why the Agency is taking technology transfer seriously. From a European perspective, technology transfer reduces duplicated research. This cuts the long-term cost of research by re-applying results elsewhere. Technology transfer also exposes ESA's technology to the outside commercial markets, thereby allowing non-space companies to inject their own expertise back into the system. A major reason for Europe supporting the space industry is the expected 'spin-off' into terrestrial applications. For a relatively small incremental investment, ESA can enhance this spin-off, which is expected by its national industries.

One of the most important benefits of technology transfer is indirect, namely to improve the ability of engineers to re-apply existing technology. Studies of technology research suggest that existing work is too often ignored, and research results are too complicated to be implemented in the short-term. Organisations would often be better off applying known technology quickly, rather than researching into complex technology which cannot be applied for years to come.

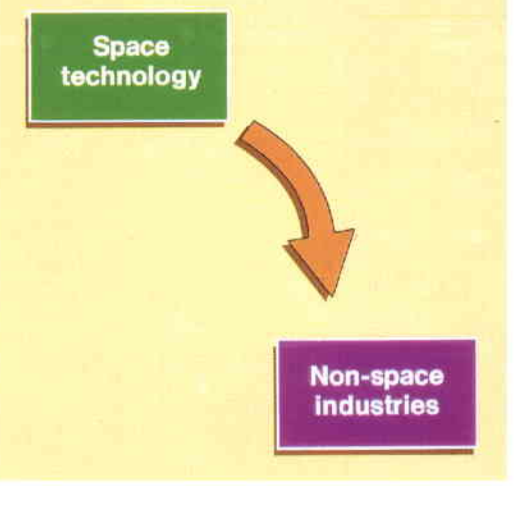


Figure 1. ESA technology transfer

* Now with Requirements Engineering Ltd., Teddington, UK

Initial reactions to technology transfer can be cynical, but when people step back and start to think a little, this attitude changes. There have already been many instances of successful technology transfer, a few examples of which are highlighted in Figure 2.

A first appraisal at ESA sites has revealed that technology transfer is already going on in many areas, with more than 30 such transfers having already occurred, and there are many other candidates available for transfer. Naturally, many of the transfers to date have been within the space industry, but there have been plenty to outside firms too. One such successful transfer has involved 'ESATAN', which is ESA-developed thermal-analysis software that is now being used outside the space industry for design and analysis work in areas where temperature analysis is a critical issue.

Figure 2 contains a preliminary list of success stories, most of which occurred before the start of the formal Technology Transfer Programme. The latter's aim is therefore to regularise and to stimulate a process that is already occurring informally.

One could argue that the products of space technology are too expensive for industrial use. Space technology is usually very expensive per component, because of the demands for extreme reliability under severe conditions. In many cases, however, the real expense lies in the initial design and qualification efforts, and unit manufacturing costs need not be excessive. In any case, the trend in modern industry is towards higher quality, lightweight, reliable equipment. The challenge in technology transfer is to see whether these advantages can be brought into more down-to-earth applications.

Technology transfer from space can involve hardware from the high-technology programmes, software, materials, and test methods. Sometimes even pure knowledge – 'know-how' – can be transferred. In this last case, the knowledge itself may be very valuable but difficult to exploit commercially.

Intellectual property

Sometimes the technology is 'owned' by the ESA Contractor, while at other times the intellectual property lies within ESA. This often depends on the history, the contractual organisation, and the nature of the innovation. For example, a contract may last several years and involve many different contractors during the course of its evolution. In these cases, the ESA staff involved are the only people who can keep a grip on the evolution of the product. ESOC's operations control software is such an example, and is in use in many different organisations around the world. The technology may be protected by a patent, but this is not always necessary to license the technology.

In other cases, the ESA contractor brings a considerable amount of prior knowledge to a contract, performs much of the design work, and manufactures the product. This represents the majority of cases, and the intellectual property will remain with the industrial contractor.

In both cases, the objective is for the non-space companies to make a licensing agreement or form a joint venture with the owner of the intellectual property. Where a space company owns the rights, ESA needs to know that the technology transfer is occurring.

The Spacelink consortium

The ESA Technology Transfer Programme is supported by the Spacelink consortium, a group of technology-broker companies specialising in the technology-transfer process. These companies have worked intensively to extract potentially transferable technologies from space companies and ESA sites, and to document them in the

Double Pendulum Michelson Interferometer
Pollutant Extractor
Advanced Remote Gas Sensor
Integrated Physiological Measurement System
Flux-Gate Magnetometer
Heat Pipes
Solid Waste Destruction by Plasma Torches
Lightning Warning and Monitoring System
Aerocoat Fire Protection Materials
Ultrasonic Flow Meters for Liquids
Composite Manufacture by Filament Winding
Process-Control Software
Active Magnetic Bearings
LUCID Image-Processing Software
Advanced Electronic Power Systems
RADFET — Miniature Radiation Dosimeter
TOPSIM — Transmission Analysis and Design
Solid-State Miniature Accelerometer
CREAM Radiation Monitor
Software Development Environment
ESA Software Standards
CFRP Structures
Human Waste Management System
Highly Reliable Cryogenic Valves
DYNAMAN Real-Time Human Simulation Tools
Plasma Chemical Oxidation of Light Metal Surfaces
Ultrasonic Testing of Composites

Figure 2. Existing technology-transfer successes

TEST (Transferable European Space Technology) Catalogues. Spacelink distributes the catalogues and coordinates the replies from non-space industry. The Spacelink companies are organised on a national basis and have a partner in every country. Initially the emphasis has been on the extraction of technology, but now it is steadily switching towards making technology transfers. The contracts are organised to reward companies for actually completing transfers.

Support available from ESA

ESA provides a variety of mechanisms to support technology transfer. The first is to pay for actually extracting, documenting and publicising the technology-transfer candidates. ESA has engaged the Spacelink consortium to document the transfer opportunities and promote them to the non-space world.

Sometimes, the technology needs minor modifications to make it appropriate for a new domain. The Technology Transfer Programme has already provided limited assistance in such cases. For example, a UK company producing software for launch-environment analysis has received a small amount of funding to help commercialise the product.

The TEST catalogue

A first catalogue of Transferable European Space Technology (TEST) was published in 1991. The ideas contained in this TEST1 catalogue were derived from visits to 100 space companies, and many interviews at ESA sites. 55 potential technologies were documented, varying from the simple to the complex, from the theoretical to the down-to-earth. Thirty thousand copies of the catalogue were distributed to non-space companies within Europe in five languages. About 5% of companies wanted further details – much higher than the Spacelink consortium expected!

The second issue of the TEST catalogue was published in mid-1992. This contained a range of new technologies. As knowledge of the target audience builds up, and understanding of technology transfer grows, we already see the degree of interest increasing.

Other organisations

ESA's Technology Transfer Programme can learn from existing technology-transfer schemes. NASA, for example, has been active for more than twenty years in this area, which has been further stimulated by Congress, which passed a specific Technology Transfer Bill in 1987. NASA's 'Tech Briefs' journal covers technology transfer within the US space organisation.

The country with perhaps the most innovative approach to technology transfer is Japan. Their complex company structures have demanded an active approach to technology transfer, even within a single company. Competition is so intense that a delay of six months in bringing a product to market may make the difference between success or failure. Yet, the overall culture is very open towards exchange of information. Japanese companies are now attuned to bringing ideas into production with the shortest possible time-lag. They employ specialists to scout the company and re-use ideas. The success of Japanese industry in applying their own and other peoples' ideas is remarkable. This requires the breaking down of the barriers between theoretical research and industry.

As part of the work to improve links with the Russian space industry, the ESA Technology Transfer Programme has been invited by the Russian Space Agency (RKA) to document the technology available from the Russian space programme. Some information on technology available from the Russian space effort may be included in the next edition of the TEST catalogue. This is an area in which cooperation between Europe and Russia could prove very fruitful.

A fundamental change in the nature of industrial research is occurring, with the realisation that such research must be closer to the industrial production process. 'Ivory tower' research institutes performing

fundamental research in the countryside are quietly fading away. Scientists are moving closer to the production process, applying simpler ideas to the end-product within months, rather than years.

Success with technology transfer
We will now look at a few examples of technology transfer from space endeavours. The Technology Transfer Programme is so young that many of the transfers are as yet in their early stages, and some transfers that took place before the Programme started are therefore also covered.

ESA's software standards
ESA's software-engineering standards show how to produce quality software from the beginning to the end of the process. These might seem an unlikely candidate for technology transfer, but the standards are a valuable asset, particularly as software has become a critically important industrial product. The standards have been used by ESA and its contractors for many years, but the latest version has attracted great interest externally. The standards represent a large investment by ESA over more than a decade. A company buying into the standards saves time and money, and buys a 'product' which has been shown to work in practice. Many organisations outside space have bought copies of the standards, or asked to be permitted to modify them for their own use.

The standards have been 'generalised' to remove any specific ESA references and will be published commercially as a book in the course of 1993 (Fig. 3). ESA's Software Standardisation Board has been actively supporting this commercialisation initiative.

Transfer of TDAS-EMC
Spacecraft are subject to all sorts of electromagnetic effects in space. These can cause problems particularly in electronics systems. TDAS-EMC is a product developed for space systems by Matra-Marconi (F) under ESA/ESTEC contract which allows a space system/subsystem's electromagnetic behaviour to be analysed already at the design stage, thereby permitting corrections to be made whilst they are still inexpensive. EMC is of special interest to spacecraft builders, but similar problems may be experienced by aircraft, telecommunications equipment, computers and microelectronics devices. Modern cars, for example, contain many integrated circuits, which must remain unaffected when cars pass radar or TV transmitter stations.

ESA's Software Standards

The ESA Software Standards

- have been generalised to remove ESA-specific terminology using TT Programme funding
- will be published by Prentice Hall for worldwide distribution beyond the space business
- will generate royalties for ESA

These Standards have been reviewed by Industry and approved by the ESA Board for Software Standardisation and Control (BSSC)

Figure 3. Transferring ESA's software standards

Waste management
Manned space activity requires that considerable attention be paid to keeping the working environment healthy and minimising the use of resources. Some of the techniques developed for application in space can be reused directly on Earth. A human-waste management system developed by ORS of Austria for ESA is one such example.

Plasma torches
Aerospatiale has worked on plasma torches for more than 20 years. These are used to simulate atmospheric re-entry by allowing materials to be subjected to extreme temperatures. This space technology has uses in such industrial fields as:
- blast overheating of ferro-manganese furnaces (SFPO)
- wind overheating of cupola furnaces (Peugeot)
- waste destruction (Rhone-Poulenc).

The industrialisation of the plasma torches was effected in conjunction with EDF and Jeumont Schneider Industrie. A pilot facility has been built to dispose of solid chlorinated

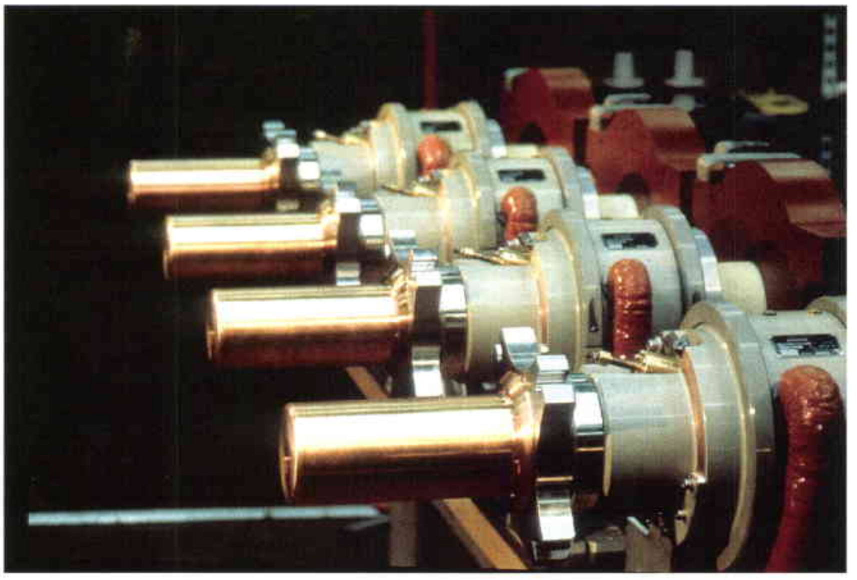


Figure 4. Plasma torches

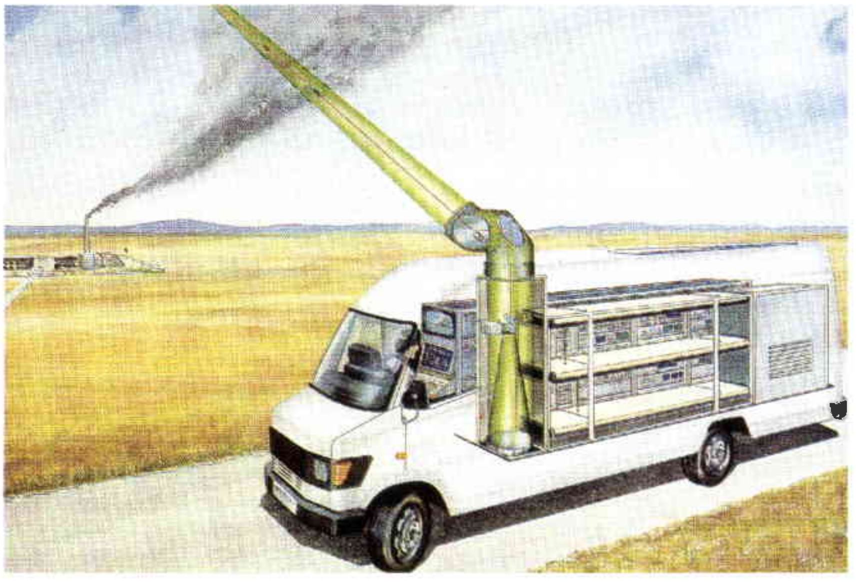


Figure 5. Artist's impression of a mobile 'Lidar' system

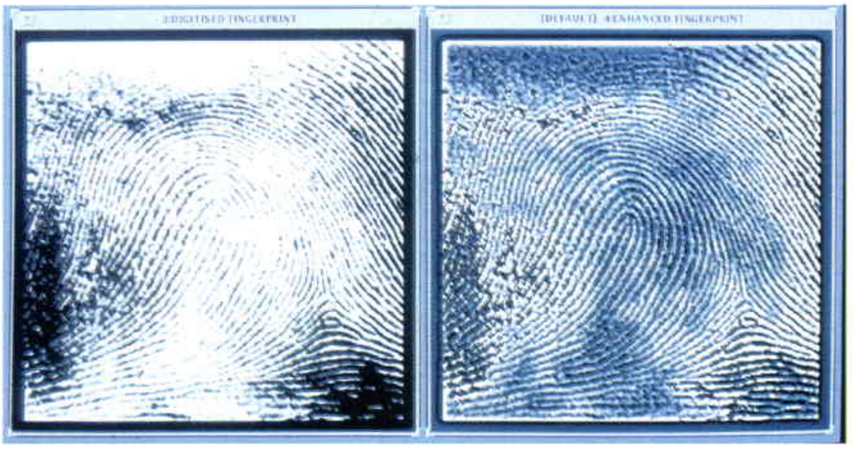
residues using the high temperatures provided by the torch.

Integrated physiological measurement systems

Helasystem, an Austrian company, developed a complete system for physiological measurements under zero-gravity conditions for the joint Austria–Soviet space mission 'Austro-Mir'. This involved producing a small, integrated system and all the handling procedures necessary for conducting on-board physiological measurements under time-critical conditions. The equipment consists of:

- a sensor jacket with integrated accelerometers, electrocardiogram systems, vibro-stimulator and other sensors
- a hand-held data-acquisition system, with real-time scrolling for visualisation of signals and memory cards for information handling
- a hand-grip ergometer with load cell and materials for sensor fixation.

Figure 6. 'Lucid' image-processing software in use for fingerprint analysis



An adaptation of this flight equipment is now available for medical experiments, such as the home monitoring of patients and stress research. The needs of space generated a system which is self-contained, easy to use, reliable, and can be used remotely – the very factors that help to promote its application on the ground.

Lightning monitoring and warnings

Thunder and lightning before or during a launch pose a considerable threat to rockets and their payloads. Although equipment is designed to resist lightning strikes and atmospheric turbulence, it is sensible to plan operations to minimise these shocks. 'Safir' is a new-generation system for real-time thunderstorm monitoring and warning of lightning. Safir covers a 300 x 300 km^2 area, with a spatial resolution of about 1 km. This is a unique tool for the operations planning and management of ground or air activities.

A group of engineers have created a new company (Dimensions) to exploit this technology under licence from Onera (F). Non-space applications could include airports, industrial sites, power and communication networks, and environmental monitoring.

Lidar

Lidar is an advanced gaseous pollution sensor derived from MBB's experience in laser technology. This probe detects contaminating gases up to 6 km away.

Lucid

Lucid is image-processing software developed by Logica (UK) for remote-sensing applications. Success in space has led to this software being used in many other fields, including medical diagnostics and fingerprint analysis.

The process of technology transfer

Can the process be defined?

Technology transfer is known to be a slow and cumbersome process and few technologies are ever put to alternative uses. The challenge is to define the transfer process (Fig. 7), measure it, and make it more efficient.

In bringing the buyers and sellers of technology together, the objective is to find as many successful matches as possible, and sometimes the process needs a little encouragement. The transfer has to be seen as mutually beneficial; both parties have to be convinced that they will benefit from the transaction for it to succeed. The chances of this happening randomly are relatively small.

Technology can fail to be applied for many different reasons; sometimes it is too early, and other times it is simply a lack of understanding. A New York scientist invented X-ray tomography, which enables body scans to be produced. He presented it to a medical meeting, but the audience could not understand the technique. He abandoned the work, and was chagrined to see that the process was subsequently 're-invented', became a technical success, and that its inventors received the Nobel Prize!

As computer users we live with many problems today because the inventors of the microprocessor did not understand the concept of virtual memory, although it had been invented more than ten years before the first microprocessor was built.

The messages of technology transfer are clear:

- *Applying existing knowledge is more efficient than inventing new technologies.*

- *Buying technology in is cheaper than inventing in-house.*

This does not mean abandoning basic research, or failing to understand the core technologies for an organisation. But we must look around to re-use existing knowledge first.

Quantifying the process

When we look at the technology-transfer process, we can see that the end-to-end success rate is relatively low. For every ten thousand brochures we send out, or for every ten million people who see a TV programme on technology transfer, we might get one or two transfers. This is an opportunity as well as a problem; if we can focus our promotional efforts on the most cost-effective mechanism, we can raise the success rate dramatically. Even a small amount of support applied at the right point may help. Understanding and measuring the technology-transfer process is vital if we are to improve this success rate. A few of the proposed techniques currently being tried are to:

1. Focus on specific technologies and companies with expertise in that domain.

   In this case, specialised institutions may have mailing lists or contacts for specific domains, such as heat transfer or structural analysis.

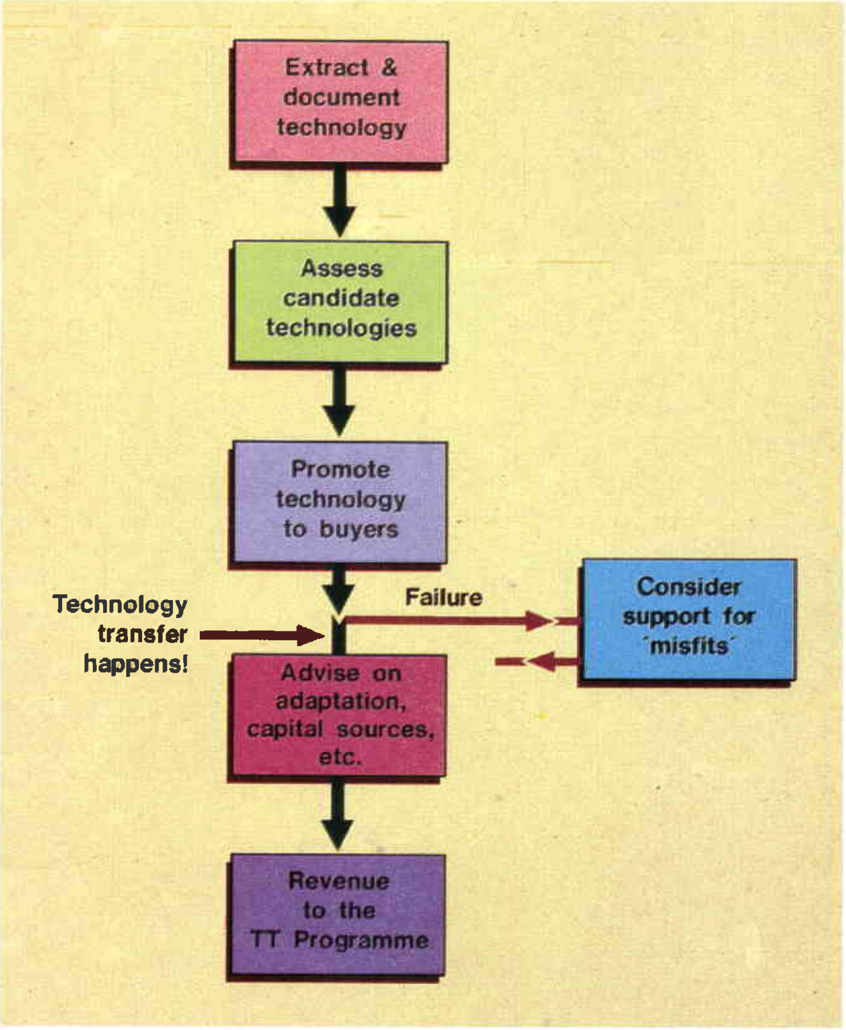


Figure 7. The baseline technology-transfer process

2. Focus on technology through individual specialised contacts.

   Very often the expert in the field will know immediately who may be interested in using a particular technology. A small amount of finance provided by the Technology Transfer Programme to adapt technology could make all the difference. This approach can short-circuit the whole process of technology transfer. The ESA programme has several such focussed negotiations underway.

3. Wider publicity through television and newspaper articles.

   Television coverage is much less focussed than the TEST catalogue, but also much less costly per contact, and therefore could reach a wider audience. Obviously, the technology to be transferred must be interesting enough for a TV science or technology programme. The ESA Technology Transfer Programme will attempt to promote technology programmes on European television in the coming months.

The simplest way to improve our Technology Transfer Programme is to copy from schemes that are successful elsewhere – another form of technology transfer! The ESA team keeps up-to-date with practical and academic work on technology-transfer processes, and if anyone finds a better way of transferring technology, we will try it!

Promotion of technology transfer

One arm of the initial process is the collection of the existing technologies on offer. The second concerns marketing of these technologies to potential customers. Promotion is an integrated part of the technology-transfer companies. Non-space companies have to be made aware of the opportunities available. Initial contact may well be made via the TEST catalogue, or through any of the promotional schemes, ranging from focussed development to broad-band publicity. Many newspaper and magazine articles have appeared discussing ESA's Technology Transfer Programme. When companies interested in buying the technology contact the Spacelink consortium, they can explore the technology in more detail, often involving a meeting with experts in the technology concerned.

A 'proactive' technology-transfer policy?

Another key area of promotion is to encourage ESA staff to think about technology transfer during the course of their work. Lateral thinking at an early stage can make development work far more marketable.

The approach discussed above involves taking existing technology and trying to transfer it as it is, perhaps with minor modifications. An alternative, 'pro-active' policy, tries to build technology transfer into the original R&D from the start. The instigator of the research is encouraged to think about potential applications during the R&D phases of the project. This pro-active policy could involve additional requirements or research, or in some cases merely stimulating companies involved to think about potential markets as the technology is evolved.

Requirements from non-space areas are then considered during the development effort. Obviously this area has to be handled very carefully, as the core of ESA's work must remain focussed on space activities, and the pro-active approach consumes more resources and time. One or two demonstrators may be used to pilot-test the pro-active approach.

Conclusion

Technology transfer is an issue that will become steadily more important to ESA and to European companies. The space industry has a duty to make its research findings available outside the space arena. Scarce resources for research must be used as efficiently as possible, and the space industry must show Europe that the investment in space is paying dividends in terms of terrestrial applications. The ESA Technology Transfer Programme may eventually affect how ESA's own engineers perceive technology as a process. Nobody should underestimate the difficulties of the technology-transfer process, but ESA can be proud to have started this scheme.

This article was prepared by the Technology Transfer Group of ESA. If you wish to be kept informed about the ESA Technology Transfer Programme or to receive TEST catalogues, please fill in the form below and send it to:

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Tel. (33) 1 42 73 73 29
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Please send further information on ESA's Technology Transfer Programme to:

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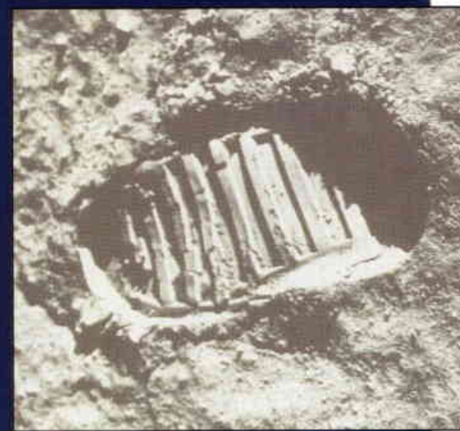

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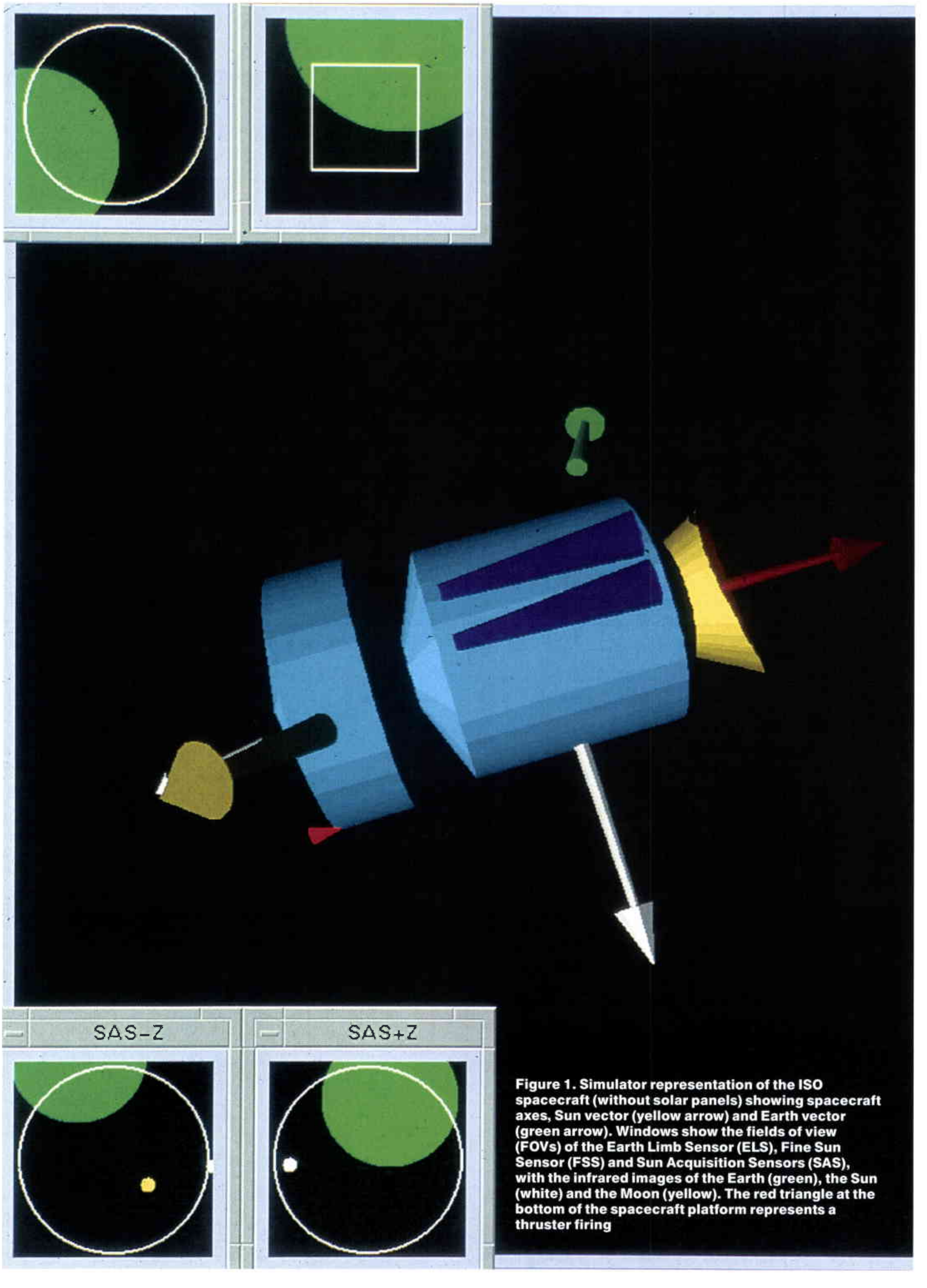

Figure 1. Simulator representation of the ISO spacecraft (without solar panels) showing spacecraft axes, Sun vector (yellow arrow) and Earth vector (green arrow). Windows show the fields of view (FOVs) of the Earth Limb Sensor (ELS), Fine Sun Sensor (FSS) and Sun Acquisition Sensors (SAS), with the infrared images of the Earth (green), the Sun (white) and the Moon (yellow). The red triangle at the bottom of the spacecraft platform represents a thruster firing

Advanced Simulation Tools to Support Satellite Operations

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Advanced simulation tools are being developed at the European Space Operations Centre (ESOC) in the context of updating the existing simulator infrastructure. The aim is to provide enhanced support for simulator development work and to offer users a flexible and more powerful simulation environment on the desk top.

Introduction

ESOC develops real-time satellite simulators for operations support during both the mission-preparation and mission-execution phases. These simulators are used primarily for the testing and validation of the Operations Control Centre (OCC) facilities and flight-control procedures, as well as for the training of the ground-network operators. They have also been applied successfully in a research-oriented context, for example for the validation of a new, advanced spacecraft autonomy concept and for the demonstration of the feasibility of using standard satellite checkout equipment for simulator validation.

Generic simulator components are being developed at ESOC to establish an advanced run-time environment as well as a graphics-based modelling environment for spacecraft subsystem models. These infrastructure tools will support efficient and reliable simulator development activities and will allow the use of low-cost desk-top computers with powerful graphics capabilities (work stations) for such tasks.

Run-time environment

A new run-time environment, known as SIMSAT (Simulation Infrastructure for Modelling SATellites), will provide the required flexibility for simulators to run on a decentralised processor architecture, which can be adapted to different processing performance needs.

The system has been conceived to run on a cluster of Digital/VAX stations, under the VMS operating system. Re-usability of the various components of this software system has been one of the main design drivers. These components are:

– A *Real-Time Kernel*: This provides facilities for simulation control, simulator com-

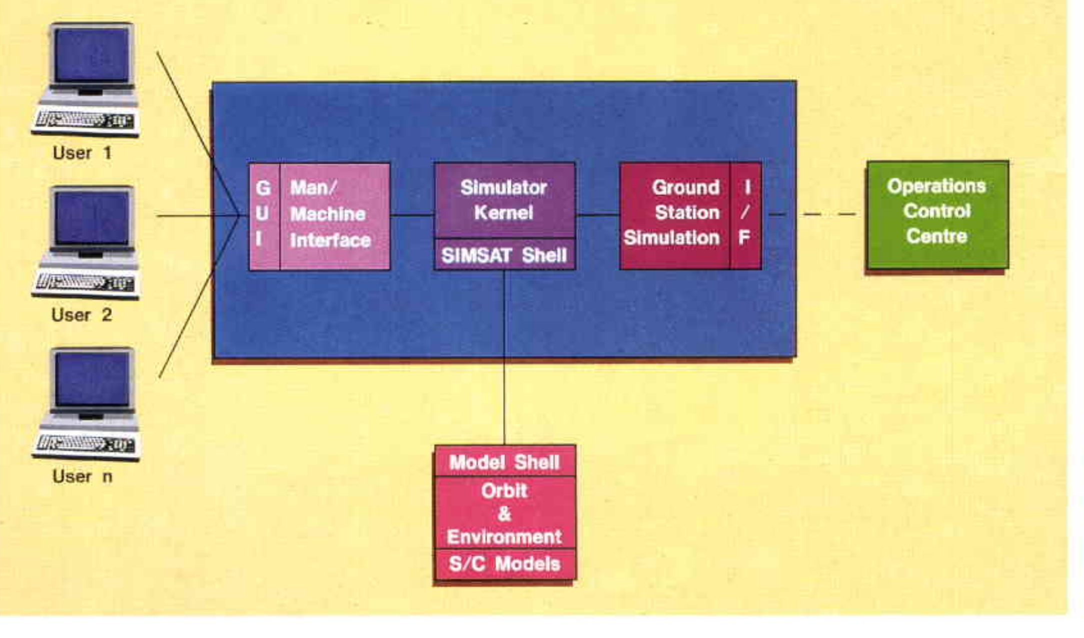

Figure 2. SIMSAT provides general-purpose simulator software as well as general-purpose models. Spacecraft-specific models can be integrated to constitute a complete simulation system

manding, model scheduling, and data logging and recording. The design is object-oriented and is based on reusable components to facilitate efficient development and maintenance. It offers a generalised interface for models in order to simulate a particular satellite. These can be attached without having to modify or re-compile the kernel code.
- A *Graphical User Interface*: This tool, based on the OSF/Motif windows standard, supports control of the simulator and the telecommanding of the simulated spacecraft, as well as the monitoring of the simulation by means of alphanumeric representations, trend graphs, synoptic diagrams and three-dimensional spacecraft animation, all in real time.
- A *General-Purpose Ground-Station Model*: The ground-station model is reusable for all satellite simulators and missions, by allowing flexible configuration of the ground stations and related equipment. It includes the simulation of standard equipment and relevant ground-network protocols. Dedicated equipment or additional ground-network protocols can be simulated by adding the required models. This component provides the interface to the Operations Control Centre (OCC).

The modular architecture allows for these components to be integrated with spacecraft models into a complete simulation system.

Model-development environment
This environment, called 'SIMAID', has been conceived to aid in the efficient design and implementation of satellite subsystem models. Using SIMAID, the simulator developer is able to build subsystem models by graphically connecting lower-level models from a library of generic templates. The resulting topological representation is then translated into Ada code by a code generator.

The Real-Time Kernel

The real-time kernel provides general-purpose simulation functions common to all simulators. It has been designed following an object-oriented approach and is being implemented using the Ada programming language.

The main advantage of the object-oriented methodology was seen in the simple fact that large software systems are much easier to design, develop and maintain if they are conceived as a set of reasonably manageable modules loosely coupled to one another. Loose coupling is best achieved by grouping together data (attributes) and related operations (functionality).

Reusability of kernel objects in other components of the simulation system has also been a driver for the design. Objects for inter-process communication and data management, for example, are re-used throughout the system.

The software has been designed to allow distributed processing, with the Graphical User Interface and the Ground Station Model components running on separate nodes. It should also be possible to distribute the various models on different processors, in order to benefit from parallel processing. Further study is, however, required in this area to achieve a suitable synchronisation and communication mechanism between the parallel running models.

Real-time access to the simulator variables is required in order, for example, to allow on-screen visualisation of the response of the spacecraft being simulated. Efficiency in doing this is essential, because of the large amounts of data to be accessed in real time and the fact that different components may be running on different nodes (implying data transfer via the network). This access is provided by keeping track of the address in memory of the so-called 'public variables', which can then be read and sent upon request in the form of data-streams to the Graphical User Interface (GUI). Memory mapping is used to capture the status of the simulator at a particular point in time, allowing the simulation to be restarted later from that point (so-called 'break-pointing').

The real-time kernel provides a generalised interface for a variety of models. To simulate a particular satellite, orbit and environment models and specific satellite-subsystem models can therefore be integrated with the real-time kernel software. The interface between the real-time kernel and the models is conceived so that the model developers do not require knowledge of the real-time kernel's internals. Hence, it is possible to build a complete simulation system without having to re-compile any of the real-time kernel.

Although the current concept is that the spacecraft models should be written in Ada, existing models written in Fortran can also be reused by building a suitable Ada shell around them. This allows one to retain the high degree of verification that has been achieved by some models after years of use and improvement.

The Graphical User Interface

The Graphical User Interface (GUI) provides monitoring and control facilities for simulators by acting as a layer between the user and the kernel of the simulator, to which it is loosely coupled via service calls. It is based on the OSF/Motif windows standard.

Although the GUI has been designed to interface with the new SIMSAT kernel described above, its general character and modularity allows it to be coupled with other simulation software also. For example, it is currently being used as a front-end monitoring and control tool for the simulator of ESA's Infrared Space Observatory (ISO) satellite, which is based on ESOC's General-Purpose Satellite Simulator Package (GPSSP).

Monitoring facilities

Log display
The simulation log keeps track of all significant events taking place during a simulation run. This option allows both viewing and reviewing (i.e. looking at the past history, searching for particular entries) of the simulation log. Message filtering is provided to enhance log readability. Hence it is possible to select certain types of messages (e.g. error messages) and particular message sources (e.g. from a certain payload) for display.

Alphanumeric display
This option allows for the visualisation of simulator variables, arranged in tables, in alphanumeric format. The user can define the layout and select any public variable to be displayed. Limits can be set for each variable; when such limits are reached, the displayed variable changes colour or an acoustic signal is triggered. Derived parameters can also be obtained and displayed by applying mathematical functions to the simulator variables (this is also possible for the other display options). Recording and playback facilities are provided in connection with display definitions.

