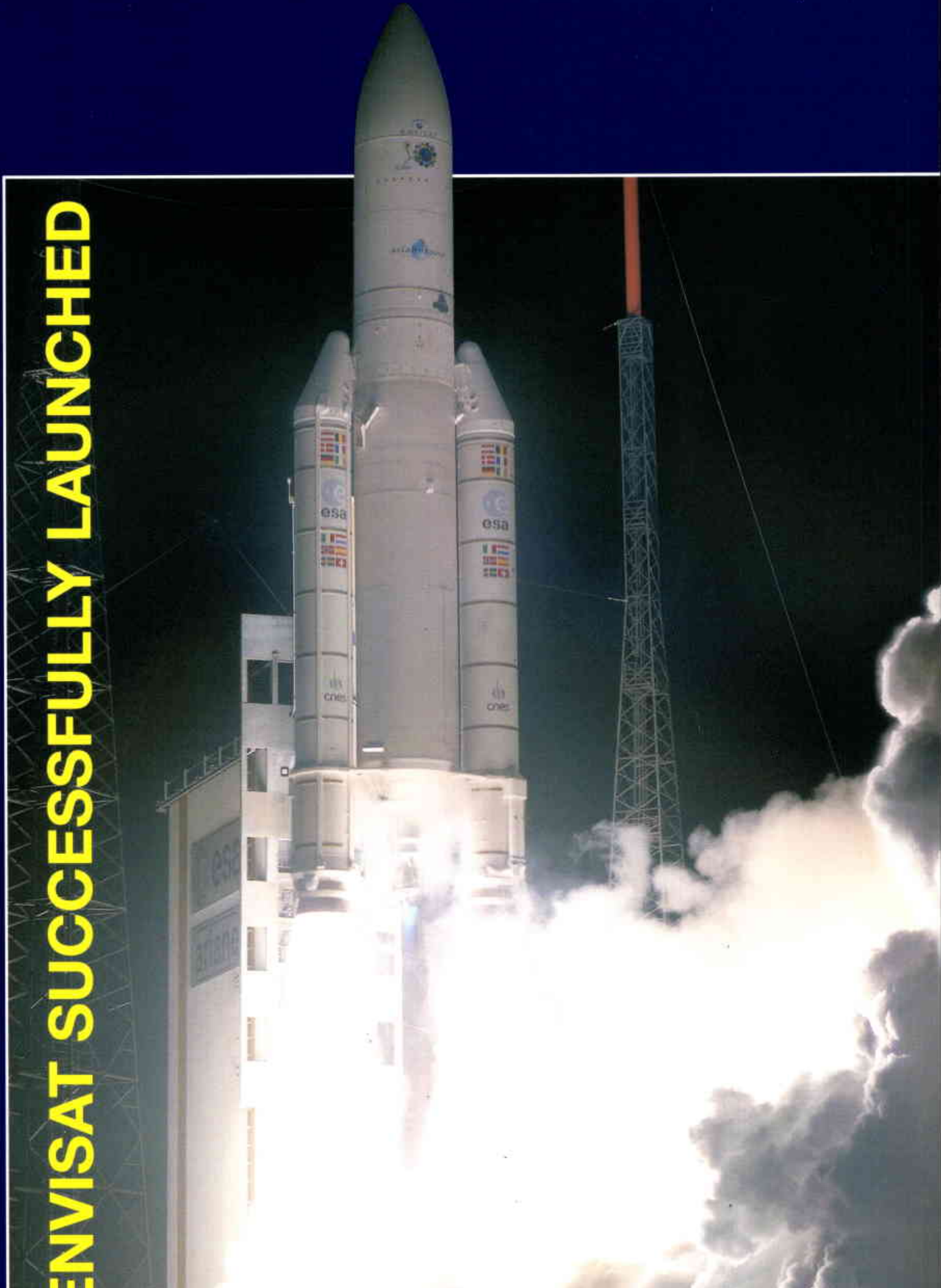
esa bulletin

number 109 - february 2002



European Space Agency
Agence spatiale européenne

esa

european space agency

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

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

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

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

The ESA HEADQUARTERS are in Paris.

The major establishments of ESA are:

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ESRIN, Frascati, Italy.

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agence spatiale européenne

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

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(a) en élaborant et en mettant en oeuvre une politique spatiale européenne à long terme, en recommandant aux Etats membres des objectifs en matière spatiale et en concertant les politiques des Etats membres à l'égard d'autres organisations et institutions nationales et internationales;
(b) en élaborant et en mettant en oeuvre des activités et des programmes dans le domaine spatial;
(c) en coordonnant le programme spatial européen et les programmes nationaux, et en intégrant ces derniers progressivement et aussi complètement que possible dans le programme spatial européen, notamment en ce qui concerne le développement de satellites d'applications;
(d) en élaborant et en mettant en oeuvre la politique industrielle appropriée à son programme et en recommandant aux Etats membres une politique industrielle cohérente.

L'Agence est dirigée par un Conseil, composé de représentants des Etats membres. Le Directeur général est le fonctionnaire exécutif supérieur de l'Agence et la représente dans tous ses actes.

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ESRIN, Frascati, Italy

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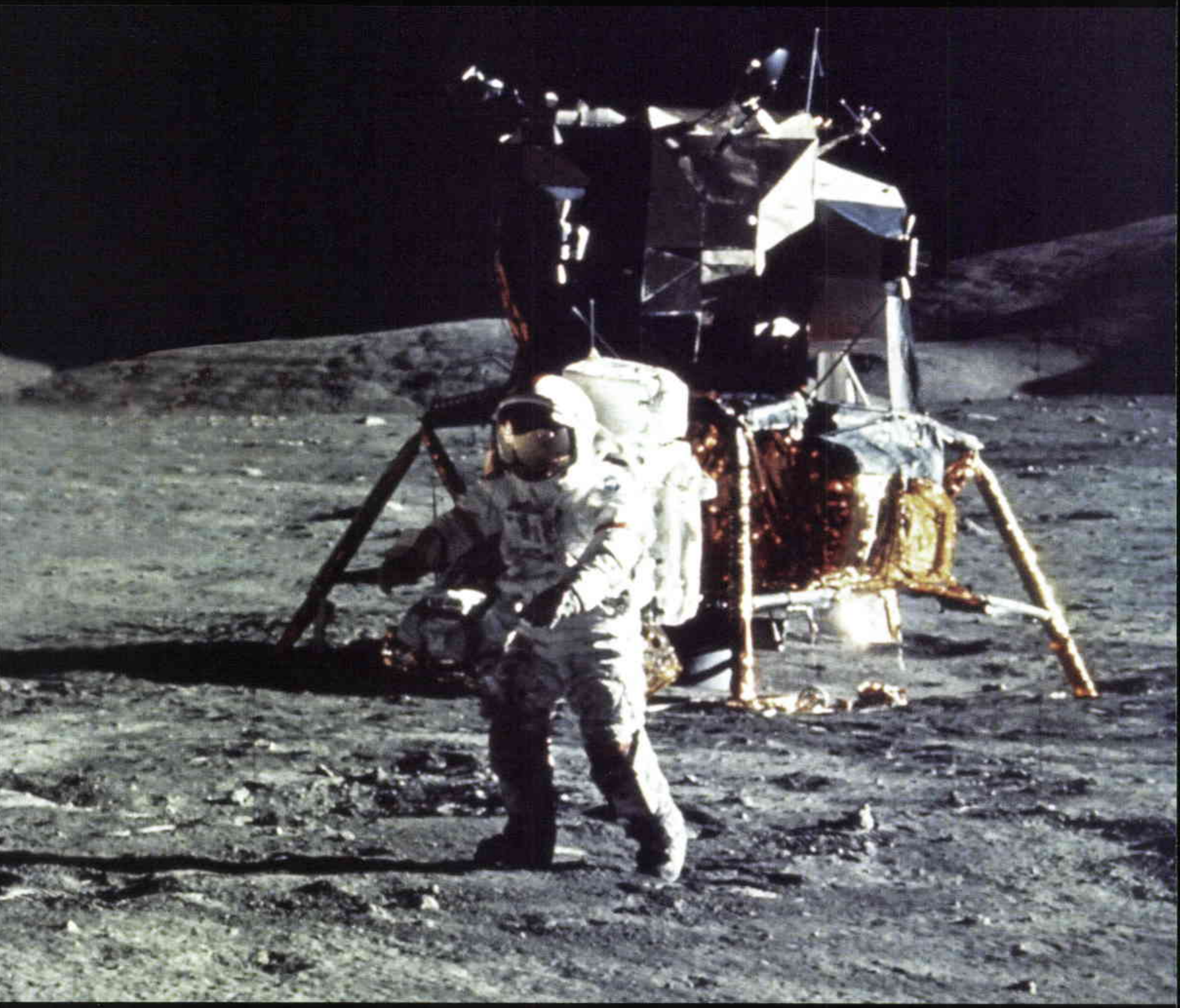

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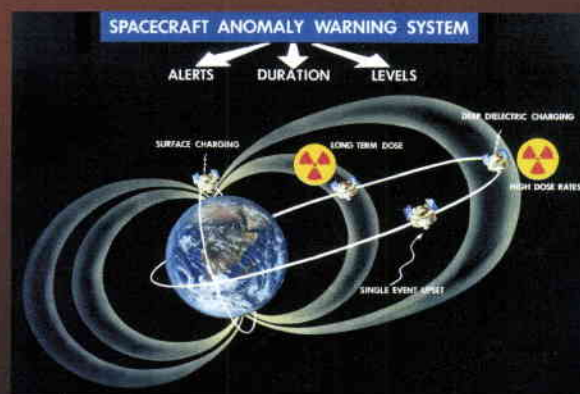
and the **DSP** operational spacecraft.



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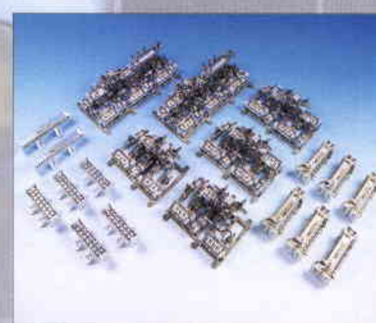

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Envisat on Watch

The eagerly awaited launch of ESA's Envisat environmental-monitoring satellite took place from Kourou, French Guiana, on 1 March at 02:07:59 hrs CET. Envisat's spectacular night-time launch also marked a return to business for Europe's Ariane-5 launcher. Rising into a clear sky and accompanied by the cheers of the engineers, scientists and project team members at the launch site, the Ariane-5 vehicle propelled Envisat towards its lofty vantage orbit some 800 km above the Earth's surface.

After a flawless lift-off, the Ariane-5 launcher put Envisat into a Sun-synchronous orbit, allowing ESA ground controllers at the European Space Operations Centre (ESOC) in Darmstadt, Germany, to take full control for the first time of the most complex satellite ever built in Europe.

"Now Envisat is in orbit, the culmination of many years' work really begins and we are looking forward to the environmental benefits the satellite is going to bring to Europe," said José Achache, ESA's Director of Earth Observation Programmes. *"The ten instruments onboard Envisat - more than on any other such satellite - cover a wide spectrum of phenomena, delivering evidence of the interactions between the atmosphere, the ocean, the polar ice caps, the vegetation as well as human activity on the surface of the Earth. We will be able to trace the smallest changes to the Earth's surface anywhere on the globe. The importance of this mission has triggered great interest in the Earth-science community, both at a European level and worldwide."*

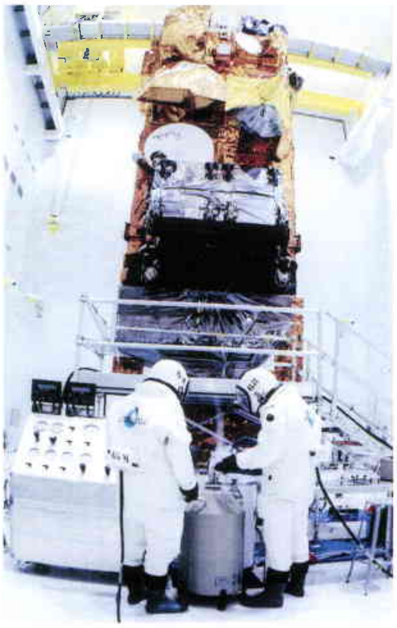
Given its sheer size, Envisat has involved almost all of Europe's space industries in the development of its numerous advanced technologies, particularly for the payload.

Its 65 m^2 of solar array were fully deployed within 75 minutes after lift-off. This deployment and the subsequent attitude stabilisation of the satellite, performed under coverage of the Perth ground station and monitored from the ESOC Control Room, were eagerly followed by the guests on the large screens of the Jupiter Control Room in Kourou and by the guests at ESOC, both benefiting from a 3D animation display driven from the telemetry being received from the satellite.

Shortly after these events, the Envisat Programme Manager, Jacques Louet, was extremely happy: *"The events of this night went like a dream: a flawless execution of the automatic sequences programmed onboard the launcher and the satellite. It is now party time for both the launcher and satellite teams. Tomorrow, we will be working hard again to finalise the various deployments, to put the full payload into operation and to start the instrument calibration. The objective is to validate the user products within six months – this means a tough job ahead of us, but we and our supporting scientists are well prepared for it. This is a superb day for all of us, and we could not have dreamt of a better start for this mission"*.

Within three days, the ASAR antenna was deployed successfully, shortly followed by the Artemis antenna communications mast. Within a week after the launch, the Launch and Early Orbit Phase (LEOP) was completed and the satellite, stabilised in fine pointing mode, was already providing stable X-band payload communication links and onboard data recording. The switch-on of the instruments is currently in progress, and ESA is looking forward to the first observations of the Earth from this high-tech observatory, which puts Europe at the forefront of environmental monitoring from space and provides a major tool to support the European Global Monitoring for Environment and Security (GMES) initiative.

The ten instruments that make up Envisat's payload – ASAR, MERIS, AATSR, RA-2/MWR/DORIS/LRR, MIPAS, GOMOS and SCIAMACHY – were described in detail in ESA Bulletin No. 106 (June 2001). An overview of the Envisat Data Dissemination System, which provides for rapid transmission of the satellite's data products to users across Europe, is to be found in the article on page 12 of this issue.



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Figures 1-12. Envisat launch preparations, from spacecraft fuelling through to Ariane-5's readiness on the launch pad

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ESOC Control Room

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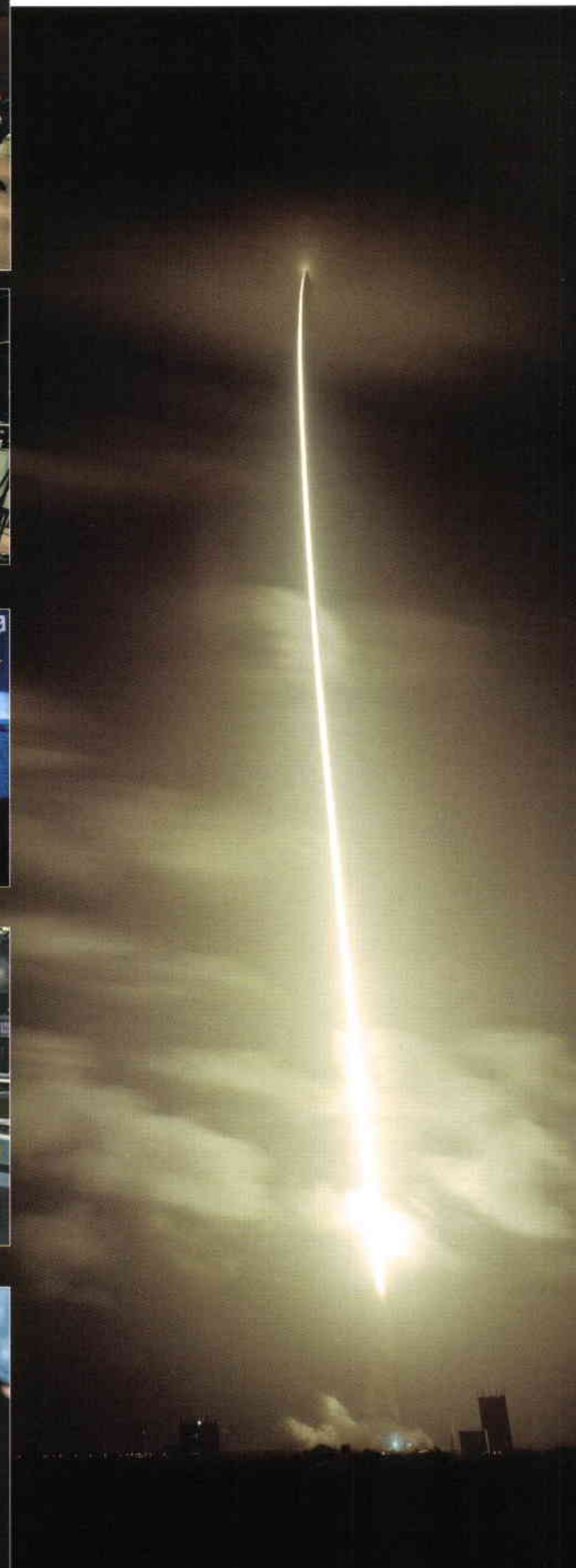
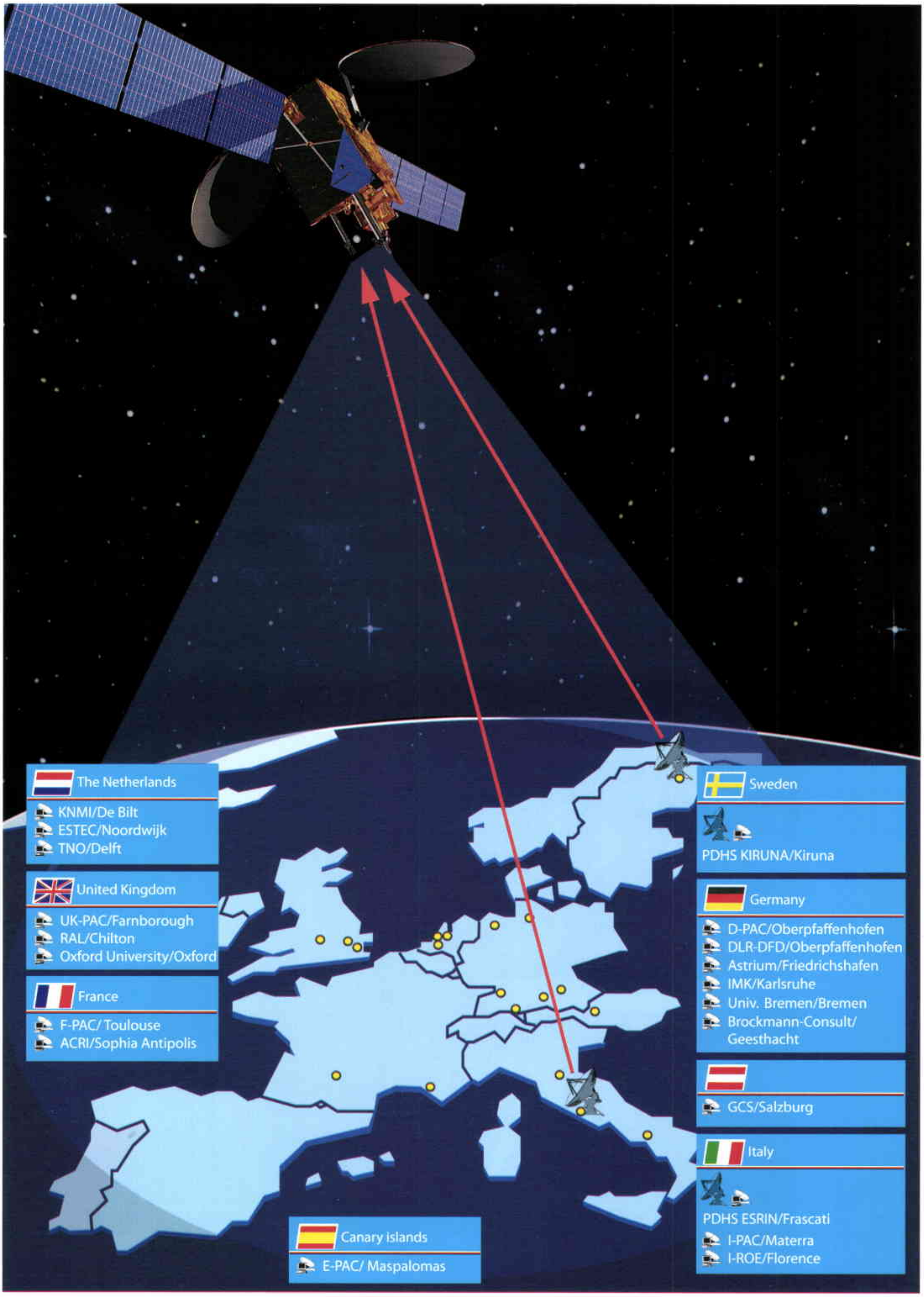
ESA's Director General (right) being congratulated by German State Secretary Uwe Thomas

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The Envisat Data Dissemination System

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The Envisat Data Dissemination System (DDS) will allow rapid dissemination of the satellite's data products to users across Europe. The system uses a commercial satellite-based network, which is based on the Digital Video Broadcasting (DVB) standard and is integrated into the Internet. It accommodates low-cost user stations and allows for cost-effective use of satellite bandwidth. It is also suitable for use in support of other missions.

Introduction

The Envisat mission calls for the dissemination of scientific data products to users within hours of sensing. This requires a ground-segment facility capable of distributing each product from the Envisat Payload Data Segment (PDS), charged with acquisition and processing of the scientific data, to one or more user premises.

In 2000, a survey of commercial data-dissemination networks available on the European telecommunications market showed none matching the Envisat dissemination requirements. Solutions based on terrestrial networks were not considered cost-effective for broad- and multi-casting tens of gigabytes per day. Turnkey solutions based on a satellite network lacked an adequate approach to the integration of data sources and satellite up-linking. Furthermore, they offered only limited reliability of transmission, and did not provide cost-effective use of the satellite bandwidth.

In the absence of an adequate off-the-shelf solution, therefore, ESA embarked on the development of a system making maximum use of commercially established elements. This involved the use of commercial satellite capacity, industrially supported subsystems for satellite-bandwidth allocation and data transmission, mass-market data-reception components and, last but not least, well-established digital transmission standards (TV and Internet).

Based on these choices, and benefiting from earlier experience within ESA and its industrial partners, it was possible to complete the development of the Envisat Data Dissemination System (DDS) in less than 12 months (Fig. 1). This included the deployment of all of the user stations that will be required during Envisat's commissioning phase. DDS development and validation has followed an incremental approach starting from a core system, which was gradually integrated with the Envisat PDS and complemented with secondary functions. This approach secured key capabilities at an early stage and allowed a proper review of progress at each stage of development and proper planning for subsequent stages.

Today's DDS architecture (Fig. 2) and functions are scalable in terms of the number of up-links and receivers and can also support a further increase in bandwidth, to allow the accommodation of new data-dissemination requirements emerging during the mission's lifetime. The DDS's design also allows for multi-mission use, i.e. other missions can make use of DDS services in parallel with Envisat. In fact, DDS is already being used to support limited ERS data distribution in parallel with the Envisat rehearsal activities.

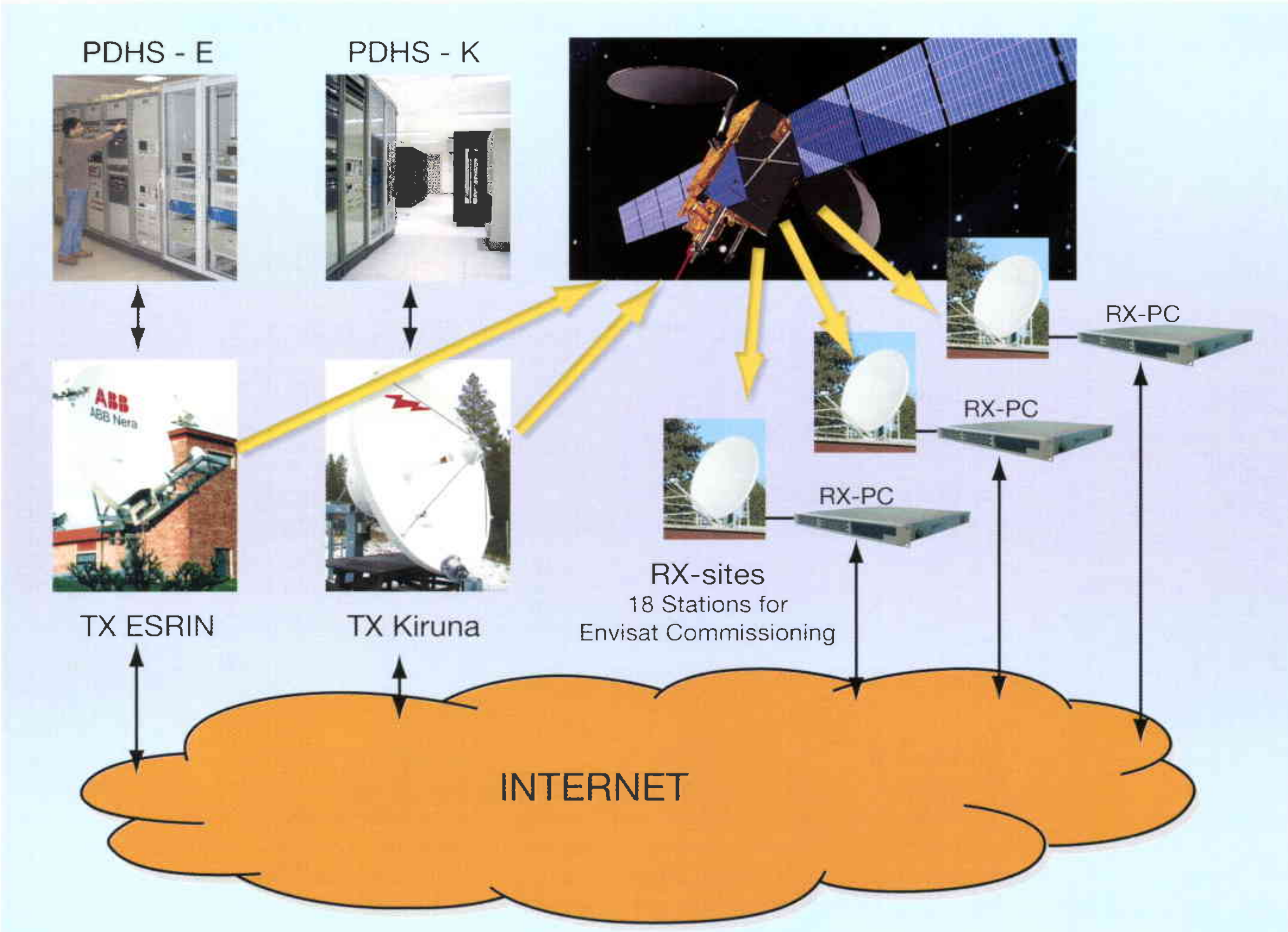

Figure 2. DDS architecture

DDS architecture

The DDS contains the following computing infrastructures and telecommunications networks:

- Two transmitting stations located at the Envisat Payload Data Handling Stations (PDHS) at ESRIN in Frascati and in Kiruna, Sweden. Each station comprises a PC infrastructure for data handling, and an antenna and RF units for data up-linking.
- A multitude of receiving stations located at user premises across Europe. Each station comprises a commercial TV antenna, and a PC with a board for digital video broadcast (DVB) data reception.
- A central monitoring and control system co-located with the Envisat Payload Data Control Centre (PDCC) at ESRIN.
- A satellite network based on dedicated, leased redundant transponder capacity on the Eutelsat W1 spacecraft (Fig. 3).

The DDS also makes use of the following terrestrial networks in order to ensure reliable data transfers:

- The Envisat Payload Data System (PDS) Communication Network (PDS-COMNET) for system-critical links.
- The public Internet for receive-only users.

The DDS interfaces externally with:

- The Envisat Payload Data System (PDS) Dissemination Facility at the two PDHS, which issues dissemination requests to the DDS and provides the data products to be transferred.
- The local networks and computing facilities at user premises, such that users can forward received data products to their computer facilities for further processing.

DDS functions

The principal function of the DDS is the delivery of PDS products to users within three hours or one day of sensing, depending on product type. Products, which can be up to several hundred Mbytes in size, are retrieved for dissemination from the PDS Dissemination Facility at the Kiruna and ESRIN PDHSs and are delivered to receiving PCs at the user premises. In performing this function, the DDS acts as a dissemination service provider to the Envisat PDS Dissemination Facility.

48 hour dissemination planning

The PDS Ground Segment Planning (GSP) issues a dissemination plan that identifies the time windows during which the PDHS transmit uplinks at Kiruna and ESRIN are required to be

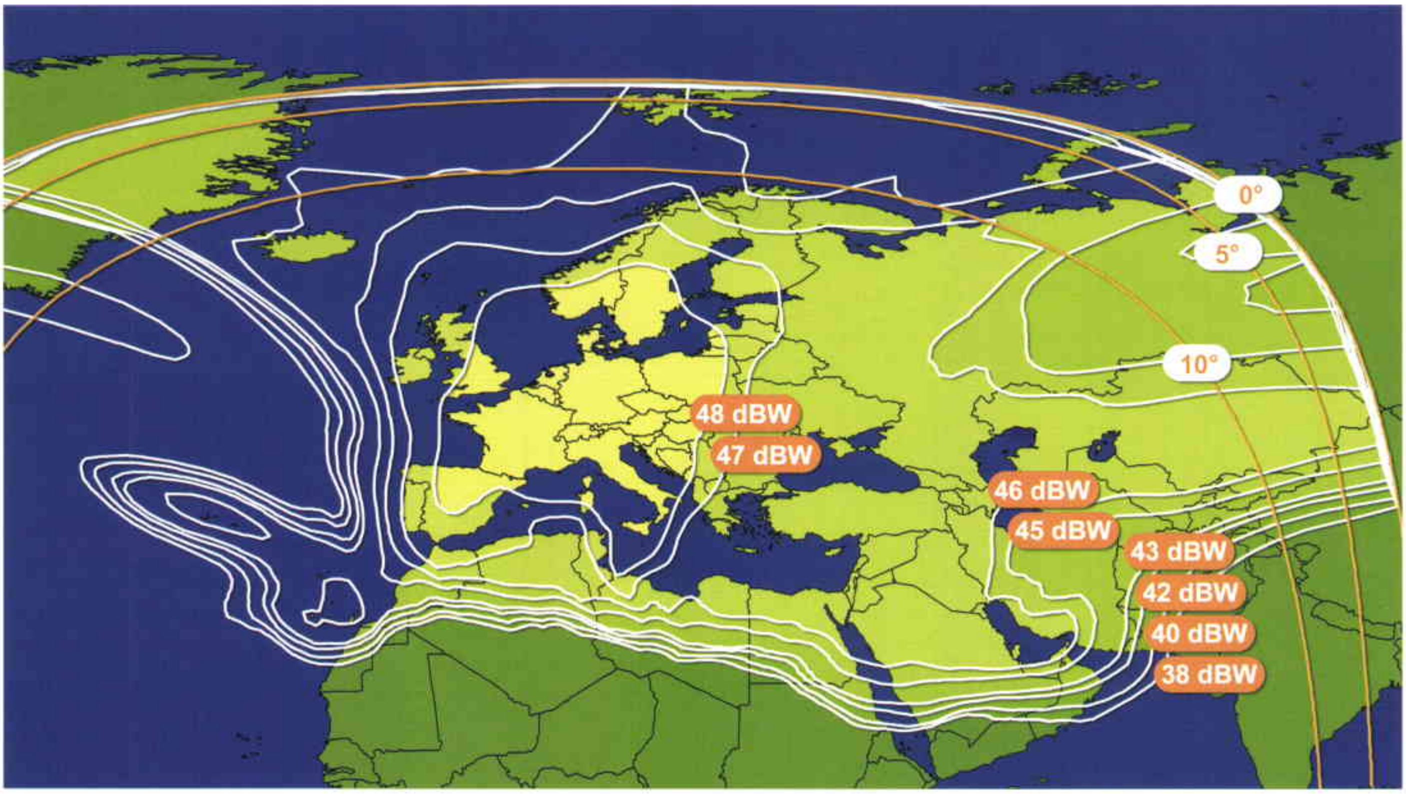

Figure 3. The Eutelsat W1 satellite's footprint from 10°E (courtesy of Eutelsat)

ready for dissemination. It provides a listing for each time window of all product dissemination requests, together with the planned dissemination start and stop times. Plans are elaborated regularly, typically every 24 hours, but can also be issued on an ad-hoc basis.

Figure 4 shows a 48 hour dissemination plan and identifies the dissemination instructions therein. The top lines identify the orbit numbers of Envisat and the time of day. The next line shows the start and stop times allowed for the planned individual dissemination requests originating at Kiruna and ESRIN, respectively. The following line indicates periods during which the TX up-link at either Kiruna or ESRIN is active and can disseminate products. Within these periods the actual time slots for individual product dissemination are identified below.

Individual product dissemination requests
The actual dissemination requests for individual products will be issued by the DF at the respective PDHS, once the product has been acquired, processed and is ready for dissemination. This happens shortly before the planned start time for the particular product in the dissemination plan. Each dissemination request identifies the product data file location at the DF, the list of receive destinations (one or more), and the planned time window for the dissemination of that product.

Data handling
The DDS provides for the data handling associated with each individual product dissemination request. Once a new request is identified, the related product is transferred locally from the DF to the DDS. The products are forwarded for dissemination via the satellite link. Urgent requests for dissemination can be inserted manually, bypassing the DF interface. Only one transmission is necessary, even if more than one user is destined to receive the product, since the transfer protocol takes advantage of the inherent broadcasting nature of satellite links. Reliable dissemination is ensured by immediate retransmission of lost packets. At the end of a dissemination, the DDS collects all dissemination reports from the addressed receivers and provides them to a central reporting point.

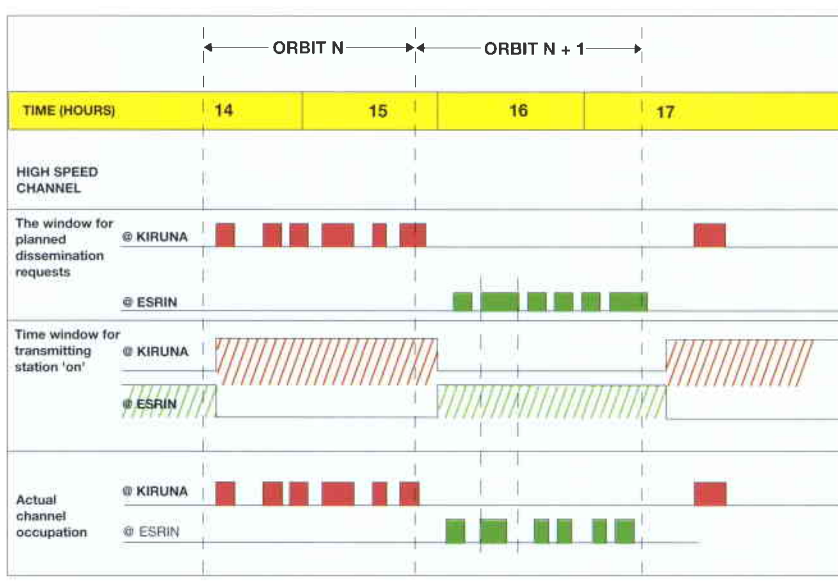

Figure 4. A 48 hour dissemination plan

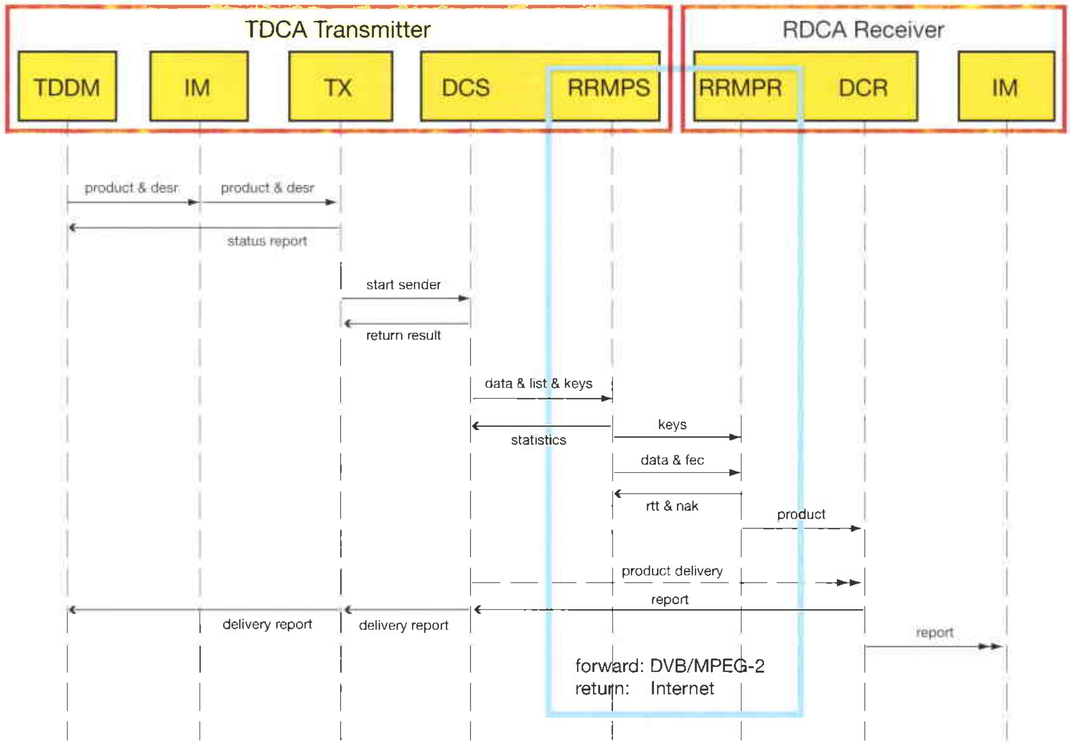

Figure 5. Dissemination protocol

Dissemination requests can be addressed to two different logical channels sharing the same satellite link. The two channels, configured as high-speed (several Mbps) and low-speed (several kbps) channels, can be used in parallel and are optimised for large and small data products, respectively. Only one product can be disseminated per channel at a given time.

DVB/IP dissemination protocol

Products forwarded for dissemination via satellite are handled using the MPEG-2/DVB-S based Datacast protocol. MPEG-2/DVB has become widely accepted as the means of transport for both digital television and Internet Protocol (IP) packets (Fig. 5). MPEG-2 uses fixed-size packets (188 bytes) each with a packet identifier (PID) to discriminate between logical channels. The Multi-Protocol Encapsulation is used to carry IP packets. DVB-S, where S stands for satellite transmission, provides sophisticated error-correction with Viterbi and Reed-Solomon coding.

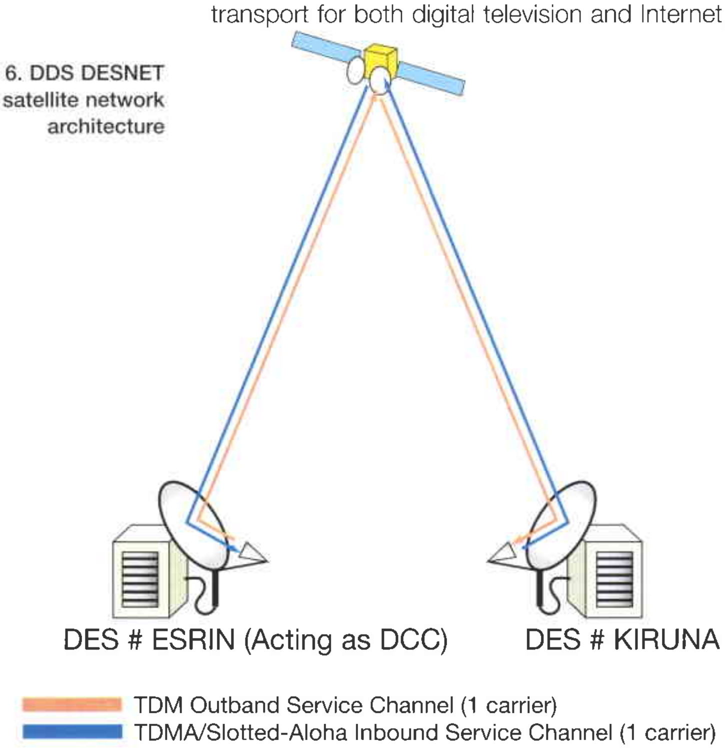

Figure 6. DDS DESNET satellite network architecture

Management of satellite capacity

The DDS allocates the satellite capacity to the transmit stations according to the active periods declared for the respective PDHSs in the dissemination plan. Only one transmit module can use the satellite capacity at any one time. The capacity assignment can be performed automatically or manually and makes use of a commercial subsystem (DESNET).

The DESNET network architecture (Fig. 6) comprises two logically overlapped subnetworks, the Traffic Data Network and the Service Data Network. DESNET is fully self-standing and does not require any special additional telecommunications infrastructure.

The Traffic Data Network (TDN), which provides for the actual product dissemination, is characterised by a fully meshed topology with DAMA/PAMA access schemes for DDS transmit modules. It employs continuous, SCPC (Single Channel Per Carrier), variable-bandwidth satellite carriers.

The Service Data Network (SDN) provides for the allocation of the Eutelsat W1 bandwidth to the transmit modules according to the

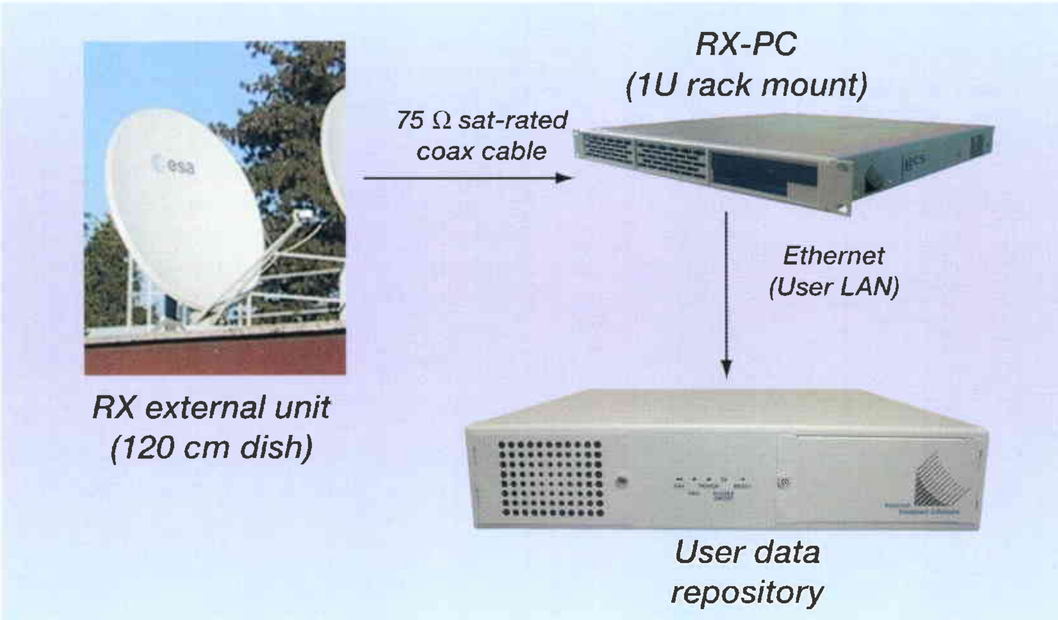

Figure 7. DDS receiver infrastructure

dissemination plan. It is star-meshed with a designated DES configured as the DESNET Control Centre (DCC) at ESRIN acting as the centre of the network.

A DESNET session corresponds to a time window allocated to a DDS transmit station. The session classification priority can be 'normal', 'priority' or 'emergency'.

DDS receiving stations

The DDS infrastructure at user premises comprises an antenna, a coaxial cable with a maximum length of 30 m, the receiver PC and a user LAN (Fig. 7).

The receiving stations are equipped with a Pentium-based PC running the Linux operating system, with hardware chosen to provide sufficient speed at moderate cost:

- 1U chassis with an 800 MHz Pentium-III
- 256 MB of RAM
- Intel EtherExpress 10/100
- 36 GB UW-SCSI hard disk.

It integrates the Broadlogic 2030-16 Satellite Express DVB receiver card, which performs the deconversion/decapsulation of DVB data streams into IP packets. This card has been shown to be the one best suited for low-rate SPCP carriers, starting from 2.222 Msymbol/sec (corresponding to 2.048 Mbps). The Linux driver is able to receive data at up to approximately 7 Mbps per logical channel.

User interface

The Envisat receiver PC provides a WWW user front end, offering maximum ease of use. The header frame shows the system information, the navigation bar provides access to one-shot information and sub-menus, and the content frame always shows the current system status (DVB link, disk usage, LAN forwarding and/or disk cleanup activated).

Figure 8 shows the in tray, which lists all of the data product files, with their reference codes and sizes, that have been received successfully and are still stored on the local PC, ready to be downloaded via the LAN. The 'LAN forwarding' menu (Fig. 9) allows one to configure for and activate manual or automatic forwarding of products from the PC to a user workstation.

The System Summary display gathers on one screen all of the parameters that are important for smooth operations, such as the disk usage of all file systems.

DDS operations and quality of service

DDS operations are integrated into the scheme

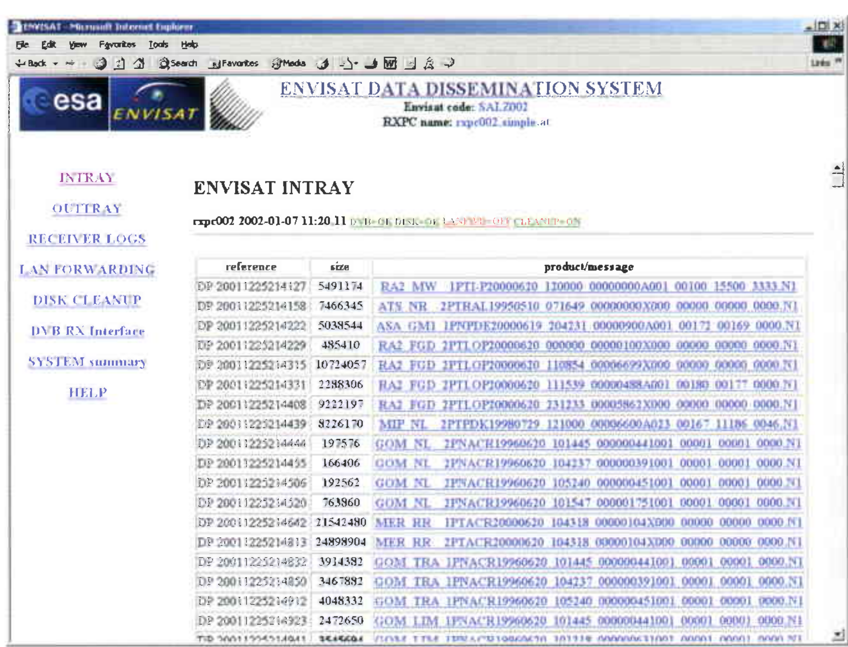

Figure 8. DDS receiver interface – in tray

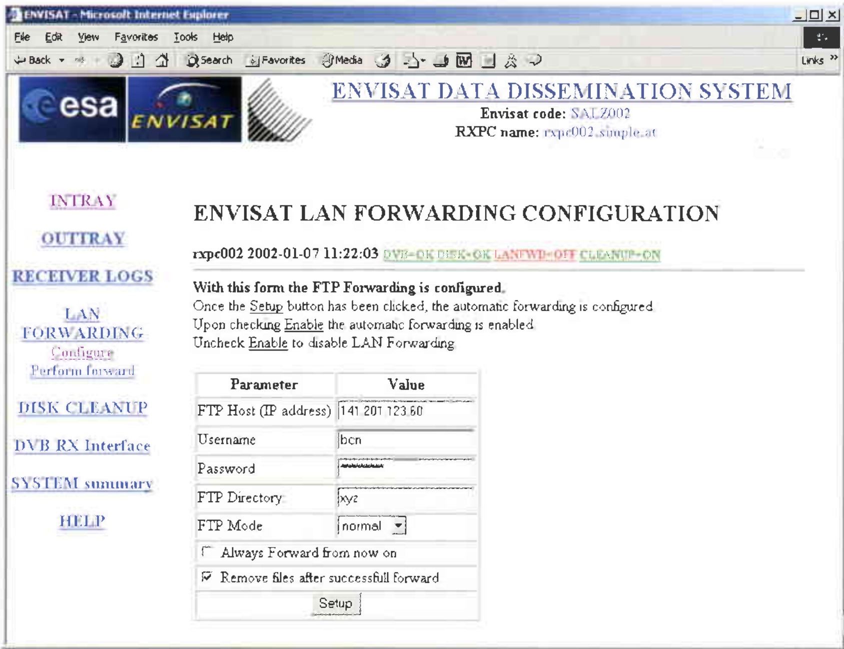

Figure 9. DDS receiver interface – LAN forwarding

Figure 10. The EO Help Desk staff

Figure 11. DDS MIMS monitoring interface

currently used at ESRIN for ERS and Earthnet/Third Party mission operations. The DDS Operations Team is responsible for the correct configuration and maintenance of the system. The shift operators will respond outside normal office hours to occurrences where a prompt intervention is required (e.g. switching to a DDS redundant chain). DDS operations will also be supported by the EO Help Desk (Fig. 10) in terms of interfacing to the users, and by the Multi-Mission Integrated Monitoring System (MIMS) as far as the DDS network and system monitoring are concerned.

ESA central monitoring and control

Two types of communications are foreseen for the monitoring: remote access from the central MIMS, whereby a file containing the current system status is read periodically, and asynchronous communication (traps) from the monitored system, generated when one of the controlled functions changes its status, e.g. an alarm is raised at a user station. Monitored-object statuses are then presented to the operator/user via graphical displays (Fig. 11).

Under each icon there is a tree of functions that can be monitored (Fig. 12); for example, parameters such as satellite link status, user interface configuration (e.g. LAN forwarding active) and use of resources (e.g. available disk space). In the case of a failure, the central operator responsible can initiate all of the required maintenance and recovery actions. For example, the DDS operator can intervene remotely to free disk space for new disseminations. MIMS provides for continuous 24 hour per day, 7 day per week monitoring of critical DDS elements.

As a complement to MIMS monitoring, DDS generates performance reports for each receiving and transmitting station, allowing the quality of service for individual users to be monitored. These reports cover both the transmit activity in terms of how may files have been transferred, the throughput, the start/stop time of the satellite session, and the receive activity for each station in terms of the number of products acknowledged as successfully received, the actual success percentage (against the number of products actually sent to the reception station), and the overall number of retransmission requests issued by the station.

Redundancy

The DDS up-link stations are fully redundant in all their components, mainly via 'hot' elements that can be activated immediately following predefined procedures, e.g. emergency operations initiated by MIMS. Redundancy of the satellite capacity has been ensured through a contract scheme with Eutelsat, which guarantees equivalent capacity in the event of an unrecoverable transponder failure.

Cost aspects of DDS

The major cost objectives for DDS development have been to minimise the investment in user infrastructure needed and to allow low operating costs. This goal has been achieved through:

- A user infrastructure making use of a standard PC, custom built into a rack unit with commercial DVB receiving board and commercial TV outdoor equipment at a total cost of about 5kEuro per receive module.
- A commercial satellite bandwidth with redundancy scheme, leased at a monthly flat rate corresponding to a cost of about 50 Euro per gigabyte of up-linked data, or 1kEuro per day.
- The integration of a large part of DDS operations and monitoring and control into the framework of Envisat operations, resulting in a marginal cost.

transmitters at other European locations, within the limits of the Eutelsat W1 footprint. Overall DDS capacity can be upgraded to 8.5 MHz/4.25 Mbps by exploiting already reserved additional capacity on Eutelsat W1. The system is dimensioned to support up to 8 Mbps.

Operations outsourcing

Some areas of DDS operations are candidates for outsourcing once the satellite-services market for data communications has matured. In particular, the leasing and access management of the satellite capacity and the provision and maintenance of the receivers could soon benefit from market offerings. The satellite resources could be managed from the service centre of a satellite network operator as part of its overall operations. ESA's New Media Service Centre (NMSC) may support such transfers. However, the actual data-handling aspects of DDS will remain closely linked to the PDHS operations and locations, at least for the duration of the Envisat mission.

The up-front investment in DDS was mainly for the two transmitting stations and the local-area networking at PDHSs. These investments can be seen as Earth-observation infrastructure investments in support of multi-mission requirements.

DDS status and possible evolution

Status

At the time of writing, the development effort has been concluded and DDS is being operated in support of the Envisat rehearsal phase. It comprises two up-link stations (TX) and 20 receiving stations (RX), including receivers at all PDS Processing and Archiving Centres. DDS uses a satellite bandwidth of 5 MHz and makes available about 2.5 Mbps of effective throughput for reliable multicasting and broadcasting. Additional capacity has been reserved with Eutelsat. Operations are managed as part of the Envisat operations, with all central tasks being handled at ESRIN.

By design, DDS is capable of supporting other missions in parallel with Envisat, interfacing with additional data sources beyond the PDS-DFs to provide dissemination handling also to users outside the Envisat community. This capability is currently being used for the rapid repatriation of ERS calibration data from Kiruna to ESRIN. The DDS architecture is scalable to increase the number of transmitting and receiving stations, even allowing for the addition of other

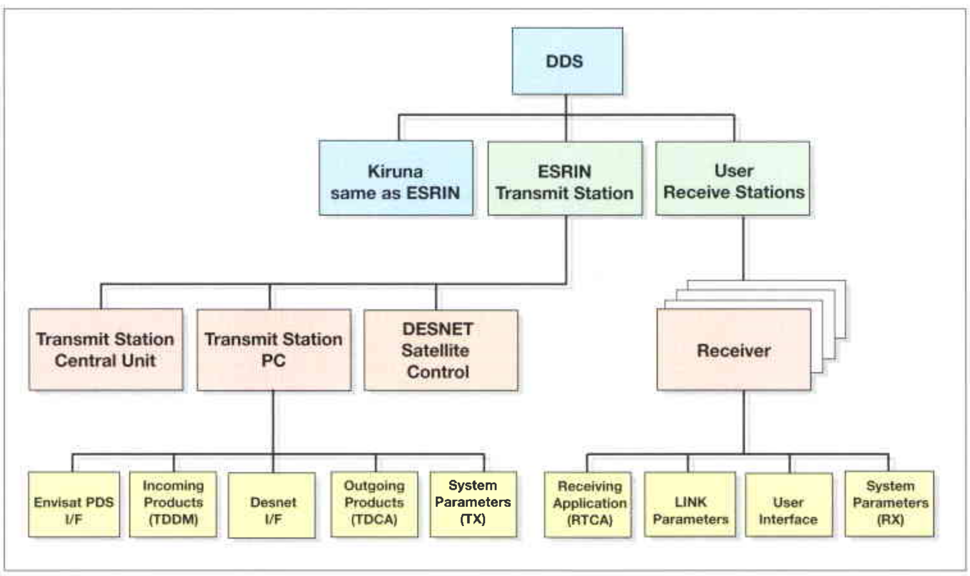

Figure 12. DDS MIMS monitoring tree

Conclusion

Ten years after the development of the ERS Broadband Data Dissemination System (BDDN), a new state-of-the-art data-dissemination system has been put in place for Envisat. It represents a decade of technological evolution in the Internet age, supported by ESA through its Telecommunications Programme. A number of ESA-sponsored trials have supported the technology transfer from digital satellite TV into the domain of Earth-observation applications. The experience gained in this process has been fundamental to conducting the DDS development so quickly. The result is a cost-effective dissemination service based on future-proof standards and commercial offerings, to the undoubted benefit of the user.

Taxi to the ISS – the Andromède Mission

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With the arrival of the first ISS expedition crew in November 2000, the permanent presence of humans in near Earth-orbit continued, taking over from what the Russian Mir space station had demonstrated for almost fifteen years previously. The way in which operations onboard ISS are conducted owes a great deal to inherited Mir experience, but many of the things happening now in orbit are quite new and are providing new opportunities also for the European astronauts.

Introduction

The French-Russian Andromède mission in October 2001 proved to be a good example of new ways of fully exploiting the limited human spaceflight opportunities currently available. Called a 'taxi mission', the flight's main purpose was to deliver a new Soyuz spacecraft to the International Space Station (ISS) and take back the old one, which had been attached to the Station since May 2001. In the Mir era, this would also have meant an exchange of the expedition crews, with the old crew returning to Earth in the Soyuz that had brought them up. The internationality of the ISS does not stop with the building blocks and the crews, but also applies to the space vehicles used to ferry the crews and provisions to and from the Station, which also come from several partners. Thus the ISS crews are being ferried up and down on US Space Shuttle flights for most of the Station's build-up phase.

This in turn means that the three crew seats of the Soyuz spacecraft can be used for stays of 6 to 8 days, and sometimes longer, on the ISS. Thus while the first Soyuz taxi flight included a tourist paying for a very special, but completely personal experience, the second Soyuz taxi flight had a programme involving scientific, operational, and educational goals, implemented as part of the European preparation for the utilisation of the ISS. All of these tasks were given to Claudie Haigneré, a European astronaut of French nationality based at the European Astronaut Centre (EAC) in Cologne, Germany. The French space agency CNES took the lead for this mission, with the French Government paying through a bilateral agreement with Rosaviakosmos for the provision of the flight and the payloads.

Figure 1. Traditions and official meetings punctuate the days before launch for the flight and the back-up crew. From left to right, Koseev, Afanasiev, Haigneré, Zalutin and Kushelnaya.

Figure 2. Three hours before launch, the functioning of Claudie's spacesuit is checked under pressure in the launch position

Letter from the Andromède Astronaut

November 2001

The Andromède mission was successfully completed just a few weeks ago. In recognition of the fact that the astronaut on board is just one link in the chain, scientific, technical and general debriefings will be conducted in the near future to disseminate useful information to all those who contributed to the success of the mission.

I am deeply grateful to the French, Russian, German, Spanish, and European-integrated scientific teams who devoted so much time and energy to developing excellent protocols to take advantage of the space environment for their particular scientific fields. I greatly appreciated the expertise of the operational and technical teams, the priceless presence of the EAC Flight Surgeon throughout all phases of the mission, and the availability and competence of the teams of engineers supporting the different phases of the mission and training, from CNES in Toulouse (CADMOS), and from ESA at EAC in Cologne and in Star City.

I would like to offer my thanks also for the friendly and professional relationships with my colleagues, astronauts and cosmonauts from Russia, NASA and especially the European astronauts at the Mission Control Centres in Russia and USA. I felt completely integrated with all the personnel and their teams and prepared for our common goal: working in space for the progress of science and in preparation for the future steps taking humans further into space. I was really happy and honoured to represent the European Astronaut Corps and ESA in space. It gave me great satisfaction to work in so harmonious an international atmosphere, with a multi-cultural crew, with two Mission Control Centres, and with the capacity to interact with the ground teams in the event of non-nominal situations occurring. The functionalities of the ISS are already very wide-ranging even in this early phase, even if it is not always easy to coordinate the schedules of the visiting and the increment crews. That also means that for so short a mission as mine, it was difficult to find enough personal time to enjoy the sights and the exceptional experience of my stay there.

We have certainly learned a lot, but we still have a lot to learn. Personally, I already feel ready for the next step. I am therefore very pleased to see new European missions and projects being scheduled for the near future aboard the International Space Station !

Claudie Haigneré

The training

In Claudie Haigneré, an experienced astronaut was chosen for the mission. She had already made a 16-day flight to Mir in 1996 and had served as back-up astronaut for three other missions, including training for a long-term stay onboard Mir involving an EVA (Extra-Vehicular Activity). She is also the only woman to have received the Soyuz Return Commander qualification, involving special training in returning the Soyuz safely to Earth in an emergency situation with an incapacitated crew.

Nevertheless, as pre-mission training is also aimed at bringing a crew together, she started courses for her latest mission in January 2001 at the Cosmonaut Training Centre in Star City, Russia. With her were two Russian colleagues: Victor Afanasiev as Soyuz Commander, a veteran of now five space flights, and Konstantin Koseev as Flight Engineer 2, a newcomer in space. Together, they travelled to France to familiarise themselves with the experiments to be conducted during the mission. At a stop-over on the occasion of the Le Bourget Airshow in Paris, the Andromède crew and their back-ups met a large number of the European astronauts and a Shuttle crew that had just returned from space. During a visit to the Johnson Space Center (JSC) in Houston, the crew was also introduced to the US segment of the ISS. For the final launch preparations, Claudie and her Russian colleagues travelled to Baikonur in Kazakhstan.

Figure 3. Months of intensive training on systems and payloads help to make a good crew: from left to right, V. Afanasiev, K. Koseev and C. Haigneré.

Onboard the ISS

In preparation for the incoming Andromède flight, the ISS Expedition Three member and Soyuz pilot Deshurov first had to 're-park' the Soyuz spacecraft from a docking node at the FGB module to another at the end of the newly arrived Russian PIRS airlock and docking port.

The Soyuz launch, the chasing of the ISS in orbit, and the docking to the newly freed port went flawlessly for Claudie and her colleagues. She proved her capabilities by being the first female and non-Russian flight engineer to

Figure 4. The Soyuz TM 31 spacecraft attached to the PIRS docking port and airlock.

occupy the seat to the left of the Commander – another 'first' in Soyuz history. The hatches between the two spacecraft were opened on 23 October, to the sound of applause from a large French delegation back on Earth led by French Prime Minister Lionel Jospin, who was watching the event from the TsUP Control Centre in Moscow.

The same night the personal items belonging to the two crews were transferred from one Soyuz to the other. Claudie set up her quarters 'around the corner' in the 'Quest' airlock compartment, a late addition to the ISS for sorties with the US space suit. There she fixed her sleeping bag to a wall and arranged some often used equipment around her. The long-term crew, who stay for up to six months on board the ISS, is given priority use of the 'cabins'. A busy programme of activities followed, with the two crews working through their planned timelines for the next eight days.

The in-flight programme

Claudie immediately started her flight programme, which consisted largely of experiments prepared by French and other international groups.

Figure 5. The shirt-sleeve environment on-board the ISS is ideally suited for experiment work

Life-science experiments

COGNI – investigated the changes in perceived spatial orientation of the astronauts by means of a computer and geometrical patterns displayed on the screen. After a virtual ride through a complicated tunnel system, the astronaut had to reproduce the navigation pattern.

Cardioscience – took up elements of investigations performed on the Mir space station, such as anambulatory registration of pulse, ECG and other physiological signals.

Biology

AQUARIUS – provided a ride into space for embryos and tadpoles of two amphibic species, Xenopus frogs and Pleurodelus salamanders, to anlyse the development of their graviperceptive organs. Their swimming behaviour in space was filmed and the data gathered will be evaluated, also with the help of school children. In a third experiment, yeast cultures were grown in space and analysed after return to Earth.

Earth observation

Lightning and Sprites Observations (LSO) – intended to clarify the nature of puzzling light emissions in the upper layers of thunderstorm clouds by observation from the ISS.

IMEDIAS – an Earth-observation experiment that will complement satellite observations with digital photographs taken by astronauts of specific problem areas on Earth where desertification, deforestation, and other processes are occurring.

Physical sciences

GCF Protein Crystallisation – made use of weightlessness to grow larger-than-on-Earth protein crystals for later X-ray diffraction analysis.

PKE – the Plasma Kristall Experiment – is a German-French-Russian collaboration to investigate the surprisingly ordered structures that micro-sized particles ('dust') show when left in a plasma without the influence of uncompensated gravity. One of the first active experiments to be conducted onboard the ISS, it opened the laboratory in space to a new group of researchers in fundamental physics.

Technology, operational aspects

SPICA-S – assessed the influence that the radiation environment inside the ISS has on electronic components by exposing such equipment and documenting its functioning.

EAC – the European Astronaut Centre's set of experiments provided a pouch container

('Mirsupio') for in-orbit use, to contain in weightlessness small objects that would otherwise behave rather like a bag of fleas. With the help of medical questionnaires, the astronauts' mood changes and sleep quality were assessed, which are important indicators of stress and the astronauts' ability to cope with the demanding work day.

Education

As the mother of a four-year old daughter, Claudie especially wanted to address children and their curiosity when demonstrating the environment of the Space Station and the effects of weightlessness. Her message was communicated in live television transmissions and interviews to various venues where young people had been assembled to learn more about space and its exploration. This also involved active participation by the children and students in the evaluation of some of the experiments, for example AQUARIUS with the yeast and the tadpoles.

Special events

In a series of television links with the ISS, the political and international dimensions of this great space endeavour were highlighted. France's political support for and interest in the mission were well demonstrated in TV links and interviews with Claudie. A link with the highest representatives of the European Union culminated in the presentation of a floating 1 Euro coin, serving as visible proof of the growing unity within Europe.

The renowned Spanish 'Prince of Asturias Award 2001 for International Relations' had been bestowed on the ISS, its crews and the ISS Partners. On the occasion of the award ceremony, the ISS crew were linked by TV with an assembly of the highest representatives of the Partner Agencies who had accepted an invitation from HRH Prince Felipe to visit Spain. A moving moment was the farewell call from NASA Administrator Daniel Goldin before giving up his post in November. All in all, Claudie, NASA Station Commander Frank Culbertson, and the whole crew proved to be excellent ambassadors for the peaceful ideals for which the ISS stands.

Help from the ground for the crew

The ISS already in the current state of its build-up is a complex machine, too complicated to be run solely by a three person crew, even given enough training time. So two Control Centres, the MCC at JSC, Houston, and the TsUP in Moscow are constantly in contact with the crew to provide planning, advice and decision support. The initial planning is refined on a daily basis and sent to the Space Station each evening for the following day's activities. All involved participate via station-to-ground links in two planning conferences per day. Communication with the prime control centre (MCC) is via the TDRSS relay satellites. During passes over Russian territory, the ground stations there can also be used with the help of VHF radio. The French project group at TsUP, including the European astronaut Reinhold Ewald serving as one of the French crew interface persons, had the opportunity to assist Claudie and guide her through difficult parts of the programme, at her request.

Figure 6. Working together in a concentrated way was the key to mission success; here Claudie (left) and her Russian colleague Konstantin Koseev are in the ISS Service Module

A group of scientists had gathered at TsUP to run reference experiments and were eagerly awaiting the data from space. Another group with supporting staff at the CNES User Support Centre (CADMOS) in Toulouse received voice, video and data through permanent lines leased for the duration of the mission. At the MCC in Houston another European astronaut, Michel Tognini, took over as NASA CapCom when the normal workday was coming to an end in Moscow.

Crew medical support during the mission

Soon after Claudie Haigneré had been assigned as a crew member to the Andromède mission, the ESA Crew Medical Support Office at EAC assigned a team consisting of a Flight Surgeon and a Biomedical Engineer to support her throughout all phases of the mission.

The Flight Surgeon, who is responsible for dealing with all mission-related medical issues, supports the medical examination and certification process, monitors potentially hazardous training, supports the launch and landing on site, provides in-flight support from the medical console in the Control Centre, and supports the post-flight rehabilitation process. The Biomedical Engineer is responsible for all

Figure 7. Floating inside the ISS from one job to another. A lot of items have to be unstored, restored, and handled, with the help of the 'Mirsupio' bag for small items

technical aspects related to medical support, and also assists the Flight Surgeon where necessary.

The medical support began with the preparations for the first Russian State Medical Commission meeting, which grants the certification necessary for the cosmonauts to enter training. This initial certification was followed by periodic examinations and some other, more extensive, investigations. Together, the results of these examinations contribute to the final certification for space flight, which is granted via another meeting just prior to the flight and can be considered the final 'go for launch!'

Another of the Flight Surgeon's tasks is to review the scientific protocols and to identify potential inconveniences due to time constraints, stresses induced by the design of equipment, and the level and intensity of the workload. For Claudie's mission, this was done in close cooperation with the EAC Crew Safety Officer. Recommendations were forwarded to the ESA Medical Board for final review and approval.

Testing of operational tools

The Biomedical Engineer had also coordinated the development of operational software dedicated to in-flight crew-operation support known as the 'Medical and Private Instruments Tool' (MaPIT). This tool has integrated medical-operation-specific and off-the-shelf software, allowing easy adaptation to the specific wishes of each crew member whilst still handling the data involved privately and securely. After a series of rigorous tests, MaPIT successfully passed the final-acceptance criteria of RKK Energia.

EAC provided Claudie with the 'Mirsupio', a general-purpose wearable bag for stowage and transport of equipment, consumables, tools and personal items. In coordination with the Andromède management and the NASA Astronaut Office, EAC also provided her with private in-flight e-mail access.

Figure 8. Safely back on Earth in the Steppes of Kazakhstan

Support from launch to landing

After supporting the launch campaign in Baikonur, the Flight Surgeon moved to the Moscow Control Centre (TsUP) to provide in-flight support. The ESA team had access to a TsUP console and stood ready to respond to any onboard medical problem, in close cooperation with the Russian medical team. At this time, the Biomedical Engineer was located at the CNES User Support Centre, where he was on standby to resolve technical issues in support of the crew member and/or the Flight Surgeon.

For the landing, the ESA Flight Surgeon flew back to Kazakhstan, to assist Claudie as soon as she emerged from the Soyuz capsule. After a quick medical check, she was flown by helicopter to the nearest airport, Karaganda. During the immediate post-flight period, an astronaut has to readapt to living on Earth, which usually involves a short rehabilitation programme. Due to the short duration of the Andromède mission, one week was sufficient for Claudie in this respect.

ISS: Columbus

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In 2001, a total of 13 assembly and logistic flights to the ISS were made, using both Russian launchers and the Space Shuttle, including flights of the first European astronauts, payloads and Multi-Purpose Logistics Modules (MPLMs). Several US, Russian and Canadian elements have already been assembled in orbit (Fig. 1) and the fourth Expedition Crew is currently onboard. The cornerstone of ESA's contribution to this enormous international undertaking in space is the Columbus laboratory.

On 27 September 2001, the Columbus flight unit arrived at the premises of ESA's industrial prime contractor Astrium in Bremen, Germany. Final integration of the module is now nearly complete and functional qualification and acceptance testing is about to start. This article summarises the characteristics and functional architecture of Columbus, its development, integration and test approach, as well as today's qualification status.

Introduction

The Columbus laboratory is the cornerstone of ESA's contribution to the International Space Station (ISS; Fig. 2). It is a permanently attached, pressurised laboratory allowing astronauts to work in a comfortable and safe environment (Fig. 3). Columbus will support very sophisticated research in weightlessness for at least 10 years by providing accommodation for experiments in the life and physical sciences, space science, Earth observation, and technology domains.

After completion of the flight-unit mechanical integration phase in Turin, the Pre-integrated Columbus Assembly (PICA) was delivered to the prime contractor's premises in Bremen on

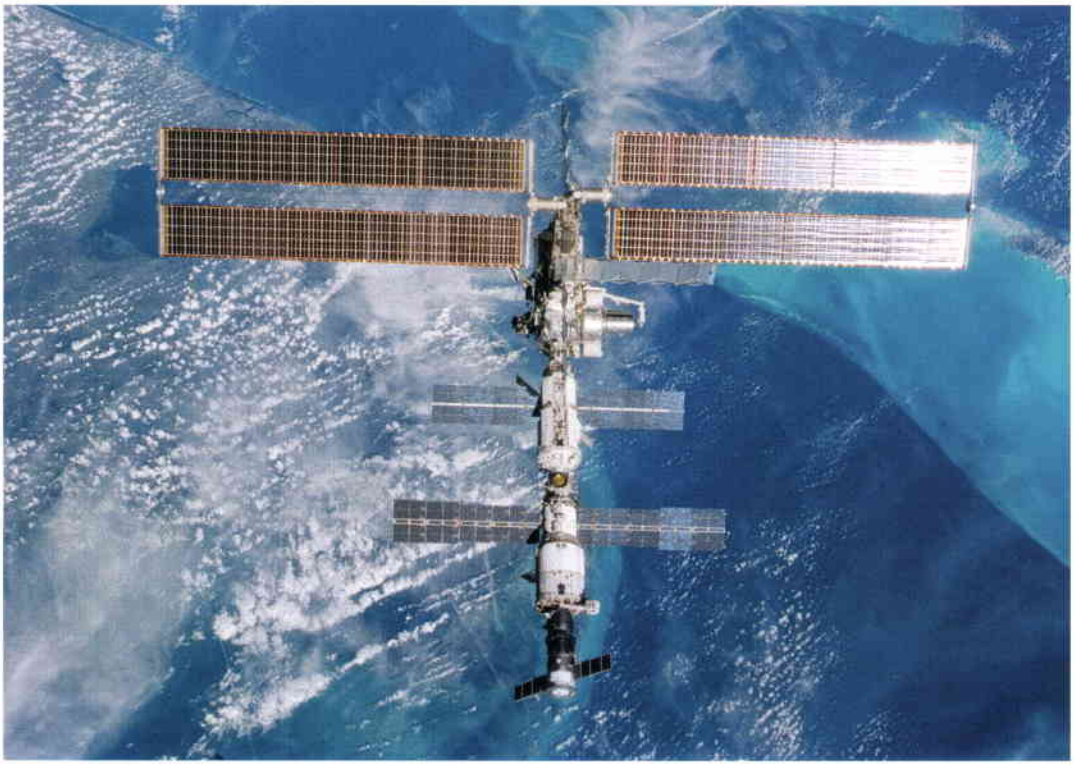

Figure 1.
Appearance of the ISS by December 2001. (NASA)

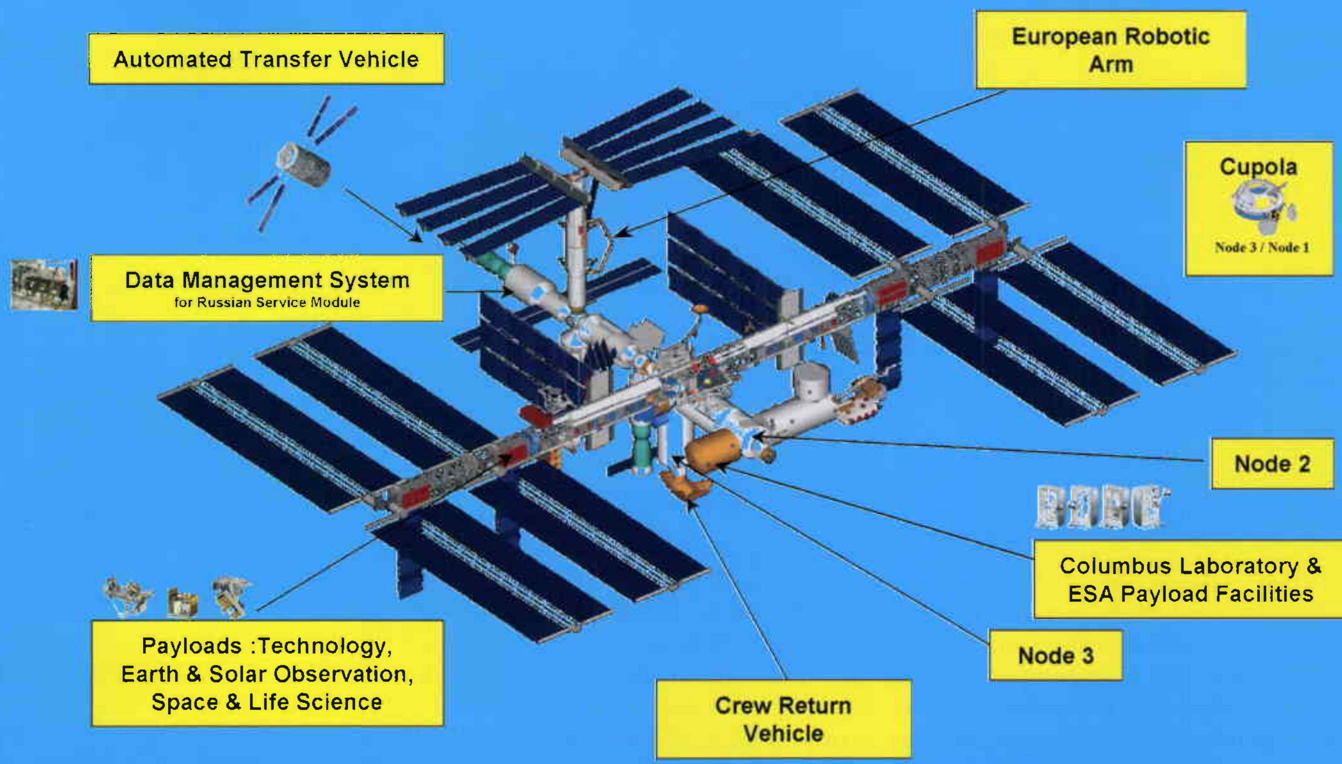

Figure 2. ESA's contributions to the ISS.

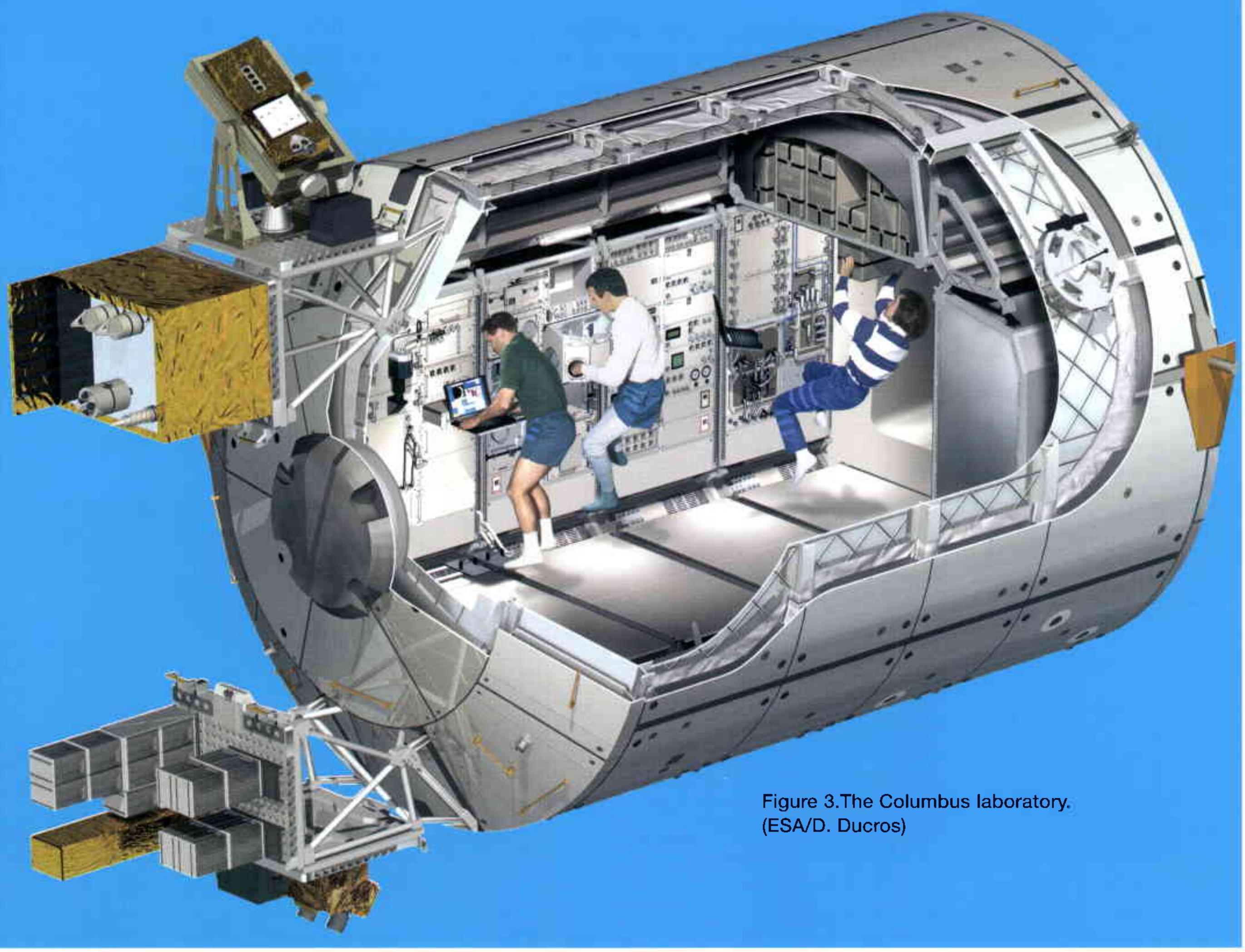

Figure 3.The Columbus laboratory. (ESA/D. Ducros)

27 September 2001 (Figs. 4–6). Flight-unit final integration will be completed by early 2002 and final system functional testing will then start, bringing Columbus a major step closer to being ready for its journey into orbit.

Columbus characteristics

The purpose of Columbus is to support experiments and payload operations once attached to the International Space Station. It therefore provides internal payload accommodation. In addition, the External Payload Facility (EPF) provides four payload platforms for experiments, which are directly exposed to space. Although it is physically the Station's smallest laboratory module, it provides the same payload volume, power, data retrieval, vacuum/venting services, etc. as the others (Table 1). This could only be achieved by careful utilisation of the available volume and high equipment packaging density.

The Columbus laboratory has a 4.2 m-diameter cylindrical section closed with welded end-cones, with a total length of 8 m, including the EPF, and weighing about 10.2 t without research equipment. The module has a pressurised habitable volume about 6.1 m long. The laboratory's total volume is about 75 m^3, of which about 25 m^3 is the working habitable volume when all racks are installed. It will be attached to the ESA-provided interconnecting Node-2 via the module's Common Berthing Mechanism (CBM).

Inside Columbus, the laboratory racks are arranged around the circumference of the cylindrical section to provide the working

Figure 4. The Columbus flight unit being unloaded from its Beluga transporter at Bremen airport, on 27 September 2001. The servicer attached to the transport container provided atmospheric control.

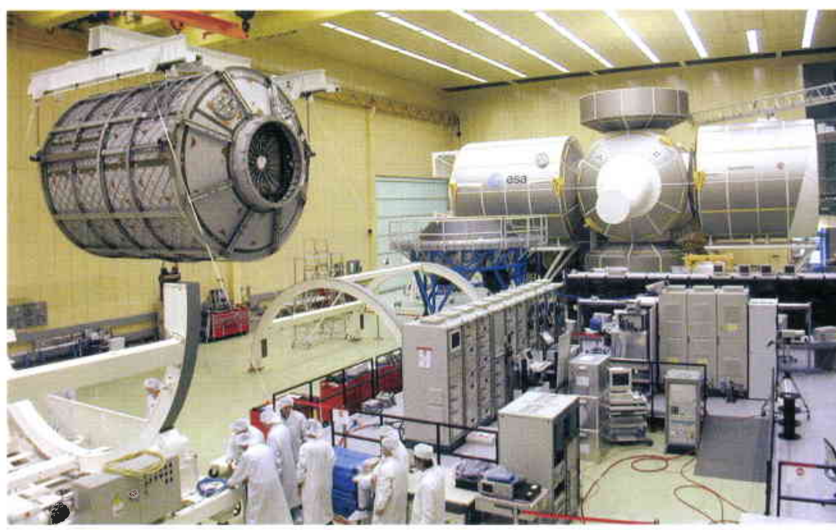

Figure 5. Columbus being moved to its integration stand in the prime contractor's integration hall. The ISS mock-up in the background includes Columbus and the Japanese Experiment Module, both attached to Node-2. The dark cabinets in front of the mock-up are the ETM racks, the lighter ones are the EGSE racks.

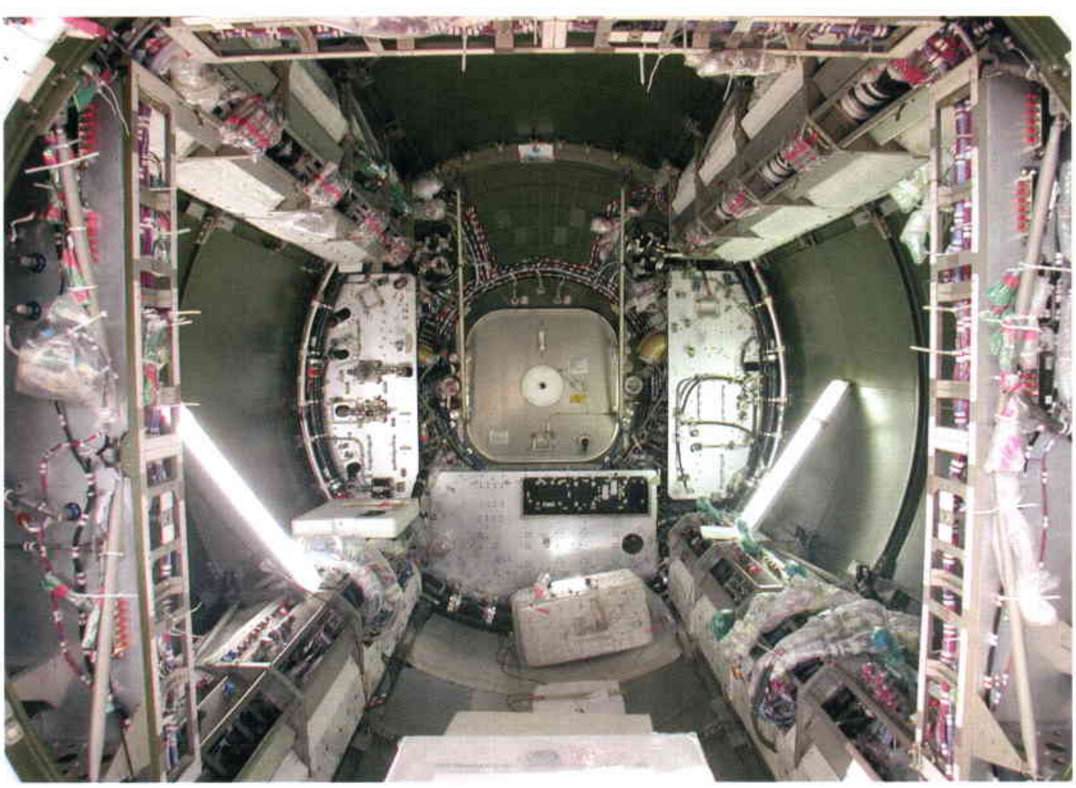

Figure 6. The Columbus interior as completed in Turin.

Table 1. Columbus payload resources

Total Resources	Internal	External	Remarks
Location:	- 10 active ISPRs - 3 Stowage ISPRs - Centre aisle	- 4 interface planes pointing to zenith, nadir & flight direction	8 lateral rack positions support Active Rack Isolation System. Functional resources from Standard Utility Panels.
Mass: - 2500 kg at launch - 10160 kg on-orbit	- 2500 kg at launch - 9000 kg on-orbit	- 0 kg at launch - 4 x 290 kg on-orbit	
Electrical Power: - 13.5 kW total - 120 Vdc	- 5 x 6kW ISPRs - 5 x 3kW ISPRs - 3 x 1.2kW Standard Utility Panels	- 2 x 1.25kW per external payload location	Overall total during mission depends on power availability from ISS. 1.2kW Auxiliary Power also available for each rack.
Cooling:	- 1 water cooling loop per active ISPR	- Passive cooling	
Data Management: - 1 dedicated payload computer - Crew interfaces by laptop - Columbus payload bus (MIL-STD-1553) - US payload bus (MIL-STD-1553) - Columbus Local Area Network (Ethernet) - American Local Area Network (Ethernet)	- 1 cold redundant per ISPR - 1 cold redundant per active ISPR - 1 cold redundant per active ISPR - 1 cold redundant per active ISPR	- 1 cold redundant per interface plane for Columbus or American bus - 1 cold redundant per interface plane for Columbus or American Local Area Network - Analogue/discrete inputs/outputs	- Telemetry and telecommand links to/from ground via ISS S-band systems - For monitoring and control of external payloads, and commanding of ISPRs
Video: - Video distribution (National Television System Committee), compression (Motion Picture Experts Group) and transmission to ground - Video recording - Video monitoring - Video cameras	- 2 interfaces per active ISPR	- N/A	either for video or high-rate data transmission.
Data: - Multiplexing and downlink (up to 43 Mbits/s via Space Station Manned Base and/ or Japanese Experiment Module - in steps of 0.5 Mbps) **High Rate Data:** - 2 Fibre Optic directly connected to the Space Station Manned Base (each active rack location) for high rate data transmission (generally used by American racks)	- 2 interfaces per active ISPR	- 2 cold redundant per interface plane	- Fibre optics interface at ISPR, electrical interface at the Columbus External Payload Facility.
Vacuum & Venting: - Vacuum line - Venting line	- 1 per lateral ISPR (x8) - 1 per active ISPR (x10)	- N/A - N/A	- < 2.28×10^{-6} bar
Nitrogen Supply:	- 1 per active ISPR (x10)	- N/A	

ISPR: International Standard Payload Rack N/A: not applicable

environment for up to three astronauts. A total of 13 racks are available for payloads, of which 10 are completely outfitted with payload resources and 3 provide passive stowage accommodation. System equipment that requires undisturbed crew viewing and handling access, such as video monitors and cameras, switching panels, audio terminals and fire extinguishers, is located on the starboard cone. The remainder of the system equipment is housed in the rest of the end-cone areas and in three of the deck (floor) racks.

Columbus will be carried to the ISS by the Space Shuttle Orbiter. A Station-common grapple fixture will allow the Station's Remote Manipulator System (SSRMS) to lift Columbus out of the Shuttle Orbiter and attach it at its final location on ISS Node-2. Columbus will be launched with up to 2500 kg of payload already in place in its payload racks, which will be complemented and/or reconfigured in orbit by later launches of additional racks. The external payloads will be installed in orbit, using the SSRMS, as standardised packages interfacing with the External Payload Facility.

Functional architecture

Columbus is a manned laboratory and is therefore equipped with an Environmental Control and Life Support (ECLS) subsystem, as well as man/machine interface provisions. Air circulation fans continuously take fresh air from Node-2, pass it into the crew cabin for ventilation and then back to the Node for refreshing and carbon-dioxide removal. Air content is monitored for contamination from the systems or payloads. The Columbus active thermal control is via a water loop, connected to the ISS centralised heat-rejection system via interloop heat exchangers. An additional air/ water heat exchanger removes condensation from the cabin air. The crew can control both temperature and humidity.

All safety-related parameters of the system and payloads are monitored and controlled by a redundant set of computers (VTCs), which alert the Station in the event of a problem occurring onboard Columbus. Both audio and visual warnings are given to the crew, and laptop interfaces allow the astronauts to 'safe' the module from any location in the Station via the ISS command and control data bus.

Non-safety-related system and payload data are generated and distributed by the Columbus Data Management System (DMS) – a series of computers and other electronic equipment, connected to the data busses and Ethernet local-area network. The DMS is the basis of the Columbus onboard software. It is extended by laptop applications and automated flight procedures to provide end-to-end system functions.

As mentioned earlier, the crew interfaces via laptops, which can be plugged into the system at many locations inside the Station.

Power for the complete Station is generated centrally by large solar wings and routed to all Station users. Inside Columbus, the power goes through the Power Distribution Unit (PDU) and from there to all payload racks, external platform locations, centre-aisle standard utility panels and subsystems.

All data collected onboard Columbus, including housekeeping, low- and high-rate payload and video data, are multiplexed and then routed through the Station to the ground control centres, either via NASA's Tracking & Data Relay Satellite System (TDRSS) or the Japanese Experiment Module and related links.

The Columbus Control Centre, a facility at the German Space Operations Centre (GSOC) in Oberpfaffenhofen, further transmits the data to de-centralised User Centres, which will have direct access to the payloads under their responsibility. In addition to handling the command and control of the module, the Columbus Control Centre will coordinate the planning and timelining of all Columbus orbital activities and will provide the real-time operational decision making.

Columbus development, integration and testing

The Columbus development, integration and test programme has a hybrid approach. The classical project review system of design, qualification and acceptance reviews are based on lower level reviews. The model philosophy at the unit level ranges from dedicated qualification units to the protoflight approach, depending on the complexity of the items. Several units common to other projects have been adopted without further qualification, after demonstration that they meet or exceed the Columbus requirements. Qualification of commercial equipment required more stringent environmental criteria to compensate for the uncertainties of the reduced design and manufacturing transparency.

A system-level engineering model as such does not exist. Columbus functional qualification is performed on the Electrical Test Model (ETM) and/or on the Protoflight Model (PFM), supplemented by analyses and best demonstrations on various mock-ups:

Electrical Test Model

The ETM is functionally identical to the Columbus flight unit for avionics and software items, and includes the complete power-distribution and data-management system. All avionics units are represented by their engineering models. These are identical to the flight models in terms of physical and functional design, differing only in their detailed manufacturing processes and parts quality. A dynamic simulation of the liquid-cooling and cabin-air loops complements the functionality of the ETM. The latter does not contain representative primary or secondary structures, and does not represent the module physically, but includes a fully representative set of power equipment and data harnesses, which are mounted in standard racks for easy access, and all onboard software.

The other Columbus system items are simulated, so that all system functions can be exercised and used for troubleshooting in parallel with the flight-model assembly, integration and test. In order to ensure end-to-end testing, the ETM is functionally attached to specific Ground Support Equipment (GSE), which simulates the ISS and payload-interface provisions.

After completion of the ETM testing, the model will be extended to become the Rack Level Test Facility (RLTF), by adding flight-identical mechanical and thermal interfaces and thereby providing all of the features required to test the payload interfaces under realistic conditions. Any future payload complement can then also be tested during the lifetime of Columbus to generate a realistic in-orbit operating scenario for the payload under test. For those payloads that will be launched within Columbus, this testing will be done before their integration into the Columbus flight configuration.

Protoflight Model
All remaining functional qualification activities that could not be performed on the Columbus ETM will be performed on the PFM. These include those requirements that need the complete physical system configuration, such as electromagnetic susceptibility, internal noise, microgravity disturbance and overall contamination levels.

Mock-ups
Mechanical mock-ups of relevant parts of the module were used in the early stages of the programme to assess several aspects of the laboratory's design, including its accessibility and maintainability (1g mock-up demonstrations). Later in the programme, a complete Columbus 'zero-gravity' mock-up has been used to verify in-orbit maintenance procedures, such as the replacement of functional units and local repair of the structure and harness, both from inside and outside the module, while complying with specific ergonomic and human-factor requirements.

Structure
Structural launch environment qualification has been achieved by analytical extrapolation of the full-scale tests performed on the ASI MPLM, from which the Columbus primary structure was derived. This analysis has been backed-up by a dedicated Columbus modal-survey test.

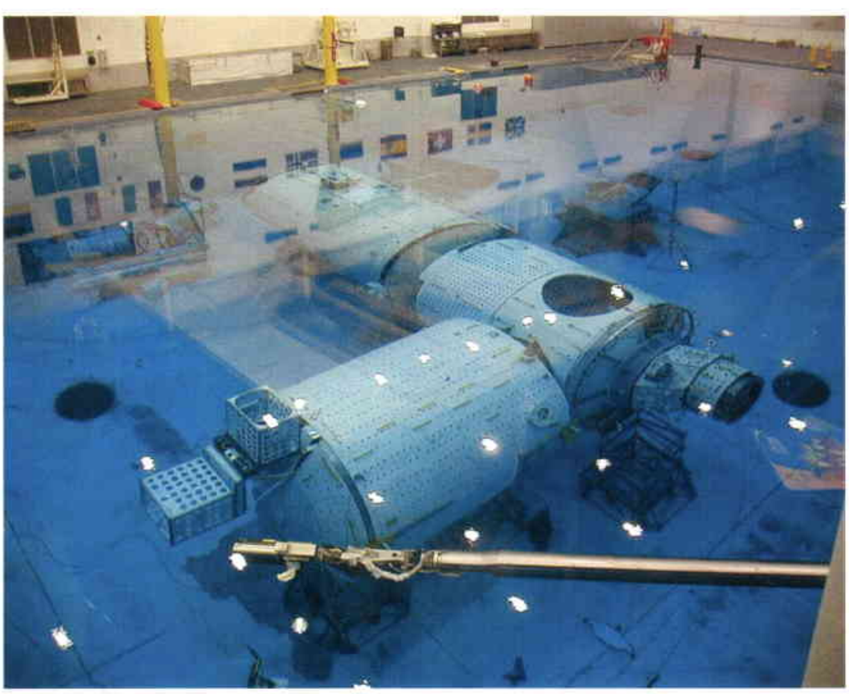

Figure 7. Columbus mock-up attached to Node-2 mock-up in the pool of NASA/JSC's Neutral Buoyancy Laboratory, where zero-gravity verification of external operations (EVA) has been performed. (NASA)

Training
In order to support the training of all ISS astronauts for Columbus throughout its operational phase, the Columbus Crew Trainer has been developed. Mechanically speaking, it represents the physical interior of Columbus and simulates its functional characteristics. One Crew Trainer is now at the European Astronaut Centre (EAC) in Cologne, and a second one forms part of the Space Station Training Facility (SSTF) at NASA's Johnson Space Center (NASA/JSC) in Houston.

A facility simulating the complete ISS onboard avionics system for trouble-shooting and change evaluation (e.g. software upgrades) across all element interfaces during the Station's operational phase is available at NASA/JSC. This facility is being extended as new elements are attached on board the ISS. The Columbus Software Verification Facility (SVF) is a functional simulator, which is being developed for integration into this overall ISS simulation facility.

Flight-unit integration and qualification
Following the successful Columbus Critical Design Review (CDR) in December 2000, flight-unit assembly, integration and test was released. Several requirements had already been verified by then, among which were the following:
- Cabin ventilation was verified in February 1999 on a mock-up of the Columbus interior, using the fans and ducting hardware.
- Fire-suppression qualification tests were conducted in March 1999 on mechanical mock-ups of the relevant areas.
- The environmental- and thermal-control systems were qualified in 1999 and 2000, using a fluid-loop breadboard equipped with the engineering models of the related assemblies.
- A mechanical mock-up was used at Alenia in Turin (I) to demonstrate and qualify in-orbit maintenance procedures under 1g. Another mock-up was used for the first zero-gravity verification of internal operations, which was performed in a water tank at Alenia with the support of ESA and NASA astronauts. They also supported the final zero-gravity verification of external operations, including ergonomics and human-factor requirements verification, performed in 2000 at the Neutral Buoyancy Laboratory at NASA/JSC (Fig. 7), which demonstrated the ability to perform Extra Vehicular Activity (EVA) servicing.

- The primary and secondary structures had been qualified in 2000 by pressure/leakage and modal-survey tests to verify pressure integrity requirements, as well as the finite-element model.
- Tests performed continuously on the ETM in Bremen helped to identify early and to resolve any compatibility problems and deficiencies.
- The first test jointly performed with NASA and the ISS prime contractor Boeing on data-communications exchange between Columbus and the rest of the ISS was successfully completed in June 2001.

The Columbus flight-unit integration began at Alenia Spazio's premises in Turin in March 2001 with the integration of the PICA (pre-integration phase), which comprises all mechanical items, such as:
- primary and secondary structures
- thermal-control system (TCS) and environmental control & life-support system (ECLS) equipment
- harness, ducting and plumbing
- illumination, crew support equipment, and
- external protection like multi-layer insulation and micrometeoroid and debris-protection items.

With the delivery of the Pre-integrated Columbus Assembly (PICA) on 27 September 2001 to Astrium's premises in Bremen, a major milestone in the development of the Columbus laboratory was achieved. Flight-unit final integration has started there, with Astrium currently integrating all functional elements into the Columbus module, including:
- power distribution units
- communications equipment (including video and audio communication)
- data-management equipment, and
- flight-application software.

The Columbus module will then be ready for functional qualification and acceptance testing, once the module's ISS interfaces have been attached to the relevant ground-support equipment:
- Electrical Ground-Support Equipment (EGSE) will provide resources for power and data exchange.
- Fluid and Gas Support Equipment (FGSE) will provide basic resources for cooling, gas and air supply.

The flight model of Columbus is planned to be powered-up for the first time in February 2002.

The ETM test campaign has been underway for over a year and will continue in parallel with the PFM test campaign. The following tests will be executed on the flight model:
- All system functions, including activation/deactivation of the subsystems.
- Hardware/software compatibility test, which will require the greatest effort. This test will include certification of the Mission Database contents, which includes onboard and ground software and all data used to configure the software, such as sensor information, command definition, downlink telemetry packet definition and event messages.
- Mission simulation test, which will require a similar effort in operating the system under flight-operations conditions.
- All systems will be verified for compliance with the specified electromagnetic environment.
- Several tests will be performed jointly with NASA and the ISS prime contractor Boeing to ensure full ISS compatibility.
- System tests for thermal and environmental control, audible noise and microgravity attenuation, offgassing characterisation of the module's interior, and illumination of the crew compartment.

A particular feature of the Columbus development programme is the involvement of ESA astronauts as part of the project team. Pedro Duque has been a member of the design team for several years, participating in the Critical Design Review, Neutral Buoyancy Test, mock-up demonstrations and functional tests. Thomas Reiter is co-located in Bremen for familiarity training. Their involvement has resulted in a design that should be crew-friendly, and provides productive on-the-job training for the astronauts involved.

Conclusion

Acceptance of the Columbus laboratory flight model from the prime contractor will take place in two steps. The first step is to certify that the Columbus system meets its system requirements, including external interface requirements, without the payload facilities having been integrated. The second step is to authorise shipment of the integrated Columbus, including payloads, to the launch site in Florida, once the payload facilities have been installed and successfully tested for compatibility with the module. Columbus will then be shipped to NASA's Kennedy Space Centre (KSC) for pre-launch processing. Final acceptance for flight will be achieved in conjunction with the NASA ISS and Shuttle programmes, and will include confirmation of the readiness of the associated Ground Segment, including the Columbus Control Centre.

The Columbus laboratory's launch is currently scheduled for October 2004.


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The ESA Laboratory Support Equipment for the ISS

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The Laboratory Support Equipment (LSE) for the International Space Station (ISS) is a suite of general-purpose items that will be available onboard the Station either as self-standing facilities or as equipment that can be used at defined locations. Dedicated to supporting system maintenance and payload operations, some LSE items are derived from commercial equipment, while others have been specifically developed for the ISS.

ESA is currently engaged in developing three pressurised facilities and one pointing mechanism that will become part of the LSE complement, namely:
- **the Minus Eighty degree centigrade Laboratory Freezer for the ISS (MELFI)**
- **the Microgravity Science Glovebox (MSG)**
- **the cryogenic storage and quick/snap freezer system (Cryosystem)**
- **the external-payload pointing system (Hexapod).**

Introduction

The LSE programme was started at ESA in 1994 following the finalisation of the Agreement in Principle for ISS Early Utilisation, which was subsequently translated into a Memorandum of Understanding (MOU) in 1997. According to this Agreement, NASA provides ESA with flight opportunities and resources for accessing the ISS before the ESA Columbus module is launched. In exchange, ESA provides NASA with goods and services. This includes the development and delivery of the two pressurised facilities – MELFI and MSG – and the external payload pointing mechanism – Hexapod.

Later, the LSE programme was extended to include the development of another pressurised facility – the Cryosystem – as well as the sustaining engineering for MELFI, MSG and Cryosystem. Those additional items were introduced with the ESA/NASA Arrangement for the Columbus Laboratory Launch, signed in 1997. In the same year, an MOU was signed between ESA and NASDA whereby NASDA provides ESA with twelve ISS Standard Payload Racks (ISPR). In return, ESA provides NASDA with a MELFI unit, identical to those to be delivered to NASA.

In addition, the LSE programme includes the development of general payload Ground Support Equipment (GSE), such as the Test Equipment for Payload Development (TEPAD), originally developed for supporting the LSE facilities, but now available as ISS interface simulators for the development of any pressurised payload (Fig. 1).

From 1994 onwards, the LSE programme established and has maintained programmatic and technical interfaces with the NASA ISS Payload Office and the NASDA Payload Organization, as well as with the NASA centres responsible for the various disciplines, which include Marshall Space Center (MSFC) Microgravity Program Office, the Johnson Space Center (JSC) Environmental Control Department, the Ames Research Center (ARC) Life Science Program Office, and the Langley

Research Center (LaRC) Earth Observation Missions Office.

As result of this activity, Joint Implementation Plans for all the projects have been established and put under the control of the Multi-lateral Payload Control Board (MPCB).

The LSE development programme

The four LSE projects are currently at different stages of implementation:
- MELFI and MSG have completed their design and development phases. MSG was delivered to NASA in October, and MELFI will be shipped in March 2002.
- Hexapod is in the final stages of development, with delivery to NASA foreseen for mid-2002.
- Cryosystem has been undergoing basic scientific and utilisation requirement assessments, before starting the preliminary design phase (Phase-B) at the beginning of February.

The same general development philosophy has been adopted for the first three projects. The Phase-B, which lasted about two years, has included the development of breadboards of the most critical equipment and assemblies and has demonstrated basic functional performance. The main development phase (Phase-C/D) was started in October 1996 for MELFI and MSG, and in January 1998 for Hexapod.

Many technical challenges have been encountered during the development of the first three payloads:
- they were among the very first to be designed for the ISS, for an environment and payload infrastructure that were not yet settled
- the ten-year-lifetime and in-orbit-maintenance design requirements for the two pressurised facilities were important novelties, and the design was heavily driven by those requirements
- the MELFI development included a significant effort for the preparation of the two key technologies on which the freezer's design was based, namely the Brayton turbo-compressor cooler and the super-vacuum thermal insulation; significant breadboarding and qualification effort was accomplished without exceeding the restricted financing available
- the MSG, as the first user of the European Standard Payload Outfitting Equipment (SPOE), had to adjust to the contemporary development of those items and at the same time serve as the test bed for their development
- the not yet settled ISS environment for the external payload rendered the development of the Hexapod external interfaces both difficult and risky; only the good technical coordination between the NASA and ESA project teams has allowed progress to be made in the development activities.

Ground models have been produced for MELFI and MSG to support the science-procedure preparation and crew-training activities. In addition, engineering models for each facility have supported the development activities and will be available for the sustaining engineering during the operational phase. With the design and development of MELFI and MSG, the rack structural design and qualification expertise for the NASDA-provided ISPR has been fully acquired by ESA.

Following the Memorandum of Understanding, NASA will assume ownership of the LSE payloads and will be responsible for their operation, but ESA will have to provide spares and technical support for their maintenance. These activities will be part of the ESA Exploitation Programme, once it is initiated and operational. Due to the time constraints, however, the detailed responsibilities and activities to be performed within the scope of the general LSE programme agreements have already had to be defined and agreed with NASA. After many meetings and discussions, it has been possible to baseline Logistic Support Plans for MELFI, MSG and Cryosystem, which have been accepted by all parties.

Conclusions

Within the ESA LSE programme, the MSG is now integrated into the MPLM ready for an expected launch by May 2002. The MELFI and Hexapod activities will soon be completed in Europe and these items delivered to NASA. The Cryosystem is entering the design phase.

Significant experience has been accumulated with these projects, not least in coping with the many challenges generated by the Inter-Agency Barter Agreement environment in which they are taking place. So far, all of the technical objectives for the individual facilities have been met within the assigned programmatic constraints. This allows us to conclude that the ESA LSE programme has demonstrated the usefulness and practicality of the Inter-Agency Agreements, whereby the participating agencies exchange goods and services without a direct exchange of funds. They have allowed optimal exploitation of the resources available at the various Agencies. Some hard lessons have also been learned, in that the mechanism only works well if the basic requirements – technical and programmatic – and the procedures for handling changes, which are unavoidable when dealing with long-duration projects, are firmly established together with the initial political agreements.

MELFI

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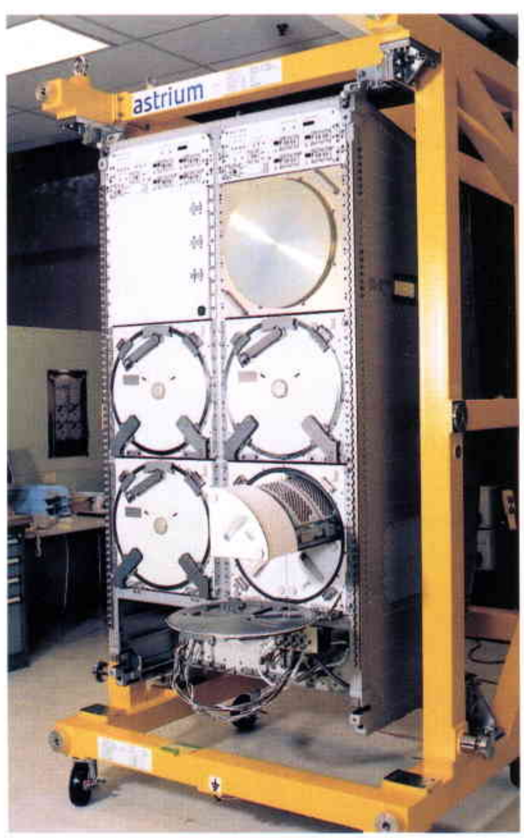
Introduction

The Minus Eighty degree celsius Laboratory Freezer for ISS (MELFI) is a rack-sized facility that will provide the Space Station with a refrigerated volume for the storage and fast freezing of life-science and biological samples (Fig. 1a,b). It will also ensure the safe transportation of conditioned specimens to and from the ISS by flying in fully powered mode in the Multi-Purpose Logistic Module (MPLM) installed in the Shuttle's cargo bay. Continuous operation for up to 24 months is foreseen for each MELFI mission.

MELFI has been developed by the Agency under various Barter Agreements, whereby ESA will deliver three MELFI flight units to NASA and one flight unit to NASDA. In addition, ESA has agreed to deliver certain ground units to NASA and to provide the necessary spares and sustaining engineering to maintain them for up to 10 years of operations.



ESA selected Astrium-Toulouse (formerly Matra Marconi Space) as its prime contractor; the other main sub-contractors participating in the MELFI industrial consortium are:
- Air Liquide (F), for the Brayton subsystem
- Linde AG (D), for the MELFI cold chain
- Kayser-Threde (D), for the electrical subsystem and some rack components
- ETEL (CH), for the motor and motor-drive electronics
- DAMEC (DK), for the utilisation hardware and concept.

After a pre-development Phase-B study, the main development phase (Phase-C/D) began in January 1997. The Preliminary Design Review (PDR) was completed by the end of that year, and the Critical Design Review (CDR) was successfully completed in summer 1999. Staggered verification reviews were completed by February 2002. The Qualification/Acceptance

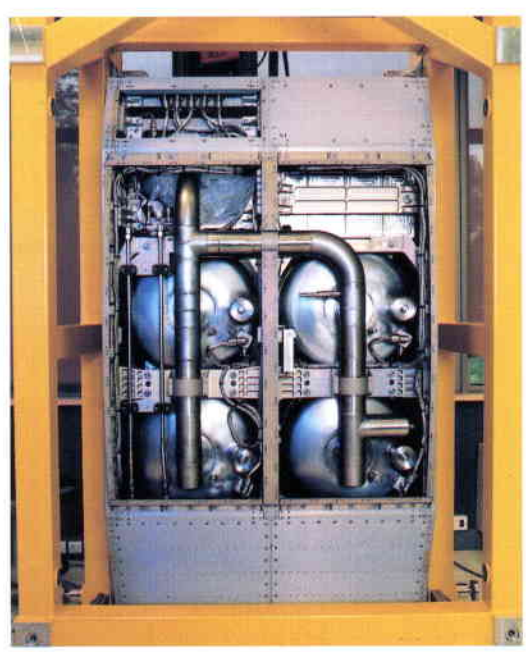


Figure 1. (a) MELFI first flight unit with one dewar door open and a tray partially extracted, and (b) rear of the unit with the cover removed to show the nitrogen piping interfacing with the cold box (upper container) and the four dewars

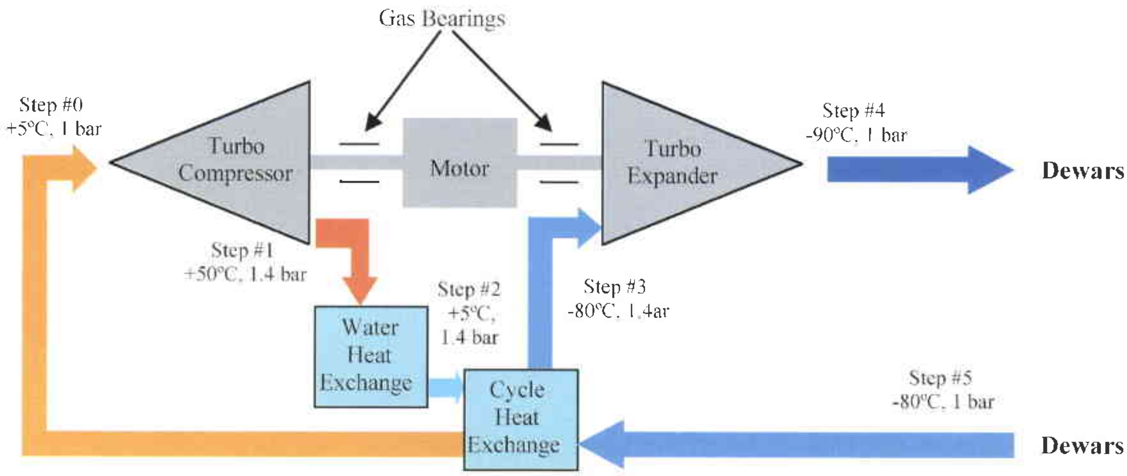


Figure 2. The reverse Brayton thermodynamic cycle

Review in Europe for the first MELFI flight unit will take place in March 2002. The final verification process using the ISS and MPLM simulators located at Kennedy Space Center will start in May 2002. Thereafter, the MELFI first flight unit will be ready for launch in September 2002. It is planned to launch MELFI to the ISS on the ULF-1 flight in January 2003.

The cooling concept

Many trade-off and technology studies were carried out before selecting the cooling concept for MELFI. The key drivers were:

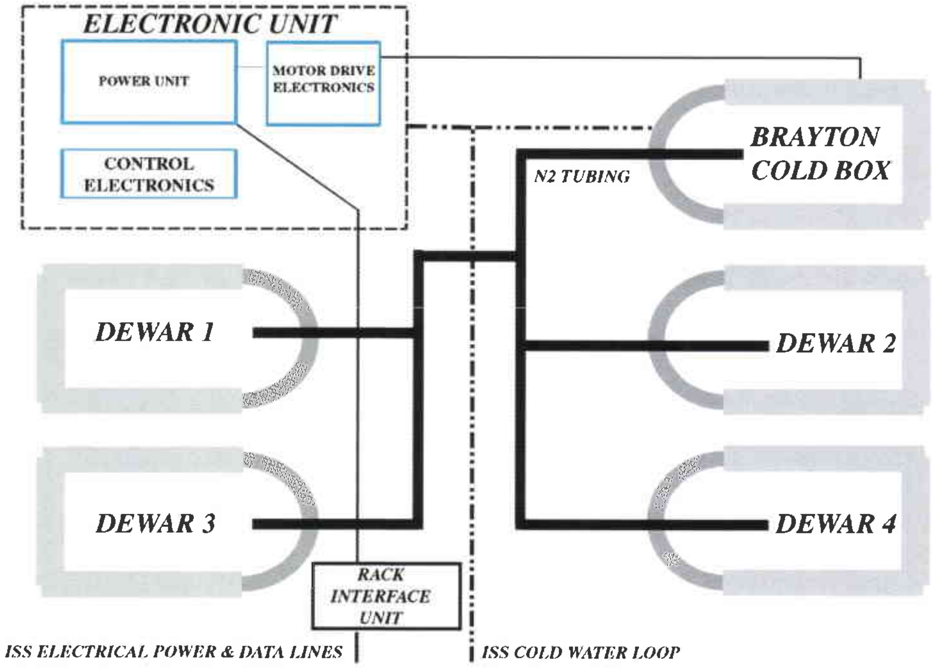
- Low electrical power-budget allocation (900 W) for the size of the cold volume and the low working temperature.
- High reliability (two years of continuous operation) and easy maintenance.
- Very low thermal leaks to cope with a power-off time of 8 hours.
- Very low disturbances to the ISS microgravity environment.
- Very low acoustic-noise requirements.

From the outset, the technology for a –80°C freezer was identified as being very difficult to achieve, involving the development of new and very challenging technologies and/or the major adaptation of existing ones.

At the beginning of the 1990's, and after an extensive trade-off with the Stirling cycle, the reverse Brayton cycle was selected for the cooling thermodynamics. It was chosen mainly for its power efficiency in the temperature range of interest and for the reduced microgravity perturbation, thanks to its being a rotating rather than a linear machine. The cold power production relies on a closed thermodynamic loop, in which nitrogen gas is compressed, cooled and expanded to achieve the low temperatures required (Fig. 2). Depending on the electrical power provided to the Brayton machine, the temperature in the expander (step #4) can reach values as low as –95°C.

The heat is removed from the samples by passive means, i.e. conduction and radiation only. Cooling by forced convection was eliminated during the early stages of the project because fans inside the cold cavity are not reliable (easily blocked by ice), increase electrical power consumption, and generate acoustic noise. Also, it is difficult to produce predictable convection flows to the samples, because the flow depends on the filling status. Natural convection due to gravity effects occurs when MELFI is on the ground, but it has been designed to meet the requirements without convection.

Figure 3. MELFI block diagram



The system and its capabilities

Figure 3 shows the main system components. The cooling engine is a Brayton turbo-machine, which provides the flow of cold nitrogen. The rotating components are the turbo-expander, the compressor and the motor magnet, all of which are integrated onto a single shaft supported on gas bearings. This bearing technology was selected because of its long lifetime and the low-perturbation requirements. Two radial bearings support the shaft close to the compressor and turbine wheels, while one axial bearing carries the axial forces introduced in the shaft by the wheels' aerodynamics. The bearings are made of tungsten carbide to withstand the friction that occurs during the starting and stopping of the shaft. The shaft itself can run at speeds in excess of 90 000 rpm, depending on the cooling energy required. The gap between the static and rotating parts of the bearings is only 10 microns. It is therefore very important to balancing the shaft very precisely, and the gas circulating in the cycle must retain very high levels of cleanliness. The machine is cooled by water running through the motor heat exchanger that surrounds the cartridge.

The Brayton motor relies on brushless and sensorless technology. Brushes are not suitable for the high speed and the long-life requirements, and they generate pollution. The sensorless technology was selected for its robustness in the cold environment and because it allows the very high rotor accelerations required to 'lift' the shaft on the gas bearings after just a few turns. Implementation of this technology proved a major challenge, especially in controlling the motor starting phase.

The heat exchangers needed to implement the Brayton thermodynamic cycle are integrated into a closed container called the Cold Box, into which the Brayton machine is inserted to form an integrated assembly called the Brayton Subsystem. A set of tubes (Fig. 1b) distributes the cold nitrogen to four independent cold cavities (the dewars). The supply and return nitrogen flows are in concentric tubes. The nitrogen tubing provides the cooling power to the dewars in a closed loop (i.e. the nitrogen is not in direct contact with the samples in the dewars), at the so-called 'cold fingers' that house the load heat exchangers. A valve at the tip of each cold finger regulates the nitrogen flow. In this way, the temperature in the dewars can be controlled independently in three operating modes (at -80, -26 and +4°C). The dewars are designed to improve the thermal coupling between the samples and the cold fingers. A battery-driven Temperature Data Recorder (TDR) provides the ability to record the temperature in the dewars when MELFI is not powered. All of the areas where the electronics could dissipate significant amounts of heat are instrumented with thermal switches that control potentially hazardous situations within the ISS (fire protection).

The electrical subsystem provides overall control of the MELFI system and powers the Brayton motor and control electronics (Fig. 4). The freezer's continuous availability is crucial to mission success and it is therefore imperative that failure of any sensitive component be recoverable within the maximum time for which MELFI can protect the samples in passive mode, namely 8 hours. Consequently, the Electronics Unit (EU) and the Brayton machine have been designed as Orbital Replaceable Units (ORU), with spares for each available onboard (Fig. 5).

MELFI is integrated into a six-post aluminium rack provided by NASDA, and manufactured by Japan's Ishikawajima-Harina Heavy Industries. The IHI rack was selected because it was already space-qualified, meets the ISPR mechanical interfaces, and is the only existing rack structure able to carry MELFI's maximum mass of about 800 kg.

Designed for an operational lifetime of 10 years, MELFI has been qualified for 15 launches in the MPLM. It has been basically designed for installation in the US Lab module of the ISS, but efforts are underway to interface it with the Japanese Experiment Module (JEM) also.

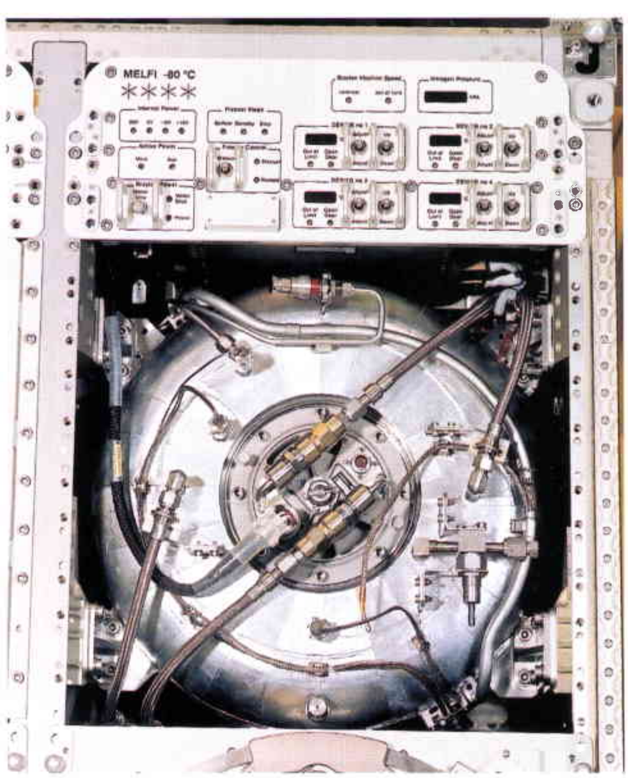
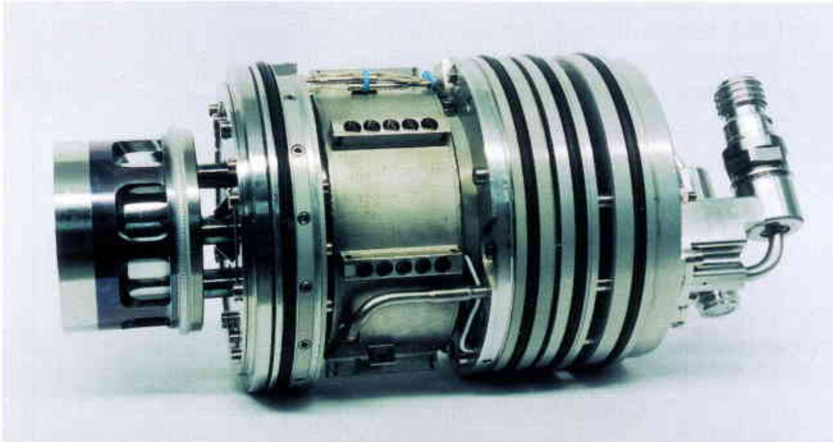


Figure 4. Close-up of the front face of MELFI, showing the active electronic unit control panel (upper right). The spare electronic unit is partially visible to the left of the active one. Below the active electronic unit, the cover plate has been removed to show the Cold Box with the Brayton machine inserted



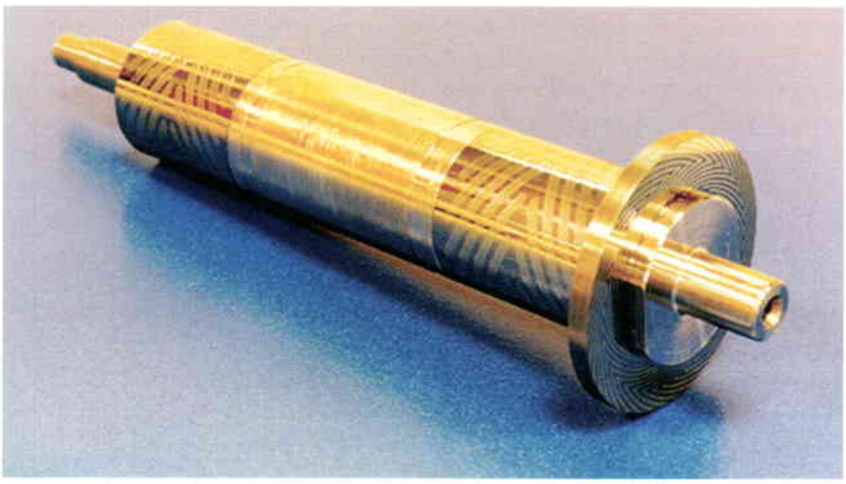
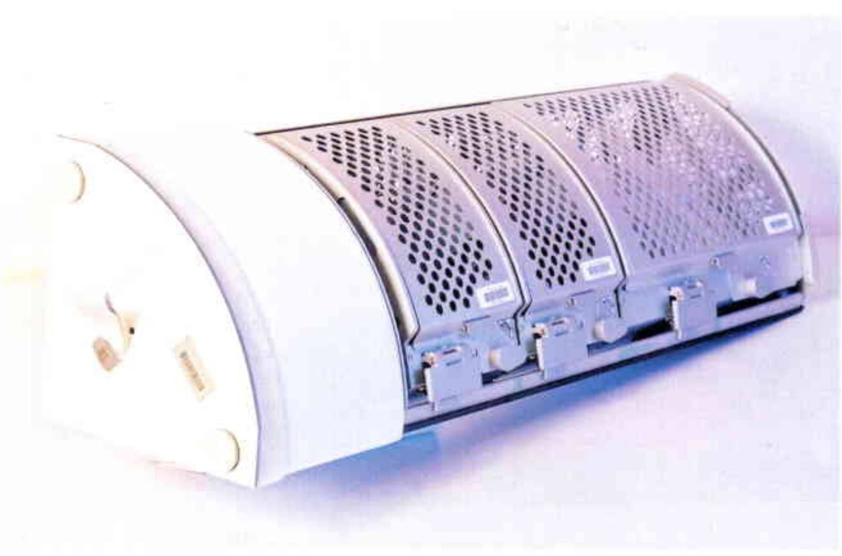


Figure 5. The Brayton machine cartridge (top) and the machine shaft, with compressor and turbine wheels removed to show the radial and axial gas bearings

Figure 6. MELFI tray with the foam insulation block attached to the front of the tray. In this configuration, the tray includes two 1/4-size box modules and one 1/2-size box module

In addition to the four flight units, the project includes the following ground units:
- Laboratory Ground Model (LGM), to be used to support scientific sample accommodation in MELFI and the development of sample integration procedures. This unit is a flight-like stand-alone dewar that includes all the standard sample-accommodation hardware.
- The MELFI Training Unit, which will support active crew training in a flight-like environment.
- The MELFI Engineering Unit, which is a fully integrated rack that will support sustaining-engineering functions.

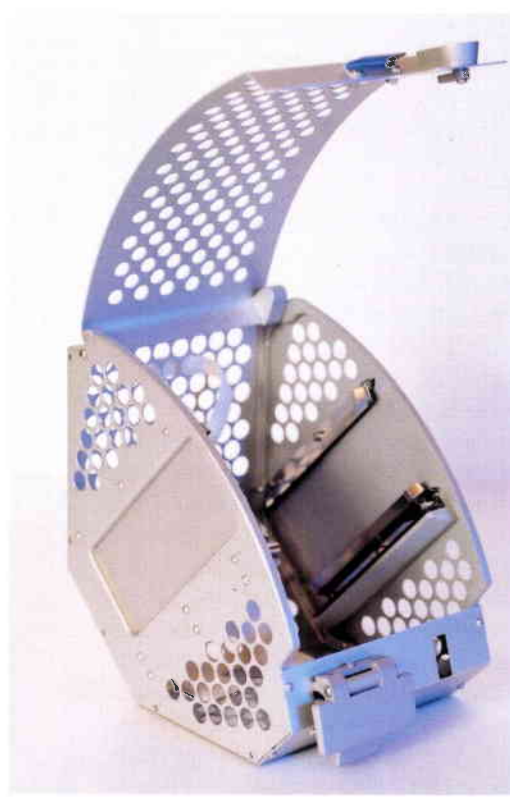


System utilisation

The utilisation of MELFI requires very close co-ordination between the scientists who will conduct the experiments aboard the ISS and the ISS 'cold storage team'. It is important to know well in advance the type of sample, sample container, and cooling and storage requirements, so that the integration of all experiments can be properly planned. The time-lining between the associated experiments and MELFI also has to be correctly co-ordinated.

The utilisation scenario will provide late access to MELFI whilst the Shuttle is on the launch pad. There will also be the possibility to have early access to retrieve the samples once the Shuttle has landed. MELFI provides the necessary ground-support equipment to carry out these operations. In orbit, the samples can be transferred at facility level by exchanging the complete rack, or at tray level by using the MELFI-provided in-orbit transfer bag.

Each dewar includes four trays, each of which can be extracted without disturbing the samples in the other three. In addition, MELFI provides standard accommodation hardware for the insertion of samples of different shapes and sizes (Figs. 6 & 7):
- *Standard vial card:* This card is a flat aluminium plate (10 x 11cm) that can carry vials ranging from 2 to 10 ml in size, and attached by elastic loops. Each card can accommodate up to 20 small vials (10 each side) or 10 large (long) ones (5 each side).



- *Contact cards:* Similar to the standard vial card, but designed to improve the thermal conductivity between the card and the box module, thereby increasing the cooling rate. This card features elastic loops to restrain vials (4 long or 8 small) on one side, and Velcro straps to accommodate irregular shapes (with one flat side) on the other.
- *Standard box modules:* The boxes interface directly to the trays and can store a number of vial cards, vial bags, or any large sample that fits the module. Elastic bands are provided to secure the cards.
- *Receiving box module 1:* This module is identical in size and shape to the standard one, but provides a dedicated interface to hold the Contact Card to improve the thermal conductivity. It also provides a special interface to accommodate 'bottle holders'.
- *Receiving box module 2:* Identical in size and shape to the standard one, it features a solid bottom profile instead of a perforated one for better thermal coupling between the tray, the box module and the inserted samples.

It will be user's responsibility to provide the dedicated accommodation hardware needed for special applications.

In-orbit commissioning

The MELFI system has been fully verified on the ground, with the thermal performances in particular being measured during extensive tests. The cooling performances that will be achieved in orbit have been predicted by analysis, using thermal models correlated during the ground tests. It is necessary to confirm in orbit that those predictions are correct.

In addition to the standard checkout of the general interfacing and system functionality of the MELFI rack, the in-orbit commissioning of the first MELFI flight unit will include verification of the actual cooling performances provided to the samples. For this, ESA has developed the MELFI On-Orbit Commissioning Experiment (MOOCE), which provides additional instrumentation in the dewar cold cavity that holds the scientific samples. MOOCE's 24 thermocouples provide comprehensive temperature mapping of the tray, the box modules and the samples. During the test, the MOOCE's external data-acquisition unit will provide continuous recording and de-multiplexing of the temperature data, which will subsequently be retrieved via the ISS Laptop and the tests results sent to ground using the ISS downlink communication services.

Conclusions

With the MELFI project, ESA and European space industry have jointly developed novel technologies and integrated them into a new space freezer that will provide the scientific community with a large permanent cold-storage facility in space for the first time. The Agency and its MELFI contractors now look forward to contributing their expertise to keeping the MELFI system operational, in order to foster and grow the interest of the scientific community in doing science aboard the ISS in the years to come.

Figure 7. A 1/4-size standard box module full of standard vial cards with frozen samples

Acknowledgement

The success of the MELFI project could not have been achieved without the dedication of the industrial teams. Their flexibility in adapting to the many changes encountered during the early development phases of the ISS infrastructure and in resolving the technical difficulties faced during the development of the challenging technologies involved merits special recognition. The support received from ESA's Technical and Operational Support Directorate at ESTEC, which helped considerably in establishing good technical communications between ESA, NASA, NASDA and the MELFI contractors, is also gratefully acknowledged. Last but not least, thanks also go to those in ESA, NASA and NASDA who have contributed to the complex co-ordination of the many interfaces involved in the implementation of the multilateral Agency agreements.

esa

MSG

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Introduction

The Microgravity Science Glovebox (MSG) for the ISS completed its development and verification in Europe in October 2001. After shipment to NASA KSC, it underwent a last series of ISS interface tests before being integrated into the MPLM on 1 March 2002. From May onwards, it will equip the ISS with unique and multidisciplinary laboratory support capabilities.

The MSG has been designed as a modular multi-user facility for performing a wide variety of materials, combustion, fluids and bio-technology investigations in the microgravity environment (Fig. 1). Primarily it provides an enclosed and sealed Work Volume (WV) equipped with lighting, mechanical, electrical, data, gas and vacuum connections, and thermal control. The WV is provided with built-in glove ports for safe handling by the crew and isolates the item under investigation from the operator area and the general ISS environment. An attached Airlock (AL) allows specimens and tools to be inserted or removed during MSG operations with limited environmental exchange between the WV and the ISS cabin. The MSG facility will also accommodate minor repair/servicing of hardware requiring a clean and/or an encapsulated working environment (e.g. the Fluid Science Laboratory's investigation containers).

Figure 1. The Microgravity Science Glovebox (MSG) ready for integration into the MPLM

The design and development of MSG has evolved substantially from the former Spacelab and Mid-deck Gloveboxes that have been flown on numerous Space Shuttle missions and on Mir. Significant enhancements include a substantially larger working volume to house bigger experiments, increased power availability, enhanced diagnostics and data control, and temperature and humidity control.

The facility has been developed by ESA for the NASA/MSFC Microgravity Program Office and includes both flight and ground units. The three ground units – Ground Laboratory Unit, Training Unit and Engineering Unit – have all been delivered to the relevant NASA entres and have already been used extensively by the MSFC Integration Team for experiment development and by the crew for training (Fig. 2).

The development contract was awarded to an industrial team composed of:
- Astrium GmbH (D), Prime Contractor, responsible for System Engineering, Integration and Verification

- Bradford Engineering (NL), responsible for the Core Facility and the Video Drawer
- Verhaert Design and Development (B), responsible for the Airlock and the Outfitting Equipment.

At a later stage, the team was joined by Laben (I), responsible for the Analogue Video Interface Board,0 and Atos-Origin (NL), responsible for the MSG Application Software.

System architecture and characteristics

The MSG has been developed following the science requirements defined by the MSFC Microgravity Science Team, and the functional and interfaces requirements for ISS payloads, defined by NASA Johnson Space Centre (JSC). It is integrated into an ISS Standard Payload Rack (ISPR).

The MSG system architecture (Fig. 3) is built around the Core Facility (CF), hosting the investigations in the WV and providing them with all the resources needed. The other main parts of the facility are:

- the rack infrastructure with ESA's Standard Payload Outfitting Equipment (SPOE), consisting of the Remote Power Distribution Assembly (RPDA), the Standard Payload Computer (SPLC), the Avionics Air Assembly (AAA)
- three ISIS stowage drawers with supporting equipment for payload operations and consumables for facility operations
- the ISIS-based Video Drawer Assembly (VD), supporting optical investigation diagnostics.

Figure 4 shows the Flight Unit (FU) rack during Electro-Magnetic Compatibility (EMC) testing at Astrium.

The MSG facility has been built for a projected ten years of operational use in orbit. It will be initially accommodated in the United States Laboratory (USLab), but could be moved at a later stage to the European Columbus Laboratory.

Core-Facility capabilities

The Core Facility includes the large Working Volume (WV), the Airlock and electronics for control, housekeeping and investigation resources and it occupies the upper half of the overall rack (Fig. 4). The Command and Monitoring Panel (CMP), located on top of the WV for ease of crew operation, monitors the facility's status and performance and provides all means for the manual operation of MSG by the crew.

The WV is a large confined volume of 255 litres offering two levels of containment for investigations. The first level is achieved by the physical barrier of the wall and the second through an under-pressure in the WV compared with the surrounding environment, i.e. in the event of a leak, any airflow will always go into and be confined within the WV. The continuous air circulation inside the WV and Airlock that maintains the under-pressure is filtered and cooled, providing both a clean-room environment and the possibility to remove up to 200 W of thermal energy from the item under investigation.

Figure 2. The MSG Training Unit

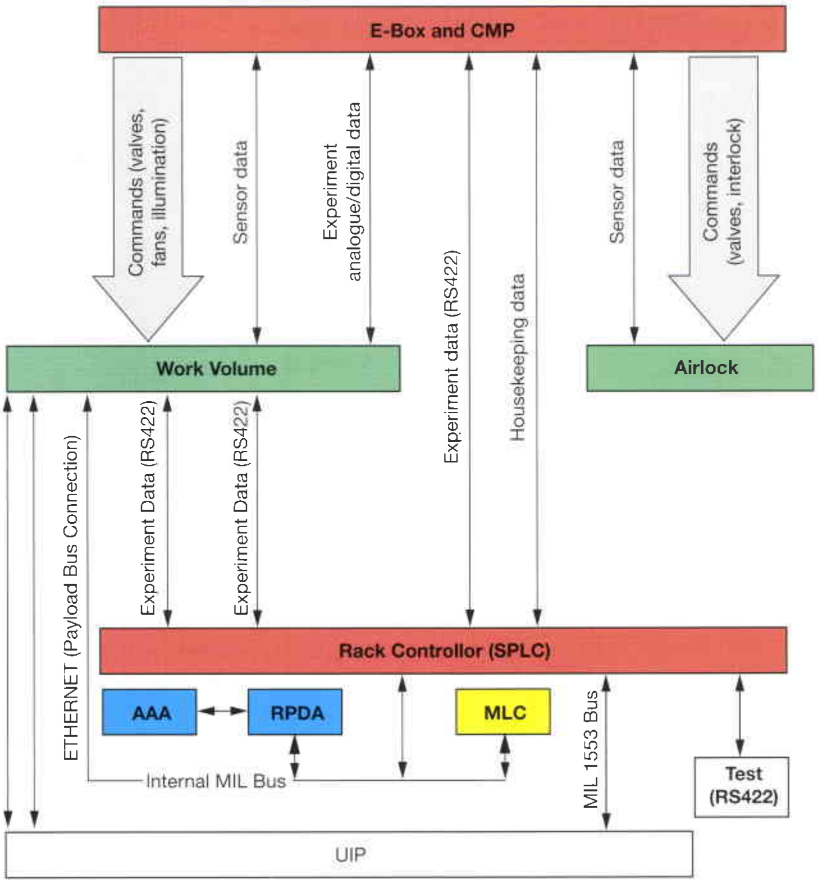

Figure 3. The MSG system architecture

Figure 4. The MSG flight-unit rack during EMC testing at Astrium

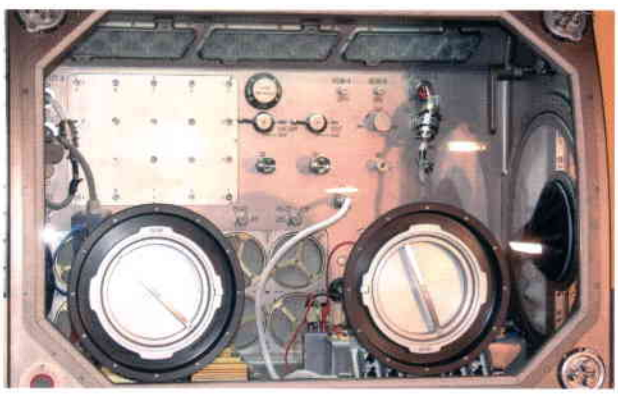

Figure 5. The MSG Work Volume (WV)

Figure 6. The MSG Airlock

The WV is provided with front and side ports for access/loading, all of which can be equipped with gloves. The WV can be slid in and out of the rack assembly to afford access to the side ports for the initial introduction and manipulation of investigations, and to fix accessories such as the cameras to selected mounting points. The entire front surface of the WV is a Lexan window, which provides the operator with a wide viewing angle. For investigations needing a darkened environment, the window and the lateral panels of the WV can be covered with special stray-light covers.

The large Work Volume and the large access ports make it possible to perform large and complex investigations, and two investigations can be accommodated simultaneously. Other experiments can be bolted to the bottom of the WV and to the left part of the back wall (Fig. 5). The WV's internal lighting can be dimmed, and there is also a spotlight to provide illumination in restricted areas. An Investigation Cold Plate embedded in the floor of the WV allows removal of up to 800 W of heat from the baseplate of the investigations.

The Airlock (Fig. 6) provides access through a sealed and tiltable top lid and has its own WV-independent internal lighting.

Video Assembly characteristics

The Video Assembly (VA) has been contributed to the MSG project by the Dutch Agency for Space (NIVR). It is integrated into a dedicated active International Subrack Interface Standard (ISIS) drawer, provided with a sliding top lid for easy access (Fig. 7). It is a self-standing subsystem including 4 colour cameras, 2 monitors, 2 analogue and 2 digital recorders, a touch pad, power distribution, a power and data line and a controller board. Thermal control for the powered components inside the Video Drawer is provided by a rear suction fan for air circulation to transfer a maximum of 125 W to the MSG internal air-cooling loop.

The VA has a dedicated controller that allows the user to command the video system via an input device connected to the RS-422 serial interface (normally connected to the MSG SPLC) or via the touch pad. The functionality provided through these digital interfaces is in addition to the fully hardwired command possibility via the drawer front-panel switches and the individual local command functions on the recorder, monitor and camera units themselves.

Three dedicated, sealed feed-through ports in the front corners of the Work Volume allow the use of all external MSG video components (video cameras, monitors, touch pad, etc.) within the WV.

Command and control capability

The MSG facility will allow both unattended and crew-attended investigations, and therefore many different command and control capabilities are offered. In the local mode, the crew can introduce commands via the Control and Monitoring Panel (CMP) and, in some

cases and for a limited set of commands, also through the Internal Control Panel (ICP) inside the Working Volume. In the remote mode, commanding is possible via:
- the MLC, which can be hooked up to the MSG internal MIL 1553 Bus at the MSG front panel. A subset of non-safety related commands is available.
- the MLC connected to the ISS MIL 1553 Bus, from the MSG
- the US Lab System via the payload MDM
- by ground commands, which are accepted in parallel with CMP controls; this mode would also allow unattended operations for non-hazardous investigations or unattended standby control.

Figure 7. The MSG Video Assembly, contributed by NIVR (NL)

Facility operations
The MSG rack will be launched in passive mode in the MPLM on ISS Utilisation Flight No.2 (UF-2), foreseen for May 2002. It will then be moved to its location in US Lab, for in-orbit commissioning. After the successful completion of this phase, it will be ready to start its operational life.

The experiments will be launched/retrieved within stowage drawers (Express Racks or Resupply/Stowage Racks) or Shuttle Mid-deck Lockers. During certain MSG operations (such as cleaning of the WV, filter change outs) they can be stored temporarily within other MSG racks and stowage drawers.

The MSG can operate in an open mode, with air circulating from the WV to the MSG rack interior, and in a closed mode with air circulating only within the Work Volume. There is also the possibility to maintain in an inert dry-nitrogen atmosphere such that the oxygen volume is kept to 10% or less.

The MSG will also accommodate ISS Laboratory Support Equipment (LSE), such as general-purpose tools, fluid-handling tools, cleaning equipment, mass-measurement devices, a pH meter, a dissecting microscope and supplies, digital multi-meters and a compound microscope. Apart from the equipment required for the general upkeep of the WV, a significant amount of resources and outfitting equipment is available for MSG science investigations.

Science and information interface
Glovebox investigations cover four major disciplines: material science, biotechnology, fluid science and combustion science. A similar peer-review process to that used for earlier Space Shuttle missions is being applied to select the investigations to be flown in the MSG by NASA's Microgravity Research Program Office (MRPO). ESA has utilisation rights for this facility and will therefore pre-screen the European-proposed investigations and then present them to NASA for final approval.

Both NASA and ESA periodically announce microgravity research opportunities via NASA Research Announcements (NRAs) and ESA Announcements of Opportunity (AOs), respectively. More details can be found at: http://floyd.msfc.nasa.gov/msg, and http://www.esa.int/export/esaHS/research.html.

To assist potential Principal Investigators (PIs), there is a MSG Investigation Integration Team located at NASA's Marshall Space Flight Center (MSFC), composed of a core group of managers, engineers, and support personnel. This Team oversees the interface and safety requirements, the schedule for meeting ISS template milestones, the administrative support for documenting interfaces to the MSG facility, and the investigation manifesting, analytical integration, and flight operations. It also supports the investigation development teams in ensuring that the engineering interfaces to the MSG and the ISS are met. The investigation integration process and schedule are defined in the Microgravity Science Glovebox Investigation Integration Plan (MSFC-PLAN-3052), which also addresses the implementation activities and the development of data products.

Acknowledgements
The Microgravity Science Glovebox's development, integration and testing have involved many different individuals and organizations, who have contributed greatly to the success of this facility. Due acknowledgements are made to the MSG Industrial Team, the ESTEC Technical and Operational Support Directorate team, as well as the MSG Teams at NASA/MSFC. We all look forward to many years of successful MSG scientific utilization!

Cryosystem

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Introduction

The Cryosystem is an ultra-low-temperature facility for supporting life-sciences payloads in space. It brings together a unique set of facilities for the optimal preparation, preservation and storage of biological samples and protein crystals at cryogenic temperatures. Thanks to its ultra-rapid cooling capability and its relatively large cold volume, it will provide a great improvement in the quality and quantity of science investigations in the fields of life sciences, physiology and biotechnology.

The Cryosystem will complete in the ultra-low temperature field (–180°C) the range of freezers provided by ESA to NASA for use on board the International Space Station (ISS), the other two systems being MELFI working in the temperature range from +4 to –80°C, and the Crew Refrigerator Freezer covering the range from +4 to –26°C.

During the Cryosystem's preliminary design phase (Phase-B), which has started in February 2002, prototypes of the complete freezers as well as some in-orbit support equipment will be developed to prove the feasibility of the proposed concepts. The design phase is therefore foreseen to last about 18 months, concluding with a Preliminary Design Review (PDR). The subsequent main development phase (Phase-C/D) will be concluded with the delivery of the last freezer unit, in 2008.

Since the ISS assembly sequence is currently under review, the first launch of a Cryosystem element is not yet fixed, but the On-Orbit Preservation Rack (OPAR) could be launched in the Centrifuge Accom-modation Module (CAM) not earlier than January 2008.

The Cryosystem industrial development team selected consists of:

- Astrium (Germany), Prime Contractor, responsible for systems engineering, integration and verification, as well as for development of the rack infrastructure
- L'Air Liquide (France), responsible for the cryogenic cubsystem, including the freezer drawers and the associated orbital and ground-support equipment
- Thales Cryogenics (The Netherlands), which will be responsible for the cryocooler's development
- Damec (Denmark), responsible for the science interfaces and utilisation hardware.

System architecture and operational scenario

The Cryosystem is being developed to meet the science requirements defined by the NASA Science Working Group, and the functional and interface requirements for ISS payloads defined by NASA Johnson Space Center (JSC).

The heart of the system is the Cryogenic Storage and Quick/Snap Combo Freezer. Contained within one drawer, it will support the following functions:

- storage and preservation of already frozen biological samples and supplies contained in vials
- ultra-rapid cooling and 'snap freezing' of various specimens, such as tissues, eggs and cells
- transportation to and from orbit of specimens and supplies
- transportation of specimens to/from other ISS racks, such as the Life Science Glovebox (LSG) and X-Ray Diffraction Facility (XCF).

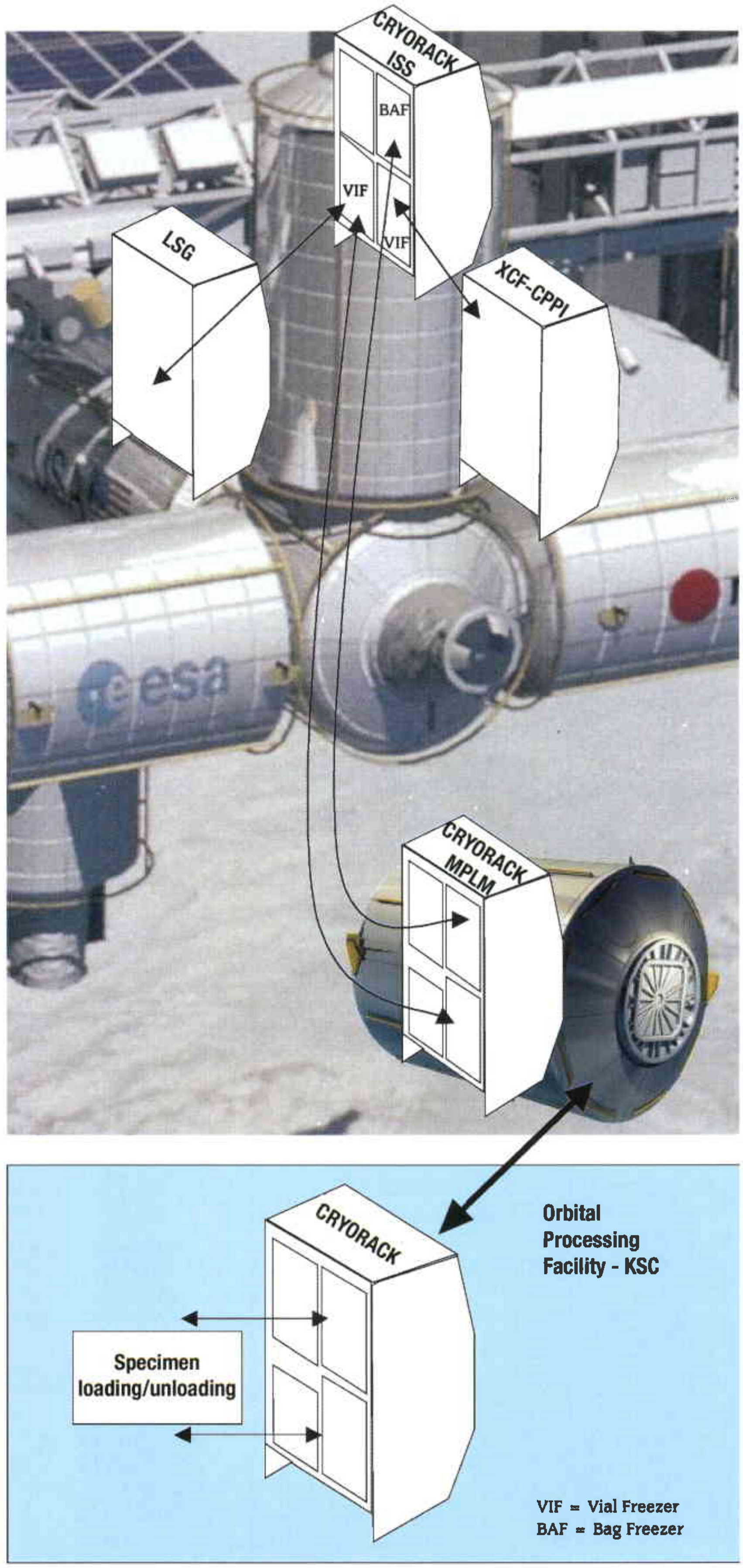
The Orbital Support Equipment (OSE), consisting of tools and ancillaries needed for the freezer operations (including maintenance) in orbit, will be stowed in a dedicated drawer.

The Cryorack is an ISS Standard Payload Rack (ISPR) outfitted with a liner (mechanical infrastructure) and subsystems to support operation and transportation of the freezers, and the transportation of passive payloads in the Mini Pressurised Logistic Module (MPLM).

NASA and ESA are also considering developing a second type of combo freezer to allow the ultra-rapid freezing and storage of specimens contained in bags, such as those used for tissue cultures.

The system will have a flexible and variable architecture, depending on the utilization needs of the various freezers. The first Cryorack will be transported to orbit within the Centrifuge Accommodation Module (CAM), and will remain there for its projected design lifetime of ten years. The other two Cryoracks will ensure the cyclical up- and down-loading of the freezers and the specimens therein. Both will support multiple missions, including installation in the MPLM, installation of freezers, transportation to and from orbit, removal from the MPLM, and refurbishment before the next mission (Fig. 1).

The Cryorack may accommodate up to three freezer drawers (for vials or for bags) and a number of International Subrack Interface Standard (ISIS) drawers, containing either the freezer orbital support equipment or additional passive payloads (Fig. 2). The ISS Cold Stowage Working Group will be responsible for defining the configuration needed for each increment, depending on the experiments planned and on the availability of resources on the MPLM and ISS.



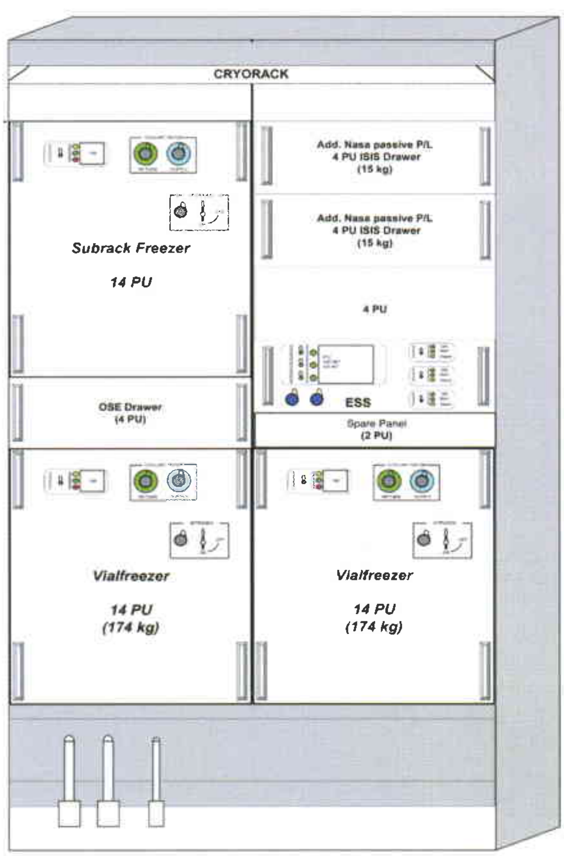


Figure 1. The Cryosystem operating scenario (courtesy of Astrium)

Figure 2. Cryorack basic outfitting accommodation (courtesy of Astrium)

The Cryorack basic structure will be an ISS Standard Payload Rack (ISPR), provided by NASA but suitably modified to allow an optimal design for the freezers and their infrastructure. The rack will be outfitted to accommodate the freezer drawers, the electrical subsystem (ESS) drawer, and the additional ISIS drawers for the passive payloads and the Orbital Support Equipment. A water loop will ensure optimal cooling of the freezers and the subsystems needed for their correct operation. Cryorack will provide the necessary power, thermal control, and command and data handling. In addition, OPAR may include a system for supplying gaseous nitrogen for humidity control within the freezers' cold volumes.

Cryogenic storage and quick/snap combo freezer

The freezer will be integrated into a drawer 14 panel units high (about 650 mm) and half a rack in width (about 450 mm). The freezer itself will be a cylindrical vessel (dewar), vacuum-insulated, and provided with a complex system of small ports to avoid heat leakage, whilst still allowing for the loading/unloading of the specimen containers (Fig. 3).