Graph display
This option allows for the visualisation of simulation variables in graph format, i.e. X–Y trend curves. Up to four curves can be represented on the same graph, each in a different oolour. Modification of axis scales and labels is possible whilst the simulator is running. Automatic forward scrolling takes place in order to show current status. Backward scrolling can be triggered manually to review previous portions of the graph. Here also, recording and playback facilities are provided in connection with display definitions.

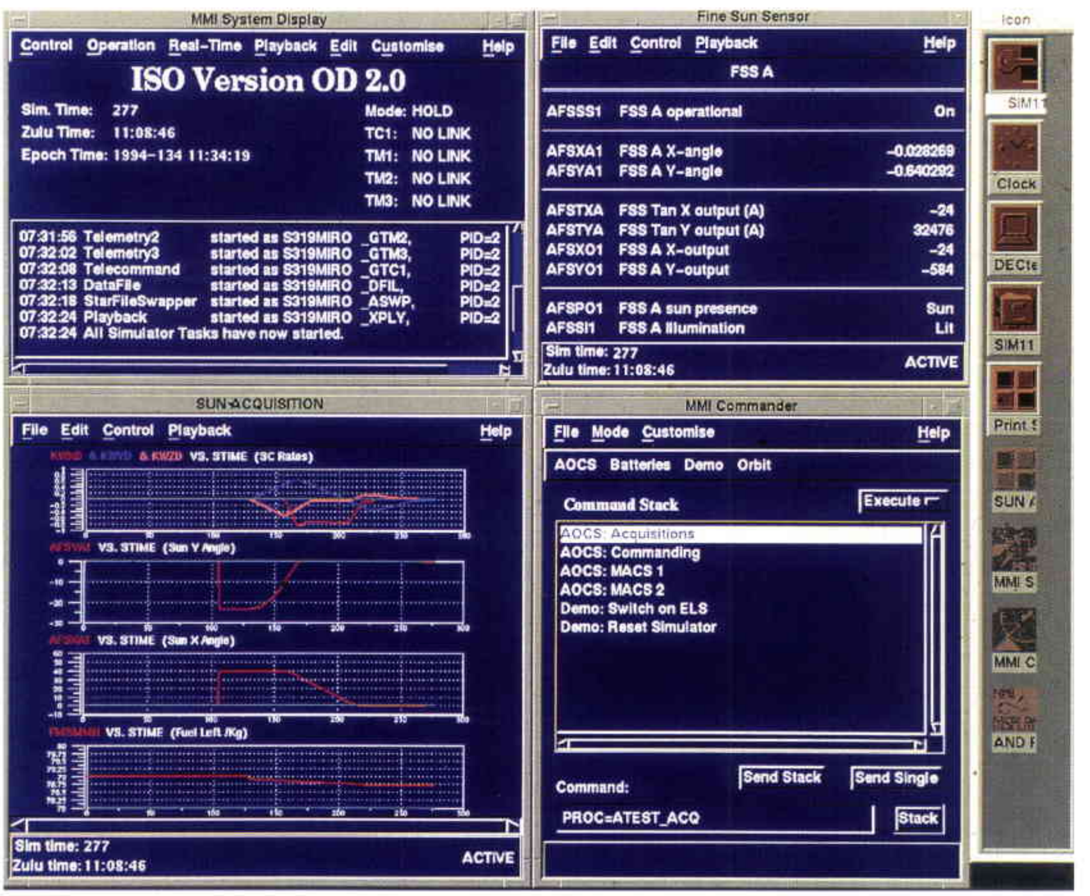

Figure 3. View of the simulator Graphical User Interface (GUI) showing the main window (MMI System Display), an alphanumeric display (Fine Sun Sensor), a graphical display (Sun Acquisition) and the command window (MMI commander)

Figure 4. View of the GUI showing synoptic diagrams for: the whole spacecraft (upper right), battery 1 (lower left), and the power distribution to the non-contaminating actuator (lower right) of the ISO simulator. The upper left window allows selection of synoptic diagrams from a library

Synoptic (mimic) display
This option allows for the graphical visualisation of the status of spacecraft subsystems or of their components via animated synoptic representations. It is possible to define up to eight levels in the representation hierarchy. From the synoptic of the whole spacecraft one can, for example, access the different subsystem synoptic diagrams by clicking with the mouse, and from there branch into any of the components and so on. The synoptic diagrams can be built from icons representing elementary components available from a library. These icons have then to be attached to the corresponding model variables. As for the alphanumeric and graphical displays, recording and playback facilities are provided.

Three-dimensional spacecraft visualisation
This option offers an animated 3-D representation of the spacecraft in real-time, showing its attitude and orientation dynamically with respect to Sun, Moon and Earth as calculated by the simulator. Further options allow the representation of the celestial chart showing a star map, the representation of the field of view of the sensors, and the representation of the terrestrial chart showing the ground stations with coverage zones and day/night threshold.

Control facilities
Simulator control commands as well as telecommands can be sent from a commander window provided by the GUI. The commands can be entered on a command line or can be selected from pre-defined command menus. These menues can be edited and then stored in a library, from which they can be loaded onto the command menu bar. Command stacks can be built, edited, stored and re-loaded at a later point in time. The command-history option allows one to keep track of commands already sent. The commander also validates the command syntax before actually sending the command to the simulator.

Another means of commanding is provided by the synoptic diagrams. For example, the switches represented on the lower right-hand-side synoptic of Figure 4 can be opened
or closed by clicking on the 'ARM' and 'DISARM' buttons, respectively.

General-Purpose Ground-Station Model
The Ground Station (GS) model can be regarded as an element common to all satellite missions and it can be adapted to each mission by configuring it accordingly. Dedicated equipment (e.g. telemetry processors) specific to a particular mission must also be accounted for. In order to cope

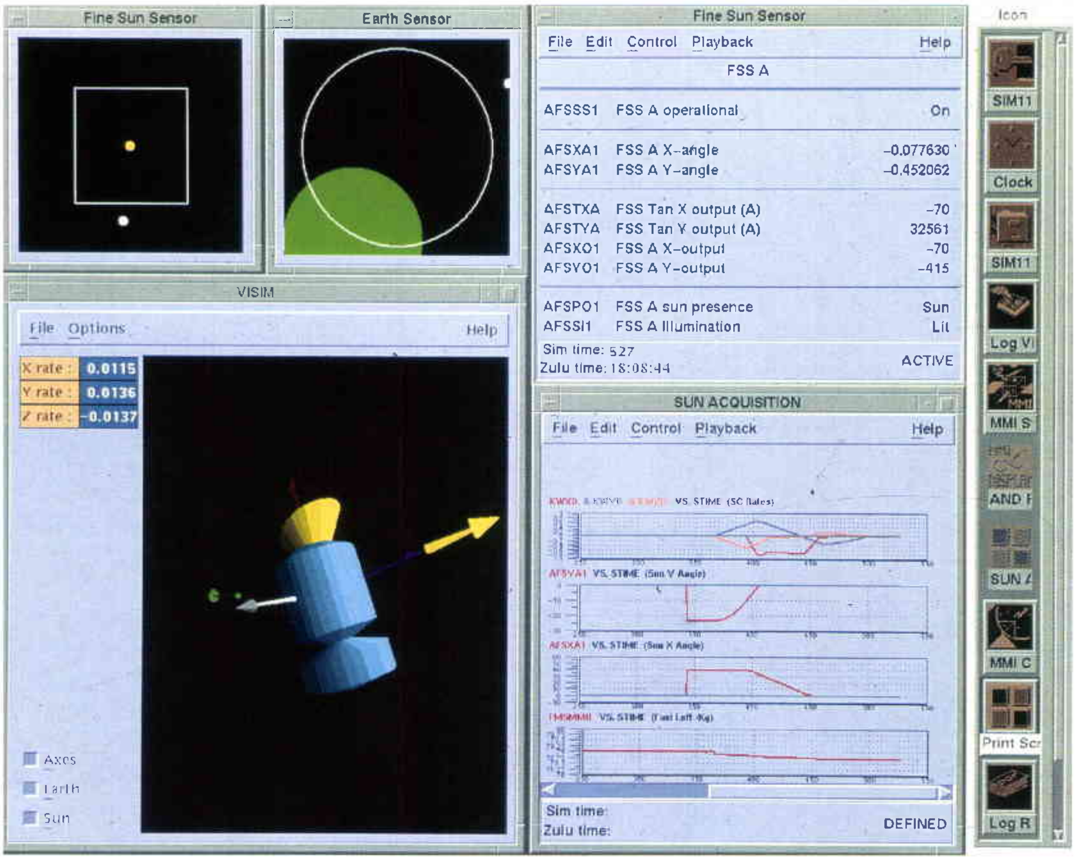

Figure 5. View of the GUI showing a typical screen configuration for following up spacecraft manoeuvres

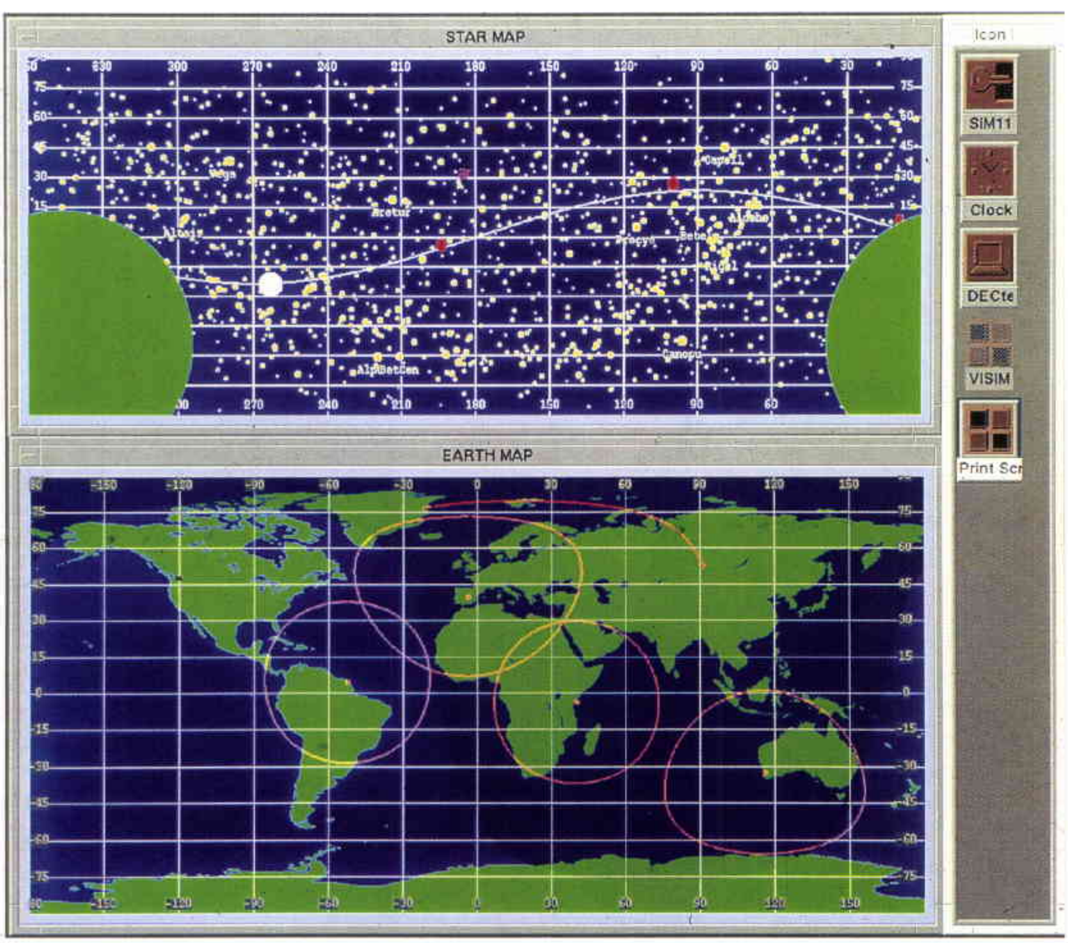

Figure 6. View of the simulator GUI showing the star map (top) as obtained during the Hipparcos mission, as well as relevant celestial bodies including the Earth (green). The Earth map (bottom) shows the positions of the ground stations and their coverage zones

with this requirement, additional models representing the equipment in question can be added to the system without changing its structure. Several relevant communication protocols are also simulated and can optionally be selected; new ones can be added if required.

The simulation of ground-system status covers mainly:
- configuration of the simulated ground system
- status of ground-station equipment
- activation of equipment models
- validation and execution of ground commands according to prescribed command definitions.

The simulation of ground-station equipment includes different types of such equipment, selectable from a library of available modules which currently includes a telecommand encoder/decoder, station computer, and ranging equipment.

The interface to the Operations Control Centre is also part of the GS simulation package and two sorts are currently supported:
- the Packetnet System Interface (PSI), which provides message transmit and receive services using the X.25 protocol
- the Open Systems Interconnection (OSI) interface, which provides message transmit and receive services using the OSI upper-layer protocols.

Model-development environment

A computer-aided modelling environment is being pursued in order to reduce the effort required for simulator model development and, at the same time, to increase model reliability (leaving less margin for human error) and to facilitate model maintenance. This environment, called 'SIMAID', should allow one to build a complete spacecraft model and, after code generation, to export it to the run-time environment described above. The functions to be provided are summarised in the accompanying panel.

Proposed SIMAID Functions

- Graphical, interactive model composition from elementary (atomic) models or from other composite models. The model developer will be able to define a certain model topology by selecting models from a model library and defining their inter-connections via mouse clicks.
- Hierarchical model building and representation. This will allow one to hide the low-level complexity, e.g. the model of a sensor, when defining the interfaces of the sensor to the rest of the attitude and orbit control subsystem. Clicking on the sensor model will reveal the internal modelling.
- *Viewpoint* representation of models: this allows certain modelling aspects of a component model to be represented whilst hiding others. For example, when modelling a spacecraft it may be convenient at some stage to concentrate on the electrical power-distribution network without having to deal at the same time with the thermal links, although internally both models – electrical and thermal – are coupled to one another.
- Access to the Ada Language Sensitive Editor for production of atomic-model templates. No pseudo-language representation will be used, thereby making the full power of the Ada language available to the model developer.
- Instantiation (re-use) of generic models. For each model, an instantiation panel will be defined which can then be invoked on the screen and the various optional parameters filled in.
- Code generation (in Ada) for a complete model from the atomic-model templates, the topological representation and the instantiation parameters.
- General interface for integrating external models, i.e. models that without being managed within SIMAID are required to provide the SIMAID models with realistic data, such as an environment or payload model developed externally.
- Configuration management of the models generated or imported, i.e. keeping track of the different versions of the models and ensuring consistency of the set used to represent a specific satellite.
- Run-time environment for preliminary verification of the models. Final verification and validation of the models will, however, take place in the target simulator run-time environment.

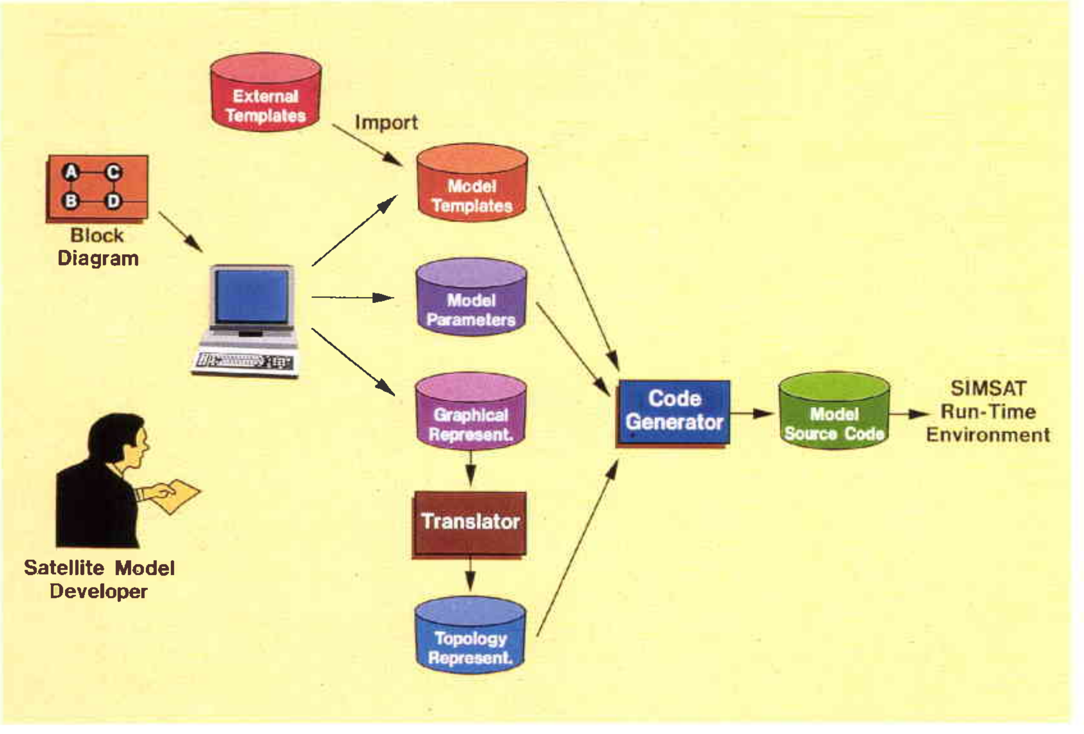

Figure 7. The SIMAID development environment allows one to build spacecraft subsystem models graphically based on a library of elementary or composite components, and to generate Ada source code from the model definition which can then be exported to the run-time environment

Conclusion

The tools presented above constitute both a simulator run-time environment and a graphical modelling environment. They are aimed at supporting efficient satellite simulator development, as well as at providing the user with a powerful and easy-to-use simulation tool. They have been designed to run in a distributed-work-station configuration, thereby enabling efficient simulators with user-friendly graphical interfaces to be available on the desk top. This, it is believed, will stimulate the wider use of real-time satellite simulators and thereby have a favourable impact on mission-preparation and mission-execution activities.

A phased approach has been followed for the implementntion of the various components of the simulator infrastructure. The GUI component is already available and is being used in combination with the ISO simulator.

The first version of the full SIMSAT system will be available this autumn. Additional ground-station equipment models and general-purpose satellite subsystem models will subsequently be implemented. SIMSAT will be used for the first time for the ESA Cluster satellite simulator.

Acknowledgement

The work presented in this article is being carried out under ESA contract by the following companies: Cray (UK) for the real-time kernel, Vega (UK) for the GUI, and CRI (DK) for the GS model and the SIMAID modelling environment (the latter with the participation of Science Systems, UK).

Simulation of Hypersonic Flight – A Concerted European Effort

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The aerothermodynamic design of vehicles that will enter or re-enter a planetary atmosphere relies largely on information gathered in ground-based simulation facilities. Owing to the different natures of the flow phenomena that occur along the flight path, different wind tunnels dedicated to particular phases of the flight are usually used. Ground simulation of the so-called 'hot' or hypersonic phase is particularly difficult because of the high powers required to generate the wind-tunnel flow.

Introduction

In any aerospace project, ground testing in wind tunnels plays an important role throughout all phases by providing detailed inputs to the designer on the performance and flight qualities of the configuration under development. In order to be able to make this important contribution, wind tunnels must simulate as closely as possible on reduced-scale models what will happen during the flight of the real aircraft or spaceplane.

The quality of such simulations is governed by so-called 'similarity laws' containing such parameters as Mach Number and Reynolds Number. A wind-tunnel test on the model of a conventional aircraft is deemed 'correct' if the ground simulation is performed at the Mach and Reynolds Number of the full-scale version. In the case of the Reynolds Number, which is defined as the ratio of the product: velocity times air density times a characteristic length of the body (e.g. wing chord) and the air viscosity, the wind-tunnel test must compensate the much smaller model wing chord of the wind-tunnel model by an increase in density, by a decrease in viscosity, or a combination of the two, so that the ground test and the flight 'happen' for the same value of Reynolds Number.

A spaceplane, when re-entering Earth's atmosphere, passes through several different flow regimes, each of which is governed by different similarity laws and therefore often requires specialised test facilities for representative simulation.

Re-entry flow simulation

During a re-entry into the Earth's atmosphere, a spaceplane encounters very different flow conditions (Fig. 1), ranging from highly rarefied flow at high altitudes where the atmosphere is 'thin' (low density), to the classical Mach/Reynolds flow regime nearer to the ground.

Coming down initially through a zone of low ambient air density using jet control, the vehicle experiences increasing density. The aerodynamic phenomena start in the hypervelocity regime, where the speed is such that nitrogen and oxygen molecules are dissociated (split up into atoms) behind the shock wave caused by the vehicle. At the beginning of the re-entry, the flow regime changes from molecular to continuous. It is then characterised by a thick boundary layer that interacts with the outer inviscid flow, which is of great importance for the pressure distribution on the vehicle. We usually call this flow regime the 'viscous interaction regime', which is dominated by high values of the similarity parameter $v = M/Re^{1/2}$, a combination of Mach and Reynolds Numbers introduced above.

Next, with further increasing densities, the space vehicle decelerates rapidly in a zone where the heat load is highest. The flow regime here could be called the 'hypervelocity regime at high density'. The real gas effects are the dissociation of the flow and the associated potential recombination of molecules.

Then, we approach a flight situation where classical Mach/Reynolds effects occur. The flight speed is already significantly reduced and the vehicle moves in the denser atmosphere closer to the ground. This flow is dominated by the state of the boundary layer (laminar, transitional, turbulent), the wall temperature ratio having a significant influence. The physical laws governing the flow behaviour are relatively well known.

Ground simulation in the hypervelocity regime at high densities is particularly important because it is here that the heat loads on the vehicle's surface are highest and therefore need to be known accurately in order to allow adequate design of the thermal protection. As indicated above, dissociation and recombination of oxygen and nitrogen are the predominant mechanisms in this flow regime. The test facility must therefore use air as a test gas flowing at speeds of between 3 and 8 km/s.

In addition, the simulation of high-speed chemically reacting flows, with dissociation and recombination occurring, requires the duplication of the number of inter-molecular collisions necessary to dissociate a molecule or to recombine two atoms. Investigations have shown that dissociation is a result of collisions between two partners, and therefore the magnitude of the dissociation effects on a model flow depends on the number of such collisions taking place in a given volume while this volume passes by the model. Thus the dissociation simulation is governed by the so-called 'binary scaling parameter', which is the product of density and linear size ($\rho \times L$) of the flow field looked at.

To simulate correctly recombination effects, for which three-body collisions are required, it is necessary to duplicate the product of density squared times linear size ($\rho^2 \times L$) in addition to speed. Therefore, in a given ground experiment with a reduced-scale model, binary and three-body collisions cannot be simulated at the same time. A test set-up for binary scaling will have the three-body reactions proceeding relatively too fast.

Another deficiency of ground testing in this flow regime is caused by the facility process of adding energy to the gas and then expanding it through a nozzle to the desired test conditions; very often the free-stream gas is already partially dissociated before it reaches the model and its bow shock, contrary to what occurs during the real flight.

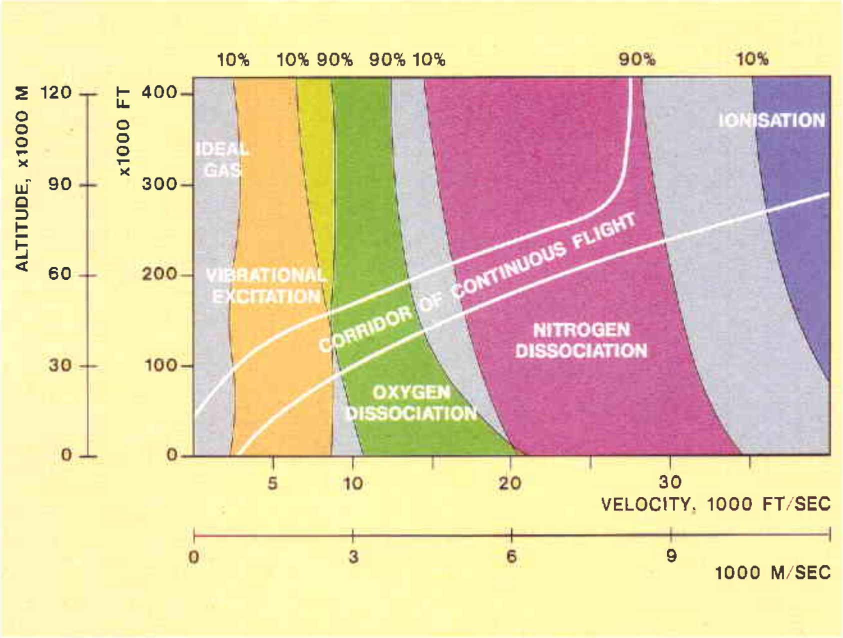


Figure 1. Flow phenomena during re-entry

To account for these deficiencies of ground testing, an interactive procedure between wind-tunnel simulation and computer simulation is necessary to provide realistic inputs for space-vehicle design. We have therefore adopted the widely accepted strategy of:

- testing in dedicated facilities, chosen according to the flight regime of interest
- calculating the conditions and results of our experiments to validate the codes
- cross-checking these codes with flight results, where available
- applying codes to real-case re-entries.

In view of this strategy, a review of existing wind tunnels in Europe was performed at the beginning of the Hermes Preparatory Programme. It was concluded that, when compared to the experimental simulation needs of this challenging programme and even after re-activation and modification of existing facilities, a considerable simulation gap existed for the flow regime in which real gas effects including chemical reactions are important.

In subsequent discussions between programme managers and representatives of the national research organisations ONERA (F) and DLR (D), it was decided to start design and construction of two complementary facilities: the F4 wind tunnel at ONERA, in Le Fauga near Toulouse, and the High Enthalpy wind tunnel at Göttingen (HEG). Because of those organisations' own interest in performing research activities in the new tunnels, the two projects were co-financed by ESA and ONERA and ESA and DLR, respectively.

The roles assigned to these two new wind tunnels are different, inkeeping with their different operating principles. HEG is mainly dedicated to producing very high speed flows (up to 8 km/s) on short time scales, in which both oxygen and nitrogen are dissociated. F4 was conceived to generate lower speed flows (up to 5.5 km/s) in which only oxygen is dissociated, with the possibility to make force measurements due to the longer test times.

Figure 2 shows the projected performances of both facilities as regards ($\rho \times L$) simulation. Their operating characteristics were chosen with an overlap in order to have a common reference point, thereby allowing binary scaling of Hermes-type re-entry over a large speed range.

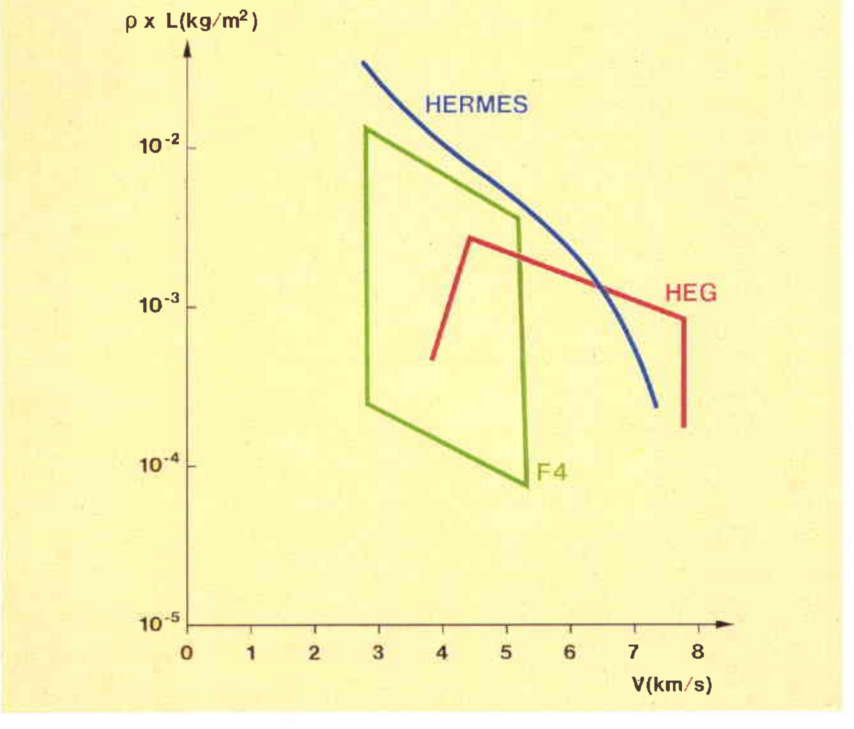


Figure 2. Projected F4 and HEG facility performances

The principle of hypervelocity testing is to create high-energy and high-pressure air conditions in a reservoir and to expand the gas from this reservoir through a convergent/divergent nozzle to the desired flow speed. Gas temperatures and pressures are usually so high that we must limit ourselves to very short run durations.

HEG's operating principle

A free-piston driver technique is used to create the necessary reservoir conditions. To produce a flow speed of 6–7 km/s in an expansion from a reservoir, the reservoir temperature has to be between about 7500 and 10 000 K with reservoir pressures of 100 MPa and more in order to achieve sufficiently high values of the product $\rho \times L$.

The rapid heating of the gas is achieved by passing a strong shock wave through it, which simultaneously accelerates it. In the reflected-shock-tunnel concept which has been applied in HEG, the gas is brought to rest by reflecting the shock at the end wall of the shock tube. From this condition, it accelerates through an expansion nozzle, resulting in a partially dissociated free stream in the test section.

To generate the desired level of reservoir enthalpies, shock speeds of the order of 5 km/s are needed, which implies that the driver gas must also be heated. Typically, if helium is chosen as driver gas, its temperature must be of the order of 4000 K. This again can be achieved by a short-duration method, the technique chosen for HEG being the adiabatic compression of the driver gas with a piston.

A schematic of the layout of the High Enthalpy facility in Göttingen is shown in

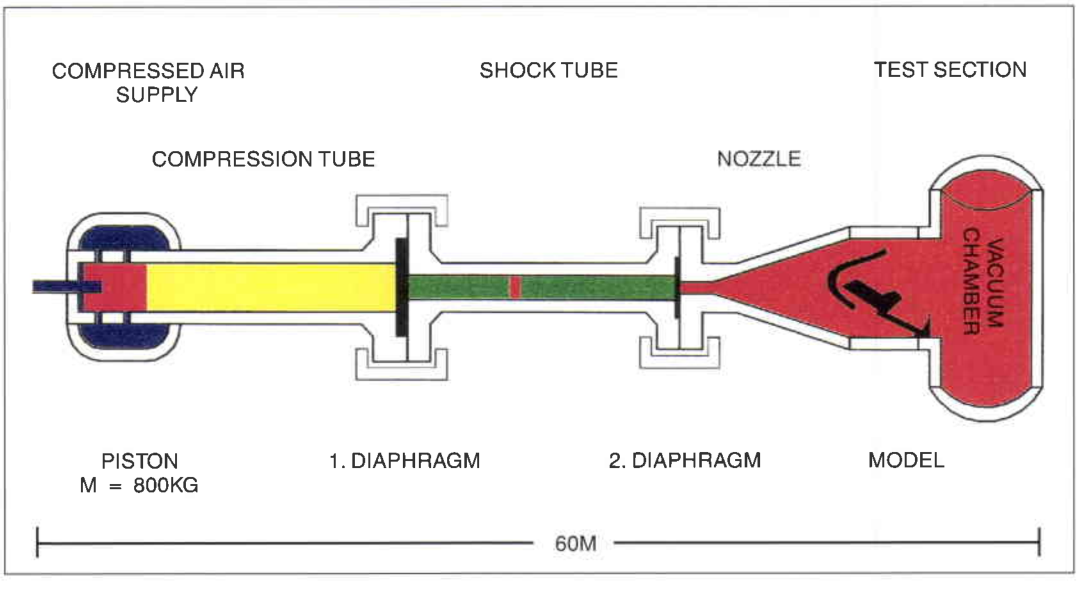


Figure 3. Schematic of the Göttingen High Enthalpy facility (HEG)

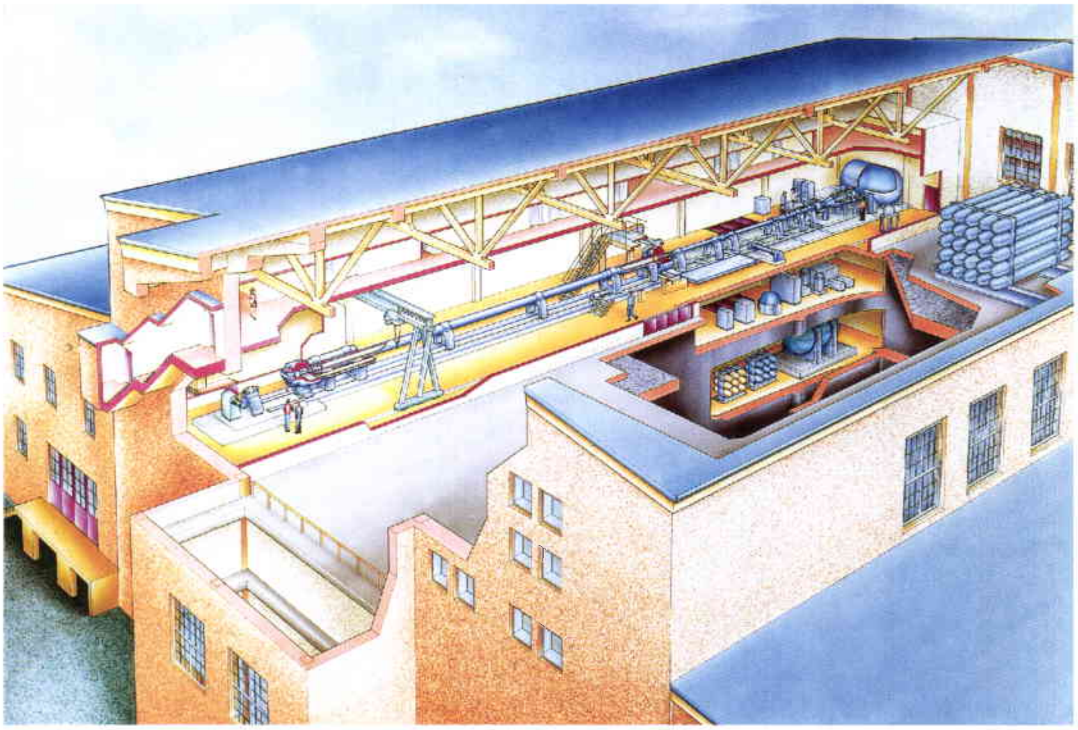


Figure 4. Artist's impression of the HEG building

Figure 3. The free-piston shock-tunnel arrangement consists of three main sections:
- the 'driver', consisting of an air buffer and a compression tube
- the shock tube, and
- the nozzle, with a large test section downstream.

The general arrangement of the facility and its auxiliaries in an existing building is shown in Figure 4. The driver tube and the piston insertion mechanism is on the left. Downstream of nozzle and test section, a vacuum vessel is visible in which the gas is collected during a run, to be exhausted later.

F4 operating principle

A hot-shot driver technique is used to create the necessary reservoir conditions for the F4 facility. A true reservoir with a volume of several litres is employed, which is initially filled with the test gas – air in our case – at pressures selected according to the final pressure level desired. The air is heated up and further compressed with an electric arc ignited between two electrodes integrated into the wall of the arc chamber surrounding the volume of air. The duration of the arc can be varied so that more or less energy can be transferred to the gas according to the desired reservoir conditions.

A schematic of the F4 facility is shown in Figure 5. The hot-shot wind-tunnel arrangement consists of the following main elements:
- the impulse machine (not visible)
- the arc chamber
- the convergent/divergent nozzle
- the test section in which the model can be mounted
- the diffuser, and
- the vacuum tank.

Figure 5. Schematic of the F4 hot-shot facility

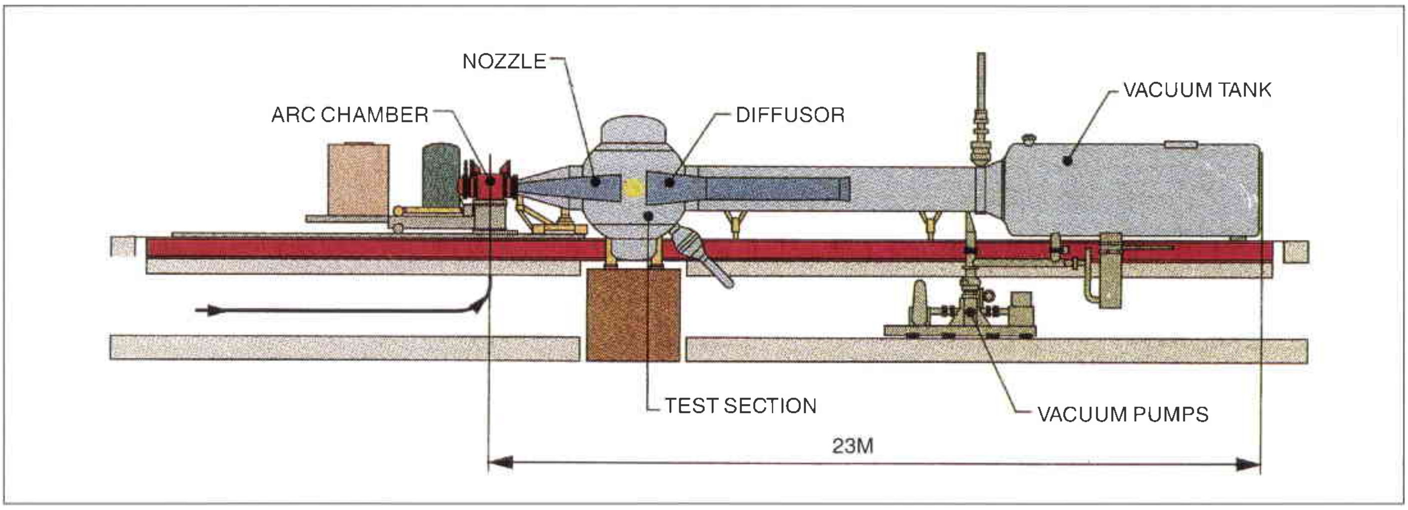


Figure 6 shows the F4 wind-tunnel when looking in the flow direction. In the foreground the arc chamber, the nozzle and the test section are visible. The two tubes attached perpendicular to the test section house a Schlieren system for flow visualisation. The diffuser and vacuum tank are located downstream of the test section. The vacuum pumping system is installed below.

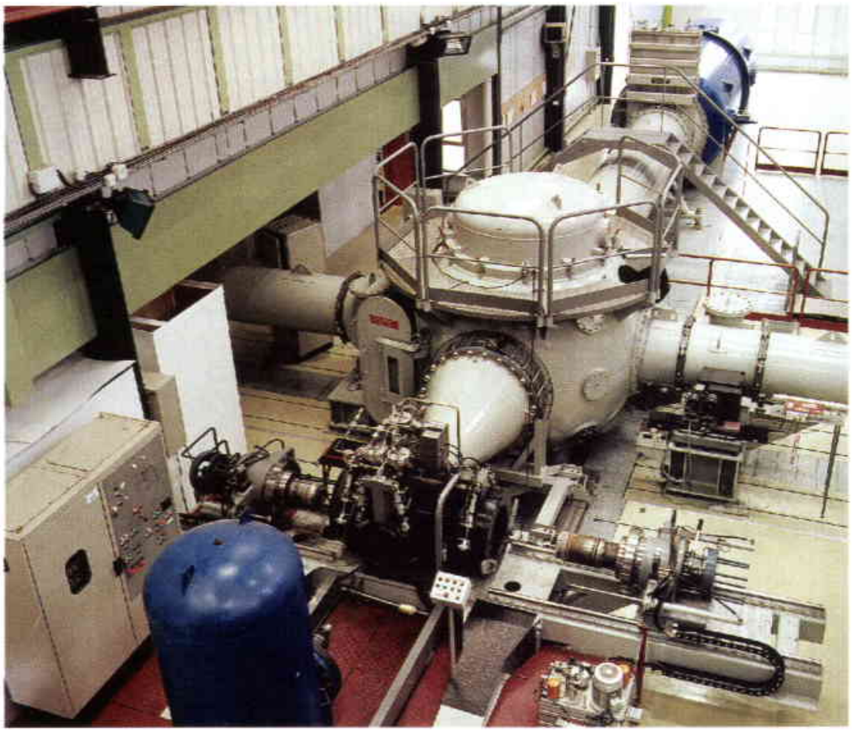


Figure 6. View of the F4 windtunnel in the downstream direction

Measurements and instrumentation

The F4 and HEG wind tunnels are also complementary in terms of their instrumentation. While both facilities are equipped with the usual static-pressure, pitot-pressure and heat-transfer gauges to probe the impinging flow, the development of more sophisticated optical methods has been shared in such a way that each facility has developed the most promising methods for its own operating conditions, but always bearing in mind the application in the other tunnel. A wide range of measurement capabilities is thereby evolving and unnecessary duplication of investment is being avoided through the close co-operation between the two organisations.

The basic measurement problem in any wind tunnel is to determine the effects of the flow on the model. In order to be able to relate the results to the real aircraft or spacecraft, the oncoming flow must be probed first because it provides the reference conditions for the calculation of the similarity parameters. In the conventional Mach/Reynolds flow regime, it is sufficient to determine the flow speed, the air density and its temperature, which is usually achieved with various pressure probes and thermocouples. Effects on the model are measured as surface pressure distributions or heat fluxes if local information is required. Global effects such as lift, drag and moments are measured with balances mounted between the model support and the model itself.

Given the high energies involved in the hypervelocity simulation, the oncoming flows in HEG and F4 will be more or less dissociated and the gas will not be in equilibrium. In other words, instead of having one temperature characterising the energy state of the test gas, we have to determine vibrational, rotational and static temperatures. In view of the small dimensions of the flow field between bow shock and body surface, advanced non-intrusive optical methods are needed in such a situation. Various techniques are under development for HEG and F4 in this context, two of which are holographic interferometry and electron-beam fluorescence.

Holographic interferometry in HEG

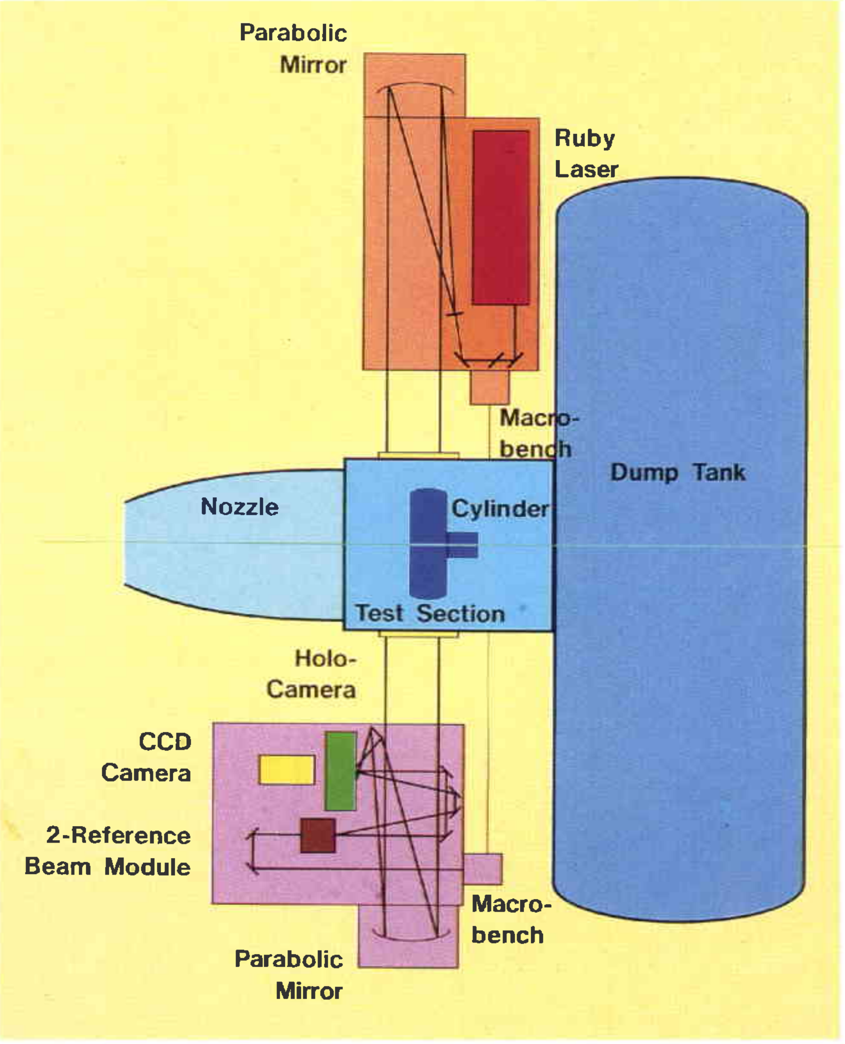
Holographic interferometry is an optical method for studying density variations in the optically transparent flow around a model installed in a wind tunnel. It is based on the ability to record and re-construct wavefront shapes by the use of diffraction grids. The information recorded is a two-dimensional representation of the (optically integrated) density of the gas in the model flow field. It is the same information as obtained by other interferometers like the Mach–Zehnder or Michelson, except that in the holographic interferometer the two wavefront shapes that are compared are obtained at different times along the same propagation path, rather than at the same time along different propagation paths.

The no-flow picture is recorded on a holographic, high-resolution, optically sensitive plate as an interference pattern between the object beam propagating through the test section and the reference beam propagating around it. This interference pattern serves as a diffraction grid when illuminated with a re-construction beam. When the re-construction beam is identical to the original reference beam, the first-order diffraction behind the recorded hologram will be identical to the object beam.

The hologram with the flow is recorded in an identical manner on the same holographic plate. When the developed double-exposed hologram is reconstructed by illuminating it with the reconstruction beam(s), the interference pattern between the two first-order waves behind the holographic plate is caused by changes of density in the test section between the two recordings, and is made visible as a series of dark and bright lines representing lines of constant density in the flow field. This interferogram can then be further analysed or used as an illustration of the flow field directly.

The reconstructed interferogram is recorded on a CCD camera connected to a computer on which the data can be processed. Figure 7b is a colour-coded infinite-fringe interferogram taken during an HEG run with a cylinder mounted in the test section perpendicular to the flow. Evident ahead of the cylinder is a bow shock, across which the density jumps. Also clearly recognisable is the start of an expansion along the cylinder's surface. As well as providing a quantitative measure of the density variations in the flow, the interferogram provides a recording from which the shock shape can be measured.

The electron-beam fluorescence technique in F4
This technique is widely used in hypersonic experimental aerodynamics to measure species concentrations and temperatures. A high-energy electron beam (20 to 50 keV) is passed through the flow to be probed.



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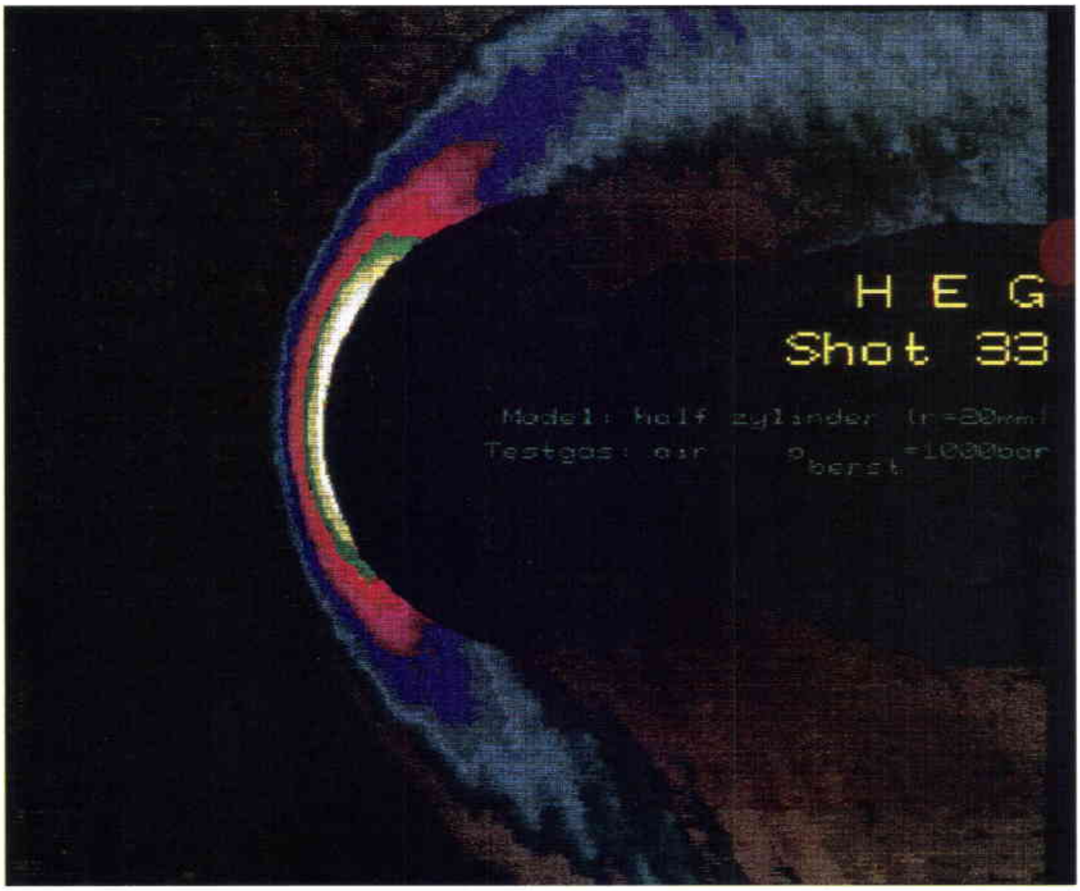

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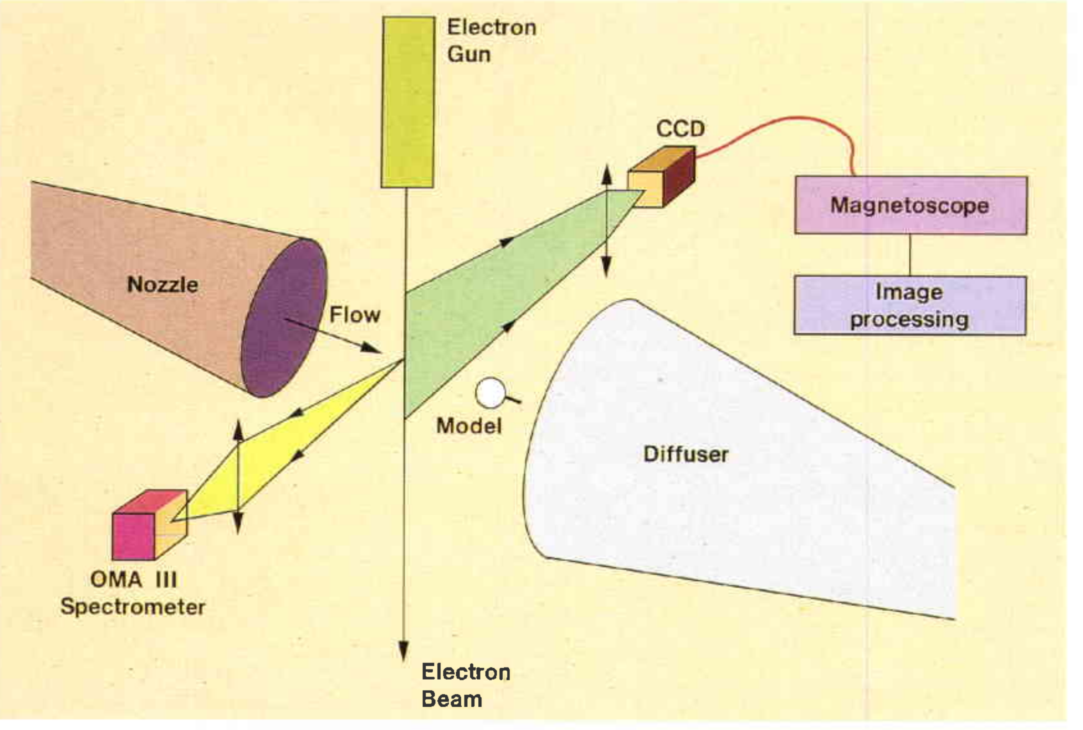
Figure 7a,b. Flow visualisation with a holographic interferometer

Figure 8a,b. Flow visualisation with the electron-beam technique



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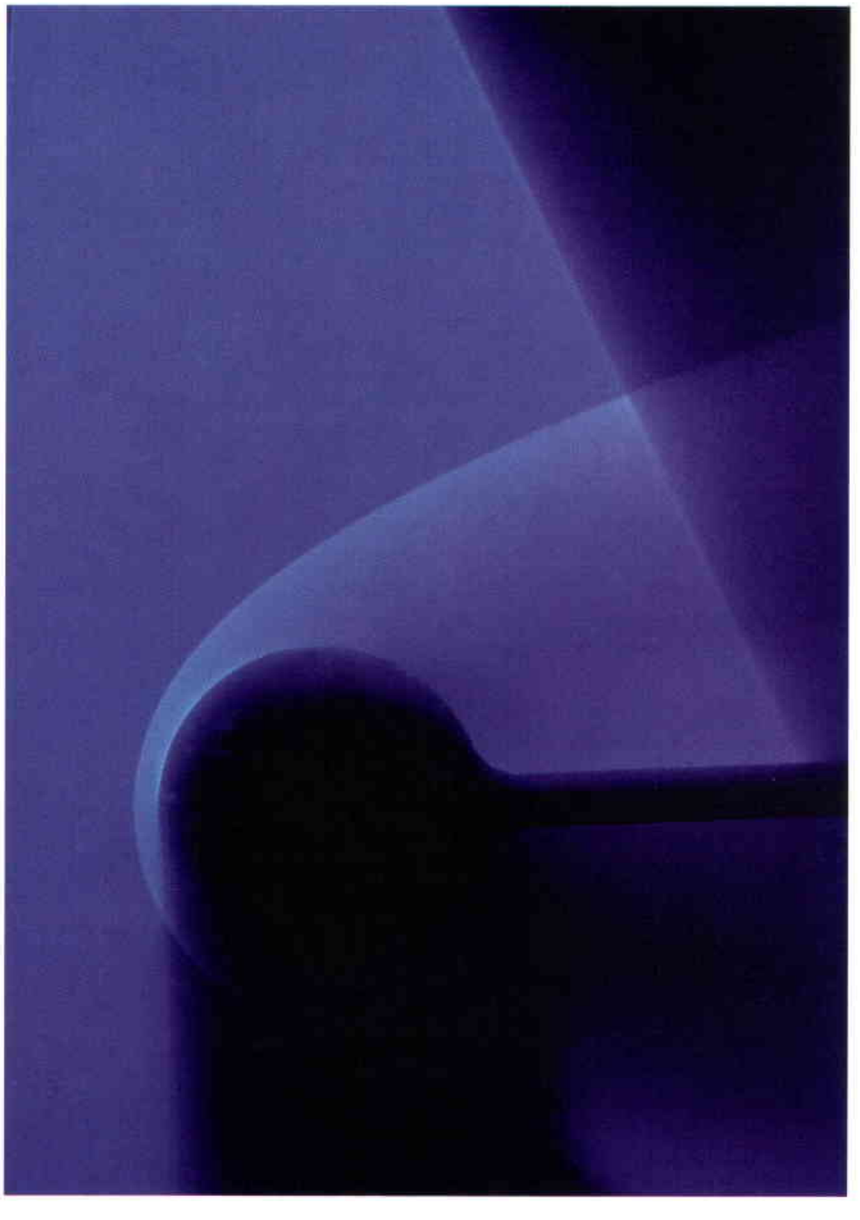

The electrons of this beam excite the molecules or atoms of the gas flow from their basic electronic energy level to a higher but unstable level. From this elevated level the molecules fall back to a stable energy state by spontaneously emitting light. Within given limits, the intensity of the emitted light is proportional to the gas density. Spectroscopic analysis of the light gives access to the vibrational and rotational energy states, and thus allows one to measure vibrational and rotational temperatures which, as noted previously, differ from one another in the hypervelocity regime because the internal degrees of freedom of the molecules are not in equilibrium.

Figure 8a is a schematic of the electron-beam apparatus setup in F4. The electron gun is directed perpendicular to the flow and can be moved along the flow axis in front of a model in the wind tunnel. For density measurements or flow visualisation, the beam can be shifted periodically along the flow axis, exciting a two-dimensional plane. This light is focussed via a lens system on a CCD camera, from which the data can be stored on magnetic tape.

Figure 8b is a photograph taken in such a setup during preliminary testing of the electron-beam apparatus in ONERA's R5 facility. The model used is a sphere placed in a Mach-10 flow from left to right. The picture clearly shows the bow shock developing around the sphere, and it is easy to determine the shock stand-off distance on the model axis. In the lower part of the figure the flow structure is less visible due to the shadowing effect of the model and its holder.

For temperature measurements on the nitrogen molecules in the flow, the light from the static beam is focussed via a lens system into a spectrometer, which registers the light intensity emitted as a function of wavelength. At a moderate wavelength resolution, the relative intensities of two suitable vibrational lines give access to the vibrational temperature of nitrogen. By further resolving one such vibrational line, the rotational fine structure of the nitrogen module becomes accessible and, via its analysis, the rotational temperature can be deduced.

The electron-beam technique is basically a low-density technique and so cannot be reasonably employed at densities above 0.001 kg/m^3. It therefore covers only the low-pressure operating range of the F4 facility. Outside this range, other methods are being used.

Status of facility development

Construction of both facilities is now complete, HEG being officially inaugurated on 5 February 1992 and F4 on 11 June 1992. Since then, intensive development testing has been taking place to explore the exact operating domains of the two wind tunnels and to determine the exact nature of their limits. Having been designed using state-of-the-art engineering methods, but for specified performance values well beyond those of existing test facilities of their type, in both cases the operating domains now available already exceed what was available previously.

Further progress will be tedious and time-consuming, however, in that the difficulties encountered in both types of facilities are the same. As a consequence of the high heat loading in the reservoir (arc chamber of F4 and end of HEG shock tube) and nozzle throat area, the surface temperatures approach the melting point of some of the materials used, leading to erosion and sometimes deformation of components because of the very high operating pressures.

Erosion is undesirable for two reasons. Firstly, it adds a gaseous metal component to the gas stream, the chemical interaction of which with this gas can be very complex, leading us further away from similarity conditions. Secondly, erosion of the throat will change the nozzle expansion of the gas over time in an unknown way, thereby increasing uncertainties in the knowledge of the oncoming flow.

Further development work is focussed in three directions:
- testing of materials with good heat-conducting properties
- development of alternative designs
- reduction of testing times to an acceptable minimum.

A concerted effort is planned during the Hermes Technology Programme between the facility operating teams, their associated instrumentation groups, and the groups working in other ESA Member States, on computer-code development for the hyper-velocity flow regime. Models of simple geometry – sphere, cylinder and blunt cone – will be tested; computer predictions of the wind-tunnel process and consequent model flow will be made and compared with test results; bodies for which flight results are available will be tested in order to compare ground simulation and real flight; and finally a spaceplane model will be tested and all the accumulated experience will be used to predict its flight characteristics with much improved confidence.

Acknowledgments

The authors would like to thank the HEG and F4 wind-tunnel operating teams and their instrumentation colleagues for the provision of material and many helpful suggestions, but most importantly for their continued devotion to these challenging projects.

ANNOUNCEMENT

SUMMER SCHOOL ALPBACH 1993

Alpbach/Tyrol, Austria, 20 – 29 July

COMPARATIVE PLANETOLOGY

The topic of this year's Summer School is Comparative Planetology. The results achieved by several planetary space missions during the last decades provide scientists with additional data to allow comparative analyses for different planets. The Summer School will cover the origin, the evolution and the chemistry of our solar system with emphasis on the inner planets, dealing with the structure and the dynamics of the planetary interiors, surfaces, atmospheres and magnetospheres. In addition some lectures will deal with the outer planets with their ring and moon systems as well as the minor bodies of the solar system.

Special processes like vulcanism and impacts, and the occurrence of water and life in the solar system will also be discussed during the morning sessions. The afternoon sessions will deal with ongoing and planned planetary missions to Mars, the Moon and the Outer Solar System. Time will be allocated for discussions and seminar sessions to allow all participants to present their own work related to the theme of this Summer School.

The Summer School is organised by the Austrian Space Agency (ASA) and co-sponsored by the Finnish Academy; the UK Science and Engineering Research Council (SERC); France's Centre National d'Etudes Spatiales (CNES); the Deutsche Agentur für Raumfahrtangelegenheiten (DARA); the Schweizerische Akademie für Naturwissenschaften (SANW); the Swedish National Space Board (SNSB); the Dutch Space Research Organisation (SRON); and the European Space Agency (ESA). It is open to graduate students, young scientists and engineers from Europe. The number of participants will be limited to 60. All participants are invited to prepare short presentation(s) of 10 to 15 minutes on work relevant to the subject of the Summer School so that they may take an active part in the planned seminars. Participants from Austria, Finland, Germany, France, Switzerland, Sweden and the United Kingdom are eligible for financial support from the corresponding national sponsoring agencies.

The registration fee will be AS 2.900,-. The working language of the Summer School will be English.

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Implementation of Biological Elements in Life Support Systems: Rationale and Development Milestones

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To ensure the complete autonomy of man in space, biological life support technologies must be developed. A survey of today's knowledge in biotechnology has been performed and technologies suited to long-duration manned missions in space have been identified. Regardless of whether they are to be used in a space vehicle or at a lunar or planetary base, most of those technologies require development times of 20 to 30 years. It is therefore essential to start development now to ensure that the life support system is ready when development of Moon or Mars bases begins.

Introduction

To ensure the complete autonomy of man in space, biological life support technologies must be developed. 'Life support' covers the theory and practice of sustaining life in an environment or situation in which the human body is incapable of sustaining its own natural functions. There are essentially three practical and non-exclusive ways to ensure the biological autonomy of man when isolated from his original biosphere:

— provide all required consumables at the start of a mission or replenish them during the mission
— regenerate life support materials during the mission, or
— use in-situ resources (in the case of manned missions to bases on a planet).

In the past, air, water and food were taken on board for a mission, and the waste was stored and returned to Earth. This is a completely open-loop life support system, and it is successfully used for short-duration space missions. As space missions become longer, supply loads become heavier and could become prohibitive, effectively limiting the duration of the mission regardless of how exciting and potentially important the mission objective may be. To permit longer missions, some loops vital to life support, i.e. the air, water, or food and waste loops, must be closed.

At present, the loops for air and water can nearly be closed: physico-chemical processes are being developed to regenerate air and water through the treatment of substances released by the crew. Unfortunately, these techniques cannot replenish the food stock; food must still be supplied from Earth. As a consequence, solid wastes have to be collected, treated, and stored. Food can only be produced through biological means, such as the cultivation of plants or the raising of small animals, and that process presents many drawbacks. A certain volume of the spacecraft, space station or planetary base must be dedicated to this function. Food production in such a restricted area is a complex operation involving careful control of many parameters such as light intensity, light and dark times, temperature and nutrient supply. If propagation from generation to generation is to be permitted, it will be necessary to continually monitor the quality of the end-products to ensure that any harmful mutations are detected and eliminated. Food production also involves the process of 'harvesting' and the further processing of the raw material to provide acceptable food products.

Although the introduction of biological techniques for food production in life support systems causes some problems, it also has positive side effects on other life support requirements and it ultimately prompts the notion of complete life support loop closure. A nearly-complete loop closure can be achieved independently for each category of life support material (air, water, or food and waste) using either a combination of physico-chemical and biological techniques, or a closed ecological system mainly based on biological techniques. The second method involves closing the three loops through a common set of bio-regenerative processes. Such a system almost completely removes the need for resupplying consumables from Earth, thereby achieving autonomy. However, it is based on many concepts that are at the boundaries of today's knowledge and technical capabilities.

To support life in space using a bio-regenerative, closed ecological system, more must be known about the behaviour, performance and ageing characteristics of the constituent biological elements in order to develop and validate the separate biological waste-processing, water-recovery, food-production and air-revitalisation systems, and finally to develop and validate the physical closure of the loop and study its long-term behaviour and control system.

To develop an autonomous, closed ecological system, it is necessary to:

— Define the biological techniques potentially applicable as life support techniques
— Select those biological life support techniques according to carefully defined criteria mainly based on the type of missions envisioned
— Propose an implementation programme for those biological life support techniques in the framework of an already-existing physico-chemical life support system, which will ultimately lead to the required autonomous, closed ecological system.

The future manned mission scenarios
The type of manned space missions for which such biological life support techniques will be developed, must be defined. Some hypothetical mission models have been built to provide a framework for the assessment of techniques and the selection of concepts.

Low Earth Orbit (LEO) missions
A Low Earth Orbit (LEO) mission, such as the International Space Station 'Freedom' or Euro-Mir, is a three-phase mission with a maximum duration of 93 days (Fig. 1). It consists of:

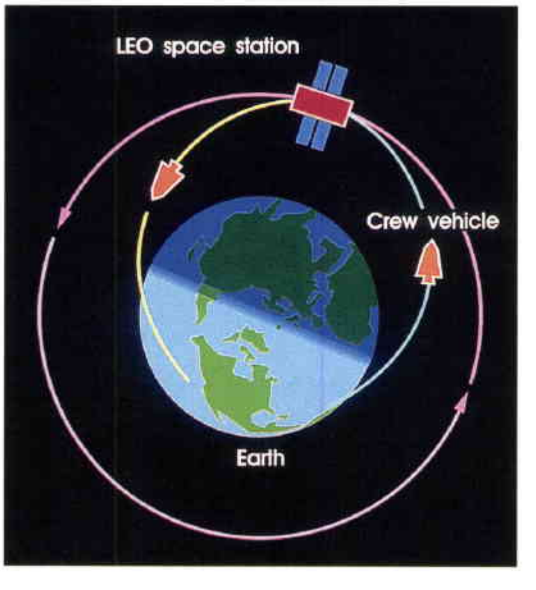
— an initial phase in which the crew travels from Earth to the LEO space station, using a 'crew vehicle'
— the residence phase spent in the space station
— the return phase in which the crew returns from LEO to Earth in the crew vehicle.

Two types of life support systems are required for such a manned mission, one for the crew vehicle and the other for the LEO space station. As the crew will only stay in the crew vehicle for a short time (up to 1.5 days at a time), the consumables required can be carried from Earth and the life support system does not need to be a regenerative one.

A maximum of 10 people will stay in the space station during the mission. During that

Figure 1. A Low Earth Orbit (LEO) mission — the phases and schedule

Phase	Duration	Vehicle/base used	Type of life support system
Initial phase (Earth to LEO)	1.5 days	crew vehicle	non-regenerative
Residence phase (in LEO)	90 days	LEO space station	regenerative
Return phase (LEO to Earth)	1.5 days	crew vehicle	non-regenerative



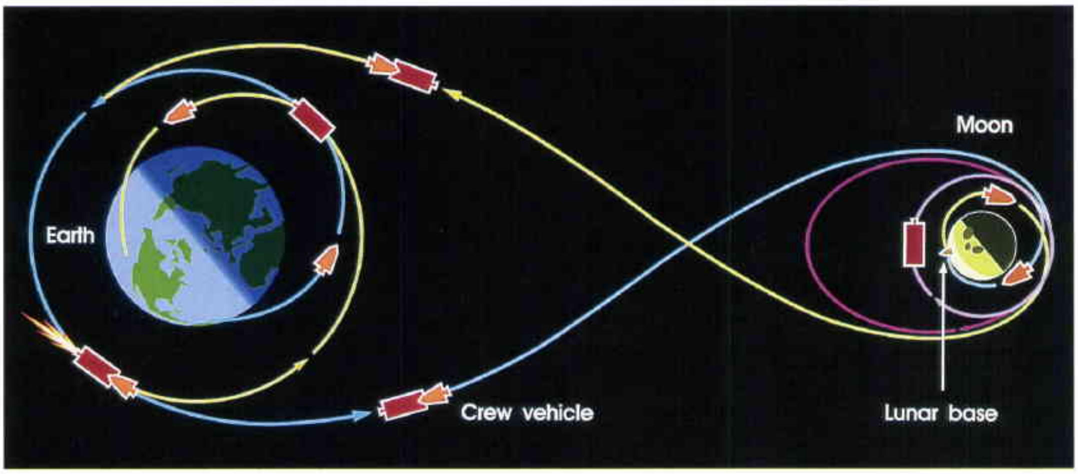


Figure 2. A lunar base mission — the phases and schedule

Phase	Duration	Vehicle/base used	Type of life support system
Initial phase (Earth to Moon)	3 days	crew vehicle	non-regenerative
Residence phase (on Moon)	90 days — 1 yr	lunar base	bioregenerative
Return phase (Moon to Earth)	13 days	crew vehicle	non-regenerative

time, they will have to undertake all hygiene activities such as showering, laundry, and dishwashing, but they will not need a large amount of fresh food. Therefore, the life support system should be regenerative but need not be bioregenerative.

The LEO station will face different environmental conditions than on Earth, namely microgravity and an increase in space radiation.

Lunar base missions

A lunar base mission is also a three-phase mission (Fig. 2), consisting of:

- an initial phase in which the crew travels from Earth to the Moon, using a crew vehicle
- a residence phase on the Moon, which is the core of the mission and may vary in duration
- a return phase from the Moon to the Earth.

During the first missions, the initial lunar base will be man-tended, with a typical stay-time of 14 days for a crew of three or four. Because of this relatively short duration, the initial missions have been classified as LEO missions for the purposes of the life support system. In subsequent missions, the duration of the residence phase is expected to increase from 90 days initially to one year, over a period of several years, and the crew size from 11 to 30 members.

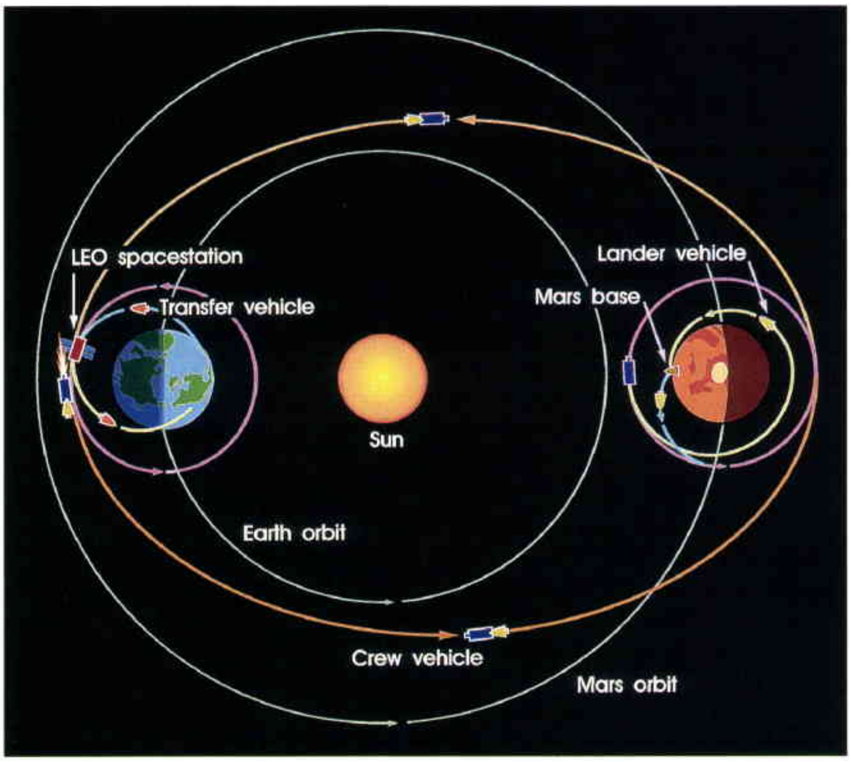
Two types of life support systems are required for lunar base manned missions, one for the crew vehicle and the other for the lunar base. As the journey from Earth to the Moon will be short (two to three days), the crew vehicle's life support system will not need to be regenerative. Although food could be supplied from Earth for the first, short-duration phases at the lunar base, it must be produced locally during long stays on lunar soil (several months to one year) and when the lunar base is permanently manned. Therefore, the lunar base's life support system must be regenerative in the first days of occupancy of the base and may be expected to evolve into a bioregenerative one as the length of the residence phase increases.

Each life support system will be subjected to very different environmental conditions: the crew vehicle will experience microgravity and space radiation, and the base will face lunar gravity (1/6 g), assuming that an adequate radiation shield will be provided.

Mars base missions

The mission to Mars that has been considered employs a split/sprint strategy: the crew and the cargo travel to Mars in two different vehicles and in two different ways. The cargo vehicle takes a longer, lower-energy trajectory, which minimises the LEO weight requirements. The crew vehicle takes a 'sprint' trajectory from LEO to Low Mars Orbit (LMO), which minimises the time that the crew is exposed to the microgravity environment and space radiation (Fig. 3). Once in LMO, the crew uses a Mars lander vehicle to land on the surface of Mars and, when the mission is completed, to return to the orbiting crew vehicle.

Figure 3. A Mars base mission — the phases and schedule



Phase	Duration	Vehicle/base used	Type of life support system
Initial phase (Earth to LEO)	1.5 days	transfer vehicle	non-regenerative
Staging phase (in LEO)	4 days	LEO space station	regenerative
Transfer phase (LEO to LMO)	204 days	crew vehicle	(bio) regenerative
Landing on Mars (LMO to Mars)	1 day	lander vehicle	non-regenerative
Residence phase (on Mars)	60 days — 1 yr	Mars base	bioregenerative
Launch from Mars (Mars to LMO)	1 day	lander vehicle	non-regenerative
Transfer phase (LMO to LEO)	204 days	crew vehicle	(bio) regenerative
Staging phase (in LEO)	4 days	LEO space station	regenerative
Return phase (LEO to Earth)	1.5 days	transfer vehicle	non-regenerative

Three life support systems are required: one for the crew vehicle, one for the lander vehicle and one for the Mars base. The crew vehicle's life support system must support the crew for approximately 410 days, the time required for a round trip to Mars. It will have to be regenerative but the need to be bioregenerative is still questionable, mainly because the behaviour of biological materials in microgravity is still largely unknown. These questions will be addressed in the second half of the 1990s.

The lander vehicle's life support system will only have to support the crew for a few hours (the time required to land on Mars or to return from Mars to the LMO where the transfer vehicle will be) and therefore it will not need to be regenerative.

The Mars base's life support system will have to support the crew for very long periods (and successive crews are expected to stay at the base) and will therefore need to be bioregenerative.

As with lunar missions, the environmental conditions that each life support system will encounter will be quite different: the crew vehicle will experience microgravity and space radiation, the landing vehicle will experience Mars gravity (1/3 g) and space radiation, and the base will experience only Mars gravity.