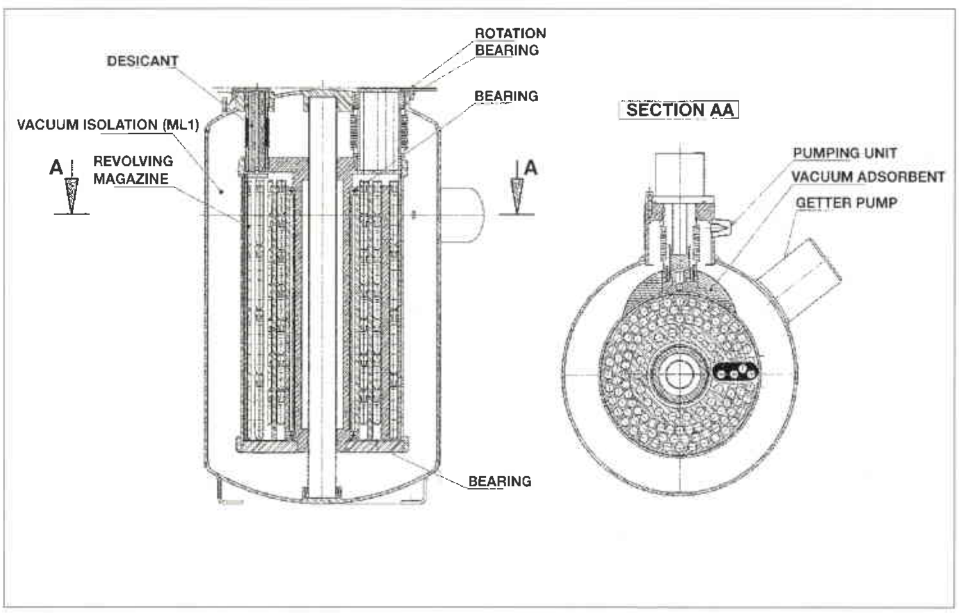


Figure 3. Schematic of vial freezer dewar

Cooling will be provided by a Stirling cooler, connected via a cold finger to the dewar's internal structure. Given the severity of the cooling requirements and the ten-year lifetime requirement, adaptation of an existing cooler – used for military applications – has already been initiated by the companies involved (Thales and L'Air Liquide). Figure 4 shows the development-model cooler displacer provided with a flexure bearing.

Figure 4. The Cryocooler's displacer and flexure bearing (courtesy of Thales/L'Air Liquide)

The dewar will hold about 800 2-ml or 400 5-ml vials, or a combination of the two. The containers will be arranged as a concentric array of tubes providing: maintenance of the required temperature, support and restraint during critical orbital phases, and the possibility of indexing every container. In particular, a carrousel mechanism integrated inside the dewar allows three-axis identification (angular, radial and in-depth) of each container. Both the dewar structure and each container will therefore be suitably labelled and coded according to the ISS Inventory Management System.

The freezer will have four basic modes of operation: storage and transportation, quick freezing, snap freezing, and collection of already processed and frozen protein crystals. To accomplish this, it will be able to interface with and to operate in different racks: the Cryorack, which is its 'home rack', the Life Science Glovebox (LSG), and the X-Ray Crystallography Facility (XCF)/Crystal Preparation Prime Item (CPPI).

Transportation of specimens and supplies to/from orbit

The Investigators' specimens and supplies will be transported from their laboratories to the Kennedy Space Center (KSC) processing facilities using dedicated ground dewars provided by the Cryosystem developer. The specimens can be stored in the freezer either before its installation in the MPLM, after its installation in the MPLM whilst still at the processing facility, or during the late-access operations with the MPLM/STS already on the launch pad.

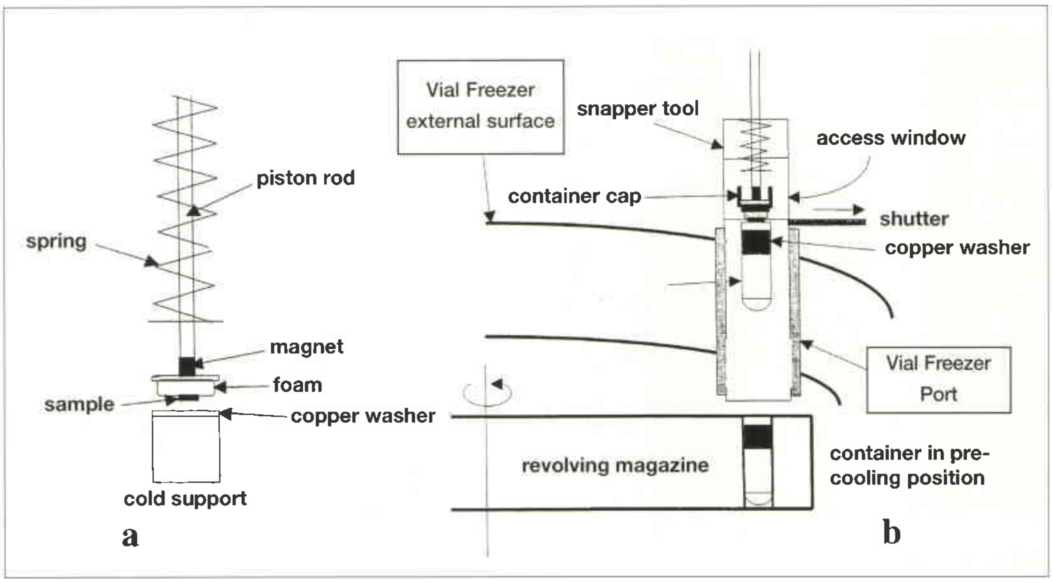


Figure 5. (a) The snap-freezing tool. (b) Operating configuration at the vial freezer port (courtesy of L'Air Liquide)

The freezer will receive all necessary power, cooling and data-handling resources from the MPLM, except for certain periods during the launch and landing phases. It is therefore designed to have sufficient thermal inertia to maintain the required temperature inside the cold volume (i.e. -180 ± 5°C) during those periods. The cold-volume temperature will be monitored throughout the specimens' lifetime in order to provide the Investigators with data to confirm the 'suitability' of their specimens for their investigations.

After the docking of the MPLM to the ISS, the freezer will be removed from Cryorack/MPLM and transported and installed by the crew into the Cryorack location in CAM. The reverse operation will be performed after the freezer has completed its mission.

Transportation of specimens to other ISS racks
A challenging requirement for the vial freezer is the ability to withstand multiple cycles of installation/de-installation in various ISS racks, as it continuously 'travels' from its home rack (Cryorack) to either the LSG or the XCF-CPPI racks and back. Wear problems are to be expected for all mechanically interfaced parts such as connectors and drawer slides.

Quick-freezing function
Quick freezing occurs when a biological specimen (plant tissue, animal tissue, animal body fluid, etc.) is removed surgically (or equivalent) from the host, inserted into a specimen container and subsequently cooled-down to below prescribed temperature limits over a period of several seconds to minutes.

These quick-freezing operations will occur with the freezer installed at the LSG. The surgical operations will be performed on the table inside the LSG working volume, while the quick-freezing tools will be contained inside the freezer. The crew will remove the tools from the freezer, transfer the sample from the surgical table to the dedicated tool and then re-insert the specimen container into the freezer's quick-freeze zone. The vial freezer will be able to cool-down a 5-ml vial filled with standard saline solution from ambient temperature to –160°C in less than 10 minutes. The freezer will be able to support multiple quick-freezing operations, according to defined scenarios, before it needs to be transferred back to OPAR for recovery and storage.

Snap freezing
Snap freezing is a process whereby exposed plant or animal tissue is rapidly frozen so that sub-cellular structure is preserved during the freezing process. During ordinary specimen freezing, the water contained within the cell forms large ice crystals that destroy sub-cellular structures. With snap-freezing, the surface of the material is frozen almost instantaneously, so that amorphous ice or very small ice crystals, which do not destroy sub-cellular structure, are formed.

Since the cooling is delivered to the specimen surface and then propagates through the material, the practical limitations of this process limit 'good freezing' to a thin region (about 15 microns thick) near the specimen's surface. The vial freezer will be able to snap-freeze samples with an area of about 36 mm^2 while having at the least 10% of this area free from cellular damage. These snap-freezing operations will take place with the freezer installed at the LSG.

A prototype snap-freezing device (Fig. 5) has demonstrated a success rate of about 80%, which is comparable with the performance of similar equipment used in ground laboratories.

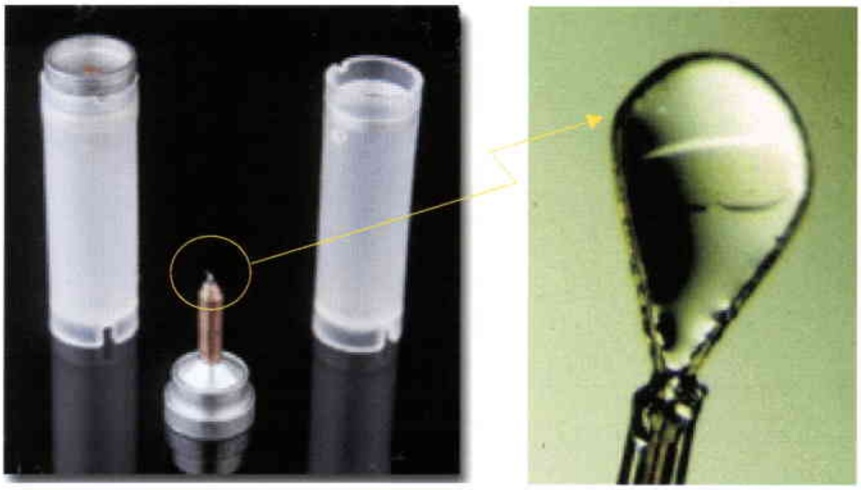


Figure 6. Cryovial, and a Cryoloop with a 'hanging' drop of protein crystal solution (photos courtesy of Hampton Research and Lawrence Livermore National Laboratory, respectively)

Protein crystal storage

The XCF is a NASA-integrated rack hosting various sub-facilities for the growth, preparation, mounting and freezing of protein crystals. In particular, the CPPI (Crystal Preparation Prime Item) will take care of the last two operations and will move the frozen containers robotically to a location where the freezer transfer port can be installed. The CPPI equipment will 'fish' the crystal from the growth solution, mount it on a 'cryoloop' and insert the latter into a suitable vial (Fig. 6).

If the vial freezer collects a specimen in unpowered status, the collection time will be limited to one hour to maintain the very strict temperature requirement for the protein crystals (-180 ± 5°C). The interfaces between the freezer and the CPPI, as well as the number of containers that can be transferred in one hour, have to be defined during the detailed design phases for both the freezer and the CPPI.

Combo Storage Freezer for bags

At the end of the Cryosystem design phase (Phase-A), it became evident that 2 and 5-ml vials would not be the only containers needed for life-science experiments. In particular, tissue cultures would require use of bigger and more complex 'bags' (Fig. 7), where the tissue can grow without any intervention from the crew other than the injection of the growth solution. These samples also need to be stored at cryogenic temperatures after growth. However, the vial freezer defined above cannot be used for this because mixing of the two container types and the various sizes would greatly reduce either the available capacity or the quick/snap-freezing performance of the freezer, or both. For this reason, NASA required ESA to propose an additional combo freezer to host those particular containers. NASA will take a decision regarding the implementation of the bag freezer in the second quarter of 2002.

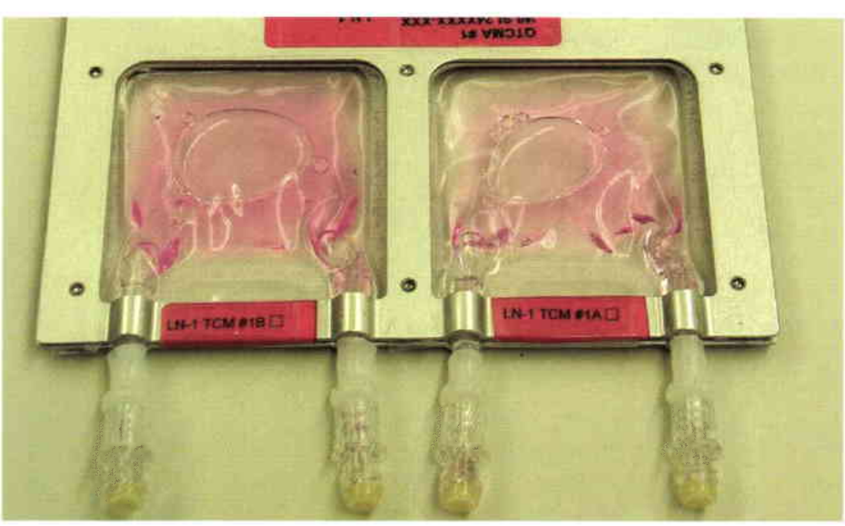


Figure 7. Biotechnology bags inserted into a metal frame (courtesy of NASA)

If NASA decides to fund this option, the bag freezer will be very similar to the previous one. The only differences will be in the internal outfitting of the dewar, since the bags are bigger and have a more complex configuration than the vials. The foreseen dewar capacity could be around 150 10-ml or 80 30-ml bags, or a combination of the two sizes. In addition, it will be possible to store about 40 sealed syringes (or other cylindrically shaped containers) of 10-ml capacity. This will allow the uploading of growth solutions at very low temperatures, to be injected into bags or vials for life-science experiments.

The quick-freezing capability will be implemented using dedicated outfitting. Snap-freezing is not possible because the specimen is not directly accessible, being confined within the bag. The bag freezer will be used only at the Cryorack, because the specimen will be contained within the bags and will not require a closed and sealed environment for its development.

The supplies and specimens will be transported to/from orbit using the same scenario as for the vial freezer.

Acknowledgements

The authors wish to thank the industrial contractors for providing preliminary drawings and descriptions of the hardware, and the ESA and NASA Cryosystem teams for their hard work during the requirement consolidation phase.

esa

Hexapod

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Introduction

SAGE III (Stratospheric Aerosol and Gas Experiment), an Earth-observation instrument developed by NASA's Langley Research Center (LaRC), was one of the first scientific external payloads selected for the International Space Station (Fig. 1). It was conceived to fly on a spacecraft able to provide ± 1 degree pointing accuracy. Since the ISS's attitude can vary by several degrees over a long period, it was therefore necessary to provide a dedicated nadir-pointing system. For this task, NASA selected the hexapod-based pointing system ('Hexapod' for short) included by ESA in the list of proposed European contributions to the ISS early utilisation phase. Launch is currently scheduled with assembly flight UF-3, although this could be modified by revisions in the ISS assembly sequence.

The development of SAGE III and the Hexapod were both approved and funded in 1994. The contract for the Hexapod design phase (Phase-B) was awarded by ESA to Alenia Spazio (I) in 1995, with Carlo Gavazzi Space (I) and ADS Italia as subcontractors. The main development phase (Phase-C/D) was initiated at the beginning of 1998, with Alenia Spazio (Prime Contractor) and Carlo Gavazzi Space. The Critical Design Review (CDR) was completed in November 2000, and flight-unit completion is scheduled by mid-2002. LaRC will then be responsible for the overall Hexapod and SAGE III payload integration.

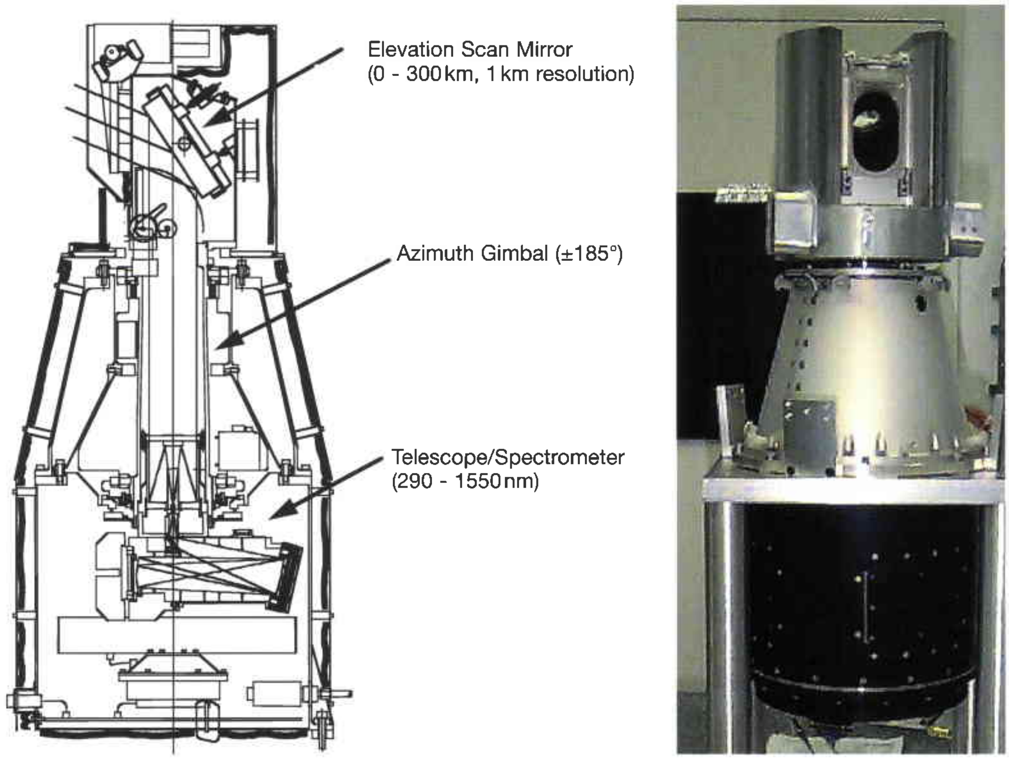


Figure 1. The SAGE III instrument's key elements

The SAGE III Scientific Instrument

SAGE III is designed for the global monitoring of the vertical distributions of stratospheric aerosols, ozone, water vapour, nitrogen dioxide and trioxide, chlorine dioxide, and temperature from Earth orbit. It uses spectrographic techniques based on light-source occultation, which typically offer the capability for self-calibration, high vertical resolution, high signal-to-noise ratio, and excellent inversion accuracy.

The core sensor is a spectrometer able to measure the extinction of both solar and lunar radiation through the Earth's atmosphere during occultation events, between 290 and 1550 nm with 1 nm spectral resolution and 1 km vertical altitude resolution. The instrument incorporates a unique charge-coupled detector (CCD) array and a single photodiode detector in the focal plane to perform the science measurements. The sensor assembly provides spatial resolution over an altitude range from cloud-top (or the Earth's surface on cloud-free days) to 300 km. Science data are taken up to an altitude of 150 km. Data sequences are also taken between 150 and 300 km altitude on some orbits to radiometrically and spectrally calibrate the instrument.

Mission overview

The Express Pallet System (ExPS) is both a Shuttle carrier and an in-orbit payload accommodation facility, which can be robotically installed on the truss of the ISS. It accommodates payloads mounted on Express Pallet Adapters (ExPA). The ExPA hosting Hexapod and SAGE III is integrated onto the ExPS on the ground, and is used as the payload carrier at launch. Hexapod will be launched unpowered, with the Orbiter providing power for its 'stay-alive' heaters after the payload-bay doors are opened in orbit.

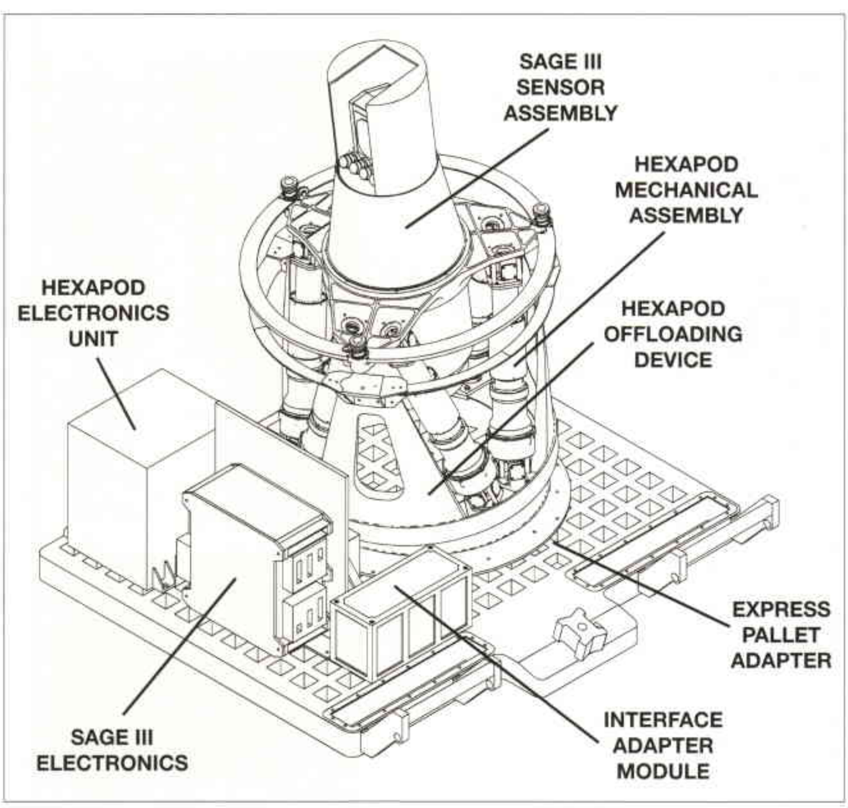


Figure 2. The Hexapod system integrated with SAGE III (together with the electronics boxes for both) on the Express Pallet Adapter

The complete ExPS will be moved robotically from the Shuttle and transported by using the ISS Mobile Base System (MBS) to its nominal in-orbit accommodation site. The location assigned is the nadir-starboard outer payload attachment site of ISS truss segment S3 (close to the thermal radiator), with Hexapod and SAGE III accommodated on the ExPA installed at the ExPS corner location in the ram-outboard direction.

Hexapod and SAGE III will be activated and start their science mission only after the ExPS is connected at its attachment site. Both are designed for five years of in-orbit operation without maintenance. Users will, however, be able to up-link Hexapod flight-software updates.

At the end of their mission, Hexapod and SAGE III will be removed from the ExPS along with their ExPA. They will remain unpowered during the transfer to the Shuttle Orbiter and during Earth re-entry. Fail-safe brakes in the Hexapod linear actuators ensure that accelerations during reentry do not cause payload displacement in the cargo bay.

Hexapod design characteristics

The key performance requirements for Hexapod consist of achieving a pointing accuracy of ±90 arcsec in the nadir direction – with a pointing stability of 0.0025 deg/sec, a pointing range equivalent to an 8 deg cone, and with an angular pointing rate of at least 1.2 deg/sec – and accommodating a 35 kg SAGE III sensor assembly.

Hexapod determines attitude based on the ISS-provided attitude state vector (attitude quaternions and GPS data), and applies an attitude correction matrix to take into account the local attitude deviations actually experienced at the mounting location. The matrix is defined on the ground, based on the actual SAGE III measurements and uplinked to Hexapod (via SAGE III) along with the telecommand data for the pointing manoeuvre.

The Hexapod flight unit, including the electronics, weighs 116 kg. The overall payload, including the SAGE III electronics boxes, harness and other system-level outfitting, will be close to the 225 kg allowance for the ExPA. The accommodation of the SAGE III sensor assembly in the volume between the Hexapod's legs takes best advantage of the specific geometry of this type of mechanism (Fig. 2).

Hexapod's power consumption in orbit varies according to the operating mode. It ranges between the power needed to survive ExPA cold phases (the in-orbit stay-alive heaters require around 100 W, with thermostatic control), and a maximum operating power of 435 W during the execution of pointing manoeuvres when all legs are moving simultaneously (not required in all cases). The estimated average power consumption is about 120 W, given that the execution of a complete pointing manoeuvre takes just a few seconds.

Hexapod consists of two main parts: the Electronic Unit (HEU), and the Mechanical Assembly (HMA). The HEU is the integrated power and control unit that handles power distribution, telemetry and telecommand management, data processing, and command and control. It provides the computer control for the co-ordinated movement of the six linear actuators. Hexapod flight software resides on the Standard Payload Computer (SPLC).

The HMA includes six electromechanical linear actuators, arranged as three trapezoids and connected by means of 12 universal joints to a bottom flange and to an upper platform. The latter's attitude and position are determined in six degrees of freedom (translation along and rotation about all orthogonal axes in 3D space) by the combination of the lengths of the six linear actuators. The resulting configuration is a statically determined structure that enables the stroke of each individual linear actuator to be changed without causing internal stresses in the mechanism. The bottom flange is fixed to the ExPA and the upper platform accommodates the SAGE III sensor assembly. The Hexapod's bottom flange includes an offset-wedge function, suitably shaped to provide static compensation of the estimated average ISS pitch bias (tilted 7 deg) and maximise the SAGE III field of view.

The other important constituent of the HMA is the off-loading device installed around the hexapod mechanism to interconnect the upper platform and the ExPA during launch. It enables the linear actuators to be protected from launch loads, thereby preserving their high accuracy for supporting the scientific mission. The off-loading device will only be disconnected once the Hexapod is in place on the ISS truss, after which the simultaneous activation of all six linear actuators will put the upper platform into its nominal operating position. The Hexapod's ability to control linear translations according to pre-defined trajectories enables the design and operation of the separation device to be simplified considerably.

Hexapod-based positioning/pointing systems are able to achieve pointing in a particular direction via a very large set of possible combinations of the six linear actuator lengths. This provides the ability to recover partially from linear actuator failures by adjusting the pointing algorithms to take into account the actual length of the faulty leg(s), and to continue to execute pointing manoeuvres using only the fully functional legs.

The electromechanical linear actuator (Fig. 3) is a key element in the hexapod mechanism. It has to guarantee a positioning accuracy of better than ±25 micron over the full pointing stroke, with a minimum resolution of 10 micron and a positioning repeatability of better than ±5 micron. The lengths of the linear actuators can range from the fully-retracted minimum of 471 mm, including the two cardan joints, to the maximum stroke length of 568 mm. Their nominal length, corresponding to the 'zero' reference position of the upper platform, is 528 mm.

A DC three-phase brushless motor is installed in direct-drive frameless configuration inside the linear actuator. The stator is installed inside the motor cage, and the rotor is installed on the satellite screw shaft. The motor is double wound for cold redundancy, with the phase commutation provided by two sets of three Hall sensors (one set for each winding). The motor can provide a continuous torque of 0.7 Nm up to 150 rpm, and a peak torque of 1.4 Nm.

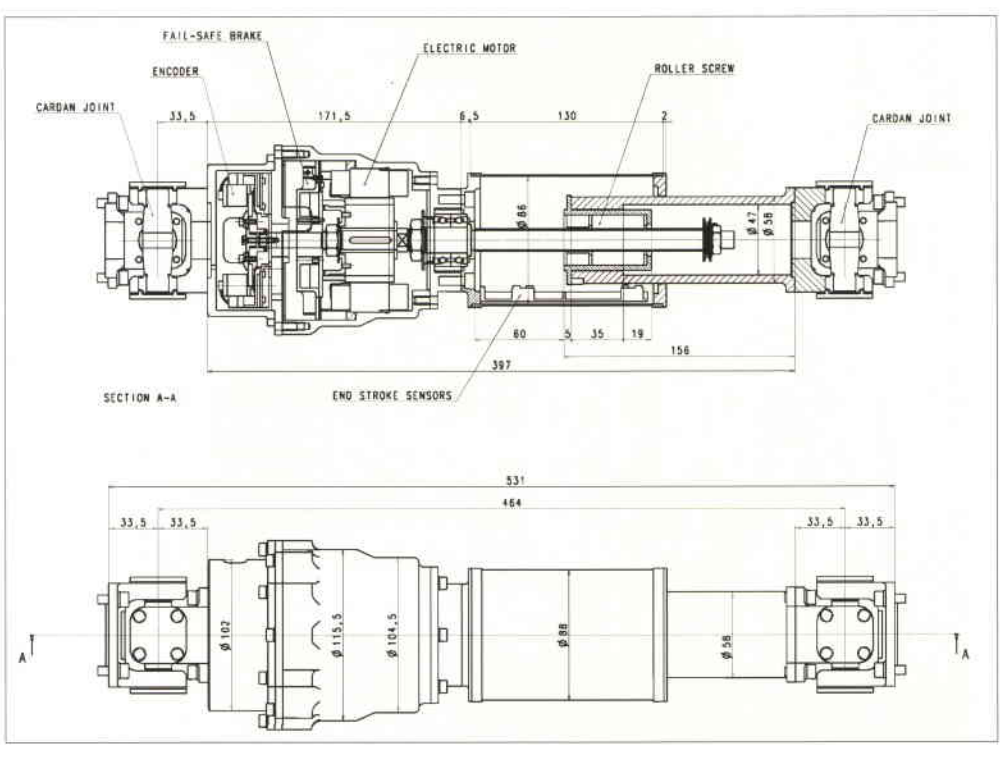


Figure 3. The electro-mechanical linear actuator

A brake is used to lock the rotor, preventing the satellite roller screw back-driving during the re-entry phase. Based on two steel-toothed rings (each with 200 teeth), the brake has two separate solenoid windings (main and redundant), each of which when energised is able to disengage the toothed rings (they are automatically engaged when power is off). The brake system, the materials of which have been specially selected to avoid debris production during engagement/disengagement, is dimensioned to resist a torque of at least 6.3 Nm.

Figure 4. The Hexapod high-fidelity mechanical-interface simulator

Hexapod ground models

Three Hexapod ground models are deliverable items to support NASA LaRC in its role as integrator of the payload system. The High-Fidelity Avionics Interface Simulator reproduces the hardware and software serial interface to SAGE III. The High-Fidelity Mechanical Interface Simulator (Fig. 4) is an exact mock-up of the essential items of the flight unit as far as overall dimensions, placement of hardware on the lower and upper platforms, and hole locations are concerned. This simulator is used for verifying that the SAGE III sensor assembly mounts properly to Hexapod, and to support payload system integration. The Engineering Unit (Fig. 5) supports sustaining-engineering functions such as anomaly resolution (hardware and software), software modifications, and on-ground verification of system changes during in-orbit operation.

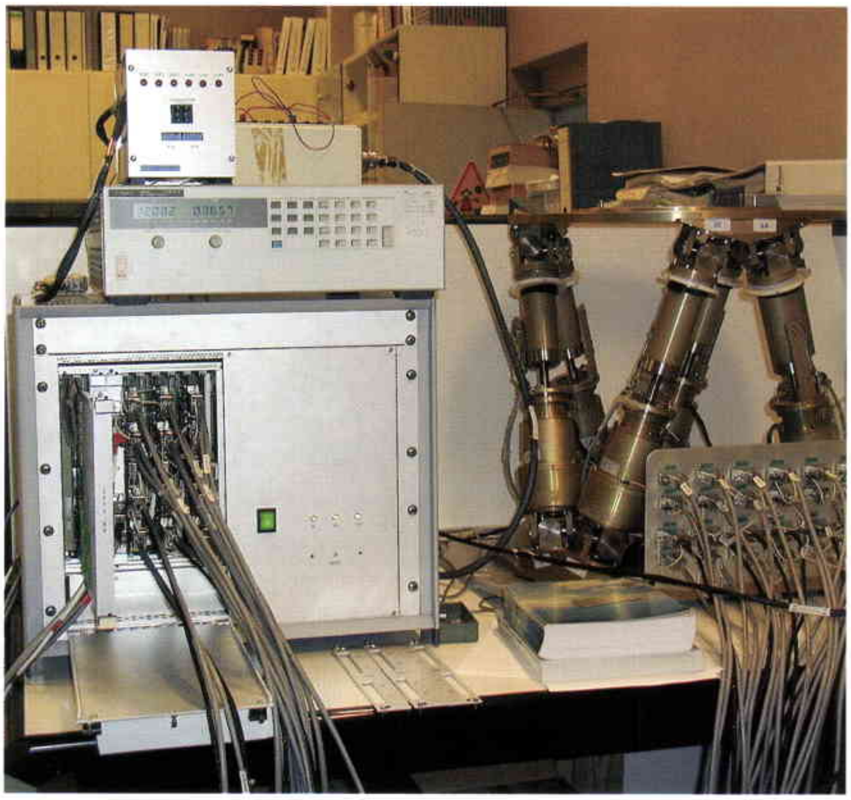


Figure 5. Functional testing of the Hexapod Engineering Unit

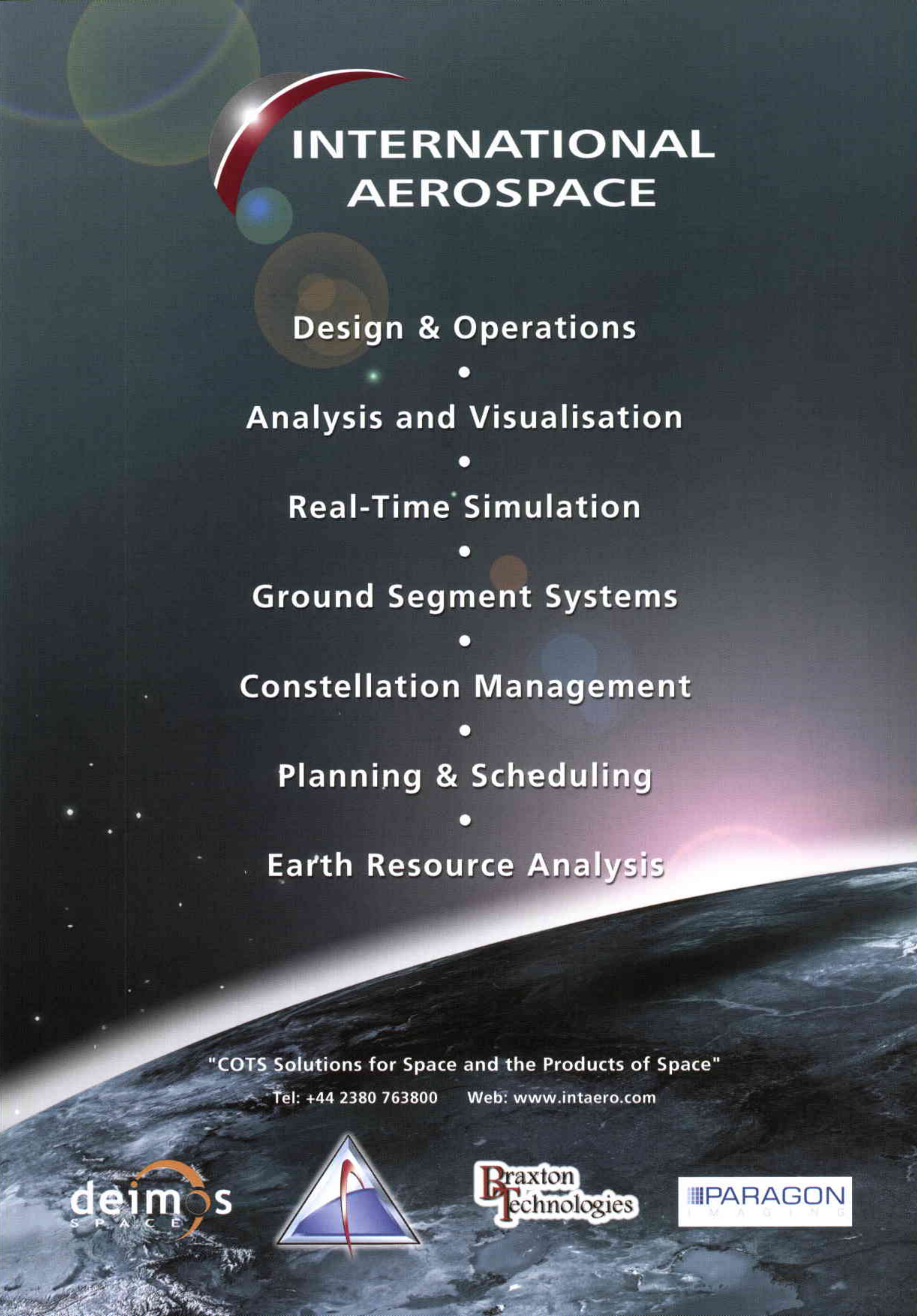
Future perspectives

ESA's development of the Hexapod marks the upgrading of hexapod-based positioning/pointing systems for space application. Although tailored to meet the SAGE III nadir-pointing requirements, it can be adapted to support other ISS external payloads, or payloads to be flown on different spacecraft carriers. Feasibility studies conducted before starting the Hexapod design phase indicated the possibility of using them for space applications requiring pointing within about ±30° cones. A target-tracking capability (not requested by SAGE III) can also be provided. The possibility to control payload attitude/position in six degrees of freedom is another attractive feature that could serve a number of space applications in which the relative displacement of two items has to be controlled with high accuracy.

Other possible applications include active jitter stabilisation at the payload interface, operating Hexapod as an anti-vibration platform. A demonstration test performed in 1996 on the Hexapod Phase-B development model indicated that it was able to react 'as-built' to a simulated disturbance by producing an in-phase dynamic response suitable for compensating low-frequency jitter of up to about 2 Hz.

Acknowledgements

The authors wish to acknowledge the efforts of all members of the ESA, NASA and Industry (Alenia Spazio and Carlo Gavazzi Space) teams who have contributed to the Hexapod project's success through their dedication and professionalism and in a friendly spirit. Last but not least, very special thanks are due to the late W. Gallieni (ADS Italia), whose innovative ideas and specialist skills were fundamental to the preliminary design-definition phases of the project.



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The Mission and Post-flight Analysis of the Atmospheric Re-entry Demonstrator (ARD)

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The ARD was flown in October 1998. Its purpose was to achieve a controlled sub-orbital flight, from separation through atmospheric re-entry to splashdown. It carried an instrumentation and data-acquisition payload so that the actual flight parameters could be compared with those predicted mathematically. The post-flight analysis was therefore an integral part of the overall project.

Introduction

The Atmospheric Re-entry Demonstrator (ARD) was launched on 12 October 1998 on Ariane-503, the third Ariane-5 qualification flight. The ARD performed a sub-orbital flight with a maximum altitude of 830 km, and landed in the Pacific Ocean, with a splashdown point within 5 km of the predicted touchdown zone. The mission profile in Figure 1 shows the trajectory, the re-entry profile, the flight communication system, and the splashdown. The Demonstrator itself is shown in Figure 2.

During the mission, key data (including pressures, temperatures, vibrations, etc.) were recorded on more than 200 measurement channels distributed over the vehicle. These measurements were stored on two recorders and also transmitted to ground and airborne telemetry stations: the Libreville ground station for ARD status data after Ariane-5 separation, and the Aria-1 and Aria-2 aircraft-based stations for data prior to and after the blackout phase.

Project objectives

The main technical objectives with ARD were to:

- test and qualify re-entry technologies and flight-control algorithms under actual flight conditions
- achieve in-flight validation of design concepts, hardware and system capability to manage compromises between various technologies
- validate the aerothermodynamic predictions

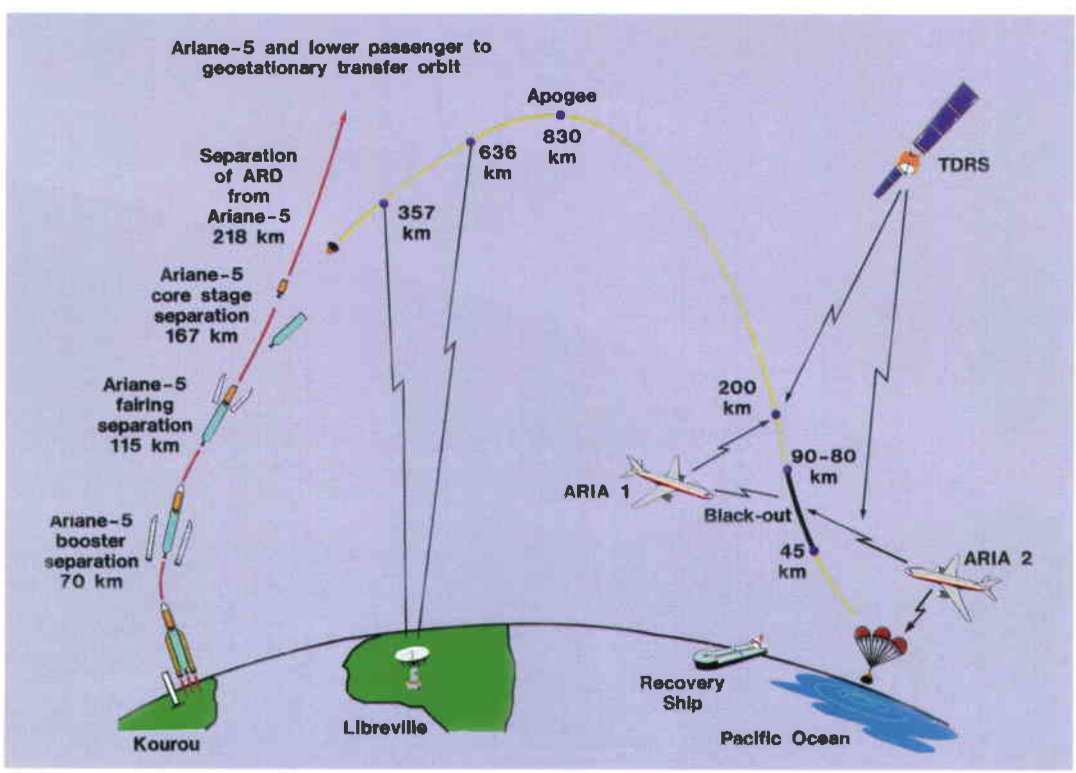


Figure 1. The Atmospheric Re-entry Demonstrator (ARD) mission profile

- qualify the design and the materials of the thermal-protection system
- assess the performance of the navigation, guidance and control system
- assess the performance of the parachute and recovery system
- study the radio communications during atmospheric re-entry
- demonstrate industrial capability within a tight schedule and with a limited budget.

The main management objectives were based on:
- a small ESA management team
- a high degree of autonomy assigned to the industrial consortium
- a direct review/acceptance approach
- an efficient development and cost schedule, as shown in Figure 3.

Project organisation

Development

Twenty-seven companies participated in the realisation of the ARD, under the lead of the then Aerospatiale, now EADS-LV:
- Belgium: ETCA (functional control bench), Sabca and Sonaca (structure), Trasys (software development)
- Denmark: Alcatel
- France: EADS-LV (Prime Contractor, TPS, GN&C, AIV, antennas), Astrium (functional electronics), Sextant Avionique, Intertechnique, ONERA
- Germany: Astrium (reaction control system)
- Italy: Alenia (descent and landing system)
- Spain: CRISA
- Sweden: Saab.

Post-flight analysis

The Agency set up a small team of experts in order to monitor the industrial activities. Under the Prime Contractorship of EADS LV (F), the following companies/institutions were involved in the post-flight analysis:
- Belgium: Von Karman Institute (CFD analyses)
- France: EADS-LV (Prime Contractor), ONERA (wind-tunnel tests), SEP (CMC sample analyses), Astrium (GPS analyses)
- Germany: MAN-T (CMC sample analyses), Astrium (FEI sample analyses), DLR (CFD analyses and wind-tunnel tests)
- Italy: Alenia Spazio (parachute analyses)
- Netherlands: Fokker (trajectory analyses)
- Switzerland: CFS (CFD analyses).

The post-flight-analysis methodology was articulated as follows (Fig. 4):

Level-0 activities: October 1998/Spring 1999
- Recovery and inspection
- Evaluation of data availability (real time, recorded)
- Initial comparison with predictions.

Phase-A evaluation: Spring 1999/Spring 2000
- Detailed data evaluation
- Correction of flight parameters and correlation with predictions.

Figure 2. The ARD vehicle

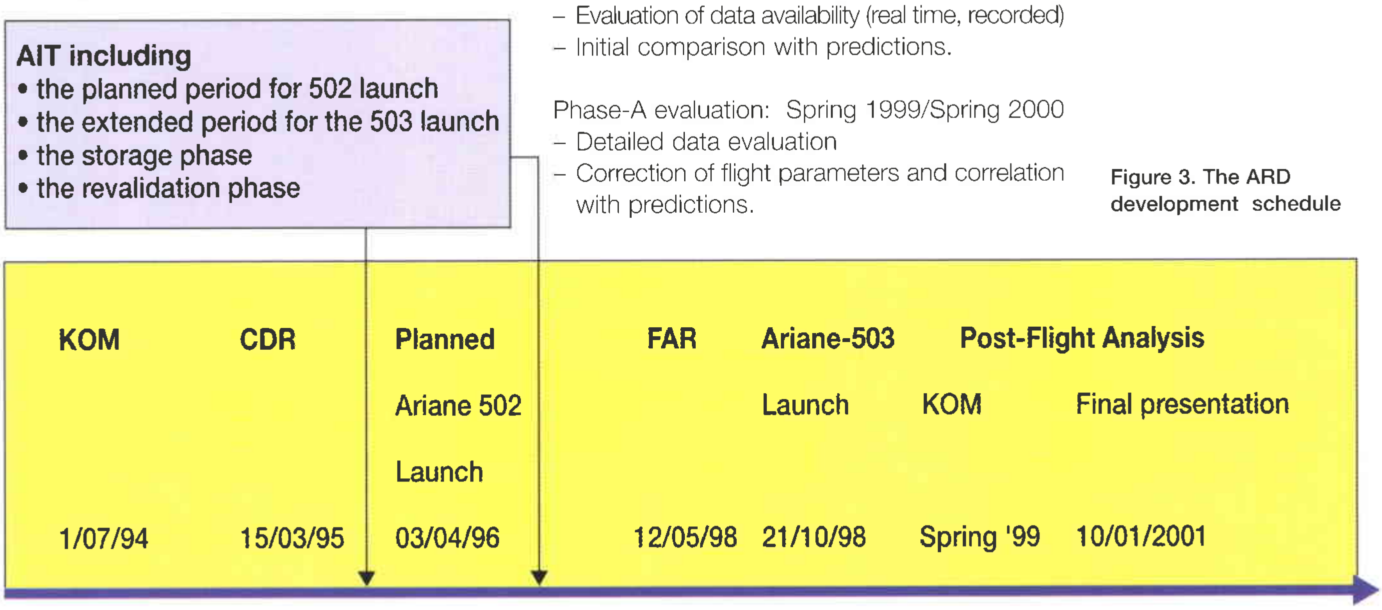


Figure 3. The ARD development schedule

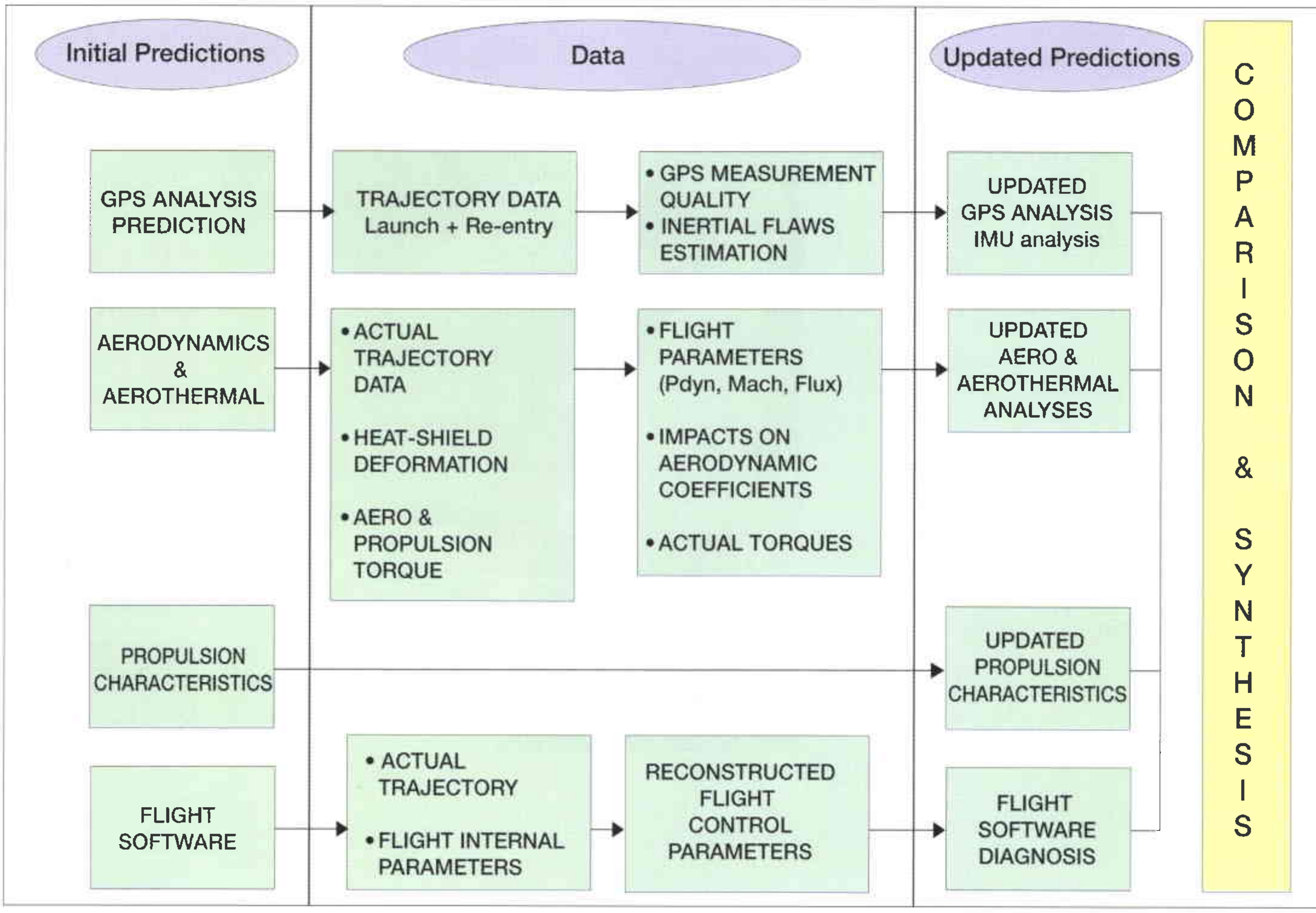


Figure 4. The post-flight-analysis work flow

Table 1. ARD post-flight analysis major events

EVENT	PREDICTION (time from H0)	FLIGHT Measurement (time from H0)
Ariane-5 separation	00 : 12 : 00 218 km	00 : 12 : 00 216 km
Injection orbit	Semi-major axis: 6798.5 km Inclination: 5.753 deg	Semi-major axis: 6802,4 km Inclination: 5,754 deg
Libreville visibility	00 : 17 : 09 to 00 : 27 : 39	00 : 17 : 38 to 00 : 29 : 20
TDRS signal received	1 : 08 : 34	1 : 09 : 10
ARIA-1 visibility	1 : 15 : 42 to 1 : 20 : 30	1 : 15 : 34 to 1 : 23 : 25
Start or reentry	1 : 18 : 58	4746 s - 1 : 19 : 06 gap in longitude : 60 km
Acceleration (max.)	3.2 g	3.7 g
Trim	22 deg	20 deg
Roll angle command (max.)	105 deg	110 deg
Black-out	Between 90 & 42 km	Between 90 & 43 km
Cross-range	68 km	67 km
ARIA-2 visibility	1 : 22 : 05	1 : 25 : 02
Parachutes opening	1 : 28 : 14 altitude 14 km	5280s - 1 : 28 : 00 altitude 14 km horizontal acc. 3 km
Splash down	1 : 42 : 55 vertical velocity: 6.7 m/s impact: 7g	6079 s - 1 : 41 : 19 vertical velocity: 7 m/s impact: 7.3 g accuracy: 4.9 km
End of mission	1 : 47 : 55	1 : 46 : 23
Recovery		9 hours

Final phase: Spring 2000/January 2001
- Updated flight predictions, flight measurements and correlations
- Synthesis of conclusions and lessons learnt.

Flight events and actual versus expected major results
Table 1 shows the predicted events timeline and major orbital parameters, and those actually achieved during the mission. It can be seen that the trajectory was very close to prediction, but that some discrete variations did occur, which had an effect on the predicted performance. However, overall the profile was very accurate and capsule recovery (Fig. 5) was achieved within five hours of splashdown.

Aerodynamics/Aerothermodynamics
In terms of aerodynamics and aero-thermo-dynamics, the analysis was supported by CFD (Computational Fluid Dynamics), computations (Euler and Navier-Stokes) and tests in the high-enthalpy F4 (ONERA) and HEG (DLR) wind tunnels.

The analysis of the hypersonic trim behaviour was consistent with a Centre of Gravity (CoG) offset during the flight of the order of 3–4 mm. This could be explained by propellant consumption and heat-shield pyrolysis. CFD calculations confirmed the overall Angle of Attack (AoA) evaluation during the flight, whereas the pre-flight data underestimated the impact of real gas effects. The systematic flight-data analysis of the relative pressure data led to the conclusion that real gas effects were also observed below Mach 10. The same trend was confirmed by the additional CFD analysis carried out during the post-flight study.

The atmospheric sensitivity analysis based on the pressure density confirmed the flight-prediction values and is coherent within the applicable uncertainty band (predictive model CIRA 86).

The heating rates were difficult to assess due to a malfunction in the thermocouple measurements, but the temperatures closest to the surface appeared to be in the 700–800°C range. However, the predicted peak heating values could be correlated with the usable flight data if chemical non-equilibrium is assumed, because for the low heating rates non-catalytic predictions are confirmed by flight data. These trends have been well-reproduced by CFD and other engineering methods. The low catalytic effects at high altitude have been confirmed, whereas the occurrence of pyrolysis effects close to peak heating inhibits the low catalytic behaviour, resulting in heating rates closer to chemical-equilibrium conditions.

Another example of surprising phenomena is the rear cone section, for which the flight data differed from those predicted. The observed overheating cannot be reproduced by current CFD analysis, for which two interpretations have been proposed. The first is the occurrence of a transitional regime that cannot be correctly described by current turbulence models, and the second is inadequate finite rate chemistry modelling.

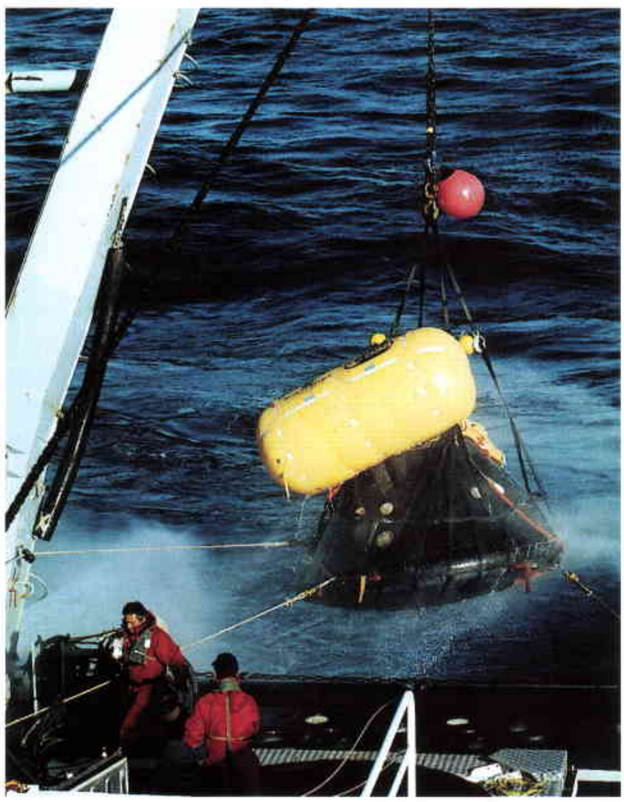


Figure 5. ARD capsule recovery

Thermal Protection System (TPS)
Several different types of TPS were applied to ARD, as shown in Figure 6:
- Aleastrasil (a compound containing randomly oriented silica fibres impregnated with phenolic resin) on the main heat shield
- Norcoat (composed mainly of cork powder and phenolic resin) for the cone section
- Samples of Flexible External Insulation (FEI) and Ceramic Matrix Composite (CMC).

A comparison of the ARD heat shield's state before and after flight is shown in Figure 7. The basic heat shield was a classical ablative, which had the function of protecting the demonstrator throughout the re-entry.

The Aleastrasil sample examination after coring confirmed the expected low surface recession

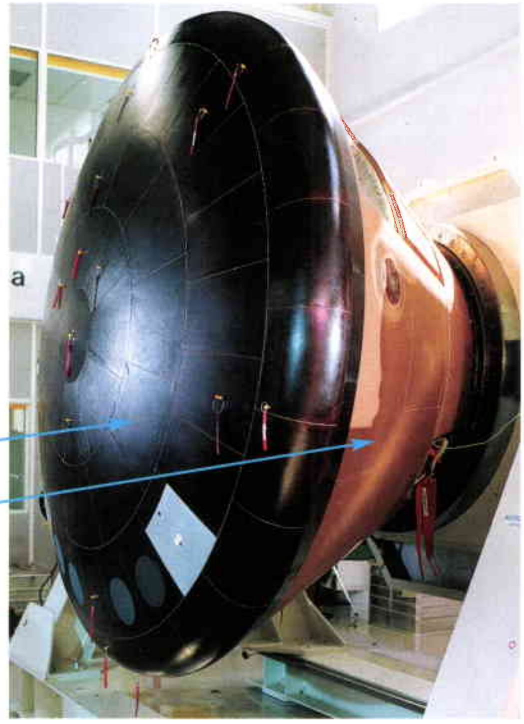


Figure 6. The ARD thermal-protection system

Figure 7. Comparison of the ARD TPS before (a) and after flight (b and c)

(a)

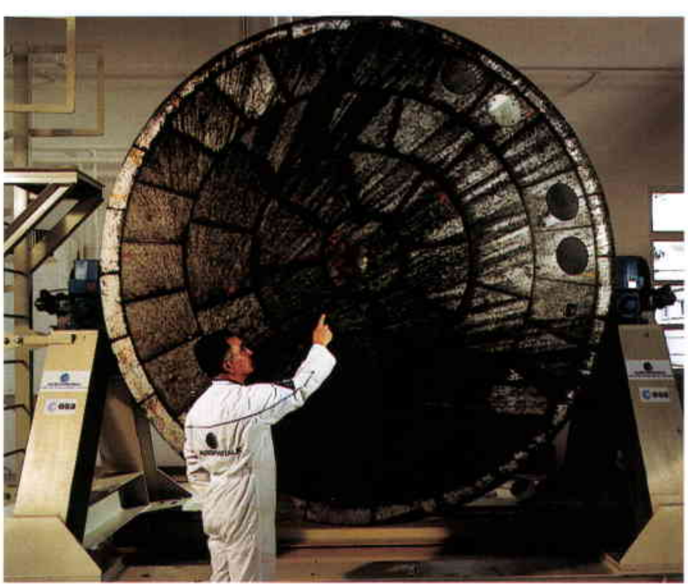
(0.1 to 0.3 mm) and provided an update to the thermal-properties data set, including measurement uncertainties to be taken into account for revised heat-flux reconstruction.

The other TPS materials are reusable, and one major test objective of the TPS flight experiment was their potential application to future re-usable re-entry vehicles.

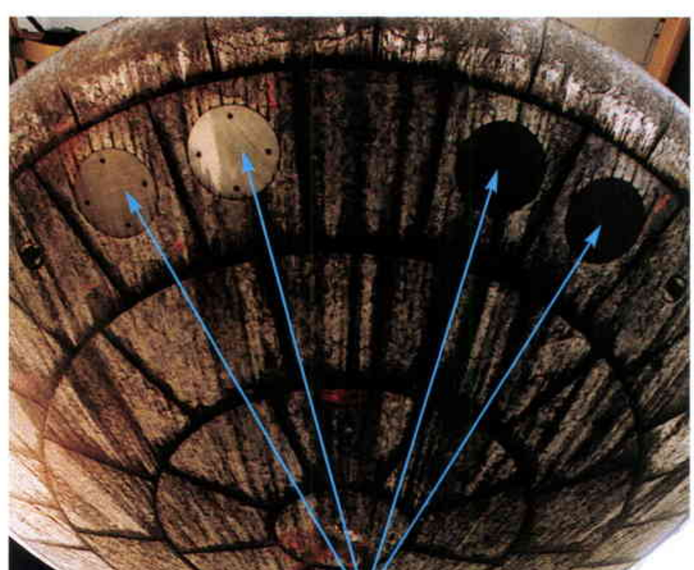
Each material has been visually inspected, demounted and processed through further mechanical tests, and finally the measured temperature values have been analysed and compared with design loads. The results were as follows:

– The FEI experiment did not show any degradation or damage due to the flight thermal environment. The thermal loads on the leeward side of ARD were significantly lower than expected, and therefore the thermal stresses on the FEI were far below its performance limit. During the recovery procedure, some severe damage was caused to the FEI by the hoisting device. Local rigid reinforcing would prevent this. Only a limited demonstration of the reusability of the FEI TPS on capsules is possible due to the severe landing conditions compared to winged RLVs.

– The CMC sample examination showed no degradation of the material's surface due to ablator contamination or the sea-water impact, and it was therefore a successful demonstration of this combination of CMC and ablator. However, due to the relatively low re-entry temperature level (the two thermocouples on the inner side registered about 900°C) only a limited performance demonstration was possible. Concerning lift-off and landing loads, no damage to either the samples



(b)



(c)

themselves or the attachment bolts was apparent. The surface morphology and oxidation protection layer remained unchanged. No signs of oxidation attack were apparent, but some slight increases in mechanical properties had occurred (explained by the witness sample manufacturing process). The maximum measured surface temperatures were around 940°C. In summary, it can be said that for all CMC samples the following applies:

- no material or oxidation damage
- no seal degradation, no carbon-fibre damage
- oxidation products probably coming from Aleastrasil pyrolysis
- no loss of mechanical properties by the samples after either the qualification test or the flight.

Another interesting experiment that was flown is the C/SiC screw. Here again, no damage has been observed on overloaded areas. The ratio of damaged thread tips is the same as that observed on virgin screws, and only a slight decrease in tensile rupture load can be observed.

The Norcoat performed as expected.

Flight control and GNC

The flight guidance, navigation and control hardware, as can be seen in Figure 8, consisted of:

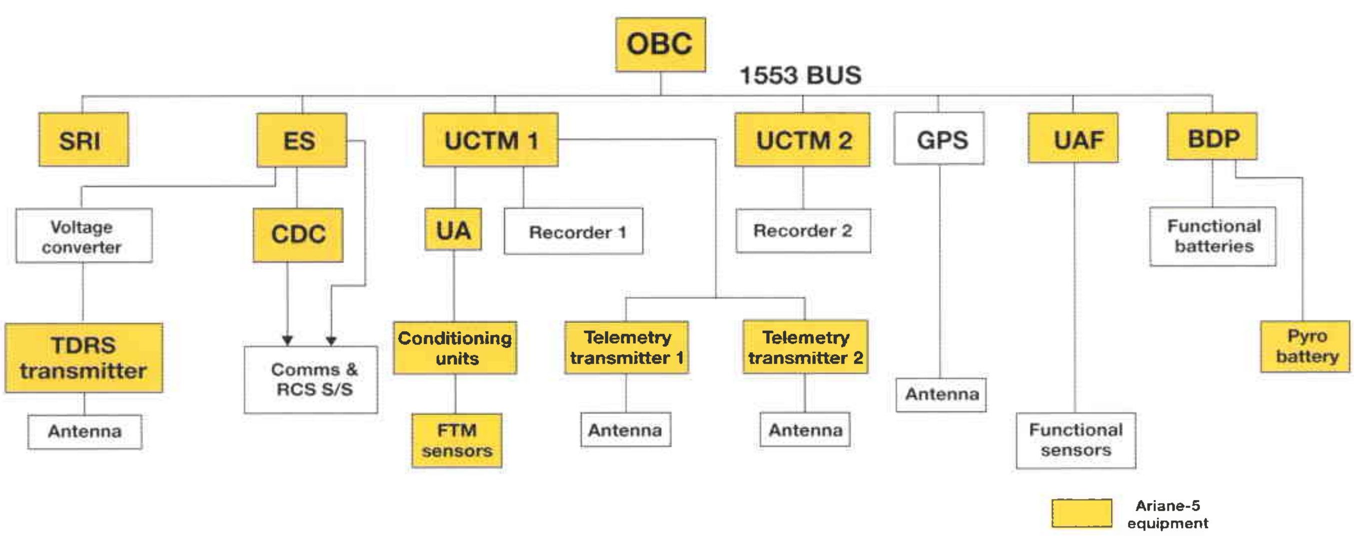
- a Global Positioning System (GPS) receiver
- an inertial navigation system
- a flight computer.

Examination of the trajectory accuracy showed that there was an attitude offset (time shift of bank-angle manoeuvre and a higher bank-angle value), including a higher load factor. These discrepancies could been explained by uncertainties in the atmospheric density model and the Mass Centering and Inertial (MCI) model. After updating these models with the CoG location, as well as the normal and axial force coefficients, the restored flight simulation was coherent with the flight data. Analysis of the propulsion model showed a higher fuel consumption than initially expected. This was due to an ARD jettisoning perturbation (CoG offset), which resulted in greater Reaction Control System (RCS) activation to reduce the range during re-entry and to cope with wind perturbations. Most of the velocity errors and hence also position errors were accumulated between 12 and 11 km altitude, due to large uncertainties in north-south wind gradients. Improvement of the atmospheric model, particularly the density element, is necessary.

The recorded Inertial Measurement Unit (IMU) and radar data were examined to establish the best-estimate reference trajectory. The ARD inertial navigation showed rather good performance. The errors at injection into orbit were lower than predicted and better than their specified value of one sigma. The ARD IMU behaved nominally during launch,during which 20 parameters were measured (biases, scale factors, misalignments, etc.). Weak residual inertial flaws were observed, but all stayed below their specified one sigma value.

The main contributors to navigation errors were the longitudinal accelerometer scale factor and IMU alignment error in trajectory characteristic data. This resulted in an updating of the IMU model for further trajectory analysis.

Figure 8. ARD functional block diagram



SRI: Système de référence inertiel, *Inertial measurement* unit
ES: Electronique séquentielle, *Sequential electronics*
UCTM: Unité centrale de télémesure, *Telemeasure central unit*
UAF: Unité d'Acquisition fonctionelle, *Functional acquisition unit*
BDP: Boitier de distribution de puissance, *Power distribution box*
CDC: Centrale de commutation, *Switching unit*
UA: Unité d'acquisition, *Acquisition unit*

Plasma and communications
Drag friction during re-entry creates a plasma (ionised gas) that can disturb the communications links. The ARD was specially equipped with eight dedicated skin antennas to prevent data loss in the TDRS and GPS satellite and Aria aircraft links (Fig. 8):
- 6 dedicated to the telemetry link
- 1 to the TDRS link
- 1 to the GPS link.

For the first time, the GPS flight data covered the launch conditions, orbital motion, and re-entry of a vehicle. The new 'code-only' mode that had been developed to enhance fast acquisition and robust tracking was successfully validated in flight. Quasi-permanent tracking of nine satellites with a single patch antenna during all accessible flight domains (except the black-out period) was demonstrated, and even the vehicle's rotating motion during the parachute phase was clearly indicated.

The analysis of the GPS data has contributed significantly to our understanding of plasma formation and its effects, which included:
- very unsymmetrical attenuation effects, lasting from 180 to 300 seconds
- forefront satellites disappeared first and reappeared last
- partial reacquisition.

The post-flight plasma analysis activities showed:

- the usefulness of axi-symmetric calculations on the windward side for studying the different effects and guiding modelling selection for 3-D calculations
- the relatively good agreement between calculations and measurements at altitudes of 85 and 46 km
- the calculated plasma frequencies and TDRS link attenuations are clearly greater than the measured ones at an altitude of 61.5 km.

The communication analysis results showed:
- blackout for GPS links on the leading edge from 92 to 28 km altitude
- blackout for GPS links on the trailing edge
- from 87 to 41 km altitude
- attenuation due to plasma for the TDRS link from 86 to 44 km altitude (no complete black-out)
- attenuation due to plasma for the Aria-1 telemetry links (backward side) from 84 to 77 km altitude
- blackout for the Aria-2 telemetry links from 70 km (beginning of recording) to 42 km altitude
- plasma measured by reflectometer (on the shield) from 100 to 42 km altitude.

The visibility picture for the between Aria-1and -2 links is summarised in Figure 9.

Parachutes
The overall study consisted of modelling using DCAP (Dynamics and Control Analysis Package) software, flight-data analysis and correlation of the two (Fig. 10).

The main results of the study confirmed:
- the suitability of the drag-area growth formulas for inflation loads
- 80% is the appropriate scaling factor to be applied for the descent-rate/drag-area calibration for the 20% porosity conical ribbon drogue chutes in capsule wake fields

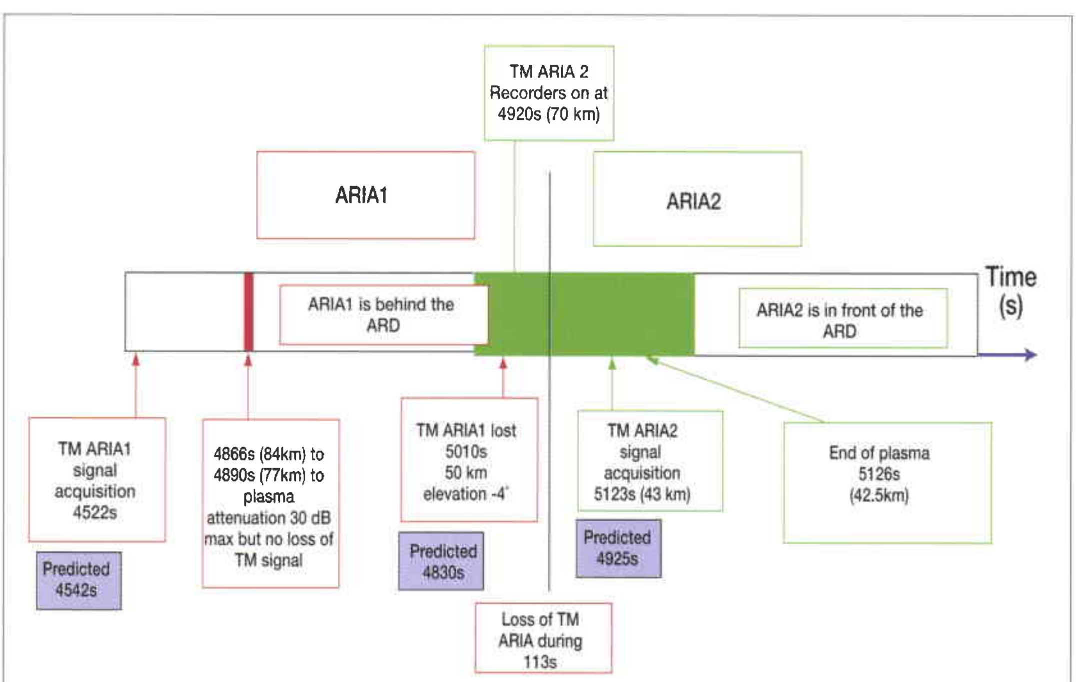


Figure 9. Visibility window with Aria-1 and Aria-2

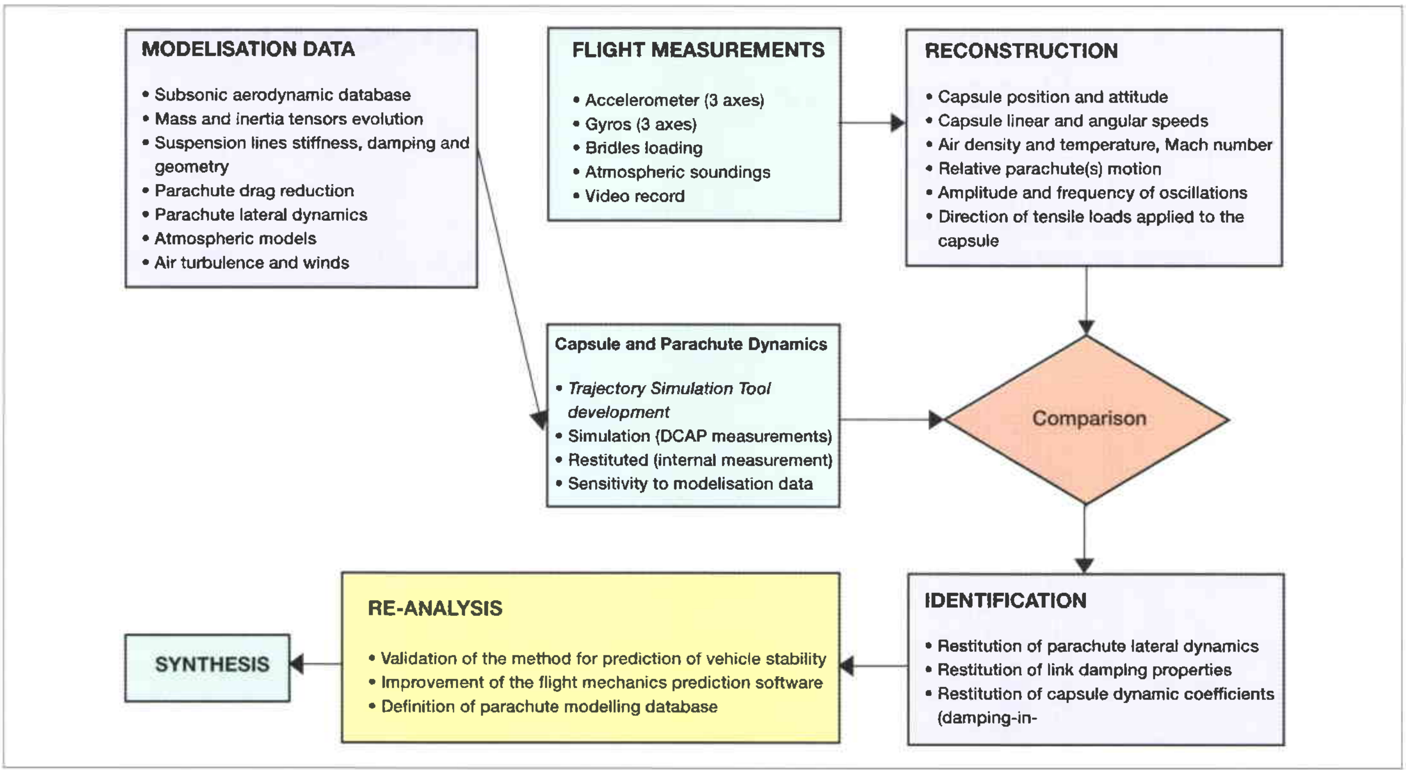


Figure 10. The parachute study elements

- simplified 1-D codes (two-body system) are fully applicable for the deployment analyses, with a safety factor of 10% for the estimation of stretch velocity and snatch force
- the suitability of the simulator for stability prediction in 2-D (pitch) analysis.

Lessons learned

In general, it can be said that the ARD flight was successful and the initial demonstration objectives set for it were fully achieved. Despite the protoflight nature of the approach applied, the initial flight-data analysis has already confirmed the following major achievements:

- demonstration of Europe's ability to master re-entry technologies
- successful overall mission control from launch to recovery
- splash-down in the Pacific less than 5 km from the expected position
- nominal behaviour of all main equipment and functions
- demonstration of Ariane-5's ability to service complex missions
- demonstration of European industry's ability to manage such a project under tight financial and planning constraints.

Nevertheless, it has to be said that complete mastery of re-entry technology is still quite a challenge. The ARD has a simple shape, and yet there were some significant discrepancies between actual and predicted results. Most could be explained, understood and corrected a posteriori, but more complex shapes can be expected to generate greater discrepancies. The flying of real hardware is therefore mandatory in a stepped approach to accumulate sufficient expertise in mastering re-entry systems. The need for flying prototypes before progressing to operational vehicles is clear.

Conclusions

This first European post-flight analysis of the complete mission scenario for a re-entry vehicle, covering its launch, orbit, re-entry and landing, has greatly improved our knowledge of the real flight environment. Europe's ability to manage a complete mission of this type, including recovery, has been successfully demonstrated. Further experience with instrumented experimental flight vehicles is mandatory to improve Europe's mastery of future space-transportation missions involving re-entry vehicles, and the results of the unique ARD flight will certainly help greatly in the preparation of future flight demonstrators (X-38/V201 and others).

Programmatically speaking, the hands-off management approach adopted by the Agency with ARD, delegating responsibility for the major development effort to Industry, proved to work well and greatly reduced the number of contract changes required. The use of non-high-reliability and off-the-shelf hardware was also shown to be perfectly adequate, with the simplified Critical Design Review and Flight Acceptance Review that were conducted.

Acknowledgement

The support and expertise of R. Molina, A. Pradier and R. Bonhomme is gratefully acknowledged.

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Vega: The European Small-Launcher Programme

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By the end of 2001, the development programme for Europe's new small Vega launcher was well underway. The System Preliminary Design Review had been concluded in July 2001 with positive results, confirming that the technical baseline is sound and consistent with the strict system and programmatic requirements. At motor-development level, the Zefiro motor that will power Vega's second stage has already undergone one demonstration and two development full-scale firing tests at the Sardinia test range. The next key milestones are the System Design Review (SDR) foreseen for early 2003 and the Critical Design Review (CDR) scheduled for March 2004. The parallel activities for Vega's new first-stage P80 motor and for the ground segment are also progressing according to plan, and are consistent with a first Vega qualification flight by the end of 2005.

Background

The origins of the Vega Programme go back to the early 1990s, when studies were performed in several European countries to investigate the possibility of complementing, in the lower payload class, the performance range offered by the Ariane family of launchers. The Italian Space Agency (ASI) and Italian industry, in particular, were very active in developing concepts and starting pre-development work based on established knowhow in solid propulsion. When the various configuration options began to converge and the technical feasibility was confirmed, the investigations were extended to include a more detailed definition in terms of a market analysis and related cost targets.