Two types of residence phases are considered: Mars build-up missions and Mars base missions. During the build-up missions, the crew, which will consist of 16 members, will stay on Mars for 60 to 120 days, and will prepare the base including its infrastructure, life support sytems, and energy source, for future base missions. During the subsequent base missions, the crew size will vary from 30 to several hundred people who will stay on the Mars surface for one year to several years.

The selection of biological life support techniques

All of the missions will encounter microgravity conditions but for a varying percentage of time (Table 1a). Since it is not yet known exactly how biological materials behave in microgravity, either the biological life support techniques selected should be considered to be applicable in both microgravity and low-gravity conditions with additional testing under microgravity conditions required, or biological life support techniques should not be part of the life support systems that will be used in microgravity.

For most of the missions, the life support system should be regenerative. However, for very long missions, the life support system must be bioregenerative because of the prohibitive mass penalty associated with using non-bioregenerative life support systems (Table 1b).

The functions of the life support system

Life support system functions that must be taken into consideration are presented in Table 2. Only the functions that can be regenerated will be discussed in detail because only these functions, if they are not regenerated, will imply an increase in mass when the duration of the mission and the size of the crew increase.

Air and water recovery, food storage, and waste storage, collection, pre-treatment and degradation, can be done through physico-chemical means. Most of the techniques required are already known and the technologies are either under development or in the tesing phases. Food cannot be produced through physico-chemical methods. Transformation of waste into food (and thereby the closure of the carbon loop) can only be accomplished by biological techniques. When a mission travels such a great distance and lasts so long that an in-situ source of food is required, inclusion of biological techniques in the life support system is remarkably advantageous when compared with physico-chemically-based life support systems. Accordingly, life support systems for lunar and Mars bases that will have to support a crew for very long periods of time, should include biological techniques, while those for LEO stations, where food can be supplied from Earth, need only to be physico-chemical systems.

For the life support system of the crew vehicle used during Mars missions, the advantages of biological techniques are not clearly defined. Biological techniques may face functional problems caused by the microgravity conditions during the travel phase from LEO to LMO. If the Mars crew vehicle is built to provide artificial gravity, it is not yet definite that the mass of a biological life support system would be lower than the mass of a physico-chemical life support system complemented with dehydrated food and a waste storage system, at least for a sprint Mars mission. Therefore, it is necessary to take into account all these factors when selecting potential biological life support techniques.

The evaluation criteria

The potential biological life support techniques will be evaluated against various criteria.

1. Energy
   Energy source and quantity are major constraints when developing space technologies. In space, biological life support techniques should rely as much as possible on regenerative sources of energy such as solar energy rather than on non-regenerative ones.

   Local energy sources can be foreseen on planet surfaces and therefore, when selecting biological life support techniques to be installed on planetary bases, energy is a less important evaluation factor.

2. Space environment
   Biological life support techniques must be able to withstand the space environment, i.e. space radiation and non-Earth gravity, or must be protected from those conditions.

3. Natural resources
   Total recycling of all types of waste is practically impossible. Therefore, wherever possible, the biological life support techniques should rely on local resources. This may be possible for lunar and Mars bases.

Table 1a. Percentage of time spent in different gravity conditions during the studied mission scenarios

Type of mission	Microgravity (μg)	Moon gravity (1/6 g)	Mars gravity (1/3 g)
LEO	100%	—	—
Lunar base	1—5	95—99	—
Mars base	54—87	—	13—46

Table 1b. Percentage of time spent in different life support conditions during the studied mission scenarios

Type of mission	Non-regenerative	Regenerative	Bioregenerative
LEO	3%	97	—
Lunar base	4—15	—	85—96
Mars base			
with bioregenerative system	0.5—1	1—1.5	97.5—98.5
without bioregenerative system during transfer phase	0.5-1	53—86.5	12.5—46.5

Table 2. Functions of a life support system

Atmosphere pressure and composition
Temperature and humidity control
Atmosphere revitalisation (Can be regenerated)
Water management (Can be regenerated)
Food production and storage (Can be regenerated)
Waste management (Can be regenerated)
Health and hygiene

4. Mission duration and crew size
For each type of mission, the mission duration and the size of the crew determine the sizing of the life support systems. The quantity of food to be produced and the amount of waste to be degraded are directly related to the mission's number of person-days. The number of person-days will also help in determining the need to close the food and waste loops, i.e. the necessity to use biological life support techniques.

5. Human requirements
Table 3 lists a human's requirements in terms of the consumables required and the waste produced per person per day. The figures presented are mean values of physiological requirements and are greatly dependent on the person's activities, gender, age, and health status.

Table 3. Average human requirements — consumables and waste per person per day

Consumables: Type	Mass (in kg)	Waste	Mass (in kg)
Metabolic oxygen	0.83	Metabolic carbon dioxide	1.00
Dry food	0.62	Water for food preparation	0.04
Water for:		Water from:	
— Food rehydration	1.15	— Metabolic perspiration and respiration	2.28
— Food preparation	0.79		
— Drinking	1.62	— Urine	1.50
		— Faeces	0.09
		Solids from:	
		— Sweat	0.02
		— Urine	0.03
		— Faeces	0.06
Sub-total	5.01	Sub-total	5.01
Packaging, bags, paper	0.89	Solid waste (packaging, bags, paper)	0.89
Water for:		Water from:	
— Dishwashing	5.46	— Dishwashing — non latent	5.43
		— latent	0.03
Sub-total	5.46	Sub-total	5.46
— Hand/face washing	1.82	— Personal hygiene — non-latent	6.68
— Shower	5.45	— latent	0.59
Sub-total	7.27	Sub-total	7.27
— Laundry	12.50	— Laundry — non-latent	11.90
		— latent	0.60
Sub-total	12.50	Sub-total	12.50
— Toilet flushing	0.50	— Toilet flushing	0.50

6. Food production
Since food production is the main purpose of biological life support techniques, it imposes many constraints such as the nature of the produced food, the nutritional qualities of the diets, the biological origin of food, and additional tasks for the crew.

7. Waste reclamation
Recyling of waste is the second most important function of biological life support techniques. Waste should be recycled with the minimum loss of matter.

Reclamation of waste imposes several constraints on a biological life support system. For example, biodegradable materials should be used for the packaging of all consumables. Washing of dishes is preferable to using disposable dishes. Use of toxic materials must be avoided. Use of pharmaceuticals for crew members' health problems should be minimised to avoid the breakdown of microbial or plant-based life support systems. Some pharmaceuticals, e.g. some inhibitors of enzymatic activities, could impair essential microbial or plant metabolic activities, or others, e.g. antibiotics, could even kill selected strains.

8. Water recycling
Recycling of water, the third most important function of a biological life support system, should provide two different qualities of water: potable water and so-called 'hygiene water'. Potable water is water that is safe for human consumption, for an unlimited length of time. 'Hygiene water' can be used for safe human hygiene and 'housekeeping' purposes, and for occasional and limited use as potable water.

An efficient water recycling system is very important given that water has the greatest mass of all the regenerable materials.

9. Production of contaminants
The control of air contaminants is the fourth purpose of the biological life support system: their production must be minimised. The contaminants are produced, for example, by offgassing and humans, and are considered to be gaseous waste.

10. Air regeneration
 The air quality required within the vehicle or base with respect to the concentrations of oxygen, carbon dioxide and contaminants, imposes physiological constraints on the biological life support system. It should consume the carbon dioxide exhaled by the crew and produce the oxygen that is necessary for crew survival.

Potential biological materials

Many biological experiments have been performed in space from the beginning of space research. Most of the experiments show some deviation in the results when compared with ground-based, control experiments. Due to the statistically-low amount of experimental data, general statements that are valid for different types of biological materials cannot be made. Moreover, large differences in experimental results concerning the same biological species have been registered and were found to depend mainly on the mission duration, experimental procedures, and the given space environment.

Biological materials that will be proposed for eventual implementation in biological life support techniques will be selected from various fields of the life sciences, and are the following:
— biological macromolecules
— microorganisms and fungi
— plant cell cultures
— animal cell cultures
— higher plants
— small animals.

For each type of biological material considered, all the techniques that have been developed, are under development, or are still at the research level have been evaluated. For example, technologies involving macromolecules are quite numerous, but when the goals and constraints of a biological life support system are considered, enzyme bioreactors, tools that have already been developed for the food and pharmaceutical industries, are well suited to the problems faced during carbon recycling. Indeed, along with food production, accumulation by plants of non-edible polysaccharides such as cellulose may markedly affect carbon recycling, eventually acting as a dead-end in the carbon loop. Use of particular enzymes such as cellulases that degrade cellulose into its elementary component — glucose, an edible sugar — is a neat solution and helps in closing the carbon loop again.

Promising techniques

Taking full account of the discriminating factors, a short-list of promising biological life support techniques has been identified (Table 4).

1. Enzyme bioreactors
 An enzyme (a protein with a specific, catalytic activity) can be immobilised by 'fixing' it to, or enclosing it in, a solid support. Using an immobilised enzyme offers a large number of practical advantages over using the enzyme in its soluble form. For example, immobilised enzymes are more resistant to shear forces and to attack by proteases (protein-degrading enzymes). They also are easily separated from the reaction medium.

Table 4. Promising biological life support techniques and their proposed functions

Biological technique	Proposed functions
Free or immobilised enzyme bioreactors	First step pre-treatment of liquid, semi-solid and solid waste Transformation of undigestible biomass into digestible biomass Production of substrates for other biological techniques
Microorganism bioreactors	Degradation and consumption of liquid, semi-solid and solid waste Production of enzymes for enzyme bioreactors Production of edible biomass Production of substrates for other biological techniques Transformation of undigestible biomass into digestible biomass
Microbial air filters	Air contaminant removal
Cultivation of higher fungi in closed and controlled area	Degradation and consumption of liquid, semi-solid and solid waste Production of digestible biomass
Cultivation of higher plants in closed and controlled area	Production of digestible biomass Reclamation of water Reclamation of air (CO_2 consumption and O_2 production) Removal of air contaminants Consumption of degraded waste
Plant cell cultures	Propagation of plants Storage of plant strains
Breeding of small animals	Production of digestible biomass Degradation and consumption of waste
Cultivation of macroalgae	Production of alternative digestible biomass Consumption of degraded waste

Immobilisation methods include covalently bonding the enzyme to a solid support, entrapping it in a gel, cross-linking the molecules to one another (molecules being only enzymes or a mixture of an enzyme and another protein such as serum albumin), or encapsulating the enzyme in a small, artificial cell (a liposome). Carefully designed systems of complex sets of coupled enzymatic reactions can be envisioned. In these reactions, the product of one reaction is a substrate for the other. Such systems could be regarded as 'artificial metabolism'.

The role of such enzyme bioreactors in a life support system includes the production of molecules considered to be essential from a nutritional point of view, such as some essential amino-acids, essential fatty acids, and vitamins. Transformation of non-digestible into digestible biomass, e.g. transformation of cellulose into glucose, processing of vegetarian food, and enzymatic breakdown of some waste, must also be considered.

Another potential application of enzymes in life support systems can be seen in the current development of heterogenous or interfacial catalysis, i.e. catalysis at the interface between two states such as at the air-liquid, liquid-solid or air-solid interface. Such technologies, which are at the forefront of today's research in enzymology, have potentially powerful applications in air contaminant removal and biotransformation of non-digestible into digestible biomass. For example, microbial air filters can only degrade water soluble contaminants. This restriction does not apply however to a direct solid-air bioreactor where the solid phase is the catalyst (enzyme) and the air phase is the substrate carrier.

In addition to this direct involvement of enzymes in life support systems, indirect use may also be possible, for example, as components of biosensors or detectors. However, because enzymes are not immortal, they must be imported from Earth or produced in-situ. If they are to be produced in-situ, specific micro-organism bioreactors must be developed.

2. Micro-organism bioreactors
To recycle all of the important chemical elements such as C, O, H, N, P, S and K, complex organic molecules occurring in waste must be degraded to make their chemical elements available for further processing such as plant cultivation. This task can be largely devoted to microbes. In this case, the term 'microbes' has to be understood in its most general meaning, i.e. all micrometer-sized unicellular or multicellular organisms. Therefore, it includes bacteria, lower fungi, yeasts, microalgae, and protozoa.

Such technologies are already in use in modern sewage and used water treatment units but they have three major drawbacks for eventual application as elements of life support systems. First, they require a large amount of space to provide a large air-water surface. Secondly, they consume oxygen and, finally, the quality and quantity of the used microorganisms are largely unknown. Strains that are able to cope with multiple tasks such as the degradation of all common biological waste, must be found. These strains should also be able to work anaerobically to avoid any unnecessary consumption of oxygen. Volume constraints are the major factors affecting the design and manufacture of such micro-organism bioreactors.

3. Microbial air filters
Microbial air filters are a particular type of microbial bioreactor. They must degrade very low concentrations of substrates that are found in the air while avoiding the production of biomass. Of the three types of air filters currently available for terrestrial applications (bioscrubbers, trickling filters and biofilters), only biofilters can be easily adapted to microgravity conditions. They consist of carefully chosen bacteria fixed on a filter bed through which waste gas is passed. Volatile contaminants are partially dissolved in the liquid phase surrounding the biolayer of the filter bed and degraded by the bacteria.

4. Cultivation of higher fungi in a closed and controlled area
Growth of higher fungi, such as mushrooms, on a solid substrate like straw is a technique that is already in use in large-scale production on Earth. It could easily provide the crew with a food supplement of good nutritional value and taste. It would also be a very attractive 'shunt' in the recycling of organic matter. Lignin and cellulosic matter would be considerably reduced. The additional energy required for food production would

be kept to a minimum: little or no light is required for growth and, except for harvesting, little crew-time is needed for maintenance.

5. Cultivation of higher plants in a closed and controlled area
Higher plants are expected to become the main source of food on missions in the foreseeable future. The suitability of all major crops for life support applications has been evaluated using 22 nutrition-, acceptability- and cultivation-related selection criteria (Table 5). Each crop's ability to fulfill life support system functions other than food production, such as water reclamation and air recycling, has also been considered. A total of 19 candidates were evaluated and the following plants attained the highest ratings: rice, wheat, soybean, peanuts, corn, and potatoes.

6. Plant cell cultures
Plant cell cultures are fundamental tools in modern plant biotechnology. For space life support systems, they can be used for plant propagation, plant storage, and metabolite production.

The major threat regarding plant culture in space conditions is the potential alteration of the genetic information during a plant's lifetime or a complete absence of sexual reproduction. As a consequence, the carefully chosen strains and varieties of plants may not remain genetically stable. One attractive way to avoid such problems is to initiate new 'seeds' for each cultivation cycle via somatic embryogenesis from master samples or plant cell cultures kept in 'normal' conditions, where they are completely protected from space radiation.

Such plant cell cultures can also be used for the production of the small quantities of special metabolites that are needed for the crew's nutrition but that are not found in the food produced. These metabolites can be either essential vitamins, fatty acids or amino-acids, or pharmaceuticals for health purposes.

7. Breeding of small animals
Small animals are already used on Earth for biotechnological, industrial and ecological applications. Although animal behaviour in microgravity is still under scrutiny, some problems with the use of animals in microgravity can be expected. Worms, fish, birds, and mammals have potential applications for space missions.

Table 5. Criteria for the selection of plants for life support applications

Nutritional and acceptability criteria
Energy concentration
Toxicity
Protein content
Carbohydrate content
Fat content
Processing requirements
Palatability
Flexibility of use
Cultivation criteria
Storage stability
Harvest index
Yield of digestible biomass
Growth habit and morphology
Environmental tolerance
Air contaminant production
Periodicity of light and temperature
Light use efficiency and light saturation
Transpiration rate
Suitability for soiless culture
Pollination and propagation methods
Suitability for microgravity

Worms are very interesting because they can grow directly on solid waste. Worm production has been developed on Earth to provide primary food for poultry and fish, and for waste valorisation or humus production. The flour obtained from the dried worms is high in protein (60%) and rich in sulfur amino-acids. A 300 L soilbed can currently yield approximately 60-80 kg of the flour per year. Worms do not provide a food source that is very acceptable to the crew members, but they are a very promising source of food for other animals such as fish, poultry, and rabbits.

Fish breeding is a potentially valuable technique for food production in space. The transformation ratio for fish is quite high, about 0.8, i.e. 1 kg of fish food leads to 0.8 kg of wet mass or 0.2 kg of dry mass of fish. Several species have already been tested in fish farming. Fish breeding imposes more constraints than raising fish because, for example, photoperiodism is mandatory for fish breeding, and some breeding problems can be expected in microgravity conditions. However, some species are very attractive: 500 kg of catfish can been grown in a 1 m^3 tank per year.

Systems used on Earth for the breeding and raising of birds such as chickens and mammals such as rabbits are very efficient. Those animals can use food produced by other systems (worms, plants, fish) and help in closing the food loop. In addition, birds and mammals offer real psychological advantages to the crew members during long-duration space missions.

8. Cultivation of macroalgae
   The growing of seaweed can offer a non-conventional food source. Acceptance of such food is currently increasing among non-Asiatic populations and therefore macroalgae could be used as a secondary or supplementary food in long-duration space missions. These algae are currently being cultivated on a large scale (sea-farming), mainly for industrial applications, and that knowledge could be transferred to growing algae in space.

Development programme

Implementation logic

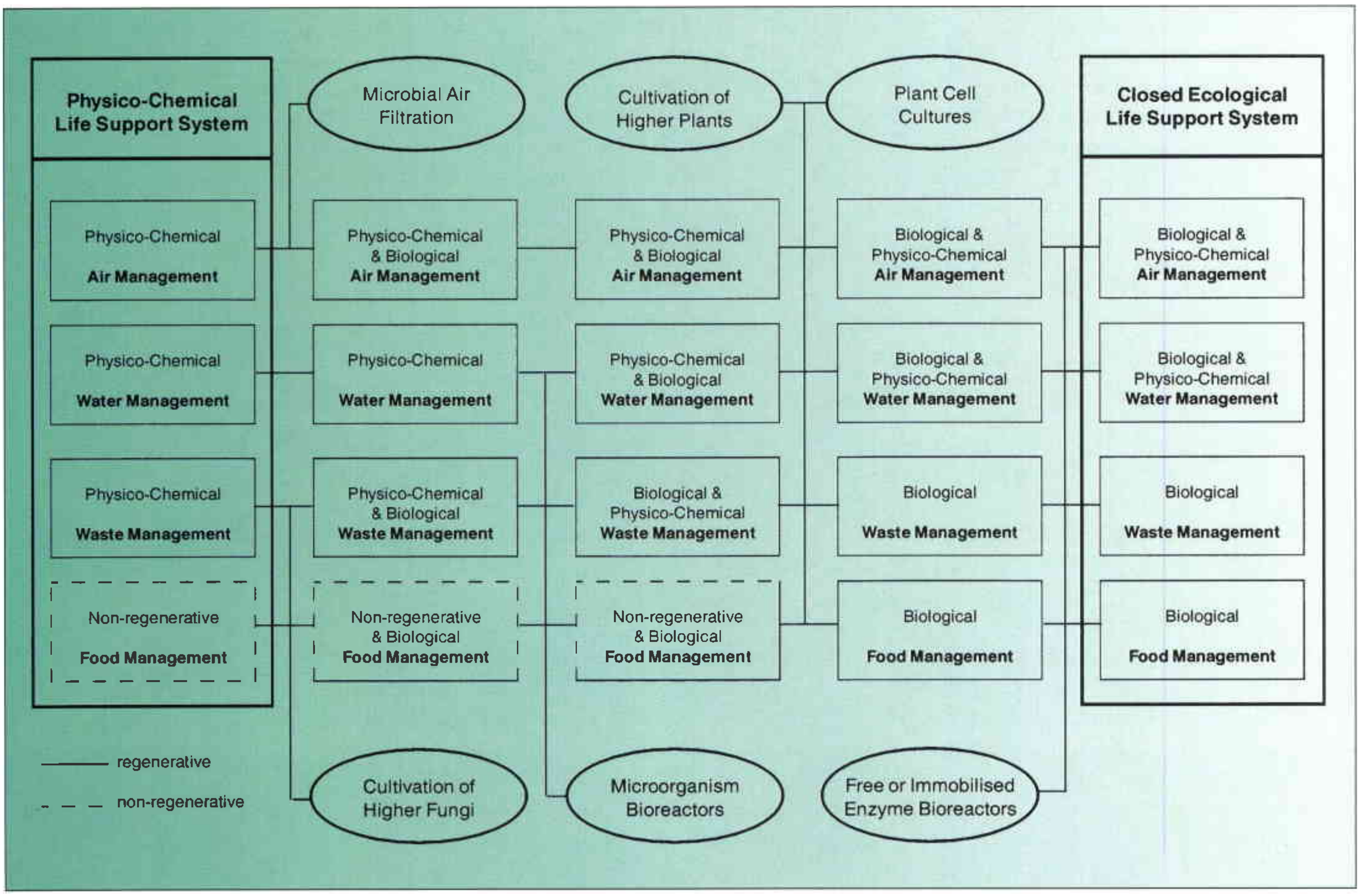
Having defined potentially applicable biological life support techniques, an implementation logic for these techniques has been selected (Fig. 4). Using this logic, a closed ecological life support system is built by implementing selected biological techniques on a step-by-step basis into a conservative system based on physico-chemical technologies, to test each biological technique. Techniques that will be used in a planetary base will be tested on ground in a closed environment. If a closed ecological life support system is planned for orbiting space systems, the test will be repeated in space.

The implementation logic is based on the two following criteria:

— Degree of loop closure
  Based on a given life support system that is partially closed by physico-chemical techniques, the implementation of biological life support techniques should progressively close the air, water, and food and waste loops on a step-by-step basis. Therefore, techniques that require major changes or that become partially unnecessary when the next technique is implemented, should not be included.

— Requirements from existing systems
  All the inputs that each new technique requires must be available before that technique is implemented. For example,

Figure 4. Implementation logic for potentially applicable biological life support techniques



the cultivation of plants can only be implemented if CO_2, nitrogen compounds and minerals provided by microbial degradation of waste are available. Thus, micro-organism-based bioreactors for waste degradation have to be tested and implemented in life support systems before the higher plant growth chambers are implemented and tested.

'Shunts' like the culture of higher fungi, can theoretically be implemented at any time. Some biological life support techniques may be implemented in a way that is totally independent from the other techniques if they do not belong directly to the closed ecological loop. For example, the microbial air filter can be installed as an independent biological element in a physico-chemical life support system.

Biological life support techniques that provide greater comfort to the crew by increasing the variety of foods available but which are not essential to the crew's survival, such as the breeding of small animals and the cultivation of microalgae, have not been included in the selected implementation logic. They can be added when a closed ecological life support system has been established and is functioning well. A complete analysis of the increase in the degree of comfort that they will provide versus the increase in the complexity of the system must be undertaken beforehand.

The milestones

There are two major steps in the development of each selected biological life support technique:

— scientific experimentation
— development of a space model.

In the first step, scientific experimentation, the biological materials to be used and their acceptance of the defined environment either in a spacecraft under microgravity conditions or in a base on the Moon or Mars, will be analysed. Some engineering aspects will be studied but the analyses will mainly assess the biological material's ability to cope with extreme conditions and with its genetic and physiological stability under those conditions. The following tasks must be undertaken:

— analysis of all the biological activities involved in the process that is to be developed
— definition of a knowledge model
— definition of the engineering aspects (the size and design of the structure)
— analysis of the limiting conditions to determine, in accordance with the knowledge model, the control criteria, control parameters and the control model.

In the second step, the development of a space model, all the steps that are generally involved in the development of a space engineering system will be followed. They include the definition of the model philosophy, breadboard activities, and the

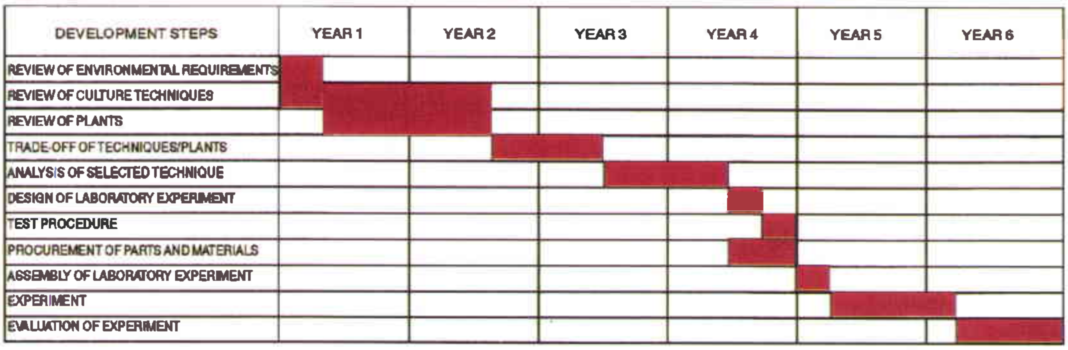


Figure 5a. Tentative schedule for the scientific experimentation with a higher-plant growth chamber

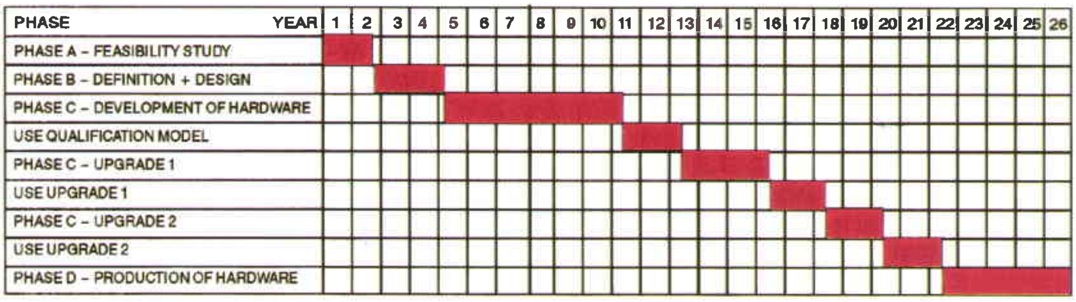
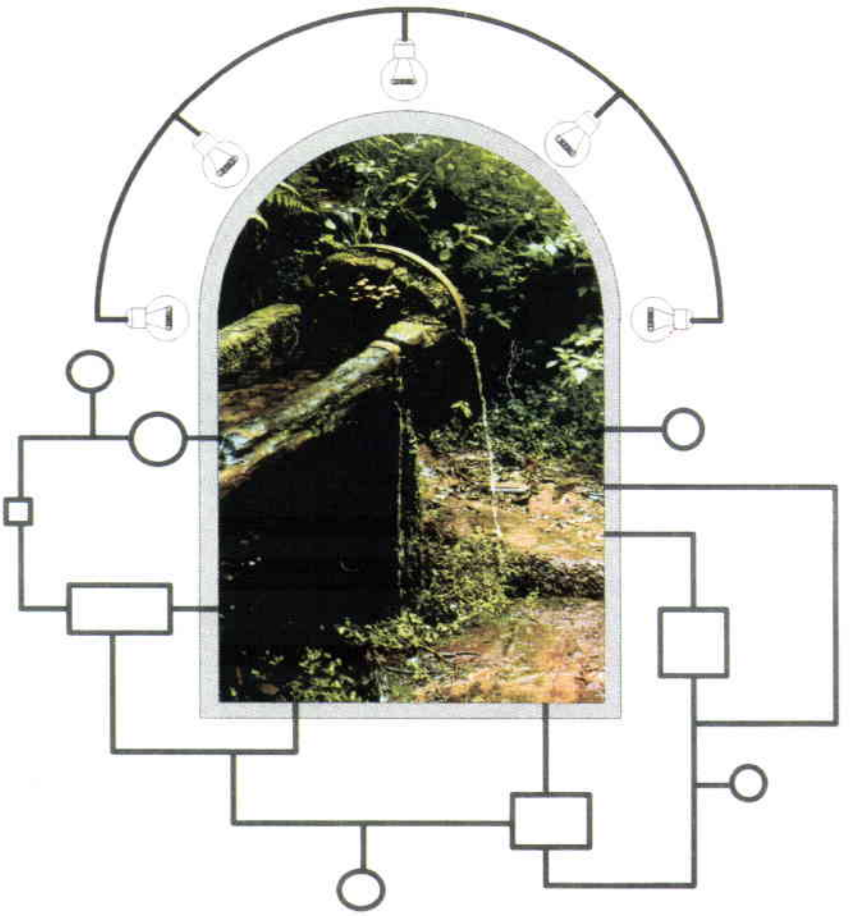


Figure 5b. Tentative schedule for the development and testing of a base model of a higher-plant growth chamber

development of demonstration models, qualification models and flight models for testing in orbit and possibly at a lunar or Mars base. Figure 5 presents typical development schedules for a higher-plant growth system that is to be implemented in a life support system under 'non-standard' gravity conditions, i.e. for planetary bases.

The development of such systems will require approximately 25 years therefore it should begin as soon as possible to ensure that such technologies are ready when the development of Moon or Mars bases is expected to begin.



General illustration of the concept of closed and controlled ecological systems

Conclusions

According to the needs for and the constraints of the biological life support systems in future long-duration manned missions in space, a short list of biological life support techniques available for a more or less direct implementation in a closed ecological life support system has been provided.

Most of the biological life support technologies of potential interest for space use have development times of 20 to 30 years. It is therefore essential to begin developing them immediately, not only because this is a far more cost-effective approach in the long term than highly expensive 'crash' actions at a later date but also because it is the only way to have these technologies available in time for the development of Moon or Mars bases. Indeed, development of space systems that include biological elements is much more complex than 'traditional engineering' because the crew must interact with the system. This creates more safety issues such as those concerning the interaction between the bacteria used or biochemicals produced and human beings.

In addition, a dedicated test bed is essential for the progressive investigation of the life support systems that will become increasingly complex as more biological life support elements are added. It is also mandatory to control an evolving biological life support system. A robust and safe control system, which ensures that such a complex system remains safe for the humans that must live with it and rely on it, must be developed in parallel.

It is worth noting that the technologies developed to solve problems encountered in the development of biological life support systems for space missions can also be applied directly or indirectly to solve problems on Earth. The technologies could be used in addressing environmental issues through the improved study of the interaction between humans and the biosphere. For example, new pharmaceuticals or recombinant microorganisms could be tested in the closed environment of the testbed developed for space-related life support systems before any introduction into the biosphere.

The Meteosat Ground Stations for NOAA

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In September 1991, it was decided that ESA would support the US National Oceanic and Atmospheric Administration (NOAA) by operating the European Meteosat-3 satellite around the much more westerly position of 90°W. As a result, ESOC's Stations and Communications Engineering Department was charged with providing additional ground facilities at the NOAA and NASA sites on Wallops Island, at ESA's Kourou facilities in French Guiana, and at ESOC itself. These new facilities had to be fully operational within one year of the commitment being made.

The technical challenge

The fact that the Meteosat-3 spacecraft was to be re-positioned around 90°W meant that direct contact between ESOC's Odenwald ground station in Germany and the satellite would no longer be possible. Economic considerations and the very tight implementation schedule dictated that satellite operations, image processing and processed data dissemination via the satellite would have to be effected using the existing expertise and processing facilities available at ESOC.

There was therefore a need for (Fig. 1):
- a remote redundant ground station
- a remote back-up ground station located at a different site
- a land-based transponder system for bi-lateral satellite ranging operations
- a redundant high- and low-speed communication system with low-speed backup links (for satellite safety).

The remote redundant ground station has been located at the NOAA Wallops ground station so that use could be made of the existing GOES (US Geostationary Operational Environmental Satellite) antenna systems there, albeit with some necessary modifications (Fig. 2).

The remote back-up ground station has been located at the NASA Wallops ground station, which is sited close to the NOAA station. Again, existing NASA antenna systems are being used.

The land-based transponder system has been located at the ESA ESTRACK ground station in Kourou, French Guiana. This site already housed such a system for European meteorological satellite ranging.

The NOAA Wallops station now conducts the following main tasks for Meteosat-3:
- satellite housekeeping telemetry acquisition
- raw image acquisition
- telecommanding
- Wefax dissemination
- high-resolution image dissemination
- bi-lateral ranging
- back-up MOCC (Meteosat Operations Control Centre)
- raw image extraction
- display of extracted imagery
- high- and low-speed ground communications
- voice communications.

The various subsystems employed at Wallops to provide these services are shown in Figure 3. The NOAA and ESOC Meteosat Communications System (Commet) terminals, handling high-rate data in both directions, are interconnected via multiple parallel links over a Panamsat relay satellite. A special Panamsat terminal (antenna system and modems) was installed at ESOC for this purpose.

Safety-critical satellite data and other low-rate data transfers between ESOC, NOAA and NASA are handled by Integrated Switching System (ISS) nodes at each location. A link between the NOAA and the NASA nodes provides alternative routings between ESOC and NOAA and ESOC and NASA, respectively.

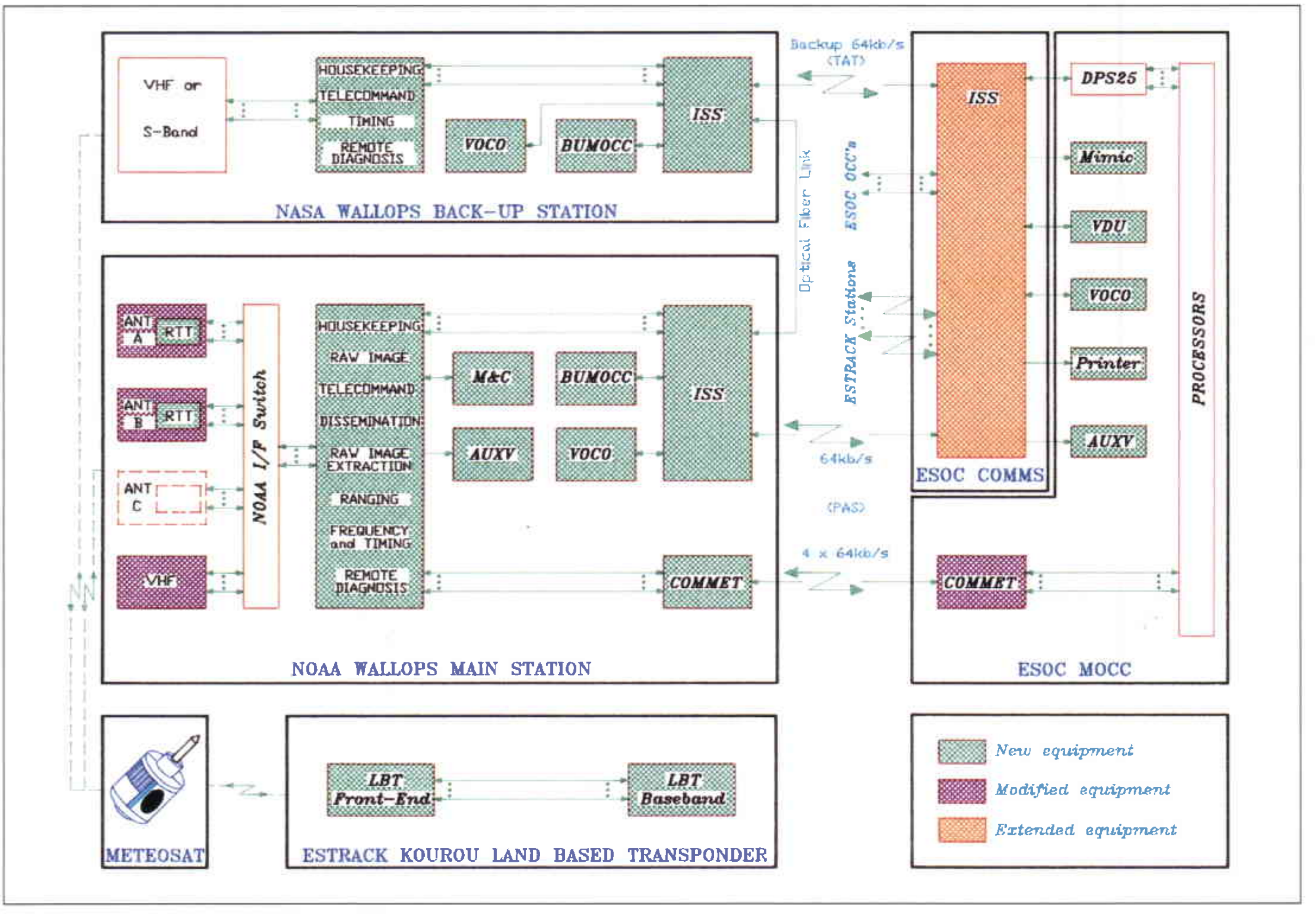


Figure 1. The structure of the overall system

Figure 2. The Wallops ground facilities

New in the design of the stations compared with the existing Odenwald station is the use of an Ethernet local area network, to which a remote diagnosis unit is connected. Some newly designed equipment can be connnected to this unit which allows remote diagnosis and software-correction to be performed from the main contractor's site in Europe. As is the case for the European station, a monitoring and control system allows remote operation and monitoring of the NOAA station from the Meteosat Operations Control Centre (MOCC) in Darmstadt, thereby avoiding the need for 'around the clock' manning. A remote mimic display at the MOCC provides an immediate overview of the station's configuration and health.

Problems of implementation
One of the major problems faced by the ESOC SCED team was the extremely tight time schedule for the work, given that the new facilities had to be up and running within a year. This in turn led to manpower availability problems at ESOC for project management, for the production, modification and check-out of 'in-house' built equipment, for support, expertise, etc. The usual problems inherent in commissioning stations at remote sites were compounded by the fact that testing and remote diagnosis is not permitted using operational ground communications systems.

Two decisions that were taken at the outset to be able to cope with the short time scale were to:
- avoid complexity whenever it was not essential
- replicate existing equipment wherever possible, given the comparatively short expected lifetimes for the new stations.

The latter approach was not advisable in some cases for reasons of reliability.

A careful trade-off had also to be made in the use of internal expertise and external manpower in striving to adhere to the strict schedule, in a period of already heavy workload involving the preparation of three remote ground stations for the Eureca project.

Replication of some older equipment items proved difficult in practice because certain electronic components were no longer in production. However, negotiations with Dornier, which had designed some of the original items, revealed that they were prepared to start re-designing equipment almost immediately. The most demanding re-design was the raw image pre-processor, which has to bandle 166 kbit/s or 333 kbit/s in normal mode, and 2.7 Mbit/s in real-time operating mode. Dornier was also able to act as the main contractor for the work, performing all integration, commissioning and testing activities, which greatly facilitated project management.

To keep the difficulties involved in commissioning remote stations to a minimum, it was decided to first check out all equipment in

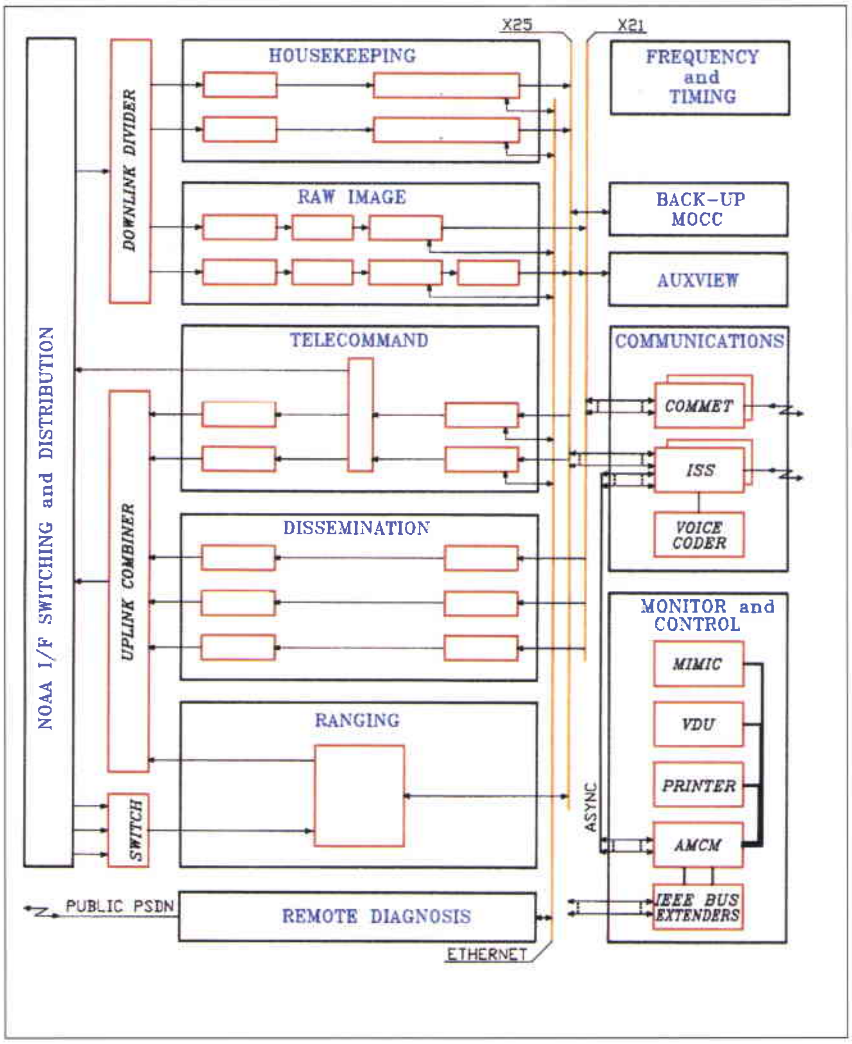
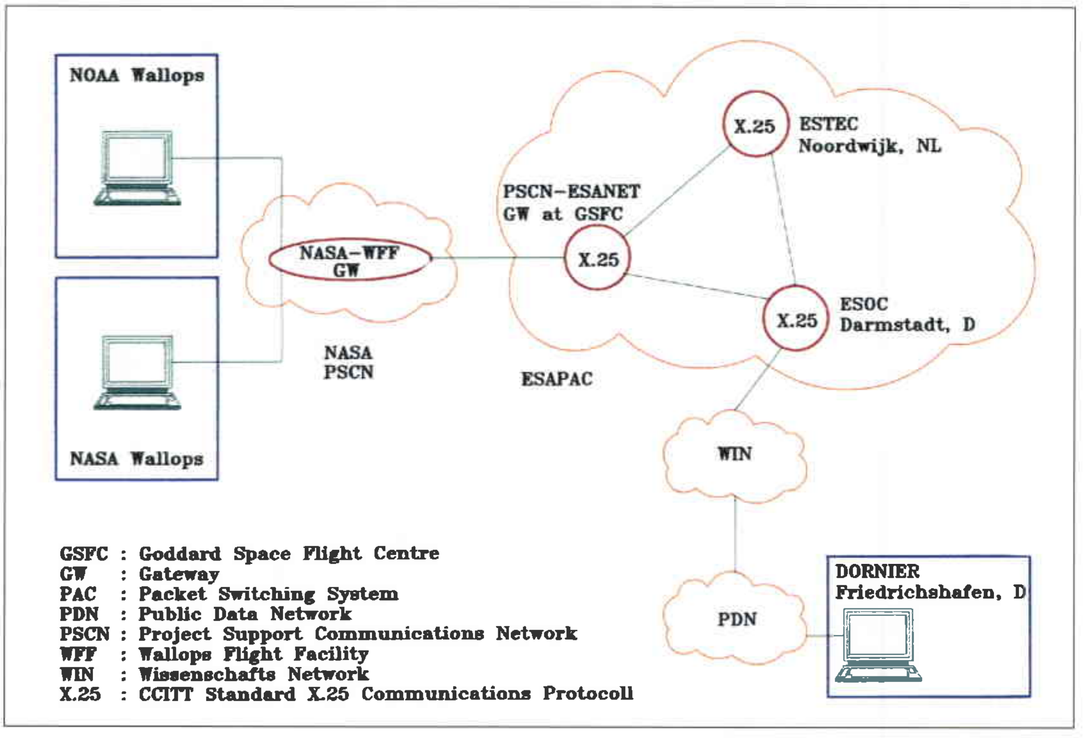


Figure 3. The NOAA Wallops back-end system

Project milestones

- September 1991: Decision to support NOAA
- November 1991: Specifications and statement of work produced and negotiated August 1992: Factory acceptance at Dornier (D)
- October 1992: System testing at Odenwald complete
- December 1992: Systems installed and tested and handed over for operations.

Figure 4. The remote-diagnosis network



a truly operational environment in Europe. This was done at ESOC's Odenwald ground station by gradually replacing existing equipment until a fully functional system was established that could be used operationally. The new Land-Based Transponder (LBT) was checked-out in an operational environment at the integrator and antenna supplier SNEC, in France, as part of this check-out activity, before being shipped to the Kourou site. Replication of the original LBT antenna had had to be rejected as an option because the unit was not sufficiently robust to function reliably in a tropical environment.

In addition, Dornier developed a remote diagnosis unit for their newly developed systems, such that fault diagnosis and the transfer of corrected software could be done from their site, without the need for time-consuming and expensive missions to the USA. Several problems that subsequently manifested themselves at the Wallops stations were resolved very quickly and cost effectively in this manner.

From Figure 1 it can be seen that the ESOC Integrated Switching Node (ISS) forms part of the main operational communications system. For safety reasons, such operational systems do not normally support initial commissioning and testing activities. To facilitate testing as far as possible in an operational environment including a satellite and the MOCC, ESOC made a special test node available and performed all ISS and Commet network management for system testing at the Odenwald station and at the Wallops stations. The subsequent switch from test node to operational node could be made in just a few days.

For the same safety reasons, industry is not allowed to connect to station equipment via the operational communications networks. To facilitate such a connection, ESOC's Computer and Network Operations Department established a link using existing public and administrative networks (Fig. 4). Future operational ground communication systems will avoid the need for such additional and complex links.

Conclusion

It is hoped that the challenges with which ESOC was faced in implementing these additional facilities at remote stations and the solutions that were adopted can be put to good use, both inside and outside the Agency, in the future. The project's success was due in large part to the very careful planning at the outset in terms both of reuse of existing technology and of the division of labour between in-house ESA staff and industry.

Focus Earth

Rome and Its Surroundings

In Figure 1, a multi-temporal ERS-1 SAR image of Rome and its southeastern hinterland, the city can be seen in the upper left corner as a large conglomeration of bright points, crossed by the River Tiber. To the southeast of the city is the round volcanic feature of the Alban Hills, also known as the Castelli Romani, including the caldera lakes of Albano and Nemi. Extending further to the southeast is the Pontina Plain with its patchwork of fields. The 3260 hectare State Forest of Circeo is well-outlined in a bluish tone. At the southeasternmost tip of the plain is Monte Circeo (541 m high), preceded by a series of lagoons and a long sandy beach which are popular in the summer. To the north of the plain lie the Lepini Mountains. These limestone hills are separated from the main body of the Apennines by the Sacco Valley, through which the motorway to Naples runs.

The colours in a multi-temporal SAR image always highlight the changes in radar back-scatter between the respective acquisition dates. The strength of this backscatter depends on both the target's shape and its dielectric behaviour, e.g. the water content of the objects on the ground. In general terms, the rougher the surface, the more radar return can be expected. A sea surface, for example, can have a very variable roughness due to the strength of the wind. Calm would mean a flat and smooth surface, appearing dark in that date's image; it would therefore make no contribution to a multi-temporal colour composite of images.

The image in Figure 1 is a composite of frames taken at three different times in 1992:

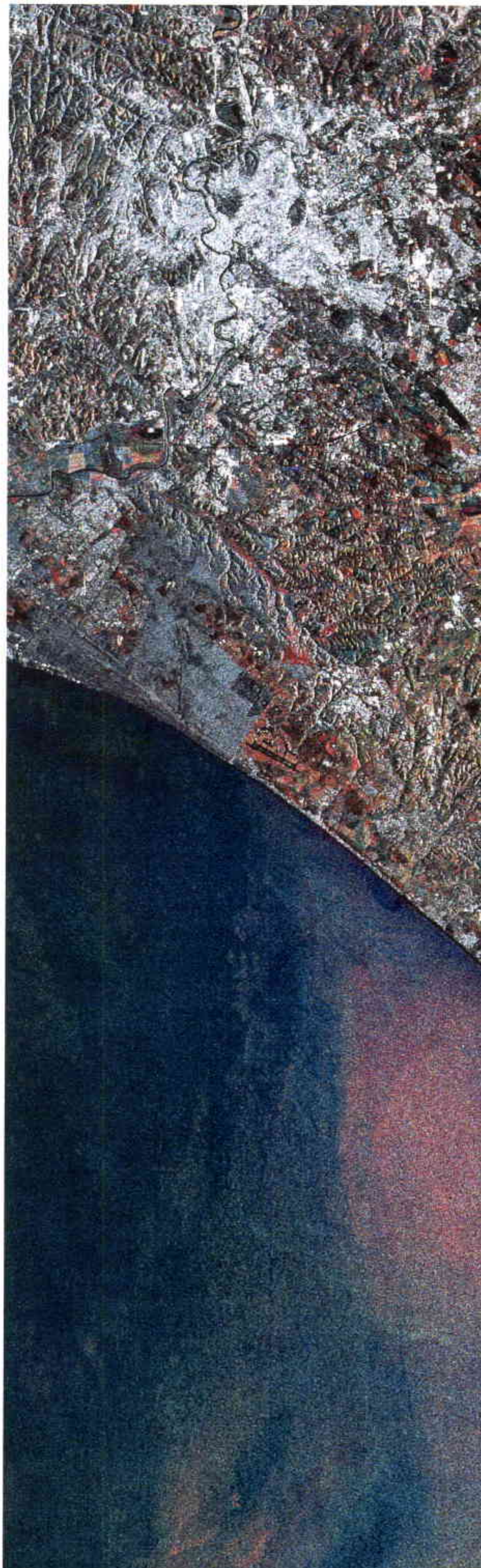
Date	Display colour	Weather conditions
3 January	Green	Clear sky, northerly wind
6 March	Blue	Overcast sky, very dry weather, northerly wind
11 June	Red	Cloudy, intermittent thundery showers, with over 50 mm of rain having fallen in the previous 24 h in some places

The image has been analysed for several different applications, the results of which are summarised below. The generally red impression of the image is due not so much to the high ground humidity on 11 June, but more to the advanced state of vegetation growth with respect to the two earlier dates.

Wood type identification
The chestnut woods of the Alban Hills appear reddish, while woods containing more evergreen trees appear darker blue. Such woods are found close to the sea, but also on the lower slopes of the Apennines. Beechwoods growing at higher altitudes appear similar in the image, perhaps because of their similar leaf size. South of Rome and adjacent to the coast, a large deciduous wood is visible in grey tones. Its easternmost corner is occupied by pines with densely closed crowns, which appear much darker. There is also a square clearing with a house in the middle.

Geology
Geomorphology is among the disciplines for which SAR images can be especially well suited. The erosional forms on the slopes of the Alban Hills reveal the friability of the volcanic ash. The complex drainage system between the volcano and the Apennines needs further study. The hard limestones of the Apennines appear very different, with rounded and sharp crests distinguishable. Geologists know that SAR imagery emphasise features perpendicular to the imaging direction, and this has to be taken into account when mapping faults. Coverage from both descending and ascending passes should be evaluated in such analyses.

Oceanography
Owing to the interaction between wind and sea surface and between different currents forming current shears, the sea presents many variations in colour. The wind was strongest on 6 March, but Monte Circeo created a wind-sheltered area.



Crop identification
This particular three-image combination is not ideal for crop-recognition purposes because of the ploughing and field-preparation activities that were taking place early in the year. Wheat fields are generally dark bluish or cyan, indicating very little contribution from the 'wet' June image. Pasture land appears dark reddish and tall grass brighter red, which on other ERS-1 SAR images can also represent sunflowers and corn. In fact, corn and sunflowers can be easily separated on other ERS-1 SAR images taken two weeks before and four weeks after the June acquisition; corn appeared rather dark and the sunflowers much brighter. This points to the important contribution made by the rain water on the leaves of these plants. Many bright red and yellow-red fields have been checked on the ground and found to be vineyards with high trellising presenting a closed 'vegetation ceiling' some 2 m above the ground. This contrasts with low-growing vines planted in distinct rows, which appear dark red in our image.

Urban cartography
In dense urban areas, the oblique-viewing ERS-1 radar does not allow such detailed mapping as vertical-viewing spaceborne optical sensors. However, when the orientation of large streets is favourable, they can still be distinguished. The famous Saint Peter's Square in Rome can be recognised, and even the obelisk in its centre can be detected. An advantage of SAR is that it images isolated houses and buildings very brightly, making the data valuable for monitoring the development of settlements. Among the linear elements visible are the motorways, which appear as very dark lines, and railways, which show up as white lines or series of dots. Metallic features may be imaged particularly strongly when favourably orientated; the bright star-like reflection just north of the town and harbour of Anzio (see Figs. 1 & 3) is merely a greenhouse with a metallic frame (Fig. 4) whose orientation differs from the satellite heading by only 5°. The roof has an inclination of 24°, almost perfectly matching the SAR's local incidence angle.

This brief analysis shows that multi-temporal spaceborne SAR imagery can be extremely valuable for many types of mapping and monitoring applications, particularly in combination with auxiliary data such as limited ground verification and weather records (especially rainfall events).

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
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Figure 1. ERS-1 SAR multitemporal colour composite of the Rome area based on data acquired on 3 January, 6 March and 11 June 1992 by the ESA station at Fucino and processed by ESA/ESRIN in Frascati. Rome is situated top left, while just above the image's centre are the Alban Hills (circular volcanic feature).

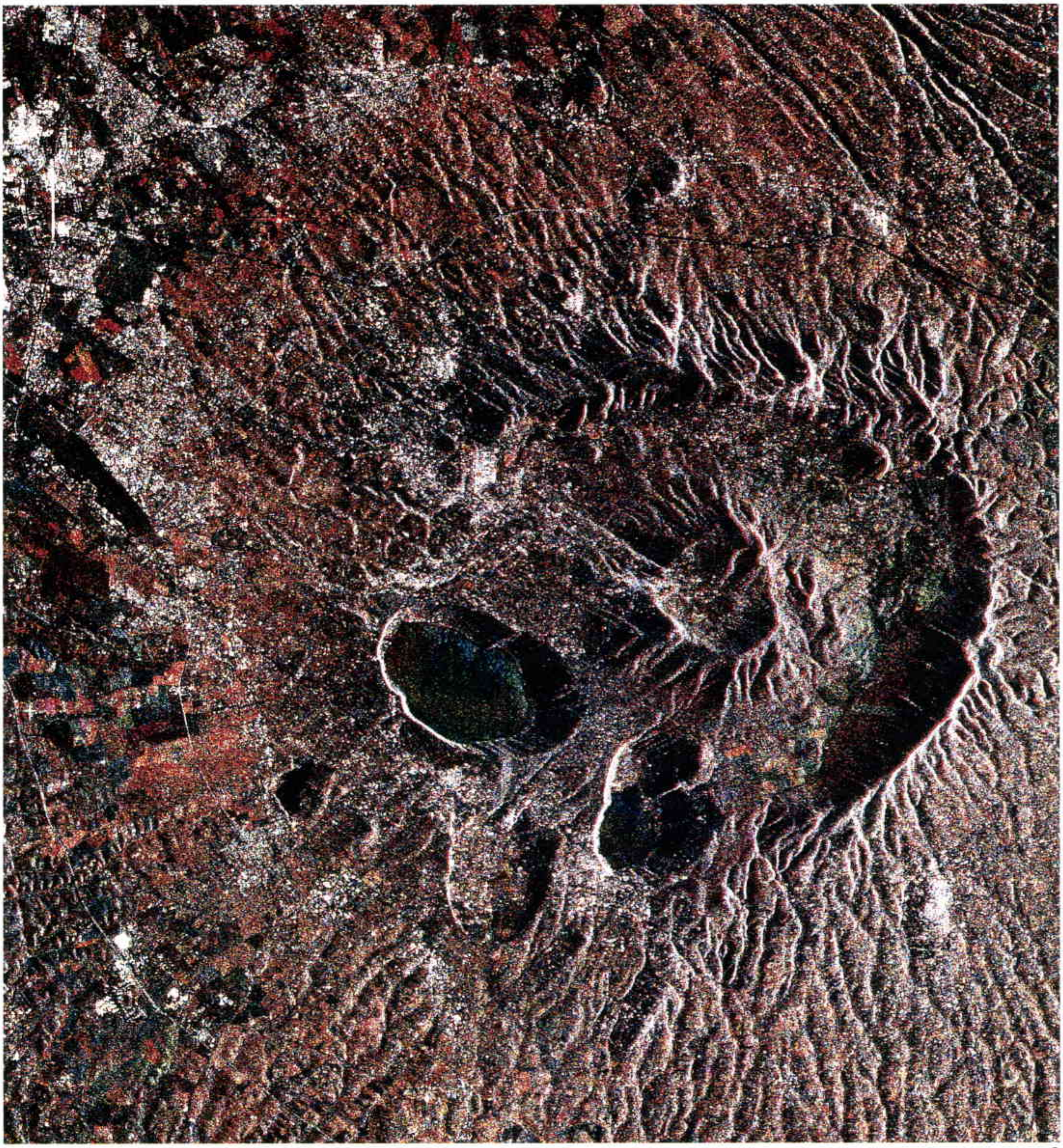

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Figure 2. The Alban Hills southeast of Rome, a popular summer resort and residence of the Roman nobility in ancient times (subscene of Fig. 1). The area is largely covered by chestnut woods, but is threatened by the sprawling city. This evidently volcanic complex was formed in three main phases: the outer ring structure is the remains of the oldest phase of vulcanism, ending some 350 000 years ago; the second phase, lasting until some 200 000 years ago, built the central crater, and the most recent hydromagmatic activity shaped smaller calderas, the most prominent of which are the lakes of Albano and Nemi. The volcano has been largely dormant for the last 20 000 years, but recently discovered documents mention small eruptions as recently as 2000 years ago.

Figure 3. The area north of Anzio (subscene of Fig. 1), which contains a target that appears very bright and star-like as it is 'perfectly orientated' towards the satellite sensor (see Fig. 4).

Figure 4 a,b. The object causing the extremely bright response is a greenhouse of metal and glass construction, completely white-washed to filter the incoming sunlight.

3

4a

4b

In Brief

ESA Maps European Forests

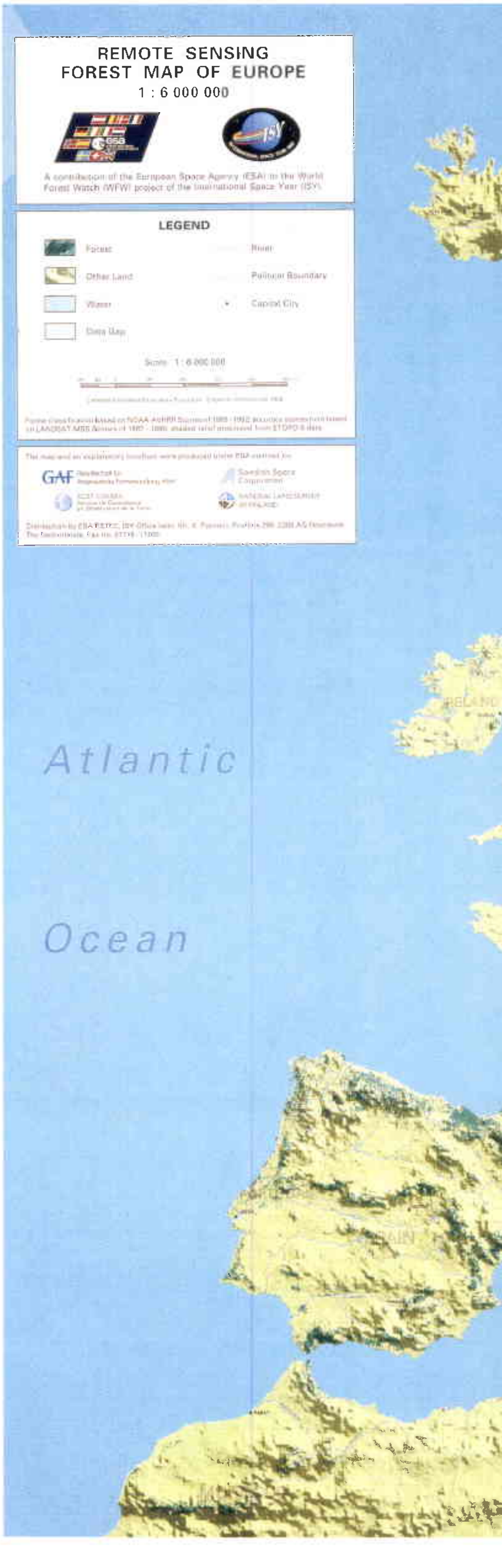
A remote-sensing Forest Map of Europe, covering the entire continent from the Atlantic to the Urals, was prepared by ESA as a contribution to the World Forest Watch (WFW) project of the International Space Year (ISY, 1992). This European forest map on a scale of 1:6 000 000 is of considerable interest for both national and multi-national decision makers working in such diverse fields as forestry, agriculture, climatology, tourism and environmental protection.

ESA was assisted in the production of the map by a consortium of four organisations, led by GAF mbH of Munich (D). The other three members of the consortium were the Swedish Space Corporation (Kiruna, S), SCOT Conseil (Toulouse, F) and the National Land Survey of Finland (Helsinki, SF).

Information about forest cover is generally available in the form of maps and inventories. Users of such maps in Europe range from local forestry experts and regional foresters to regional and national organisations. Supra-regional and supra-national organisations dealing with large conservation and development programmes need regularly updated maps on a scale of 1:2 000 000 to 1:6 000 000.

Feasibility studies for the ESA ISY mapping project, begun in 1991, showed that one of the best sources of data for such maps at that time was the Advanced Very High Resolution Radiometer (AVHRR) on the NOAA-1 spacecraft. This AVHRR data fulfilled the requirements for the World Forest Watch project in that they were both global in scope and continuous in nature (the NOAA–Tiros satellite series is planned to be continued well into the next century). ESA's feasibility studies also showed, however, that the sensor's ability to discriminate between different forest types is limited in certain respects. For example, its accuracy in distinguishing coniferous forest from a deciduous one can be somewhat low. Forests in Europe are predominantly of the 'Boreal', 'Central European' and 'Mediterranean' types. They vary greatly in appearance due to regional variations in climate, soil and management practices.

The most important criteria for data selection for the map were the availability of cloud-free images and the acquisition time (season of the year and time of the day). Radiometric and



The ESA Remote-Sensing Forest Map of Europe atmospheric suitability were also important. It sometimes proved difficult to meet all of these criteria; in some cases, for example, cloud cover made large parts of a scene unusable. Hence whilst in theory the European continent can be covered by 17 NOAA scenes (even if only the central part of the swath is used), in practice a much larger number of scenes was needed: a total of 112 images were acquired based on a quick-look evaluation, of which 72 were finally selected for use. To ensure optimal reflectance and spectral discrimination capabilities, only scenes taken around noon (when the Sun's elevation is a maximum) in June, July and August were used.

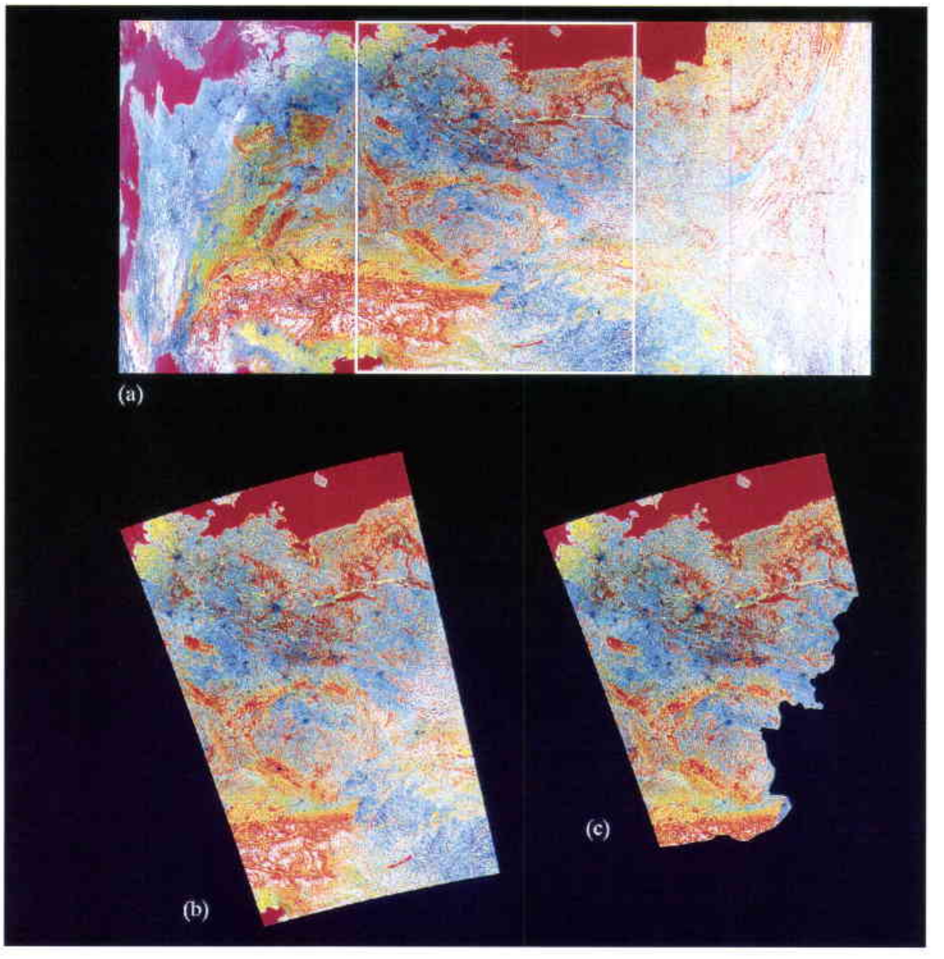
Data classification was confined to two classes, 'forest' and 'non-forest'.

Three major steps were involved in this Europe-wide mapping concept:
- Pre-processing of the data
- Thematic processing and accuracy checking
- Output product generation.

Classification accuracy was evaluated by comparing the classification results of NOAA AVHRR with those of Landsat Multi-Spectral Scanner (MSS) data. Among the parameters calculated were overall accuracy, which was found to be 82.5%, and surface-area accuracy, found to be 93.8% on average.

As specified at the outset, the project resulted in a 1:6 000 000 map and a digital data set. The final map shows the forest distribution in Europe, also in the context of topographic relief. The digital data set can be used at scales of up to 1:2 000 000 and, thanks to its availability, potential users – planners, meteorologists and other decision makers – can now exploit the map as a whole or just those pieces of it that meet their particular needs. This map can also be updated periodically in the future with a minimum of effort, thereby allowing changes in forest extent on a continental scale to be detected and monitored both rapidly and efficiently.

K. Pseiner & B. Pfeiffer, ESTEC



Typical NOAA AVHRR image. Due to the off-nadir radiometric and geometric degradation, only the central parts (boxed in white in (a)) were used for further processing. The rectified central part (b) with clouds masked out (c) was used for the final classification step.

First European Conference on Space Debris Held

Since the launch of Sputnik in 1957, there have been more than 3400 space launches. Each of these missions has left debris in space, which eventually either re-enters into the Earth's atmosphere, escapes from Earth orbit into deep space, or remains in Earth orbit. In addition to the operational satellites, the debris can include rocket bodies discarded after use, spent satellites, and hardware released during payload deployment, as well as small-sized debris such as particles of paint or fragments from explosions. Currently, more than 7000 man-made objects are being tracked. Most of those objects are debris that is orbiting the Earth in the regions where space activity is the greatest, i.e. in the Low Earth Orbit (LEO) and the geostationary orbit (GEO).

These objects are a growing concern: a 1 cm fragment travelling at over 18 000 km per hour or 5 km per second (so-called hypervelocity) can shatter a satellite. During its projected lifetime of 17 years, the Hubble Space Telescope has about a 4% chance that it will be severely damaged by a collision with an object larger than 1 cm. In turn, collisions create many smaller fragments which then increase the probability of further collisions.

Finding a solution

Since debris is a global issue, all spacefaring nations must cooperate in addressing the problem. ESA has conducted bilateral discussions on the issue with NASA and other space agencies since 1987. On 2 and 3 April, representatives from ESA, NASA, the Russian Space Agency, and the Japanese Space Agency NASDA, met in Darmstadt, Germany, for the first multilateral talks on the space debris issue. It was agreed to establish a Space Debris Coordination Committee that would regularly meet and that would be supported by technical working groups. Within the framework of this cooperation, the four agencies will exchange technical information and experience relating to space debris, and will prepare common strategies to address the space debris problem.

Those talks were followed by the ESA-organised First European Conference on Space Debris, on 5 to 7 April. More than 250 experts from 17 countries including the USA, the CIS, Japan, China and India gathered.

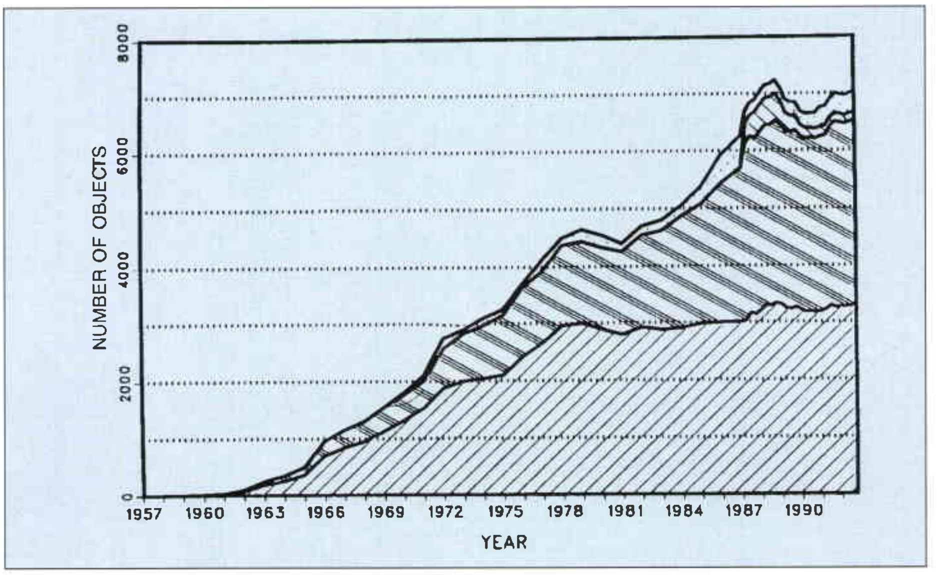
Preventive measures

Due to high orbital velocities, the clean-up of debris is neither technically practical nor economically feasible. Thus, efforts must be focussed on preventing the creation of debris.

Several preventive measures have been implemented:

— releasing residual propellant in rocket upper stages to minimise the possibility of a future explosion which would generate many smaller objects
— moving the spacecraft at the end of its operational lifetime to a higher, disposal or 'graveyard' orbit to avoid collision with other, operational satellites
— changing the design of the spacecraft to incorporate fewer releasable parts, use of debris catchers for example for explosive bolts, and multiple payloads on a single launch.

Other preventive measures have been proposed including transferring the spacecraft to an orbit with a limited lifetime of 10 years for example, where the spacecraft will gradually re-enter the Earth's atmosphere and 'burn-up'.



Catalogued objects in orbit (objects in LEO larger than 10—50 cm, and objects in higher orbits with a diameter of more than 1 m). Approximately 6% are operational satellites and 46% are fragments resulting from spacecraft and rocket upper stage break-ups.

Protective measures
Several protective measures are also being studied, particularly for crewed vehicles. The main method consists of 'shielding' the spacecraft against hypervelocity impacts using a double wall structure: the outer wall acts as a bumper and shatters the impacting object allowing the inner wall to only be hit by smaller molten or vapourised particles. However, shielding is only effective against particles that are smaller than 1 cm.

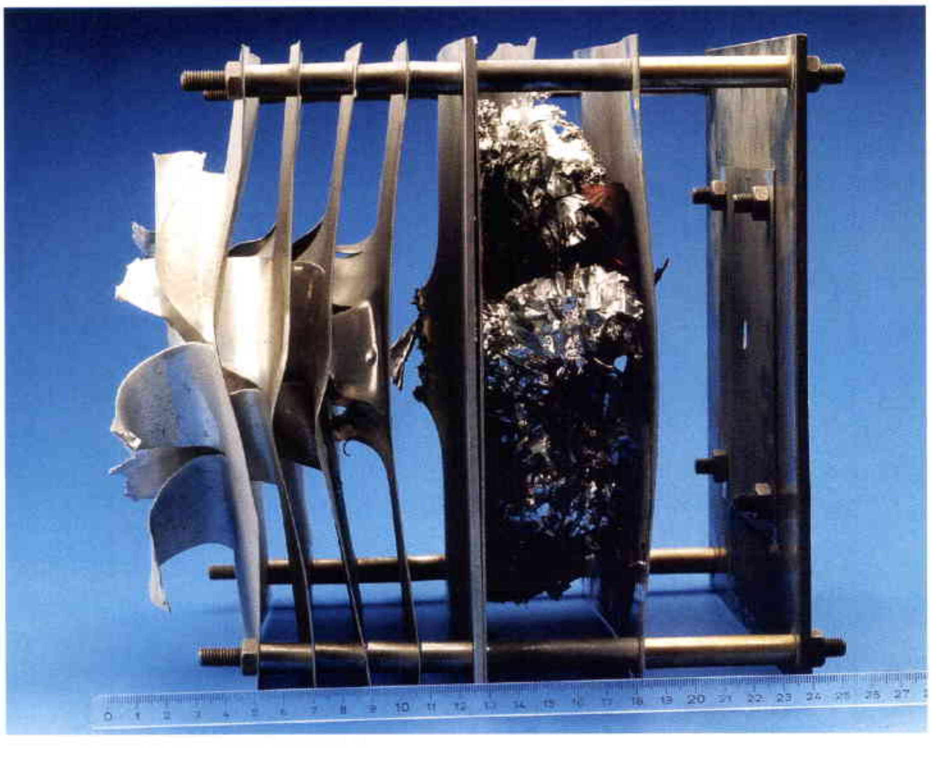
Ground-based tracking of objects with radar and optical facilities, and data modelling are continuously being carried out to assess the risk of collision and to allow a spacecraft to take measures to avoid the collision, such as manoeuvring away from the object.

Efforts to characterise the mid-size debris population (1—50 cm size objects) are in progress. Shielding against these objects is not practical and the knowledge of the spatial distribution is not very accurate.

Regulating space debris
Although three space treaties, the Outer Space Treaty 1967, the Liability Convention 1972 and the Registration Convention 1976, provide very general guidelines regarding the pollution of space, existing space law does not explicitly address the space debris issue. The measures that each agency has taken to date have been done under their own initiative. However, those same agencies and international regulating bodies are now beginning to study the development of such policies.

ESA's activities
ESA is coordinating space-debris-related activities in Europe. The ESA Council passed a resolution on space debris in 1989, and a research programme, being undertaken by ESA and some of its member states, is addressing the orbital debris environment, risk assessment, and preventive and protective measures. ESA is already sending its geostationary satellites into a graveyard orbit and will soon begin implementing propellant depletion on all Ariane launches.