As a conclusion of these preparatory activities, in February 1998 ASI proposed that a small launcher – in the meantime called 'Vega' – be developed within the ESA framework as a co-operative project with other ESA Member States. The main requirements as then defined were:
- launch of an 800 kg payload into Sun-synchronous orbit (SSO) at 1200 km altitude
- launch from Kourou, French Guiana
- a 2 m payload-envelope diameter
- maximum synergy with other Ariane developments
- low recurring cost (less than US$ 20 million)
- a first launch before early 2003.

The programme was adopted by ESA in June 1998, but the funding was limited to a Step 1, with the aim of getting the full approval by the European Ministers meeting in Brussels in May 1999. This milestone was not met, however, because it was not possible to obtain a wide consensus from ESA's Member States for participation in the programme. This gave rise to a period of political uncertainty and to a series of negotiations aimed at finding an agreeable compromise. It is important, on the other hand, to record that during the same period the technical definition work continued without major disruption, and development tests on the Zefiro motor were successfully conducted.

The subsequent extension of the duration of Step 1 provided the opportunity to revisit and update the market analysis, based on the evolution taking place in terms of potential customers and competitors. The result of this exercise indicated the need to refocus the reference mission towards Earth-observation payloads, and to increase Vega's performance to be able to launch a 1500 kg satellite into a 700 km polar orbit, whilst still maintaining the cost target. Several iterations were performed to optimise the configuration, the results of which are summarised later in this article.

One of the major options selected after technical and programmatic trade-offs is represented by the adoption, as the first stage for Vega, of a new high-performance solid motor featuring several technology advances, in particular a filament-wound (FW) case structure not yet available in Europe for the size, propellant mass and internal pressure combination needed. This new motor, called P80 FW in association with the 80 tonnes of propellant mass, will not only offer increased performance and lower production costs, but also pave the way to future applications for medium-size launchers complementary to Ariane-5 and for a new generation of boosters for Ariane-5 itself.

After about two years of definition and consolidation activities, the Vega configuration, including the new P80 FW first stage, two additional solid stages (Zefiro 23 and Zefiro 9) as, respectively, second and third stages, and the upper module AVUM, was established and ready for development as an ESA programme. On the other hand, the choice of the P80 FW implied a stretching of the duration of the programme to allow for the demonstration of the new technologies involved. Consequently, the first launch of Vega is now scheduled by the end of 2005. The formal funding was granted by the participating European States in December 2000, within a financial envelope of 335 million Euros. Seven countries have subscribed to the programme: Italy, France, Spain, Belgium, the Netherlands, Switzerland and Sweden. In parallel, the development of the P80 FW motor was approved, with a budget of 123 million Euros, about half of which is provided by Fiat-Avio as an industrial contribution. In addition to Italy, France, Belgium and the Netherlands are participating in the funding of the P80 development.

Market opportunities for the Vega launcher

The decision to develop a small launcher is a response to a Resolution in the Space Transportation Strategy adopted by the ESA Council in June 2000, aiming at: *"completing, in the medium term, the range of launch services offered by the addition of European-manufactured small and medium launcher, complementary to Ariane, consistent with diversified users' needs and relying on common elements, such as stages, subsystems, technologies, production facilities and operational infrastructure, thereby increasing the European launcher industry's competitiveness".*

Vega will also satisfy a potential market for launching small satellites identified in several forecasts. NASA, for example, is putting an emphasis on 'small missions' making use of low-mass satellites and low-capacity launch vehicles, and several European space agencies, especially the French and Italian agencies, will follow similar paths. The development of small-satellite standard platforms, such as Minisat, Proteus and PRIMA, has already been initiated. It is expected that the availability of such standard platforms will attract several applications, allowing cost reductions and new project starts.

From a technical point of view, the recent evolution in Earth-observation technologies is allowing a reduction in satellite masses. Optical and infrared detectors are now much smaller and, even in the field of radar observation, all-weather surveillance can be performed using satellites with masses of around 1 ton. ESA's Earth-Observation Programme currently has two main components: Earth Explorer, science-driven missions, and Earth Watch for application missions. Both are based on multiple small missions instead of another single large satellite like Envisat. Small satellites are increasingly being considered a suitable alternative to traditional satellites for visible- and radar-imaging military Earth-observation missions also.

For its scientific missions too, ESA is proposing a family of small satellites to demonstrate enabling technologies to be used for future larger missions (SMART for electric propulsion, etc.).

In the field of telecommunications, two possible types of mission are identified for small launchers. 'Little LEO' constellations, which are dedicated to data transmission, store and forward services in real time and messaging applications, are based on satellites weighing some hundreds of kilogrammes. These satellites may be launched as a single or multiple payload by a small launcher. 'Big LEO' constellations are based on satellites of about one ton. For these systems, spares management is not a trivial process, and the timely replacement of a failed spacecraft typically in less than two months allows a major saving. With constellations relying on a very large number of satellites, the market potential for small launchers is linked to the need for such replacements, it being understood that the overall deployment strategy will rely mainly on medium and heavy launchers.

As a result of several different, independent assessments of the potential market for a European small launcher, it has been estimated that the number of European (and a few non-European) governmental missions that will make use of a small launcher will initially be of the order of two per year, and may grow to four per year after 2005, with a total of 30 to 35 launches in the period 2004 – 2013.

Current projections show that for little-LEO constellation deployment, and for big-LEO (e.g. Globalstar, Iridium) and broadband LEO satellite replacement, the market is very uncertain. Taking into account the rapid changes and the uncertainties as to how constellations will develop, the number of additional payloads originating from the commercial applications is estimated to be one or two per year. In the long term, an increased launch rate may be envisaged as a consequence of two possible events:

- confirmation of the validity of the small-mission approach

– improvements in miniaturisation technologies for small satellites.

In conclusion, combining the forecasts for the various categories of customers described above, the projected market for a European small launcher may be three to four launches per year in the initial years, starting from 2004. This is expected to grow to five or six launches per year once the service is well established, and the vehicle is marketed internationally by an experienced organisation such as Arianespace. This projected market represents a realistic baseline for Vega operations.

Obviously, the key parameter driving the commercial success of a new launcher is the cost of the launch service it can offer. The target set for Vega from the beginning of the programme was that of being at least 15% cheaper than the market competitors offering western standards of launch services. Figure 1 provides a comparison of Vega's position vis-à-vis estimates for other launchers.

Vega small-launcher objectives

On the basis of the identified European needs, particularly in the field of radar satellite systems, and of the requirements emerging from the market survey, the in-orbit capability for the reference mission is specified as:

- 1500 kg of payload to a 700 km altitude, circular polar orbit
- Kourou as the launch site.

In addition to the reference mission, Vega will be able to launch satellites for a wide range of missions and applications, for instance with a range of orbital inclinations from 5.2 degrees to SSO, altitudes between 300 and 1500 km, and payload masses between 300 and 2500 kg.

Vega provides a minimum payload dynamic envelope, in a single launch configuration, defined by a cylindrical volume of 2.35 m diameter and 3.5 m height, plus an additional conical volume of 2.8 m (with a height of 2.8 m). Growth-potential studies are being carried out to investigate the design impact of increasing the length and/or diameter. The payload is supported by a standard 937 mm-diameter mechanical interface, the separation device being provided by the launcher. The probability of a Vega launcher failing to inject its payload into the specified orbit, due to failure or malfunction of any component, shall not exceed 0.02 (i.e. minimum reliability of 0.98, with a confidence level of 60%).

Limiting the cost whilst preserving and improving the launcher's competitiveness, is one of the major objectives in Vega's development. The key factor in that cost limitation is to streamline the industrial organisation and to maximise synergy with the Ariane launchers, by using the same components, the same production facilities and launch infrastructure, and relying on technologies, facilities and hardware developed within the Ariane and other national programmes. To improve competitiveness, the Vega development includes new technologies, particularly in the field of solid propulsion. All of these new technologies offer potential spin-offs to Ariane.

Consistent with the market projections and the performance to be offered, the ultimate programme objective is to achieve the qualification launch of Vega by the end of 2005.

Characteristics of the launcher

Vega is designed as a single-body vehicle composed of three solid-propulsion stages, an additional liquid-propulsion upper module, and a fairing for payload protection (Fig. 2).

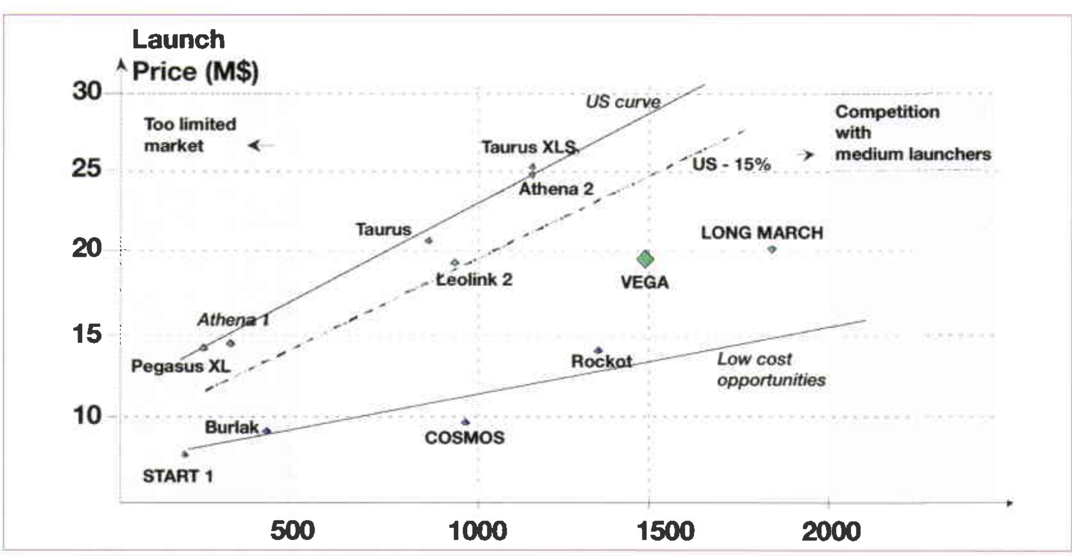


Figure 1. Price/performance comparison for Vega and other launchers

The three solid stages perform the injection of the upper composite into a low-altitude orbit. The liquid upper module, called 'AVUM' (Attitude and Vernier Upper Module), is necessary to improve the accuracy of the primary injection (compensation of solid-propulsion performance scatter), to circularise the orbit and to perform the de-orbiting manoeuvre. This module will also provide roll control during the third-stage boost phase and the three-axis control during ballistic phases and before payload separation. The launch sequence is shown in Figure 3.

First stage

The first stage is based on the adoption of the new P80 solid-rocket motor to be developed through a parallel programme slice. This new motor is sized to respond to the basic requirements of the Vega first stage. The specific features of the P80 motor development are described later. In addition to the P80 motor, the first stage is composed of the structural elements needed to connect it to the second stage (interstage 1/2 aft part) and to the ground infrastructure (interstage 0/1), and to host the stage avionics. Those airframes are aluminium shells, with integrated stiffeners on the inside. The rear skirt (interstage 0/1) is a cylindrical structure, while the interstage 1/2 is a conical structure, in order to match the different stage diameters.

Second stage

The propulsion for the Vega second stage is based on a stretched version of the Zefiro 16 solid-rocket motor (SRM), with the propellant mass increased to 23.8 tons. Three firing tests of the Zefiro motor have been performed, in June 1998, June 1999, and December 2000,

Figure 2. The Vega launcher

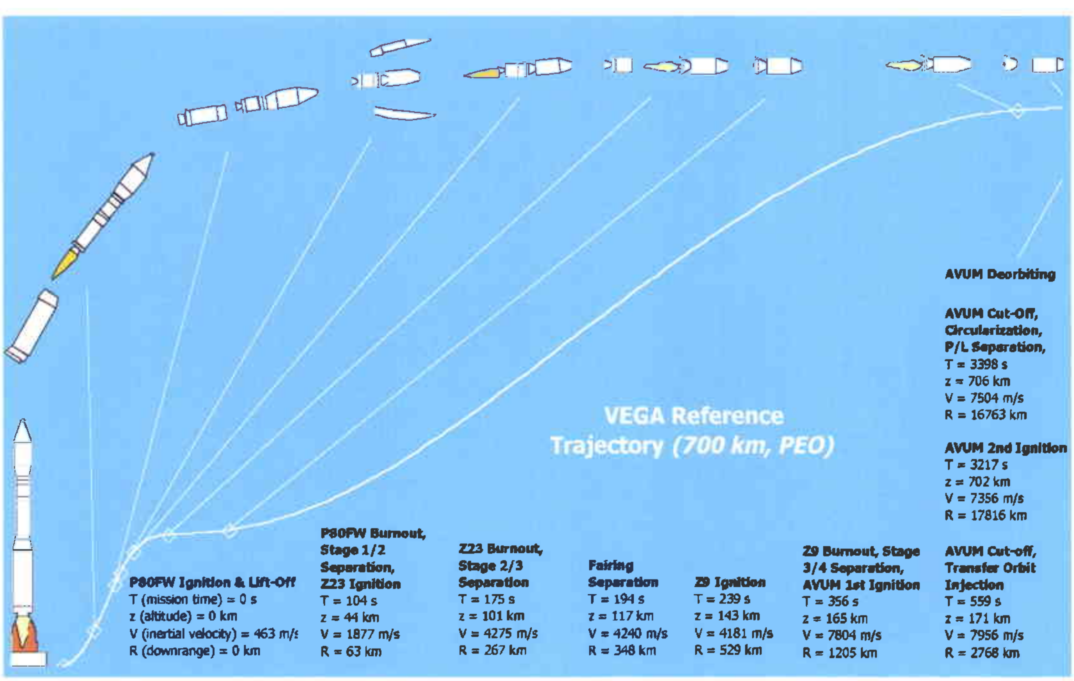


Figure 3. The Vega launch sequence

all with good results. Figures 4 and 5 show the last firing test performed on 15 December, at the Salto di Quirra test bench in Sardinia.

The new stretched SRM is known as Zefiro 23 and employs:
- a lightweight carbon-epoxy case
- low-density EPDM-based thermal insulation, charged with glass microspheres
- HTPB 1912 composite propellant
- a moving nozzle, based on flexible-joint technology.

Polar fittings and interstage flanges are high-strength aluminium forgings. The propellant grain has a finocyl shape, with the star section in the aft zone of the motor near to the maximum polar opening. The star-shaped section consists of a conventional star, with a 3D-transition region coupled to the cylindrical region. The maximum vacuum thrust and pressure of Zefiro 23 SRM are 1200 kN and 95 bars, respectively. The nominal burning duration of the second stage is about 71 sec. The nozzle throat diameter is 294 mm and the expansion ratio is about 25. In addition to the Zefiro motor, the second stage includes the structural elements needed to connect it to adjacent stages and to host the stage avionics. In particular, interstage 2/3 is an aluminium cylindrical structure composed of shells with integrated stiffeners on the inside.

Figure 4. The Zefiro 16 QM1 firing test at Salto di Quirra, Sardinia, on 15 December 2000

Figure 5. Preparation of the Zefiro 16 QM1 motor for the firing test on the Salto di Quirra test bench

Third stage

The Vega third-stage propulsion is based on a solid-rocket motor with a propellant mass of 9 tons, known as Zefiro 9 SRM, and strictly derived from Zefiro 16. Zefiro 9 employs a carbon-epoxy filament-wound case, a low-density EPDM-based thermal insulation, HTPB 1912 composite propellant, and a moving nozzle based on flexible-joint technology. Its maximum vacuum thrust and combustion pressure are 280 kN and 67 bars, respectively. SRM ignition occurs after a coasting phase of several seconds (according to the required trajectory), after Zefiro 23's burnout. The nominal SRM combustion duration is about 117 seconds. The nozzle throat diameter is 164 mm and the expansion ratio is 56.

The interstage connects Zefiro 9 to the AVUM, and hosts the stage avionics and the safeguard main unit.

AVUM

The AVUM upper stage is composed of two different sections, one hosting the propulsion elements (APM: AVUM Propulsion Module) and one dedicated to the vehicle equipment bay (AAM: AVUM Avionics Module). The APM provides attitude control and axial thrust during the final phases of flight, in accordance with the mission requirements. It fulfils the following functions:

- roll control during third- and fourth-stage flight
- attitude control during coasting flight and the in-orbit phase
- correction of axial velocity error due to solid-rocket-motor performance scatter
- generation of the required velocity change for orbit circularisation
- satellite pointing
- satellite-release manoeuvres
- empty-stage de-orbiting.

The current technical baseline includes the adoption of a liquid bipropellant system for the primary manoeuvres, using nitrogen tetroxide (NTO) as oxidiser and unsymmetrical monomethyl-hydrazine (UDMH) as fuel, both fed by gaseous helium under pressure, and a cold-gas system (GN2) for attitude control.

The total propellant loading will be between 250 and 400 kg, depending on the configuration definition and the mission to be performed.

The AAM hosts the main elements of the launch vehicle's avionics subsystems.

Upper composite

The upper composite includes the payload adapter and the fairing. The upper-stage configuration imposes the use of a conical structure in order to provide the required payload standard interface of 937 mm diameter. The reuse of an existing Ariane adapter design is foreseen.

For the fairing, a two-shell configuration has been defined, with a 2.6 m external-diameter cylindrical part and a total height of 7.5 m – including a 3.5 m cylindrical part. The structure is made of two composite shells, composed of aluminium honeycomb and carbon skins. Several access doors are provided on each shell. Moreover, the fairing is equipped with venting ports (Ariane-5 type). The fairing is jettisoned by the combined action of a clamp-band attachment and pyrotechnic longitudinal separation system during the coasting phase between the second- and third-stage propulsion phases.

Avionics

To keep the development and recurring costs to a minimum, Vega's avionics will be largely based on the adaptation of existing hardware and/or components already under development. For the same reason, particular attention has been paid to defining the most appropriate architecture for the avionics subsystems. The baseline architecture consists of a centralised approach, somewhat similar to the Ariane-5 concept. Four main subsystems are defined for the electrical system:

- Power Supply and Distribution
- Telemetry
- Localisation and Safeguard
- Flight Control and Mission Management.

The safeguard subsystem is the only Vega chain with complete redundancy, in order to comply with the launch safety requirements. For the functional subsystems, there are specific redundancies at equipment level, where relevant, to improve the launcher's reliability.

The Flight Control Subsystem will use an on-board programmable flight computer, an Inertial Measurement Unit (directly derived from that used on Ariane-5), and thrust-vector control electronics for guidance, navigation and control.

A multi-functional box will deliver electrical commands for mission management, and stage and payload separations on reception of signals sent by the on-board computer. The telemetry subsystem will be similar to that of Ariane-5, as it must be compatible with existing standards and protocols in use in ground stations.

For the safeguard subsystem, the Ariane-5 tracking architecture will be applied, reusing already developed components (transponders, antennas). The destruct functions will be managed through new equipment, the Safeguard Master Units (SMUs) and Safeguard Remote Units (SRUs) located in the stages.

Main features of the P80 motor

The improvement of solid-propulsion capabilities by the adoption of advanced technologies is one of the building blocks of the European strategy. The development effort has two primary objectives:

- demonstration of most of the technologies necessary to guarantee the Ariane-5 solid-rocket booster's competitiveness
- development and qualification of the first stage of the European small launcher, representing the first step towards a new generation of European solid motors (Fig. 6).

Figure 6. The P80 motor

The motor is tailored and is directly applicable to the Vega small launcher, but its scale is also representative for validating technologies applicable at a later stage to a new generation of Ariane-5 solid boosters. A comparison between a Vega first stage, based on current Ariane-5 technologies, and the new P80 solid boosters is shown in the accompanying table.

Table 1. Main technology choices

Component	P85 Metallic, Ariane-5 derived	P80 FW
Case	Metallic, re-use of Ariane-5, D6AC steel, two segments	CFRP monolithic carbon fibre
Propellant grain	Monolithic Finoxil aft star	Monolithic Finoxil aft star
Propellant	18 14 PBHT	19 12 PBHT
Insulation	GSM55-EG2 (Ariane-5)	EG1LDB3 (from Zefiro) low density
Nozzle throat	3D C/C	3D C/C new low-cost material
Exit cone	Metalllic housing + thermal protection	Composite, structural carbon phenolic
Flex joint	Boot-strap protection	Self-protected/low-torque
TVC actuator	Hydraulic	Electro-mechanical

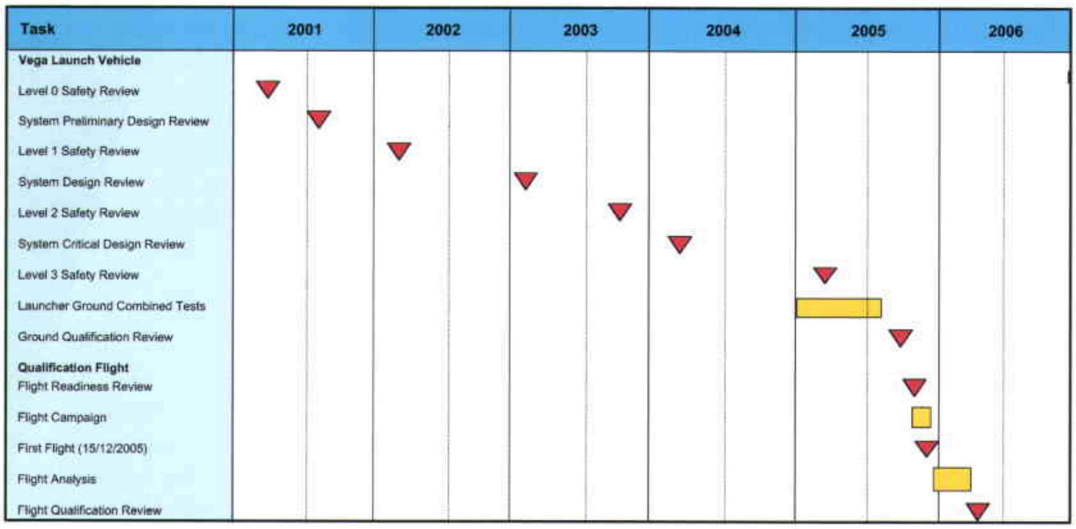


Figure 7. The Vega Master Development Plan

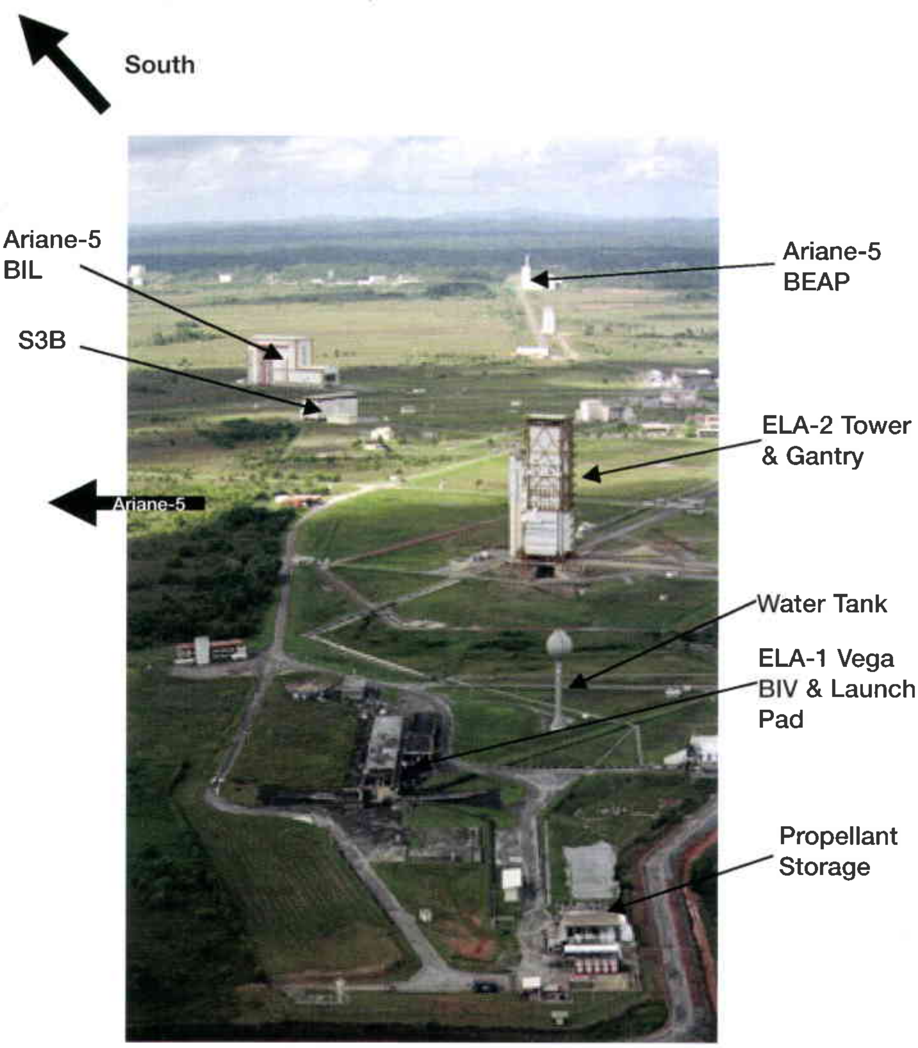
The development milestones are consistent with the requirements of the Vega Small Launcher Development Plan, and the P80 Solid-Propulsion-Stage Demonstrator development, including its qualification at stage level, should therefore be completed by 2005 (Fig. 7). Maximum reduction of the recurring cost is a driving parameter at all levels of the solid-rocket motor's design (subsystems, components, equipment, ground infrastructure, operations, etc.).

The target of a 25–30 % reduction in recurring cost with respect to that of the 'metallic case boosters' has been set for both the Vega first stage and the new-generation Ariane-5 booster. There is a further reduction in the specific launch cost due to the increased performance achieved by the new generation of booster.

The ground segment

The European launch facility (CSG) in Kourou, French Guiana, offers a variety of launch azimuth capabilities (equatorial, polar and intermediate inclinations) and existing infrastructures, services and logistic support, which make it the natural choice for the new European small launcher. The actual site selected for Vega, following a trade-off between the different options possible in Kourou, is ELA-1, located between the Ariane-4 and Ariane-5 launch areas (Fig. 8).

Figure 8. The Vega launch and integration area



The new Vega ground segment will make use of the existing Ariane infrastructure, such as the Ariane-1 launch pad at ELA-1 and the Ariane-5 Control Centre. Vega will be assembled on the launch pad. The assembly and integration operations will be performed in a new BIV (Bâtiment d'Intégration Vega) building. The BIV will be a mobile integration building which, after the launcher's final assembly, will move away from the launch pad. Launch operations will be conducted from a dedicated room within the Ariane-5 Control Centre (CDL-3).

XMM-Newton In-Orbit Calibration

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Two years after launch of the XMM-Newton Observatory saw a gathering of about 350 scientists at ESTEC for the Conference 'New Visions of the X-ray Universe'. This huge interest in the mission and the rapidly increasing number of scientific papers published as a result of XMM-Newton observations show the importance of ESA's latest observatory for astrophysics in the 21st century.

A vital part of the scientific interpretation that enables this work is the accuracy and reliability of the instrument calibration. To highlight this feature, a session at the Conference was devoted to a Calibration Workshop, allowing the instrument teams to explain the details of the improving knowledge and remaining limitations. This article reflects some of the presentations made in that Workshop, and reviews the general in-orbit calibration activities, explaining some of the complexities involved.

Introduction

We are familiar with the high-resolution, often dramatic, images being produced by astronomical observatories in recent years. While astronomers frequently infer vital information from such images, more detailed diagnostics of temperature, pressure, chemical composition and dynamical state are indispensable for probing the true nature of celestial objects. Spectroscopy is perhaps the major tool for accomplishing these astronomical investigations, and so XMM-Newton was conceived as a mission to exploit X-ray spectroscopy as a tool for probing the conditions in some of the hottest and most extreme environments in the Universe.

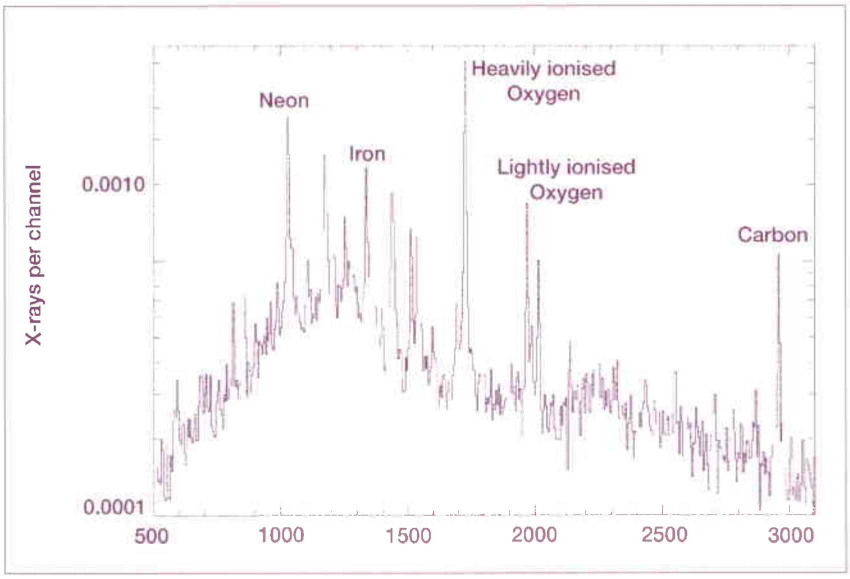


Figure 1. A typical spectrum produced by the XMM-Newton Reflection Grating Spectrometer (RGS) instrument. The horizontal axis is proportional to the energy of incoming X-rays. Strong features have been identified with different states of certain ionised elements in the hot atmosphere of the star being observed

In Figure 1 we highlight how this can be done, with the spectrum detected by the XM-Newton Reflection Grating Spectrometer instrument plotted as intensity versus wavelength. The relative intensities of the different bright features reflect the probability of transition of electrons between different energy states of ionized atoms, and are in turn directly related to the temperature and density of the plasma responsible for the X-ray emission. However, unless we know precisely the relative detection efficiency of the instrument for each wavelength, this diagnostic is lost. This example therefore illustrates the essence of the calibration activity – namely that we must have an accurate description of the instrument parameters and how they affect the recorded data. Moreover, we need to specify for the scientific end-users how reliable this information is.

Cosmic standards

For many years, the community of ground-based astronomers observing in the visible wavelengths of light has used 'spectrophoto-metric' standards – namely stars with well-known characteristics of light emission in different colours – for calibration activity. Essentially each new instrument or telescope has only to look at a handful of these different standard stars to be able to reference its performance to other instruments, and to the fundamental physics knowledge that is embodied in the simple emission mechanisms of these stars.

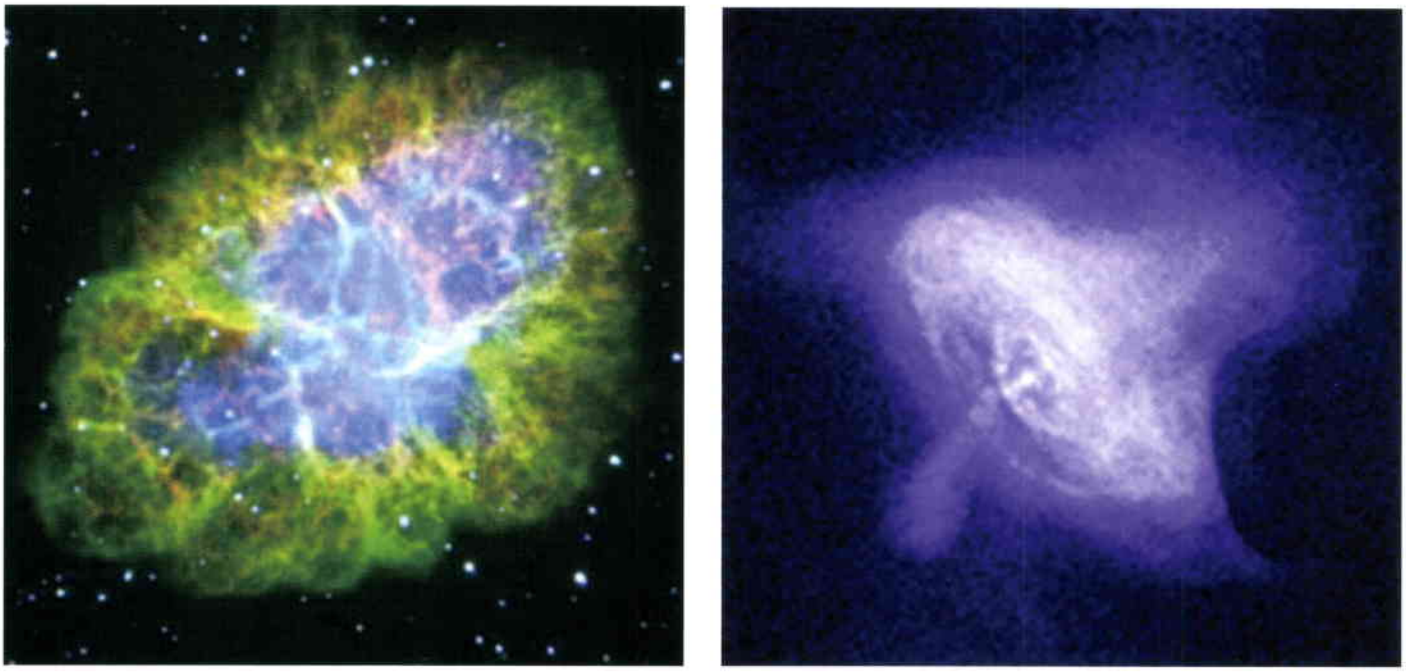


Figure 2. The Crab Nebula seen in visible light (left, courtesy of ESO) and X-rays (right, courtesy of NASA/CXC/SAO). The visible light image traces filaments of hot gas, which are a remnant of the stellar explosion. The X-ray emission comes from electrons spiralling in a strong magnetic field, and therefore the two images trace totally different components of this complex region

In X-ray astronomy, no such 'standard candles' are known. At best, in the 1960's and 70's, which represented the early years of X-ray astronomy's development, most instruments were pointed to the Crab Nebula as part of their calibration activity (Fig. 2). This is about the brightest object in the X-ray sky, and is believed to represent the remnant of a titanic stellar explosion in the year AD 1054. The spectrum of X-radiation given off by the remnant is assumed to have a simple form that decreases with energy by a simple power law. The instrument's response can be cross-checked against this assumption. Nevertheless, the inferred brightness and detailed physics behind these energy characteristics of the Crab have always been a little in doubt.

To compound the problem for modern observatories, their collecting power is now so much more enormous than previous instruments, that generally they are unable to observe the Crab Nebula in normal operating modes, because the brightness exceeds their ability to count the individual X-rays properly! The challenge therefore has been to devise a programme of observations of a wide variety of cosmic sources that is suitable for verifying ground-based measurements of the instruments or substituting for our inability to make representative measurements on the ground, and interpret the data in a manner suitable for science analysis.

Ground limitations

In principle, one could measure all the necessary properties on the ground before launch, but this usually proves difficult, and indeed was not possible for XMM-Newton for a number of diverse reasons:

(a) Lack of time – instrument completion is typically one of the last hardware phases in the mission development, such that waiting for several months for end-to-end calibration of the complete instrument would add a significant and expensive delay to the overall programme. In any case, to collect enough X-rays at representative brightnesses would take a huge amount of time.

(b) Replacement of flight units – late in the hardware delivery programme, a number of flight units had to be replaced due to unexpected failures, and spare detectors were eventually flown which were not calibrated to the depth and accuracy of the former intended flight units.

(c) Parallel beams – X-rays from cosmic sources illuminate the telescope entrance in essentially parallel beams. On the ground, the facilities for creating X-ray beams from tiny high-voltage vacuum tubes are implemented in very long test facilities, which are designed as much as possible to mimic flight conditions. However, even a small diversion of light rays from a point source prevents complete illumination of the entrance aperture.

(d) Changing knowledge – only on completion of the accelerated on-ground measurement programme was the detailed analysis of instrument performance made, and some subtle aspects revealed that with the benefit of hindsight more or different measurements were required to interpret accurately.

Special XMM challenges

XMM-Newton carries the largest-ever focusing X-ray mirrors. This is a key element of its spectroscopic performance, because astronomers need to collect as many photons as possible at all X-ray wavelengths. This inevitably means that any systematic misunderstanding in its collection efficiency becomes evident above statistical fluctuations much sooner than would be the case in smaller observatories.

An additional novel feature of XMM-Newton is the simultaneous operation of all its instruments, pointing to and observing the same patch of sky. Observing an object with different instruments with their very different characteristics can in some senses aid the calibration by providing a crosscheck for each other. On the other hand, the general observer also wants to combine data from the different instruments for his/her own analysis and needs a very secure knowledge that the cross-calibration is reliable. For previous observatories, it was possible ignore cross-calibration difficulties under the assumption that the astronomical target had perhaps varied between different observations.

To maintain the greatest possible flexibility, the XMM-Newton instruments have been provided with different operating modes. For example, the CCD arrays of the EPIC camera can be programmed to read out restricted areas only of the focal plane in order to accommodate very bright objects. These cameras also have different filters that can be deployed in the focus to provide different amounts of visible-light-blocking capability, should the target happen to be a very bright visible magnitude star, which might swamp the X-ray signal, for example. The RGS instrument has the capability to select out a small portion of the spectrum and rapidly read out the data with high time resolution. Nevertheless, each and every operating mode needs to be calibrated with the appropriate accuracy, putting an additional burden on the development of the calibration database.

Early commissioning-phase activities

The spacecraft subsystems were declared to be commissioned in early spring 2000, at which point the long-planned sequence of observations of calibration and performance/verification targets was started. In reality this phase was also used to debug and tune a large range of ground-segment changes. This was necessary partly due to the accelerated launch date, which did not leave time for comprehensive testing of the ground software systems, and partly because of the usual array of unexpected instrument operation details that arise when new detector systems are deployed in orbit for the first time.

Early calibration activity was therefore performed in the context of a hectic cycle of instrument updates, observation re-planning, trouble-shooting the received data files, and updating of software. The modus operandum was generally that the data sets were sent to the hardware teams, who worked out new processing routines and associated calibration quantities, through improved understanding of the physics of the detectors. The ESA Science Operations Centre (SOC) team revised the data file formats, and co-coordinated changes in the science analysis software, which was being continually improved by the members of the Survey Science Consortium and ESA. Their software calls upon Current Calibration Files, which embody the latest calibration knowledge, and which in turn are maintained by the ESA SOC team, who were also responsible for near-real-time planning of updated sequences for the in-orbit operations.

By summer 2000, this hectic pace resulted in a large number of early science results being reported in a special issue of the journal *Astronomy and Astrophysics*. Thereafter the instrument teams and ESA staff started to plan special calibration observations to determine particular facets of the calibration knowledge that had been shown to be lacking by such science analysis. This required careful co-ordination to understand the deficiencies, define a target that would provide the required information, determine the detailed instrument setup needed for the observation, insert the sequences into the mission planning cycle, then on completion of the observation co-ordinate the analysis and interpretation. This planning cycle could be frustratingly long: sometimes the ideal target might be available in an accessible portion of the sky only months after its definition as an imperative observation. Even then, the time taken to understand the results and recode software might be a further impediment to instantaneous improvements.

Now the situation is a little more relaxed, so that we are driven by the requirements of the exciting new science that is enabled by XMM-Newton's amazing capabilities, but which also pushes the requirements for calibration knowledge still further. The ESA team has to respond to the requests from the scientists for further improvements by continuing the cycle of planning and executing the new observations, coordinating analysis and software changes.

In the following paragraphs, we review some of the important instrument parameters that have been explored in the calibration campaign, highlighting some of the complexities involved.

Astrometry

One of the most obvious properties of an astronomical object is its position in the sky. For

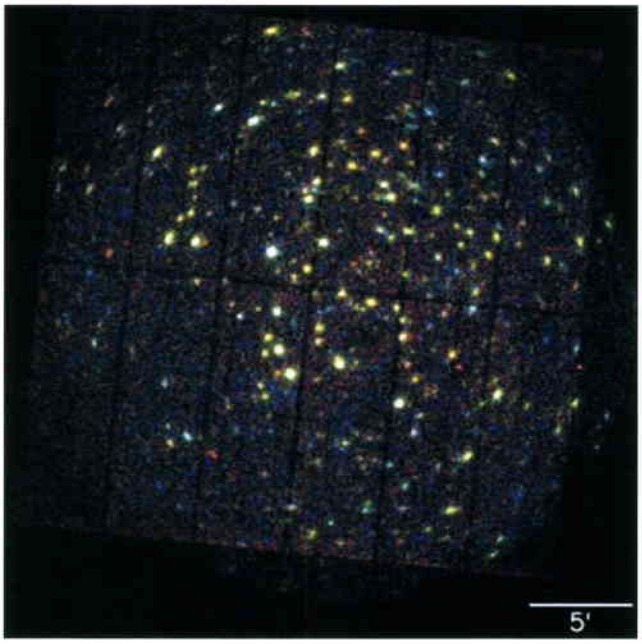


Figure 3. The XMM-Newton view of the stellar cluster known as NGC2516. The colours represent the temperature of detected stars. Yellow and red are probably from the relatively cool (millions of degrees!) stars, but the blue objects are likely to be emission from massive black holes residing in very distant galaxies in the background. The scale bar of 5 arcmin is equivalent to less than 1/5th the diameter of the full Moon

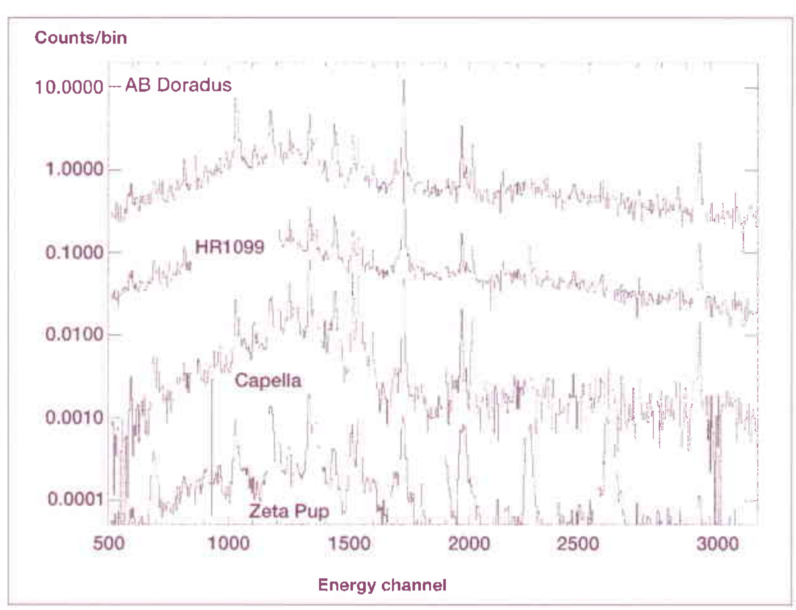
example, when we discover new objects, they are catalogued, so that follow-up at other wavelengths of light can be performed in order to characterise the objects better. Localising the positions with as high an accuracy as possible is important, so that large ground-based telescopes can zoom in to an accurate position without wasting valuable time searching for the correct candidate. In many typical XMM-Newton observations, about 100 objects, many of them never previously detected, might be imaged. The sharpness of XMM-Newton's telescopes, in principle, allows each of these to be centred to a precision of about 1 arcsecond (the width of a 1 Euro coin viewed at a distance of 5 km!). Such performance needs to be matched by the accuracy of the location of the cameras behind the bore sight of the telescopes, the relative location of all the camera readout devices within the camera, the pointing accuracy of the spacecraft star trackers and their relative alignment to the telescopes, etc. This accuracy has now been achieved by observing a number of selected fields containing enough bright point-like objects whose positions were previously known from other catalogues.

Figure 3 shows one of those special fields – a relatively nearby stellar cluster known as NGC2516. While more than 100 stars are precisely located in visible light, their association to the bright X-ray sources is not always secure. Some of the objects in this image may be background galaxies, and some of the true stellar X-ray sources rather dim in the optical. After very careful matching of different catalogues, we have satisfied the requirement of 1 arcsec accuracy. Now this target is observed several times a year to check for potential ageing effects, such as the carbon-fibre tube connecting mirrors to instruments being affected by bending as a result of out-gassing.

Wavelength scale

Identifying the precise energy of any of the bright emission lines of a spectrum can be very important. For example, the energies of different atomic species are precisely known from laboratory measurements, so identifying such features allows astronomers to make a census of atomic diagnostics to be measured. Due to motions within the target or to cosmological recession from our Solar System, the line energy might be changed due to the Doppler effect shifting the X-ray energies to shorter or longer wavelengths. By measuring

Figure 4. Solar coronal loop image from TRACE (courtesy of M. Aschwanden of Lockheed Martin Solar Astrophysics Lab.). X-ray emission on the Sun traces small flares originating in magnetic loops. We cannot see such structures directly even on the nearest stars, but the X-ray measurements allow us to measure the temperatures, sizes and motions of large active regions on many stars, in order to assess how these flares may differ between stellar types. The XMM-Newton RGS instrument observations of a number of such stars were compared to determine if the wavelength scale was stable (emission features in the right-hand panel stay in the same place)



these shifts precisely, the dynamical state of gas within an object might be measured.

The accurate wavelength scale has been determined by observing a number of well-known bright stars. These have been selected for the presence of very bright emission-line features at well-determined wavelengths.

Figure 5. Close-up of an XMM-Newton Mirror Module. The 57 gold-coated thin nickel shells are concentrically stacked and fastened to spokes that help the shells maintain their correct positions. The nickel shells are about 1 mm thick, with a separation of about 4 mm between them

PSF

The sharpness of images from a telescope is characterised by a parameter called the Point Spread Function, or PSF. Generally, the mirrors of optical observatories are made by accurate grinding and polishing of glass blanks. The same technology was used to fabricate the telescope in the Chandra Observatory, but for XMM-Newton the need to provide a large collecting area precluded launching the necessary equivalent of tons of figured glass. Instead, XMM-Newton's mirrors have been fabricated from thin foils of nickel into the correct shape (Fig. 5), but this inevitably meant that the focusing is not as sharp. It is important to measure this image quality, so that the astronomer can be sure whether an image of an object is truly extended, or if it is an intrinsic property of the mirror focusing. Furthermore, when measuring the amount of X-ray light detected from an object, a circle of interest can be drawn which excludes neighbouring sources, but then it is important to know precisely what fraction of detected light is within the circle.

Calibrating this quantity turns out to be far from trivial. A high signal-to-noise ratio is necessary to make an accurate measurement, but bright objects suffer from an important problem in the EPIC cameras: during the finite readout time (~seconds) of each image frame, more than one X-ray might fall on each picture element (pixel), so that it becomes impossible (for example) to discriminate between a pixel with a single X-ray photon with 2 kilovolts of energy or two photons of 1 kilovolt. In fact, for the brightest targets, the on-board electronics rejects events that are merged together in neighbouring pixels, so that a hole of reduced brightness of valid events is seen at the core of the image – an artefact known as pile-up (Fig. 6). Conversely, using faint sources to avoid pile-up limits the calibration, either through lack of time to build up the necessary image, or because the background of fainter stars confuses the clarity of the wings of the PSF.

To add complexity on top of complexity, the PSF is expected to vary significantly across the field of view and with X-ray energy. While a number of measurements were made to characterise the PSF in orbit, the approach adopted has been to use these to verify metrology measurements made on the mirror shells on the ground, and derive a model for expected performance in space.

Energy redistribution

Naturally, it is important to understand the relationship between the energy of an incoming X-ray and the signal transmitted to the ground. For a variety of reasons some of the photons' energy absorbed by the detector may not be correctly registered: the absorption may be in a partially dead entrance layer; perhaps some of the energy might be lost during the process of transferring the minute electrical signals across the focal plane; or the amplification process adds some noise and uncertainty to the measurement. In order to calibrate this 'response function' we need to observe some X-ray emission with individual features isolated

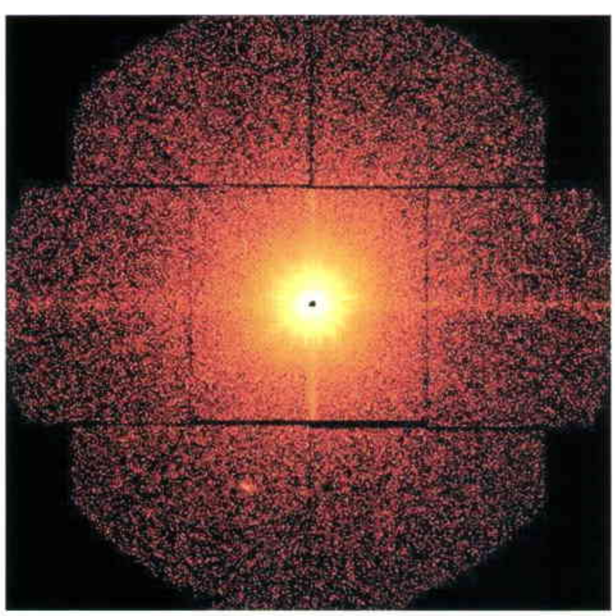
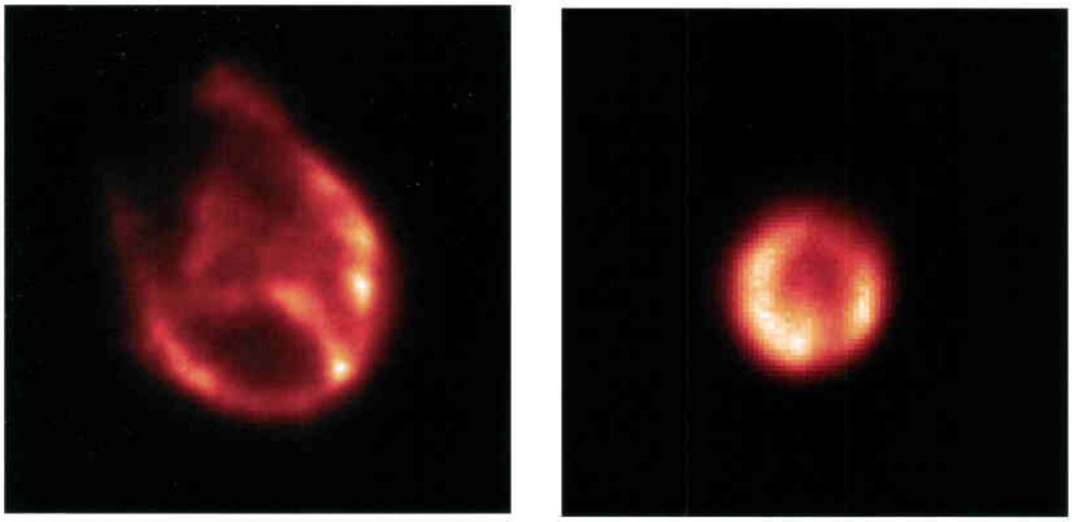


Figure 6. An image from XMM-Newton's EPIC camera, which shows some of the complexity involved in calibrating the mirror Point Spread Function (PSF) when observing a bright target. One of the brightest X-ray objects observed by XMM-Newton, it is probably a binary system comprising a normal low-mass star orbiting either a black hole or neutron star. Due to the piling up of many X-rays at the same position at the very core of the image, the onboard electronics cannot recognise valid signatures in that region and a 'hole' appears in the image. Radiating away from the centre are faint beams caused by the scattering of radiation from the supporting structures seen in Figure 5. Also, the whole image has a faint halo, which is caused by X-rays from the target scattering off interstellar dust grains in space – very interesting to astronomers, but certainly no help to the calibration scientist trying to understand the intrinsic focussing properties of the mirrors



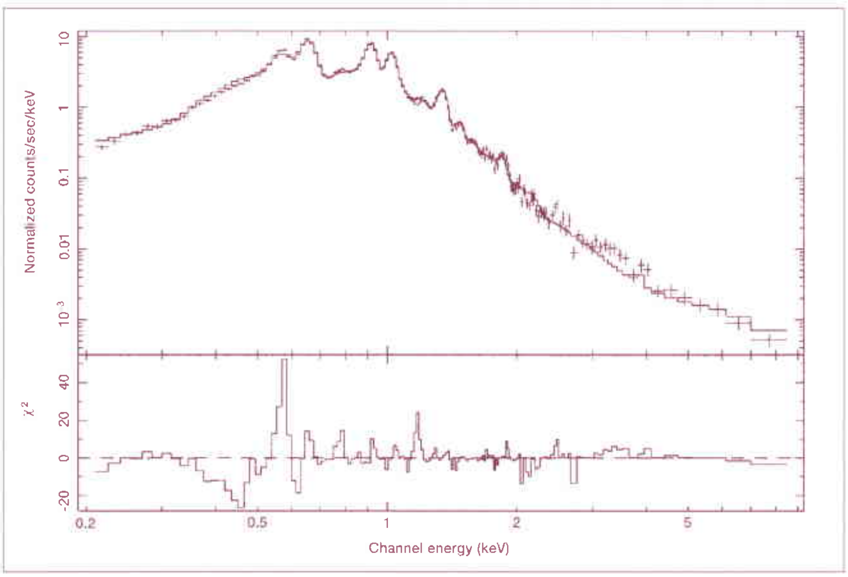


Figure 7. With the powerful imaging capability of XMM-Newton it is possible to view these Super Nova Remnants (SNRs) even in our neighbouring galaxy (100 000 light years away). The panel below shows the spectrum recorded by the EPIC camera and the ratio between a model for this spectrum and the real measured data. This provides a measure of how well the energy response of the camera is known (or more likely in this case how much detailed knowledge of the plasma physics of these remnants remains to be established)

in X-ray energy. Part of this can be done with an internal radioactive source, but it has limited energy range. Therefore, we supplemented the measurement with observations of some bright supernova remnants, with rather different characteristics than the Crab Nebula. In the neighbouring galaxies to the Milky Way, known as the Magellanic Clouds, are two well-known and rather bright remnants in which the X-ray emission is produced by a hot tenuous gas. This gas cools by radiating most of the energy in the form of X-ray lines. Observing these lines provides a very useful method of determining the response across a wide range of the X-ray spectrum.

Background

Not all of the information we need has been derived from deliberately scheduled observations of particular targets, and to minimise the amount of precious observing time spent on calibration the SOC team has made ingenious use of existing data sets, by carefully examining lots of Guest Observer images to extract useful supplementary information. One example is the compilation of data that represents the detector background.

In addition to the required X-ray data of every cosmic field, there is an unwanted and annoying background signal that must be accounted for or subtracted from the desired signal. Often the observer can find a portion of image near his or her target of interest that is apparently devoid of X-ray emitting objects. Any signal in this 'empty' region is assumed representative of the background in the image area of the desired target, and can therefore be subtracted out. However, there are many occasions when this procedure cannot be followed, for example when the target of interest covers a large fraction of the field of view.

To facilitate such observations, we have developed a template set of data that contains no bright sources, but also equivalent to a very much longer exposure time than normal observations so that statistical errors will be negligible. Needless to say, with the power of XMM-Newton's telescopes, no portion of the true sky appears without some sources of reasonable brightness. Therefore, we resorted to selecting a number of 'deep field' observations with no obvious central target, removed all data from the brightest objects in each field, and then co-added all the remaining data together, so that the locations with missing data were filled in and faint source locations diluted by the other fields (Fig. 8).

These methods allowed us to save nearly half a million seconds of observing time that would otherwise have been dedicated to special calibration observations, and furthermore produce a quality that is not obtainable under normal conditions. Nevertheless, for these data to be trustworthy, the calibration scientists have to take great pains to establish the effect of

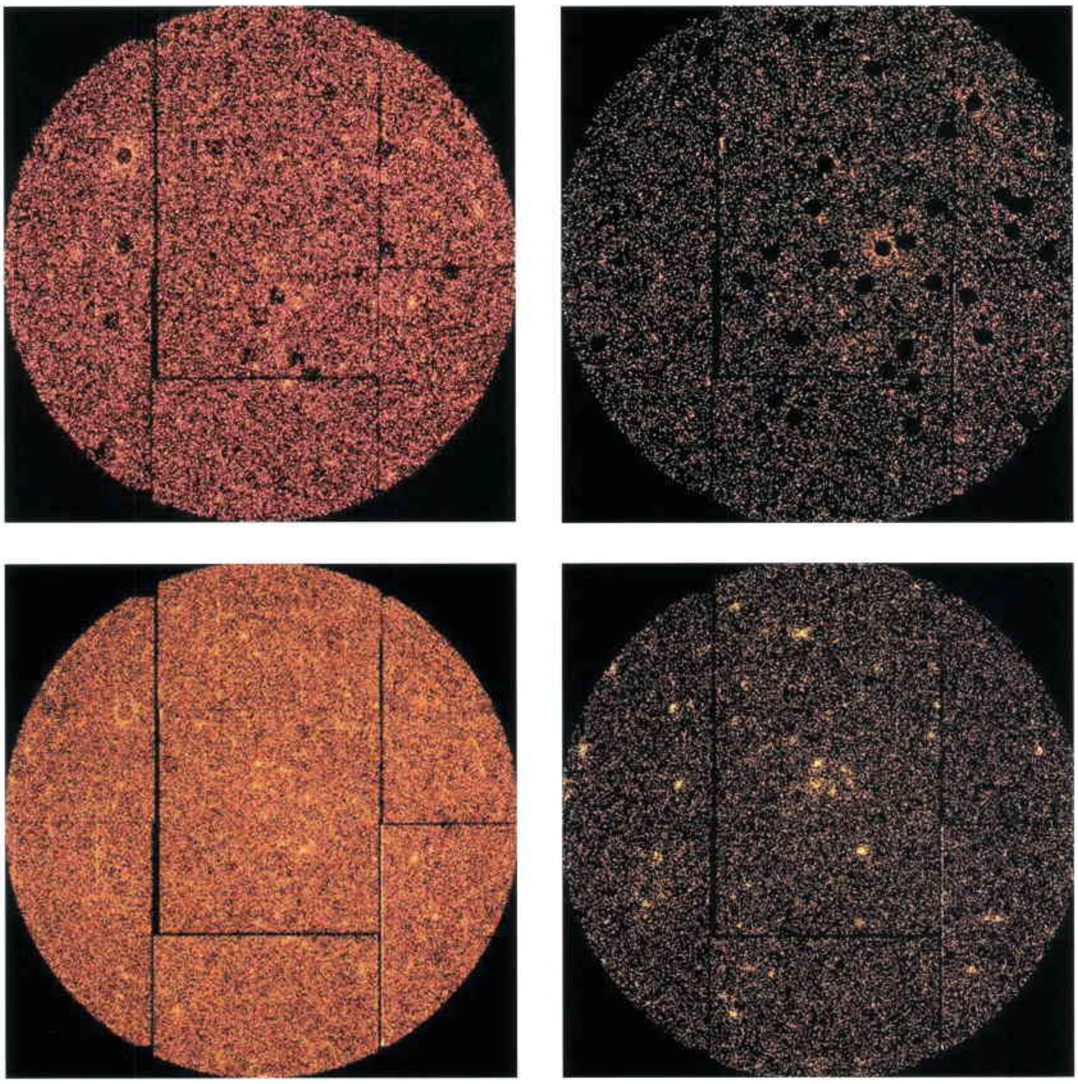


Figure 8. Different fields are combined together to make an artificial star field for background analysis. Clockwise from the top left, three fields from the true sky were selected. In the first two, some holes are just visible where bright sources have been removed. In the third field, some remnant low-level faint sources are still visible, but after adding many such fields together a rather smooth averaged field remains (bottom left)

the various selection criteria on other users' analysis, and provide detailed explanations and caveats or recipes for their use. Otherwise, there is a danger that the average scientist with no detailed knowledge of the instruments may jeopardise his/her analysis with erroneous application.

Conclusion

The status of all these and other calibration measurements were reported at the New Visions conference. Most participants were grateful for the chance to have a thorough review of this existing knowledge. It gave them an up to date snapshot that allowed them to judge whether their scientific interpretations were valid, and to see what areas of concern might need to be accounted for. In most cases, the existing calibration accuracies were shown to match or exceed the specifications laid out by the XMM-Newton Mission Science Team more than six years ago. What became clear, however, is that a number of exciting new science areas that are being enabled by the unique capabilities of XMM-Newton are actually demanding still higher calibration accuracy. Inevitably, this is an on-going process of improving knowledge and development that continually presses the XMM-instrument teams to refine the calibration information year by year, so that this activity will continue with a high priority.

Acknowledgement

The author gratefully acknowledges the efforts of the Principal Investigator camera teams who carried out much of the calibration work, and contributions from other members of the XMM-Newton Science Operations Centre.

Studies on the Re-use of the Mars Express Platform

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The studies that were carried out in 2001 around the possibility of re-using the Mars Express platform have proven the effectiveness of a fast approach between ESA and the scientific community. It was only in March 2001 that ESA issued a 'Call for Ideas' to react to the identified possibility of a low-cost mission based on the re-use of the platform developed for Mars Express, which will be launched in 2003. A strict schedule was imposed, in order to benefit from these special circumstances, aiming at a launch date for the new mission in 2005, which is the next 'window' for missions to Mars. In response to the Call for Ideas, the scientific community presented a wealth of interesting and challenging proposals.

In order to proceed with the necessary studies leading to a possible decision within the year, the advisory bodies of the Scientific Programme made an in-depth but fast evaluation of all of the proposals, resulting in a recommendation to further study three of them: Venus Express, with the objective of exploring the inner planets of our Solar System, focussing on Venus; Cosmic DUNE, aimed at studying the interplanetary cosmic dust as well as the interstellar contribution; and SPOrt Express, measuring the polarisation of the Cosmic Microwave Background.

The definition studies for the three missions were carried out between mid-July and mid-October 2001, including payload, accommodation on the platform, mission analysis, and scientific performance. The results, which are summarised in the following contributions, were presented to the Solar System and Astronomy Working Groups, which made their recommendations for a possible implementation. In November, the ESA Space Science Advisory Committee (SSAC) recommended Venus Express as a candidate mission for inclusion in the Agency's Science Programme. This recommendation was finally presented to the Science Programme Committee (SPC) in December 2001 and Venus Express will thus be considered in the current planning exercises. If finally implemented, this mission will take Europe to Venus, thereby giving the scientific community complete access to all of the Solar System's inner planets (together with the Mars Express mission to the red planet and the BepiColombo mission to Mercury).

Venus Express

by J-P. Lebreton

Introduction

The Venus Express spacecraft – an Orbiter for the study of the atmosphere, plasma environment and surface of Venus – is derived from the Mars Express bus, with some modifications to cope with the hotter thermal environment at Venus (Fig. 1). The scientific payload included in the Venus Express Study comprises six instruments derived from Mars Express or Rosetta flight-spare units. In addition, during the study it was found scientifically reasonable and technically feasible to replace the standard Mars Express engineering Video Monitoring Camera by a scientific instrument known as the Venus Monitoring Camera (VMC).

Venus Express is foreseen to be launched from Baikonur in November 2005 by a Soyuz-Fregat rocket onto a direct transfer trajectory to Venus. It would arrive at Venus about 150 days after launch and be inserted into a highly elliptical polar orbit The baseline orbit selected during the mission-definition phase is a quasi-polar orbit with a pericentre altitude of ~250 km and an apocentre in the 30 000 – 45 000 km range, corresponding to an orbital period of 9.6 to 16 hours. A nominal mission duration of 2 Venusian days (480 Earth days) is foreseen.

Together with the Mars Express mission to Mars and the BepiColombo mission to Mercury, the proposed mission to Venus, through the expected quality of its science results, would ensure a coherent programme of terrestrial-planet exploration and secure for Europe a leading position in this field of planetary research. The international cooperation formed in the framework of the Mars Express and Rosetta missions will be inherited by Venus Express, and will include the efforts of scientists from Europe, the USA, Russia and Japan. The Venus Express orbiter will play the role of pathfinder for future, more complex missions to the Earth's twin planet, and the data obtained will help to plan and optimise future investigations.

Venus studies can have significant public outreach given the exotic conditions on the planet and the interest in comparing Venus to Earth, especially in a context of concern regarding the climatic evolution on Earth.

Scientific objectives

The fundamental mysteries of Venus are related to the global atmospheric circulation, the atmospheric chemical composition and its variations, the surface/atmosphere physical and chemical interactions including volcanism, the physics and chemistry of the cloud layer, the thermal balance and role of trace gases in the greenhouse effect, the origin and evolution of the atmosphere, and the plasma environment and its interaction with the solar wind. The key issues of the history of Venusian volcanism, the global tectonic structure of Venus, and important characteristics of the planet's surface are also still unresolved. Beyond the specific case of Venus, resolving these issues is of crucial importance in a comparative-planetology context and for understanding the long-term climatic evolution processes on Earth-like planets.

The above problems can be efficiently addressed by an orbiter equipped with a suite of remote-sensing and in-situ instruments. Compared with earlier spacecraft missions, a breakthrough will be accomplished by Venus Express by fully exploiting the existence of spectral 'windows' in the near-infrared spectrum of Venus' night side, discovered in the late 1980s, in which radiation from the lower atmosphere and even the surface escapes to space and can be measured. Thus, a combination of spectrometers, spectro-imagers, and imagers covering the ultraviolet to thermal-infrared range, along with other instruments such as a radar and a plasma analyser, is able to sound the entire Venus atmosphere from the surface to 200 km altitude, and to address specific questions on the surface that would complement the Magellan investigations. This mission will also tackle still-open questions about the plasma environment, focusing on the studies of non-thermal atmospheric escape. This issue will be addressed via traditional in-situ measurements, as well as via innovative ENA (Energetic Neutral Atom) imaging techniques.

The Venus Express mission will achieve the following 'firsts':
- first global monitoring of the composition of the lower atmosphere in the near-infrared transparency 'windows'
- first coherent study of the atmospheric temperature and dynamics at different levels of the atmosphere from the surface up to ~200 km altitude
- first measurements of global surface temperature distribution from orbit
- first study of the middle and upper atmosphere dynamics from O_2, O, and NO emissions
- first measurements of the non-thermal atmospheric escape
- first coherent observations of Venus in the UV to thermal-IR range (Pioneer Venus did this, but Venus Express will do it better)

Historical Context

The first phase of Venus spacecraft exploration (1962 – 1985) by the Mariner, Venera, Pioneer Venus and Vega missions established a basic description of the physical and chemical conditions prevailing in the atmosphere, near-planetary environment, and at the surface of the planet. At the same time, they raised many questions about the physical processes sustaining these conditions, most of which still remain unanswered today. Extensive radar mapping by Venera-15, Venera-16 and Magellan orbiters, combined with earlier glimpses from landers, have expanded considerably our knowledge of Venus' geology and geophysics. A similar systematic survey of the atmosphere is now in order. This particularly concerns the atmosphere below the cloud tops which, with the exception of local measurements from descent probes, has remained inaccessible to previous Venus orbiters. Many problems of the solar-wind interaction, particularly those related to its impact on planetary evolution, are still not resolved.

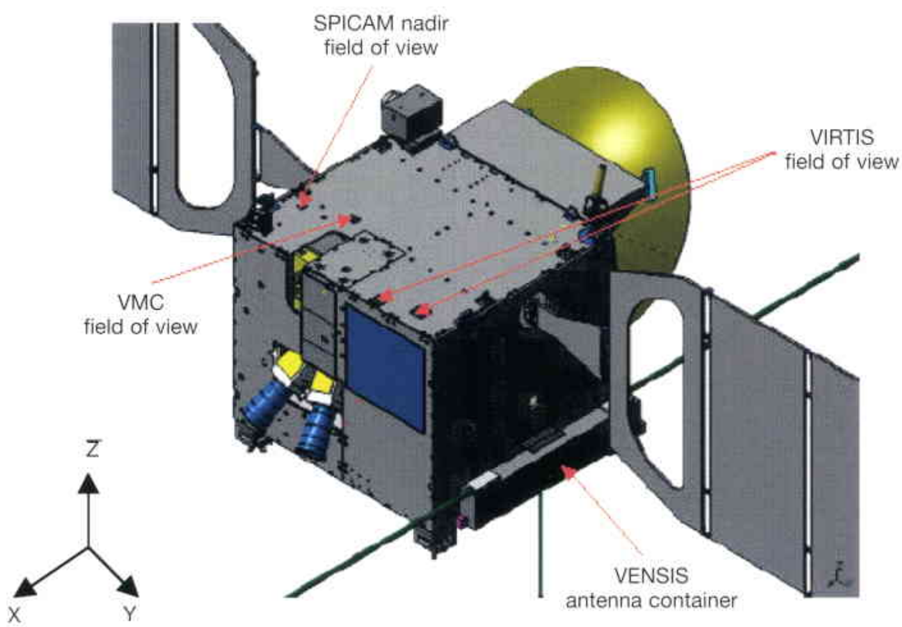


Figure 1. The Venus Express spacecraft with solar panels and VENSIS antennas deployed

- first application of the solar/stellar occultation technique at Venus
- first use of a three-dimensional ion-mass analyser, high-energy-resolution electron spectrometer, and energetic neutral-atom imager
- first sounding of the Venusian top-side ionospheric structure
- first sounding of the Venusian subsurface.

Scientific payload

In order to be able to develop a mission in less than three years, the Call for Ideas for the re-use of the Mars Express platform required that the Venus Express payload be selected from existing flight-spare units developed for previous planetary missions.

During the proposal phase, five available flight-spare instruments developed for the Mars Express and Rosetta missions that were best-suited for addressing the scientific objectives laid down above were identified. A list of potential additional instruments that were worth considering during the study phase were also identified. Following the recommendation of the Solar System Working Group, the VENSIS radar sounder was included in the payload-accommodation studies. In addition, the Mars Express engineering Video Monitoring Camera, whose main function aboard Mars Express is to take images of Beagle-2, was replaced by a scientific instrument called the Venus Monitoring Camera (VMC).

The main characteristics of the scientific instruments are therefore as follows:

- SPICAM: a versatile UV-IR spectrometer for solar/stellar occultations and nadir observations (heritage Mars Express)
- PFS: a high-resolution IR Fourier spectrometer (heritage Mars Express)
- ASPERA: a combined energetic neutral-atom imager, electron, and ion spectrometer (heritage Mars Express)
- VeRa: a radio-science experiment (heritage Rosetta)
- VMC: a wide-angle Venus imaging camera (heritage new/Rosetta/Mars Express)
- VENSIS: a surface, subsurface and ionosphere sounding radar (heritage Mars Express)
- VIRTIS: a sensitive visible/IR spectro-imager and mid-IR spectrometer (heritage Rosetta).

Addition of a high-resolution solar occultation infrared channel to SPICAM and of a magnetometer sensor to ASPERA is under consideration.

Spacecraft configuration

The Venus Express spacecraft is derived from the Mars Express platform and is based on a box-like shape of 1.7 x 1.7 x 1.4 m^3. Power is provided by a steerable, two-winged solar array with one degree of freedom. Its symmetrical configuration is favourable for aero-braking techniques (a capability built into the spacecraft design, but not foreseen to be used at Venus) and minimising the torques and forces on the arrays and drive mechanisms during orbit-insertion manœuvres performed with the main engine. The spacecraft has a fixed high-gain antenna.

Within the overall integrated design of the spacecraft, there are just four main assemblies, to simplify the development and integration process:

- the propulsion module with the core structure
- the Y lateral walls, supporting the spacecraft avionics and the solar arrays
- the Y/+X shear wall and the lower and upper floors, supporting the payload units; the +Z face is nominally nadir-pointed during the science-observation and communications-relay phases around the planet and Aspera-3
- the X lateral walls supporting the high-gain antenna (-X) and instrument radiators (+X).

Attitude and orbit control is achieved using a set of star sensors, gyros, accelerometers and reaction wheels. A bipropellant reaction-control system is relied upon for orbit and attitude manoeuvres, using either a 400 N main engine or banks of 10 N reaction-control thrusters.

The data handling is based on packet telemetry and telecommanding. The electrical power is generated by solar arrays, and stored by a lithium-ion battery. A standard 28 V regulated main bus is available to the payload instruments.

The RF communication system is designed to transmit X-band telemetry via the high-gain antenna at rates between 28 and 230 kbps, depending on the planet-to-Earth distance. A variable telecommand rate between 7.81 and 2000 bps (overall) is foreseen.

The Mars Express platform needs to be adapted to the hotter thermal environment at Venus. The modifications required, which include adaptation of the thermal accommodation of the instruments, have been well identified during the industrial study phase and present no particular challenge.

Mission design and operations scenario

Venus has a near-circular orbit with a radius of approximately 0.72 AU, an inclination of 3.4 deg with respect to the ecliptic, and an orbital period of just over 224 days. The transfer to a Venus crossing can be accomplished with an Earth escape velocity of approximately 2.8 km/sec, which is the minimum-energy case. The shortest possible transfer period from Earth to Venus encounter is 120 days. By contrast, the minimum-energy transfer to Mars requires a higher escape velocity, at 3.25 km/sec, and a transfer period of 220 days.

Venus Express is proposed to be launched with a Soyuz-Fregat rocket from Baikonur in November 2005 on a direct trajectory to Venus. After a transfer phase of about 150 days, it will be inserted into a highly elliptical five-day orbit around Venus. The spacecraft will be transferred to its operational orbit by lowering the apoapses to an altitude in the 30 000 – 45 000 km range.

Mission development schedule

The proposed Venus Express mission design builds on a strong heritage from the Mars Express platform and on both the Mars Express and Rosetta payloads, which are fully compatible with the Mars Express bus. Therefore, in order to save money, the spacecraft will be designed using a proto-flight-model approach, with direct integration of the flight-model payload instruments. The overall development schedule is shown in Figure 2.

Following the SPC's recommendation in December 2001, Venus Express is a candidate mission to be included within the revised ESA Science Programme that is under review. A final decision is expected in June 2002. In order to maintain a schedule compatible with a November 2005 launch date, pre-Phase-B activities on the spacecraft and payload have been initiated in February 2002.

Conclusion

The Venus Express mission-definition study demonstrated the feasibility of the proposed mission to Venus in 2005. The Mars Express spacecraft bus can accommodate Mars Express and Rosetta flight-spare experiments with little or no modification. The Soyuz-Fregat launch can deliver the spacecraft to a polar orbit around Venus with a pericentre altitude of ~250 km and an apocentre of ~45 000 km. This orbit will provide complete coverage in latitude and local solar time. It is also well-suited for atmospheric and surface sounding, as well as the studies based on solar and radio occultations. Compared with the Pioneer-Venus spinning spacecraft, Mars Express is an advanced three-axis-stabilised platform that provides significantly enhanced spectroscopic and imaging capabilities. The proposed duration of the nominal orbital mission is two Venusian days (sidereal rotation periods), equivalent to ~500 Earth days.

The Venus Express mission takes advantage of existing payload instruments, which offers a significant cost-saving aspect for the national funding of instruments. The re-use of the Mars Express platform also offers a quick and unique opportunity for a mission to Venus that fills a gap in ESA's terrestrial-planet exploration programme at a cost comparable to that of Mars Express.

Acknowledgement

The ESA Venus Express Study was directly supported by the Mission Science Coordinator and Principal Investigator Teams. The Industrial Study was led by Astrium France, with support from Astrium UK.

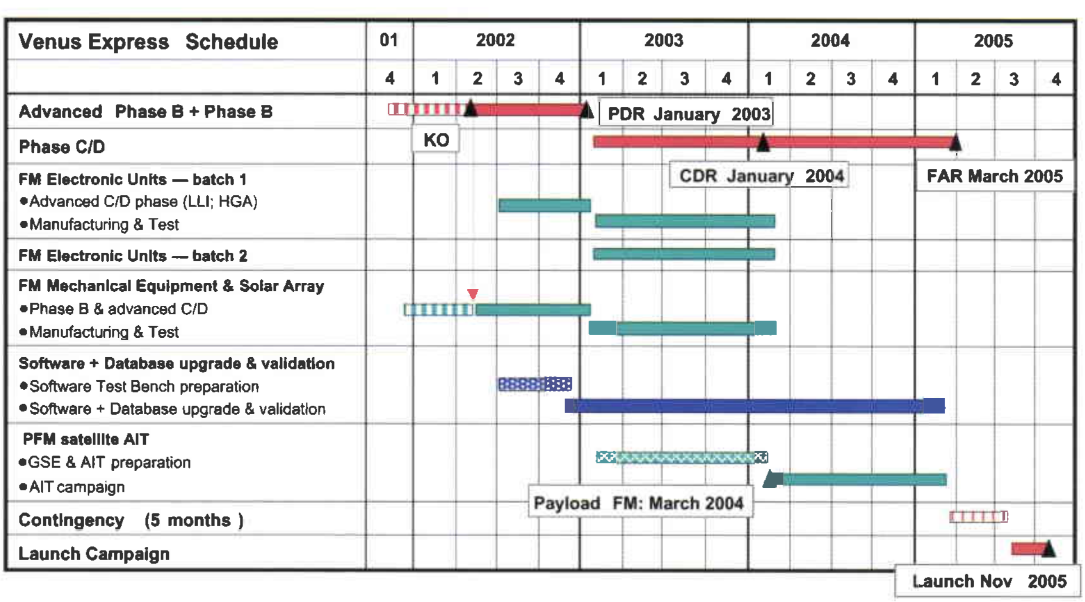


Figure 2. The Venus Express mission schedule

Cosmic DUNE

by H. Svedhem

Introduction
The Cosmic DUNE (Cosmic DUst Near Earth) mission is dedicated to the investigation of interstellar dust, an important but little-studied component of the interstellar medium. It also addresses many of the questions concerning the interplanetary dust complex, which has only been partially studied previously. The mission has been judged to have high scientific merit and has been found feasible both technically and programmatically. The payload selected is largely based on existing, but nonetheless advanced, instruments already flying on other spacecraft and can be accommodated on the spacecraft with only minor modifications to the Mars Express bus (Fig. 1). The operational requirements at both mission and payload level are low.