A second conference is expected to be held within two to three years to discuss the progress being made.



A simulation of the wall of the Columbus Attached Laboratory after being hit (from the right) by a 10 mm aluminium projectile at a velocity of 6 km/s. From right to left, the layers are: the shield or first bumper, the second bumper, multi-layer insulation (before the test, it resembles many layers of foil but has been shredded by the impact), the wall of the spacecraft, and several witness plates used only in testing.

Belgium Opens Remote Operations Centre

The Belgian Space Remote Operation Centre was formally opened on 22 March. Located at the Royal Institute of Meteorology of Belgium (IRMB), in Brussels, the Centre will provide the facilities for telescience operations — the decentralised, interactive operation of a payload.

The first mission that the Centre participated in was the Atlas-2 mission (see related article). The Centre received real-time and playback data from two instruments on the Atlas-2 mission: the Solcon and the Solspec. In addition, the Solcon experiment was remotely controlled from the Centre. A video link between the Centre and the POCC at Marshall Space Flight Center (MSFC) allowed the co-investigators in Brussels to participate in Science Operation Planning Group (SOPG) meetings held at MSFC during the mission and to communicate with the principal investigators at the POCC.

The installation of the facilities at IRMB will be completed to allow the Centre to participate in the Atlas-3 mission in November 1994. IRMB will be linked to other Belgian institutes and research centres through a data network that allows the transfer of data from space experiments in real-time or off-line. Those institutes and centres will have access to remote payload operations via the network node at IRMB.

J.-M. Luton (left), Director General of ESA, J.-M. Dehousse, Belgian Minister of Science Policy, D. Frimout (right), Belgian astronaut, and J. Wautrequin, General Secretary of the Belgian Science Policy Office, at the Centre during a video conference with the Atlas-2 team at the Marshall Space Flight Center (MSFC) in Huntsville, Alabama.

Atlas-2 Studies Sun's Activity and its Impact on the Atmosphere

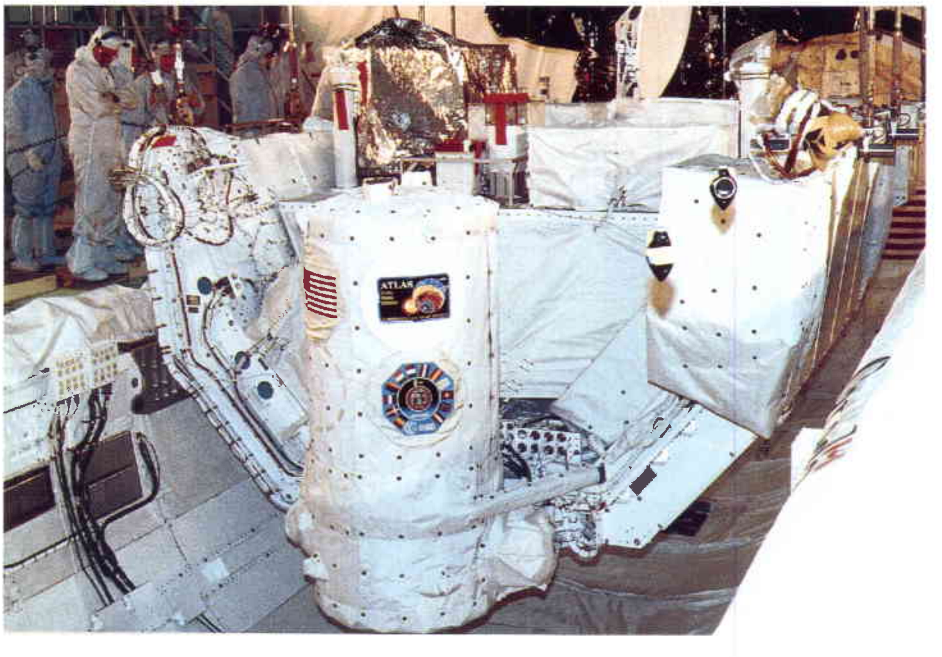
The second Atmospheric Laboratory for Application and Science (Atlas-2) mission was launched on 8 April. This one-week mission (STS-56) will help scientists to better understand the Sun's activity and the Earth's atmosphere, and their interactions. It was the second in a series of 10 missions originally planned for the 11 years of the solar cycle. The Sun's activity is decreasing and will reach its minimum in 1996. It reached its maximum in 1990.

These one-week missions, which will all occur at different times of the year to allow seasonal variations to be studied, will carry instruments that have been included in previous payloads and have undergone an overhaul and high-precision recalibration. Seven of 12 instruments flown on the Atlas-1 mission a year ago (in March 1992) were part of the Atlas-2 payload. The data gathered during this series of missions will allow scientists to produce better mathematical models of the atmosphere's chemistry and behaviour, and measure the effects of pollution and ozone depletion.

The instruments

Among the seven instruments that were again part of the payload, there are three European instruments: the Solcon and the Solspec which measured the amount of energy emitted by the Sun and received by the Earth's atmosphere, and the MAS which measured gases in the atmosphere.

— The Solar Constant Radiometer (Solcon) measured the amount of



Spacelab carrying the Atlas-2 payload, being placed in the cargo bay of the Space Shuttle 'Discovery' before the mission

energy needed to maintain the thermal balance between two identical cavities, one of which is exposed to solar radiation. It will contribute to the knowledge of the absolute value of the solar constant, i.e. the amount of solar energy received in the Earth's orbit.
- The Solar Spectrum Irradiance Monitor (Solspec), working in parallel with the Solcon experiment, studied solar radiation with a wavelength between 180 and 3200 nm (ultraviolet, visible and infrared). The data will be used in determining the spectral distribution of the energy associated with solar radiation, and its long-term fluctuations. Those fluctuations cause variations in the composition of the stratosphere and, in particular, in the distribution of ozone. They are linked to the solar cycle.
- The Millimetre Wave Atmospheric Sounder (MAS) measured the absorption spectra of water vapour and trace gases in the Earth's upper atmosphere. It included measurements of ozone and chlorine monoxide, which contributes to the depletion of the ozone layer. In addition to providing a fuller understanding of the concentration and distribution of such molecules, the measurements will allow the study of temperatures and pressures at altitudes between 20 and 100 km.

Joint observation data collected

In addition to the Solcon and Solspec experiments, two other European instruments, carried on board the European Retrievable Carrier (Eureca) which is currently in orbit (see related article), namely the Solar Variation (SOVA) and the Solar Spectrum (SOSP) instruments, also measured the solar constant at the same time and the data acquired will be compared. It will also be compared with that gathered by NASA's research Nimbus-7 satellite, Upper Atmosphere Research Satellite (UARS) and ERBS during their routine operations. This will allow the measurement characteristics of each instrument to be established, in relation to the others. In turn, solar constant and spectroscopy data that had previously been collected can be corrected.

The arrival of telescience

Telescience — the decentralised, interactive operation of a payload — will provide scientists with the ability to monitor their experiments that are in orbit, in real-time and from their own laboratories. An investigator could repeat the experiment while it is still in orbit using different parameters, process experiment data and consult with the project team, and redirect the operation when interesting phenomena are observed. The complex space-to-ground communications links and the tools to control the experiment from the scientist's laboratory will be designed to be as transparent and user-friendly as possible.

Upon ESA's proposal to NASA to test telescience during Spacelab missions carrying European experiments, the concept was first introduced during the Atlas-1 mission. A prototype link was established between the Space Shuttle and ESA's space research and technology centre, ESTEC, in The Netherlands, and the principal investigator for the Solcon experiment used it during the mission to send commands to the instrument.

Crew of the Atlas-2 mission (from left to right): Ken Cockrell (mission specialist), Stephen Oswald (pilot), Michael Foale and Ellen Ochoa (mission specialists), and Ken Cameron (commander)

During Atlas-2, telescience was taken one step further. All the measurements made by the Solcon instrument were commanded from the Belgian Space Remote Operation Centre in Brussels (see related article). The solar spectrum data from the Solspec instrument was also transmitted in real time to the Centre allowing researchers to observe the measurements obtained. The scientists at the Centre were in constant contact with the Payload Operations Control Center (POCC) at NASA's Marshall Space Flight Center in Huntsville, Alabama.

ESA Selects Astronauts to Participate in Mir Precursor Flights

ESA has selected four astronauts who will train to participate in the precursor flights to Mir-1 that are scheduled for 1994 and 1995. Two of those four will eventually be selected as crew members.

The four chosen to date are Ulf Merbold and Pedro Duque for the ESA/Mir flight in September 1994 (Mission 17), and Christer Fuglesang and Thomas Reiter for the flight in August 1995 (Mission 19). The first flight will last for 30 days and the second one for 135 days. The ESA astronaut on the second mission will perform extravehicular activities.

The selection was made on the recommendation of ESA's European Astronaut Centre, following a series of physical and medical tests.

The four astronauts will begin a special training course for Mir missions at Star City, the Russian astronaut training centre near Moscow, in August. About eight weeks before each mission, the astronaut chosen to fly and the back-up will be named and both will subsequently train in parallel. About a week before the mission, following the final medical assessment, the final crew will be selected.

Through these precursor flights, the astronauts will gain experience in crewed flight in preparation for the future programmes that ESA is currently planning to undertake in cooperation with both NASA and the Russian Space Agency (RKA). At the same time, a number of scientific experiments, mostly relating to microgravity, will be performed.

Ulf Merbold

Pedro Duque

Christer Fuglesang

Thomas Reiter

ESA Astronauts at the Paris Air Show

Between 10 and 20 June, ESA will again be participating in the Paris Air Show, one of the largest air shows in the world. This will be the 40th show. This biennial event is held at Le Bourget airport on the outskirts of Paris, and is open to the public.

To demonstrate the difficulties that astronauts working in microgravity conditions must overcome, ESA astronauts will perform their training exercises and actual tests in a specially-designed aquarium, which is six-metres deep, and using a structure representing the Columbus Attached Laboratory. The aquarium will later be used for development tests for orbital laboratories.

Models of many spacecraft will also be displayed, including satellites such as Meteosat, ERS and Artemis, and launchers such as Ariane-4 and Ariane-5, whose first flight is scheduled for the fall of 1995. Visitors will also be able to take a 'voyage' between Earth and space using a holorama, or discover new virtual reality simulation techniques.

IUE Observatory Celebrates Satellite's 15th Anniversary

On 10 March, ESA's Villafranca del Castillo Satellite Tracking Station in Madrid, Spain, celebrated the 15th anniversary of the launch of the International Ultraviolet Explorer (IUE) satellite.

The satellite was launched in January 1978 by a Thor-Delta rocket and has since been in a geosynchronous orbit over the Atlantic Ocean. It is an orbiting telescope with a 45 cm aperture for spectroscopy in the ultraviolet wavelength range. Over the past 15 years, it has collected more than 90 000 ultraviolet spectra of all classes of astronomical objects. At the time of launch, the IUE was expected to last for a maximum of five years. The high precision of its attitude control system has been maintained even though only two of the original six gyroscopes are currently operating.

The IUE Observatory is responsible for the management of access from outside the U.S. and U.K. to a public domain archive that contains all data collected. The Observatory has also contributed greatly to astrophysics and space science in general by supporting scientists, particularly in Spain and in developing countries.

V. Claros, Director of the Villafranca Satellite Tracking Station, welcomes guests to the celebration

D-2 Mission Launched

The second German Spacelab (D-2) mission was launched on 26 April aboard Space Shuttle 'Columbia'. It is carrying 92 experiments, 32 of which were developed with ESA funding. It is dedicated to fundamental research in the fields of life sciences, material sciences, Earth observation and robotics.

The German Aerospace Research Establishment (DLR) is directing and controlling all payload activities on board the Spacelab from its dedicated control centre in Oberpfaffenhoffen, near Munich, Germany. Results are being transmitted in real time to ground at NASA's Johnson Space Center (JSC) in Houston, and from there they are transmitted to the DLR control centre where the scientists who developed the experiments are able to record the data and analyse it immediately.

The ESA facilities on board include the Anthrorack facility used for research into human physiology under microgravity conditions, and the Advanced Fluid Physics Module (AFPM) used to determine the effect of microgravity on the properties and behaviour of fluids. Two other experiments will be used to evaluate concepts developed for the future Columbus Attached Laboratory, namely a system that uses two portable computers to allow communication and the exchange of graphic information between the astronauts and the scientists on the ground, and another system that is used to assess the level of microgravity to which experiments are being submitted. More details on these experiments will be provided in the next issue of the Bulletin.

Two payload specialists from DLR are also part of the seven-member crew.

The crew of the D-2 mission on-board Columbia (from left to right): Bernard Harris and Charles Precour (mission specialists), Hans Schlegel (payload specialist, from DLR), Jerry Ross (commander), Ulrich Walter (payload specialist, from DLR), and Tom Henricks (pilot)

Preparing for the First HST Servicing Mission

The crew of the Space Shuttle mission (STS-61) to service the Hubble Space Telescope (HST) has begun preparing for the mission. It will be launched at the end of 1993 and will be the first of several missions to maintain and improve the HST's performance over its projected life of 15 years.

During this 11-day mission, a record number of five Extra Vehicular Activities (EVAs) or 'spacewalks' are scheduled, with the capability for an additional two, if they are needed. During the spacewalks, the priorities are to replace gyroscope units, the solar array and the Wide Field/Planetary Camera, and to install a device that will correct the spherical aberration of the primary mirror, the Corrective Optics Space Telescope Axial Replacement (COSTAR).

The replacement solar array deployed in the clean room

Crew training

To prepare for the mission, the crew will participate in numerous training sessions in a water tank, some of them with support from the Mission Control Center. Each of these 'joint integrated simulations' will last 10 to 36 hours. In addition, the crew will practise many individual tasks both on land and underwater.

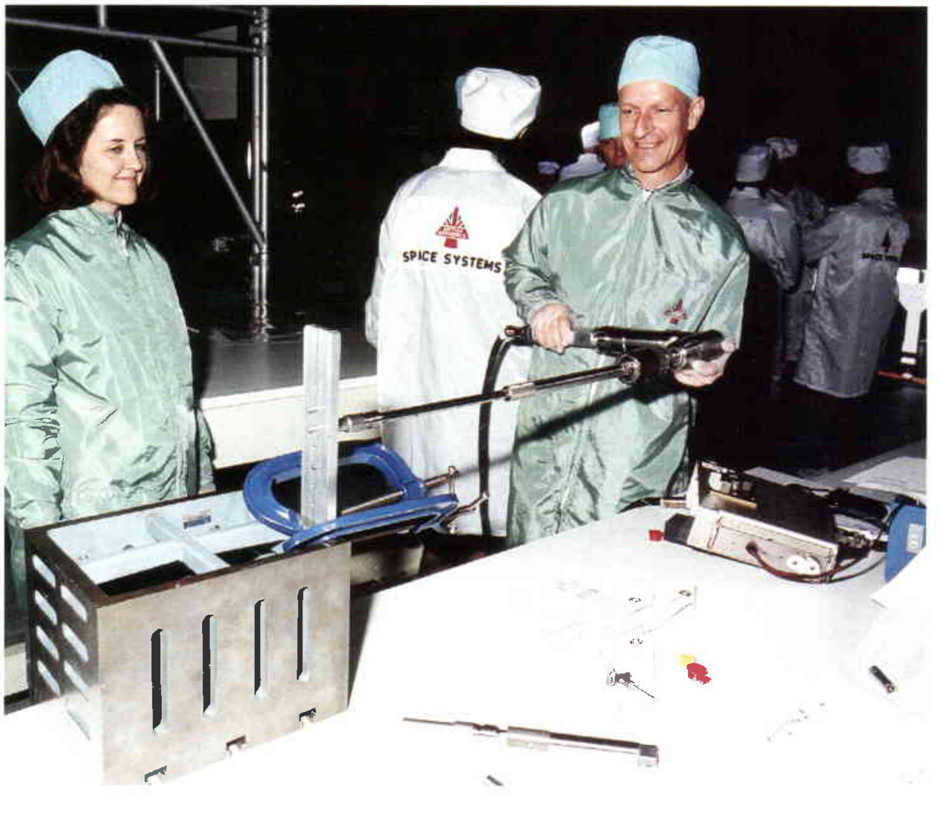
The experience gained during training will be used to refine the method of performing each task before the mission. The knowledge gained during missions leading up to STS-61 will also be integrated into the crew training. For example, a mission in June and another in July will both include spacewalks to evaluate tools developed for the HST mission.

Replacing the solar arrays

One of the tasks to be accomplished during the EVAs is to replace the two wings of the solar array with a new, modified pair. The original ones were designed to be replaced after a number of years in orbit (the HST was launched in 1990). Radiation and other processes degrade spacecraft such as the HST that are in low-Earth orbit, and the array's power output eventually falls below the amount that it produced following the launch. In addition, thermal expansion and contraction at orbital sunrise and sunset cause an undesirable 'jitter' of the telescope's existing array — a problem that will be corrected in the new design.

In March, five of the seven crew members visited British Aerospace Space Systems Limited's satellite manufacturing and test facility (Bristol, UK) to familiarise themselves with the replacement array. The array is being built, as the first one was, under contract from ESA as part of the European contribution to the HST.

Two roll-out solar array wings will be installed. The solar array converts solar radiation into electrical power for the HST's instruments, communications payload and on-board systems. When deployed, each wing is 12 metres long and 2.8 metres wide, contains almost 25 000 solar cells and, including all mechanisms, weighs approximately 160 kg.



ESA Astronaut Claude Nicollier practises in the clean room in preparation for the first HST servicing mission. Another crew member, Kathryn Thornton, a mission specialist from NASA, looks on.

Eureca to be Retrieved

After having spent a successful nine months conducting microgravity research in orbit, the European Retrievable Carrier (Eureca) is to be retrieved in June. It is the first carrier dedicated to long-duration microgravity research. It will be retrieved by the Space Shuttle 'Atlantis' on the third day of the STS-57 mission.

By the end of January 1993, Eureca's baseline on-board experiment programme had been completed, in accordance with the mission plan. The payload consists of 15 different experiment facilities. Sufficient power and thermal resources were still available on board to allow the operation of those experiments with an open-ended experiment programme (mainly space science and technology experiments) to continue. Those facilities that had already been completed remained 'deactivated', awaiting Eureca's retrieval.

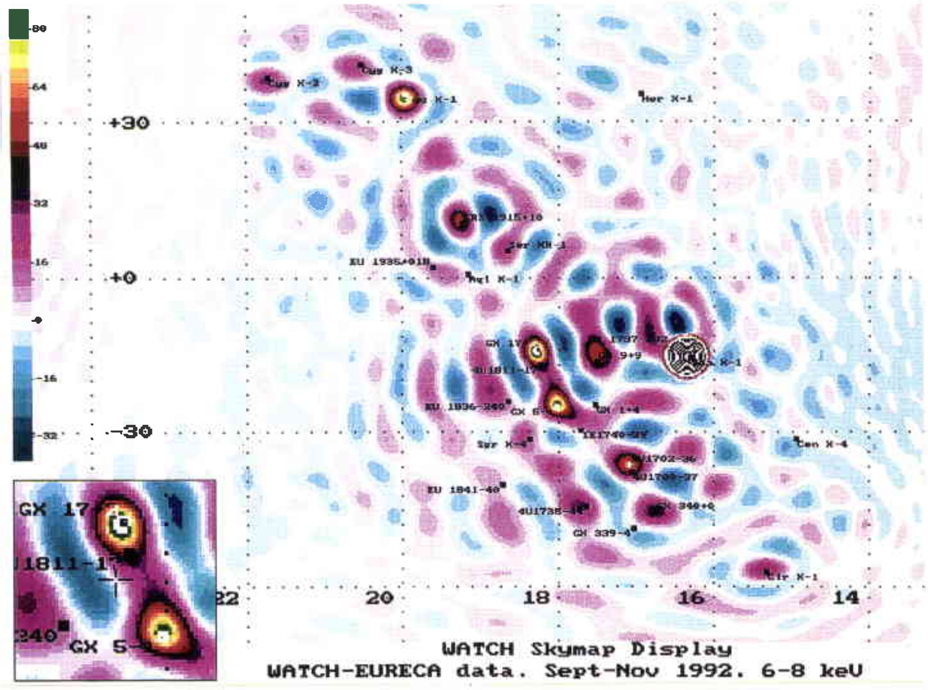


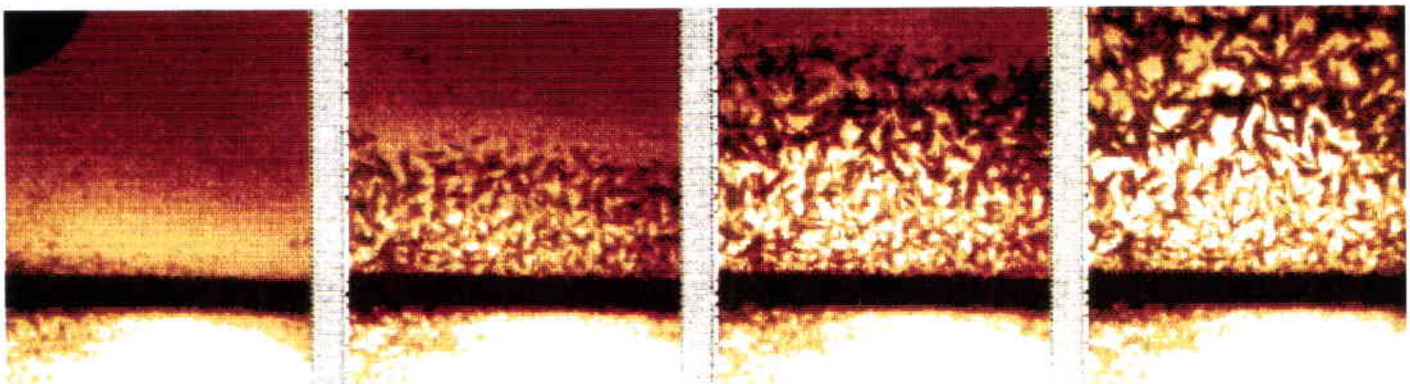
Image of the X-ray sky toward the centre of the Milky Way, taken by Eureca's WATCH

In preparation for the retrieval, Eureca's orbit, having been lowered to approximately 490 km by natural drag, will be adjusted in May in such a way that the drag-induced decay during the remaining duration of the flight will lower Eureca to the rendez-vous and retrieval altitude of about 476 km. After the rendez-vous of the two spacecraft, the Shuttle's remote manipulator arm will grapple Eureca and place it in the Shuttle's cargo bay for the descent to Earth.

Although most of the results will not be known until after all samples returned from space have been analysed, the mission is considered to be successful. Most notably, five new transient X-ray sources have been discovered using the Wide-Angle Telescope for Cosmic Hard X-rays (WATCH), and a very short gamma-ray burst (2 sec) was observed. That telescope monitors a wide band of the sky, seeking variable X-ray sources or the appearance of new sources or cosmic gamma-ray bursts. Following the tradition in X-ray astronomy, the new X-rays have been given names such as EU 1722+256, where EU represents Eureca and the numbers indicate the position of the source.

In addition, Eureca participated in a campaign to gather joint observation data on the Sun's irradiance and its spectral energy distribution — two of its instruments, the Solar Variation (SOVA) and the Solar Spectrum (SOSP) instruments, made measurements at the same time as two corresponding instruments on the Atlas-2 mission, the Solar Constant Radiometer (Solcon) and the Solar Spectrum Irradiance Monitor (Solspec) (see article on Atlas-2 mission). The results gathered will be compared and the various instruments can then be synchronised. Consistent and well-calibrated solar data is crucial to the understanding of the variations in the Earth's atmosphere.

Alpha-crustacyanin protein crystals growing in microgravity in Eureca's Protein Crystallisation Facility (PCF). The dark line is the barrier at which crystal growth begins. The crystals appear to be large and well shaped but their structure will have to be confirmed after their return to Earth.



ESA's Eurosim Offers Real-time Simulation

Eurosim — the European Real-time Operations Simulator — is entering its final implementation phase. This facility will enable the execution of software models that approximate real-life space-related situations, in real time. It will support the simulation needs of ESA programmes until the year 2000 and beyond.

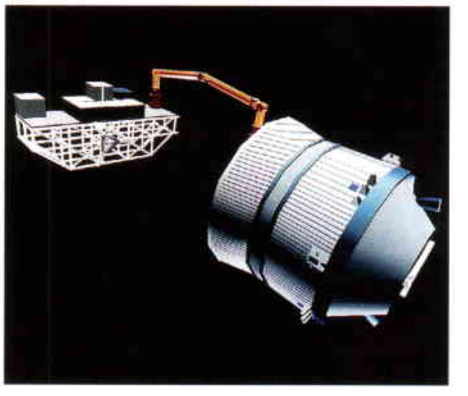
To date, a prototype has been implemented and has been used for several different studies, including:
- simulations of the European Robotic Arm (ERA)
- assessment of a spacecraft's crewed rendez-vous and docking operations, in manual and semi-automatic mode
- simulation of the re-entry and landing of winged vehicles
- simulations of mobile robotic rovers, for example, on Mars.

Following several studies which began in 1988 under the framework of ESA's Technological Research Programme, a team of contractors, lead by Fokker Space and Systems (NL), devised a generic real-time simulation tool that satisfied the needs of different users while providing significant performance and flexibility. The Eurosim prototype was then implemented in 1990 at ESA's research and technology centre, ESTEC, in The Netherlands for evaluation and has since been used in on-going programmes and research activities. This prototype has allowed both ESA and industry to gain valuable experience in the design, development and operation of a large real-time simulation facility.

While most simulation facilities are developed for a specific project, Eurosim is a generic facility — standard Eurosim packages are reconfigured or replaced to suit the mission that is being simulated. This results in a reduced simulation development time and a greater confidence in the software. In addition, actual hardware and other equipment, such as an instructor facility or a 'cockpit' can be connected.

Based on the vast amount of experience gained through the use of the prototype, the implementation of the operational system will now begin, with the final delivery expected in 1995.

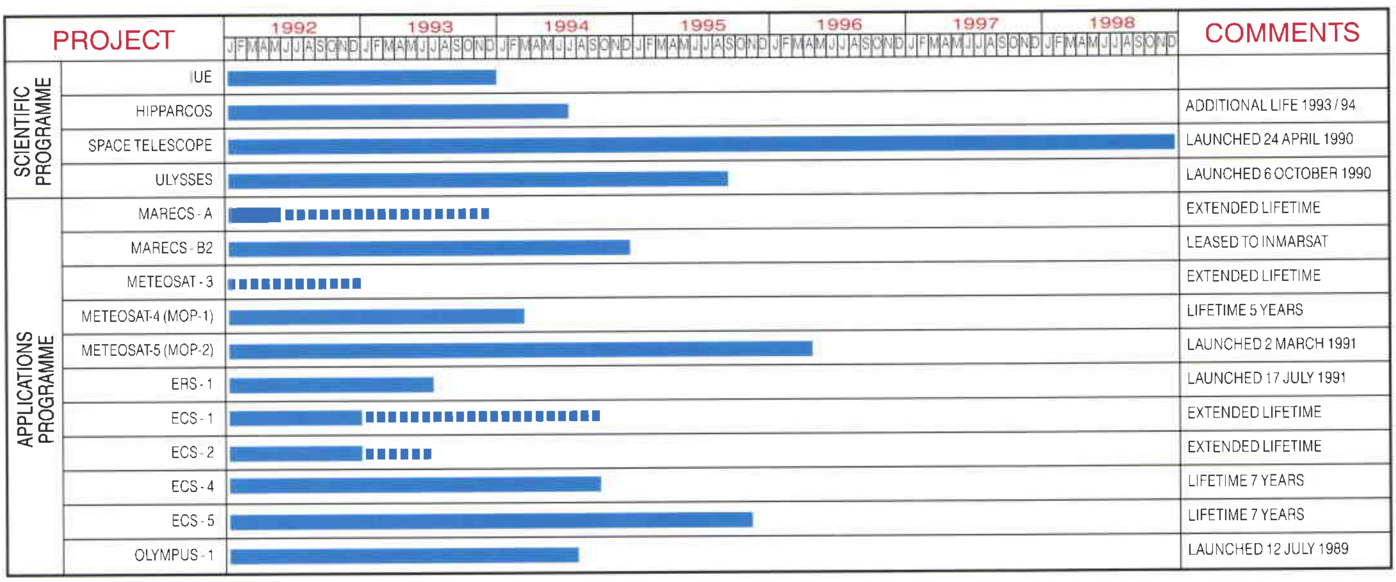
The development of this operational version of Eurosim will be funded by the National Agency for Aerospace of The Netherlands (NIVR), and will allow the Dutch aerospace industry to gain a greater competence and competitiveness in real-time simulation. The team of contractors, lead by Fokker Space and Systems, will produce the generic real-time environment. Discussions about the development of the real-time image-generation subsystem are underway with the Spanish Agency for Industry (CDTI) and the Spanish firm CASA.



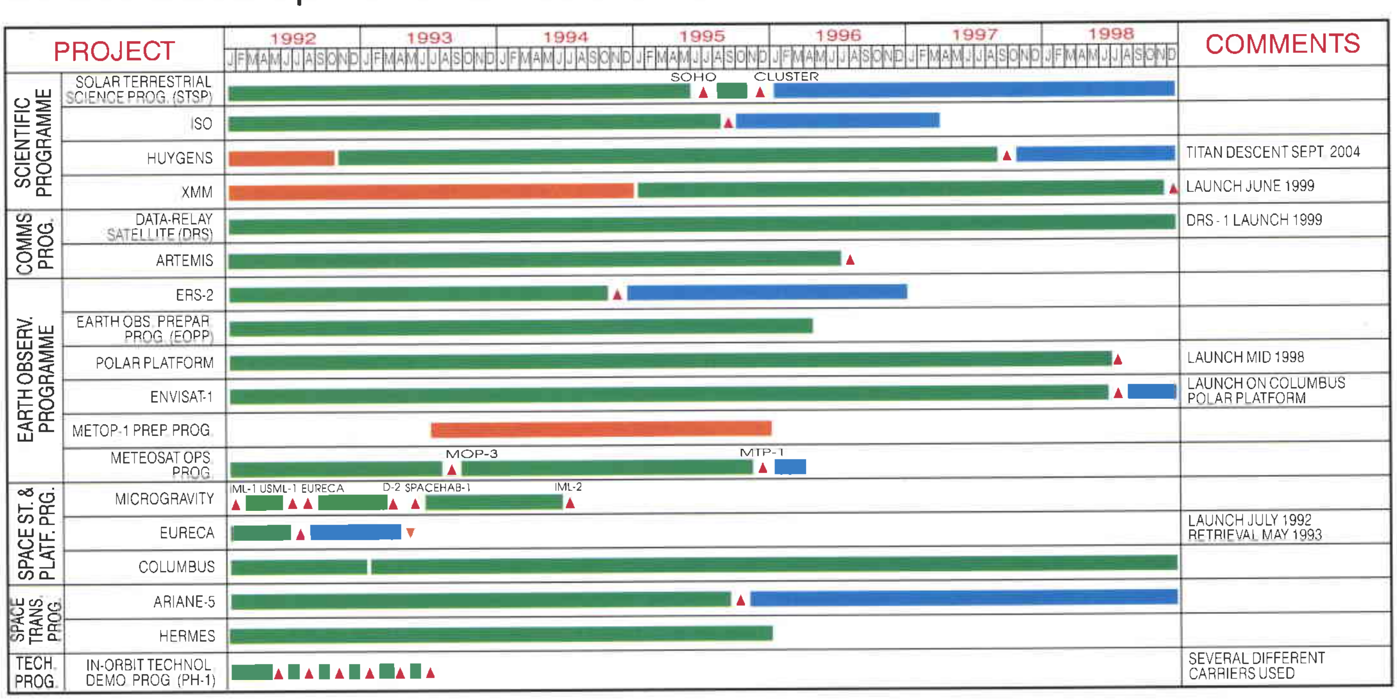
Eurosim simulation of the European Robotic Arm (ERA), which is attached to the spacecraft on the right and is grappling the spacecraft on the left

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

HST

Les travaux réalisés dans le cadre de la participation de l'Europe à la première mission de desserte du télescope spatial Hubble (HST) sont maintenant très avancés. C'est la première fois que la NASA va réaliser la desserte d'un véhicule spatial conçu et construit de façon à pouvoir être entretenu et réparé en orbite. Les missions de ce type réalisées jusqu'ici ont été des missions de réparation rendues nécessaires par un défaut de fonctionnement du satellite.

L'ESA participe à la mission de desserte HST dans deux domaines critiques. Tout d'abord, elle fournit les réseaux solaires de remplacement, les réseaux actuels ayant tendance à vibrer, notamment lors du passage de la nuit au jour orbital et inversement. A la différence de la Terre, le HST connaî des jours de 90 minutes environ. Ce nouveau réseau solaire ramènera les perturbations cycliques à un niveau négligeable.

La contribution de l'ESA consiste ensuite à remettre en état le modèle structurel et thermique de la caméra pour objets faiblement lumineux (FOC/STM). Ce modèle ainsi que d'autres matériels et logiciels européens seront utilisés pour réaliser un essai de bout en bout du système COSTAR qui corrigera l'aberration sphérique bien connue du miroir primaire du HST. C'est parce qu'un tel essai n'a pas été réalisé avant le lancement du HST que le défaut du miroir a pu passer inaperçu.

La fabrication des réseaux solaires de vol est maintenant terminée et la phase finale des essais est en cours, avant leur expédition au Centre spatial Goddard début mai. Tous les essais d'ambiance, notamment les essais vibratoires et acoustiques sont achevés. Les astronautes qui se chargeront du remplacement ont passé une semaine début mars chez BAe, à Bristol (R-U), où les panneaux solaires ont été fabriqués, afin de se familiariser avec le matériel sur lequel ils travailleront en orbite.

Les travaux sur le FOC/STM en Europe sont maintenant achevés et le matériel a été expédié chez Ball Brothers à Boulder, Colorado (USA), responsable du COSTAR. Matra et LAS, responsables des matériels et du logiciel, y réaliseront à l'aide du COSTAR les essais de vérification préalables au lancement.

Tout cela montre que les activités seront désormais centrées sur les Etats-Unis, où tous les matériels et logiciels de cette première mission de desserte feront l'objet d'essais poussés avant le lancement de la mission, prévu pour le 2 décembre 1993.

Ulysse

A l'exception de l'anomalie décrite ci-dessous, la mission Ulysse s'est poursuivie sans heurt au cours de ces trois derniers mois. La charge utile scientifique continue à fournir d'excellentes données sur les conditions hors du plan de l'écliptique, et le taux moyen de récupération est resté régulièrement supérieur à 95%.

Le véhicule spatial a connu une anomalie le 14 février alors qu'il était suivi par la station du réseau de l'espace lointain de la NASA à Madrid: le satellite est passé spontanément en mode 'sécurité', mettant hors tension tous les éléments non essentiels branchés sur l'alimentation. La logique de bord a mis tous les instruments scientifiques hors tension et, immédiatement après, la reconfiguration de tous les sous-systèmes s'est déclenchée de façon autonome, ce qui a interrompu la télémesure. Celle-ci a été rétablie environ cinq heures plus tard et les vérifications de l'état du satellite ont confirmé qu'il s'était reconfiguré correctement.

Le satellite et sa charge utile ont donc retrouvé leur configuration nominale sans autre problème. La cause exacte de cette anomalie, la deuxième de ce type depuis le lancement il y a deux ans et demi, n'a pas été établie à ce jour.

Soho

Industrie

L'intégration et les essais des deux modèles de développement du véhicule spatial ont progressé depuis le dernier rapport, la revue de la conception du matériel tenue fin septembre 1992 ayant donné le feu vert à ces activités.

Tous les modèles structurels des expériences et tous les équipements ont été installés dans la structure du module de charge utile (PLM) et les essais de charge statiques et d'analyse modale ont été menés à bien au centre d'essais d'IABG à Ottobrunn (D).

La structure du module de servitude a été livrée en décembre 1992 et soumise aux essais statiques. L'essai d'analyse modale fera suite, également à l'IABG.

Le premier modèle d'identification d'une expérience, GOLF, a été intégré à la maquette du PLM et essayé fin décembre chez Matra Marconi Space (R-U). A la fin de février 1993, six expériences avaient été intégrées et essayées avec un rendement croissant. Les premiers sous-systèmes (télécommunications et traitement des données) ont été livrés à Matra Marconi Space à Toulouse (F) fin février. La phase principale de l'intégration et des essais du modèle d'identification du module de servitude de Soho a alors pu débuter.

Des revues de lancement en fabrication ont lieu en Europe afin d'officialiser l'approvisionnement des modèles de vol de tous les éléments. La fabrication de certains éléments du modèle de vol (structure du module de charge utile, réseaux solaires, matériel de propulsion, par exemple) est déjà bien avancée. Une attention particulière a été accordée au début de l'année à l'approvisionnement des pièces des modèles de vol de façon à ce qu'elles parviennent en temps voulu pour la fabrication et l'assemblage de tous les éléments.

Les techniques et procédures de contrôle de propreté, déjà présentées à la revue de la conception du matériel, font l'objet d'une définition détaillée en vue de leur application dans les séquences d'AIV (assemblage, intégration et vérification) des modèles de vol de la charge utile et des modules de servitude, au cours du deuxième semestre 1993.

Les activités d'ingénierie visent maintenant à préparer la revue de conception critique de la mission, prévue au troisième trimestre de cette

HST

Europe's participation in the first Hubble Space Telescope (HST) servicing mission is now well advanced. This will be the first time NASA has conducted a mission to service a spacecraft conceived and built with in-orbit servicing in mind. Previous missions of this type have been repair missions necessitated by spacecraft malfunctions.

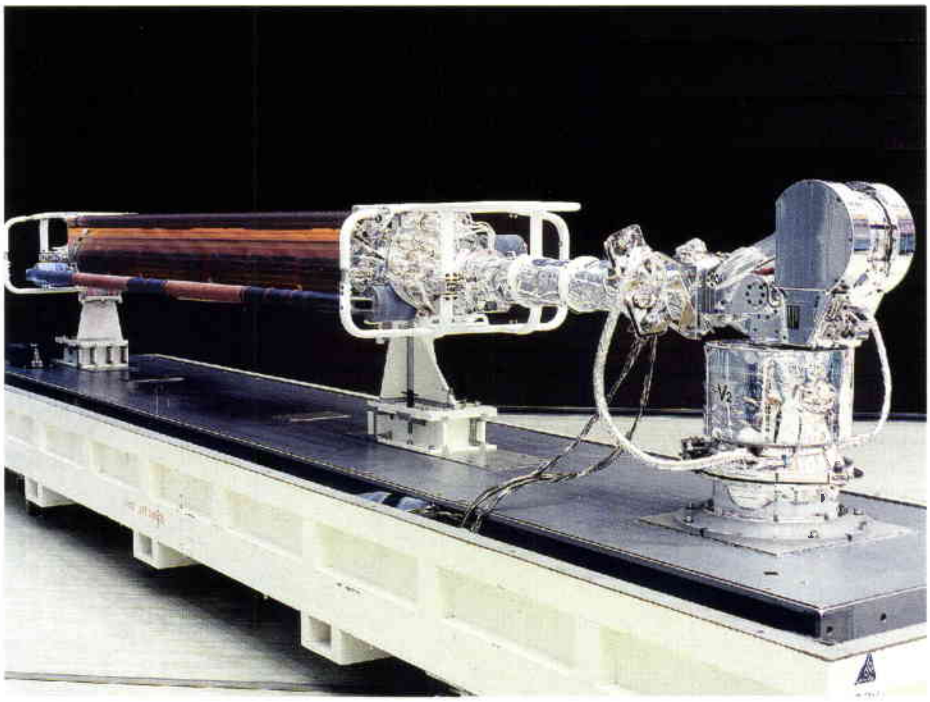
ESA is contributing to the HST servicing mission in two critical areas. Firstly, it is providing replacement solar arrays for those currently on HST, which exhibit a tendency to 'jitter', especially when passing from orbital day to orbital night, and vice versa. Unlike on Earth, which has a 24-hour cycle, HST's days and nights last approximately 90 minutes. The new array will reduce this cyclic disturbance to a negligible level.

The other area in which ESA is contributing is via the refurbishment of the Faint Object Camera's Structural and Thermal Model (FOC/STM). This, together with other European hardware and software, will be used to make an end-to-end test of the COSTAR system, which will correct the well-publicised spherical aberration in the primary mirror of HST. It was the lack of such an end-to-end test prior to HST's launch which permitted the flawed mirror to pass unnoticed.

The flight solar arrays have now completed manufacture and are in the final phases of testing prior to their shipment to Goddard Spaceflight Center (GSFC) in early May. All environmental testing, such as vibration and acoustic tests, is now complete. During early March, the astronauts who will effect the change-out spent a week at BAe, in Bristol (UK), where the solar arrays have been built, in order to familiarise themselves with the hardware they will be working with in orbit.

The FOC STM work in Europe is now complete and the unit has been shipped to Ball Brothers in Boulder, Colorado (USA), who are responsible for COSTAR. There, Matra and LAS, who were responsible for the hardware and software, will be conducting pre-launch proving tests with COSTAR.

As can be seen from the above, the focus of the activity is now shifting from Europe to the USA, where extensive testing of all of the First Servicing Mission hardware and software will take place prior to the launch of the mission itself, scheduled for 2 December this year.



New Hubble Space Telescope solar array under test at ESTEC (NL)

Le nouveau générateur solaire du télescope Hubble aux essais à l'ESTEC

Ulysses

With the exception of one anomaly reported below, the Ulysses mission has continued to run smoothly during the past three months. The scientific payload continues to return excellent out-of-ecliptic data, and coverage has consistently averaged more than 95%.

The Ulysses spacecraft experienced an anomaly on 14 February while being tracked by the Deep Space Network (DSN) station at Madrid (E), when the satellite autonomously entered its 'safe' mode by disconnecting non-essential loads on the power supply. This resulted in all scientific instruments being switched off by on-board logic, followed shortly afterwards by an autonomous reconfiguration of spacecraft subsystems, which switched the telemetry off. Telemetry was regained some five hours later, however, and spacecraft health checks confirmed that the satellite had reconfigured itself correctly.

Ulysses and its scientific payload were subsequently returned to their nominal configuration without further problem. As yet, the exact cause of this anomaly, the second of its type to have occurred in the two-and-a-half years since launch, has not been established.

Soho

Industry

The integration and testing of the two development spacecraft models of the Soho programme has been progressing during the reporting period, following the Hardware Design Review in late September 1992 which gave the go-ahead for these activities.

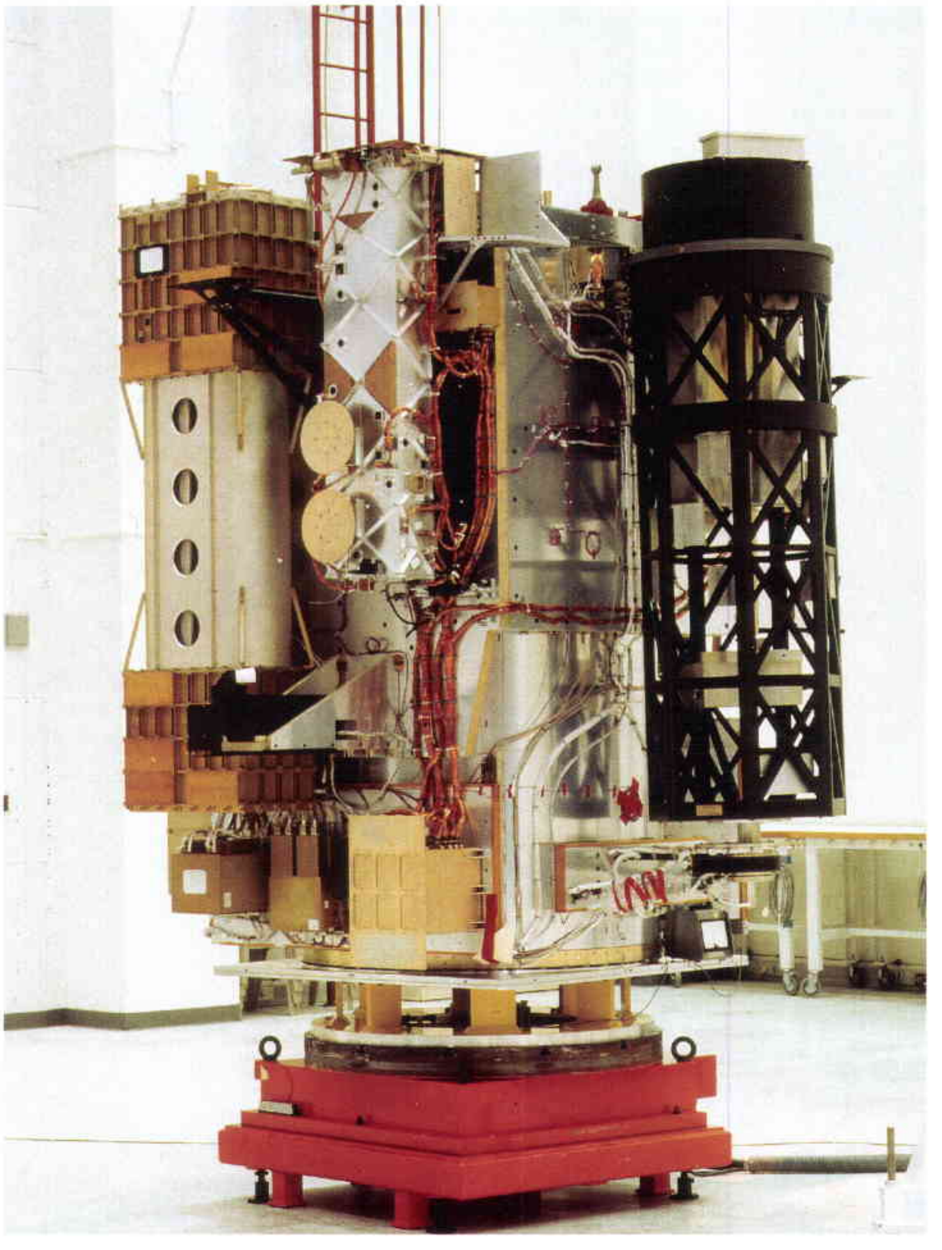
The payload-module structure has been equipped with all experiment structural models and equipment units and has successfully undergone static-load and modal-survey testing at IABG's test centre in Ottobrunn (D).

The service-module structure was delivered in December and has completed its static testing. Its modal-survey testing will follow, again at IABG.

The first experiment (GOLF) engineering

Modèle structurel du véhicule spatial Soho chez Matra, Toulouse (F)

Structural model of the Soho spacecraft at Matra, Toulouse (F)
(photo courtesy of Meauxsoone, Toulouse)



année, qui donnera le feu vert aux activités d'intégration des modèles de vol dans l'industrie.

Coopération ESA–NASA

Les essais de la plupart des unités de vol de l'amplificateur haute puissance destiné aux deux projets STSP (Soho et Cluster) étaient achevés fin février.

Les essais d'interface entre le modèle du prototype de vol de l'enregistreur à bande et le sous-système de traitement des données de Soho ont été menés à bien en décembre 1992 et ont confirmé les bons résultats des essais de Cluster, conduits plus tôt dans l'année.

Des problèmes sont toutefois apparus lors des essais de l'enregistreur à bande du second modèle d'identification, aux niveaux les plus bas de débit binaire et de température spécifiés pour le STSP. Les techniciens et les responsables suivent ces problèmes de très près, et l'ESA et la NASA ont défini ensemble des moyens de les résoudre.

La définition des interfaces avec le lanceur Atlas IIAS approche de la maturité. Un point final a été mis à la définition des interfaces thermiques au moment du lancement, et leur incidence sur la conception thermique du véhicule spatial a été évaluée.

Une analyse dynamique couplée réalisée à l'aide de modèles d'expériences corrélés en cours de développement au Centre de recherche Lewis de la NASA sera utilisée lors des essais de vibrations sinusoïdales du modèle structurel en mai–juin.

Les travaux sur les activités opérationnelles en vol et la mise en oeuvre du secteur sol passent à la phase d'exécution. Les travaux s'intensifient à la NASA; parallèlement, les discussions entre les Groupes de travail Mission et Exploitation scientifique, qui se réunissent régulièrement, sont de plus en plus détaillées.

Charge utile

Tous les expérimentateurs ont livré leurs modèles structurels au cours du dernier trimestre 1992. Les livraisons des modèles d'identification se font également en temps voulu et s'harmonisent avec les activités en cours.

Les activités relatives aux modèles de vol de nombreuses expériences ont bien progressé; elles ont été abordées en détail à la réunion du Groupe de travail scientifique du 16 au 18 janvier 1993 et lors des revues finales des expériences qui ont débuté fin février.

Cluster

Le modèle structurel du satellite a été remis en état après l'anomalie décelée au cours des essais aux vibrations l'été dernier et a été renvoyé à l'IABG (D) pour que l'ensemble du programme de qualification puisse être mené à son terme. Les essais de vibrations sinusoïdales et aléatoires ont été menés à bien et les essais de vibrations acoustiques doivent avoir lieu fin avril.

Le programme relatif au modèle d'identification se déroule maintenant de manière satisfaisante. Deux équipes se relaient pour réduire les retards provoqués par la livraison tardive de sous-systèmes. L'intégration de la charge utile est terminée et le programme d'essais électriques de l'ensemble du système doit être achevé d'ici fin avril.

Le programme relatif au premier satellite au modèle de vol a également démarré avec l'intégration du faisceau de câbles sur la plate-forme principale chez model was integrated and tested on the payload-module (PLM) mockup in late December at Matra Marconi Space (UK). By the end of February, six experiments had been integrated and tested, with increasing efficiency. The first sub-systems (communication and data handling) were delivered to Matra Marconi Space in Toulouse (F) by the end of February. With their arrival, the main integration and testing process for the Soho service module's engineering model has started.

The procurement of the flight models of all units is being formalised with Manufacturing Readiness Reviews across Europe. Some flight-model items (e.g. payload-module structure, solar arrays, propulsion hardware) are already in an advanced state of manufacture. Parts procurement for the flight models was given particular attention at the beginning of the year, to ensure their timely flow in the manufacturing and assembly of all units.

Cleanliness control techniques and procedures, already identified at the Hardware Design Review, are being defined in detail to be implemented in the AIV (Assembly, Integration and Verification) flows of the flight models of the payload and service modules in the second half of this year.

The engineering activities are now geared for the mission's Critical Design Review, planned for the third quarter of this year, which will decide on the release of the flight-model integration activities to industry.

ESA–NASA cooperation

Most of the High-Power Amplifier (HPA) flight units for the both STSP projects (Soho & Cluster) had been tested by the end of February.

Interface testing in December of the tape recorder proto-flight model with the Soho data-handling subsystem confirmed the results of the equally successful Cluster test earlier in 1992.

Tape-recorder tests on the second engineering model, however, showed problems in meeting the lowest specified bit rates and temperatures for STSP. These problems have received considerable attention at both technical and managerial level, and ESA and NASA have jointly defined plans to resolve them.

The definition of interfaces with the Atlas IIAS launch vehicle is now reaching maturity. Definition of thermal interfaces at launch has also been finalised and their impact on the spacecraft thermal design assessed.

A coupled-load analysis, using correlated experiment models under development at NASA's Lewis Research Center, will be used for structural-model spacecraft testing (sine tests) in May/June.

Work on the flight operations and on implementation of the ground segment is now entering the implementation phase. The scale of the effort at NASA is increasing, and with it the level of detail of the ongoing discussions between the Mission and the Science Operations Working Groups that are regularly taking place.

Payload

All experimenters delivered their structural models in the last quarter of 1992. The deliveries of the engineering models have also been timely and are optimised with the ongoing activities.

The flight-model activities are already advanced for many experiments and were discussed in detail at the Science Working Team Meeting on 16–18 January and in Experiment Final Reviews that started in late February.

Cluster

The structural-model spacecraft has been refurbished following the anomaly that occurred during vibration testing last summer, and it is currently back at IABG (D) completing the full qualification programme. Sine and random vibration testing has been completed successfully and acoustic vibration is scheduled for end-April.

The engineering-model programme is now progressing satisfactorily with a two-shift operation implemented to reduce the schedule delays caused by late subsystem deliveries. The payload has been fully integrated and the final system electrical test programme is expected to be completed by the end of April.

The first flight-model spacecraft programme has also started, with integration of the harness on the main platform at Dornier (D) and integration of the reaction-control system in parallel at British Aerospace (UK).

Delays in the delivery of some essential subsystems and units have necessitated the introduction of system-level work-around solutions using engineering-model units to maintain the momentum of integration. Despite these work-arounds, the system-level programme is showing a three-month delay in completion of the four spacecraft. This delay has been accommodated within the system schedule margin, however, and the launch date remains unchanged at 1 December 1995 on Ariane Apex flight V501.

The payload flight-model-unit manufacturing programme is well advanced, with deliveries currently foreseen to take place on schedule in June/July 1993.

The Cluster Science Data System (CSDS) has recently successfully passed a major review milestone, namely the System Requirements Review. All participating data centres provided inputs to the review, and the only major change is a proposed amalgamation of the two German data centres into a single centre based in Berlin.

The contract for the Joint Science Operations Centre, a science support function to CSDS, has recently been kicked off wth Rutherford Appleton Laboratory (RAL, UK). The Centre will support the scientific planning of the mission and will be staffed jointly by ESA-sponsored and RAL staff. Its operation is foreseen through to 1999 following the implementation phase.

The engineering model of the Mars-94 mass memory has been delivered to IKI in Moscow and has been successfully integrated into the spacecraft mockup. Manufacture of the flight models is now underway.

ISO

Scientific instruments

All flight-model electronic units of the

Dornier (D), conduite parallèlement à l'intégration du système de commande d'orientation chez BAe (R-U).

Les retards de livraison de certains sous-systèmes et unités essentiels ont conduit à adopter des solutions de rattrapage au niveau système en utilisant des modèles d'identification pour ne pas compromettre le rythme d'intégration. En dépit de ces mesures, le programme au niveau système présente un retard de trois mois pour l'achèvement des quatre satellites. Toutefois, ce retard a été intégré dans la marge de calendrier du système, de sorte que la date de lancement a été conservée au premier décembre 1995 sur le vol Ariane-Apex V501.

Le programme de fabrication du modèle de vol de la charge utile est bien avancé, des livraisons étant prévues en juin/juillet 1993.

Avec l'achèvement de la revue des impératifs système, le système de données scientifiques de Cluster (CSDS) vient de franchir avec succès une étape importante. Tous les centres de données participants ont apporté leur contribution à cette revue et la seule modification importante est le regroupement proposé des deux centres de données allemands en un seul basé à Berlin.

Le contrat relatif au centre commun des opérations scientifiques, conçu pour offrir un soutien scientifique au CSDS, a été récemment signé avec le laboratoire Rutherford Appleton (RAL, R-U). Ce centre, qui comprendra du personnel fourni par l'ESA et le RAL, aidera à établir la planification scientifique de la mission. Son fonctionnement est prévu jusqu'en 1999, à la suite de la phase de mise en oeuvre.

Le modèle d'identification de la mémoire de masse de Mars-94 a été livré à l'IKI à Moscou et intégré avec succès dans la maquette du satellite. La fabrication des modèles de vol est en cours.

ISO

Instruments scientifiques

Toutes les unités électroniques des instruments scientifiques du modèle de vol ont été intégrées sur la plate-forme supérieure du modèle de vol du module de servitude. L'essai des unités du plan focal et des rechanges de vol, qui pourraient être prêtes à être livrées au deuxième trimestre de cette année, se déroule de manière satisfaisante.

Satellite

L'intégration du modèle de vol de la charge utile a commencé en janvier et progresse de manière satisfaisante, conformément au calendrier. Le modèle de vol du télescope a été intégré et la qualité de ses images aux températures de l'hélium liquide a été jugée bonne. D'autres modifications de détail doivent être apportées aux vannes du modèle de vol, qui devront subir des essais avant d'être installées dans le module charge utile en septembre.

L'intégration du modèle de vol du module de servitude se déroule également de manière satisfaisante. Les sous-systèmes d'alimentation, de radiofréquence et de traitement des données ont été intégrés et les essais ont montré qu'ils fonctionnent de manière satisfaisante. La plupart des unités du sous-système de commande d'orientation sont sur le point d'être livrées au contractant principal pour être intégrées dans le module de servitude. Toutefois, le suiveur d'étoiles et le gyroscope connaissent quelques retards et des mesures sont actuellement prises pour accélérer ces travaux.

Sur un plan général, les travaux relatifs au satellite se déroulent conformément au calendrier pour un lancement prévu en septembre 1995, au début de la fenêtre d'hiver.

Secteur sol

Les préparatifs de l'exploitation en vol du satellite se déroulent de manière satisfaisante. Les opérations scientifiques font actuellement l'objet d'une revue en vue notamment de parvenir à des simplifications et à un contrôle plus étroit des interfaces.

De nouveaux progrès ont été enregistrés en ce qui concerne les possibilités de coopération internationale sur ISO. Un accord de principe a été conclu aux termes duquel le Japon travaillera en soutien de l'allongement de la durée d'exploitation quotidienne d'ISO si une deuxième station sol peut être mise à disposition. On examine actuellement une proposition de la NASA, qui porte sur la fourniture de cette deuxième station sol et sur le raccordement du réseau.

Huygens

En ce qui concerne la phase de développement proprement dite (phase C/D) de la sonde, les procédures d'appel d'offres, les évaluations et les négociations contractuelles préliminaires sont maintenant achevées. A sa réunion finale du 2 février, la Commission d'évaluation des offres a approuvé les conclusions des différentes évaluations tout en attirant l'attention des responsables du projet sur les domaines à analyser plus en détail et à suivre de près dans les années à venir. Dans son rapport, la Commission a recommandé d'engager la phase C/D en autorisant la préparation d'une proposition de contrat à soumettre à l'approbation du Comité de la politique industrielle.

Le projet a atteint un de ses objectifs techniques importants, à savoir l'achèvement du programme d'essai en soufflerie des parachutes de la sonde. La dernière série d'essais a porté sur le déploiement et le fonctionnement du système de parachutes à vitesse supersonique, principalement à Mach 1,5. Conduits dans un centre de l'armée de l'air US du Tennessee, ces essais visant à simuler les paramètres d'entrée dans l'atmosphère de Titan ont permis de constater le déploiement parfait des parachutes. Lors de leur visualisation rapide, les données enregistrées se sont révélées conformes aux prévisions, apportant ainsi une preuve supplémentaire de la qualité de conception des parachutes.

DRS

La proposition de contrat relative à la phase de développement proprement dite (phase C/D) d'Artemis a été approuvée par le Comité de la politique industrielle en septembre 1992, de sorte que les activités industrielles ont pu démarrer. Artemis emportera deux instruments principaux, à savoir une charge utile de pointe en bande L pour le service mobile terrestre et une charge scientific instruments have been integrated on the upper platform of the service-module flight model. Good progress is being made in testing of the focal-plane units and flight-spare units, which should be ready for delivery in the second quarter of this year.

Satellite

Payload-module flight-model integration started in January and is proceeding satisfactorily and according to schedule. The flight-model telescope has been integrated and its image quality at liquid-helium temperatures has been found to be good. Further detail changes are to be made to the flight-type valves and proved by testing before they are installed in the payload module in September.

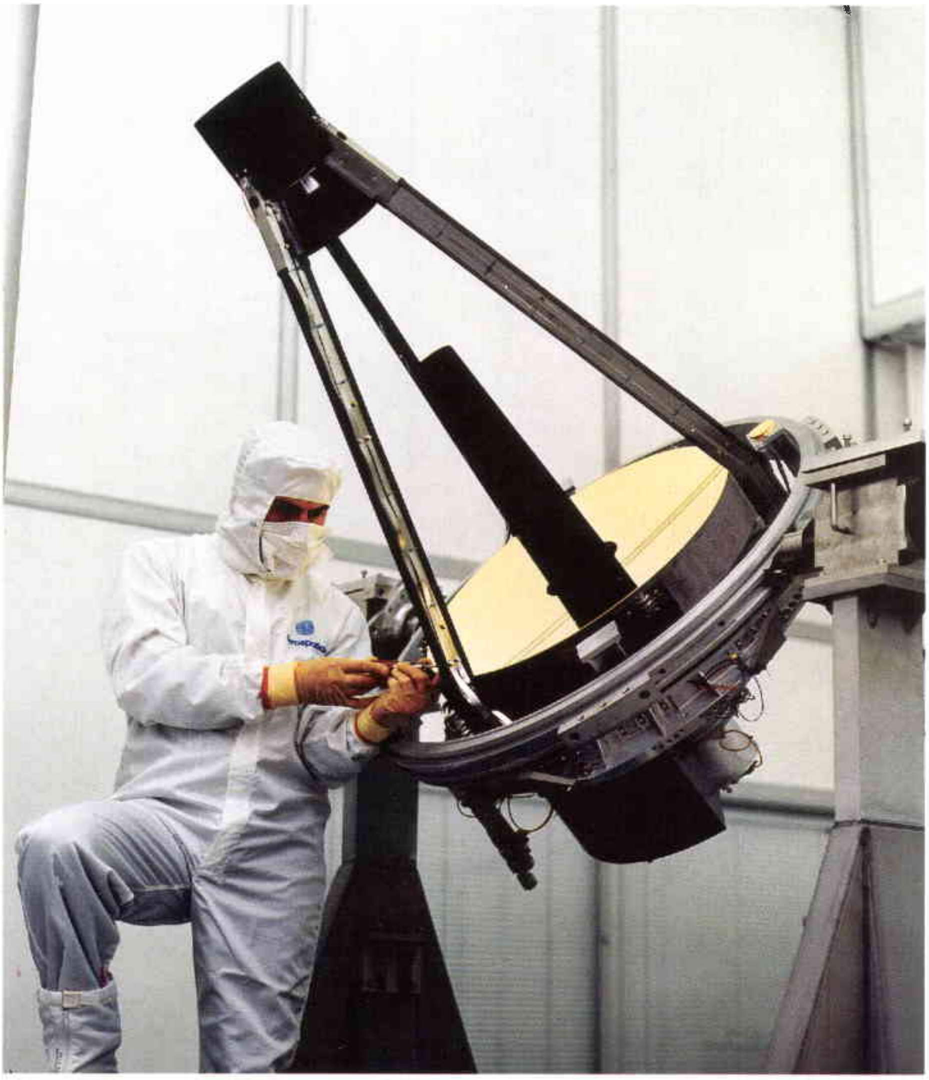
The service module's flight-model integration is also proceeding satisfactorily. The power, radio-frequency and data-handling subsystems have been integrated, and tests have shown their performance to be satisfactory. Most units of the attitude-control subsystem are about to be delivered to the Prime Contractor for integration into the service module. The star-tracker and gyroscope units are somewhat delayed, however, and action is being taken to expedite this work.

The overall satellite work is on schedule for the planned launch in September 1995, when the winter launch window opens.

Ground segment

Spacecraft flight-operations preparations are proceeding satisfactorily. The science operations are under review, with special efforts being made to find simplifications and to control interfaces tightly.

Further progress has been made with regard to possible international cooperation on ISO. The principles have been agreed whereby Japan will support ISO's extended daily flight operations if a second ground station can be made available. A proposal by NASA to provide that second ground station and to adapt the network interface is currently being discussed.



Huygens

Tender actions, evaluations and preliminary contract negotiations for the main Huygens development phase (Phase-C/D) are now complete. The Tender Evaluation Board, at its final meeting on 2 February, agreed with the findings of the various evaluation panels, whilst drawing the project's attention to areas that warrant further investigation and close monitoring in the future. The Board's report recommended proceeding with Phase-C/D, permitting preparation of a contract proposal for approval by the Agency's Industrial Policy Committee (IPC).

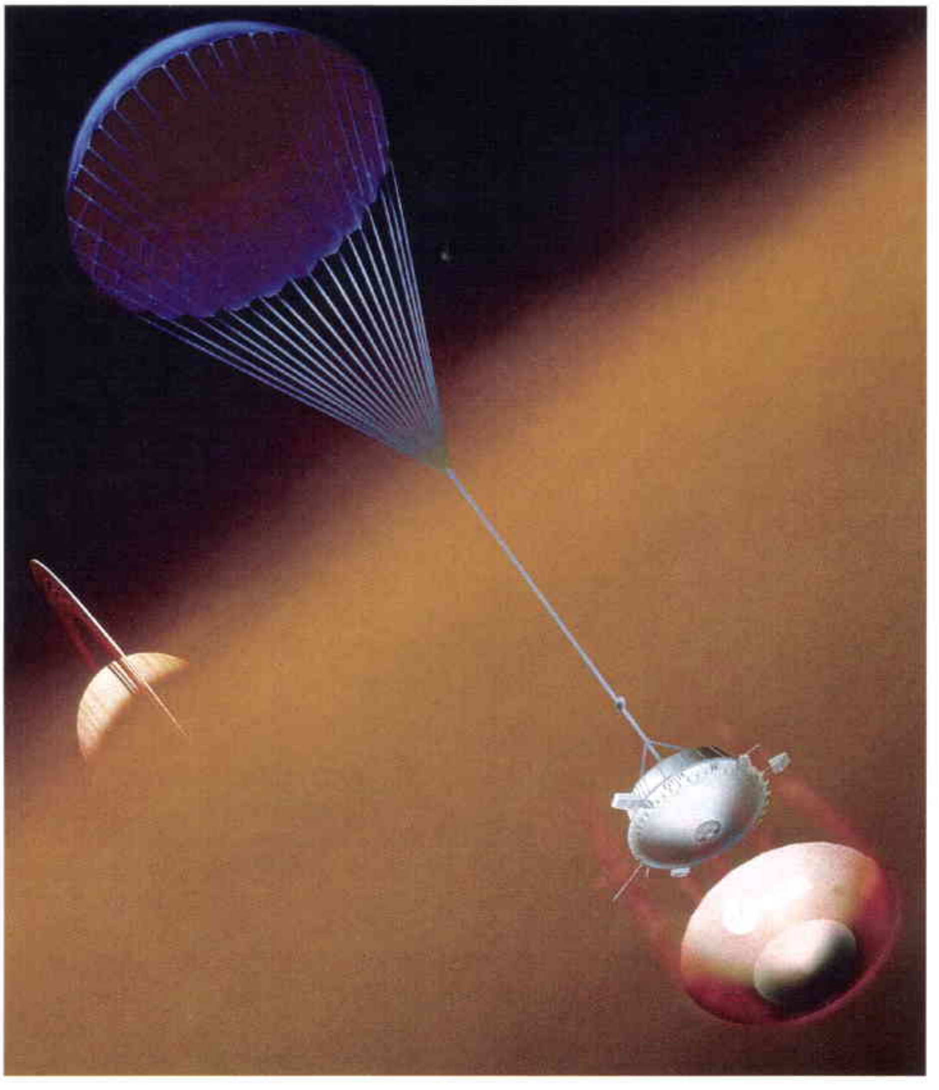
A significant technical objective has been reached with the completion of the formal wind-tunnel testing programme for the Probe's parachutes. The final tests involved deployment and operation of the parachute system at supersonic velocities, centring on a wind velocity of Mach 1.5. These tests, carried out at the US Airforce facility in Tennessee, USA, simulated the Titan entry parameters and showed perfect deployment of the parachutes. Quick-look analysis of the recorded data is in line with predictions, adding significantly to confidence in the parachute design.

DRS

The main development phase (Phase-C/D) contract proposal for Artemis was approved by ESA's Industrial Policy Committee (IPC) in September 1992 and thus kick-off of full industrial activities has been initiated. Artemis will carry two main payloads, an advanced L-band land mobile payload and a data-relay payload to provide links to low-Earth-orbiting satellites at S-band, Ka-band and optical frequencies.

Assembly of ISO telescope at Aérospatiale in Cannes (F)

Assemblage du télescope d'ISO à l'Aérospatiale à Cannes (F)



La sonde Huygens

The Huygens Probe

utile de relais de données assurant les liaisons avec des satellites sur orbite terrestre basse en bande S et Ka ainsi qu'aux fréquences optiques.

La fabrication des terminaux de relais de données en bande S et aux fréquences optiques pour le satellite de télédétection français Spot-4 et le relais de données via Artemis est en bonne voie. La livraison des modèles électriques suit son cours, tandis que les premières livraisons commencent pour les équipements de vol à intégrer aux terminaux. L'élément de programme 'Système de relais de données' (DRS) ayant été approuvé par le Conseil réuni au niveau ministériel à Grenade en novembre dernier, les activités de définition du système ont repris.

ERS

ERS-1

Au cours de ces derniers mois, le fonctionnement du satellite a été marqué par une très grande stabilité; la disponibilité est restée supérieure à 99% pour la plate-forme et à 98% pour les instruments. Il ressort de l'analyse du fonctionnement des instruments sur les dix-huit premiers mois de la mission une très bonne corrélation entre les premiers résultats de la phase de recette et les valeurs mesurées actuellement.

Pour maintenir l'orbite du satellite dans la zone de garde à ±1 km par rapport à l'orbite nominale, on a mené à bien une manoeuvre hors du plan de l'orbite à la mi-décembre. Une manoeuvre identique est envisagée en mai.

En février de nouvelles versions du logiciel de traitement des produits à 'livraison rapide' ont été mises en service dans les stations de l'ESA; il s'agit notamment d'un algorithme amélioré de traitement des vagues pour l'AMI et d'une version mise à hauteur du modèle d'extraction des vents.

Le réglage fin de l'asservissement de bord de l'altimètre radar a nettement amélioré la fonction de poursuite au-dessus des glaces de mer et des terres émergées.

Les données du radar à synthèse d'ouverture (SAR) ont été acquises pour répondre à la demande des utilisateurs et pour assurer la couverture complète des masses terrestres dans les zones couvertes par les stations de l'ESA ainsi que par les stations nationales et étrangères. Celles de l'ESA ont élaboré des produits à livraison rapide (FD) qui ont été stockés sur des cassettes Exabyte en vue d'être archivées par l'installation de traitement et d'archivage (PAF) allemande (produits de Kiruna) et par l'ESRIN (produits de Maspalomas et Fucino).

Les stations de Kiruna (S), Gatineau (CDN), Maspalomas (Iles Canaries) et Prince Albert (CDN) ont fait l'acquisition régulière de données à faible débit (LBR) à l'échelle du globe. Des produits LBR FD ont été également élaborés, archivés et diffusés. Les PAF d'Allemagne, du Royaume-Uni, de France et d'Italie ont régulièrement procédé à l'archivage de données SAR et LBR.

Il convient également de noter la préparation et la distribution en différé de produits de données standard SAR et LBR. Des données FD de l'altimètre radar et du diffusiomètre 'vents' pour l'ensemble de 1992 et des données de niveau 2 de l'altimètre radar pour le premier cycle de 35 jours ont été distribués à des chercheurs principaux choisis.

Sur un total de plus de 5000 commandes de produits SAR livrés en 1992, près de 2500 sont allées à des chercheurs principaux et des projets pilotes, plus de 300 à des utilisateurs commerciaux et le reste à l'ESA pour des opérations d'étalonnage et de validation, d'évaluation de qualité et autres activités.

Development of the data-relay terminals operating at S-band and optical frequencies to fly on the French Earth-observation satellite Spot-4 and to relay data through Artemis is proceeding, with delivery of the electrical models now taking place, and delivery of the flight equipment for integration at terminal level commencing.

Following the decision by the ESA Council Meeting at Ministerial Level in Granada (E) last November to approve the Data Relay System (DRS) programme element, work is recommencing at a low level to continue definition of the system.

ERS

ERS-1

The satellite's performance has been extremely stable during recent months, with platform availability remaining above 99% and instrument operation above 98%. Analysis of ERS-1 instrument performances over the first 18 months of the mission shows extremely good correlation between early commissioning results and present measured performances.

To maintain the spacecraft's orbit within the Earth-fixed reference repeat cycle deadband of ±1 km, an out-of-plane manoeuvre was successfully performed in mid-December. The next such manoeuvre is foreseen for May.

New fast-delivery software releases were activated at the ESA stations in February, including an improved Active Microwave Instrument (AMI) wave-processing algorithm and an upgraded version of the wind-extraction model.

Fine tuning of the Radar Altimeter's on-board tracker has significantly improved tracking performance over sea-ice and land.

Synthetic-Aperture Radar (SAR) data has been acquired both to support user requests and to achieve full coverage of land masses within range of the ESA, national and foreign stations. Fast-delivery (FD) products have been generated at the ESA stations and stored on Exabyte cassettes for archiving at the German Processing and Archiving Facility (Kiruna products) and at ESRIN (Maspalomas and Fucino products).

Low-Bit-Rate (LBR) global data has been acquired routinely at the Kiruna (S), Gatineau (Cdn), Maspalomas (Canary Islands) and Prince Albert (Cdn) stations. LBR FD products have been generated, archived and disseminated. SAR and LBR data has been archived routinely at the Processing and Archiving Facilities (PAFs) in Germany, the United Kingdom, France and Italy.

Off-line SAR and LBR standard data products have been generated and distributed. Radar Altimeter (RA) and Wind Scatterometer FD data for the whole of 1992 and RA Level-2 data for the initial 35-day cycle have been distributed to selected Principal Investigators.

Of a total of over 5000 orders for SAR products delivered in 1992, nearly 2500 went to Principal Investigators and Pilot Projects, over 300 to commercial users, and the rest were used for ESA calibration/validation activities, quality assessments and other purposes.

The CD Guide to ERS-1 (on compact disc) and a full set of SAR coverage maps were prepared for distribution in early 1993. The first is an information package which includes the ERS-1 system description, technical documentation on products, and applications literature. The second is a collection of geopolitical maps covering the Kiruna, Fucino and Maspalomas visibility areas, on top of which SAR swaths for the 35-day cycle have been superimposed.

A second release of 'DESC', a PC program providing users with a display of ERS-1's SAR coverage, has been distributed.

ERS-2

Progress on ERS-2 has remained highly satisfactory and within the planned schedule. The AMI, IDHT and RA instruments have been delivered and payload integration is well advanced.

The ATSR-2 optical radiometer is almost ready for delivery. The Microwave Radiometer has been delivered and is ready for integration with ATSR-2.

Problems with the platform's propellant tanks have been resolved. The thruster problem is still under investigation, but appropriate work-arounds are in place to avoid delays.

The prototype Global Ozone Monitoring Experiment (GOME) has now been fully integrated and its functionality established. An important milestone was recently achieved with the successful vibration testing of the instrument. Manufacture of long-lead items for the flight unit has been initiated.

Meteosat

Meteosat-3 was moved to its new position at 75°W in order to support NOAA by filling the gap in their GOES/GOES Next programme. The new ground station, installed by ESOC on Wallops Island, was inaugurated in February. The spacecraft is controlled from ESOC, Darmstadt, via a trans-Atlantic satellite link to this ground station.