Scientific objectives
The Cosmic DUNE observatory is designed to characterise interstellar and interplanetary dust in-situ, in order to provide crucial information not achievable with remote astronomical methods. Galactic interstellar dust constitutes the solid phase of matter from which stars and planetary systems form. Interplanetary dust, from comets and asteroids, represents remnant material from bodies at different stages of early Solar System evolution. Thus, studies of interstellar and interplanetary dust with Cosmic DUNE in Earth orbit will provide a comparison between the composition of the interstellar medium and primitive planetary objects. Hence, Cosmic DUNE will provide insights into the physical conditions during planetary-system formation. This comparison of interstellar and interplanetary dust is highly important for both planetary science and astrophysics.

The discoveries of interstellar dust in the outer and inner Solar System during the last decade suggest an innovative approach to the characterisation of cosmic dust. Cosmic DUNE establishes the next logical step beyond NASA's Stardust mission, promising four major advances in cosmic-dust research:
- analysis of the elemental and isotopic composition of individual cosmic dust grains
- determination of the size distribution of interstellar dust
- characterisation of the interstellar dust flow through the planetary system
- analysis of interplanetary dust of cometary and asteroidal origin.

Additionally, in supporting the dust science objectives, Cosmic DUNE will characterise and monitor the ambient plasma conditions near the Earth's magnetotail.

Scientific payload
The science payload consists of a dust telescope, comprising space-proven instruments based on dust-detection techniques successfully used on Giotto, Vega, Cassini, Stardust, Rosetta and other missions. They are optimised for: (i) large-area impact detection and trajectory analysis of micron-sized and larger dust grains, (ii) determination of the physical properties of sub-micron-sized grains, such as flux, mass, speed, electrical charge, and coarse chemical composition, and (iii) high-resolution chemical analysis of cosmic dust. Previous experiments by the proposing team using similar instruments have shown that the heavy-element and isotopic compositions of carbon, hydrogen and nitrogen (C, H and N) can be measured.

The instruments utilise different detection methods and thereby complement each other to yield robust measurements for more reliable statistical analysis. A plasma monitor supports the dust charge measurements. The viewing directions of all dust instruments are co-aligned with narrow fields of view. About 1000 grains are expected to be recorded by this payload every year, with 10% of these providing elemental compositions.

The following instruments make up the scientific payload:

- Cosmic Dust Analyser: CDA is an impact ionisation detector with an aperture of 0.1 m^2, capable of measuring dust masses above 10^{-15} g and velocities from 1 to 100 km/s. It measures rough composition, at a resolution of about 50 amu, for those particles entering the central part of the detector.
- Cometary and Interstellar Dust Analyser: CIDA is a high-resolution impact ionisation time-of-flight mass spectrometer with a resolution of 250 amu and an aperture of 0.012 m^2. It is mounted outside, but co-aligned with, the dust telescope.
- Dust Detector System: D2S consists of two parts, an upper part for particle-trajectory determination, based on grid wires detecting the electrostatic charge on the particles, and a lower part, based on a permanently polarised PVDF film. When a particle hits the film, part of the film is vaporised and a proportional charge is detected. The aperture is 0.11 m^2 and the mass threshold is 3×10^{-12} g. Particle charges above 10^{-15} C are detected.

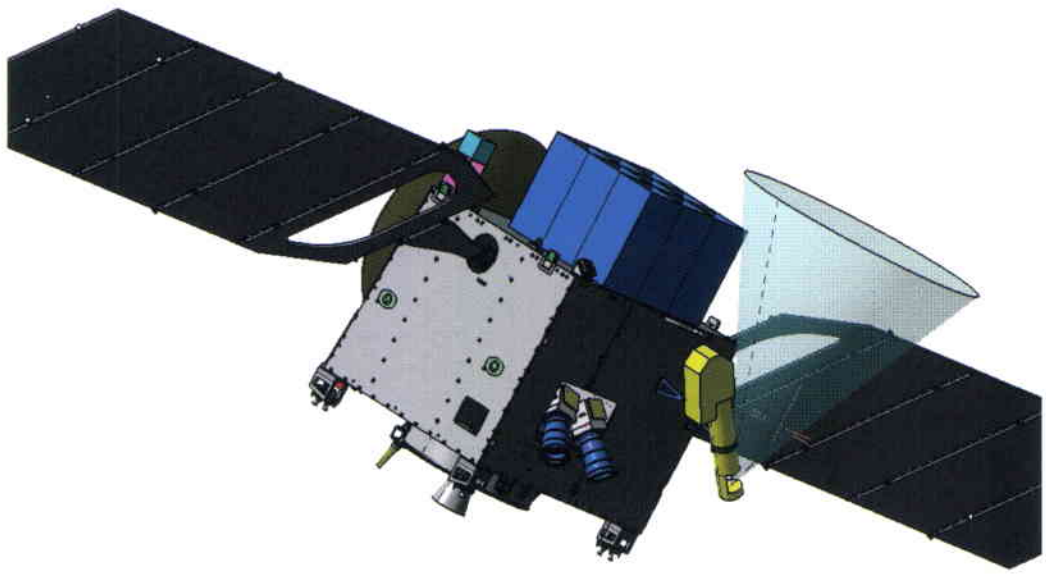
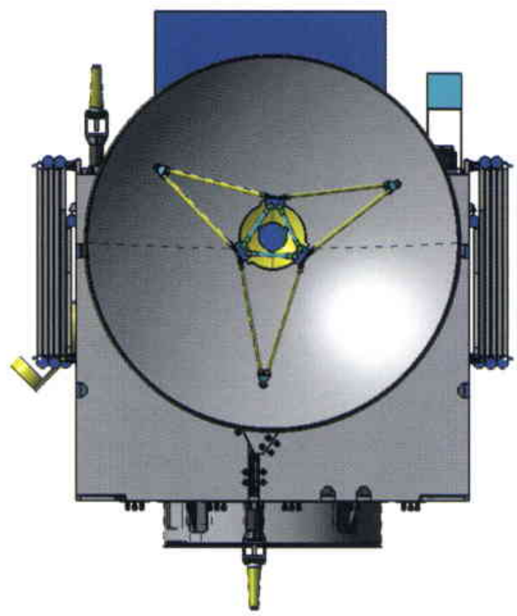


Figure 1. The Cosmic DUNE dust-telescope payload integrated on the Mars Express bus. The nine D2S modules form a telescope with a 25° half-width and a sensitive area of 1 m^2. ISIDE and CDA are attached to the impact plane of D2S, with each replacing one PVDF impact module (lower left). CIDA is attached to the side (optimum mounting angle 40 deg), while PLASMON is mounted with a stand-off structure to measure the solar wind

- Impact Sensor for Interstellar Dust Exploration: ISIDE is a piezo-electric-based momentum sensor with an active area of 0.06 m^2. It can detect particle impact momentums above 10^{-9} Ns.
- Plasma Monitor: PLASMON will characterise the environmental electrons, ions and magnetic field in the 0.35 – 4200 eV, 40 – 8000 eV, and 10 pT – 1000 nT ranges, respectively.

Nine of the D2S units make up the dust telescope, seven of them where the PVDF detectors are used, one where CDA is used, and one where ISIDE is used as a 'focal plane' instrument. The total payload mass is 63 kg and the power required is 53 W.



Spacecraft configuration

The differences in accommodation between the Cosmic DUNE and Mars Express satellite configurations concern only the payload. All instruments point towards +Z, except PLASMON which points towards -X (i.e. towards the Sun). The alignment-accuracy requirements are not severe, being about 0.5° for all instrument lines of sight.

All instrument sensors apart from CIDA are accommodated on the +Z wall of the platform. The CIDA sensor is accommodated on the external face of the platform +X wall. The main instrument electronics boxes are housed in the two enclosures located in the +X part of the platform, where they replace the Mars Express payload. The large D2S sensor box occupying most of the volume above the +Z face (the 'Dust Telescope') is a lightweight structure and cannot carry any additional mechanical loads. The original +Z low-gain-antenna support will have to be extended upwards to offer an adequate field of view. The +Z Sun-acquisition sensor's location will also have to be modified.

The functional architecture of Cosmic DUNE is very similar to that of Mars Express, being modified only to accommodate the new instruments. Owing to the low data rates between the spacecraft and the payload, the 1355 IEEE high-speed data bus is not used for any payload element. All of the main electronics units of the instruments are linked to the OBDH bus via the RTU. Two instruments (CDA and PLASMON) will require cover mechanisms, actuated by pyrotechnic devices after launch.

The satellite operates in two different modes: the observation mode, in which the satellite and its solar array are kept in an inertially fixed attitude typically for 1 to 4 weeks, and the communications mode in which the satellite is pointed towards the Earth for 1 or 2 days for transmitting the payload data stored in the onboard mass memory. In observation mode, the spacecraft's health is monitored from Earth via the low-gain antennas. Spacecraft house-keeping actions (reaction-wheel management, station-keeping, etc.) are performed in communications mode only, to avoid disturbing the instrument observations.

The power-budget figures for Cosmic DUNE are: spacecraft bus (communications on) 479 W, payload 54 W, and a 10% system margin, totalling 673 W. Cosmic DUNE's solar array will be a recurrent version of the Mars Express solar array. The total power requirement of 673 W calls for a 5.8 m^2 solar array. The present Mars Express solar array is about 11 m^2 in size. The fuel budget is sized for the Soyuz three-stage worst-case situation and the specific impulse (I_{sp}) for the main-engine boost is taken as 316 sec (this includes simultaneous firing of the small thrusters for satellite attitude control). The delta-V for station-keeping (4 m/s) is provided by small thrusters with an I_{sp} of 285 sec. The AOCS fuel and residuals are taken from Mars Express figures, which are worst-case figures for orbit at the second Lagrangian point (L2), where only the solar radiation pressure creates perturbing torques. For Cosmic DUNE, the fill ratio is 74% (with 5% margin), which is well within the allowed limits.

The adaptation of the Mars Express platform for the Cosmic DUNE mission presents no technical difficulties. The satellite development drivers include:
- New payload interfaces: these will necessitate modifications to the platform structure, thermal control, and electrical system and an early payload electrical interface validation activity is therefore proposed in the development plan.
- The satellite magnetic moment needs to be characterised for the plasma instrument (PLASMON).
- The Mars Express satellite has not been designed with magnetic-cleanliness require-ments in mind.

Mission design and operations scenario

Cosmic DUNE is designed for a Lissajous orbit around the second Lagrangian point (L2) of the Sun–Earth system. In this position, which is about 1.5 million km from the Earth and on the opposite side of the Earth as seen from the Sun, the spacecraft appears stationary in a reference frame with the Sun–Earth line fixed. The spacecraft will orbit the Sun as well as the Earth once per year. This orbital position can be easily reached with the Soyuz/Fregat launch combination, and the transfer orbit can be phased such that very little fuel is required for the L2 orbit insertion.

This operating location has been selected because it is a stable orbit sufficiently far from the Earth to avoid confusion due to debris particles orbiting the Earth. The interstellar dust particles that have been found to enter the Solar System from a well-defined direction at about 26 km/s will be encountered at a relative velocity of about 56 km/s during northern winter. This will enhance the chances of detecting the smallest particles. On the other hand, during northern summer these particles will be encountered from the apparent opposite direction at 4 km/s. This will improve the separation of the interstellar from the inter-planetary population. Cosmic DUNE's operation would be organised in blocks of two to four weeks, within which the inertial pointing would be constant in order to collect sufficient data for reliable statistical analysis. During these observing blocks, no mechanical action is allowed on the spacecraft to minimise noise effects. The resulting de-pointing of the solar panels can be accepted thanks to the large available power margin. The payload produces a modest amount of data and telemetry sessions are only required at one- to four-week intervals.

A mission duration of 2 years is required. The first year of observations would focus on interstellar dust, while the second year would also include a number of observations dedicated to the different interplanetary dust types. A possible one-year extension would allow dedicated studies of specific sources like ß-Pictoris and other dust-rich nearby stars, meteor streams, or other targets of opportunity.

Acknowledgement

The ESA Cosmic DUNE Study Team consisted of:
- E. Grün, Max-Planck-Institut für Kernphysik, Heidelberg, Germany
- A-C. Levasseur-Regourd, Univ. Paris VI/ Aeronomie CNRS, Verrieres, France
- N. McBride, The Open University, Milton Keynes, United Kingdom
- P. Palumbo, Università Parthenope, Naples, Italy
- R. Srama, Max-Planck-Institut für Kernphysik, Heidelberg, Germany.

SPOrt Express

by J. Tauber

Introduction

SPOrt Express – the Sky Polarisation Observatory for reuse of the Mars Express Platform – is a proposal for a mission to measure the polarisation of the Cosmic Microwave Background (CMB) and the polarised emission from the Milky Way at microwave wavelengths. It is based on the SPOrt-ISS experiment, which is being developed to fly on the International Space Station starting around 2005. Instrumentally, there are two main modules in SPOrt Express: LARMI (Low Angular Resolution Multifrequency Instrument) which measures the Stokes Q and U parameters of the sky emission with 7.0 deg angular resolution at four frequencies between 22 and 90 GHz, and HARI (High Angular Resolution Instrument) which measures Q and U with 0.5 deg angular resolution at 90 GHz only. LARMI is essentially identical to the payload of SPOrt-ISS, whereas HARI is a new addition allowed by the Mars Express bus.

Accommodation of the SPOrt Express experiment on the Mars Express bus was studied for ESA by Astrium in Toulouse (F) between July and October 2001. That study indicated that only minor modifications to the bus would be needed (Fig. 1). The main critical item identified was related to the low temperature required to be passively achieved, and the associated cryogenic testing at system level, which could become relatively complex.

In parallel, a study team was formed by ESA to address the scientific questions raised by its Astronomy Working Group (AWG) in its pre-evaluation. In short, the study team's mandate was to examine the scientific merit of SPOrt Express, particularly in the context of the capabilities of other ongoing experiments such as MAP (a NASA mission in operation) and Planck (an ESA mission under development and due for launch in 2007).

Scientific objectives

Measuring the polarisation signature of the Cosmic Microwave Background (CMB) has very high scientific interest, due to its potential to provide original information on the characteristics of the early Universe. Of particular interest for SPOrt Express is its ability to shed light on the epoch at which the re-ionisation of the intergalactic medium took place. Many experiments dedicated to this problem, both ground- and balloon-based, are already gathering data or in development. There are high expectations that MAP and Planck will detect and image at least the brightest polarised components of the CMB. The community is also starting to design the next generation of CMB observatories based in space, which will undoubtedly be dedicated to the measurement of polarisation.

There are two major components to the science case for SPOrt Express: CMB-related science, and Milky-Way-related science. The study team concentrated on the CMB element of the scientific case, trying in particular to put it into the current context of similar ongoing space- and ground-based experiments.

Observationally, the objective of SPOrt Express is to make maps of the linear polarisation of the sky (via the Stokes parameters U and Q; the parameter I – which parameterises intensity – is not accurately measured by the receiver concept; and since the CMB is not expected to generate circular polarisation, no emphasis is put on measuring V). The maps will be used to estimate the angular power spectra of the E(or gradient)-component and B(or curl)-component of the CMB. The E-component is expected to be the brighter of the two and is therefore the main target for SPOrt Express.

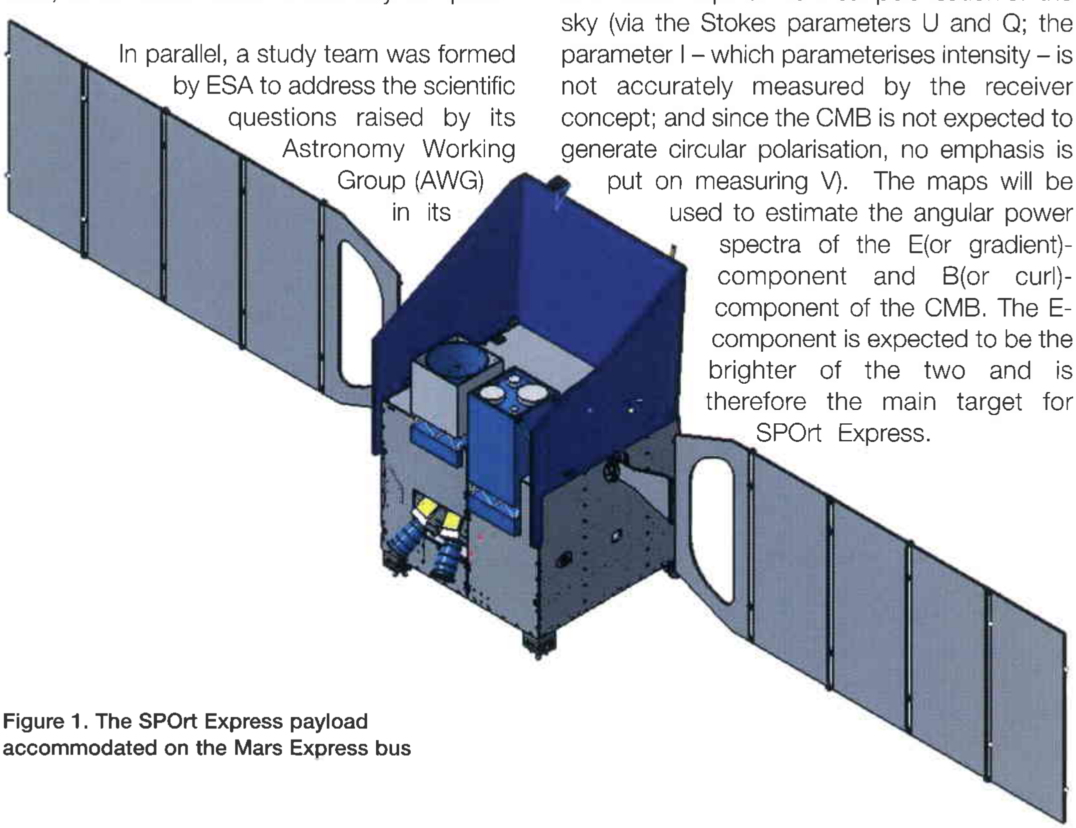


Figure 1. The SPOrt Express payload accommodated on the Mars Express bus

Scientific payload

Much of the scientific case for any CMB experiment rests on its instrumental performance, and the Team therefore looked closely at this aspect. The critical performance phase space for CMB experiments includes such parameters as sensitivity, sky coverage, frequency coverage, and angular scale coverage. It is generally agreed that the best CMB experiment will cover as much of this phase space as possible, which implies a better ability to recover the angular power spectrum of CMB emission, and therefore to extract cosmological parameters.

When only comparing the nominal performances of the SPOrt Express payload with that of Planck, it is apparent that the latter is superior by a significant factor. However, instrumental systematic effects, rather than the nominal performances, may turn out to be the limiting uncertainty in the measurements of Q and U. The SPOrt Express design has a definite advantage over Planck in this respect, exploiting a receiver concept that has been designed from the start to measure polarisation, and is robust and effective at suppressing such systematic effects. It was assumed that in the case of SPOrt Express, instrumental systematic effects would have a negligible impact.

Under the above assumption, the analysis by the study team indicated that the following main objectives could be achieved by the baseline concept presented in the SPOrt Express proposal:

- it would obtain all-sky maps of galactic foregrounds at 22 and 32 GHz
- it would make measurements of the CMB polarisation with a significance that depends on cosmological parameters: the current analysis shows a detection at a significance level between 1 and 7σ (depending mainly on the level of cosmic re-ionisation)
- it would make a measurement of the optical depth of the re-ionised cosmic medium (with a 1σ confidence level of ~0.03 if $\tau_{reion} = 0.05$).

In addition to the above nominal performance, the study team identified some potential enhancements to the (CMB-related) scientific return of SPOrt Express which could be achieved through relatively minor modifications to the payload concept: (a) changing the observing strategy from a (shallow) all-sky survey to a (deeper) scan of a small patch of the sky (as allowed by the three-axis pointing capability of the Mars Express bus); and (b) increasing the angular resolution of the HARI module (which appears achievable within the volume and mass constraints of the Mars Express bus).

Conclusion

Unfortunately, after weighing all scientific and programmatic considerations, the AWG felt *'unable to recommend implementation of the SPOrt Express payload with the re-use of the Mars Express platform. Nevertheless, recognising the compelling scientific importance of measuring CMB polarisation, the AWG sees this as a key area in which ESA should be involved in the future. Therefore, the AWG supports and encourages the community to continue to develop approaches to CMB polarisation studies, with the aim to provide a strong proposal for consideration at the next available ESA mission opportunity'.*

Acknowledgement

The ESA SPOrt Express Study Team consisted of:

- S. Volonte (ESA HQ), Chair
- J. Tauber (ESA RSSD), Study Scientist (and Planck Project Scientist)
- E. Carretti (IASF), SPOrt Express Project Manager
- A. Challinor (Cambridge Univ.)
- S. Cortiglioni (IASF), SPOrt Express Principal Investigator
- P. De Bernardis (Univ. Roma)
- R. Laureijs (ESA RSSD, ISO team)
- P. Leahy, supported by A. Wilkinson (Jodrell Bank)

Additional support was provided by J. Hamaker (Dwingeloo) and K. van 't Klooster (ESA/ ESTEC). The accommodation study was carried out by a team of Astrium (Toulouse, F) engineers, led by C. Koeck.

The Erasmus Virtual Campus

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The Erasmus Virtual Campus was inaugurated in September 2000 to bring together scientists and engineers interested in using the International Space Station and other facilities for their research. It also provides the foundation for creating Virtual Institutes in selected scientific disciplines. The current capabilities of the Campus are highlighted, along with plans for the future.

What is the Erasmus Virtual Campus?

The purpose of the Erasmus Virtual Campus, based at ESA's ISS Erasmus User Information Centre in Noordwijk, The Netherlands, is to bring people together, increase their collective knowledge and facilitate cooperation between them. The target audience for the Campus is European scientists and engineers who are interested, or already involved, in using the International Space Station (ISS) or other space and ground facilities to which the ESA Directorate of Manned Spaceflight and Microgravity (D/MSM) can provide access.

The Virtual Campus also provides the foundation for the creation and operation of Virtual Institutes in selected scientific areas.

Who can use the Campus?

The Virtual Campus is open to anybody interested, or already involved, in using the research facilities developed and operated under the responsibility of D/MSM or for which this directorate coordinates and facilitates the access of European users. These facilities cover the European elements of the ISS, as well as other orbital and ground-based research facilities such as the US Space Shuttle, Russian Foton capsules, European Maser and Maxus sounding rockets, parabolic flight campaigns with the Airbus A300 aircraft, drop towers and selected ground facilities for research in life sciences and physical sciences.

Figure 1. The Erasmus building houses the ISS User Information Centre

The Erasmus Virtual Campus is thus open to a large potential user community:

- scientists who are interested in using any of the above facilities for their research;
- project engineers and managers involved in the development, building or operation of these facilities;
- scientists and engineers in the European User Support and Operations Centres (USOCs) who deal with the utilisation of these facilities;
- politicians who decide on research activities and who want to obtain information on the objectives and results of the work performed in these facilities;
- students in search of reference material for their university studies or of information and guidance in their personal career choices;
- public and private educational institutions and exposition centres that focus on the popularisation of science and technology activities in space;
- laypersons and media representatives with an interest in research and high-technology subjects.

Who is the primary target group of the Campus?

The primary target group of the Virtual Campus consists of the scientists, engineers and research coordinators who are involved in the various research or development projects of ESA's Microgravity Application Programme (MAP) or Technology Application Programme (TAP), or who are members of one of the 'Topical Teams'. The Campus wants to encourage and facilitate the setting up of MAP and TAP project teams and Topical Teams and support the communication and cooperation among their members.

What are the MAPs, TAPs and Topical Teams?

MAP aims at involving industry in applied research aboard the ISS, by identifying those areas where the utilisation of space could be an important element in the research and development of an industrial programme. Groups of scientists are encouraged to team up with industry. The MAP initiative was started by ESA in 1999 with an Announcement of Opportunity for proposals in which researchers and research teams, with partners from industry, suggested ideas and new approaches to include the microgravity research in their overall product-oriented and market-driven applied-research activities.

The 125 MAP proposals resulted in 44 concrete research projects. For the first 2 years, the financing is focused mainly on ground-based research. During this period, industrial questions that can be answered by future microgravity experiments are being identified. Thereafter, precursor experiments are planned in selected research areas using early opportunities on the ISS, Space Shuttle/Spacehab flights and sounding-rocket missions.

A similar programme, directed at applied research activities in technology, is being set up by ESA as the Technology Application Programme (TAP).

The MAP and TAP initiatives are supplemented by broadening the approach through the establishment of Topical Teams. In these Teams, new space-environment applications are discussed in a series of workshops with industrial participation. Covering the different disciplines of material science, fluid sciences and biotechnology, these workshops have proved to be an important step in identifying applied-research problems that could be solved by using microgravity as a key tool.

Why do these teams need a Virtual Campus?

The MAP and TAP projects and the Topical Teams unite people from different scientific disciplines and professional corporations on a common research objective. The teams are international and the members often do not know each other well at first. Becoming familiar with each other's discipline, sharing existing knowledge, working with the same reference documentation and jointly working out plans and proposals is a constant preoccupation of these teams. The Erasmus Virtual Campus makes this task easier.

It is expected that the Campus, thanks to its particular information and communication tools, can cater for a more interactive type of information exchange and a higher degree of group interaction among the team members than was possible in the past with the classical one-to-one information and communication tools.

What are the principal functions of the Virtual Campus?

Firstly, the Campus is an information portal. It facilitates access to information that exists somewhere, but is difficult to find.

Secondly, the Campus is itself an information content provider. It is a warehouse for validated and up-to-date reference information. It packs this information into appropriate boxes, writes the description of content on top and stores the boxes in a structured way on shelves where they can easily be found.

Thirdly, the Campus is a broker. It contributes to making the ideas and projects of people known to other people and helps them to connect with each other.

Fourthly, the Campus is a cooperation facilitator. It provides information and communication tools that allow research teams to work on a common research project even though they are geographically separated.

Fifthly, the Campus is a time-saver and trouble-shooter. The ISS User Information Centre selects or develops for the Virtual Campus information and communication tools that are compatible and complementary. It ensures coherence and standardisation in the use of tools throughout the whole Virtual Campus community and helps participants to set up these tools and become familiar with their operation. It runs the Internet servers and the communication hubs through which the members of the Virtual Campus can share information and communicate.

What does the Virtual Campus look like?

The Virtual Campus is structured very much like a campus in the physical world. It is a city with places and buildings connected by streets. While some buildings may be open to all visitors, others have a restricted access for members only. There is a Forum for discussion and for meeting new people, an Amphitheatre for lectures and presentations and a Coliseum for events. There is a Library and an Archive. The Virtual Campus can also host Virtual Institutes. These Virtual Institutes will be operated in a shop-within-a-shop mode. They would be the masters of their own business, but they could make use of a common information and communication infrastructure and of certain services provided by the Virtual Campus.

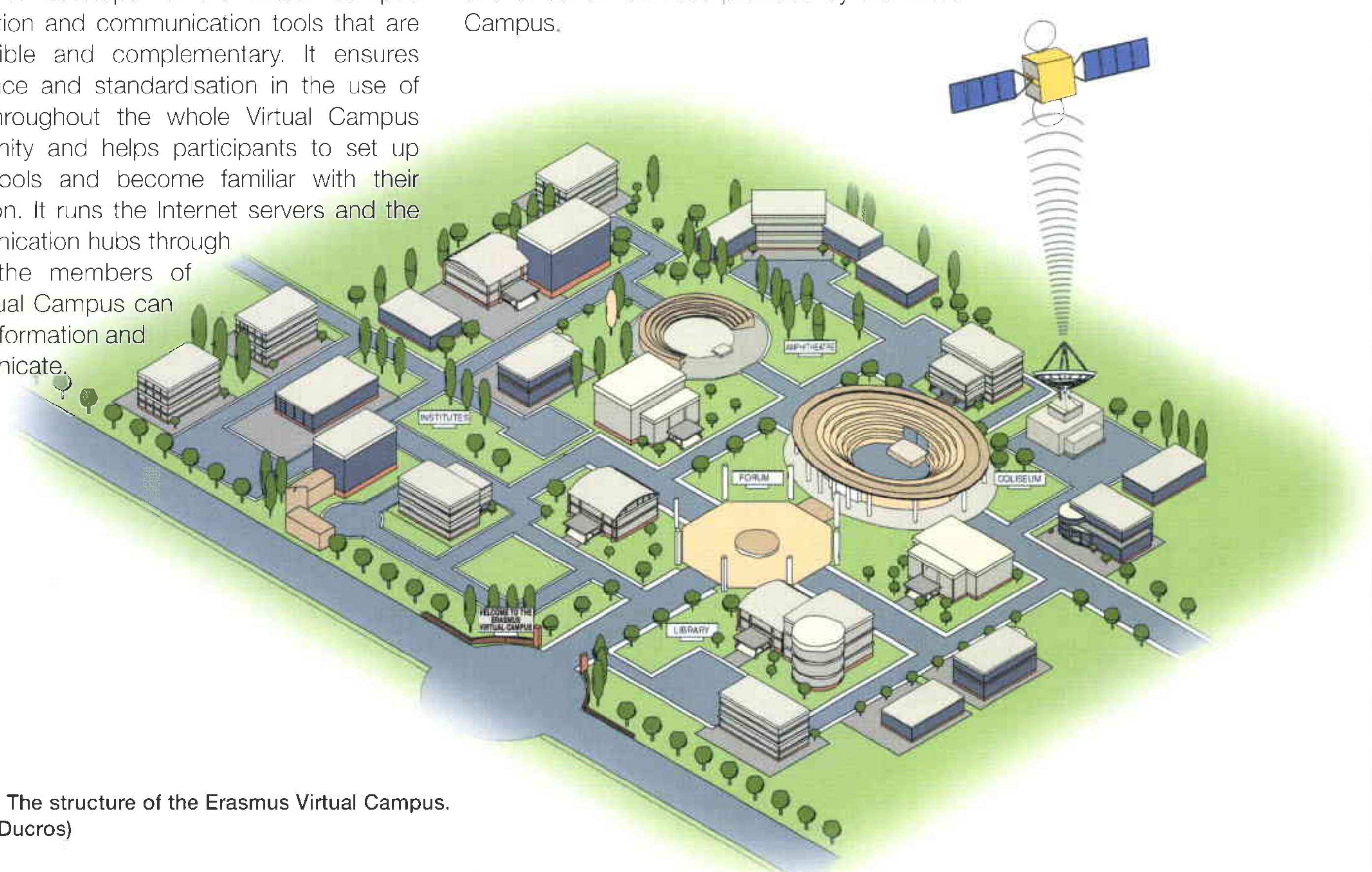

Figure 2. The structure of the Erasmus Virtual Campus. (ESA/D. Ducros)

What are the products and services of the Virtual Campus?

Internet site

The core product of the Virtual Campus in its triple function as an information portal, an information content provider and an information broker is the Internet site at *www.spaceflight. esa.int/users*. This site is structured into the following main areas: Facilities, Disciplines, Mission and Campaigns, Coordination of Research, Information, Advice and Support, and Databases.

Facilities contains information on the various facilities for research and applications that are covered by the Erasmus Virtual Campus. The Internet site catalogues all these facilities, presenting their purpose, technical and operational characteristics, responsibilities and access rules. Page structure and content are such that the advantages as well as the limitations of the facilities can easily be identified and the facilities compared with each other.

Disciplines shows the relevance of the available facilities for the various disciplines and points to the scientific or technical results that have already been obtained or are envisaged to be obtained with these facilities.

Mission and Campaigns identifies past and future activities that use these facilities, presents the scientific content of these missions and campaigns, and points to the scientists and engineers involved in these activities.

Coordination of Research is both a noticeboard for the announcement of research opportunities and a meeting place for people who are involved in research on the ISS and other facilities.

Information, Advice and Support is where the Campus visitor can find contact points and counterparts who can answer specific questions and give advice and support in the preparation and execution of research projects.

Databases gives an overview of and provides access to databases such as the Erasmus Experiment Archive, Internet-based documentation depositories and the Photo and Video Archive.

This Internet site is not meant to be a simple online equivalent of public-relations-oriented information brochures, but a resource of validated up-to-date reference information for scientists and engineers. It is therefore based on two essential concepts: the avoidance of information duplication; and data and information ownership.

Avoiding duplication is the prerequisite for efficient configuration control of the reference information contained in the many pages of an Internet site that is expected to cover about 1000 individual pages once it is completed. Any fact or figure that is expected to evolve over time is presented on a minimum number of different pages. The ideal is a single reference page to which other pages then refer. Structuring the Internet site accordingly is therefore a major effort.

The other concept, which ensures that the information on the site is up-to-date, unambiguous and contradiction-free, is the ownership of data and information. For each page, the owner or owners of the reference information contained are clearly identified and agreed upon. The content of each page is then either submitted for the endorsement of the information owner or, if appropriate, the full responsibility for maintaining the page is handed over to the information owner. In order to make this concept feasible, the site *www.spaceflight.esa.int/users* is based on a rather complex Oracle database linked to a Cold Fusion server.

Document Server

In its role as a cooperation facilitator, the Campus allows its members to store documents of common interest and share them among team members. As a first step, the documents are uploaded upon request by the various research teams participating in the Campus by the collaborators of the ISS User Information Centre. As a second step, an interactive document server is envisaged to allow easy upload and maintenance of the stored documents by the individual research teams themselves.

Photo and Video Archive

A function similar to the interactive document server, but for the shared storage and access of photo and video files, is already operational as the Photo and Video Archive. This archive is also based on the information ownership concept and the individual owners of the files in the archive can decide themselves whether they want to restrict access to a particular user community or share them with the public.

At present, the interested viewer must first download the video files in the archive before they can be seen. The technical capability to receive the video files via streaming video is under preparation. This will make the Photo and Video Archive particularly attractive for use in tele-education activities on the Campus. Computer-based familiarisation and training sessions can then be accessed easily as video-on-demand streaming video files.

Remote working sessions

In its role as a cooperation facilitator, the Virtual Campus is setting up a tool that allows geographically separated research teams to work in real-time and interactively in Word, Powerpoint and Excel, and to speak to each other through the Internet. It is true that there is already an abundance of similar tools – some of them are even offered for free download from the Internet. However, while most of these tools work well between two computer enthusiasts connected through their individual modems, they often fail, or even create serious software operations conflicts, when they have to be compatible with existing office software tools and the firewall protection techniques that are typically used in the computer networks of research institutes, space agencies and industrial companies. The ISS User Information Centre is therefore setting up a dedicated server and procuring the necessary numbers of licences for a tele-conferencing and tele-education tool that will work with the software and firewall environment of the Campus participants. It will also familiarise the participants with the use of this tool and provide support during its operation.

Experience with existing, ISDN-based video-conferencing tools has shown that they are not yet widely accepted as a replacement for face-to-face meetings. They are difficult to set up, have limited field of view and offer insufficient resolution and interactivity for dealing with documents, images and drawings. The tele-conferencing and tele-education tool selected for the Virtual Campus will avoid these problems, and its combination with other communication tools, such as satellite communication, 3D television and the Interconnected Ground System (IGS) network that links the USOCs with ESA, can increase the attraction of this form of remote cooperation to potential users.

Chat and discussion forums

In addition to the interactive working sessions in closed-circuit mode, the Virtual Campus will organise chat sessions and discussion forums with a broader audience and the general public. These tools will be part of the *www.spaceflight.esa.int/users* Internet server.

Figure 3. Working in the Multimedia Library

Video production and broadcast facilities

The ISS User Information Centre is equipped with a TV studio and the resources for producing video films (including 3D). It also has its own satellite television uplink and downlink facility and access to a Ku-band transponder on a Eutelsat satellite, so video productions and live events can be broadcast from Noordwijk to the whole of Europe for the Erasmus Virtual Campus.

The ISS User Information Centre had already contracted and supervised the production of a number of video recordings with leading scientists and engineers to illustrate the Station's utilisation in the various user

Figure 4. The control room for the TV and video facilities

disciplines at the ISS Forum 2001 in Berlin in June 2001. There is much raw material that was not used at the Forum, and it will become the initial stock for the production of lectures and educational films in the framework of the Erasmus Virtual Campus for broadcast via TV satellite and as streaming video-on-demand.

Presentations, lectures and live events
The television studio of the ISS User Information Centre in Noordwijk is complemented by an auditorium for 120 spectators. Together with the existing satellite broadcast facility and the planned Internet streaming video broadcast facility, the auditorium can be used for regular presentations and lectures on selected topics of interest to the Virtual Campus and which can be broadcast live to Europe via satellite and Internet.

The same tools and resources also ensure a wider distribution for launch and ISS in-flight events, in particular for events with a scientific or educational connotation.

European viewing sites
The satellite uplink station of the ISS User Information Centre was designed mainly for distributing satellite feeds to other TV broadcasters. It is therefore equipped for using a Ku-band digital satellite transponder in the Single-Carrier-per-Channel (SCPC) mode. The ESA Television Service normally uses a leased transponder on a Eutelsat satellite at an orbital position of 10°E. Although typical consumer-type equipment can receive this satellite, it is not expected that many potential viewers who the Erasmus Virtual Campus hopes to reach will have the necessary equipment installed and pointing at 10°E. This TV satellite is not widely used by the public and the SCPC mode requires an antenna diameter of at least 1.2 m.

The Virtual Campus will therefore base its programme of lectures and event transmissions around a number of viewing sites in Europe that have the necessary satellite TV reception equipment and an appropriate auditorium to host interested viewers from their geographical area. The USOCs are expected to play a key role in this network of viewing sites. Apart from the satellite reception, these centres are also connected to the Erasmus User Information Centre through the ESA-internal IGS network, which offers additional possibilities for communication, including 2-way. Commercially funded user support centres like ALTEC in Turin, Italy, and BEOS in Bremen, Germany, are invited to become part of the network of viewing sites.

In a second step, it is envisaged to extend the network to interested research institutes and organisations, universities, other space agencies, industrial companies, and education and popular science centres.

Figure 5. Live TV coverage of the Campus inauguration

What is the status of the Virtual Campus?
The Erasmus Virtual Campus was formally inaugurated on 8 September 2000, in the presence of the ESA Director General, A. Rodotà, and the Director of Manned Spaceflight and Microgravity, J. Feustel-Büechl, with a series of presentations and a roundtable discussion on the life sciences utilisation of the ISS. The event was transmitted live to Europe via satellite and as streaming Internet video.

Subsequently, the work focused on the development and refinement of the tools, in particular in the area of television and Internet. Working with the TMP company in Bayreuth (D), a new 3D television system was developed and made operational. It was presented for the first time to the general public during the International Radio and Television Exhibition IFA 2001 in Berlin in August 2001 with a live 3D TV transmission from Noordwijk to Berlin.

In parallel, the Internet site at *www.spaceflight.esa.int/users* has been set up, together with the Photo and Video Archive. A substantial area of concern has been the insufficient bandwidth of ESA's access to the Internet backbone for streaming Internet video activities. This is critical for reaching a large audience of the Virtual Campus in a cost-efficient manner. With the expected increase in the course of 2002 from 4 Mbit/s to 34 Mbit/s, these problems should be resolved.

The success of the Internet video streaming of the whole ISS Forum 2001 conference in real-time and as video-on-demand – organised by the User Information Centre – not only increased our experience with the technique, but also demonstrated the high interest in this form of information distribution within the potential target audience of the Erasmus Virtual Campus.

With most of the tools now being developed or ready for operation, the next step is to bring life to the Erasmus Virtual Campus. It is planned to highlight the concept and resources of the Campus in a series of presentations to its primary target users, namely the members of the MAP and TAP project teams and the Topical Teams.

The emphasis over the coming months will be on the Internet, tele-conferencing, events, education and Virtual Institutes.

Teams will be offered the opportunity to present their activities on the Internet site at *www.spaceflight.esa.int/users* and to use it for exchanging project information, documents, and photo and video files.

The efficiency and acceptance of the tele-conferencing tools will be tested and evaluated during a number of joint ESA/NASA sessions on ISS payload safety, with engineers and scientists meeting in parallel in Houston and Noordwijk, and during the joint 8th European Symposium on Life Sciences Research in Space / 23rd Annual International Gravitational Physiology Meeting in Stockholm this June. Based on our experience with the particular advantages and limitations of the various tools during these sessions, a standardised tele-conferencing support concept will then be presented to the MAP/TAP project teams and the Topical Teams.

In the area of events, the emphasis is on establishing the initial viewing sites and initiating joint events with the USOCs. The technical and organisational measures will be implemented to use the ESA IGS network for these events.

For education, the approach is two-fold. Working with the scientists concerned, the video footage produced for the ISS Forum 2001 will be 'upgraded' into a collection of short educational video films explaining the background, objectives and benefits of research on the ISS and other research facilities, in selected disciplines. In parallel, scientists will be invited to elaborate a joint concept for a cycle of presentations and lectures given at regular intervals in the auditorium of the ISS User Information Centre beginning in 2002.

Figure 6. Hosting coverage of the Zvezda launch

For the Virtual Institutes, it is planned to present the principal possibilities and the available resources of the Virtual Campus to interested scientists, and to assess with them how they could benefit from the Virtual Campus for creating their own Virtual Institutes.

Contact point

Scientists and engineers from the potential user community of the Virtual Campus who would like to receive additional information or who would like to be among the foundation members of the Campus are invited to contact:

Dieter Isakeit, Manager, ISS Erasmus User Information Centre, Directorate of Manned Spaceflight and Microgravity (mail code MSM-GAU), ESA/ESTEC, PO Box 299, NL-2200 AG Noordwijk, The Netherlands. Tel +31 71 565-5451, Fax +31 71 565-3661, Dieter.Isakeit@esa.int

esa

The Orbital Liquid Experiment (OLE)

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ESTEC, Noordwijk, The Netherlands

The SUCCESS competition

In 1998, ESA initiated a European student contest to support the early utilisation phase of the International Space Station (ISS). SUCCESS (Space Station Utilisation Contest Calling for European Student Initiatives) was officially presented at the Second Space Station Utilisation Symposium held at ESTEC on 17 November 1998. Its main aim was to have European students thinking about space and working on a proposal for an experiment aboard Europe's Columbus laboratory module of the ISS. The contest was open to all disciplines in order to stimulate new space science initiatives for the ISS.

The student Orbital Liquid Experiment (OLE), winner of the Agency's SUCCESS competition, has been built and successfully operated. OLE, which investigates the impacts of liquid drop against liquid surfaces, flew on ESA's 30th Parabolic Flight Campaign. Achieving conditions unobtainable under normal gravitational effects, valid data were recorded for 44 parabolas during the three flights of the campaign. The preliminary results show that, in microgravity conditions, there is an absence of any kind of reflection of the liquid following impact.

SUCCESS was addressed to all students in more than 950 universities all around Europe – more than a million students from all disciplines. The year-long contest was organised in three phases. In the first phase, the students had to register and briefly describe their ideas; 485 proposals from 229 universities were received by the deadline of 18 February 1999. A Professional Day was organised in March 1999, when ESA experts answered online questions from the students.

In the second phase, the students had to write a proposal describing their initiatives in more detail. ESA received 103 experiment proposals from 126 students, in Austria, France, Germany, Ireland, Italy, The Netherlands, Norway, Spain and the UK, spanning the fields of technology, life sciences, physics, materials science and Earth observation.

ESA's Space Station Utilisation Panel (SSUP) served as the competition's jury and decided on the best essays to select the participants for the third phase. A Team Day was organised at ESTEC on 23 April 1999, when the participants met for the first time and worked together on their proposals. The objective was to provide first-hand information about the ISS and Columbus, as well as to encourage participants with similar proposals to form teams with members from other countries.

In this phase, the teams elaborated detailed proposals for flight experiments. The SSUP chose the winners. The award event was organised in connection with the 50th International Astronautical Federation congress, in Amsterdam, in October 1999. Under the aegis of ESA's Director for Manned Spaceflight and Microgravity, Mr Jörg Feustel-Büechl, prizes were awarded to:

First Prize: José Mariano López Urdiales, Fernando Mancebo Ordóñez, Daniel Meizoso Latova and Pablo Valls Moldenhauer (Universidad Politécnica de Madrid, Spain);
Second Prize: Paolo Ariaudo (Università degli Studi di Napoli 'Federico II', Italy);
Third Prize: Alexander Roger and Anna Glennmar (University of Glasgow, UK).

The First Prize was the opportunity to work on the experiment at ESTEC and test it on a parabolic flight campaign. Second Prize was a laptop; Third was a trip to Kourou to witness an Ariane launch. This article describes the activities and results that followed from the award of the First Prize to the Orbital Liquid Experiment (OLE; Figs. 1 and 2) team.

Background

Behind the beauty of the apparently simple event of a liquid drop impacting against a liquid surface lies a complex and unsolved physical system. Given the initial conditions and properties of the liquid, we are not yet able to

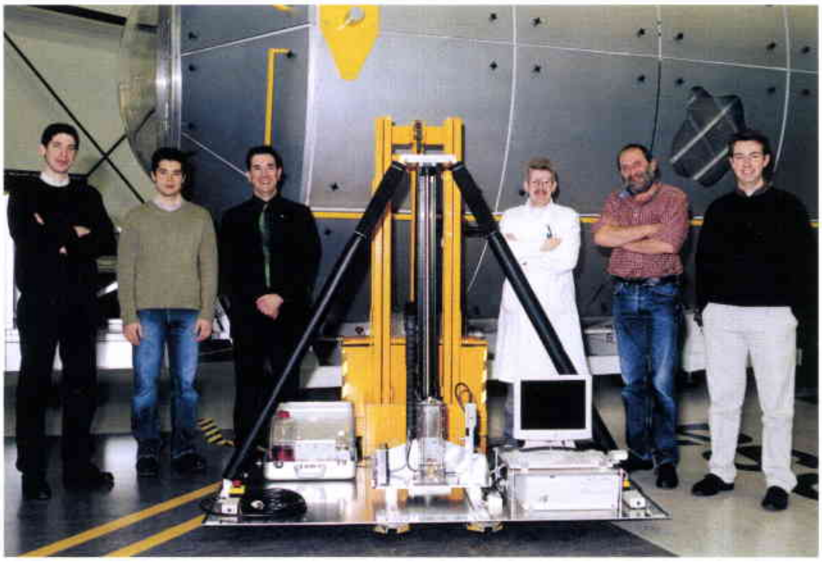

Figure 1. OLE ready for shipping to Bordeaux

Figure 2. OLE during an experiment run, poised at the top of the bearing rail

fully explain or predict what will happen. The subject has important implications for a wide variety of fields of science, including fluid dynamics, chemical engineering, space research and meteorology. It is important for many technical applications in the pharmaceutical, metallurgical and food industries. The investigation of drop collision and coalescence processes as a whole is leading to new and more efficient technologies. The main objective of this research is to gain a better understanding of liquid drop impact phenomena under a wider range of physical conditions than can be achieved in a ground-based facility.

Fluid dynamics researchers have studied impacts of liquid drops against flat liquid surfaces since the early photographic work of Prof. A.M. Worthington in the 19th Century. Many experiments of this type have been carried out using liquids of different properties (from water to superfluid helium) and drop diameters of up to 6 mm. However, they were all carried out under normal gravity, which imposed two limitations in the range of conditions that could be explored. First, the drop diameter was limited to less than 6 mm; second, the gravity in the impact reference frame was always the same. OLE was conceived to elude these limitations by providing experimental conditions in which the gravity of the reference frame of the impact was a control parameter, while being able to form drops larger than on the ground.

The outcome of the impact depends on the properties of the drop fluid, the target fluid and also of the fluid the drop travels through before it impacts. It also depends on the diameter of the impinging droplet, the impact velocity and the level of acceleration. Also, the boundary and initial conditions play an important role that may vary the results of similar experiments. The two main physical parameters on which the phenomenon depends are the Weber and Bond numbers, which are respectively the kinetic energy and the gravitational energy of the drop, both normalised to the surface energy. Using high-speed imaging, the impact can be observed and the shape and size of the impact crater can be measured to characterise the phenomenon.

Each different impact condition can be associated with a point in the Weber-Bond plane. The part of the plane already explored in ground-based laboratories is shown in Figure 3 This part can be divided into regions, each representing a different impact regime. Results so far show three different regimes: bounce, coalescence and reflection. Short descriptions of these regimes in drop-flat fluid surface collisions are given below.

Bounce
It may happen that the gas surrounding the free surfaces is trapped between them as they close in. The thin gas layer then inhibits the contact between them and the drop bounces off the flat surface. The deformation and drainage of the thin gas layer depends upon external factors such as the gas pressure, the shape of the impacting droplets and the behaviour of the trapped gas. This phenomenon is difficult to reproduce because it occurs only under very specific conditions.

Coalescence
In this case, the air layer escapes from the gap between the drop and the fluid surface. After initial contact, a liquid bridge appears between

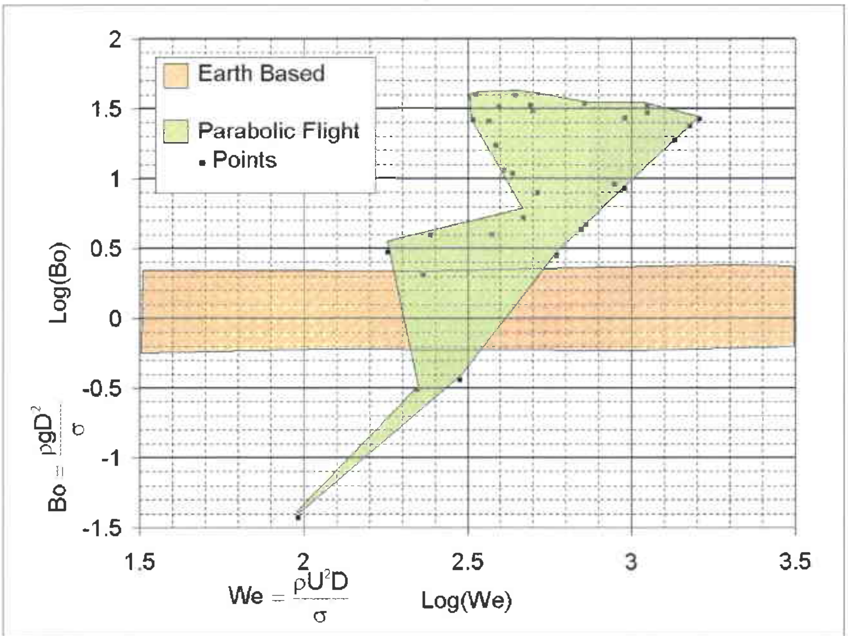

Figure 3. The Weber-Bond plane

them; the mass inside the drop joins the fluid of the target in a process called coalescence.

Reflection
The process is similar to that of coalescence – the drop merges with the target surface but then a new drop separates, of different mass. If the Weber Number of the impact is higher than about 65, a jet is reflected upwards and a new drop is pinched off at the tip of the jet (Rayleigh instability). Even higher Weber Numbers produce more complicated reflections: smaller, satellite drops are generated behind the main drop.

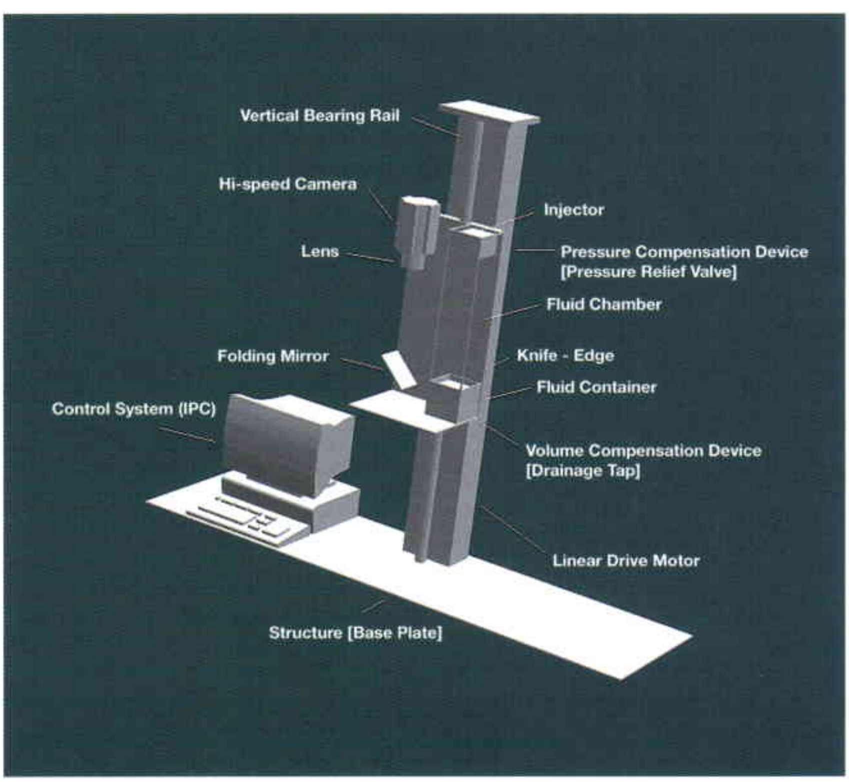

Figure 4. Schematic of the selected hardware concept

Before the OLE team's arrival at ESTEC, a series of experiments in the Universidad Politécnica de Madrid generated results in the previously known regimes and provided hands-on experience with drop impacts and high-speed imaging. This preliminary work paved the way for the project's rapid progress.

OLE was designed to study impacts of drops of various diameters in microgravity, and impacts of very large drops in conditions simulating the gravities of Titan, Mars and Earth. Figure 3 shows the impact conditions that were achieved in the experiment. All these impacts are beyond the previously explored range.

The experiment hardware

Many concepts for the experiment were studied from October to December 2000; Figure 4 shows the final version. The main hard-ware components are the:

- working fluid;
- injector system;
- fluid cell system;
- high-speed digital imaging system;
- illumination system;
- servo-controlled linear motor;
- power system;
- data-acquisition and control system;
- structure.

Distilled water was selected as the *working fluid* because it has a high surface tension and it is relatively safe and easy to handle. The *injector system* consists of a set of adapters, syringes, tubing and Teflon needles to form single drops in microgravity. Figure 5 shows the Teflon needles and an adapter. The drops were formed by pumping water manually with the syringes. Manual operation provided greater flexibility of operation than using a digitally controlled syringe. To form drops of various sizes, different drop injection sets (with needles of diameters ranging from 0.1 mm to 0.8 mm) were attached to the top of the fluid cell using custom-made adapters. The injector system was assembled at the Microgravity Laboratory in ESTEC.

The *fluid cell system* provides a watertight volume where the liquid is stored and drops can be formed and impacted against a flat liquid surface. The cell chamber is a straight prism with a square 100 mm section made of transparent polycarbonate sheets. The injection sets were attached at the top of the cell. One critical requirement for the experiment to work was to keep the surface of the liquid flat even during microgravity time. This was achieved with the aid of a laser-cut stainless steel plate 150 microns thick, its surface was treated with an experimental non-wetting coating provided by 3M (L16154). Ground tests and microscopy inspections were performed to characterise the properties of the sharp edge. However, the only way in practice to fully validate this solution was to test it in microgravity, which was obviously not a realistic option. Fortunately, this solution proved to be very effective because the surface remained pinned to the sharp edge of the plate for more than 90% of the parabolas. In the rest of the cases, the surface was probably destabilised by a small but sustained negative residual accel-eration during the first seconds of the parabola, causing the liquid to 'fall' upwards. The fluid cell was built in the main workshop in ESTEC.

Figure 5. The Teflon needles and adapter

The impacts were imaged by a high-speed 256-level greyscale, digitally controlled *digital imaging system*. The camera was capable of a resolution of 256x240 pixels at 1000 frames per second (fps). The camera head weighed only 1.6 kg and could accommodate different lenses via a standard C-mount. The camera and the lenses are shown in Figure 6. Up to 4 s of images, or 256 MB, were recorded in real time at each impact. The whole system was extremely compact and comprised only the CCD camera, a high data-rate cable and a PCI card plugged into a slot of the motherboard of the computer. The camera was triggered manually with a negative TTL trigger built at ESTEC. Using custom camera software, at the end of each parabola, one experimenter selected the time interval during which the impacts occurred and stored it on the hard-drive in order to free the D-RAM for the next parabola. Photon kindly loaned the camera and the PCI card. Different illumination solutions were tested; the best proved to be a white diffused background. The *illumination system* consisted of a set of four off-the-shelf 12 Vdc 50 W halogen dichroic lamps and a diffusing sheet. Together, they provided the intense diffuse background illumination that the camera required to take images at 1000 fps.

One of the requirements for OLE was to reproduce phenomena under different gravity conditions. In the original proposal for SUCCESS, intermediate gravity was to be achieved via a small centrifuge. After studying the new requirements (shorter microgravity time than aboard the ISS) as well as the additional opportunities afforded by the A300 aircraft (higher volume, mass and power available), a *servo-controlled linear motor* was found to be a better option to provide the required 0.01-1 *g* for 3 s. It also simplified the analysis and interpretation of the results because of the purely linear acceleration and the absence of Coriolis forces. The drop injection, fluid cell, high-speed camera and illumination systems were all rigidly mounted on a linearly moving platform. The platform was attached to the thrust block of the linear motor, which moved along a vertical rail fixed to the aircraft. The overall length reaches 1.6 m, providing 1.3 m of travel. The position of the motor was monitored constantly, with an optical linear encoder providing 5-micron accuracy. The motion profiles of the motor were pre-programmed in Mint™ language and downloaded to the NextMove™ PCI controller during the intervals between parabolas. A series of ground tests set the parameters and gains of the controller for each motion profile.

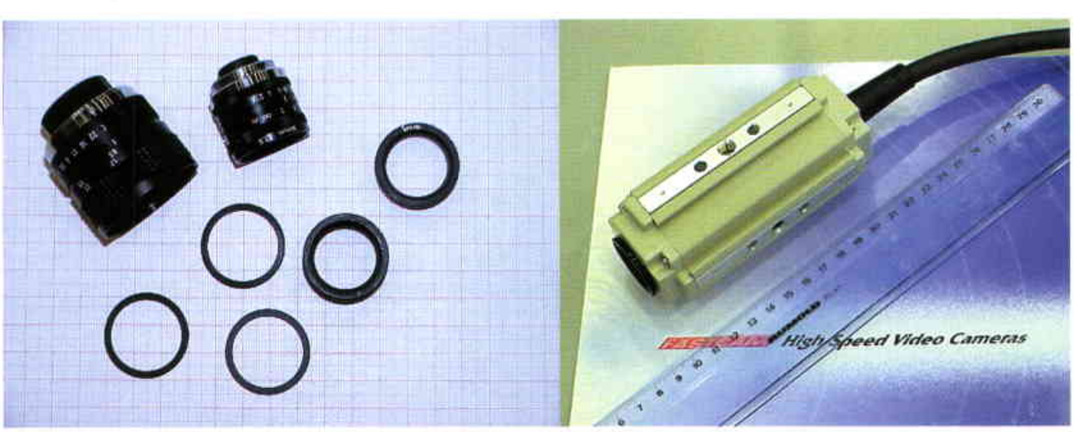

Figure 6. The high-speed camera head and lenses

The tests were performed moving the motor in a horizontal direction to simulate the conditions of motion in microgravity. In each operation cycle, there was a motion profile characterised by three values of the acceleration. The first phase was the initial acceleration, which had two different purposes. It detached the droplet from the needle and provided a certain relative velocity between the drop and the flat surface. Until shortly before impact, the motor kept moving in the same direction but at a different acceleration in order to provide the desired acceleration value during the impact process. After impact, the platform stopped in the minimum distance compatible with the loads that appear on the platform; that was the third level of acceleration. The experiment used the *power system* provided by the aircraft's electrical panel #1, which supplied up to 2 kVA of 220 V at 50 Hz. In order to obtain flicker-free illumination, a rectifier feeds the illumination system with 12 Vdc.

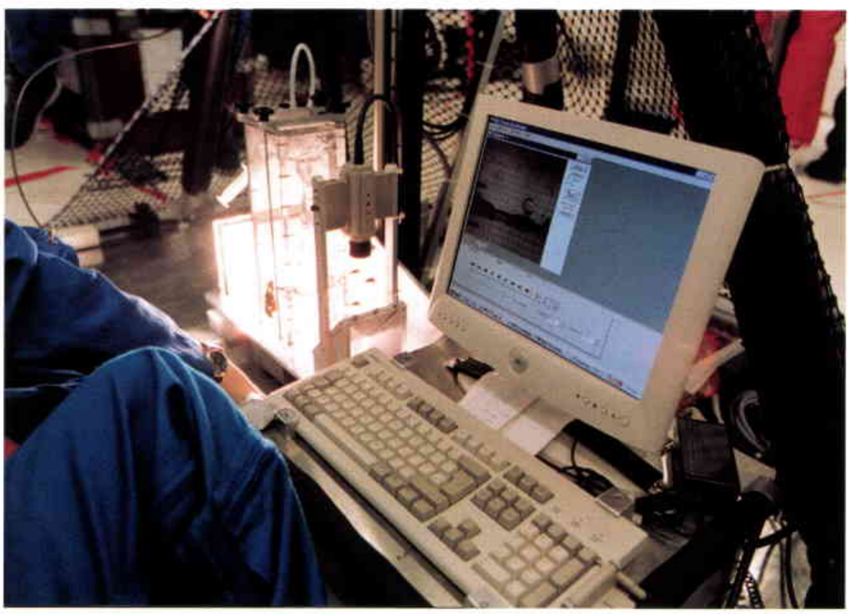

Figure 7. OLE during flight: operating the high-speed camera from the computer

The *data acquisition and control system* consisted of a PC with two dedicated PCI cards and custom software. During parabolas, the system was used to control the linear motor and imaging system simultaneously. Operated by one experimenter, the computer ran under Windows 98. Instead of a normal mouse, which would not work properly in microgravity, a Microsoft Ballpoint was used as a pointing device. This trackball proved to be very comfortable to operate and it performed flawlessly under all gravity conditions. The computer was supplied by Serco.

As with any experiment flown on the A300 aircraft, the hardware had to meet rigorous mechanical requirements imposed by the vehicle's flight profile. The most prominent is an acceleration of 9 *g* along the aircraft's main axis towards the nose. The primary structure is a set of aluminium beams of full square cross section attached to a reinforced plate of aluminium. This structure holds the linear motor bearing rail vertical. All the linearly moving items are attached to the platform. This one was built in aluminium and designed to be rigid enough to prevent any vibrations or misalignments between the camera, mirror and fluid cell. Auxiliary structures were designed and built for the electronics boxes and the computer. All the structures were built in ESTEC's main workshop.

The parabolic flight campaign

OLE (Fig. 7) was one of 14 experiments that flew on the 30th ESA Parabolic Flight Campaign from Bordeaux (F) on three flights 15–17 May 2001. Each flight included 31 parabolas, each providing about 20s of microgravity. As usual on all parabolic flights, each period of microgravity was preceded and followed by a short phase of hypergravity of about 1.8 *g*. The crew from Novespace and Sogerma, the French companies that operate and maintain the aircraft, were especially helpful in meeting the security requirements and safely attaching the experiment to the seat tracks on board.

For the first part of the first flight, the experimenters familiarised themselves with the singular and breathtaking sensation of weightlessness. These first parabolas also confirmed that the fluid surface remained flat under microgravity. Two experimenters (PV, DM) then learned the intricate art of pumping single drops of increasing size in weightlessness. To prevent jetting or, even worse, the drop staying on the tip, a fine compromise was reached between the pumping speed and duration. At the same time, JML, via the PC, operated the high-speed camera and the linear drive, and between parabolas was responsible for selecting and storing on the hard drive all useful portions of video data.

The experiment required a high degree of manual interaction, so a highly detailed procedure was devised and tested on the ground for weeks before the flights. A comprehensive set of programs for the linear drive was prepared for operational flexibility – critical for succeeding with any new experiment.

During the first flight, some drops intended for low-velocity impacts failed to detach from the needle: the initial acceleration of the moving platform was too low for those particular motion profiles. The antiwetting coating was extremely important for holding the fluid inside the container and the drop attached to the tip of the needle as long as possible. It became clear that very small drops would not detach from the needle, whereas large volumes were easily ejected even for low values of the induced acceleration. Hence, the knife-edge and each needle were carefully covered with antiwetting coating before each flight and the analysis focused on drop sizes larger than those obtainable at 1 *g*. The timing had to be precise because the longer it took to form the drop the more unstable became the fluid (inside both the container and the drop). However, the fluid had to be injected slowly into the drop in order to avoid detachment before the linear motor was triggered. Therefore, it was necessary to pump the volume slowly enough and to trigger the motor immediately after drop formation. It took several parabolas before the procedure was trimmed. The ratio of successful impacts rose from 8 out of 31on the first day, to 17/31 on the second and 19/31 on the third. An impact was considered successful if a single drop was detached and impacted in the field of view against a reasonably flat liquid surface, with the whole process recorded on the computer. During the third flight, a few bonus impacts under hypergravity were recorded between parabolas. However, the drop size could not be controlled and was always roughly the natural size of a detaching drop at 1.8 *g*.

During video processing, all of the 'Titan' (1.4 ms^{-2}) runs were found to be defective

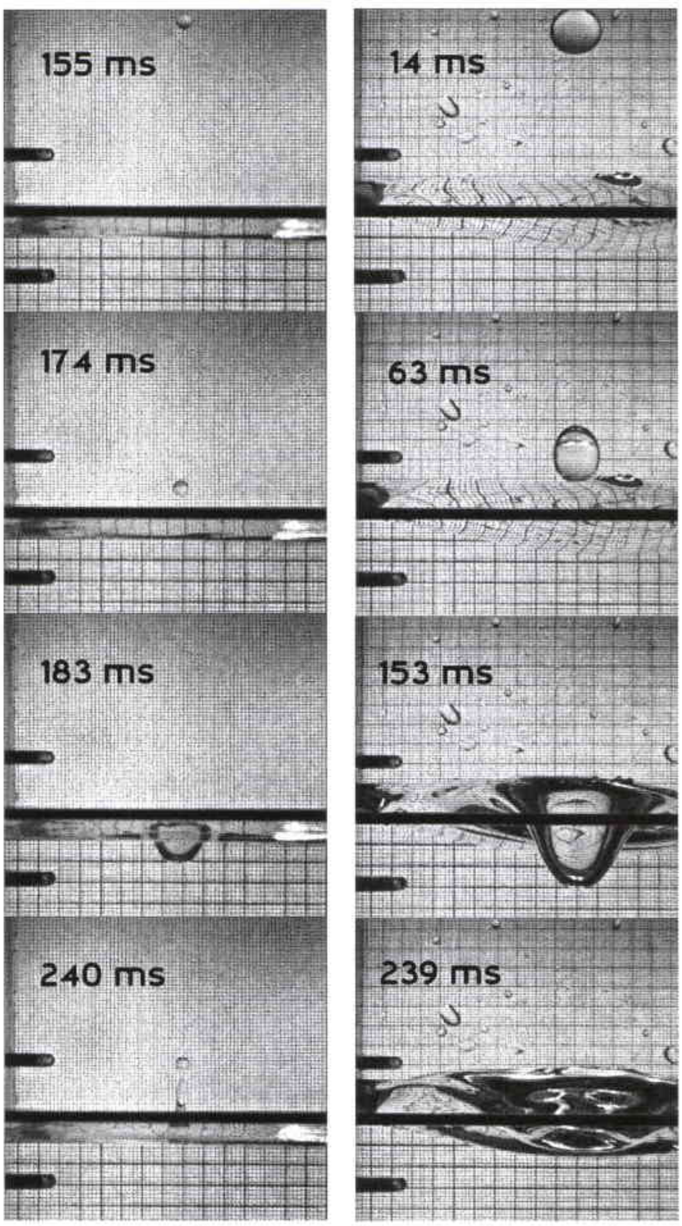

Figure 8. Comparison between two impacts of similar Weber Number: ground-based reflection (left) and pure coalescence in microgravity (right). Note the difference in the drop sizes

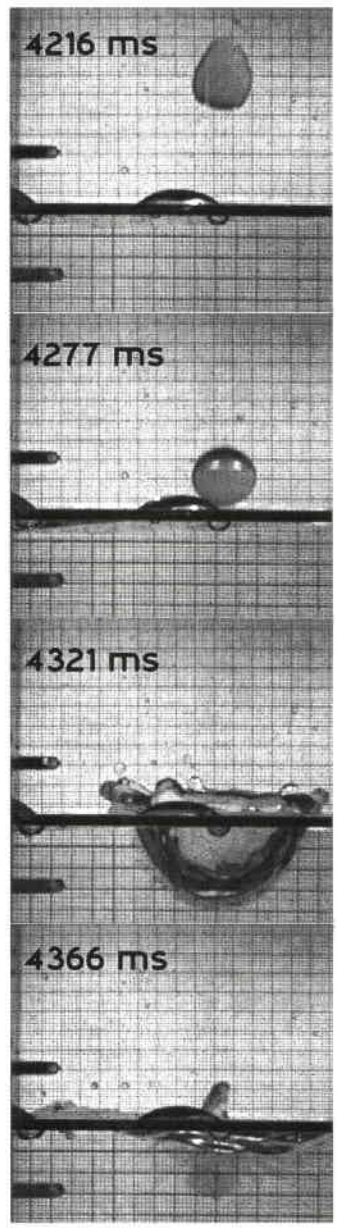

Figure 9. The impact of a 15 mm-diameter coloured drop at 1.4 ms^{-1} in Earth gravity

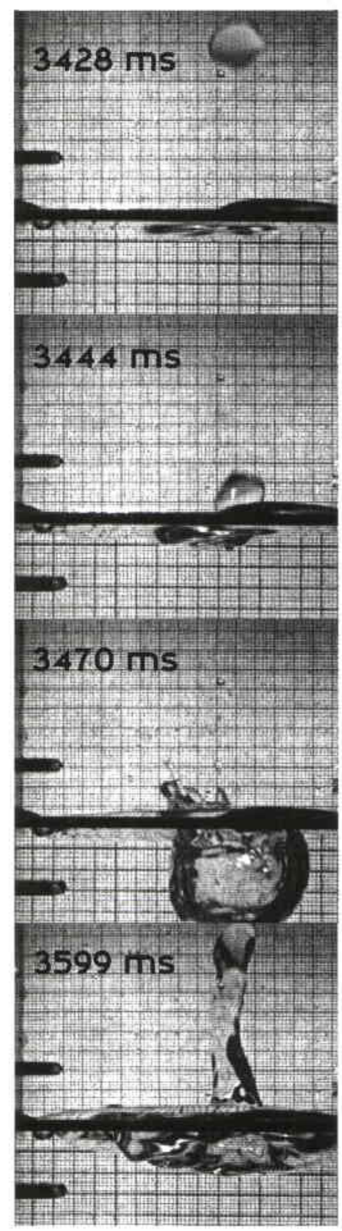

Figure 10. The impact of a 9 mm-diameter drop at 2.3 ms^{-1} in martian gravity

apparently because of an instability breaking the fluid surface just before impact. Despite this minor setback, an excellent set of successful impacts was recorded for the Mars (3.8 ms^{-2}), Earth (9.81 ms^{-2}) and pullout phases (18 ms^{-2}) for various sizes and different speeds.

During the last few parabolas of each flight a few impacts were reproduced using coloured water. The violet colouring agent was potassium permanganate, chosen because it leaves the surface tension and density almost unchanged. These impacts are useful because they allow us to see what happens to the fluid inside the drop after impact.

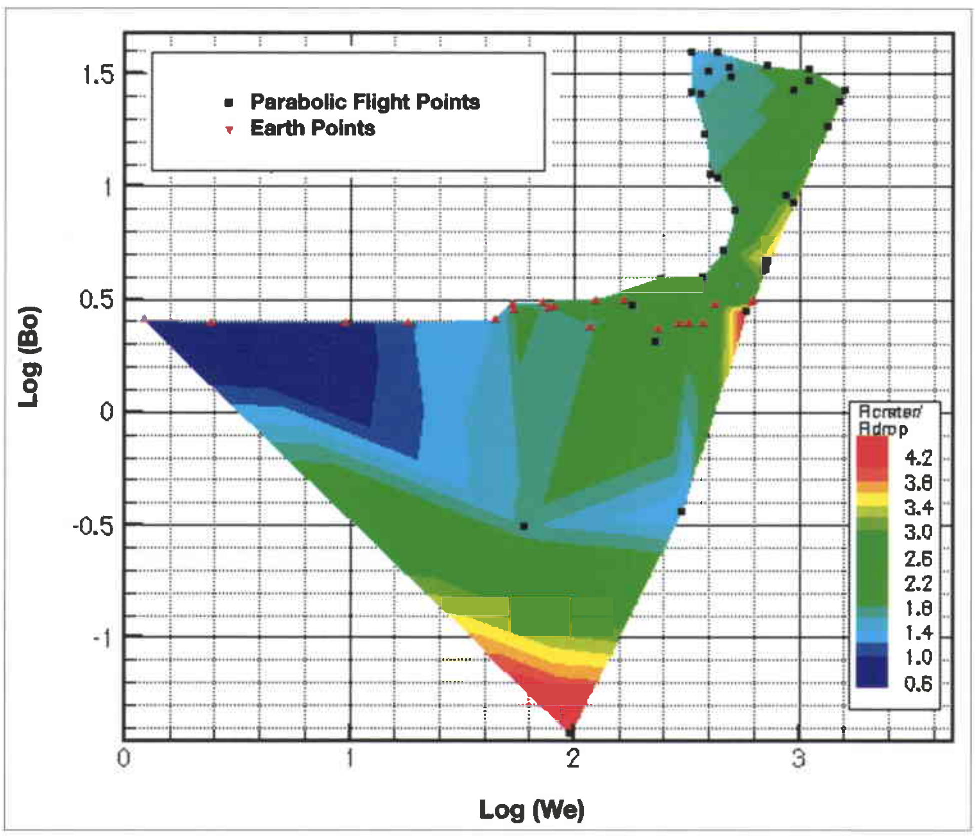

Figure 11. Radius of the impact crater, normalised to the radius of the impacting drop, as a function of the Bond and Weber Numbers

Preliminary results

One of the most striking results concerns the reflection phenomenon. In the range of explored Weber Numbers, a drop impacting a flat liquid surface in microgravity always coalesces with the target fluid, preventing reflection. Even for impacts with Weber Numbers up to 300, no drop or jet is ejected in the opposite direction. From this, we infer that the familiar phenomenon of reflection is caused by gravitational effects. This is seen in Figure 8, which compares an impact recorded on the ground with one in microgravity, with similar Weber Numbers. With gravity, there is a reflection while in microgravity the drop simply coalesces. Gravity has a strong influence on the shape of the impact crater and particularly in the way it collapses.

About half of the impacts were obtained while accelerating the platform at 9.81 ms^{-2} (1 *g*). In this case, the novelty of the experiment came from the large drop sizes: 7-18 mm in diameter. Figure 9 shows a 15 mm coloured drop impacting at 1.4 ms^{-1}.

Particularly exciting are the impacts recorded under 'martian' gravity. A series of drops 7–18 mm in diameter and at impact velocities of 1.2–2.5 ms^{-1} was made to fall and impact under martian conditions. All yielded Weber Numbers high enough for reflection. The reflected jet was always much wider and reached further than similar impacts under terrestrial gravity. If, as many planetary scientists believe, water once rained down on a martian ocean, the impacts probably looked something like Figure 10.

During June 2001, more than 50 image sequences were analysed. Emphasis was placed on determining the main features of the impact crater and its maximum size. Figure 11 combines data from the parabolic flights and the results from ground-based experiments. It graphically represents the radius of the impact crater, normalised to the radius of the impacting drop, as a function of the Bond and Weber Numbers.

Acknowledgements

The authors are indebted to W. Van Hoogstraten and R. Wakka for their valuable advice and expertise throughout the design and building process of OLE, and to H. Ravensbergen for her help throughout. They thank ESA D/MSM and their supervisor, U. Merbold, for providing this wonderful opportunity to develop the experiment at ESTEC. Special thanks are due to P. Schiller, J. Becker, A. Dowson, K. Debeule and J. Maroothynaden, of ESA-TOS, for their continuous assistance in solving all kind of problems and for their encouragement. Thanks are also due to Serco, Photron and 3M for providing essential elements of the OLE hardware. The authors also extend their gratitude to all the people who supported and encouraged them from the beginning to the successful conclusion of the OLE project.

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The ESA Education Office and Some Current Projects

I. Duvaux-Béchon & P. Messina
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ESA has recently reinforced its policy with respect to education and outreach, which was presented to Council in June 2001 in a document titled 'The European Space Education Programme'. Education is one of the mandatory activities foreseen by the ESA Convention, and the Long-Term Policy Committee proposed two actions directly linked to education in its latest report. The Education Office and its mandate have therefore been enlarged and several new initiatives have been launched. This article puts the Agency's increased commitment to educational activities into perspective, brings you up-to-date with the latest news, and introduces some of the projects currently under development.

Introduction

ESA's European Space Education Programme is aimed at:
- challenging and motivating a large number of young people through active involvement in exciting projects in order to enhance their literacy in science and technology in general, and space-related matters in particular
- identifying competent and creative students in order to foster a highly talented workforce for the 21st century.

Such ambitious goals call for a pro-active and innovative approach with a strong 'marketing' slant, i.e. making ourselves and our initiatives appealing to our target groups.

To achieve these two objectives we need an effective strategy relying on, among other things, internal and external networks. Such an external network will comprise European academic institutions, national and local authorities, teacher and students associations, other European organisations as well as representatives from ESA's industrial partners. The role of such a network will be to provide inputs, opportunities, and exchanges of information for the benefit of the ESA Educational Programme and thereby constitute the ideal complement for its successful implementation.

External co-ordination

The Advisory Committee on Education (ACE) forms the first element of the external network. This Committee brings together representatives from the ESA Member States and additional national experts to advise the Director General on education policy and initiatives. It also serves as primary chain of transmission for information between ESA and the national agencies. The Secretariat to the ACE is provided by the Education Office. There are points of contact in each ESA Directorate, so that ACE will also become a useful tool for all ESA groups that carry out educational activities in their own specific fields of interest. ACE also welcomes representatives of the European Commission and European industry in order to foster a forum in which to discuss and define a truly European policy for education both in space-related matters and in science and technology in general.

The first meeting of ACE was held in Paris on 24 October 2001 and was opened by Antonio Rodotà, ESA's Director General. The second meeting was held on 29 January 2002.

Internal co-ordination

The second meeting of the internal Education Team (E-Team) was held in December 2001. This team consists of representatives from the various ESA Directorates involved in educational activities. These meetings (two per year) promote fruitful discussions and an easy exchange of information within the Agency, bringing together the various ideas and projects and thereby making better use of the resources available within ESA. At this meeting, the various plans and projects for 2002 were presented, together with the new publication 'EDUnews' (see below) and the future ESA Education Web Site (see ESA Bulletin No. 108, November 2001).

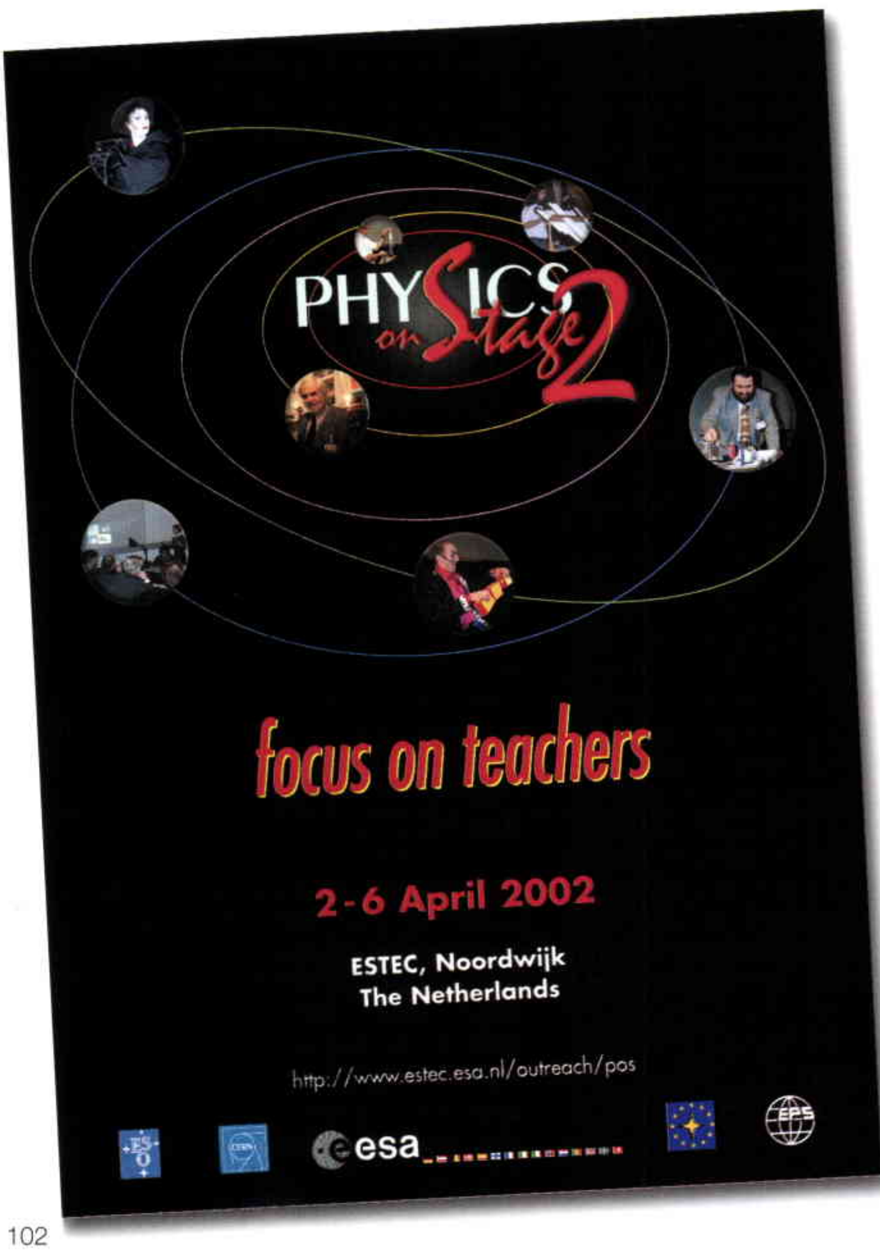
The Education Office is creating a database of volunteers from ESA who are willing to participate in education activities, by giving presentations at schools and universities, tutoring young visitors, preparing educational material, participating in video-conferences with schools, providing useful addresses or forwarding documentation, or translating small texts into their mother tongue. By the end of 2001, more than 100 staff from all ESA

Establishments had already volunteered. We are now structuring this database of volunteers so that requests for help can be quickly satisfied and all potential needs are covered (covering each programme domain and each Member State language, for example).

Current activities and projects

Prior to taking on its new co-ordination role through its enlarged mandate, the Education Office has already organized numerous successful projects and activities. Many of them have already proved very popular over the past years, such as the IAF Congress Outreach Programme, through which several hundreds of European students have had the opportunity to participate in this annual International Astronautical Federation event.

Through its Student Parabolic Flight Campaign, a project that has already been running successfully for several years, the Education Office gives several student teams drawn from all over Europe the opportunity to design, develop and finally fly a microgravity experiment during a two-week flight campaign every year in Bordeaux. The best student experiments subsequently get the chance to fly on professional parabolic flights and may one day end up on the International Space Station (ISS).



The Education Office has also teamed up with colleagues from other European research organisations, namely CERN and ESO, to make the 'Physics on Stage' event happen. The first festival took place at CERN in Geneva (CH) in November 2000 and attracted hundreds of European teachers and other educators. The EC Commissioner for Research and Technology, Philippe Busquin, was among those who attended. This year, the Education Office is organizing Physics on Stage 2 at ESTEC in Noordwijk (NL) from 2 to 6 April (see below).

Another example of an appealing project for students is SSETI. It is a challenging and innovative way for teams drawn from universities all over Europe to design a spacecraft using a web-based platform. It has led to the creation of a very active 'virtual community' of space-interested students.

EDUnews

The 'marketing' approach being pursued by the Education Office requires several ways of communicating and getting our message across in the most effective way. Along with the new web site that is being developed, the need for an education newsletter was strongly felt. We therefore enlisted the help of the ESA Publications Division to launch 'EDUnews' as a communications tool for all ESA entities and individuals dealing with educational matters.

We believe that EDUnews will prove a very effective means of informing interested individuals, raising awareness and establishing new contacts throughout the Member States and beyond. It will provide the possibility for our partners to promote their space-related education events and initiatives also.

EDUnews will be made available from the ESA Education portal by e-mail, as well as being distributed by e-mail or in hard copy to our mailing list and during appropriate events.

ESA external traineeships and relations with European universities

The Education Office and the Human Resources Department will share responsibilities with respect to the revision of the ESA external traineeship policies and the Young Graduate Trainee (YGT) scheme. Human Resources will remain the actual recruiter and the counsellor for recruitment matters vis-a-vis the ESA Directorates, whilst the Education Office will be responsible for the upstream part of the programme, such as defining and promoting the YGT Scheme and integrating it fully and coherently into the ESA educational policy.

One improvement that is being developed is to give interested young Europeans the opportunity to apply for the YGT scheme via an interactive Internet-based system, known as the 'Young Friends of the Agency Database'. Apart from being a modern promotional and information-gathering tool, an important feature of this database will be the ability to create an updated roster of YGT candidates for browsing and pre-selection by ESA's line managers. It will help in matching the flow of applications from specific groups (e.g. young graduates with systems-engineering skills/experience) with ESA's future needs, as well as providing a snapshot of young people interested in a career in space.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EDUnews

esa Education Office

Dear EDUnews Reader,

The idea of an education newsletter for the European Space Agency (ESA) has been around for quite some time. Now at last here it is. EDUnews is a newsletter devoted to educational themes and activities at ESA. There are many things going on – many interesting projects to learn about, many excellent people to get to know and many ideas to share and discuss. With EDUnews we have a dedicated publication in which all such information is collected.

The Newsletter is published with the support of the ESA Publications Division and it is co-ordinated by the ESA Education Office. Its content, however, is open to contributions from everybody involved in educational initiatives at ESA and beyond.

We hope to provide everybody who is interested in the subject of education in science and technology in general and space in particular with an informative and pleasant tool and a practical guide to the different initiatives and programmes. Help us make it grow and become more appealing and complete!

We hope you enjoy this first issue. We would be grateful if you would share your suggestions, criticisms, experience and ideas with us. Feel free to contact us at education@esa.int

Contents

Along with the traineeship policy review, the Education Office has started thinking about how to improve relations with academia for educational purposes. Even though extensive ties already exist between ESA and European Universities, there are still gaps and a lack of coordination. The rationale is to fill these gaps (a new PhD grants programme is about to be launched) and provide interested ESA parties with a framework for carrying out projects with, and thereby enhancing their relations with, universities.

Projects for primary and secondary schools

Physics on Stage

During 'Physics on Stage 2', from 2 to 6 April 2002, ESTEC will play host to more than 300 physics teachers from 22 European countries (selected by national steering committees) who will discuss new ways of teaching physics in order to make it more attractive for children, and show and share the educational materials that they have developed. They will also select what they believe to be the best examples, which ESA will then help to disseminate as widely as possible. These teachers will be taking home a lot of new methods and ideas for interesting more young Europeans in studying and pursuing a career science. Further details can be found at: http://www.estec.esa.nl/outreach/pos/pos2.htm.

From 2003, the event will be extended to more disciplines (like biology) and will be called 'Science on Stage'. It will be organised by a foundation that is part of EIRO (European Inter-governmental Research Organisations), which groups together the main Research Organisations in Europe like CERN, ESO, EMBL, ESA, etc., and is supported by the European Commission.

Netdays

'Netdays' is an event organised every November by the Directorate of Education and Culture of the European Commission. Education Office participated in the event of 2001, when the main subject was 'Youth on the Net'. We asked young Europeans to send us their ideas about space as texts, poems or drawings. ESA staff replied to questions posted on the Internet.

Netdays 2002 will include a question-and-answer forum on the Education website. There will be links to space images and videos on the Internet, and we will show specially developed films to help children learn about space.

Learning materials

The material available within ESA, at the moment mainly CD-ROMs, is being reviewed and adapted for primary and secondary school use. Translations are being prepared for special items so that material for younger children is available in all Member State languages. Materials that have already been developed in the Member States will also be translated, in order to make as much interesting material as possible available to everybody. Initially, priority

L'espace est un univers très vaste : j'ai l'impression que les hommes n'arriveront jamais à tout connaître sur sa dimension et ses secrets.
Mais l'espace est pour moi un spectacle grandiose, parce que quand nous contemplons l'univers, nous sommes spectateurs de merveilleux paysages, cela est très agréable.
Les satellites nous apportent les télécommunications et cela permet de créer des emplois.
Grâce à l'espace nous apprenons beaucoup et nous avançons plus loin dans la technologie.
Mais ce que je préfère malgré tout, c'est cette impression d'être si petite, presque rien par rapport à l'univers qui, lui, est immense.
J'aime l'espace parce que rien que d'y rêver me procure un grand bien !
Myriam, Paris

Aélia Voisin, Loiret, France

is being given to adapting existing material rather than developing a lot of new material.

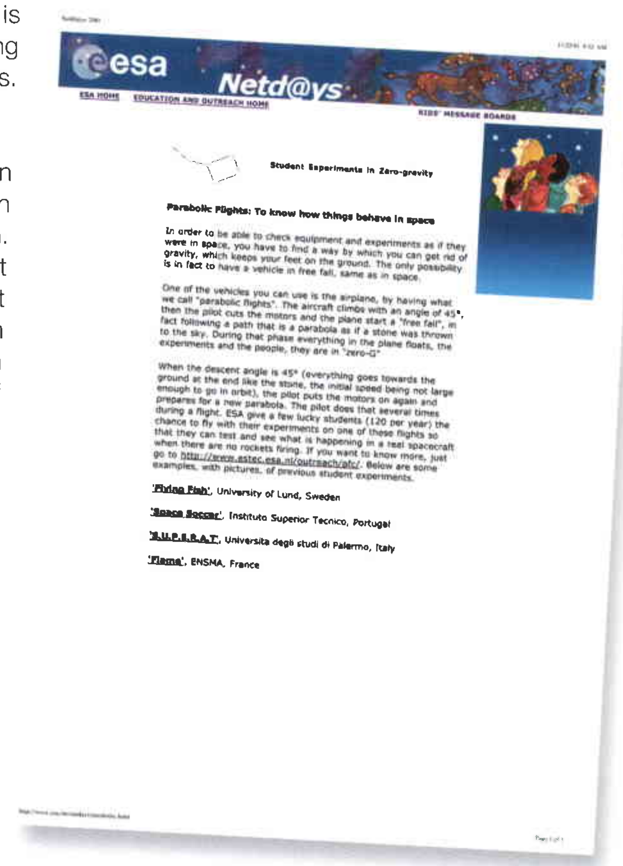
Partnerships with publishers
Partnerships with publishers for youth publications have been started, initially in France, to ensure that information on space matters in these publications is accurate and of the right level and that ESA and its programmes are well-represented. It is planned to extend this initiative to working also with editors in the other Member States.

ESA material in schools
Another important task for the Education Office is to assess where space topics can be introduced into the school curriculum. We are trying to help teachers by putting at their disposal information, material, fact sheets, and projects for the classroom. In this way we can help to increase European children's – and parents' – knowledge of science in general and space-related science and technology in particular..

'L'Enfant du Cosmos'
This project, proposed by Pierre Comte and the Aéro Club de France, links art and space technology. About 32 000 children in Europe will make an imprint of their hands on large plastic squares, which will then be assembled to form the shape of a child (300 m x 400 m). Helicopters, aircraft and satellites (SPOT and ERS or Envisat) will take pictures and radar images of the figure, which will then be sent to the children. The children will also receive basic information and practical exercises relating to Earth Observation. CNES and ESA will provide the satellite images and help with the educational material. The ESA Member States will help with the translation and dissemination of the material.

Participation in World Space Week
This week, organised by the United Nations, takes places every year between 4 and 10 October. The theme for 2002 is 'Space and Daily Life'. The Education Office is proposing one project titled 'Space and Daily Life in 45 Years, the case of the Martian Base'. Information to be provided to the teachers and children could include basic data on Mars, a list of life-sustaining needs for man, and a guide for the teachers to help them to grade the children's proposals. The best projects selected and submitted to ESA will be rewarded and presented on the ESA web site. The children will be encouraged not only to draw or build a model of a Martian base, but also to explain the various parts of it and why and how man would be able to live there.

The above are just a sample of the many projects that are in progress or under development within the ESA Education Office. If you have education-related questions, or if you wish to subscribe to EDUnews, please write to: education@esa.int and visit http://www.esa.int/education. esa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ESA HOME EDUCATION AND OUTREACH HOME KIDS' MESSAGE BOARDS

Student Experiments in Zero-gravity

Parabolic Flights: To know how things behave in space

In order to be able to check equipment and experiments as if they were in space, you have to find a way by which you can get rid of gravity, which keeps your feet on the ground. The only possibility is in fact to have a vehicle in free fall, same as in space.

One of the vehicles you can use is the airplane, by having what we call "parabolic flights". The aircraft climbs with an angle of 45°, then the pilot cuts the motors and the plane start a "free fall", in fact following a path that is a parabola as if a stone was thrown to the sky. During that phase everything in the plane floats, the experiments and the people, they are in "zero-G"

When the descent angle is 45° (everything goes towards the ground at the end like the stone, the initial speed being not large enough to go in orbit), the pilot puts the motors on again and prepares for a new parabola. The pilot does that several times during a flight. ESA give a few lucky students (120 per year) the chance to fly with their experiments on one of these flights so that they can test and see what is happening in a real spacecraft when there are no rockets firing. If you want to know more, just go to http://www.estec.esa.nl/outreach/pfc/. Below are some examples, with pictures, of previous student experiments.

'Flying Fish', University of Lund, Sweden

'Space Soccer', Instituto Superior Tecnico, Portugal

'S.U.P.E.R.A.T.', Universita degli studi di Palermo, Italy

'Flame', ENSMA, France

The UN/ESA Course Follow-up Programme — A Vietnamese Success

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The one-year UN/ESA/Vietnam project described here illustrates how successful a joint effort in the environmental domain can be when supported by national authorities and people working with enthusiasm and dedication. A fundamental cornerstone was the on-going long-term co-operation between the UN and ESA, particularly in the field of space-technology applications. The Vietnamese experience underlines the fact that Earth-observation training initiatives are most effective when participants are offered the opportunity to immediately put into practice what they have learned, through the establishment of operational tools and methodologies and with experts on hand to advise and assist.

Introduction

ESA has worked closely for many years with various specialised agencies of the United Nations to promote and demonstrate the potential of space applications in helping to achieve sustainable development. Normally, this work is done through the organisation of joint training courses by the UN and ESA for participants from developing countries. For these 'non-typical' projects, ESA as a research and development organisation in the space field relies on the UN's expertise to assess the prevailing conditions and needs in those developing countries.

The objective of these joint UN/ESA projects is to demonstrate the importance of space applications for developing countries and that, through using space technologies, they can leap-frog steps in their development path. This is particularly true for telecommunications, but also for remote-sensing applications, where satellite data can provide the accurate information needed for better decision making in carrying out national development programmes. The UN/ESA project described here is an example where this approach has been particularly successful.

The UN/ESA Course Follow-up Programme

The UN/ESA Course Follow-up Programme on the use of remote-sensing technology in sustainable development activities was formally endorsed by the United Nations (Department of Economic and Social Affairs, and Office for Outer Space Affairs) and ESA on 9 April 1998. It was initially conceived to provide hands-on experience to participants of four UN/ESA training courses and was designed with two essential goals in mind:

- to support selected on-going projects of national/regional importance in the areas of natural-resource management, environmental monitoring, sustainable development, and disaster management, by providing the necessary technical assistance and related support/capacity building in the use of remote-sensing technology;
- to improve the effectiveness of on-going applications projects in the above-mentioned areas.

Further details of the historical background to this unique UN/ESA Programme are reported in the accompanying panel.

Historical Context

In 1992, an agreement was reached between the United Nations Office for Outer Space Affairs and ESA/ESRIN to undertake a series of four training seminars for regional experts in remote sensing on the applications of data from the European Remote-Sensing Satellites (ERS-1 and ERS-2) to natural resources, renewable energy and the environment. Funding of this training programme was to be assured through co-financing using regular programme resources from each institution involved, and additional funds made available by the Italian Government to the United Nations Department for Economic and Social Affairs through the Natural and Renewable Sources of Energy (NRSE) trust fund to support technical cooperation activities.

Each session of the training course addressed technical professionals with some degree of expertise in remote-sensing applications from a single geographical region, starting in 1993 with professionals from francophone African countries of the Economic Commission for Africa (ECA). The following year, it was the turn of professionals from the Economic Commission for Latin America and the Caribbean (ECLAC) region to attend, followed in 1995 by professionals from the Economic and Social Commission for Asia and the Pacific (ESCAP). The fourth and last training course took place in 1997 for technical professionals from English- and Portuguese-speaking countries from the Economic Commission for Africa.

Although the basic structure of the training course has remained the same throughout the programme, adjustments have been made to take into account specific regional characteristics, technological improvements, and lessons learnt throughout the series. Each training-course session was co-financed with contributions from all three parties, with the UN Secretariat contributing resources from the NRSE trust fund to finance the participation of the group of trainees, the partial cost of the administration of the course, and the cost of participation by its technical staff. Participant's travel costs were covered by a contribution from the UN Office for Outer Space Affairs in Vienna, while facilities, teachers and training material were provided by ESA through ESRIN.

Following the second training course in 1994, representatives of some participating government institutions, participating governments and ESA indicated their interest in some form of course follow-up activities through which the pre-operational applications of space-related technology could benefit national and regional efforts addressing issues dealing with natural resources, energy and the environment. As the principle of continued support was endorsed by the United Nations, ESA and the Italian Government, an agreement was reached to earmark additional NRSE funding for that purpose. Though an initial effort to identify candidate projects took place in 1995, it was not until 1997 that the issue was re-activated with the process of preparing the fourth and last training course in the programme.

At that time, a consensus was reached on the purpose and goals of a course follow-up programme. It was agreed that the latter should support selected on-going or newly formulated projects of national and/or regional importance in the areas of: (a) natural-resource management, (b) environmental monitoring and sustainable development, and (c) disaster reduction, prediction and preparedness by providing the necessary technical assistance and related support in remote-sensing technology and capacity building. Similarly, the follow-up programme should improve the effectiveness of on-going space-related activities in the above-mentioned areas.

In order to set the course follow-up programme in motion, a joint agreement on project selection, implementation and management was reached by the UN and ESA in 1998. This agreement included a framework for UN – ESA cooperation that identified goals and objectives, problems to be addressed, expected results, target beneficiaries, and selection criteria for candidate projects, assigned responsibilities and coordination mechanisms. A tentative programme implementation timetable was also part of the agreement.

Candidate projects for the UN/ESA Course Follow-up Programme were identified by asking participants in the four UN/ESA training courses, selected institutions and specialised government organisations to submit proposals based on detailed guidelines prepared by the UN and ESA. This was essential to facilitate the subsequent evaluation and ranking of all of the project proposals. By the submission deadline of June 1998, fifteen proposals had been received: seven from Africa, four from Latin America, three from Asia/Pacific and one from Eastern Europe. Qualitative criteria for the evaluation and assessment of the proposals included such elements as relevance to development issues, impact of the proposal on the limited resources available, government and self-reliance commitment, development needs assessment, project duration, human-resource development, and an early success demonstration capability.

Following a thorough evaluation process that also considered links with existing on-going related activities in the country or region, the relevance of remote sensing to the proposed project, and realistic end-product expectations, three candidate projects located in three separate geographical regions were selected for support by the programme: one in Africa involving Burkina Faso and the regional AGRHYMET Centre in Niamey (Niger), one in Latin America (regional project involving Argentina, Bolivia and Chile), and one in Asia located in Vietnam.

The Asian element

The Vietnamese project proposal was entitled 'Applications of Remote-Sensing Technology for Coastal Zone Management in Vietnam' and was submitted by the Remote Sensing Centre of the General Department of Land Administration of Vietnam (RSC/GDLA), based in Hanoi. The purpose of the project was to contribute to the improvement of coastal management through the strengthening of national capacity for the application of remote-sensing technology using ERS, SPOT and Landsat data to establish geographic information systems for the management and development of Vietnamese coastal zones.

Essentially, this project was aimed at contributing to the establishment of a database for comprehensive coastal management and development through the application of remote sensing, in particular using the combination of radar (ERS) and optical (SPOT and Landsat) data. By covering the whole Vietnamese coastal zone with optical and radar imagery and appropriately analysing the data therein, the project was designed to address more fully the needs for sustainable social and economic development of large concentrations of human settlements, promote the better use of natural resources, protect the coastal environment from the impact of industrial and other pollution sources, and contribute to improved disaster management, including disaster-impact reduction, and climatic and meteorological monitoring assessments. To achieve these objectives, the follow-up project was designed to enhance national capabilities by providing, in addition to selected radar image data and processing equipment, some technical and training support in processing and analysing the radar imagery.

The target was to enable the immediate application of a comprehensive database to allow the production of thematic maps of Vietnam's coastal regions covering such aspects as land use, urbanisation and infra-structure, wetlands, mangrove growth changes, erosion and deposit patterns, monitoring and impact of environmental pollution, and coastal sensitivity. The database would also contribute to the on-going monitoring process linked to disaster mitigation and early-warning systems associated with the work of the Vietnamese Central Committee for Storm and Flood

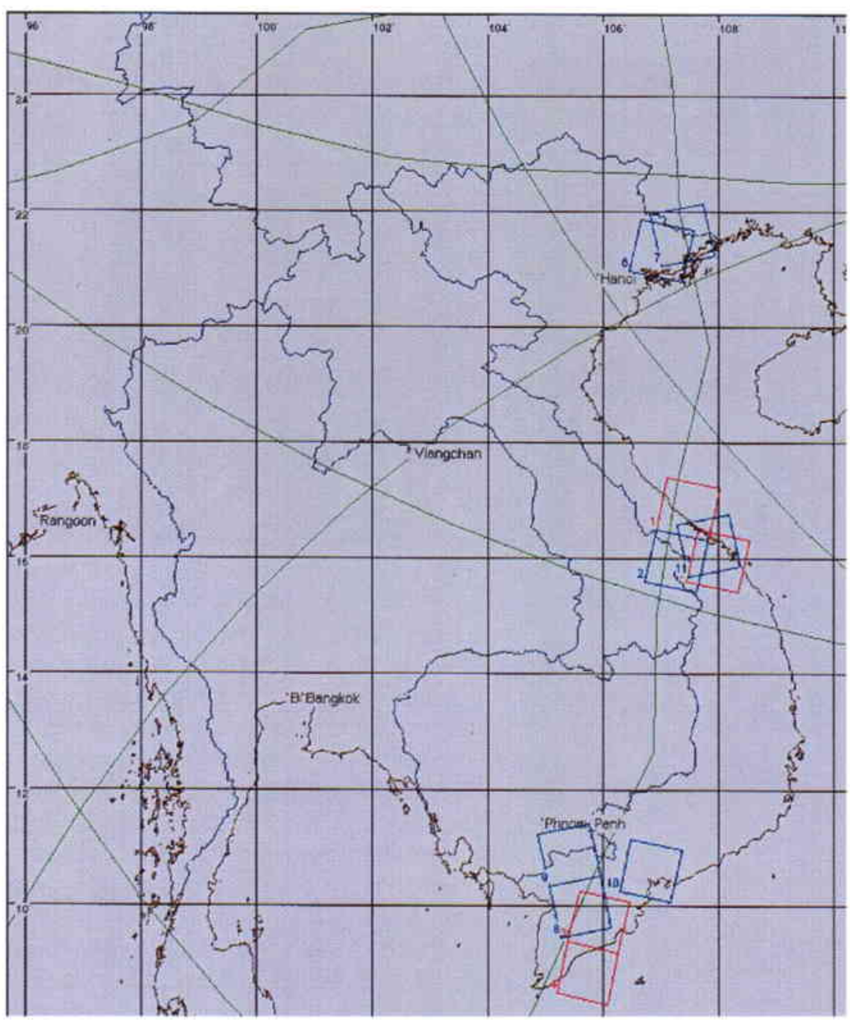

Figure 1. The three project pilot/test sites in Vietnam

Control, as well as to the work of other national and provincial agencies involved in development planning activities.

Following the selection of the project, the UN/ESA Course Follow-up Programme team and the Vietnamese project counterpart authorities fine-tuned and finalised the project proposal in the form of a formal project document approved by all parties and ready for implementation in early 2000.

Implementation in Vietnam

In order to ensure regular, high-quality support to the project, ESRIN, as the cooperating ESA agent with responsibility for overall technical expertise and support in Earth-observation-related areas, and with the UN's agreement, assigned the technical monitoring and the specific training activities to support the Vietnamese project authorities to a consultant with solid experience in the region. Mr Rob Schumann, now Managing Director of RS-Tech Consulting Co. Ltd. based in Bangkok, Thailand, was formerly the ESA representative in Thailand at the Asian Institute of Technology. He was chosen for his skills in remote-sensing training and data processing and his experience with remote-sensing applications in the region.

Figure 2. The UN/ESA/Vietnam project team at the Remote Sensing Centre of the General Department of Land Administration in Hanoi

The work formally started with the first project workshop, held at the Remote-Sensing Centre in Hanoi on 13–19 April 2000. During this first workshop, both government and user institutions with coastal-management-related responsibilities were visited in Hanoi, namely:
- the Institute for Fisheries Economics and Planning, within the Ministry of Fisheries
- the National Environment Agency, within the Ministry of Science, Technology and Environment
- the Disaster Management Unit, within the Ministry of Agriculture and Rural Development
- the UNDP Office.

In addition, pilot-project sites were visited in the north (Hai Phong and the Ha Long coastal areas), where a visit was paid to the Hai Phong Institute of Oceanology, and in the central part of the country (Hue Da Nang region).

The implementation of the project was divided into three distinct elements, namely preparations, technical training, and practical application. The first of these was a prerequisite to all that was to follow in the course of the project, with the training and practical application elements being conducted more in parallel.

Preparations

Three main study areas were selected in coastal zones, in the northern, central and southern regions of the country, respectively. For all three areas, the 'catch-all' application was coastal-zone mapping. The end objective was to develop methodologies for integrating the application of remote-sensing data into an operational map-production chain, with emphasis on the use of synthetic-aperture radar data in particular, which could subsequently be extended to include the mapping all of Vietnam's coastal zones.

In the north, the area of the Red River Delta centred on Hai Phong and extending north-eastwards to include Ha Long bay, was chosen because of the widespread occurrence of erosion and deposition along the coast, the highly varied agriculture practised in the area, and the system of dykes used for flood protection. The area is backed by a range of mountains to the north that extends all the way down to the coast at the eastern edge. South and west of Hai Phong itself is the coastal flood plain, where a great variety of agriculture is practised in a fairly heterogeneous mix, dominated by rice, but including corn, beans, cabbages and many other vegetables, on very small, family-cultivated plots.

The coastal area around Da Nang is characterised by a very narrow coastal plain rising within a few kilometres of the coast into steep mountains. The topography, in particular the way in which the mountains funnel run-off onto the plain, produces spectacular flash-floods during the rainy season, the most damaging of which in recent years occurred in late 1999 with significant loss of life and property.

The study area in the south was itself divided into two sub-areas. The first, with a focus on rice agriculture and coastal erosion/deposition, was centred around Soc Trang Province, in the heart of the Mekong River Delta. The second focused on one of Vietnam's largest remaining mangrove forests, which lies to the south of Ho Chi Minh City (Saigon) and the agricultural areas that lie across the main river channel from it.

Each area has different characteristics and hence problems, but this also allowed examination of the mapping potential of remote-sensing techniques for a wider range of coastal features than would have been the case if only a single area had been selected.

With the three areas selected, attention turned to ensuring that adequate data were available for each of them. RSC/GLDA had available SPOT coverage for the whole country acquired in 1996 and 1997, and for many of the study areas good multi-temporal ERS datasets were also available from the ESA archive for 1995 and 1996. These periods were therefore focussed upon, but with the intention of also using recent and newly acquired data for the twelve months of the project. In the end, archive data was the most extensively used, although fresh data acquisitions were made for the project for an area of the Mekong Delta close to the Cambodian border that was hit by major flooding in September 2000.

While well-equipped in terms of computer hardware, the GDLA software environment was oriented more towards GIS and to map production than to the digital analysis of image data. To satisfy the image-processing requirements, project funding allowed the purchase of suitable software for installation on GDLA-provided hardware. Both the UN and ESA made additional funds available to the project to support data needs, as a reflection of their special interest in this pilot endeavour. The RSC project authorities made a special request for access to images from the Enhanced Thematic Mapper of the Landsat-7 spacecraft, as this data was considered crucial to the current work. The agreement achieved by ESA/ESRIN with the data distributor allowed 19 Landsat-7 ETM datasets covering a large part of the country to be bought within the available budget. ESA, within the framework of its training programme, also made available 70 ERS SAR image datasets to the project. These ERS datasets included 48 Precision Images and 22 Single-Look Complex Images for advanced remote-sensing applications.

Technical training

Perhaps not surprisingly, with few in-house image-processing resources available before the start of this project, GDLA also needed to focus on training staff so that they could make effective use of the new tools being put at their disposal. A significant element of the project was therefore 'on-the-job' training for the analysts charged with processing the data that was being provided to them in fairly substantial quantities.

The challenge, to which GDLA and their staff rose enthusiastically, was therefore to take new and unfamiliar data and process it with new and unfamiliar software while also using new and unfamiliar techniques/procedures. To assist with this training and the parallel technical support elements, the project needed to address two different tasks:

- the introduction of digital image processing concepts and methodologies through lectures and practical exercises
- the introduction of the basic principles of synthetic-aperture radar as a means of acquiring Earth-observation data, and extending image-processing techniques to the analysis of this sort of data.

Figure 3. One of the training sessions given to Remote Sensing Centre staff by the project consultant

Owing to the tight time constraints, the first of these, the basic introduction to digital image processing for remotely sensed data, had to be carried out using available data in advance of the receipt of data ordered specifically for the project. This training lasted one week and was divided roughly 60:40 between lectures and practical. It provided a basic knowledge of the subject, ranging from 'what is an image?' through to classification and post-classification techniques. This laid the necessary foundation for the subsequent training and practical work.

The second and longer phase of training, conducted one month after the first and, significantly, after ERS data requested for the project had started to arrive, lasted for two weeks and followed a similar split between lectures and practical work.

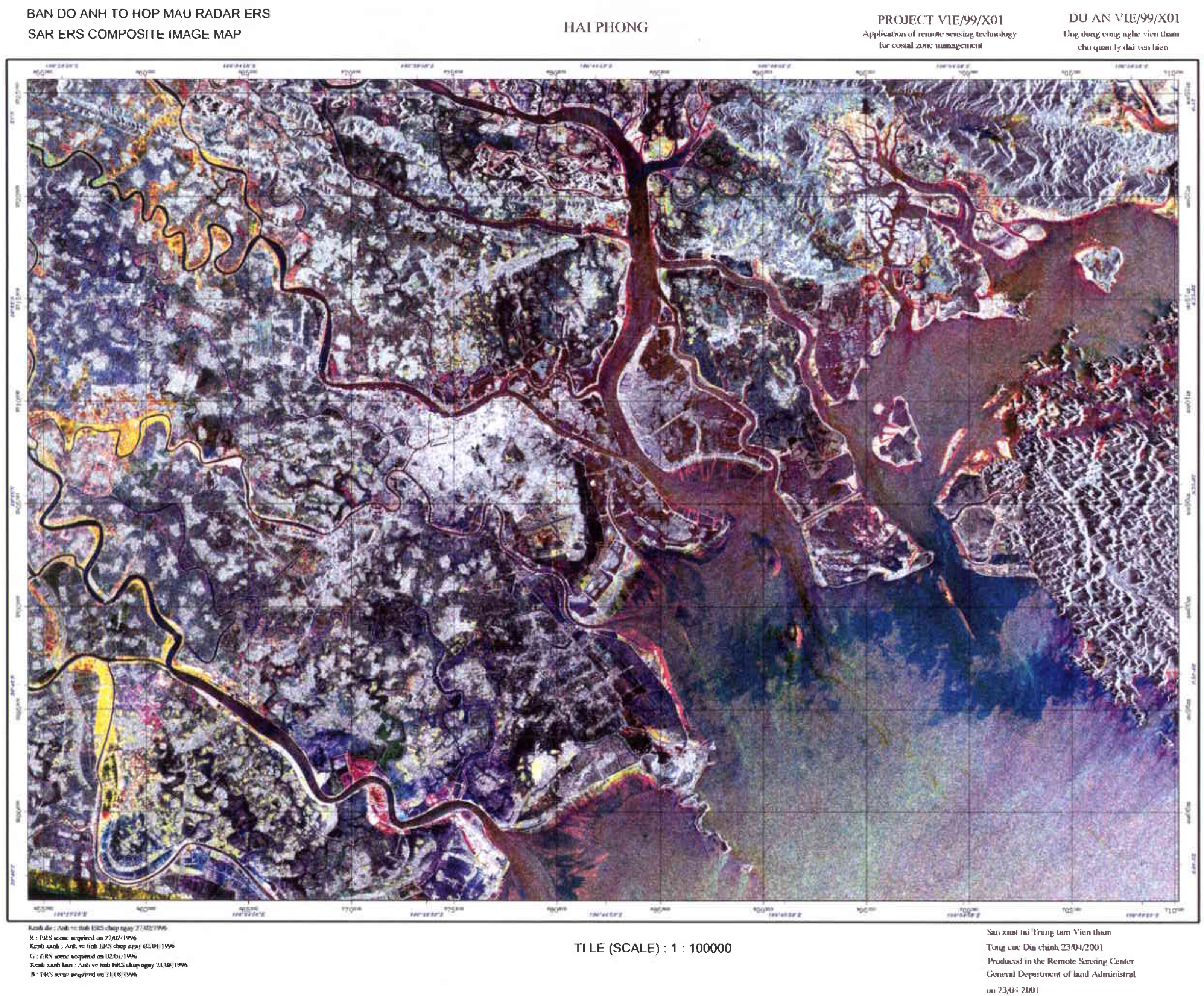

Figure 4. Hai Phong –ERS SAR multi-temporal image, with the image acquired on 27 February 1996 in red, that acquired on 4 February 1996 in green, and that acquired on 21 August 1996 in blue. Features appearing in black and white have not changed their characteristics between the first and last acquisition dates. Coloured features show that a change has occurred, whilst the actual colour indicates in which period during the acquisition sequence it happened

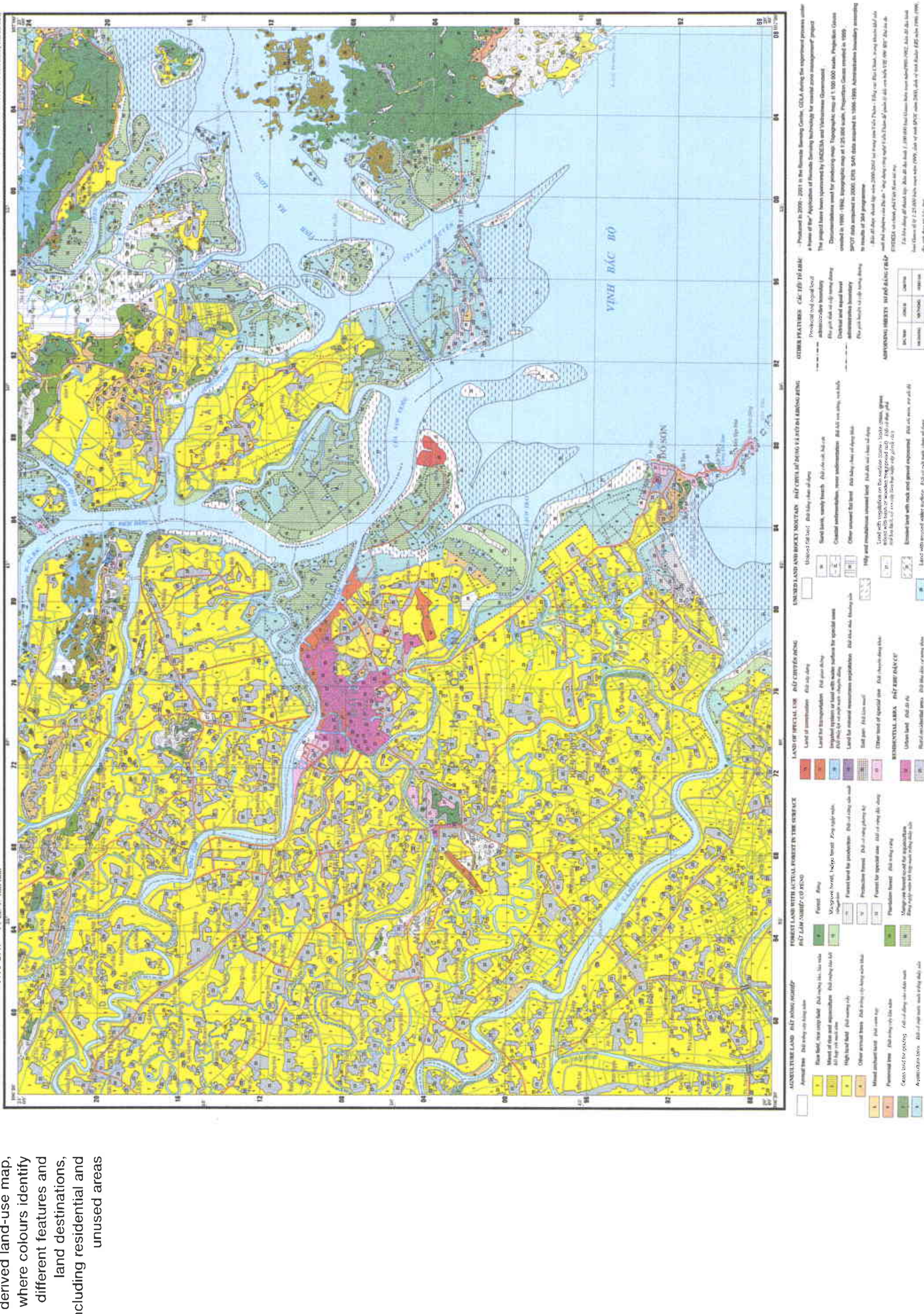

Figure 5. Hai Phong – derived land-use map, where colours identify different features and land destinations, including residential and unused areas

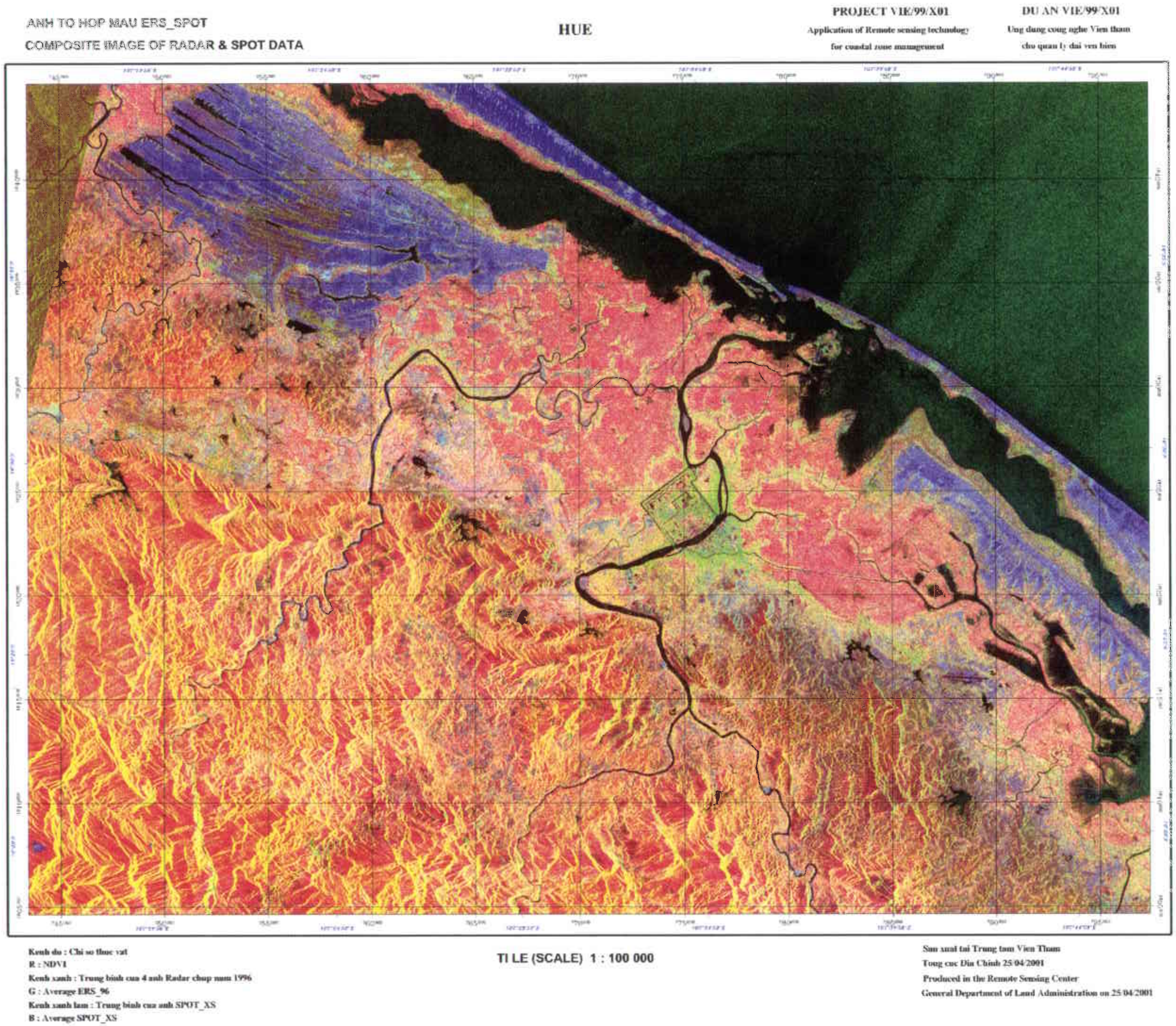

Figure 6. Hue – ERS-SPOT composite image, in which red was assigned to the Normalised Difference Vegetation Index (NDVI) derived from SPOT XS data, green to the average ERS image data in 1996, and blue to the average SPOT XS image data

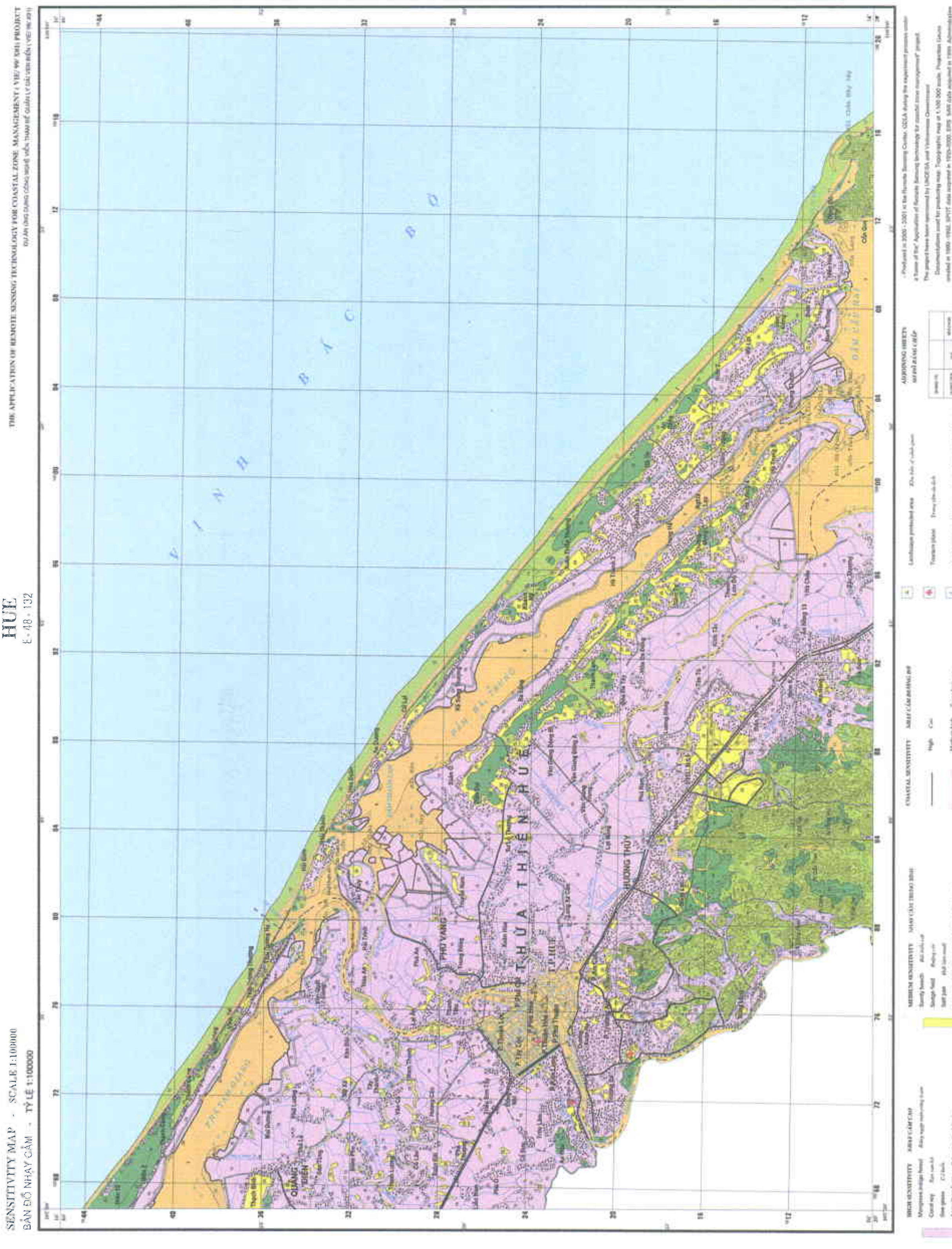

Figure 7. Hue – derived sensitivity map, in which colours indicate different degrees of sensitivity (green = lowest, to pink = highest), areas dedicated to special uses, and areas with features of high economic importance

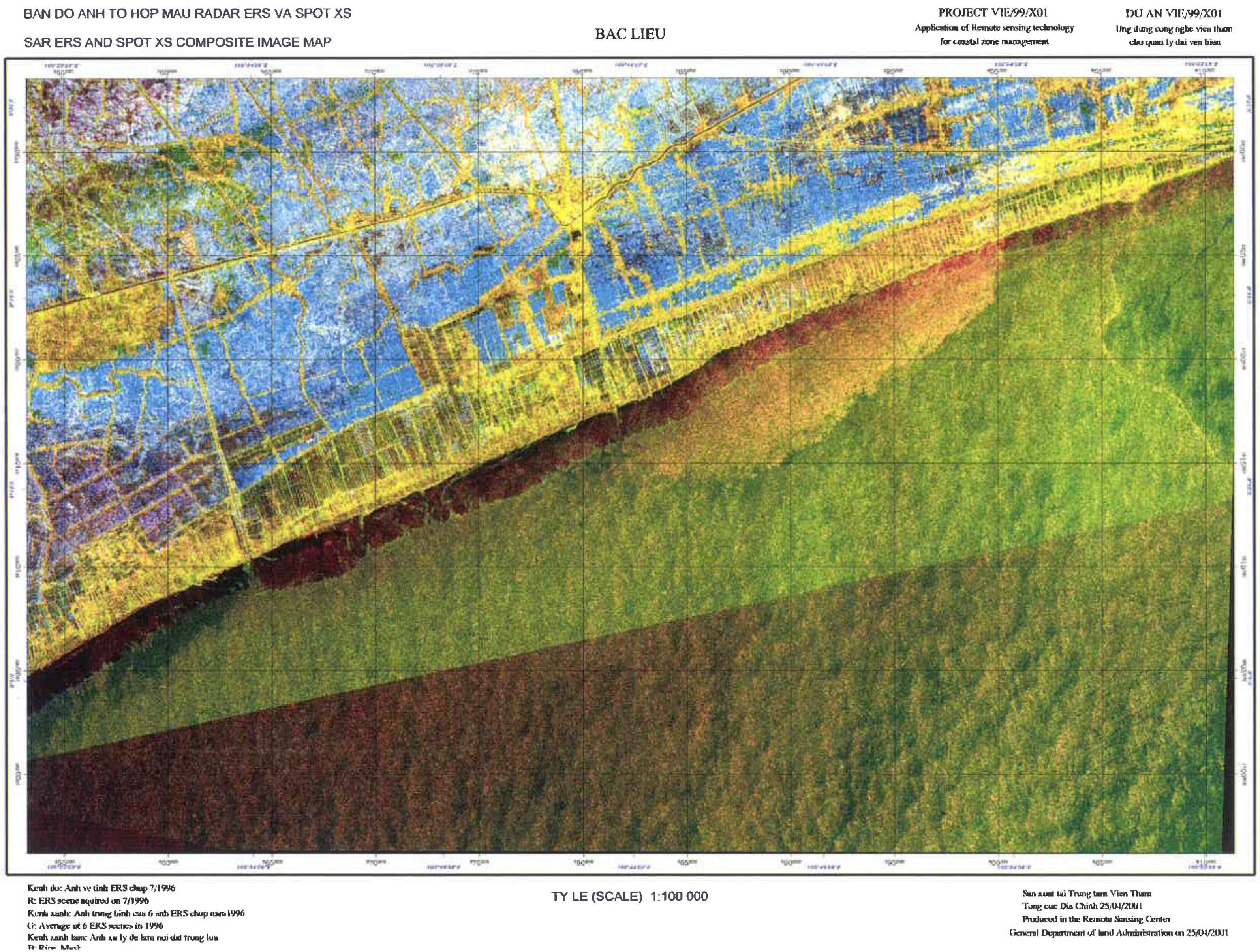

Figure 8. Bac Lieu – ERS-SPOT composite image, in which red was assigned to the ERS SAR image acquired in July 1996, green to the average of six ERS SAR images acquired in 1996, and blue to the rice mask derived from SPOT image data

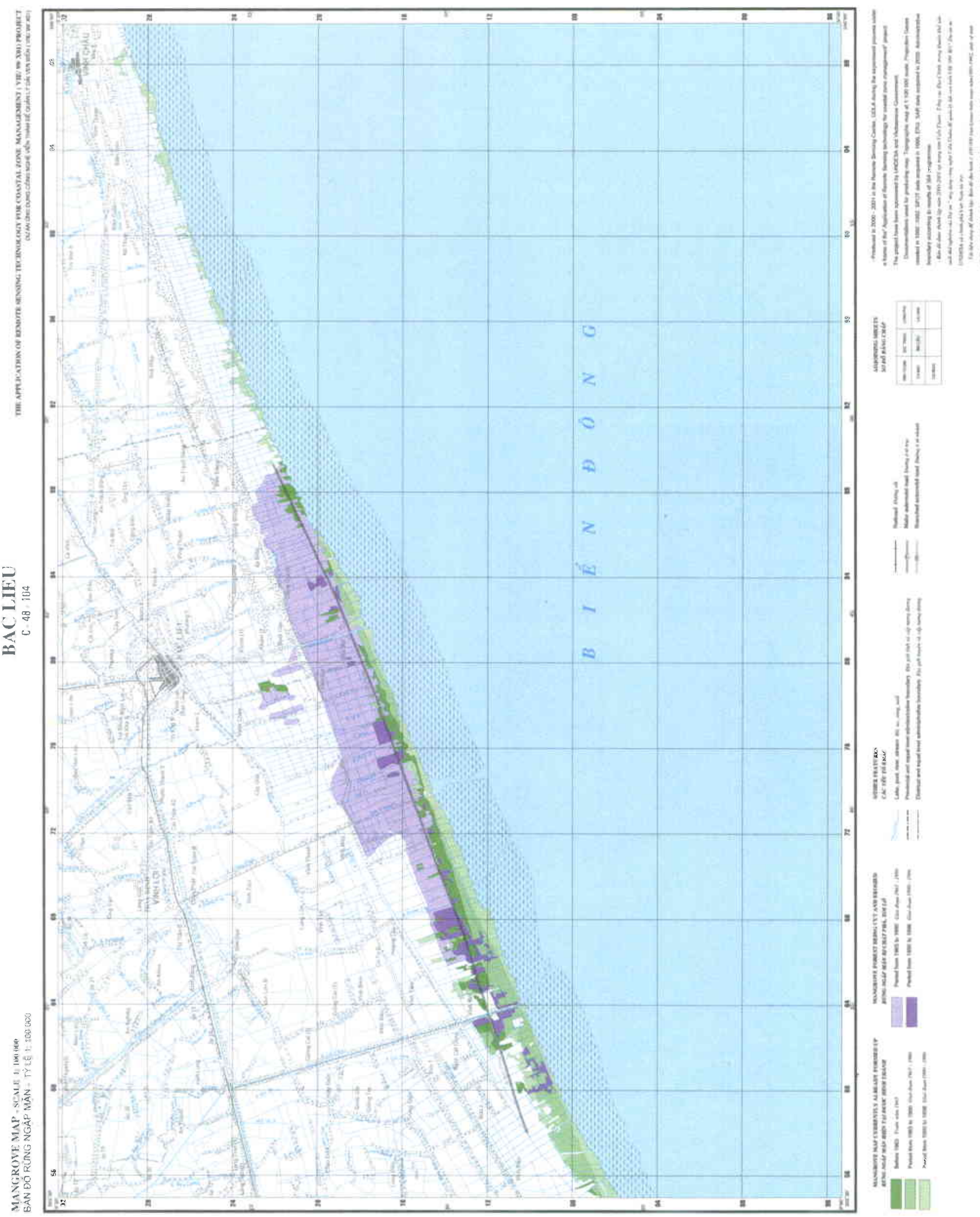

Figure 9. Bac Lieu – derived mangrove map, showing in different green tones areas with mangroves already established (dark green before 1965, medium green between 1965 and 1990, light green between 1990 and 1996) and in violet areas where mangrove forest was cut or eroded (light violet between 1965 and 1990, dark violet between 1990 and 1996)

Both training sessions were attended by approximately 40 persons, drawn from GDLA and other agencies, including the Ministry of Agriculture, Disaster Management Unit, Forestry and the Hai Phong Institute of Oceanology.

The second phase of training also saw the start of the real work of the project, allowing what had been covered in the lectures to be applied directly to project data in the practical sessions, with the support of the course lecturer to resolve any difficulties that arose. Multi-scene registrations and initial processing steps were all carried out over the SocTrang area during this period, enabling GDLA staff to proceed unaided with similar processing of the data from the other areas when it arrived.

Figure 10. The opening of the final project workshop. From left to right: the UN/DESA officer, the ESA/ESRIN representative, the expert from RS-Tech Consulting, the Deputy Head of RSC's Cartographic Updating Division, and the Director of RSC

The project consultant made regular visits after the second training period, monitoring progress and providing first-hand assistance wherever needed. However, the emphasis throughout was on GDLA staff doing the work and taking the decisions themselves that determined its direction. The result of this approach was a growing confidence on the part of all GDLA team members as the project progressed, to the extent that they were also able to help teach each other by the project's mid-point.

At this point, a third element to the training was injected into the original calendar, this time involving participants from other countries in the Mekong basin and hosted by the Asian Institute of Technology, still with UN and ESA support. With 14 participants, eight of whom were from the project team in Vietnam, the goal was to explore more advanced processing methodologies and at the same time spread this training to a wider audience. This two-week event introduced some aspects of interferometry and the use of differences and ratios in the analysis of extended time series of SAR data. It also allowed a number of SAR-based case studies to be presented, including a focus during the second week on flooding, backed up by newly acquired ERS data over the Mekong Delta floods that had occurred just a month before the workshop.

Practical application

Data handling and processing involved a variety of operations carried out sequentially during the course of the project. In particular, data was co-registered – ERS to ERS, ERS to SPOT, and eventually all data to maps. SAR images were filtered to reduce the speckle, and feature measurements were performed. Time-series analysis, feature enhancement and masking were also carried out. Product export and integration into the mapping chain were eventually implemented.

During the later stages of the analysis work in Vietnam, emphasis was given to the visual features required for mapping purposes. This was a conscious decision on the part of the team and, while it would have been possible to go further with the digital processing, it was felt that results thus obtained contained too much detail and would have been less readily integrated with the later stages of the map-production process operating within GDLA. This was crucial to the acceptance of this new input into the mapping process for Vietnam, to the successful conclusion of the project, and to the likelihood of it being picked up and used in a fully operational way in the future.

At the time of the final report in May 2001, sample map sheets for each of the three primary study areas had been produced, although not all topographic layers had been completed, each map sheet requiring over 20 separate layers.

Findings, difficulties and achievements

In general, the use of SAR data within the mapping process was found to enhance the ability to map coastline changes and was, not surprisingly, particularly useful in highlighting the structural differences between objects. Sadly, there was no opportunity to back up the data analysis with real-time ground truth and all analysis was done using already archived data, as opposed to new acquisitions. Cross-checking of results relied upon first-hand knowledge of the areas in question and upon available land-cover maps. The results achieved were nevertheless felt by GDLA to be extremely encouraging. The close integration of training into the general framework of the project was found to have been highly beneficial both to the project itself and, on a personal 'development of skills' level, to the individuals involved in it.

Chief among the difficulties encountered was the almost impossibly short time frame in which to design, implement and finish such an ambitious undertaking. That finished map sheets were indeed produced stands as a remarkable achievement, given the point from which work had commenced just 12 months earlier. Other difficulties, which were perhaps to be expected, included the initial delays in getting the data through to GDLA at the beginning of the project, with the practical work on real project data not really getting underway until two months into the year available. It all then pretty much arrived together, presenting the enviable problem of being faced with too much data all at the same time, although this too got turned to advantage in terms of developing data management and organising the analysis approach that was adopted.

Conclusions

This Asian element of the UN/ESA Course Follow-up Programme was successfully completed in one year and the results are certainly of a very high quality. The skill, dedication and professionalism of the RSC staff will ensure that the GDLA Remote Sensing Centre will be able to provide other institutions in Vietnam and further afield with products and services of the highest quality.

It is important for deriving maximum benefit from the project that the final outcome is properly communicated, documented and promoted via national/international meetings and conferences and the media. With the permission of GDLA and the RSC authorities, the detailed results will be disseminated via the UN and ESA web sites and publications.

One conclusion drawn is that tying the project and training events closely together and running them in parallel was of great benefit. It meant, for instance, that the resources invested in the training of the Vietnamese staff were very effectively utilised because the subjects covered in theory and in idealised training lab exercises could immediately be tried out using real data, with which the participants came to be intimately familiar during the year. Future training programmes should certainly take this into account. Potential future participants should also be given every possible assistance in writing and submitting their project proposals in a form that gives them a reasonable expectation of getting accepted.

The UN's and ESA's expectations in embarking on this project have certainly been met in terms of its achievements, in that:

(a) A focal point of expertise both nationally and within the region has been established, which will allow the RSC staff to train other applications experts and promulgate their experience.
(b) Greater international co-operation has been achieved in the region, with the starting of specific application projects for sustainable development, related particularly to environmental and hazard monitoring and resource and risk management.
(c) The links between Vietnam and Europe have been strengthened.
(d) The way to the exploitation of ESA's Envisat satellite products and services has been paved.

The results achieved by the project confirm the fact that the real value of satellite data resides in the unique information that it carries and which is best exploited when space data is integrated with information from more conventional sources. The project has also been a very successful demonstration of one of the ways in which the UN and ESA can implement the UNISPACE III recommendations.

Figure 11. The final project workshop: presentation of project results by RSC staff to UN and ESA representatives in Hanoi

Acknowledgements

The support provided to the project by the UN, ESA and GDLA authorities and the teams involved is gratefully acknowledged. Special thanks go to Rob Schumann, Managing Director of RS-Tech Consulting Co. Ltd., who served as remote-sensing expert consultant to this project and whose experience and dedication were key to the successful completion of this ambitious endeavour. esa

Polar Bears and Spacecraft Tracking

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Spitzbergen is probably more often associated with polar bears and extreme Arctic winters than with high technology and cutting-edge satellite ground stations. This is now changing! Since the end of 2000, ESOC has been tracking the ERS-2 spacecraft from a ground station at Spitzbergen. Now, a new phase in the cooperation between ESA and Norway is about to commence, with the establishment of a long-term agreement for the provision of launch and early-orbit-phase and routine-operations services from Spitzbergen for the soon to be launched Envisat satellite.

Introduction

The Svalbard satellite station at Spitzbergen is the most northerly ground station in the world. It is this unique location (Fig. 1) in the Svalbard archipelago, at 78 deg 13 min north, that provides the station, known as SvalSat, with its unique coverage. SvalSat is the only station able to provide ground contact for all orbits of ERS-2 and Envisat and most other polar-orbiting satellites. For Earth-observation satellites, this means an opportunity to perform a global data dump for each orbit at a single site. It also means that, with just one ground station, Telemetry Tracking and Commanding (TT&C) services can be provided for every orbit.

Based on its experience with the ERS-2 service, ESOC has placed a long-term frame-contract with the Tromsø Satellite Station (TSS) company for support from SvalSat. A first slice covers Launch and Early Orbit Phase (LEOP) support and extensive tracking support for Envisat (five passes per night throughout the mission's lifetime), as well as a continuation of the current ERS-2 support (two passes per

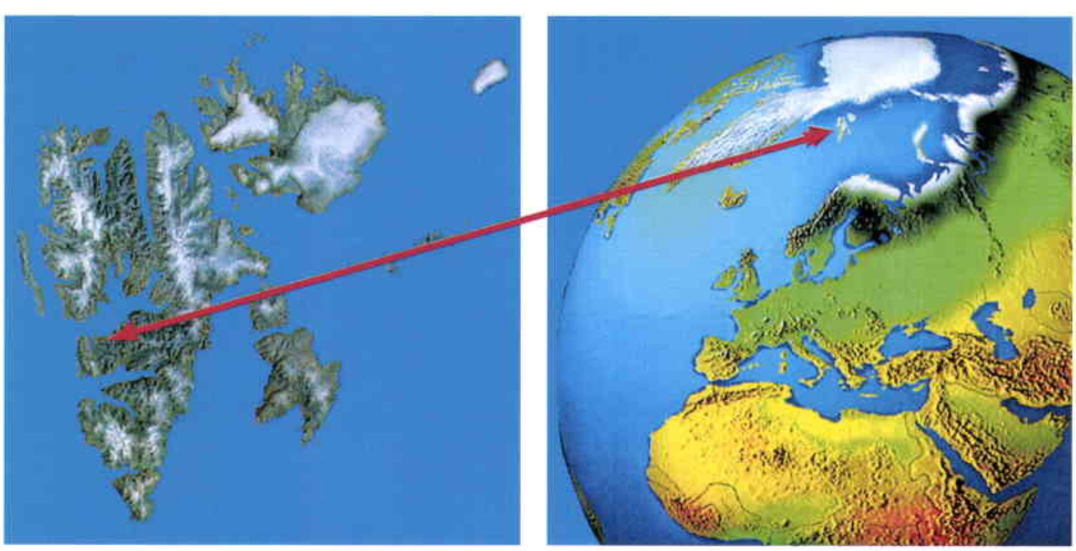

Figure 1. Location of SvalSat

night). In addition, any future ESA or third-party Earth-observation mission with a polar orbit that is operated from ESOC will also be covered by this frame contract.

SvalSat's history
As some Bulletin readers may remember, ESRO/ESA had a VHF station on Spitzbergen in the 'early days'. The station used now, however, is not owned by ESA but by Norwegian industry, and is installed at a different location. This new facility has been established by the Norwegian Space Centre (NSC) with support from TSS. It was designed, procured and constructed between 1996 and 1998. The construc-tion work included the provision of an access road, power, the station building and related infrastructure and all basic services.

The development at Svalbard was triggered by NASA, who had requested a location for an antenna to be used for its Earth Observing System (EOS) Polar Ground Network. The NASA-dedicated TT&C activities from SvalSat were initiated in 1997 when TSS started operating the ground station on the Svalbard archipelago under a contract with NSC. Today, TSS has 11 staff working permanently on the island. The station is manned around the clock and operations and maintenance are handled by three shifts.

Technical installations
The antenna infrastructure at SvalSat today consists of two operational 11-metre S- and X-band systems applied both for TT&C and for data reception (Fig. 2). The number of satellite operators signing up for service provision from Svalbard is growing steadily and TSS is therefore currently finalising the installation of a third complete multi-mission (13 m) ground station to be co-located with the existing ones (Figs. 3 & 4). This third system will become operational in February 2002 and will be supporting ESA's Envisat and ERS-2 missions on a priority basis.

The Norwegian telecommunications provider Telenor also has several antenna systems installed at SvalSat and provides telecom-munications services to the Norwegian mainland. The communications to and from Svalbard have generally been recognised as a critical issue for reliable operations. TSS has therefore established a dedicated communi-cations link directly between Tromsø and SvalSat, which is now the primary link for all operations tasks. To maintain communications redundancy between TSS and SvalSat, switched ISDN lines are used as a backup in case of prime satellite link failure. Near-real-time services requiring very reliable and fast distribution systems are offered by TSS, who are presently distributing data to customers at rates ranging from 9.6 kbit/s to 2 Mbit/s. Further possibilities are to establish dedicated satellite links.

Figure 2. The radome housing the 11m antenna for NASA support

Operations concept
SvalSat is manned around the clock by a team of 11 TSS engineers and an operations manager. They carry out all operations and maintenance at SvalSat. Additional managerial support in terms of special maintenance, financial administration and quality assurance is provided from TSS in Tromsø. Two engineers staff the station at all times, ready to respond immediately on site if anomalies occur. One of the antenna systems available at SvalSat (the NASA-dedicated system) is operated locally by this TSS crew. The remaining two (including the new TSS antenna) are remotely controlled and operated by the Tromsø Network Operations Centre (TNOC).

TNOC is a part of TSS and since December 2000 it has been providing operational S-band support to ESA's ERS-2 satellite. Since 1 April

Figure 3. The new 13 m SvalSat antenna

Figure 4. Installation of the radome for the new 13 m antenna

2001, TNOC has also been certified for full operations on several NASA missions. There are also two engineers available at TNOC at all times, to respond immediately to operational or technical-support requests. Any scheduling of the remotely controlled installations is also handled by TNOC (by e-mail or voice communication).

The remote operations are supported by a powerful Unix-based station computer. The telecommunications connection between the ground segment at Svalbard and TNOC is via a leased satellite link. In the event of a failure in that link, the station can be controlled locally by the SvalSat staff.

Continuity and experience are important factors when operating an advanced technical installation in the Arctic, and the staffing of the Tromsø office and the Svalbard site is therefore seen in an overall context, with engineers being rotated from time to time between the two. This helps to maintain both the technical competence and Arctic experience within the organisation. The fact that operating in an Arctic environment calls for special competences to ensure personnel safety is also focused upon.

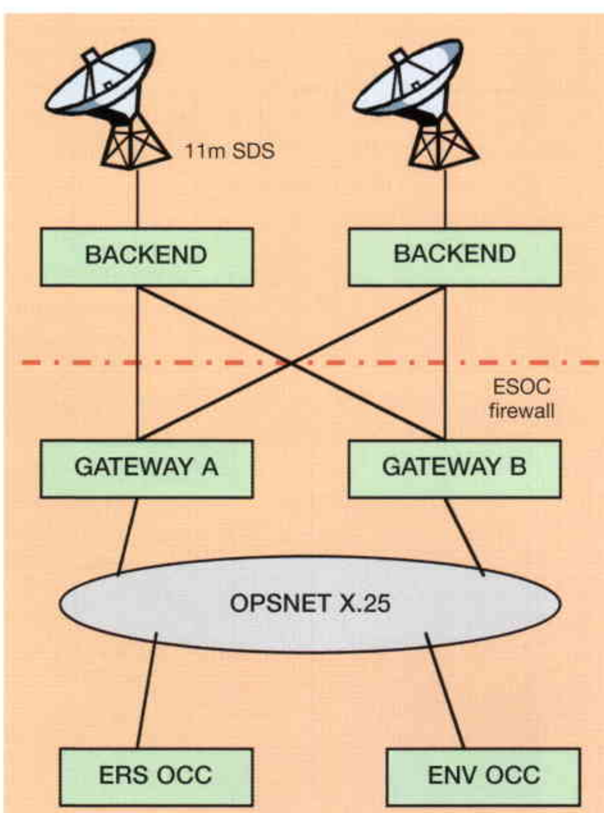

Figure 5. SvalSat TT&C links to ESOC

Preparing to support ESA

The procurement of a pure TT&C service from an external station, without having any ESA installations on site, was a first for ESOC. Before starting the endeavour, therefore, a number of technical and operational changes had to be implemented. At ESOC's end (Fig. 5), a gateway had to be developed that translates the different formats and protocols used at the Svalbard station into something that make it look like a standard ESA ground station (it translates Svalbard's TCP/IP-based protocol to the standard ESA SDID/X.25 format). Connection with SvalSat is initiated from ESOC, in Darmstadt (D), by calling either of the gateways. Traffic between SvalSat and ESOC is routed via a firewall. At the SvalSat end, some specific features required for ERS and Envisat had to be installed in the station's up- and down-link chains.

During the initial service-optimisation phase, ESOC teams visited the TSS control centre and the Svalbard site (Fig. 6) and thereby experienced first hand the particular challenges of operating such an installation in an Arctic desert. In winter, the weather can change rapidly from good, with no snow or wind, to very bad, with strong winds and dramatically lower temperatures. When conditions do deteriorate, the road from the local settlement to the station has to be closed and the crew transported by helicopter (Fig. 7). The station is equipped to survive for a week or two without a fresh supply of water or waste removal (for environmental reasons, everything that goes up to the station has to be removed after use).

Apart from the obvious climatic peculiarities, there is a real danger of encountering polar bears outside the settlement. Consequently, everyone leaving the settlement or even just walking between the equipment building and antenna radome has to be accompanied by station staff carrying large-calibre guns. This frontier atmosphere also pervades the hotel bar at the settlement, where a special cupboard is available for depositing the guns whilst having a drink!

Outlook

The current NASA missions supported from SvalSat include Landsat-7, AM-1/Terra, EO-1, SACC-C, Acrimsat, Champ, QuickScat, Kompsat, Cobe, Aqua and Quicktoms.

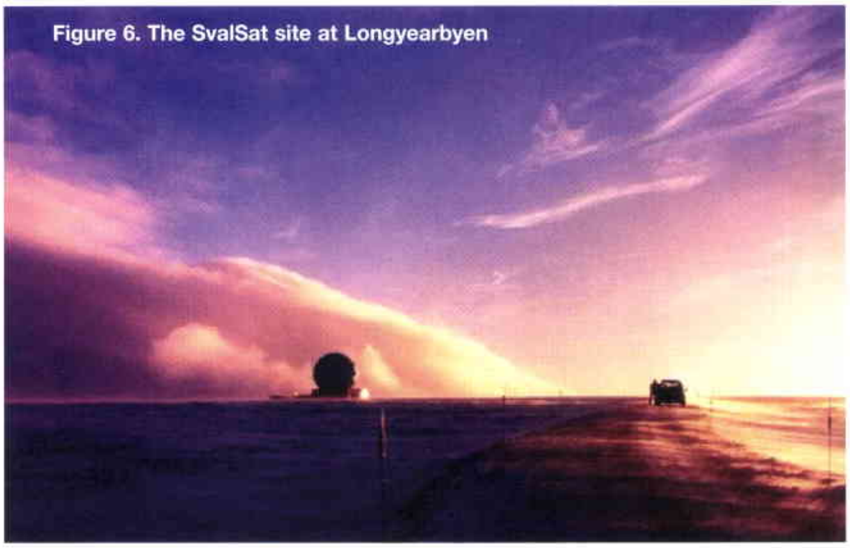

Figure 6. The SvalSat site at Longyearbyen

Preparations for new NASA missions are also in progress. The European meteorological satellite organisation, Eumetsat, has also decided that SvalSat will be their prime site for polar-orbiting missions, which will result in the installation of two complete EPS ground stations (10 m antennas). Eumetsat has already signed a contract with TSS for providing the Polar Site Infrastructure and Operational Services for the EPS system. The MetOp satellite that ESA is providing to Eumetsat for this programme is planned to be launched in 2005.

With ESA's 'return' to the Svalbard location, ESOC is now in a position to offer excellent coverage for polar-orbiting missions. The service from Svalbard complements the proven support already provided from the ESA station at Kiruna, and will enable ESOC to react more flexibly to the programmatic and operational needs of its customers.

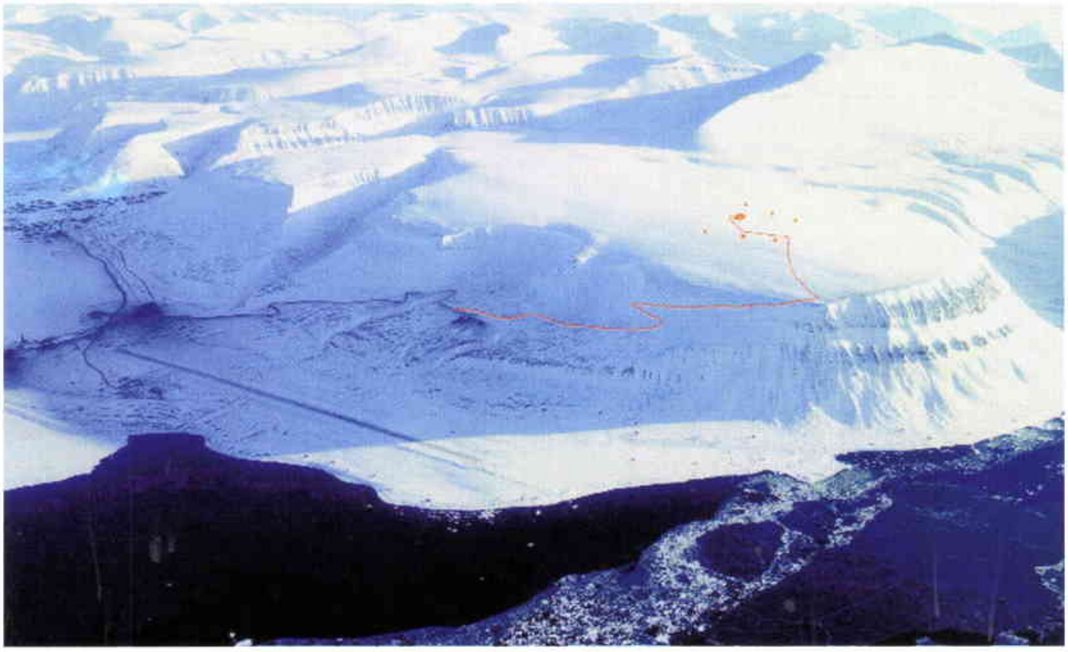

Figure 7. The route to the plateau

MATED – Improving ESA's Model and Test Philosophies

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Today's space activities are characterised by growing cost and schedule constraints, often combined with greater technical/industrial complexity. This impacts on the Assembly Integration and Verification (AIV) process that is a fundamental step in the development cycle of any space system. The question then is, how can the process be improved to reduce the duration and cost of the AIV process whilst still maintaining the necessary quality and an acceptable level of risk?