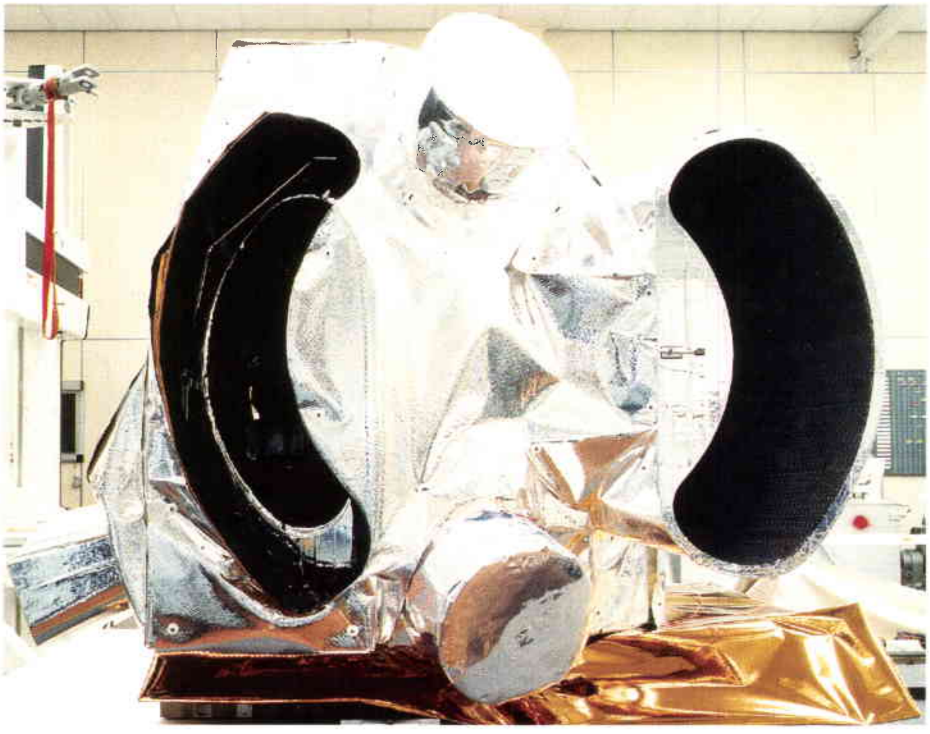
Meteosat-4 has continued operations in its fourth year, one year beyond its specified nominal lifetime in orbit.

During the seasonal switch-over between onboard imaging chains, necessitated by a power-supply instability which causes a degradation in picture quality, several interruptions in the image dissemination were experienced. These seasonal change-over difficulties are probably due to a combination of ageing of the spacecraft's thermal protection, and the exceptional thermal sensitivity of Meteosat-4 (a secondary feature of the power-supply instability mentioned previously). Circuit changes have been made to all subsequent spacecraft in the Meteosat series to avoid these power-supply instabilities.

Meteosat-5 is still being kept as an in-orbit spare.

MOP-3 (Meteosat-6) is undergoing environmental testing in preparation for a launch in November this year. The test programme is proceeding according to plan.

Agreement has been reached with Eumetsat regarding the contractual arrangement to build one more spacecraft of the Meteosat type under



Essai du radiomètre de l'ATSR pour ERS-2

Testing of the ATSR optical radiometer for ERS-2

Le Guide d'ERS-1 sur disque compact et un jeu complet de cartes de la couverture SAR ont été préparés pour être distribués début 1993. Le premier est un dossier d'information qui contient la description du système ERS-1, des informations techniques sur les produits et les applications. Les secondes sont des cartes géopolitiques des zones de visibilité de Kiruna, Fucino et Maspalomas sur lesquelles sont superposés les passages du SAR pendant le cycle de 35 jours.

On a également distribué la seconde version de 'DESC', programme compatible PC qui permet aux utilisateurs de visualiser la couverture du SAR d'ERS-1.

ERS-2

L'avancement de la réalisation d'ERS-2 est très satisfaisant et les travaux se poursuivent conformément au calendrier. L'AMI, l'IDHT et le RA ont été livrés et l'intégration de la charge utile est bien avancée.

Le radiomètre optique ATSR-2 est presque prêt pour la livraison. Le radiomètre à hyperfréquence a été livré et est prêt pour l'intégration avec l'ATSR-2.

Les problèmes de réservoirs à ergol de la plate-forme ont été résolus. Celui du propulseur est toujours à l'étude mais des solutions appropriées de remplacement sont mises en place pour éviter les retards.

Le prototype de l'instrument de surveillance de l'ozone à l'échelle du globe (GOME) est entièrement intégré et il a été établi qu'il fonctionnait correctement. Les essais en vibrations récemment menés à bien marquent une étape importante de la réalisation de cet instrument. La fabrication des éléments à longs délais de livraison du modèle de vol a été lancée.

Météosat

Météosat-3 a été transféré à son nouveau poste à 75° ouest pour aider la NOAA à combler le trou entre les programmes GOES et GOES-Next. La nouvelle station sol installée par l'ESOC à Wallops Island a été inaugurée en février. Le satellite est commandé de l'ESOC à Darmstadt, via une liaison transatlantique par satellite qui aboutit à cette station.

Météosat-4 a continué d'assurer son service opérationnel pendant sa quatrième année d'existence, soit une année de plus que sa durée de vie nominale spécifiée.

Lors du passage saisonnier d'une chaîne image à l'autre à bord du satellite, rendu nécessaire par une instabilité de l'alimentation électrique qui provoque une détérioration de la qualité des images, la dissémination des images a été interrompue plusieurs fois. Ces difficultés sont probablement dues au vieillissement de la protection thermique du satellite et à la sensibilité thermique exceptionnelle de Météosat-4 (cause secondaire de l'instabilité de l'alimentation électrique mentionnée précédemment). Des modifications ont été apportées aux circuits sur tous les satellites ultérieurs de la série Météosat pour éviter ces instabilités.

On conserve Météosat-5 comme satellite de réserve en orbite.

MOP-3 (Météosat-6) subit actuellement les essais d'ambiance en vue du lancement prévu pour le mois de novembre de cette année. Ce programme d'essai se poursuit conformément au calendrier.

On est parvenu à un accord avec Eumetsat sur les arrangements contractuels relatifs à la fabrication d'un satellite supplémentaire de type Météosat au titre du Programme Météosat de transition. Les travaux industriels ont déjà commencé et le calendrier prévoit la livraison du satellite à Eumetsat pour un lancement en décembre 1995.

Earthnet

La mise à hauteur du secteur sol du satellite japonais JERS-1 a progressé: les chaînes de traitement SAR ont été livrées aux stations de Fucino (I), ESRIN (I) et Tromsø. Des mires d'essai ont été préparées et les stations de Fucino, Kiruna, Tromsø et O'Higgins (Antarctique) ont acquis des données.

La réalisation de la chaîne de traitement ETM de Landsat-6 a progressé dans le cadre des activités préparatoires du lancement prévu pour cet été.

the Meteosat Transitional Programme (MTP). The industrial work has already started and the schedule calls for delivery of the spacecraft to Eumetsat in time for a December 1995 launch.

Earthnet

Upgrading of the JERS-1 ground segment has advanced, with delivery of the SAR processing chains to Fucino (I), ESRIN (I) and Tromso (N). Test images have been generated and data acquired at Fucino, Kiruna, Tromso and O'Higgins (Antarctic).

The development of the Landsat-6 ETM processing chain has progressed in preparation for the Landsat-6 launch, foreseen for this summer.

The new chains will also be able to process the historical Multi-Spectral Scanner (MSS)/Thematic Mapper (TM) data collected with the earlier Landsats, allowing the original processing chain, which is now more than 15 years old, to be dismantled.

Landsat-5 MSS and TM data recording, archiving and processing operations have been proceeding normally in the Earthnet Ground Station Network.

Maspalomas has continued to provide Marine Observation Satellite (MOS) data to the user community. This station has also continued to provide Spot Image with Spot data acquired there.

The Scanzano (Palermo, I) station has been integrated into the Earthnet-coordinated NOAA Tiros Network. The latter currently includes eight stations, i.e. Tromso, Maspalomas, Oberpfaffenhofen, Niamey, Nairobi, La Reunion, Cairo and Terranova Bay.

Under the OCEAN (Ocean-Colour European Archive Network) Coastal-Zone Colour Scanner (CZCS) Project, Level-2 and 1–2 data products have been made available together with a new CD-ROM dataset of all CZCS browse products, readable by IBM or McIntosh PCs.

The final presentation of the GENIUS (Global Environment Space Data Network) contract took place at ESRIN in December.

An acquisition campaign is being planned at the Bankok station, which is currently being upgraded to acquire, record and process ERS-1 SAR data within the ASEAN Project.

An AVHRR work station has been delivered to Manila for AVHRR data processing.

EOPP

Aristoteles
Following further discussions at Council level and with the Earth Observation Programme Board, the current Aristoteles activities are being run down and a revised solid-Earth programme strategy is being defined.

Meteosat Second Generation
The Enabling Resolution for Meteosat Second Generation was adopted by the Agency's Council on 16 December 1992. Potential Participants' Meetings continue in order to finalise the Programme Proposal and Programme Declarations. Meanwhile, the industrial Phase-A activities are proceeding according to schedule.

Low-Earth-orbit missions
Work continues on the definition of the Metop-1 Phase-A industrial study requirements and on the definition of studies and technology requirements for future instruments for follow-on missions to Envisat-1.

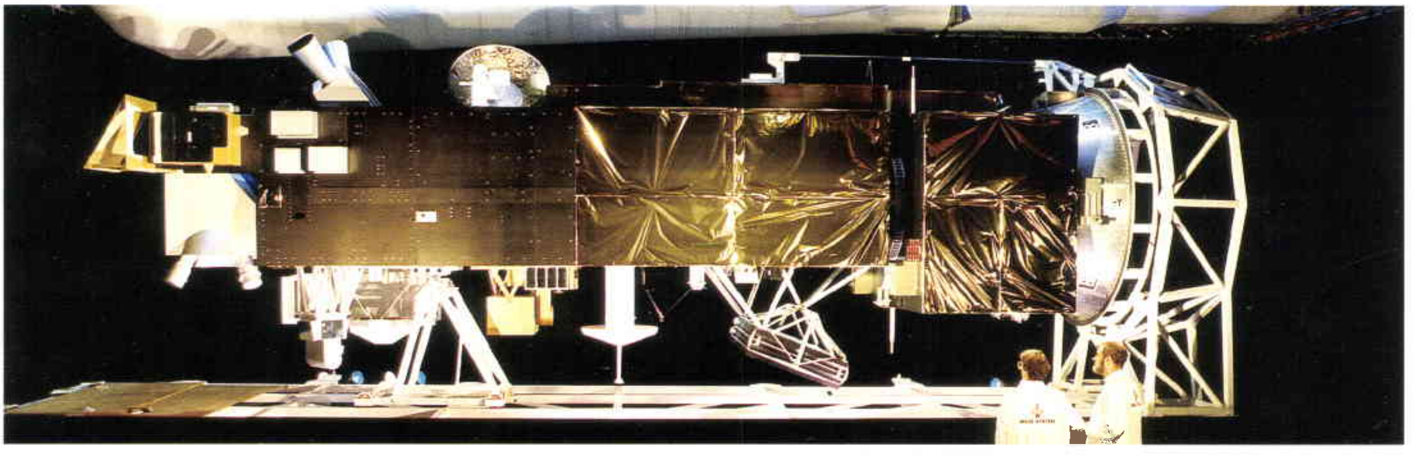
Campaigns
First data-analysis results have been obtained from the Sarex campaign.

Preparations are in hand to define a multi-sensor campaign, known as 'EMAC-94/95', planned to be organised jointly with JRC and NASA.

Polar Platform

Following the decisions taken at the Council Meeting at Ministerial Level in Granada (E), the Polar Platform design has been adapted to support the Envisat-1 mission.

In particular, a preliminary definition has been made of the essential Platform parameters necessary to support this mission, in close cooperation with the Envisat-1 project team and Industry (payload module with four sections; solar generator with 14 panels; number of reaction wheels, etc). This work is being actively pursued and should be completed in the first quarter of 1993.



Full-scale model of the Polar Platform in Envisat configuration at BAe in Bristol (UK)

Modèle grandeur nature de la Plate-forme polaire en configuration Envisat chez BAe à Bristol (R-U)

Les nouvelles chaînes pourront également traiter les données historiques des analyseurs multibandes à balayage (MSS) et des instruments de cartographie thématique (TM) des premiers Landsat; on pourra ainsi démonter la chaîne de traitement d'origine qui a maintenant plus de 15 ans.

Les activités d'enregistrement, archivage et traitement des données MSS et TM de Landsat-5 se sont poursuivies normalement au sein du réseau de stations sol Earthnet.

La station de Maspalomas a continué de fournir aux utilisateurs des données du satellite japonais d'observation des mers (MOS) et à SpotImage des données Spot qu'elle a acquises.

La station de Scanzano (Palerme, Italie) a été intégrée au réseau Tiros de la NOAA coordonné par Earthnet. Ce réseau compte actuellement huit stations, à savoir Tromsø, Maspalomas, Oberpfaffenhofen, Niamey, Nairobi, La Réunion, Le Caire et Terranova Bay.

Des produits de niveau 2 et des produits de données de niveau 1–2 ainsi qu'un nouvel ensemble de données sur CD-ROM de tous les produits CZCS (Analyseur couleurs de la mer pour zones côtières) à consultation rapide sont désormais disponibles dans le cadre du projet CZCS du réseau OCEAN (Réseau européen d'archivage des données sur la couleur des océans); ces produits peuvent être lus sur PC IBM ou McIntosh.

La présentation finale du contrat GENIUS (Réseau mondial de données spatiales sur l'environnement et système d'information utilisateurs) s'est déroulée à l'ESRIN en décembre.

Une campagne d'acquisition est projetée à la station de Bangkok que l'on met actuellement à hauteur pour qu'elle puisse acquérir, enregistrer et traiter des données SAR d'ERS-1 dans le cadre du projet ASEAN.

Un poste de travail AVHRR a été livré à Manille pour le traitement de ces données.

EOPP

Aristoteles

A l'issue de nouvelles délibérations au niveau du Conseil et au sein du Conseil directeur compétent, les activités d'Aristoteles sont mises progressivement en sommeil tandis qu'une révision de la stratégie du programme d'études du solide terrestre est en cours de définition.

Météosat de deuxième génération

La résolution habilitante a été adoptée par le Conseil de l'Agence le 16 décembre 1992.

Les participants potentiels se réunissent périodiquement pour mettre au point la proposition de programme et les déclarations. Pendant ce temps, les activités industrielles de phase A se poursuivent selon le calendrier.

Missions sur orbite terrestre basse

Les travaux se poursuivent sur la définition des impératifs de l'étude industrielle de phase A pour Metop-1 et sur la définition des études et impératifs technologiques des futurs instruments destinés aux missions suivantes conduisant à Envisat-1.

Campagnes

Les premiers résultats de l'analyse de données de la campagne Sarex ont été obtenus.

On prépare actuellement la définition d'une campagne multidétection dénommée EMAC 94/95, qu'il est projeté d'organiser en commun avec le JRC et la NASA.

Plate-forme polaire

A la suite des décisions prises par le Conseil siégeant au niveau ministériel à Grenade, la conception de la plate-forme polaire a été adaptée à la mission Envisat-1.

On a notamment établi, en étroite coopération avec l'équipe de projet Envisat-1 et avec l'industrie, une définition préliminaire des paramètres essentiels de la plate-forme qu'impose cette mission (module charge utile à quatre sections; générateur solaire à 14 panneaux; nombre de roues à réaction, etc. Ces travaux se poursuivent activement et devraient s'achever au premier trimestre 1993.

Cette révision de la plate-forme polaire de référence servira de base aux travaux de développement ultérieurs. Pour consolider cette réorientation, il est prévu de tenir pour Envisat-1, pendant le deuxième semestre 1993, une revue de conception préliminaire (PDR) de la plate-forme polaire de référence révisée couplée avec la charge utile Envisat-1.

Les travaux de développement se sont poursuivis en parallèle. Le modèle grandeur réelle de la plate-forme polaire a été reconfiguré pour la mission Envisat-1 et sert à préciser les interfaces des instruments. Le modèle structurel du module de servitude est pratiquement terminé.

A la suite des résultats de la PDR au niveau système, une attention particulière est portée à la conception mécanique du réseau solaire, compte tenu de sa complexité, en ce qui concerne notamment le mécanisme de déploiement primaire (PDM) et les moyens de contrôle du déploiement. La PDR du réseau solaire a été fixée à avril 1993.

Les travaux ont également progressé en ce qui concerne le module charge utile. Il a été possible de réduire la complexité des sous-systèmes DRS en bande Ka en révisant les impératifs techniques et en mettant en oeuvre un système de pointage d'antenne en boucle ouverte et non en boucle fermée.

Toutes les pièces à haut degré de fiabilité du module de servitude ont été livrées. Certains problèmes d'approvisionnement ont été rencontrés avec les composants électroniques du terminal en bande Ka.

Une analyse préliminaire du couplage dynamique lanceur-satellite est en préparation; elle sera menée par Arianespace au second semestre 1993.

POEM-1

Programme préparatoire
Etudes de phase B au niveau système et instruments

Ces études sont pratiquement achevées.

This revised Polar Platform baseline will form the basis for the follow-on development. To consolidate this reorientation, an Envisat-1 Preliminary Design Review (PDR) of the revised Polar Platform baseline combined with the Envisat-1 payload, is foreseen for the second half of 1993.

In parallel, development activities have continued. The full-scale Polar Platform configuration model has been reconfigured for the Envisat-1 mission and is being used to refine the instrument interfaces. The Service Module's structural model is nearly complete.

Following the results of the system PDR, careful attention is being paid to the mechanical design of the solar array in view of its complexity, in particular the Primary Deployment Mechanism (PDM) and deployment monitoring features. The solar-array PDR is foreseen for April 1993.

The Payload Module activities have also progressed. The DRS Ka-band subsystem's technical complexity has been reduced by revising the requirements and implementing an open-loop rather than a closed-loop antenna-pointing system.

All high-reliability parts for the Service Module have been delivered. Some procurement problems have been encountered with electronic components for the Ka-band terminal.

A preliminary launcher coupling dynamic analysis is in preparation and will be carried out by Arianespace in the second half of 1993.

POEM-1

Preparatory Programme

System and instrument Phase-B studies

These studies are close to completion.

Testing of Advanced Synthetic-Aperture Radar (ASAR) transmit/receive modules and optimisation of the antenna radiation panels will continue until the end of April.

ASCAT and MIMR instrument Phase-B studies

The Phase-B/Rider-1 for ASCAT is planned to be completed with a final presentation/review in mid-March 1993. The subsequent ASCAT and MIMR activities are now disconnected from Envisat, and will become part of the Metop Preparatory Programme.

Ground-segment Phase-B

The ground-segment architecture studied within the framework of the on-going industrial Phase-B has been redirected to take the Envisat-1 payload confirmed at the Granada Council Meeting into account.

Envisat-1

The main Envisat-1 instruments (MERIS, MIPAS, GOMOS, RA-2 and ASAR) are all in a so-called 'Phase-C1', the main objectives of which are full system analyses, establishment of lower-level specifications and detailed design. Not all instruments are yet advanced to the same level, since ASAR and GOMOS were only confirmed as Envisat-1 payload instruments in Granada, and key subsystems of MIPAS are not yet totally frozen.

Updated Phase-C/D proposals for MERIS, MIPAS and RA-2, and the first Phase-C/D proposals for ASAR, GOMOS and the Microwave Sounder are expected in March. Their evaluation will allow the industrial team to be finalised and preparations to start for the main development phase (Phase-C/D).

Eureca

Spacecraft operations have continued without any major anomaly during the reporting period, except for the loss of some solar-cell strings on wing no. 1. Nevertheless, power margins remain more than adequate for the tasks planned.

Processing of all of the samples in the various microgravity facilities has been completed and the major scientific goals of the mission have therefore been achieved, subject to satisfactory retrieval and post-flight analysis. The other experiments on board continue to provide scientific data to their respective users.

The Inter-Orbit Communication (IOC) experiment continues to transmit spacecraft and experiment data via ESA's geostationary satellite Olympus to portable ground stations.

The Flight Operations Review for the Eureca retrieval mission has been held at Johnson Space Center (JSC). This was followed by a Technical Interface Meeting with Kennedy Space Center (KSC) personnel. It is currently planned to retrieve Eureca on Shuttle mission STS-57 in May.

A very successful Eureca Workshop and Press Briefing was held on 8 February at ESA's European Space Operations Centre (ESOC), in Darmstadt (D), at which the Principal Investigators presented the purpose, progress and preliminary findings of their experiments.

Dialogue with ESA's Research and Technology Centre (ESTEC) in Noordwijk (NL) has been initiated concerning post-flight activities as part of ESA's general technological studies on subjects such as spacecraft micro-meteoroid and debris impacts in low Earth orbits.

Space Station Freedom/Columbus

Following the ESA Council Meeting at Ministerial Level in Granada (E) on 9/10 November 1992, activities have focussed on the implementation of the relevant provisions, particularly the preparation of the Declaration and associated documents. The Declaration is to be signed by the 31 March 1993.

The Attached Laboratory

The technical baseline and launch date have been maintained and work has progressed to be able to arrive at an agreed final price with Industry before the contract for the development phase is presented to the Agency's Industrial Policy Committee (IPC).

There is still a shortfall of approximately 5% in the contributions, which remains to be solved.

Work has progressed regularly on ground-segment activities and the preparations for utilisation.

L'essai des modules émetteur/ récepteur du radar à synthèse d'ouverture de pointe (ASAR) et les travaux d'optimisation des éléments rayonnants des antennes se poursuivront jusqu'à la fin avril.

Etudes de phase B des instruments ASCAT et MIMR
Pour ASCAT, l'avenant 1 de phase B doit prendre fin avec une présentation finale et une revue à la mi-mars 1993. Les travaux ultérieurs sur ASCAT et MIMR seront alors disjoints du projet Envisat et feront partie du programme préparatoire Metop.

Phase B du secteur sol
Les études d'architecture du secteur sol menées dans le cadre de la phase B industrielle en cours ont été réorientées pour prendre en compte la charge utile Envisat-1 confirmée à la session du Conseil de Grenade.

Envisat-1

Les principaux instruments d'Envisat-1 (MERIS, MIPAS, GOMOS, RA-2 et ASAR) en sont à la phase dite C1 dont les principaux objectifs sont des analyses complètes au niveau système, l'établissement de spécifications à un niveau inférieur et la conception détaillée. Les instruments ne sont pas tous parvenus au même niveau d'avancement, ASAR et GOMOS n'ayant été confirmés en tant qu'instruments d'Envisat-1 qu'à Grenade, alors que les sous-systèmes clé du MIPAS ne sont pas encore entièrement figés.

On attend au mois de mars des propositions actualisées de phase C/D pour MERIS, MIPAS et ERA-2, et les premières propositions de phase C/D pour ASAR, GOMOS, et le sondeur hyperfréquences. Avec leur évaluation, il sera possible d'arrêter définitivement l'équipe industrielle et de lancer les préparatifs de la phase de réalisation proprement dite (phase C/D).

Eureca

La mission s'est poursuivie sans anomalie majeure, excepté la perte de plusieurs chaînes de photopiles sur le panneau no. 1. Les marges de puissance restent toutefois plus que suffisantes pour les tâches prévues.

Tous les échantillons des expériences menées en microgravité ont été traités. Les principaux objectifs scientifiques de la mission sont donc atteints, sous réserve de la récupération et de l'analyse satisfaisantes des échantillons après le retour sur Terre. Les autres expériences embarquées continuent de livrer des données scientifiques à leurs utilisateurs.

L'instrument de télécommunications interorbitales (IOC) continue de transmettre à des stations au sol transportables, par l'intermédiaire du satellite Olympus de l'ESA, des données sur la plate-forme et les expériences.

La revue des opérations en vol de la mission de récupération d'Eureca, qui s'est déroulée au Centre spatial Johnson, a été suivie d'une réunion sur les interfaces techniques avec le personnel du Centre spatial Kennedy. Il est prévu de récupérer Eureca en mai lors du vol STS-57 de la Navette.

Lors de l'atelier et de la conférence de presse du 8 février à l'ESOC, le Centre des opérations spatiales de l'ESA à Darmstadt (Allemagne), les chercheurs principaux ont présenté les objectifs, l'état d'avancement et les premiers résultats de leurs expériences.

Des discussions ont été engagées avec l'ESTEC, le Centre européen de recherche et de technologie spatiales de Noordwijk (Pays-Bas), au sujet des activités à mener à la suite de cette mission dans le cadre des études technologiques générales de l'Agence, sur des thèmes tels que les impacts sur orbite terrestre basse de micro-météorites et de débris provenant de véhicules spatiaux.

Station spatiale 'Freedom'/Columbus

A la suite du Conseil ministériel de Grenade les 9 et 10 novembre 1992, les activités ont été axées sur l'élaboration des textes juridiques correspondants, en particulier sur la préparation de la Déclaration et des documents connexes. La Déclaration doit être signée au plus tard le 31 mars 1993.

Laboratoire raccordé
La base de référence technique et la date de lancement ont été maintenues et les travaux ont avancé en vue d'arrêter le prix final avec l'industrie avant que le contrat portant sur la phase de développement soit présenté au Comité de la politique industrielle.

Il reste encore à combler un déficit de contributions de l'ordre de 5 %.

Les activités ayant trait au secteur sol et à la préparation de l'utilisation ont progressé normalement.

Vols précurseurs
A la suite des débats menés au sein du conseil directeur du programme Columbus, ce programme a été modifié, notamment en ce qui concerne Eureca dont la base de référence prévoit maintenant une période de mise en attente initiale suivie, sous réserve du financement adéquat, d'un deuxième vol.

Future station européenne
La coopération avec NPO Energia (CEI) s'est poursuivie. Des modifications ont été apportées à la proposition portant sur cet élément du programme afin de réorienter les études en fonction de l'importance que les Délégations souhaitent accorder à la station euro-russe postérieure à Mir-2, de préférence à la station Mir-2 proprement dite. Les travaux sur Mir-2 seront désormais limités à des domaines d'un intérêt immédiat pour la future station.

Hermes

Technologie et concepts système
Le programme d'étude technologique Hermes a été défini et les propositions d'approvisionnement sont en préparation. La plupart des activités doivent démarrer immédiatement après la signature de la nouvelle Déclaration de programme.

Des études internes ont été réalisées pour pouvoir entreprendre, avec le soutien de l'industrie, des études d'arbitrage sur des véhicules de rentrée avec et sans voilure pour des missions en coopération au service de la future infrastructure, qui comprend notamment

Precursor flights
Following discussions within the Columbus Programme Board, this programme has evolved particularly concerning Eureca, which is now baselined with an initial period of storage followed by one further flight, subject to adequate funding being available.

Future European station
The work with NPO Energia (CIS) has continued. The proposal for this element has been modified to reorient the studies according to the emphasis that the Delegations wish to put on the post-Mir-2 Euro/Russian station, rather than Mir-2 itself. Activities on Mir-2 will now be limited to areas of direct benefit for the future station.

Hermes

Technology and system concepts
The Hermes Techology Study Programme has been established and procurement proposals are presently in preparation. Most of the activities are planned to start immediately after signature of the new Programme Declaration.

Internal studies have prepared the ground for trade-off studies to be performed with industrial support on winged and non-winged re-entry vehicles for cooperative missions, which will support the future infrastructure, consisting in particular of Mir-2 and Space Station 'Freedom'. Four studies are presently in progress with European firms.

Following the preparatory work by the strategy group for ESA/Russian cooperation, the first meetings between the Chairmen of the Space Transportation and Technology Working Teams have established plans for the joint Hermes/RKA studies to start in March.

Close-out of the Hermes baseline
The close-out of activities continued with the aim of terminating the Hermes baseline development phase (Phase-1) with coherent and conclusive results. The prime contractor, EuroHermespace, has demonstrated in a summary review that the current status corresponds in most areas to the 'Stage-2 definition', originally planned as the starting point for the hardware development phase.

Whereas most activities have already come to an end or will terminate in the coming months, items that are critical for winged re-entry vehicles will continue as part of the Technology Programme now in preparation. The Board of Euro-Hermespace has decided to put the company into a dormant state on completion of the close-out tasks in mid-1993.

The first set of Hermes studies initiated in 1992 with Russian industry has generally confirmed the high expectations, and most of them will be completed in the coming months.

Hermes ground segment
The new large high-enthalpy wind tunnels in France and Germany are nearing completion of their acceptance testing. The detailed definition of the large 'Scirocco' aerothermal facility to be constructed in Italy has started. The baseline operational scenario and the associated definition of the ground-segment elements have been completed in the form of a consolidated reference concept.

ACRV
The two parallel Phase-A studies for the Assured Crew Return Vehicle (ACRV) are nearing completion and preparations for the Phase-B study, due to start this autumn, are in progress.

Servicing elements
The close-out of the Hermes EVA and HERA activities has been completed and the re-orientation towards cooperative development scenarios has been implemented. The continuation of these activities with the new objectives is covered by the ERA and EVA 2000 projects.

Preparations for the industrial activities for the Automated Transfer Vehicle (ATV) and the Automated Rendezvous and Capture (ARC) projects, are in progress.

Ariane

P230 soiid-propellant stage
The B1 test, the first test-stand firing of the Ariane-5 solid booster, took place on 10 February on a booster with a reinforced structure. Initial findings during and immediately after the test were very satisfactory.

The aims of the test were to:
- check the behaviour of the full-scale nozzle
- check the behaviour of the booster charge and the internal ballistics in a segmented configuration similar to the nominal configuration (the ignition transient in particular)
- assess the behaviour of the internal thermal protection in order to optimise its definition.

First analyses showed that the booster, when loaded with 230 tons of solid propellant which burnt for 130 s, produced the expected pressure profile, and the nozzle was activated several times to a 3° angle as forecast.

The next test, scheduled for June, will be carried out on a booster with all subsystems representative of flight units, especially the metal structure.

H155 cryogenic main stage
Development of the cryogenic stage continues according to schedule, especially the delivery of the first stage, used for the dynamic mockup, and the qualification testing of the forward skirt and the vibration testing of the aft part of the stage.

The Vulcain engine has undergone 125 tests involving a total of 20 000 s of operation.

L9 stage
Two important steps have been taken regarding the development of the Aestus engine with which the storable propellant stage will be equipped. Vacuum tests have started successfully and the first long-duration test (1380 s) has taken place with no damage to equipment.

All of these recent events show that development of the Ariane-5 launcher is well in hand.

Mir-2 et la Station spatiale 'Freedom'. Quatre études sont en cours dans des sociétés européennes.

A l'issue des travaux préparatoires exécutés par le groupe chargé de définir la stratégie de la coopération entre l'Agence et la Russie, les présidents des Groupes de travail chargés du transport spatial et de la technologie ont établi, lors de leur première réunion, des plans pour les études communes Hermes/RKA qui doivent débuter en mars.

Clôture de la configuration de référence d'Hermes

Les activités menant à la clôture du programme se sont poursuivies afin de mettre un point final à la phase de développement de la configuration de référence (phase 1) avec des résultats cohérents et concluants. Le maître d'oeuvre EuroHermespace a démontré, lors d'une revue de synthèse que l'état actuel du projet correspond, à bien des égards, à 'l'étape 2 de la définition', qui devait initialement être le point de départ de la phase de réalisation du matériel.

Bien que la plupart des activités soient déjà terminées ou doivent l'être au cours des prochains mois, les travaux relatifs aux éléments critiques pour des véhicules de rentrée à voilure se poursuivront dans le cadre du programme de technologie actuellement en préparation. Le Conseil d'EuroHermespace a décidé de mettre la société en sommeil à la mi-1993, à l'achèvement des activités de clôture.

La première série d'études Hermes lancée en 1992 avec l'industrie russe a, dans l'ensemble, confirmé les espoirs qu'elles avaient suscités; elles seront pour la plupart, achevées au cours des mois à venir.

Secteur sol d'Hermes

Les deux grandes souffleries à haute enthalpie qui viennent d'être construites en France et en Allemagne en sont actuellement aux derniers essais de recette. La définition détaillée de la grande installation aérothermique Scirocco, qui doit être construite en Italie, a démarré. Le scénario d'exploitation de référence et la définition correspondante des éléments du secteur sol ont été achevés sous forme de concepts de référence consolidés.

ACRV

Les deux études parallèles de phase A relatives au véhicule de secours pour le retour de l'équipage (ACRV) sont en voie d'achèvement et les préparatifs de l'étude de phase B, qui doit démarrer cet automne, sont en cours.

Eléments de desserte

On a procédé à la clôture des activités portant sur les EVA et l'HERA d'Hermes au profit d'une réorientation vers des scénarios de développement en coopération. La poursuite de ces activités dans le cadre des nouveaux objectifs est couverte par les projet HERA et EVA 2000.

Des préparatifs sont en cours en ce qui concerne les activités industrielles relatives au projet de véhicule de transfert automatique (ATV) et de rendez-vous et capture automatiques (ARC).

Ariane

Etage à poudre P230

L'essai B1, premier tir d'essai au banc du propulseur à poudre d'Ariane-5, avec une structure renforcée, s'est déroulé de façon très satisfaisante, d'après les premières constations faites pendant et immédiatement après le test qui a eu lieu le 16 février. L'essai B1 avait pour but:

- *de vérifier le comportement de la tuyère à échelle 1*
- *de vérifier le comportement du chargement et de la balistique interne dans une configuration segmentée proche de la configuration nominale (transitoire à l'allumage en particulier)*
- *d'évaluer le comportement des protections thermiques internes afin d'en optimiser la définition.*

D'après les premières analyses, le propulseur chargé de 230 t de poudre, qui a brûlé 130 s, a fourni le profil de pression attendu et la tuyère a été activée à plusieurs reprises jusqu'à un angle de 3° conformément aux prévisions.

Le prochain essai prévu en juin sera exécuté avec un booster dont tous les sous-systèmes seront représentatifs des exemplaires de vol, notamment la structure métallique.

Propulseur à poudre P230 d'Ariane-5 pendant son transport vers le banc d'essai à Kourou

Ariane P230 solid booster being rolled out to the Kourou test facility

Etage H155

Le développement de l'étage cryotechnique H155 se poursuit conformément aux prévisions notamment avec la livraison du premier étage, utilisé pour la maquette dynamique, avec les essais de qualification de la jupe avant et avec les essais de vibration de la partie arrière de l'étage.

Le moteur Vulcain, quant à lui, en est à 125 essais cumulant 20 000 s de fonctionnement.

Etage L9

Il faut également signaler deux étapes importantes pour le dévelopement du moteur 'Aestus' équipant l'étage à ergols stockables L9 puisqu'en effet, les essais de ce moteur sous vide ont débuté avec succès et que le premier essai de longue durée (1380 s) s'est déroulé sans dommage pour le matériel.

L'ensemble de ces événements récents montre que le dévelopement du lanceur Ariane-5 est bien maîtrisé.

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.

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G. BJORNSTROM ET AL.

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A FEEDBACK CONTROL LOOP FOR AUTONOMOUS TIME SYNCHRONISATION FOR MOBILE SATELLITE SYSTEMS, INCLUDING SATELLITES IN ANY EARTH ORBIT
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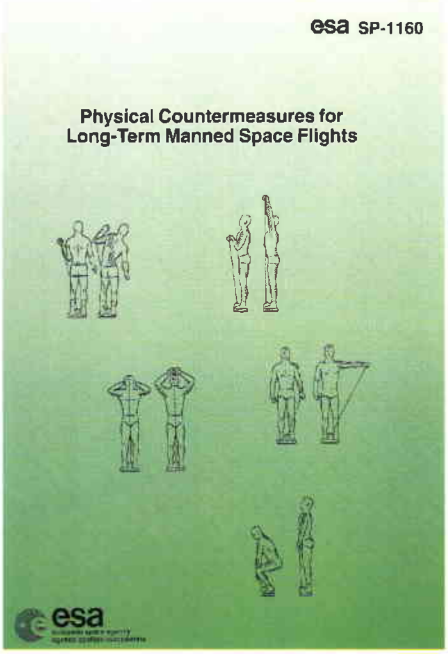

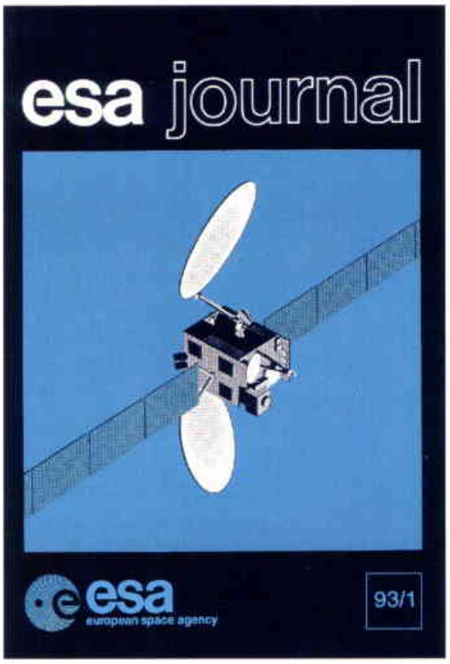

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(EDS. N. LONGDON & T-D. GUYENNE)

PREPARING FOR THE FUTURE, VOL. 3, NO. 1, MARCH 1993
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ESA Scientific and Technical Memoranda

ESA STM-246 // 35 DFL
ETHOLOGY IN SPACE, A UNIQUE OPPORTUNITY FOR BEHAVIOURAL SCIENCE
R.E. STARK

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