The ESA-developed Model and Test Effectiveness Database (MATED), and its associated methodologies, is proposed as a viable tool for supporting such an initiative. This article describes the prototype database, the types of data that can be shared, the proposed analysis methodologies, and the potential benefits.

Introduction

In the last decade, the pressure from the space market to shorten the development time from system concept to launch has continued to grow, with the aim of reducing development time and cost without jeopardising mission success. The Assembly, Integration and Verification (AIV) process makes up an important part of the space system's development cycle, constituting typically 20-30% of the costs and 60-70% of the schedule. The model and test philosophies that form the basis of the AIV process are therefore important cost drivers.

The existing standards and industry practices that define the requirements to be applied in the preparation of test specifications and procedures are generally based upon tradition and need to be improved in the light of the latest modelling and test-effectiveness criteria.

It was against this background that an ESA study on 'Improving the Effectiveness of the Model and Test Philosophy Applied by ESA Programmes' was contracted to an industrial consortium led by Alenia Spazio SpA, with Astrium GmbH as subcontractor. The study's main objective was to develop a Model and Test Effectiveness Database (MATED), together with the associated methodologies, to serve as a repository for AIV, Non-Conformance Report (NCR) and Flight Anomaly (FA) data to be shared between European industry, agencies and space organisations. This novel resource should foster a continuous improvement in the AIV process itself, the related model and test philosophies, and the associated verification and testing standards.

The MATED concept

The main functions of MATED are to:
- archive data on anomalies encountered during the ground testing and flight operations of different spacecraft
- archive data on the AIV processes for different spacecraft, with particular emphasis on the cost-driver-related activities
- provide data-analysis functions that support identified methodologies for test-effectiveness evaluation and AIV programme-optimisation purposes
- ensure security of data, remote and multiple access, and flexibility of installation and utilisation.

MATED's architecture (Fig. 1) is based on a commercial Relational-Database Management System (RDMS) with a client/server approach compatible with the World Wide Web (Fig. 2). The study objectives were to:
- assess the state-of-the-art in the model and test-effectiveness domain and the available data sources
- analyse the AIV process as defined in the European (i.e. ECSS) standard, identifying cost drivers and improvement trends
- identify the methodologies for the analysis of the associated AIV data
- realise a prototype database that archives on-ground and in-orbit anomalies and other AIV-related space-project data
- populate the database with inputs from several projects in development and in operation (both applications and scientific missions)

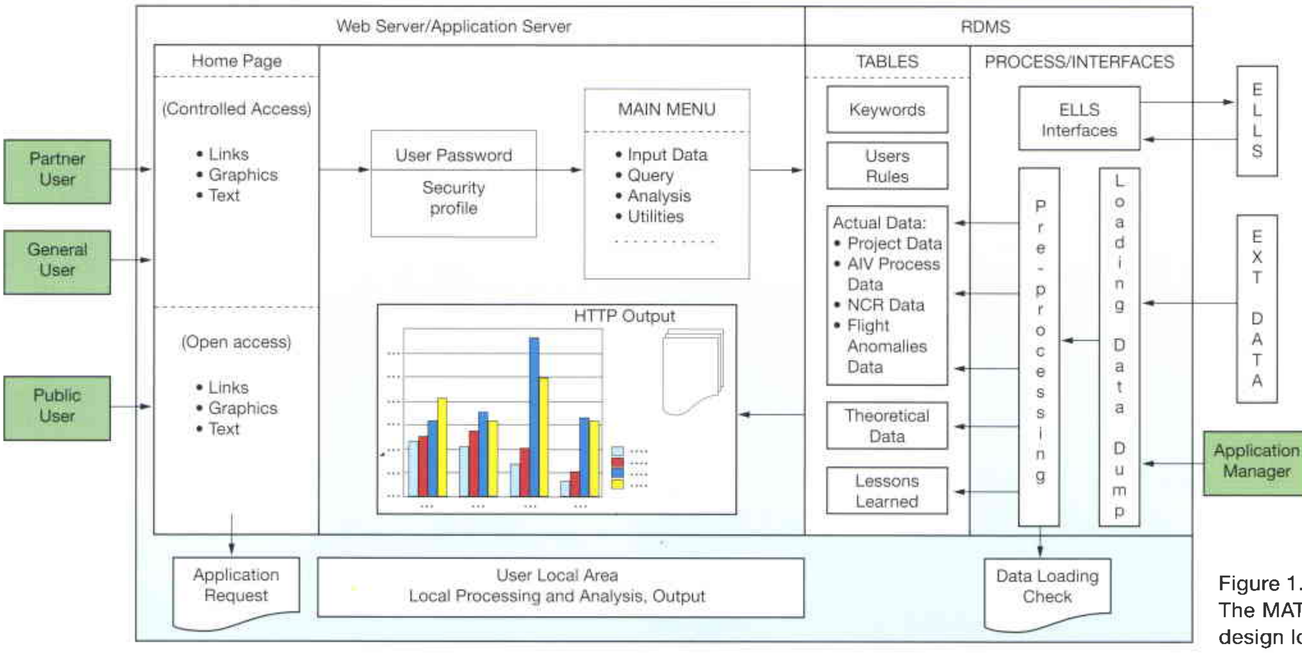


Figure 1. The MATED design logic

– carry out a first set of analyses to demonstrate the validity of the concept and the associated methodologies
– recommend methodologies for using the analysis results in updating and maintaining the European standards
– evaluate future development towards an operational system.

Access to the MATED data loading, reading and analysis functions is regulated by a password system based on user-specific prerogatives. Free user access to the welcome, news and information pages is also foreseen.

The MATED data

On the basis of the study findings, the foreseen analysis needs, and the industrial consortium's experience, four categories of data have been defined: Project Data, AIV Process Data, NCR Data and FA Data (Fig. 3). The innovative

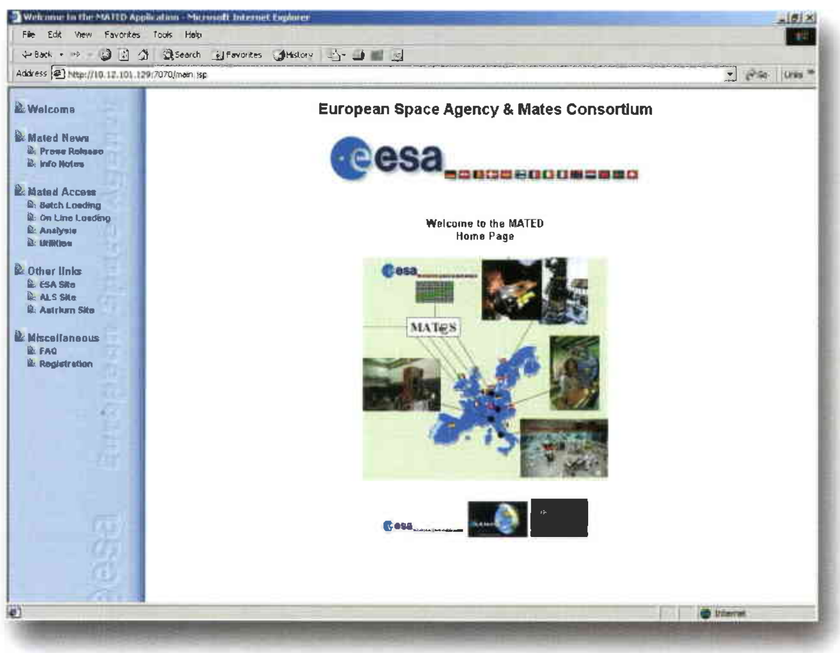


Figure 2. The MATED web site

PROJECT DATA
- PROJECT CODE/TYPE
- CUSTOMER
- PROJECT MASTER PLANNING
- MISSION TYPE/DESRIPTION
- PERCENTAGE AIV COSTS
- INDUSTRIAL CONSTRAINTS
- TECHN. CONSTRAINTS
- PRODUCT TREE (INCLUDING QUANTITY, CATEGORY, DESCRIPTION, QUAL. STATUS, HERITAGE)
- PROJECT TECHNOLOGY (INCLUDING NUMBER OF ELECTR. PARTS, MASS, DIMENSIONS, ETC.)

AIV PROCESS DATA
- REQUIREMENT VERIFICATION MATRIX
- VERIFICATION STRATEGY
- MODEL PHILOSOPHY (INCLUDING MODEL, LEVEL, REPRESENTATIVENESS, QUANTITY, UTILIZATION, ETC.)
- VERIFICATION AND TEST SUMMARY (INCLUDING AIV ACTIVITY, METHOD, TYPE, CONDITIONS, FACILITY,STAGE, PRODUCT, MODEL, COST PARAMETERS, ETC.)
- AIV PLANNING (INCLUDING ACTIVITY DURATION, START DATE, ETC.)

NCR DATA
- NCR NUMBER
- SPECIFIC PRODUCT
- NCR TITLE
- NCR SUMMARY
- NCR DISPOSITION
- NCR CAUSE
- NCR CLASSIFICATION
- NCR DATE
- NCR IMPACT
- NCR NOT EARLY DISCOVERY REASON

FA DATA
- FA NUMBER
- SPECIFIC PRODUCT
- FA TITLE
- FA SUMMARY
- FA CAUSE
- FLIGHT ACTIVITY
- FA SEVERITY
- FA DATE
- FA NOT EARLY DISCOVERY REASON
- FA AIV FEEDBACK

Figure 3. The MATED data tree

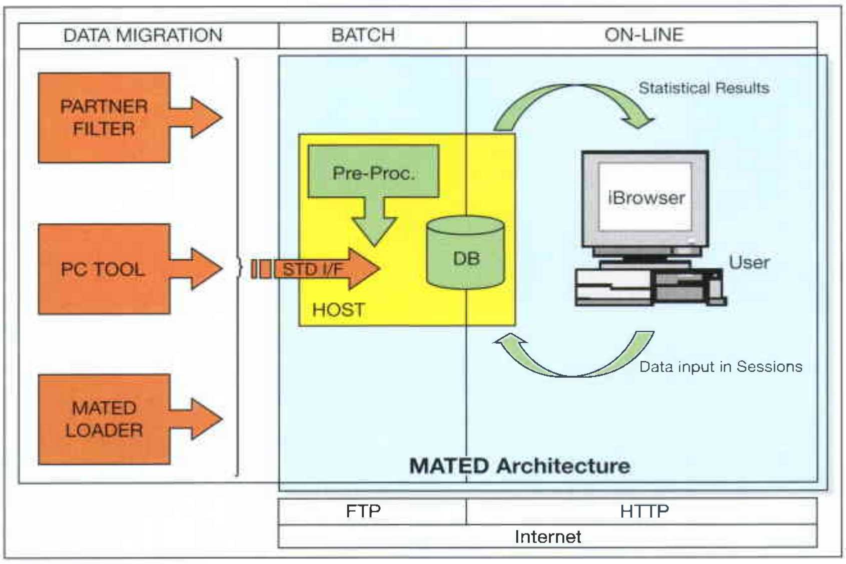


Figure 4. MATED data-collection scenario

feature of MATED compared with existing systems is the linking of the project products to the respective AIV activities, ground failures and flight anomalies. The associated time and cost aspects of the AIV process are also documented, albeit in relative values for reasons of confidentiality.

Data can be loaded into MATED using both the batch-loading and the on-line-loading capabilities of the system. In the case of batch-loading, a simple ASCII interface table can be generated either by a commercial PC tool, by filtering existing company databases, or by using a dedicated 'MATED loader'. The data currently collected in the MATED prototype consist of: 7 projects (both applications and scientific missions), 24 models, about 800 products, more than 300 AIV activities, about 400 NCRs and 50 FAs. The system-level data are substantially complete, while additional lower-level data will be collected during the next phase together with new project data.

The MATED analyses

As shown in Figure 5, four levels of analysis have been defined:

L1: on-ground, in-orbit and combined failure statistics

L2: technical and financial test-effectiveness evaluations

L3: model and test-effectiveness-index evaluations and time/cost parameter simulations

L4: risk assessment, risk/cost comparison, sensitivity analysis and optimisation.

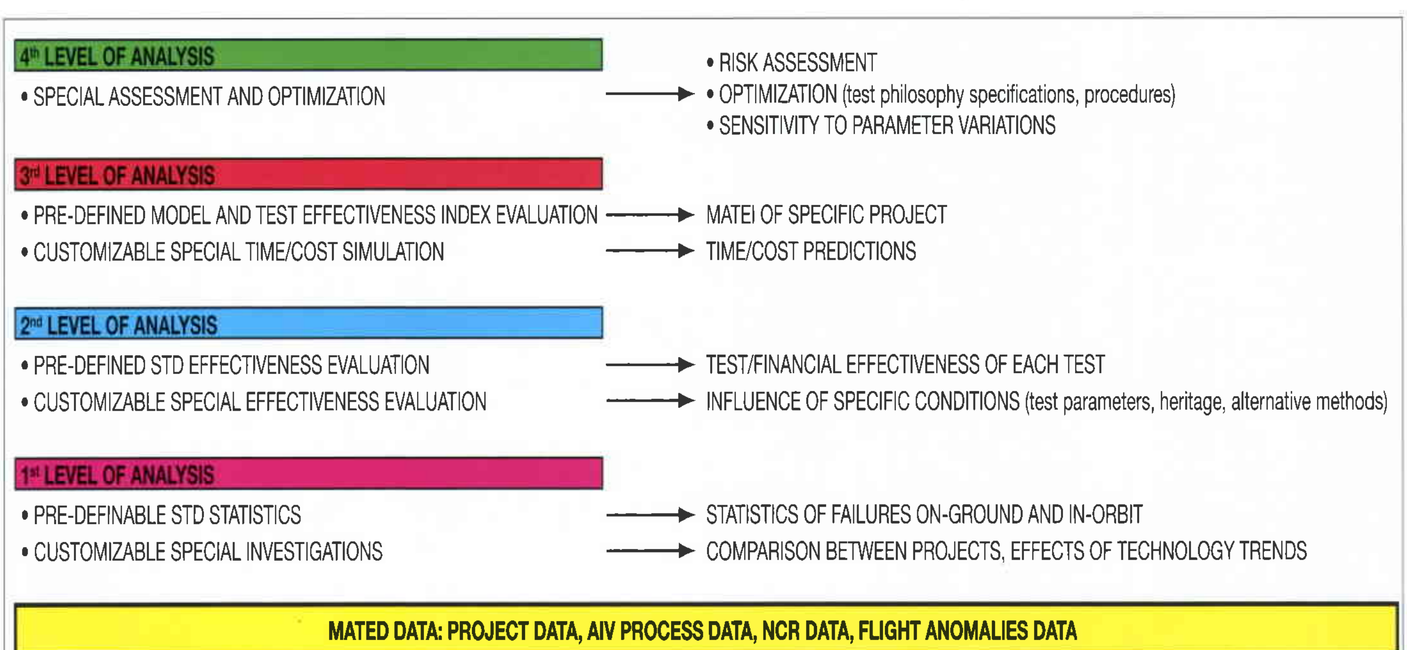
The higher-level analyses are based on the results of the lower-level analyses, and the L1 and L2 analyses are also customisable in the sense that other selected parameters can be introduced. The MATED analyses can be applied to the entire database or just a subset of it (i.e. investigation field), considering only certain projects or limited ranges of the different key parameters. The system allows one to select the applicable investigation field (Fig. 6).

Potential of MATED results

MATED analyses can answer such questions as:

- Which tests are discovering more NCRs? At which stage and what level?
- What are the most critical subsystems or equipment items in the ground testing?
- Which AIV activities are more impacted by design or workmanship failures?
- Is there any correlation between failures and time into test?
- Is an alternative verification method more effective?

Figure 5. MATED analyses



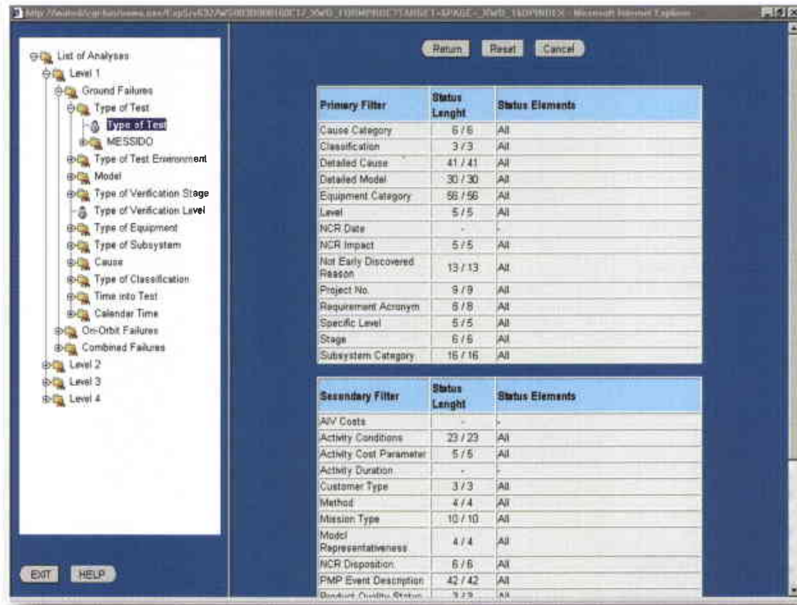
- Which subsystems/equipment items are more critical to operations?
- What is the technical and financial effectiveness of a test?
- How we can compare two model and test philosophies?
- Which test is the most likely candidate for deletion?

In terms of L1 Ground Failure (GF) statistics, MATED allows one to derive distributions of the numbers of NCRs, in absolute or relative terms, normalised to the number of electronic parts (to take into account project complexity), as a function of several key parameters. Figure 7, for instance, shows the distribution of NCRs vs type of test, with the ranking of the different tests highlighted. The distributions can also be customised to include a selected third parameter.

In terms of L1 In-Orbit Failure (OF) statistics, similar distributions can be derived as a function of the key parameters and are also subsequently customisable. Figure 8 shows the customisation of the failure-analysis distribution vs type of severity with respect to the 'FA AIV feedback' parameter, where the anomalies with the severest consequences (partial loss of functionality and redundancy switching) suggest the need to improve EMC, end-to-end communication, functional and performance, life and thermal-vacuum testing.

In terms of L2 Test-Effectiveness Evaluations, the Technical and Financial Test Effectivenesses (TTE and FTE indices) can be calculated. The TTE corresponds to the number of NCRs in the test of interest, divided by the sum of the total NCRs plus the FAs in the early flight period. The FTE multiplies the TTE by the ratio between the cost of the mission and the cost of the test (i.e. for the same TTE, the FTE is greater if the test costs less). The TTE can be customised for a third parameter, such as different test conditions (e.g. number cycles in thermal vacuum). Figure 9 shows the TTE and FTE for an acoustic test.

In terms of L3 Model and Test-Effectiveness Index (MATEI) and Time/Cost Parameter Evaluation, a reference index as been defined corresponding to the level of completeness of a certain model and test philosophy with respect



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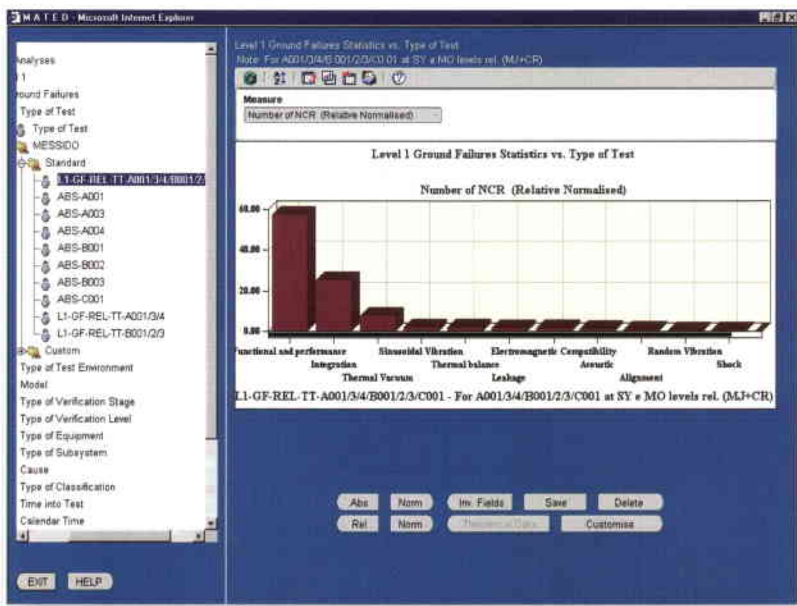

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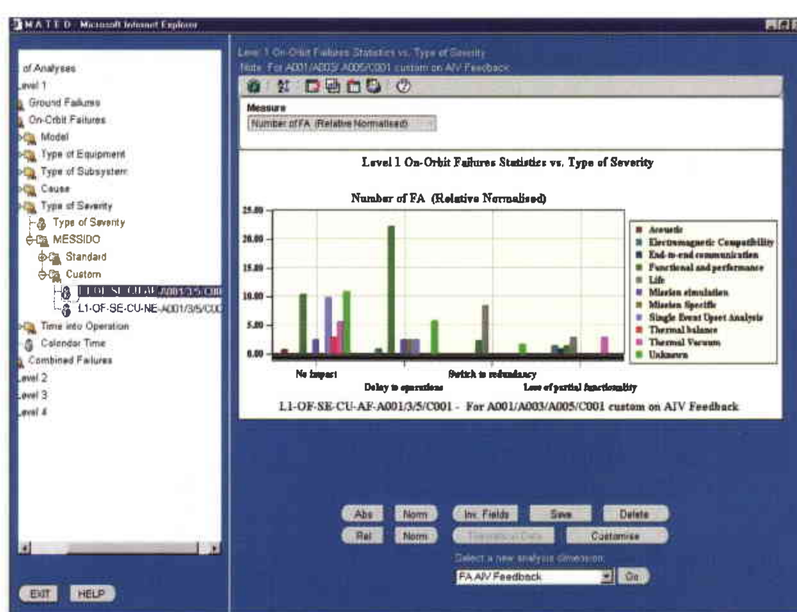

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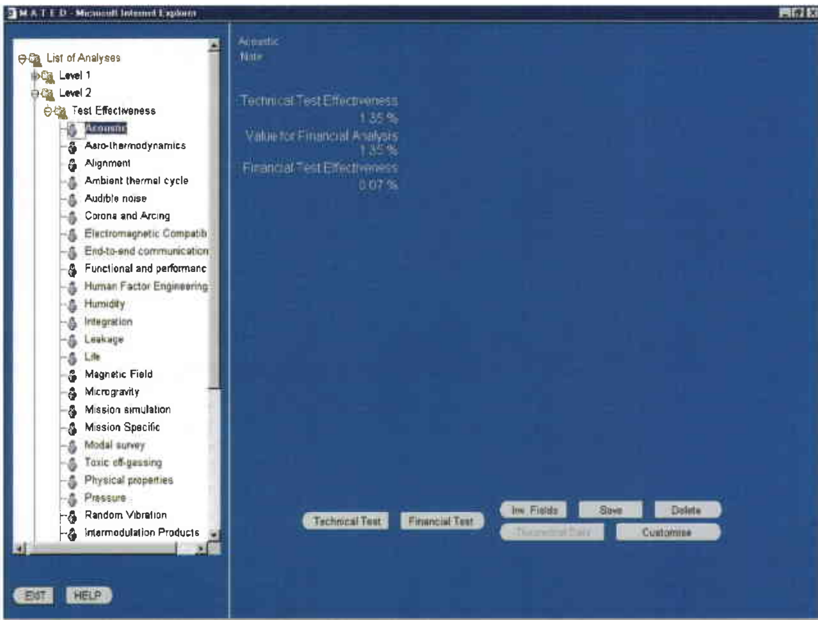
Figure 6. Investigation field selection

Figure 7. Typical L1 ground-failure statistics

Figure 8. Typical L1 customised in-orbit-failure statistics



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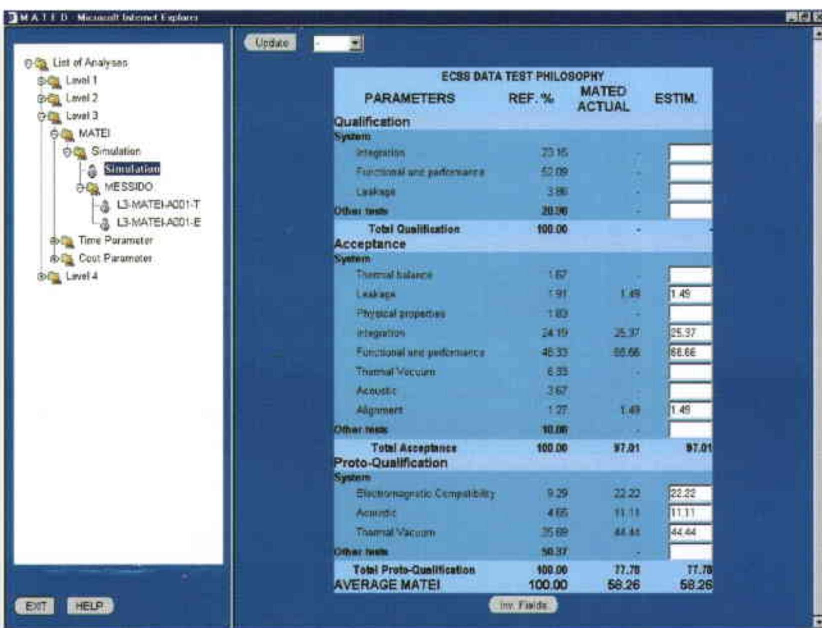

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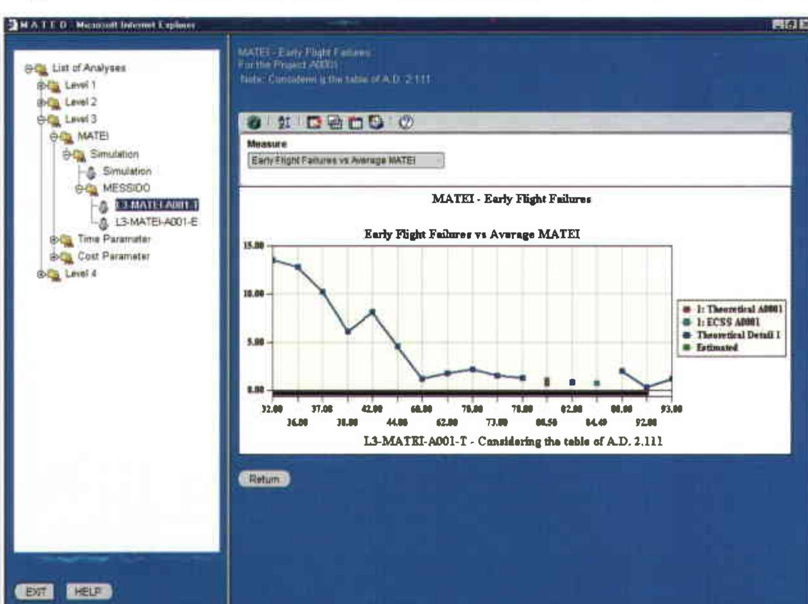

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to the ECSS (European Cooperation for Space Standardization) verification and testing standards. Figure 10 shows the MATEI ECSS Test Philosophy table.

Given a pre-determined model and test philosophy, it is therefore possible to estimate the MATEI and try to anticipate the number of early failures to be expected (Fig. 11). The validity of that MATEI can subsequently be checked/verified during the operational lifetime of that particular spacecraft or space system. An equivalent approach can be followed for cost and time-parameter aspects.

In terms of L4 Sensitivity Analyses and Optimisation, MATED offers the user the ability to carry out risk assessments, risk/cost comparisons, sensitivity analyses and optimisations for current and new projects. This type of analysis is usually supported by a suitable set of L3 and sometimes L2 analyses, as well as other offline investigations such as risk assessments. Figure 12 shows a typical result, where the data are expressed as percentage deviations with respect to the baseline.

The MATED operational scenario

The future application scenario foreseen for MATED, which could be made operational very soon, is as follows:

- ESA would serve as the MATED host and database administrator.
- The MATES Industrial Consortium would support ESA as applications manager for data loading, system upgrading, maintenance, special analysis and user feedback.
- Other European and world-wide companies, agencies and organisations would become 'partner users', providing data and statistics and receiving tailored access to MATED functionalities. They could also be supported by the MATES Industrial Consortium with suitable training and maintenance support.

Conclusion

Streamlining of the model and test philosophies for Europe's future spacecraft and space systems is crucial to reducing the time, and hence the investment, needed for their development whilst still keeping the degree of risk under control. The proposed sharing through the MATED database initiative of the European space sector's AIV knowledge and

Figure 9. Typical TTE and FTE evaluation

Figure 10. Typical MATEI ECSS test-philosophy table

Figure 11. Typical early-flight-failure diagram

experience accumulated over many years would represent a major step forward in this respect. The first results have already demonstrated the validity of such an initiative. The number of spacecraft developed in Europe is not so high in a global context, and the number of in-flight anomalies that have been experienced to date by ESA spacecraft is actually very low. For MATED to be a success, therefore, as many participants and inputs as possible are needed, in order for the results to be statistically significant. It is therefore hoped that the many companies, agencies and organisations both in Europe and around the World working in the space domain will be motivated to join in this initiative, which holds the promise of substantial mutual financial benefits for the participants. esa

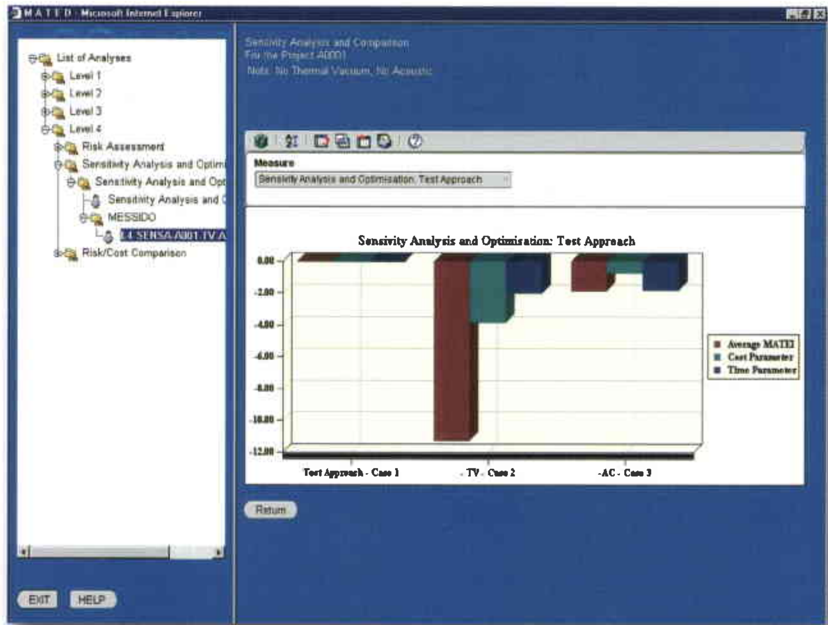

Figure 12. Typical sensitivity analysis and optimisation result

Detecting, Tracking and Imaging Space Debris

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Among the more than 8700 objects larger than 10 cm in Earth orbits, only about 6% are operational satellites and the remainder is space debris. Europe currently has no operational space surveillance system, but a powerful radar facility for the detection and tracking of space debris and the imaging of space objects is available in the form of the 34 m dish radar at the Research Establishment for Applied Science (FGAN) at Wachtberg near Bonn, in Germany.

In this article, the current space-debris environment surrounding the Earth is briefly presented and the hazard that it and meteoroids represent is discussed. The more than ten years of successful cooperation between FGAN and ESA's European Space Operations Centre (ESOC) in the field of space-debris research is also summarised.

Earth's space-debris environment

Today's man-made space-debris environment has been created by the space activities that have taken place since Sputnik's launch in 1957. There have been more than 4000 rocket launches since then, as well as many other related debris-generating occurrences such as more than 150 in-orbit fragmentation events.

Currently, there are more than 8700 objects larger than 10–30 cm in Low Earth Orbit (LEO) and larger than 1 m in Geostationary Orbit (GEO) registered in the US Space Command Satellite Catalogue. US Space Command tracks these objects with radars and optical telescopes to determine their orbits and other characteristic parameters, including their sizes (Fig. 1). Approximately 6% are operational spacecraft, 21% are old spacecraft, 17% are rocket upper stages, 13% are mission-related debris, and 43% are fragments from (mostly) explosions or collisions. Consequently, about 94% of the catalogued objects no longer serve any useful purpose and are collectively referred to as 'space debris'. In addition, there are a large number of smaller objects that are not routinely tracked, with estimates for the number of objects larger than 1 cm ranging from 100 000 to 200 000.

The sources of this debris are normal launch operations (Fig. 2), certain operations in space, fragmentations as a result of explosions and collisions in space, firings of satellite solid-rocket motors, material ageing effects, and leaking thermal-control systems. Solid-rocket motors use aluminium as a catalyst (about 15% by mass) and when burning they emit aluminium-oxide particles typically 1 to 10 microns in size. In addition, centimetre-sized objects are formed by metallic aluminium melts, called 'slag'. They typically amount to 1% of the propellant mass and leave the motor with low velocities at the end of the burn. There is evidence from ground-based radar measurements that 16 of a total of 31 nuclear reactors used by Russian RORSATs (Radar Ocean Reconnaissance Satellites) have lost their sodium-potassium (NaK) coolant, following their reorbiting and subsequent core ejection in disposal orbits at between 700 and 950 km altitude. The size of the NaK droplets observed ranges from 6 mm to 4.5 cm. The NaK population is assumed to consist of about 60 000 objects, with a total mass of about 50 kg.

It is unclear how severe the space-debris situation will be in future years, because this depends on the scale of future space activities, the degree to which debris generation is controlled, and the effectiveness of any mitigation measures adopted. This problem can be analysed with a space-debris environmental model like ESA's MASTER (see below), which describes the spatial distribution and particulate flux as a function of its size and location in space. These mathematical models have to be validated with measurement data.

Europe still has only very limited capabilities for the detection and tracking of 'uncooperative' space objects. As a general rule, radars are primarily used for the characterisation of the space-debris population in LEO, whereas optical telescopes are used for more distant orbital regions such as the geostationary ring (GEO). One high-performance radar facility in Europe able to probe the Earth's space-debris environment and track and even image space objects is the FGAN Tracking and Imaging Radar (TIRA) system. Because of its unique capabilities, it is used for civil protection (orbit determination and imaging of re-entering risk objects) and to a limited extent for externally funded research-oriented studies, as well as defence-related activities. FGAN therefore cooperates with institutes in Germany and abroad, as well as with national and international organisations such as DLR, ESA, NASA and NASDA.

With beam-park experiments with TIRA alone, or jointly with the Max-Planck-Institute of Radio Astronomy's 100 m telescope at Effelsberg in Germany (bi-static mode), snapshots typically of 24 hours duration can be taken of the current space-debris population to provide statistical information and rough orbit parameters for objects as small as 1 cm at altitudes up to 1000 km. In several such experiments, uncatalogued centimetre-sized debris could be detected, and in some cases the possible sources identified, such as the droplets generated by RORSAT reactor cores and debris from a Pegasus upper-stage explosion. Ground-based radars are therefore important tools for validating space-debris models.

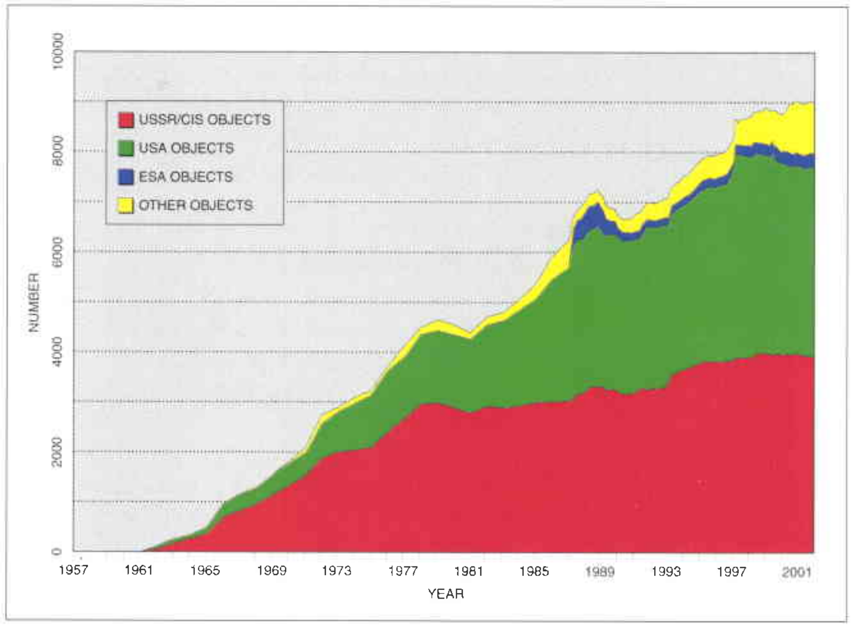


Figure 1. History of catalogued objects in orbit

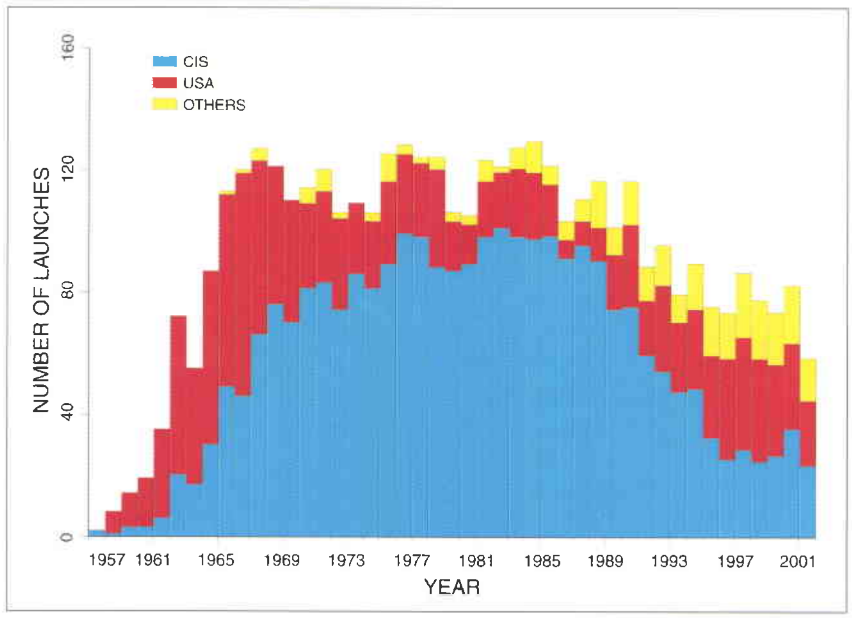


Figure 2. History of successful rocket launches

The hazards posed by space debris and meteoroids

The major concern with debris is that it might hit an operational spacecraft or a larger object such as the International Space Station, with a whole variety of detrimental consequences. The average collision velocity in LEO is greater than in the much higher circular (GEO) orbits and typically ranges between 8 and 12 km/s. In a LEO collision between an operational spacecraft and a catalogued object, it is likely that both would be destroyed and hence many more space-debris fragments would be generated. If these fragments were large enough, they too could generate additional debris through further collisions.

Up to now only one operational spacecraft, the French Cerise reconnaissance satellite, has been hit by another catalogued object, being struck in 1996 by a fragment from the third stage of an Ariane launcher that had exploded ten years earlier. Evidence of the degrading nature of the space environment, however, is provided by the increasing numbers of close encounters in space. Several times per week, the flight path of ESA's ERS-2 Earth-observation satellite is carefully examined for potential close encounters or collisions with catalogued objects. If the chance of a collision exceeds a certain tolerance, a collision-avoidance manoeuvre is carried out. ESA performed two such evasive manoeuvres with the ERS-1 spacecraft in June 1997 and March 1998. The most recent collision-avoidance manoeuvre, with the International Space Station (ISS), took place on 15 December 2001, when Space Shuttle 'Endeavour' increased the Station's altitude by 1 km to avoid a collision with a Russian SL-8 upper stage launched in 1971.

The natural meteoroid environment does not pose a serious hazard to most spacecraft in Earth orbit. Exceptions are meteor streams with high Earth-approach speeds such as the Leonids, which were traveling at 71 km/s, which may necessitate special safety measures for operational spacecraft.

The FGAN system

The main subsystems of the FGAN Tracking and Imaging Radar (TIRA) are: a 34-m parabolic antenna (Fig. 3), a narrow-band mono-pulse L-band tracking radar, and a high-resolution Ku-band imaging radar. The sophisticated, fully computer-controlled, 34-m parabolic Cassegrain-feed antenna is mounted on an elevation-over-azimuth pedestal. It is shielded from atmospheric influences by a rigid 49 m-diameter radome.

The L-band radar is used primarily for the detection and tracking of space objects. Using a double-Klystron power stage, it generates high-frequency pulses of typically 1 to 2 MW peak power and 1 ms pulse length. The signal-processing concept supports target tracking in angular direction as well as in range and range rate. In this operating mode, up to 30 statistically independent observation vectors per second are measured with the tracking filter. The main components of an observation vector are: time, azimuth and elevation angles, range, range rate, echo amplitude and phase, and the transmitted peak power.

Figure 3. The TIRA facility

The Ku-band radar's main application is in the imaging of space objects, being operated simultaneously with the tracking radar on the same target. Typically, linear frequency-modulated radar pulses of 13 kW peak power, 256 microsec pulse length and 800 MHz bandwidth are generated by a travelling wave tube. The signal processing is based on the de-ramp principle, and the matched-filter operation is realised by fast Fourier transformation in a post-processing mode. Up to 400 range profiles per second are acquired with 25 cm resolution (Hamming window applied) in imaging mode.

The main space applications of TIRA are:
- searching for and tracking space objects (orbit determination)
- characterisation of the space-debris environment
- validation of space-debris models
- tracking re-entering (risk) objects
- imaging space objects (verification of operational procedures, attitude determination, emergency operations, damage and fragmentation analysis)
- radar measurements of meteoroid streams.

Searching for and tracking space objects

For space-object tracking, there is generally a priori information available, such as some orbital elements and the approximate size of the object (radar cross-section). The radar beam is pointed to a pre-determined position in space and after detection the object is tracked and observation vectors are collected, from which its orbital parameters and radar signature can be computed. The latter provides clues as to the object's intrinsic motion (rotation or tumbling rate). This mode of observation is called 'target-directed' and is used when the uncertainty in the knowledge of an object's orbit is unacceptably high and more precise information is required, for instance for collision-avoidance manoeuvres for operational spacecraft and for reentry predictions for potentially dangerous objects.

Another application is for tracking support during the launch and early operations phases of a mission, which may include confirmation of reaching the nominal orbit after launch, or searching for spacecraft and determining their actual orbits following a non-nominal launch.

Characterisation of the space-debris environment

An important tool in the characterisation of the small-size debris population are so-called 'beam-park' experiments. In this operating mode, the radar beam is maintained in a fixed direction with respect to the Earth and all objects that pass through the beam are registered. In the course of one day, the Earth's rotation scans the beam through 360 deg in inertial space. From the backscattering of the radar signal, the size of the object and some of its orbital parameters can be determined. The FGAN radar is sensitive enough to detect 2 cm-sized objects at a distance of 1000 km. This primarily statistical information on the small-size terrestrial debris population in the LEO region can be used to validate space-debris models.

Several US radars are carrying out beam-park experiments from Haystack (Mass.), Goldstone (Calif.), and Kwajalein (in the Pacific). Until recently, the Haystack radar was the only data source for objects as small as about 2 mm. Between 1990 and 1994, space debris was observed for more than 3000 hours and the results of these measurements have influenced most space-debris models.

The first European beam-park campaign was carried out in 1993. During a 10-hour experiment, the TIRA L-band radar's ability to detect small-size debris in LEO was successfully demonstrated. The first operational measurement campaign was subsequently performed on 13/14 December 1994, when the FGAN L-band radar was operated in beam-park mode for 24 hours and the Fylingdales Phased-Array Radar (UK) also participated for 24 hours. The Herstmonceux 20 cm telescope (UK) also operated for 3 hours with good weather conditions, but the Zimmerwald 50 cm telescope in Switzerland unfortunately experienced bad observation conditions. All sensors were pointed at the centre of the same observed volume.

Within the framework of ESA/ESOC study contracts with FGAN, hardware modifications were introduced in 1995/1996 to improve TIRA's sensitivity: new low-noise amplifiers (0.3 dB) were fitted to the L-band receiver's front end and directly connected to the switched limiters. On the transmitter side, two modulation decks were reconstructed in order to operate the transmitter at higher peak power levels (increased from 1 to about 2.5 MW) with reduced inter-pulse noise. These modifications roughly doubled the distance at which objects can still be detected.

With the more powerful radar in place, a third measurement campaign was performed on 25 November 1996. This time the TIRA L-band radar was operated in bistatic 'COoperative BEAM-park mode' for 24 hours. A second data-collection system was installed at the World's largest steerable, 100 m parabolic antenna, at Bad-Münstereifel Effelsberg in Germany, operated by the Max-Planck-Institute of Radio Astronomy in Bonn, and about 21 km from the TIRA system. On the same day, the Haystack radar in the USA, and during the same week the TRADEX radar on Kwajalein, were also operated. This COBEAM campaign (Fig. 5) showed that the FGAN L-band radar can indeed detect 2 cm objects at 1000 km distance. When combined with the Effelsberg radio telescope as a secondary receiver, objects as small as 0.9 cm can be detected at the same distance. Pointing the Effelsberg antenna in azimuth to 90 deg E (or 90 deg W) provides an unambiguous relationship between Doppler frequency measurements and orbital

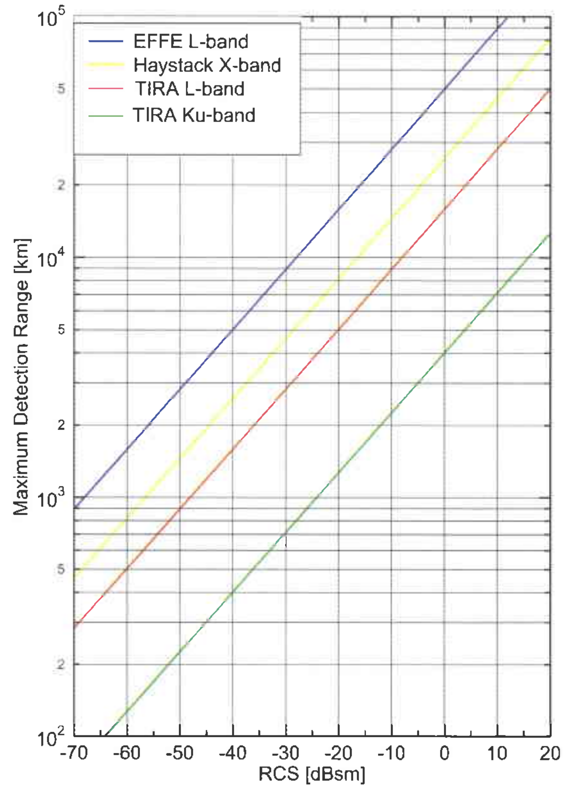


Figure 4. Range performance for bi-static radar operation with the 100 m Effelsberg radio telescope, for the FGAN L-band and Ku-band radars, and for the Haystack X-band radar. The plots are for single-pulse processing with a signal-to-noise ratio of 3 dB

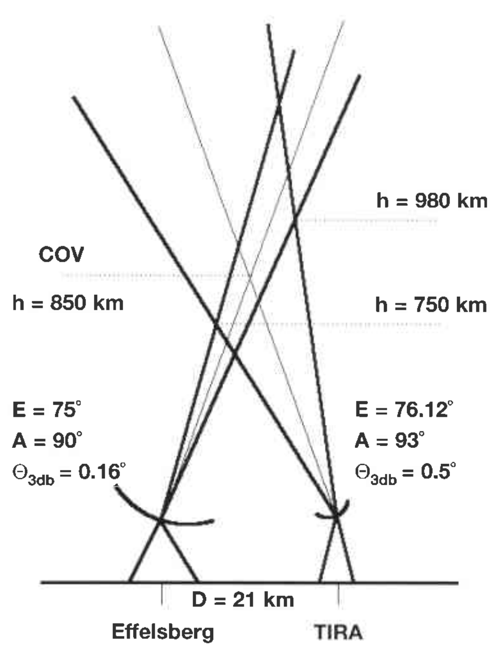


Figure 5. The 'beam-park' experiment geometry

inclination of detected targets for circular orbits. Together with the corresponding pointing angles for the two antennas, there was an altitude overlap of more than 200 km.

During the 24-hour COBEAM observation campaign, 371 objects were detected by Effelsberg and 317 by FGAN. 189 objects were seen by both sites and the total number of objects detected was 499. The many detections around 900 km altitude are most likely due to the NaK droplets from RORSATs. The increased detection rate at 600 km is probably due to debris generated by the explosion of a Pegasus hydrazine auxiliary propulsion stage five months prior to the COBEAM experiment. This explosion of the Pegasus stage illustrates the highly dynamic nature of the space-debris environment, which means the beam-park experiments must be frequently repeated to monitor the constantly changing (mainly increasing) risk of collisions as a function of the altitudes and orbital inclinations of operational satellites. Four more 24-hour experiments have therefore been conducted in the meantime, and one or two such campaigns per year are planned for the future.

Due to improved data-processing capabilities, the observation windows of the campaigns in 2000 and 2001 were extended to cover distances from 350 to 2000 km. As a result, nearly 500 objects are now detected by FGAN in 24 hours, i.e. one every three minutes. Figure 6 shows an altitude versus Doppler inclination plot for the 471 objects detected in October 2000. Only 94 of these objects appear in the US Space Command Catalogue. Various clusters such as the NaK droplets at 900 km and 65° inclination, and the Globalstar constellation at 1400 km and 55° inclination, are clearly apparent.

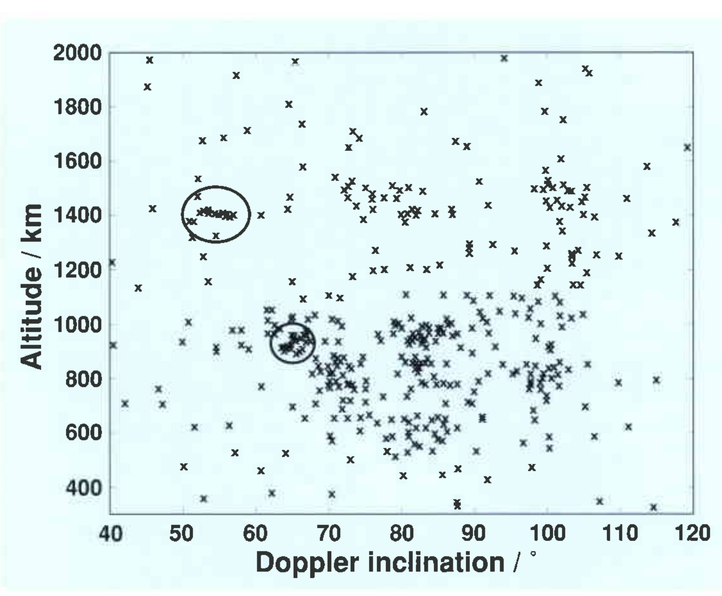


Figure 6. Altitude versus Doppler inclination for objects detected during the October 2000 beam-park experiment

The main results of these beam-park experiments, however, are the comparisons provided with the space-debris models. Every 24-hour experiment in the past confirmed that our understanding and modelling of the space-debris environment was incomplete; in some orbital regions, twice as many objects were detected as were predicted by the models. The observational data have been and will continue to be used to improve our space-debris models.

Validation of space-debris models

In order to describe the spatial distribution of the debris population that is not yet catalogued, mathematical models have been developed. ESA's reference model for space debris and meteoroids, called 'MASTER', was jointly developed with researchers at the Technical University of Braunschweig in Germany. The most recent model, MASTER 99, is based on the catalogued population, the known historical fragmentations and non-fragmentation debris. Particles as small as 1 micron are taken into account. It also contains the Divine-Grün-Schaubach meteoroid model, which provides directional fluxes.

For the construction of a meteoroid and debris reference model, several assumptions have to be made which introduce uncertainties. Most models take the cataloged population as a basis and add fragments from known breakups in the micron to 50 cm size regime to account for the incompleteness of the catalogue. For sizes larger than 50 cm, the breakup model parameters are calibrated such that the theoretical population fits the catalogued population. For the size range between 1 mm and 50 cm, however, observational data are sparse and the uncertainties in the models increase considerably with decreasing object size. However, validation of the models in the size range from a few millimetres to 50 cm can be achieved with special ground-based measurement campaigns using high-performance radar facilities like TIRA.

Tracking re-entering (risk) objects

Since Sputnik I was launched, more than 17 000 catalogued objects have reentered the Earth's atmosphere and most did burn up completely. In the case of compact and massive spacecraft, the melting and evaporation process will not be complete and fragments of the vehicle may reach the ground, as has been the case with Skylab, Kosmos-954 and Salyut-7/ Kosmos-1686. The standard procedure for large objects for which re-entering fragments constitute a safety hazard on the ground, is to carry out a controlled re-entry in an uninhabited oceanic area. Recent examples are the de-orbiting of the Russian Mir space station and of NASA's Compton gamma-ray spacecraft.

If a massive space vehicle becomes uncontrolled at low altitude, the task of determining the re-entry window (time and location) and the dispersion of the re-entering fragments along the ground track will be very difficult. Also in the case where the re-entering object is still controllable, but the available propellant for the de-orbit manoeuvre is very limited, the orbit-prediction task will be fraught with difficulties. The main reason is that aerodynamic forces will increasingly influence the trajectory, which cannot then be modelled with sufficient accuracy. Other factors that limit the prediction accuracy are changes in atmospheric density and the attitude of the space vehicle.

Radar tracking of re-entering risk objects is thus of paramount importance. It allows us to determine the changes in the orbit parameters and hence to calculate the re-entry window in time and along the ground-track. Recent examples of re-entering objects for which FGAN has provided this support to ESA are Salyut-7/ Kosmos-1686, Kosmos-398, China-40 and the Mir space station (Fig. 7).

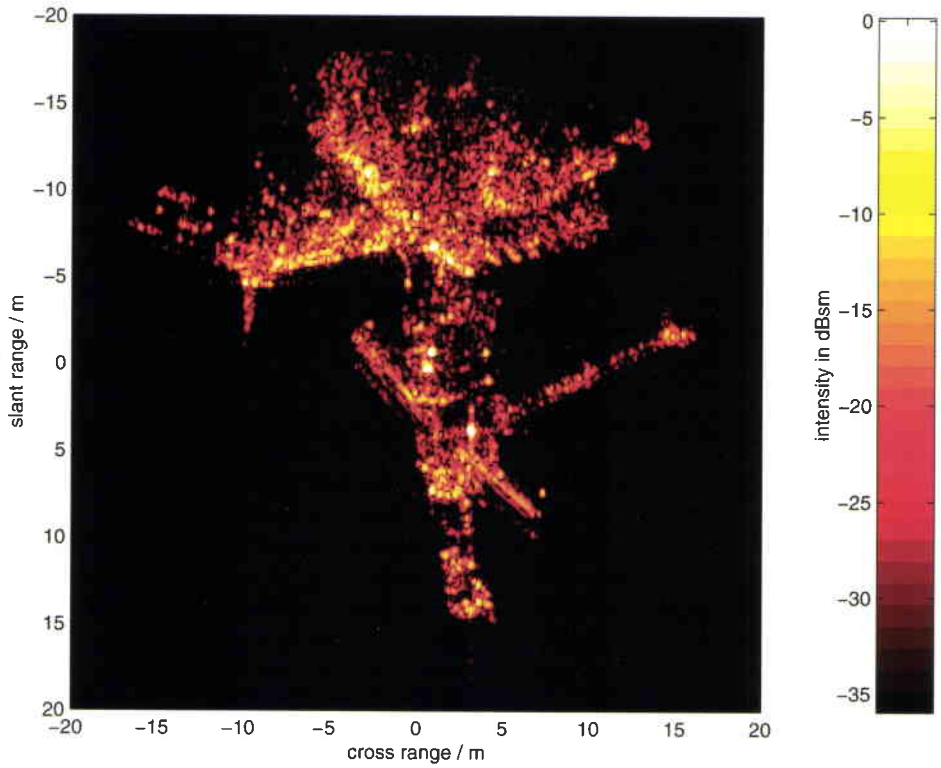


Figure 7. Radar image of the Mir space station

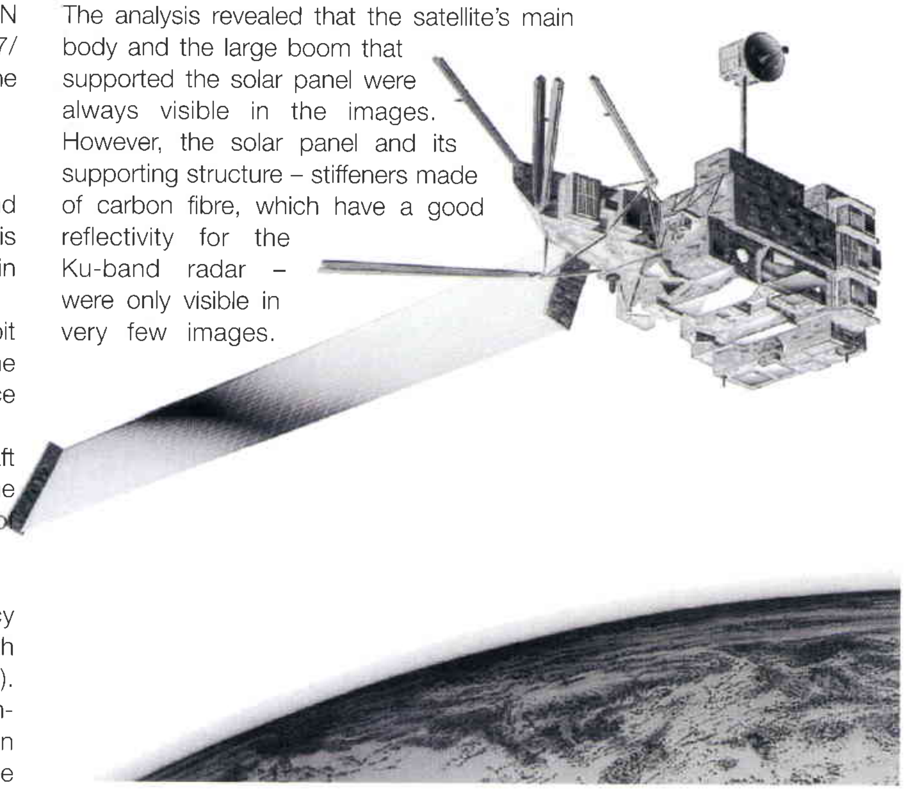
Imaging space objects

The imaging capability of the TIRA Ku-band radar is not only of relevance for space-debris research, but also for space operations in general. Its main applications are:

- in the support of Launch and Early Orbit Phases (LEOPs), including verification of the deployment of moveable elements of a space vehicle, and
- as a diagnostic tool in the event of spacecraft anomalies, including determination of the attitude, shape and configuration of the spacecraft.

An example of just such an emergency situation was provided by the Advanced Earth Observation Satellite, ADEOS (Fig. 8). Launched on 17 August 1996 into a 797 km-altitude circular orbit with 98.6 deg inclination and designed for a lifetime of more than three years, ADEOS operations had to be terminated on 30 June 1997 due to loss of electrical power. The spacecraft's main body was 4 x 4 x 7 m^3 and it had a 3 x 24 m^2 and 0.5 mm-thick solar panel. Several passages of ADEOS were observed on 7 and 14 July 1997 with TIRA. From the Ku-band measurements, images were computed to investigate the cause of the malfunction. For the altitude assessment, a three-dimensional wire-grid model was constructed and two-dimensional projections of this model were overlayed on the images. The analysis revealed that the satellite's main body and the large boom that supported the solar panel were always visible in the images. However, the solar panel and its supporting structure – stiffeners made of carbon fibre, which have a good reflectivity for the Ku-band radar – were only visible in very few images.

Figure 8. Schematic of the ADEOS spacecraft



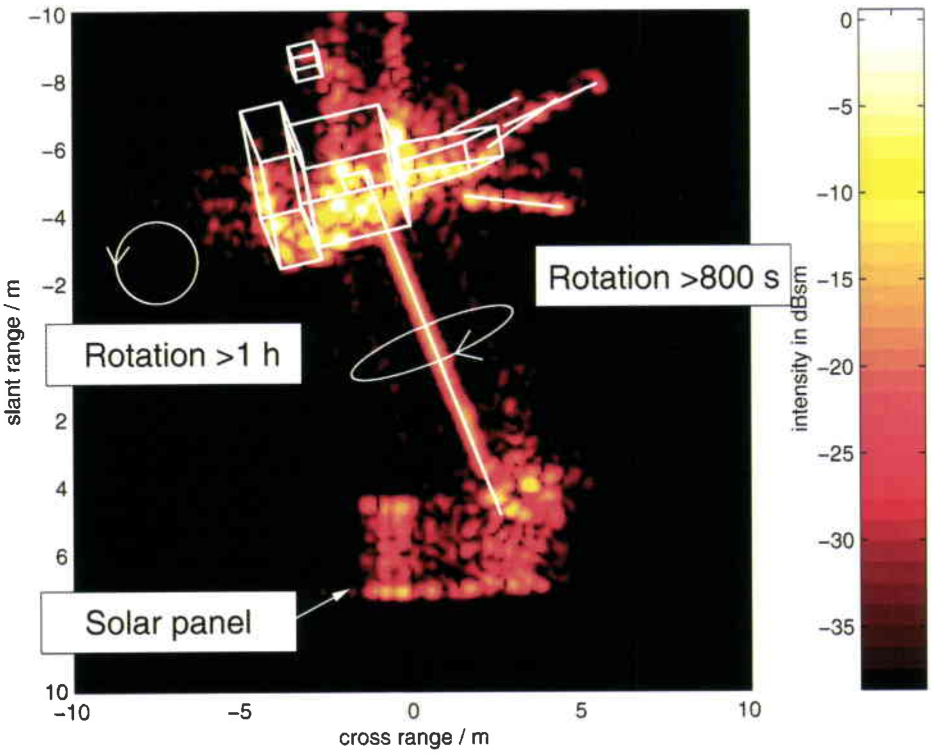


Figure 9. Radar image of ADEOS with overlayed wire-grid model and the results of intrinsic motion and damage analysis

Instead a cluster of scatter centres at the end of the boom was always visible. It is therefore assumed that the solar panel was snapped off at the base near the spacecraft's main body. Figure 9 clearly shows the dislocated solar panel at the end of the boom.

The analysis of the intrinsic motion of ADEOS identified basically two rotation components: one around the satellite's main body with an angular velocity of approximately 0.1 deg/s, and another around the satellite's boom with an angular velocity of about 0.4 deg/s.

Radar measurements of meteoroid streams

Another application of the TIRA system is the detection of meteors, in particular during meteoroid streams. As we marvel at the sight of visible meteors, not everybody is aware of the fact that for every one we see there are many much smaller ones that cannot be seen with the naked eye, but are detectable by high-power radar systems. Owing to their high speed, even these naturally occurring small meteoroids, which typically range from a fraction of a micron to a few millimetres in size, are potentially hazardous to Earth-orbiting spacecraft. The situation is particularly critical in the case of high-speed meteor streams such as the Leonids.

Because the progenitor of the Leonids, Comet Tempel-Tuttle, had passed through perihelion in February 1998, strongly enhanced meteoroid activity was expected with the Leonid shower of 17/18 November 1998. The very high approach velocity of the Leonids (more than 70 km/s) compensates for their small size and they thus constitute a real safety hazard for satellites. ESA therefore took special safety measures to protect its own spacecraft in orbit against potential impacts. It also warned other European satellite operators of the hazards and advised them on how to reduce the risk. In the event, on 17/18 November 1998 over a period of about 25 hours the Earth passed through a shower of relatively large meteoroids, which arrived at a rate of some 200 per hour (zenithal hourly rate, ZHR). This was the most severe shower since the previous Leonids meteor storm in 1996.

The question of how many radar-detectable meteors can be expected in a meteor storm like the Leonid event was the motivation for a measurement campaign with the FGAN L-band radar in 1999. The Leonids meteor storm was observed from 23:30 UT to 12:00 UT during the night of 17/18 November. A total of 176 meteor tracks were detected that night which, given the small 0.5 deg field of view of the TIRA system, is quite impressive. However, a closer analysis of the angular distribution of the meteor trails showed that very few of the meteors detected actually belong to the Leonids, the vast majority subsequently being assumed to form part of the sporadic background.

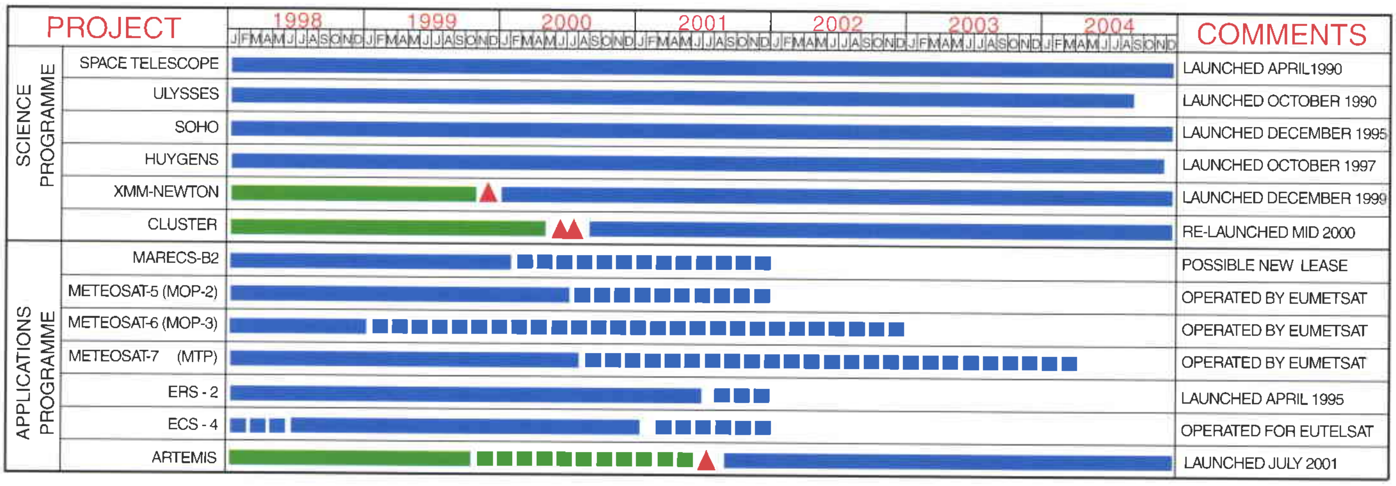
In order to understand better the measurements that were made in 1999, in 2001 another campaign was initiated that was designed specifically to measure the number of background meteors. On 18 November 2001, a ZHR of about 2000 was recorded. The data collected during the background campaign are still under investigation, but preliminary results indicate that the radar-detected meteors are indeed dominated by the sporadic background.

Another interesting aspect of the TIRA observations is the radar detection of meteoroids that arrive at speeds higher than 80 km/s. Particles arriving at these speeds cannot originate within our Solar System, and must be coming to us from interstellar space. As the highly sensitive dust detector on ESA's Ulysses spacecraft already detected such interstellar particles back in 1992, the TIRA detections of such fast meteors are credible. Therefore, high-power radars like TIRA can not only provide valuable information about space debris, but can also be used for high-quality space-physics observations.

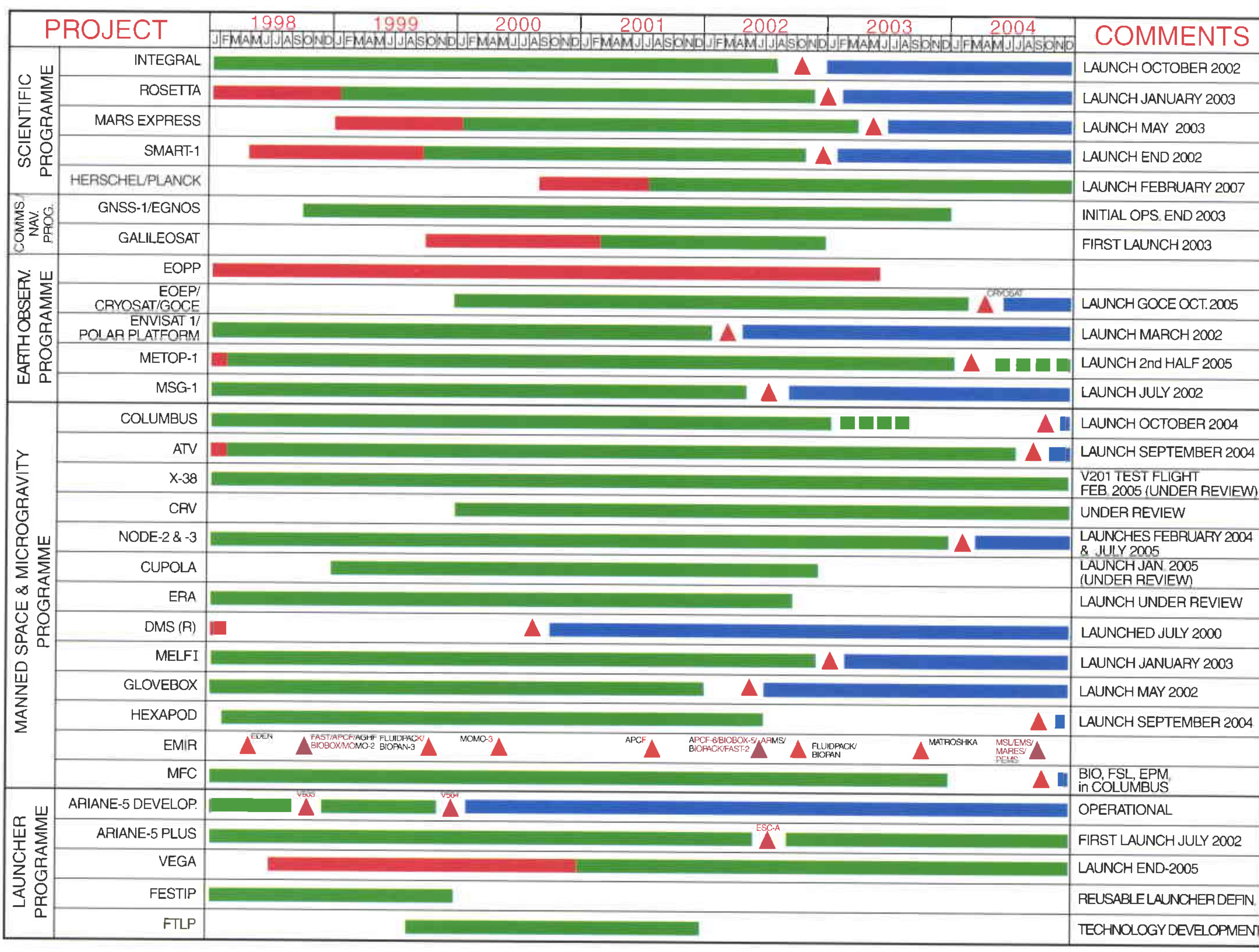
Programmes under Development and Operations

(status end-December 2001)

In Orbit



Under Development



DEFINITION PHASE
MAIN DEVELOPMENT PHASE
LAUNCH/READY FOR LAUNCH
OPERATIONS
ADDITIONAL LIFE POSSIBLE
RETRIEVAL
STORAGE

ISO

With the end of the Post-Operations Phase in December 2001, ISO has entered its five-year Active Archive Phase. This phase will focus strongly on increasing the 'off-the-shelf' usability of the ISO archive products, while continuing to support and encourage the scientific community in the exploitation of the ISO data. The work will be pursued in close collaboration with the National Data Centres (NDCs) that are funded for the Active Archive Phase, and with groups in the community.

Over the past few months, ongoing wrap-up activities for Post-Operations Phase have been directed towards the release of a reference Legacy Archive, to contain all ISO data products automatically reprocessed with the latest calibrations and software. That bulk reprocessing has already been completed and refinement of the explanatory documentation is also nearing completion.

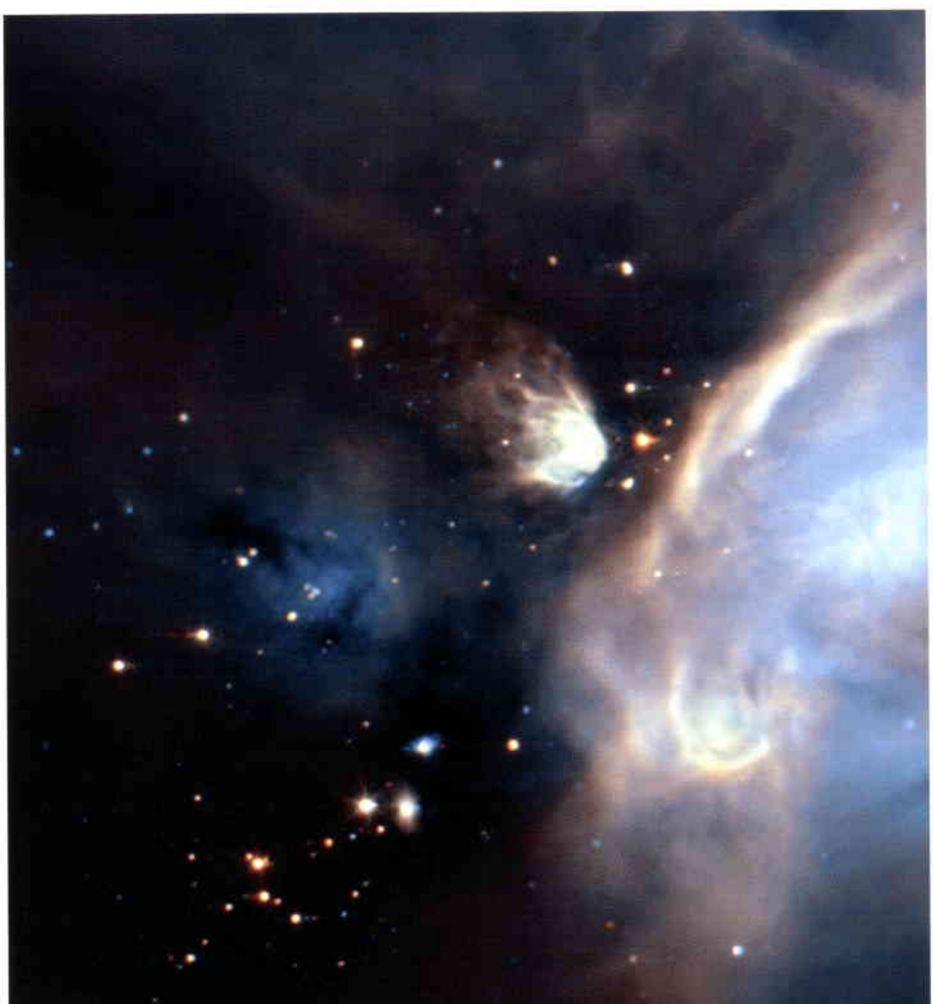
There are now over 1200 registered external users of the ISO Data Archive.

Science highlights

As ISO's Post-Operations Phase came to a close, exploitation of the ISO archive continued with around 120 refereed papers being published during the year.

Recent highlights included the finding of thirty brown dwarfs, elusive objects at the boundary between planets and stars, in the rho Ophiuchi cloud. ISO results suggested they form star-like, by accretion from a gaseous sphere, rather than forming planet-like, out of a disk orbiting a star. Many brown dwarfs have their own disks.

The discovery of more than 30 Earth masses of carbonates in two planetary nebulae has suggested formation mechanisms not associated with the presence of liquid water. This calls into question the previously assumed role of water (aqueous alteration) in the formation of carbonates in the early Solar System, with strong implications for estimates of the time of first appearance of liquid water, and of liquid-water-bearing planets, in the system.



The impressive rho Ophiuchi cloud, located 540 light-years away in the constellation Ophiucus, as seen by ISO

XMM-Newton

XMM-Newton operations continue to run smoothly. In the last quarter of 2001, some science time was unavoidably lost due to solar activity, but recently there have been almost no interruptions.

In December 2001, the ESA Science Programme Committee (SPC) unanimously approved the extension of XMM-Newton operations for four years until March-2006. During the extension discussions it was agreed that the so-called 'guaranteed-time programme' would be completed as soon as possible. This is important to the overall observing programme, as it will prevent important celestial targets from being 'proprietary' for too long a period. Implementation of this will mean a delay of six months in starting the Second Announcement of Opportunity (AO-2) observations, and a delay of approximately three months in their completion.

A successful observation of a gamma-ray burst, following a BeppoSAX trigger, took place on 12 December 2001. XMM-Newton was on target approximately 10 h after the burst was detected. This was an excellent (overnight) achievement by ESA's VILSPA (E) and ESOC (D) teams. An electronic circular giving the precise position (10") was issued some 7 h after the start of the observation. The data, which were processed and made public on 27 December, are still being analysed, but a preview is available at:
http://xmm.vilspa.esa.es/news/GRB011211/grb011211.html

The overall XMM-Newton data-processing and data-shipment activities are going according to plan. So far 1427 observation sequences have been executed, and the data for 1282 of these have been shipped. A new, improved-calibration version of the XMM-Newton Science Analysis Software (SAS), developed jointly by ESA and the Survey Science Centre (SSC), will be released at the end of February 2002.

The XMM-Newton satellite will enter its fifth eclipse season in March 2002, and

The Integral launch pad in Kazakhstan ten months before launch

preparations for this have already been started. Work on the development of the XMM-Newton Science Archive (XSA) continues, and it will be released in the first quarter of 2002.

A very successful symposium, attended by some 330 astronomers, entitled 'New Visions of the X-ray Universe in the XMM-Newton and Chandra Era', was held at ESTEC (NL) from 26 – 30 November 2001. The Proceedings will be published shortly by ESA Publications Division as ESA SP-488 (on paper and CD-ROM).

Integral

The two remaining flight-model instruments – the IBIS imager and the JEM-X X-ray monitor – have been delivered and integrated on the spacecraft. Integral is therefore now complete and ready for the final phase of its environ-mental test campaign at ESTEC. The current status of work in all areas is compliant with the October 2002 launch date.

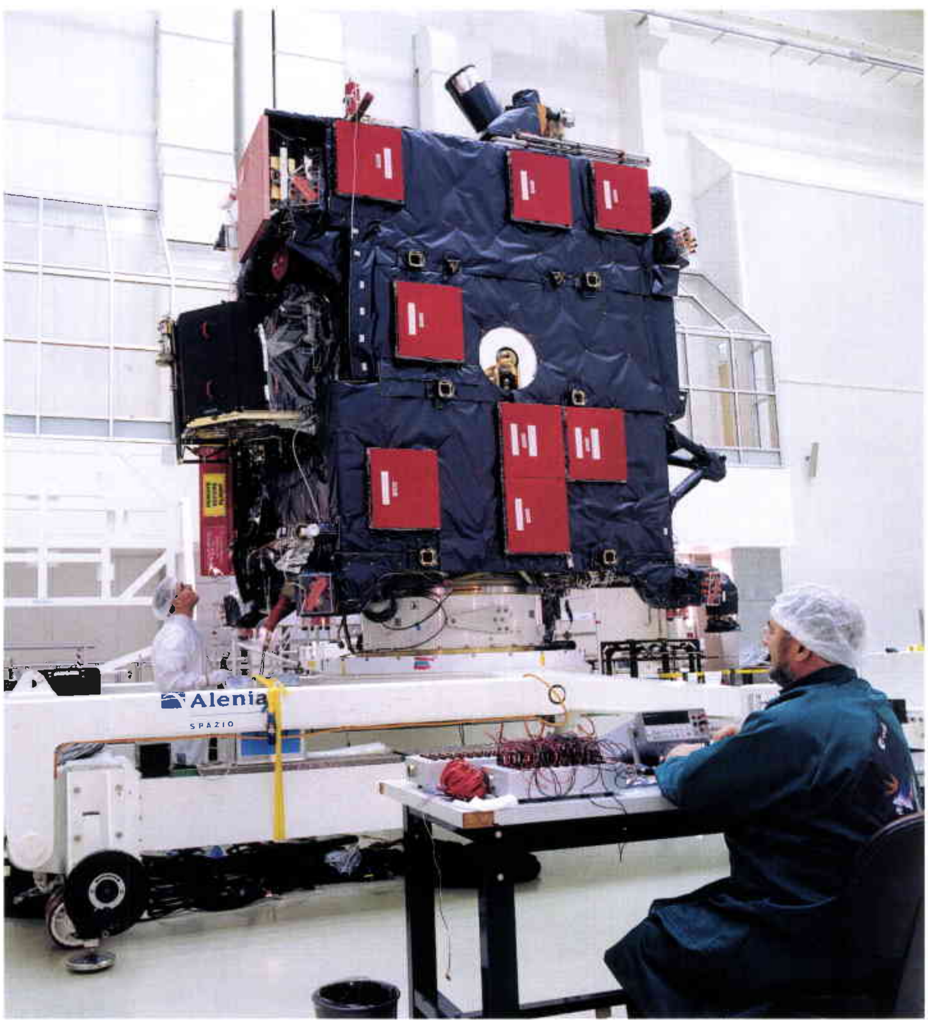
The electromagnetic-compatibility test and subsequent system tests, the first such tests with the complete payload integrated on the spacecraft, have been successfully completed. The payload-calibration campaign, during which the performances of the various scientific instruments will be verified using radioactive sources, has been kicked off.

The next major environmental test will be the acoustic test planned for the first quarter of 2002. It will be followed by thermal tests and final functional testing. The Flight Acceptance Review is scheduled for July 2002.

The manufacture of the Proton launcher by the Russians is progressing satis-factorily. A recent visit to the Baikonur Cosmodrome in Kazakhstan showed that the Integral-specific adaptation work needed at the launch site has also been progressing according to schedule.

Rosetta

The flight-model spacecraft is now fully integrated and is undergoing final functional testing before the environmental test programme begins. It was moved from Alenia in Turin (I) to ESTEC in November 2001 and thermal-vacuum testing will commence there at the end of January 2002. Many minor problems have occurred which have necessitated three-shift-per-day working. The transponders



The Rosetta flight model under test at ESTEC in Noordwijk (NL) have now been delivered, and also the onboard software required for the test phase. The electrical qualification model programme is continuing in parallel and is being used to debug all system functional test sequences before they are run on the protoflight model.

The scientific performance problems with the COSIMA instrument have now been identified and a new unit is being manufactured, which will be substituted later in the programme. The rest of the scientific payload is operating nominally on the spacecraft.

The Lander is integrated on the spacecraft, but some problems were experienced during final testing with the deployment of the landing gear. Solutions to improve the gear's robustness are being investigated and retrofits to the existing gear will be introduced later.

The Ground Segment Implementation Review successfully took place during November 2001 at ESOC in Darmstadt (D). Most ground-segment elements are progressing according to plan, but the operational readiness of the New Norcia ground station, which is now planned for August 2002, is a cause for concern.

The Launcher Preliminary Mission Analysis Review has successfully taken place with Arianespace. The launcher's performance for the Rosetta mission is now confirmed, but some aspects of this unique Earth-escape mission need still to be qualified on the ground.

Mars Express

One of the major events in the project's life cycle took place in October, namely the successful completion of the mechanical qualification of the structural model at Intespace in Toulouse (F). In the case of Mars Express, the structural model is the final flight model, except that mass dummies replace the electronics boxes and the solar arrays. All other elements of the spacecraft are already of flight quality, including the main structure and the entire propulsion system.

After successful completion of the campaign, the model was transported back to Alenia (I), where the flight-model test programme started in early November. By the end of December the harness and several flight-model sub-systems had been integrated onto the platform.

As regards the scientific payload, the sequence of Instrument Delivery Reviews started before Christmas. Their main objective is to review the completeness of all instrument activities and release them for integration on the spacecraft.

As far as the ground segment and the launch services are concerned, there has been nominal progress towards readiness for the launch of Mars Express on 23 May 2003.

SMART-1

Spacecraft

The development work has made good progress in the last months of 2001. After completion of the second phase of electrical system testing, involving the payload and most of the spacecraft equipment, including the electric-propulsion electrical models, the third phase involving the flight models has started. The development and integration of the onboard software has been completed. The system tests are now proceeding at Spacebel (B) for the data-handling part, and at Swedish Space Corporation for the application cores.

The flight-model structure has been manufactured and painted by APCO (CH) and sent for integration to Saab Ericsson Space in Linkoping (S). The spacecraft Critical Design Review was held in September and followed by a Mission Critical Design Review in November, where all of the mission elements were closely scrutinised. The current plan foresees launch-readiness by December 2002. However, a firm launch date cannot yet be committed to by Arianespace, as this is driven by the main passenger with whom SMART-1 will share the Ariane-5 ride.

Payload

The development of all six payload instruments is generally proceeding according to plan. All the electrical-model tests have been completed. The Critical Design Reviews have also been successfully held for all instruments. Three instrument flight models – AMIE, EPDP and SPEDE – have been electrically and shock tested.

Propulsion

The qualification of the new electric-propulsion engine (PPS-1350G) has been completed, but the lifetime test will run until the end of 2002. The SMART-1 thruster firing test has been successfully performed (see accompanying photo). The Power Processing Unit (PPU) flight model has been manufactured and tested by ETCA (B). All other flight-model units have also been manufactured, with the exception of the Pressure Regulation Electronics (PRE); being a new development, a PRE qualification model has been made for further testing with the SMART-1 system unit at Swedish Space Corporation.

Operations

The ground-segment preparations are proceeding according to schedule, despite some difficulties in the interface verification with the spacecraft simulator and database. The Science and Technology Operations Coordination has been established at ESTEC (NL), sharing the facilities with the Rosetta Science Operations Centre.

The SMART-1 thruster during firing tests at SNECMA (F)

The flight model of the SMART-1 PPU at ETCA (B)

Launcher

All launcher activities are on schedule. Work is also proceeding on the planning of the launch campaign in Kourou, to be conducted in parallel with that for Rosetta.

Herschel/Planck

The system-design activities for both spacecraft are progressing as expected. The first major system-design review, the System Requirements Review, was completed on 12 October with the successful conclusion of the Review Board Meeting. The results of that review and the action items that resulted from it dominated much of the subsequent system-engineering work during the remainder of the year.

The Herschel/Planck procurement activities also progressed during the last quarter. The first subcontractors were brought onboard following successful evaluation of the first batch of offers and the decisions of the Senior Procurement Board. Invitations to Tender (ITTs) and Requests for Quotation (RFQs) for the second of a total of five batches were issued and the evaluation of the offers received is nearing completion. The decisions on this second set will be taken at the end of January 2002, leading to a new round of contract negotiations with the selected contractors and a further enlargement of the Herschel/ Planck industrial team.

Regarding the procurement process, it is worth noting that, following a training programme between ESA's Contracts Department and the main contractors, Herschel/Planck is the first ESA programme for which Industry can issue procurement actions directly using the ESA EMITS computer-based system. A second major milestone has been the approval to place a contract with a Portuguese company for the supply of Documentation Control and Planning Support, making it the first contract awarded by the Herschel/Planck project to ESA's newest Member State.

The mid-term review for the large, 3.5 m-diameter Herschel silicon-carbide telescope was successfully completed at the end of November at Astrium SAS in Toulouse (F). All items being developed under this contract are progressing according to plan.

Regarding the Planck reflectors, the Agency's participation in the procurement of these items together with the Danish Space Research Institute was approved by ESA's Industrial Policy Committee (IPC) in early December, and the technical progress on this activity at Astrium GmbH is going according to plan.

With respect to the payload, the work on updating the instrument interface documents continued during the last quarter of 2001, with the aim of completing the revision process and achieving approval and signature of the documents in the near future. The development status of the instruments will be reviewed as part of the upcoming Instrument Baseline Design Review, to verify compliance with the spacecraft development programme. This Review will also formally release the start of manufacture of the first hardware development models.

The co-ordinated parts procurement for Herschel and Planck, now part of the industrial contract for spacecraft development, is running smoothly. Activities are at present centered around the parts procurement for the scientific instruments and will more and more include the parts procurement for the two spacecraft.

Artemis

Following its arrival in the parking orbit at an altitude of 31 000 km, all of Artemis's subsystems were commissioned and found to be working normally. The satellite is still in Earth-pointing mode. Its orbital period of 19 h means that it is over a given point on the equator every 5 days. This allows payload performance testing, albeit with limitations since not all frequencies are allowed to be used from the spacecraft's non-nominal position. Nevertheless, it has been demonstrated that all payload functions are available and that the communication programmes can be executed as planned, once the satellite reaches its nominal orbital position.

The two main and most complex functions are working nominally: the large inter-orbit antenna operating at Ka-band is able to follow its partner satellite in low Earth orbit in both programmed tracking and closed-loop RF tracking mode. Most spectacular has been the demonstration of the SILEX system, the inter-orbit data link operating at laser wavelengths. The SILEX terminal on SPOT-4 transmitted its image data via a laser link to Artemis, which then retransmitted the data to the Spot Image processing centre in Toulouse. Up to now, all 26 links commanded have been successfully established and maintained. The communication link's quality is almost perfect, with a bit error rate of better than 10^{-9}.

The preparation of the new software needed to support the contingency orbit raising using the spacecraft's ion thrusters took more time than expected. It was therefore not possible to start this phase in September as initially hoped. The final software was delivered by the middle of January 2002 and is now being validated using the satellite simulator at Telespazio, in Fucino (I). Nevertheless, the electrical propulsion system has been checked out and the availability of all hardware elements for the orbit-raising manoeuvre confirmed.

The orbit raising will be performed by the almost continuous firing of two ion thrusters, each delivering a thrust of just 15 milliNewton. Due to their low thrust, it will take about 200 days for Artemis to reach its final orbital position, during which less than 20 kg of xenon will be consumed. This will still leave enough gas in the tanks to support a 5 to 7 year mission. Once Artemis is on station, the xenon will be used for north-south station keeping, and chemical fuel for east-west station keeping and wheel desaturation.

Earth Observation Envelope Programme (EOEP)

Three Earth Watch elements were subscribed to at the ESA Ministerial Council in Edinburgh (UK) in November:

- The GMES services element: This element is meant to ensure a sustained European supply of EO-based information products and services derived from current and future EO missions, in line with the goals of the joint European Commission-ESA GMES initiative. This will be achieved by supporting the putting into operation of these EO-based services. In the initial phase, this element will necessarily concentrate on services derived from current missions.

- The InfoTerra/Terrasar consolidation element: InfoTerra is an initiative aimed at exploiting the requirements for geo-information services for institutional and commercial users. It is based on the exploitation of the Terrasar system, and includes satellites flying L-band and X-band SAR instruments. The consolidation phase will ensure completion of the system studies prior to the InfoTerra/Terrasar implementation. Activities related to the pre-development of the L-band SAR have been started at the end of 2001 and will provide an L-band SAR demonstrator.
- The Fuegosat consolidation element: Fuegosat is intended to be a demonstration mission for the Fuego constellation, aimed at providing early warning for and monitoring of forest fires in the Mediterranean areas and at similar latitudes in the rest of the world. The consolidation phase will prepare for Fuegosat's implementation. These activities are planned to start in 2002.

The Aladin instrument second phase (manufacturing and testing of pre-development model) was kicked off in October. The PDM development and test contract should last two years. The instrument developed will be flown on the ADM/Aeolus mission, planned for launch in 2007.

The APEX Phase-C/D proposal was not fully accepted by the Tender Evaluation Board, and so the bidder will submit an amended proposal at the beginning of 2002. To ensure optimum coordination with the EOEP-funded elements, ESA will perform the technical management of Phase-C/D.

The L-band SAR predevelopment activity has been kicked off in January 2002 with Astrium Ltd. as the main contractor. This activity is planned to last 28 months, roughly in line with the expected completion of the activities within the Earth Watch InfoTerra/Terrasar consolidation element.

In the Market Development area, the five new short-term and five new longer-term activities, selected as a result of two Invitations to Tender (ITTs) issued in May and July 2001, were started in November. All of these activities target the exploitation of the new capabilities offered by Envisat. An Earth Observation Market Development Workshop was held at ESRIN in Frascati (I) in October.

Earth Observation Preparatory Programme (EOPP)

The Earth Science Advisory Group (ESAC) has recommended three Earth Explorer Core Missions, following the Third Earth Explorer Consultation Meeting held in Granada last October:

- EarthCARE (Earth Clouds, Aerosol and Radiation Explorer), carrying a cloud radar, a lidar, an imager, a radiometer and a spectrometer, will peer closely at the interaction between clouds, aerosol and radiation to better understand their impact on climate. It is a joint ESA/NASDA mission.
- SPECTRA (Surface Processes and Ecosystem Changes Through Response Analysis), carrying a high-performance imaging spectrometer and a thermal imager, will study the relationship between vegetation and climate change, across the entire world's ecosystems.
- WALES (Water vapor and Lidar Experiment in Space), carrying a differential-absorption lidar (DIAL), will map atmospheric water-vapour concentrations. It will provide improved insights into the distribution of atmospheric water vapour and information on aerosols in the troposphere and lower stratosphere.

Following the ESAC's recommendation, the Executive submitted the Phase-A study implementation proposal to the November meeting of the Agency's Earth-Observation Programme Board (PB-EO) and secured its approval. The relevant ITTs will be issued in the first quarter of 2002.

Comments were sent to the Lead Investigators of 29 outline proposals for Earth Explorer opportunity missions received in September. As a result, 25 consolidated full proposals were subsequently received by the 8 January deadline. They will be evaluated in the coming months and the recommendations submitted to ESAC in April.

The Phase-A for SMOS has been completed. The Preliminary Requirements Review took place successfully in October. Following the results of the scientific review, ESAC recommended to proceed with the mission beyond Phase-A. The Earth-Observation Programme Board will decide on the Phase-B authorisation in January.

Meteosat Second Generation

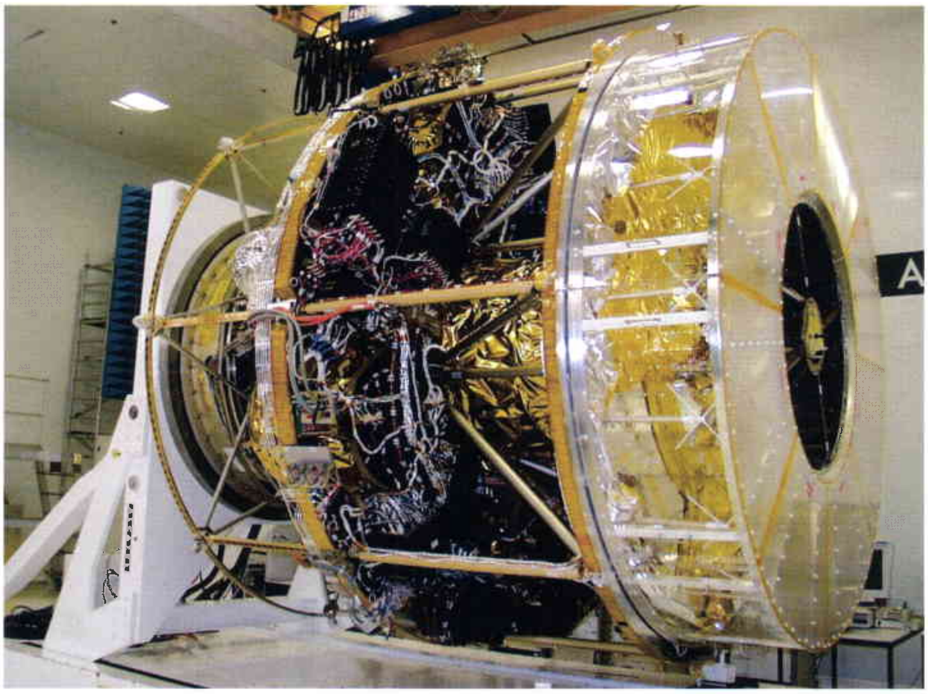
The preparation of the MSG-1 spacecraft for a July 2002 launch on an Ariane-4 launcher is proceeding on schedule. Consent to ship to the Kourou launch site in French Guiana is being sought in the March 2002 timeframe. During January 2002, System Verification Tests are being executed with the spacecraft located in Cannes (F), but monitored and commanded via telephone lines from ESOC and Eumetsat, both of which are located in Darmstadt, Germany.

MSG-2 and MSG-3 and the engineering model will remain in storage until after the MSG-1 launch.

MetOp

The satellite Critical Design Review (CDR) was successfully concluded in October 2001, and an action plan has been agreed with the MetOp Prime Contractor Astrium (Toulouse) to address the CDR Board's recommendations.

The final step in the implementation of MetOp Assembly, Integration and Verification (AIV) restructuring programme has been achieved, with the approval of the related contract proposal by Eumetsat's Council in December 2001. The space-segment integration baseline now accommodates the extended Eumetsat ground-segment development period, as well as the recently announced delivery dates for the third-party instruments. Subject to the timely delivery of the IASI instrument's proto-flight model, MetOp-2 is now earmarked as the fist MetOp satellite for launch in 2005. MetOp-1 will complete its nominal AIV programme without the IASI instrument and will go into storage in 2004. The integration of the IASI flight-model



The MSG-2 spacecraft under integration at Alcatel Space Industry in Cannes (F)

Within the framework of the Soyuz launcher activities, the Preliminary Mission Analysis Review (PMAR) has been completed with the launcher authority Starsem (F). In parallel, Astrium has completed the first phase of the satellite/launcher compatibility study.

Envisat

Throughout the fourth quarter, Arianespace was striving to understand and correct the launch anomaly that afflicted the EPS upper-stage engine on flight 510. More than two hundred tests have now been performed on two test

instrument is foreseen as part of the subsequent de-storage campaign.

Meanwhile, the Payload Module integration work at Astrium in Friedrichshafen (D) continues on the proto-flight model. Several ad-hoc adaptations of the integration sequence have allowed these activities to cope with new instrument-delivery problems.

Following the interleaving logic of the restructured AIV baseline programme, the integration of the Payload Module FM-2 model has also commenced with the installation of the flight avionics.

The IASI engineering model – comprising the instrument avionics units IMS and DPS and an IASI sensor interface simulated by EGSE – has completed testing at the premises of the instrument manufacturer Alcatel in Cannes (F), and is now on its way to Astrium in Friedrichshafen. The status of the IASI flight model's development will be subject of the instrument Critical Design Review planned to take place during the first two months of 2002.

The Delivery Review Board for the SMMS proto-flight model – representing the structural, thermal and propulsion sub-systems as well as the harness of the MetOp Service Module (SVM) – has been successfully concluded in December at Astrium (Stevenage). The further integration of the Service Module proto-flight model will take place at Astrium in Toulouse, starting with the avionics integration.

Envisat in the integration hall at Centre Spatial Guyanais (CSG) in Kourou engines, and Arianespace believes that it understands the most likely causes and has established a clear calendar for the Envisat launch campaign. The latter was resumed on 3 January 2002, leading to a launch on 28 February 2002 (Kourou time).

In the meantime, Envisat has remained in storage in Kourou. A two-week maintenance campaign was carried out starting in late October, with completely satisfactory results.

Taking full advantage of the launch delay, the ground-segment and industrial-support teams have concentrated their efforts on the Ground Segment Overall Validation (GSOV) and the training of operators. The Flight Operation Procedures within the Flight Operations Segment (FOS) are complete and have been reviewed and validated by simulations at ESOC, with support from the project team and industry. The remaining simulations have been re-phased to adapt to the launch delay.

As far as the Payload Data Segment (PDS) is concerned, efforts have been concentrated on:
- The GSOV, with all external interfaces tested, realistic operation scenarios exercised jointly by the mission planning facilities at FOS and PDS, and recently an overall data-product circulation and dissemination test.
- The training of the operation teams in Kiruna (S) and at ESRIN (I) for the early operations after instrument switch on.
- The integration of the Processing and Archiving Centres (PACs), which were initially accepted as standalone items and have subsequently been integrated successfully within the PDS.

In terms of preparation for the satellite Commissioning Phase, the Expert Support Laboratories and the Principal Investigators (PIs) have reorganised the planning of their activities to cope with the launch delay, and have been working to improve the quality and readiness of the tools to be used for the calibration and validation activities.

CryoSat

The CryoSat project has now entered in the core of its main development phase (Phase-C/D). After a detailed review of the satellite's design during November 2001, the industrial partners of the Prime Contractor, Astrium GmbH, are now preparing their manufacturing files.

Within the ground segment, development of the Payload Data Segment has also been initiated. The development of the algorithms for the processing of the scientific data (up to Level-1b) is also progressing nominally. An Announcement of Opportunity (AO) for the Calibration and Validation activities has also been issued.

GOCE

The contract for the GOCE space segment was signed at Alenia Spazio in Turin (I) on 23 November. The contract covers Phases-B/C/D/E1 of the GOCE satellite project, but only the Phase-B and advanced Phase-C/D activities have been released so far.

Good progress has been achieved in the competitive selection process involving the various equipment suppliers, although the micro-propulsion area remains problematic. On the basis of the results of the breadboard testing carried out by the various bidders and of the analyses performed at platform/system level, it has finally been decided to select the Field-Emission Electric Propulsion (FEEP) technology. However, due to lack of sufficient lifetime-test evidence, the final supplier has not yet been selected. It was concluded that specific lifetime-demonstration testing with the two FEEP suppliers was needed before making the final choice. During December, those test activities have been agreed and kicked-off with both potential suppliers.

The Gradiometer Preliminary Design Review (PDR) was carried out between mid-November and mid-December. The Board concluded that, despite the progress achieved, additional efforts had to be made before the Review could be considered successfully closed. The majority of the related actions are planned to be completed by end-January 2002.

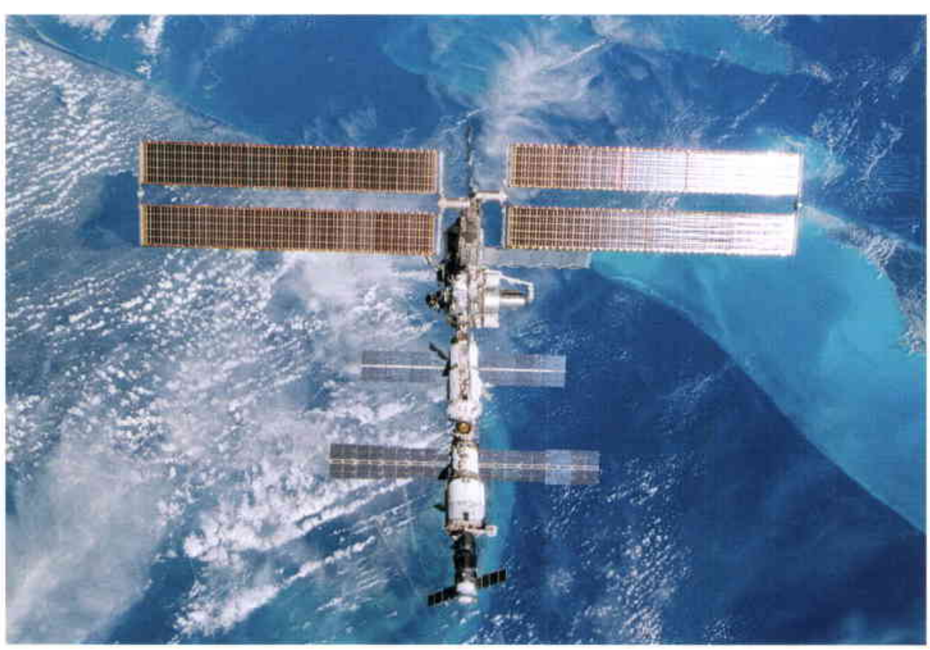
The GOCE Preliminary Design Review (PDR) is scheduled for the second half of February 2002.

The GOCE Web site has been released as a part of the new ESA Earth Explorer site under ESA's Living Planet Programme (http://www.esa.int/livingplanet/goce).

International Space Station

ISS Overall Assembly Sequence

Three assembly and logistic flights were made to the ISS during the last quarter of 2001. A Soyuz 'Taxi' Flight 3S, launched on 21 October, took ESA astronaut Claudie Haigneré to the ISS. The following Progress flight was launched on 26 November, while Assembly Flight UF1



ISS in-orbit configuration, December 2001

(STS-108) launched on 5 December was the fourth MPLM flight (uploading experiment and storage facilities) and third crew rotation, with the Expedition Four crew taking over.

Columbus Laboratory

Integration work continues. The Qualification Review for the Data-Management System (DMS) has been completed, and all flight-model hardware has been delivered and is being integrated. Qualification testing on the electrical test model is continuing.

Columbus Launch Barter

Nodes-2 and -3

Node-2 flight-unit integration is progressing, with the secondary-structure and harness deliveries required for module integration having been completed. Node-3 primary-structure manufacturing continues, and the harness and secondary-structure Critical Design Reviews (CDRs) have been completed.

Crew Refrigerator/Freezer (RFR)

The Preliminary Design Review (PDR) for the RFR has been successfully completed. Cryogenic Freezer (CRYOS) negotiations with NASA, to agree on a final configuration, have continued.

Cupola

The Cupola CDR and Safety Review-I/II have been successfully completed. Preparations for the Structural Test Article (STA) vibro-acoustic test are underway. It will be the last qualification test on this unit prior to its delivery to NASA in March 2003.

Automated Transfer Vehicle (ATV)

The contract rider has been signed and the ESA/NASA Segment Specification, reflecting the Preliminary Design Review (PDR) results as agreed with NASA, has been finalised and signed by ESA. All elements of the structural/thermal model (STM) have been delivered to ESTEC and assembled, and the acoustic test – the first in a series of environmental tests – was performed successfully in December. The spacecraft electrical test model (ETM) integration is progressing, but the propulsion-subsystem schedule is being impacted by additional Ariane-5 tests that are occupying the same test facility.

X-38/CRV and Applied Re-entry Technology (ART)

A further drop test with the V131R vehicle was successfully completed in December 2001. Work is continuing in industry for the delivery of the European contributions to the X-38 vehicle, and a contract amendment has been signed allowing further industrial activities. The US Congress has approved a $40 million budget line for X-38 continuation in 2002, and NASA has tentatively re-scheduled the X-38 flight to 2005.

Ground-segment development and operations preparation

The submission and evaluation of the Columbus Control Centre subsystem proposals is continuing and should be completed by end-March 2002. Implementation is proceeding incrementally to avoid schedule delays. The Request for

The Automated Transfer Vehicle (ATV) structural/thermal model at ESTEC, in Noordwijk (NL)

The X-38 parafoil descent, December 2001

Claudie Haigneré on board the ISS, October 2001

Quotation (RFQ) for the ATV Control Centre has been released.

The ATV-CC Operations Preparation Definition Phase has been kicked off with CNES. The offer for the equivalent contract with DLR has been received and is being evaluated.

Utilisation

Preparation

A significant number of the Microgravity Applications Promotion (MAP) projects have successfully passed their mid-term reviews. Of the 44 projects selected, 39 had been fully initiated by end-2001 and a further four are foreseen to start early in 2002.

Payloads and their integration

The industrial proposal for the main development phase (Phase-C/D) of the Atomic Clock Ensemble in Space (ACES) has been received, but it indicated a considerably higher cost than expected for part of the industrial work, and negotiations with industry are continuing. The earliest launch date for ACES now appears to be February 2006. For other external payloads, i.e. Solar, Export and EuTEF (European Technology Exposure Facility), the Phase-C/D activities have been running according to plan. Preparations for design (Phase-A) studies of two space-science instruments (Lobster and EUSO) that could also use the Space Station have been in progress. The Phase-A accommodation study for a commercial Earth-observation instrument (RapidEye) was completed. The PDR for the Matroshka radiation-measurement facility baselined for the Russian segment of the ISS was completed. The unit is planned for flight in 2003.

Analytical integration of the Microgravity Facilities for Columbus (MFC) – Biolab, Fluid-Science Laboratory and the European Physiology Modules – and for the European Drawer Rack (EDR) has continued. The Requirements and Design Definition Phase for the User Support and Operations Centres (USOC) is also in progress, with completion planned early in 2002. The schedule and budgetary planning for USOC implementation has been initiated.

Astronaut activities

The French/Russian Andromède mission with ESA astronaut Claudie Haigneré onboard as Soyuz Flight Engineer was successfully launched on 21 October. The Soyuz vehicle docked with the ISS on 23 October, and then returned safely to land in Kazakhstan on 31 October.

ESA astronaut R. Vittori has continued his training in Star City for a Soyuz Taxi Flight to the ISS in April 2002. F. de Winne, who will fly on a later mission, joined him in training. They have successfully completed the first round of examinations on Soyuz systems.

ESA astronauts R. Vittori and F. de Winne in training for flight in a Soyuz vehicle

The second period of ISS Advanced Training at Johnson Space Center (NASA/JSC) was successfully concluded on 16 November. The Advanced Training continued at NASDA on 12 December, with one week of training for each of the participating ESA astronauts - P. Nespoli, P. Duque, L. Eyharts and T. Reiter - and one NASDA colleague. The first ISS Advanced Training session at the European Astronaut Centre (EAC) is in preparation and will take place in July 2002.

Astronaut A. Kuipers has continued with the complementary Basic Training courses during his stay in Star City.

The mechanical configuration of the Columbus Trainer for EAC has been delivered and was installed in December.

Early deliveries

Data Management System for the Russian Service Module (DMS-R)
The DMS-R is continuing to be problem-free in operation. The accumulated run time in orbit (24 h per day) reached 18 months at the end of December.

European Robotic Arm (ERA)
The ERA flight-model functional qualification testing at the prime contractor Fokker (NL) is continuing. The pre-flight Mission Preparation and Training Equipment (MPTE) has been accepted by ESA.

The ERA launch date, which is also heavily influenced by the current US budgetary situation, is still open. A credible schedule is not now expected before late-2002.

Laboratory Support Equipment (LSE)
The Microgravity Science Glovebox (MSG) verification testing at Kennedy Space Center (KSC) has continued to be problem-free. The use of MSG for ESA's experiments is under discussion with NASA, as is the possible location of the ground model in Europe (at ESTEC) to support preparations and initial training for European experiments to be carried-out on upcoming Taxi Flights.

The verification test campaign for Flight Unit 1 (FU1) of MELFI (-80 degC Freezer) has continued. The Final Safety Review was successfully completed in November, and the FU1 launch is now scheduled for January 2003.

The qualification test campaign on the Hexapod linear actuator started in November.

ISS Exploitation Programme
All five International Partners have agreed the text of the multi-lateral ISS guidelines document for commercial ISS use. Formal programme approval is planned for early 2002.

Although approval of the Commercialisation Programme Proposal by the ESA Ministerial Council was postponed in November, activities are continuing to define and implement pathfinder projects, and to safeguard the proposed industrial contribution under the co-operation agreement. A first commercial experiment has been agreed with ASI to fly on the upcoming Italian Taxi Flight mission.

Due to NASA's budgetary problems and to changes in the content of the Programme Proposal for Exploitation Continuation, the ESA RFQ sent out earlier was no longer fully valid. Following the approval of the Exploitation Continuation for Period 1 by the Ministerial Council meeting in Edinburgh in November 2001, ESA will update the RFQ and industry will submit a binding offer in April 2002.

The Exploitation Programme Continuation and in particular the Period 1 funding were approved in Edinburgh, but with 60% of that funding blocked until October 2002, contingent on the US reconfirming its commitment to the implementation of the Inter-Governmental Agreement (IGA). The available funding is sufficient to start the time-critical procurement of spare parts, the ATV production programme, as well as maintenance and sustaining-engineering activities.

Microgravity

The Microgravity Programme Board has approved the experiments selected from the Physical Sciences 2001 Announcement of Opportunity (AO), the ESA payload for the April 2002 Taxi Flight, and the replacement of the Maser-10 sounding-rocket flight by the more powerful Maxus-6 within the EMIR-2 Extension Programme. The related Maxus-6 experiments were also approved.

Preparation of the ESA microgravity research facilities for flight on the STS-107 Space Shuttle mission has continued. This mission is now scheduled for June 2002 and the six ESA facilities for this flight are currently in various stages of readiness. Similar preparations have been continuing for the flight of ESA facilities (Fluidpac, Biopan and Stone) on the Russian Foton-M1 recoverable-capsule mission, which is now scheduled for launch in October 2002. The flight of the Maser-9 sounding-rocket mission originally planned for November 2001 has been postponed to March 2002. The 31st parabolic-flight campaign took place successfully in October, with 10 experiments including two student experiments being conducted.

As the flight of the R-2 Spacehab mission, which would have represented a major new flight opportunity for ESA payloads, has become increasingly less likely, alternative flight opportunities are being sought.

The development within the EMIR programmes of facilities for use on the ISS has continued. These include the European Modular Cultivation System (EMCS), the Expose facility for exobiology research, the Mares facility for muscle research, and the PCDF facility for protein-crystallisation research.

The Advanced Protein Crystallisation Facility (APCF), which had been flying on the ISS since August 2001, was returned to ground in December and analysis of the results has started. APCF was ESA's first microgravity facility to fly on the ISS, enabling 108 days of protein crystal growth.

The Granada protein-crystallisation box, which had been flying on the Space Station and which was recently returned to Earth on a Russian Taxi Flight, has been opened and the crystallised proteins removed for analysis.

Microgravity Facilities for Columbus (MFC)
Within the Microgravity Facilities for Columbus (MFC) Programme, the various experimental facilities are well into their development. The Biolab engineering model has been accepted, the Science Reference Model Critical Design Review (CDR) has been concluded, and flight-model subsystem procurement/manufacturing is proceeding well. For the Fluid Science Laboratory (FSL), the

engineering-model integration tests on all subsystems have been completed, with the exception of the facility core element, and the FSL baseline CDR has been closed-out. For the Materials Science Laboratory (MSL) in the US Lab, the Solidification and Quench Furnace (SQF) CDR was successfully concluded and the engineering-model system testing preparation is almost complete. The contract for Phase-B of the Electromagnetic Levitation Furnace in MSL has been signed. For the European Physiology Modules (EPM), the CDR was in preparation. For the EPM contribution to HRF-2, the flight model was delivered to NASA at the end of November and integration initiated in its HRF-2 facility.

PROBA

Following launch on 22 October 2001, the in-orbit commissioning of the spacecraft platform lasted until early January. It has confirmed that all of PROBA's subsystems are performing as intended.

The commissioning team, composed of ESA and Verhaert engineers, is now busy with the validation of the payload and the most advanced autonomous onboard functions. All of the instruments (SREM, DEBIE and CHRIS) have already been switched to acquisition mode and have returned excellent data, which are now being analysed by the scientists.
PROBA is currently being operated from its dedicated ground station and control centre at ESA's Redu station in Belgium, with additional support from the Kiruna (S) station. However, extension of the ground segment with the installation of a second identical ground station at Kiruna or Svalbard has been initiated. This will greatly enhance the imaging capability for the Earth-observation community exploiting data from the CHRIS instrument.

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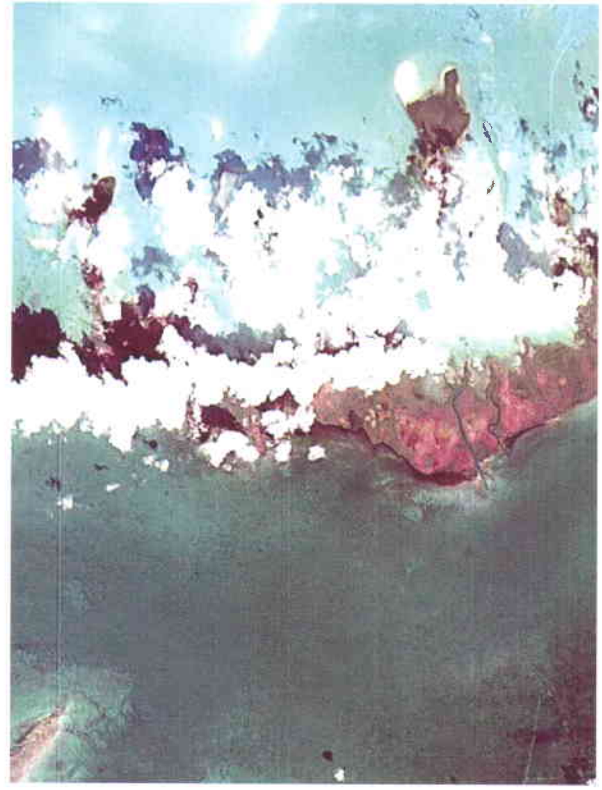


Image of the coast of Cuba reconstructed from data in three spectral bands acquired with PROBA's CHRIS instrument

In Brief

Focus on Foton

The ISS User Information Centre at ESTEC has a new exhibit: a Foton science capsule. Marked by the fires of its 2500-degree reentry – if visitors stand close enough, they can still smell the scorched heat-shield – the small Russian spacecraft is the descent module from the Foton-12 mission, launched in September 1999.

Foton craft have been flying since the mid-1980s, carrying anything up to 650 kg of scientific experiments into an orbit around the Earth. This means around two weeks of excellent weightlessness conditions. At launch, Foton weighs roughly 6.5 tonnes and consists of three modules: a battery module, a service module, and the descent module with the scientific payload. A Soyuz booster from Plesetsk near Archangel launches the craft; once its mission is completed, the descent module lands near the border between Russia and Kazakhstan and its contents are usually available to researchers within a few hours.

ESA has been a Foton partner since 1987 – long enough to develop an excellent working relationship between the agency and the Russian manufacturers and launch teams. The Foton programme gives researchers the opportunity for relatively low-cost work in weightlessness for much longer durations than with sounding rockets and a faster turn-around than they could expect with long-term experiments aboard the International Space Station.

ESA Technical Officer Antonio Verga has worked with Foton for years. "It's very good value for money. Foton carries a multi-disciplinary payload – anything from biological experiments to fluid physics and technology testing. Since the spacecraft is unmanned, logistics are greatly simplified and safety concerns are minimised."

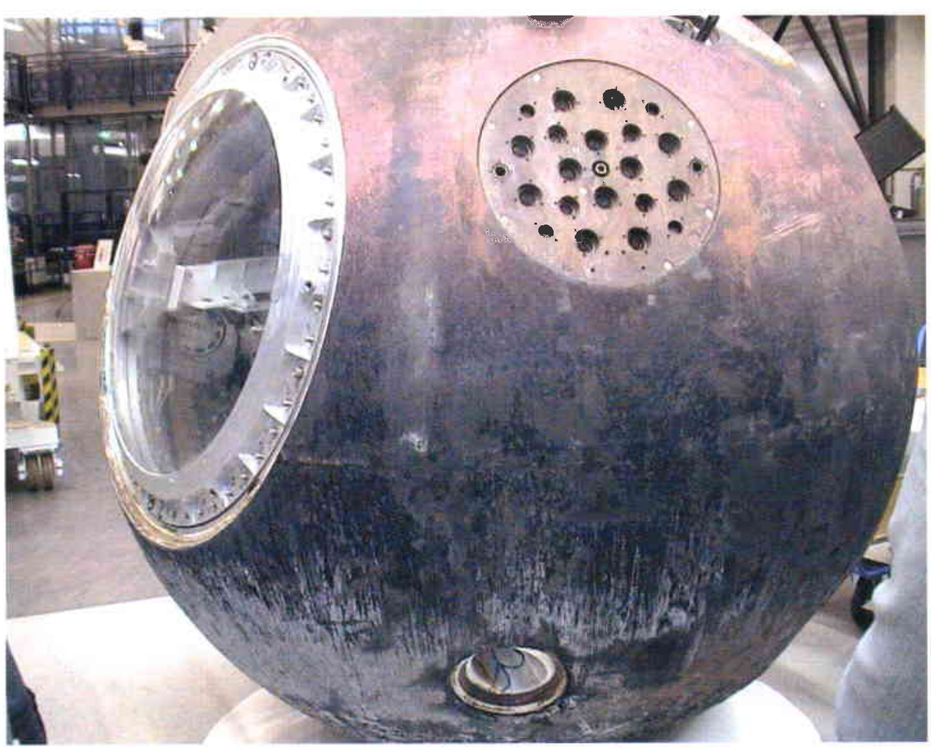
Foton is about opportunity. "It's not a museum piece," says Verga. "It's there to show visitors what is possible." Foton-12, its experiments long since removed, is not quite an empty shell. "You can still see some of its major characteristics: the external vacuum venting line, the power supply interface and the parachute compartment, for example." Verga hopes that visitors to the User Information Centre will see it as a potential platform for their ideas for experiments. The next Foton mission – Foton M-1 – is scheduled for October 2002, and will include experiments designed by student groups from York, Edinburgh and Zurich.

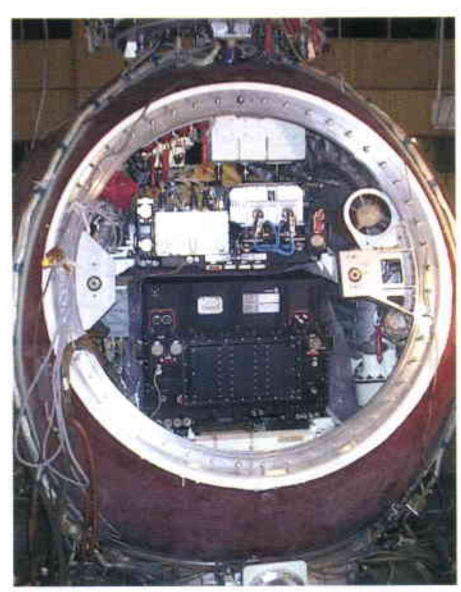
Focus on Foton Seminar

The Foton group is organising a "Focus on Foton Seminar" at the User Information Centre on Wednesday 20 March.
The seminar for scientists and non-scientists covers facts on Foton as a 0g-research platform, programmatic highlights and testimonials by past scientific users.

For more details on the seminar and registration forms contact Antonio Verga (ext. (+31) 71 565 3098) or Pietro Baglioni (ext. (+31) 71 565 3856).

The Foton capsule in the ISS User Information Centre





Fluidpac on Foton

When Time is Critical: Charter Website to Assist Rescue Operations

On 16 January, the members of the International Charter on Space and Major Disasters launched a new website that will assist rescue teams dealing with severe disasters. It will enable satellite planners to accelerate the immediate tasking of space-based resources, including ESA's ERS, CNES's SPOT, Canada's Radarsat-1 and soon selected Indian and US satellites, to acquire new images in order to assist humanitarian help.

The International Charter was set up in the framework of the UNISPACE III conference of the UN in 1999 and has been in force since 1 November 2000. It aims to put space technology at the service of rescue authorities in the event of major disasters. To date the Charter has been activated to deal with floods, landslides, volcanic eruptions, oil spills and earthquakes in all corners of the globe. For example, it provided important assistance to rescue operations following a series of earthquakes in El Salvador in 2001.

Current members of the Charter are the Canadian Space Agency (CSA), the French Space Agency (CNES), the Indian Space Research Organisation (ISRO), the US National Oceanic and Atmospheric Administration (NOAA) and the European Space Agency.

The new website offers information about updates in procedures, disasters covered and links to non-governmental organisations, civil protection agencies, international organisations involved in disaster mitigation and humanitarian assistance, and the individual partner agencies. For more information, check on *http://www.disasterscharter.org*

Jérôme Béquignon, ESA member of the International Charter's Executive Secretariat, commented *"this website is an important step forward in promoting the Charter and the results obtained and in assisting rescue teams during real emergencies"*.

esa

New Director for Earth Observation Programmes

José Achache
(photo: CNES/E. Martin 2000)

On 1 January 2002 José Achache took up his duties as ESA's Director of Earth Observation Programmes for a period of four years. The ESA Council had made this appointment at its restricted session on 20 December.

José Achache, 48, obtained his doctorate in geophysics at the Pierre et Marie Curie University in 1979 and his doctorate in physical sciences at the René Descartes University in 1984. He joined the Institut de Physique du Globe de Paris (IPGP) in 1978 and was a Visiting Scholar at Stanford University for one year. In 1989 he was appointed Professor, created the Department of Space Studies at the IPGP, and from 1989 to 1995 he was Director of the Post-Graduate School of Earth Sciences.

In 1996 he joined the Bureau de Recherches Géologiques et Minières as Deputy Director of the Research Division and the following year became its Director. In 1999, he was named advisor to the President of the French Space Agency (CNES) and in 2000 was appointed to the post of Deputy Director General for Science.

José Achache has published more than 60 refereed papers on such subjects as geodynamics, plate tectonics, the magnetic fields and environments of the Earth and other planets, natural hazards, Earth observation and space technology.

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18 November 2001: The Leonids Have Been Back!

The Leonids are small dust particles that enter the Earth's upper atmosphere with a very high velocity of about 71 km/s, burn up and appear in the night sky as shooting stars. They are visible every year in November when the Earth passes through or close to the debris cloud of comet Tempel-Tuttle. They are called "Leonid" events because the meteors seem to be coming from the direction of the constellation Leo. There is evidence that this comet has created meteor showers and meteor storms for more than 1,000 years. Tempel-Tuttle, named after Ernst Tempel and Horace Tuttle who first discovered the comet in 1865 and 1866, has a nucleus about 4 km in diameter and orbits the Sun with a period of just over 33 years. At its closest approach to the Sun, it also passes close to the Earth's orbit. The Earth passed through that same region in space on 18 November 2001 and Leonid observers saw an increase in the amount of cometary debris.

The 2001 Leonid meteor storm

The intensity of the Leonids is usually measured in zenithal hourly rate (ZHR). The ZHR indicates how many meteors per hour would be visible if the observed shower were to come from the direction of the zenith under optimum observing conditions (no moon, no clouds). The limit of visibility is at 100 micrograms per dust particle that travel at 71 km/s, which is equivalent to a magnitude of 6.5 or a diameter of about 0.5 mm. The 1999 Leonids were a virtual storm with an hourly rate above 1000, but in 2000 they took it a bit easier with a maximum ZHR of about 500. Still, scientists awaited the arrival of the Leonids in 2001 on 18 November with great suspense. Predictions by Asher/McNaught and other scientists suggested two peaks, the first one around 10 UT and a second larger one at about 18:15 UT with possibly 8000 meteors per hour.

The best place to observe the first peak was North-West America. For the later second peak Australia was a favourable location. ESOC participated in an observation campaign organised by Peter Jenniskens from NASA Ames Research Center. The campaign consisted of two groups: one climbing Mount Lemmon in

-4 mag Leonid, 2001 Nov 18, 19h22m26s, (c) ESA/RSSD

Arizona equipped with cameras to film the first peak, the second group waiting in Alice Springs, Australia for the big storm.

The first data arriving from Mount Lemmon showed that at 10:00 UT the ZHR had passed 500 and increased continuously until about 11:00 UT when the computed ZHR peaked at about 2500. Within a few minutes it dropped back to below 500. The first peak was about 1 hour later than expected but quite spectacular. ESOC then had to wait about 3 hours until the constellation Leo rose above the horizon of Alice Springs. The first data from there indicated that Leo was prepared to roar again with a ZHR of 500 and continuously increasing. Around 18:00 UT the activity reached its maximum ZHR of about 2000 and for more than one hour 20 shooting stars dashed through the sky every minute!

Prudent spacecraft operations at ESOC

The curve of the meteor rate was displayed on the ESOC web-page. It was the only website where people all around the world could follow the Leonid peak in real-time if they were not lucky enough to be under a clear night sky with the constellation Leo above the horizon. Many journalists and amateur astronomers were among the 18000 hits on the web-site, but the spacecraft operators at ESOC were also keeping a close eye on the activity level of the Leonids. They were worried about the physical integrity of their spacecraft: ERS-2, XMM, the 4 Cluster spacecraft, Marecs B2 and ECS-4 are under ESOC control, but also SOHO and the Hubble Space Telescope were under threat of getting hit by a tiny meteoroid.

The ERS-2 payload, for example, was switched off in the evening hours of the day before the predicted peaks to minimise the risk that an impact of a meteoroid could permanently impair the electronics of the spacecraft due to plasma generated by the collision. Additionally, the thrusters and gyros were warmed up, the spacecraft was switched to Fine Pointing Mode (a more robust flight mode), the solar array was placed in an automatic Sun re-acquisition mode, the payload heater thresholds were lowered and the on-board memory and the power system were continuously checked.

At 21:32 UT the Kiruna ground station received telemetry from ERS-2 indicating that the satellite was healthy. In the following hours it became clear that the other ESA spacecraft had also survived the Leonids unscathed. This year, if the predictions are as reliable as last year, there will be the last Leonid storm for many decades to come. For this storm Europe will be the place to be! esa

More Space for Space

Minister Jorritsma-Lebbink and the ESA Director General on a tour through the new buildings.

Three new buildings at ESTEC in Noordwijk (NL) give more space for satellites under test, more storage space for workshop equipment and – of course – more working space for engineers and scientists in offices. The three buildings were officially opened on 16 January by the Dutch Minister for Economic Affairs and Deputy Prime Minister, Mrs A. Jorritsma-Lebbink, with ESA's Director General Antonio Rodotà and ESTEC's Director Gaele Winters also present.

The most important of the new buildings is an extension to the satellite test facilities, which are already among the largest and most advanced in the world. The new satellite integration hall provides an additional 19-metre high clean room and several preparation rooms. This means that three large satellites can now be tested at the same time.

The other new buildings are somewhat more conventional. Even so, they are much needed. These buildings will, in part, replace temporary offices that have been in use for many years and will provide a new workshop with office space and a new wing for ESTEC's main building to accommodate the ESA engineers and scientists. esa

Automated Transfer Vehicle Test Model at ESTEC

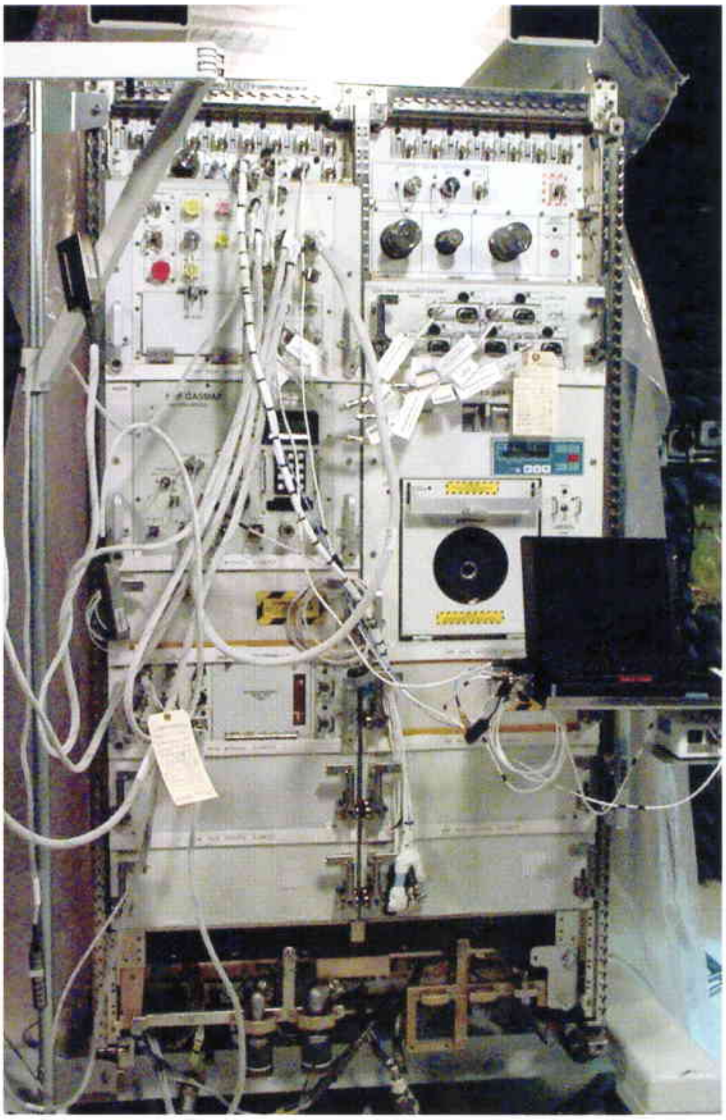
The Automated Transfer Vehicle (ATV), has successfully started its 11-month test programme at ESTEC in Noordwijk (NL). The first successful test of the full-size model in the Large European Acoustic Facility (LEAF) was to simulate with acoustic vibrations the stress the ATV will encounter during the first three minutes of launch on top of the powerful European Ariane-5 launcher. Detailed computer analysis of the test data acquired during the acoustic tests will continue in parallel with the post-test inspection and reconfiguration of the ATV for the next tests. Until next October, the ATV mock-up will undergo a series of mechanical and critical thermal tests, including solar-array deployment.

The 20-tonne cylindrical cargo-ship financed by ESA has been designed to periodically service and re-supply the ISS with up to 7500 kg of cargo, starting in Autumn 2004. About once a year a new ATV will fly unmanned and automatically dock with the ISS. The ATV can remain docked for up to six months before being loaded with waste and then disposed of in a destructive re-entry.

The ATV is sharing the ESTEC Test Facilities with two other ESA spacecraft: Rosetta and Integral are also being tested in Noordwijk before they are launched. esa

Transfer of the ATV to the LEAF facility

First Flight Hardware Delivery for the ESA Pulmonary Function System (PFS)



The PFS (top left) integrated in the NASA Human Research Facility

ESA has delivered a science module, the Pulmonary Function System (PFS), to NASA for use on board the International Space Station (ISS). It forms part of the Microgravity Facilities for the Columbus programme and the co-operation between ESA and NASA in the field of human physiology research.

The PFS forms part of the European Physiology Modules (EPM) facility and was originally planned to be launched in the Columbus Laboratory. However, in view of the high NASA interest, ESA was offered an earlier flight opportunity as part of the NASA Human Research Facility (HRF-2) to be launched on ULF-1 in November 2002 and installed in the US Destiny Laboratory.

The PFS is designed to determine the concentration of the different components of a respirated gas mixture (oxygen, carbon dioxide, etc.) by using photo-acoustic methods. The gases for inhalation are supplied by the Gas Distribution System in the NASA HRF facility. The PFS analyser system is a low-power consumption system that can detect gases contained in the breath of the test subject with great sensitivity.

These specific features of the PFS offer exciting possibilities, both with regard to research opportunities on board the ISS and also for clinical medicine on Earth.

The flight model has been delivered to the Johnson Space Center for integration in the HRF-2 Laboratory. Following completion of the testing programme, the HRF-2 will be shipped to the Kennedy Space Center for launch.

The PFS was built by the Danish company INNOVISION S/A and is a fourth-generation ESA development, with the first two generations already launched in 1993 and 1995, and the third planned for flight in mid-2002. INNOVISION S/A, a high-tech company specialised in the field of biomedical engineering, has played a key role in each of these developments. They have also used the expertise gained from each space hardware development to develop and market a corresponding ground-based instrument.

The commercial instrument derived by INNOVISION S/A from the PFS is called INNOCOR. The main purpose of this instrument is to non-invasively measure cardiac output in patients with cardiovascular diseases. In many cases the INNOCOR replaces a potentially dangerous invasive method, which involves insertion of a catheter into the patient's heart. INNOCOR was recently approved for CE marking and is thus ready for sale in all EU countries. The potential market for INNOCOR is estimated at several million Euros, as it is intended for use with patients with such common diseases as heart complaints and hypertension. esa

Transponder for ATV Arrives at Astrium

An important step in the development of the communications systems for ESA's Automated Transfer Vehicle (ATV) was achieved at the end of December, with the successful delivery of the electrical qualification model (EQM) Transponder to Astrium SAS by Alcatel Espacio. This TDRSS-compatible transponder will handle communication with the TTC ground stations via the NASA Tracking and Data Relay Satellite System (TDRSS).

When work on the EQM is completed, Alcatel Espacio will deliver the flight units for each ATV mission to the International Space Station. It is estimated that there will be one such mission per year, with a first mission planned by 2004. esa

Sophisticated Thermometer

A special device will allow monitoring of the temperatures in the MELFI payload on board the International Space Station (ISS). MELFI, the "Minus Eighty Degrees Laboratory Freezer for the ISS" will provide cooling and storage capabilities for scientific experiments at three different temperatures (4, -26 and -80°C). In order to confirm that MELFI is meeting the requirements in orbit, a team at ESTEC has developed, built and tested MOOCE – the MELFI ON-Orbit Commissioning Experiment.

MOOCE consists of two parts – one inside one of the four MELFI trays and a laptop-based data-acquisition unit on the outside.

The connection between the two parts is provided by wires going through the MELFI door, which caused some initial problems and hardware restrictions. In order to give a complete temperature map of the tray and the samples, special Multiplexers operating at -80°C are used to read out the 21 temperature sensors.

Another restriction for MOOCE was that it should minimise the additional work for the astronauts. A specific temperature measuring scheme has been developed and tested, and almost all sensors are mounted on the tray or the sample holders themselves, minimising the need for the astronauts to place temperature sensors directly on the samples after insertion. The device has been successfully tested at ESTEC with a temperature measurement accuracy better than 0.5°C. As a next step, MOOCE will be integrated into a flight model of MELFI for a final performance and qualification tests to verify compliance with the strict requirements for ISS payloads. esa

All About Space Weather: Alpbach Summer School 2002

If you want to learn more about space weather, Alpach in Austria is the place to be. This year's Alpach Summer School from 23 July to 1 August has the theme "Space Weather: Physics, Impacts and Predictions".

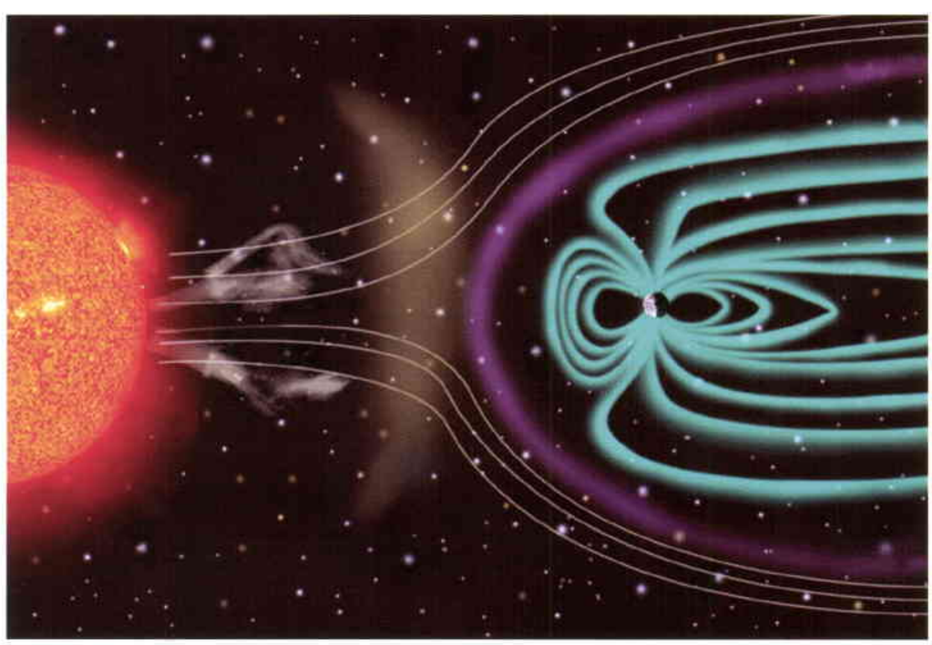
The school has a long history. Started in 1975, it takes place every year and addresses different subjects of space research. The aim of the Summer School is to offer advanced training and working experience to European graduates and post-graduate students as well as young scientists and engineers on subjects that are not usually part of the academic curricula. The Summer School is co-organised by the Austrian Federal Ministry of Transport, Innovation and Technology and the Austrian Space Agency (ASA) and co-sponsored by ESA and the national space authorities of its Member States. The Summer School is also supported by the Government of Tyrol.

There will be lectures on the basics of space plasma physics and more detailed ones addressing the impact of space weather events ('space storms') on the technical infrastructure in space and on the Earth's surface. Students will also be provided with information on the scientific instruments and data sets that are most important for space weather applications and will be introduced to the engineering tools that are used for designing space missions. Last but not least, the students will learn about new numerical techniques that are used in space weather predictions. Participants can deepen their knowledge in workshops, in which case-studies or representative space projects are conducted. The lecturers are renowned scientists and experts in the field, from universities and space-related agencies.

The application deadline for the Summer School is 29 March. Detailed information can be found at *http://www.asaspace.at*

Two competing teams will each deal with three topics. The workshop teams will be guided by experts, who will act as tutors for the workshops. The lecturers will also participate in the workshops, providing assistance in the definition of the mission to be designed. The results of each workshop team will be presented by the students on the last day of the Summer School to a review panel.

An accompanying social programme will provide students, lecturers and tutors with a convivial atmosphere for informal discussions. esa



First Image Transmitted by means of an Optic Laser between Artemis and Spot-4

On 30 November 2001, the first-ever transmission of an image by laser link from one satellite to another took place. The system used, called SILEX, consists of the Opale terminal on Artemis and the Pastel terminal on the Spot-4 satellite. It was designed in close cooperation between ESA, the French space agency (CNES) and manufacturer Astrium with over 20 European contractors involved. The terminals exchange high-definition imagery data at 50 megabits per second. Artemis subsequently beams the data to the receiving station operated by Spot Image at Toulouse, using a conventional 20 GHz radio link.

The potential of the new technology extends beyond Earth observation; it promises to revolutionise sat-to-sat communications for constellations in low-earth orbit, geostationary satellites and deep-space exploration probes.

Further information was provided in ESA Bulletin 108, page 114.

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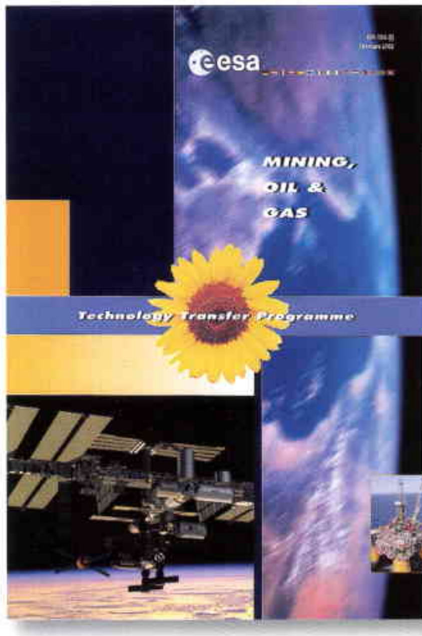

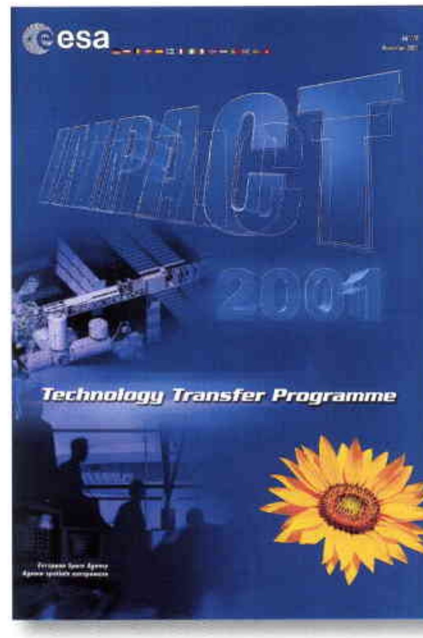

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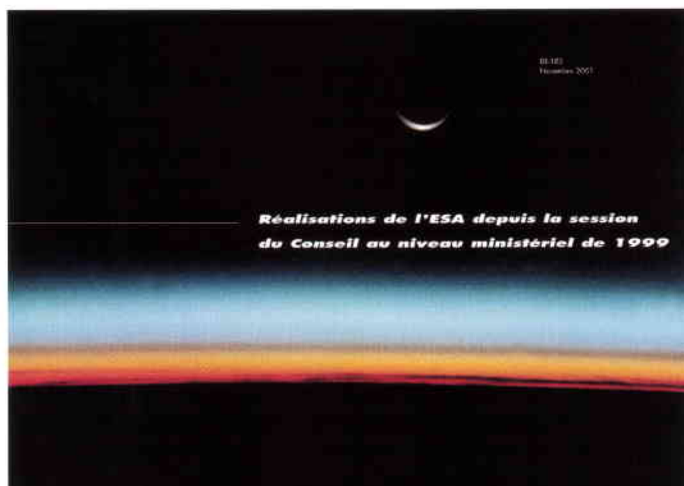

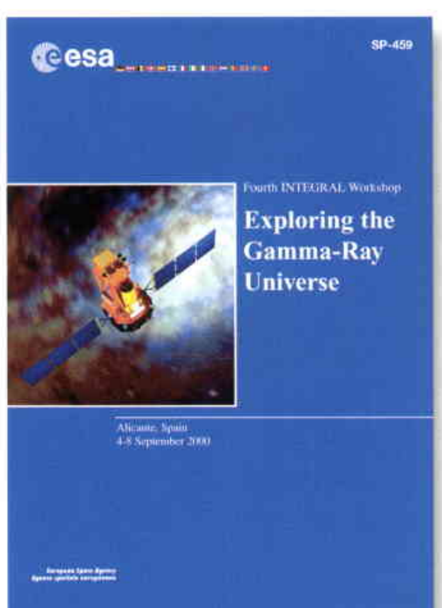

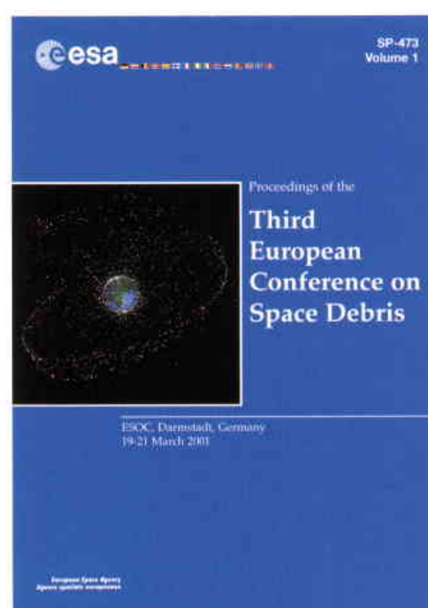

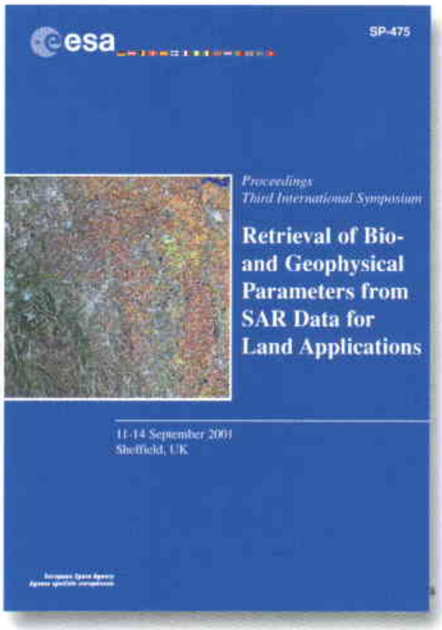

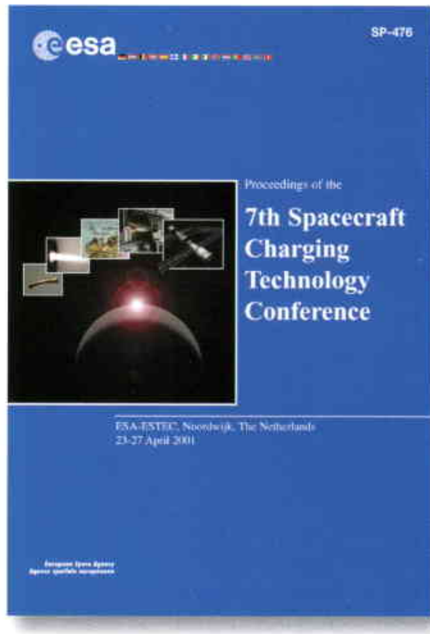

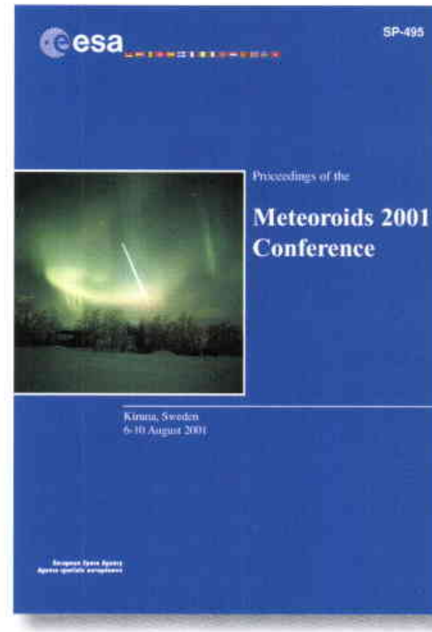

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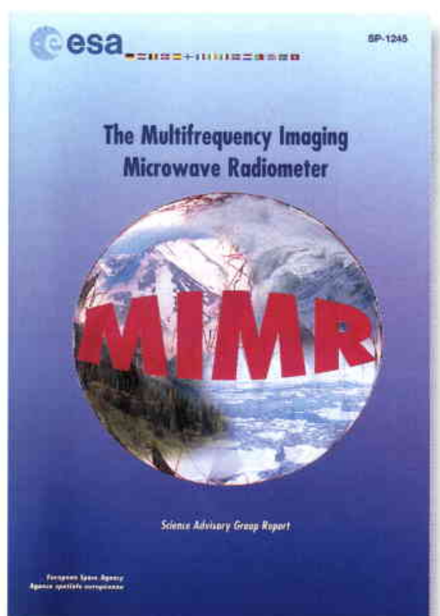

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"La Vie Commence dans l'Espace"

Pierre Brisson & Frederic Loeb

La conquête spatiale est un rêve et en tant que tel,personne ne saurait se l'approprier.
L'essence même du rêve tient dans son existence: on le réalise mais on ne le possède point!
Les auteurs s'attachent dans cet ouvrage à répondre aux multiples interrogations suscitées par la conquête spatiale, nouvelle dimension infinie de liberté et de paix, mais également à l'exploitation d'un espace utile, composante stratégique de notre futur.
Comment vivre ailleurs que sur notre fragile planète, à échéance de vingt ou trente ans?
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Innovative Technologies from Science Fiction for Space Applications

By D. Raitt, P. Gyger & A. Woods

The idea that perhaps science-fiction (SF) literature contained innovative technological ideas that could possibly be brought to the point of development with either today's technology or technology that is just around the corner was the driving force behind a recent European Space Agency (ESA) study entitled "Innovative Technologies from Science Fiction" (ITSF).

The main objectives of the study were to review the past and present science-fiction literature, artwork and films in order to identify and assess innovative technologies and concepts described therein which could possibly be developed further for space applications. In addition, it was hoped to garner imaginative ideas, potentially viable for long-term development by the European space sector, which could help in predicting the course of future space technologies and their impact.

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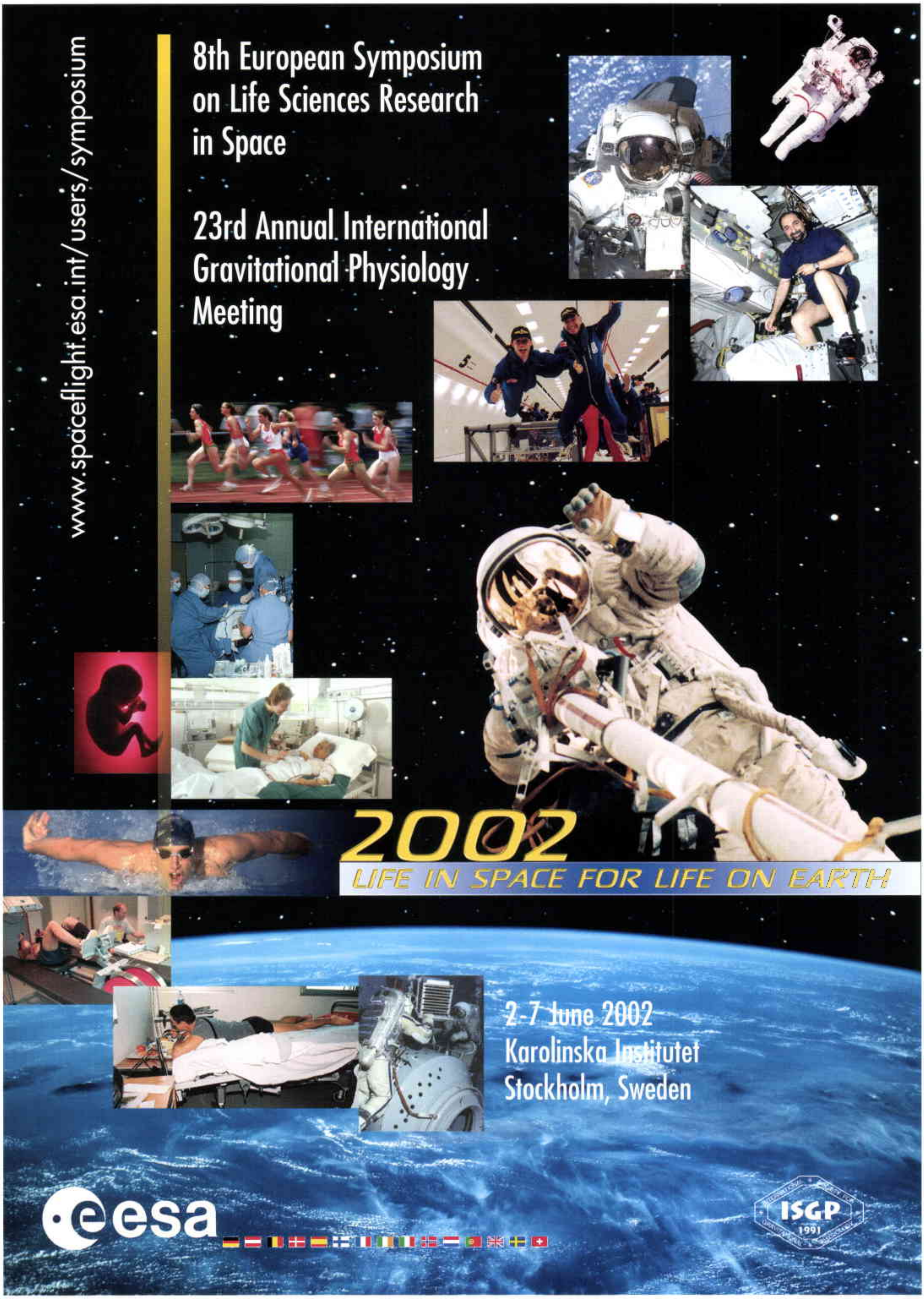

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