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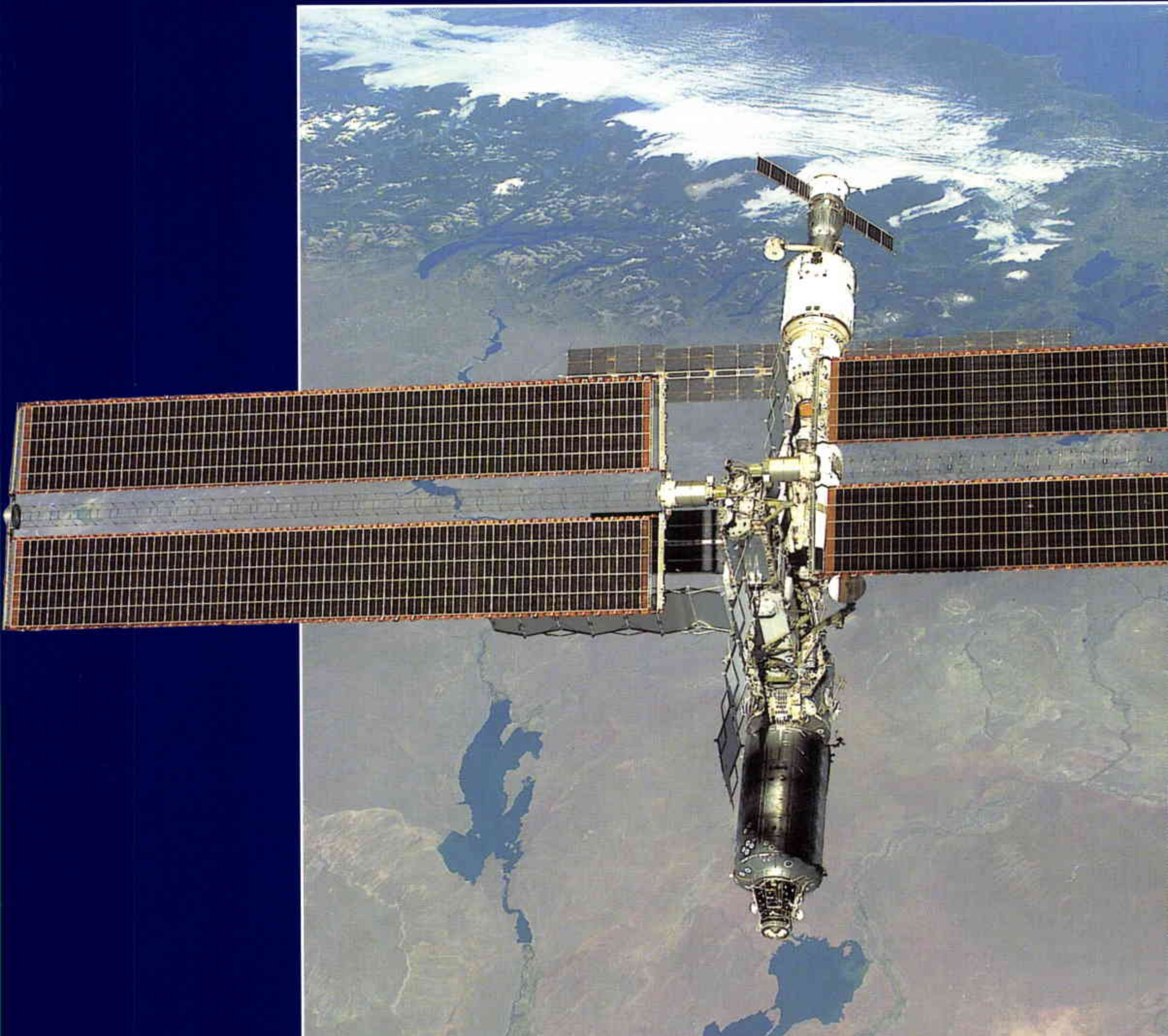
number 105 - february 2001



European Space Agency
Agence spatiale européenne

european space agency

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agence spatiale européenne

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Cover: The International Space Station photographed over Argentina from Space Shuttle 'Atlantis'. The Shuttle was departing on 16 February after delivering the Station's first research module 'Destiny' (bottom).

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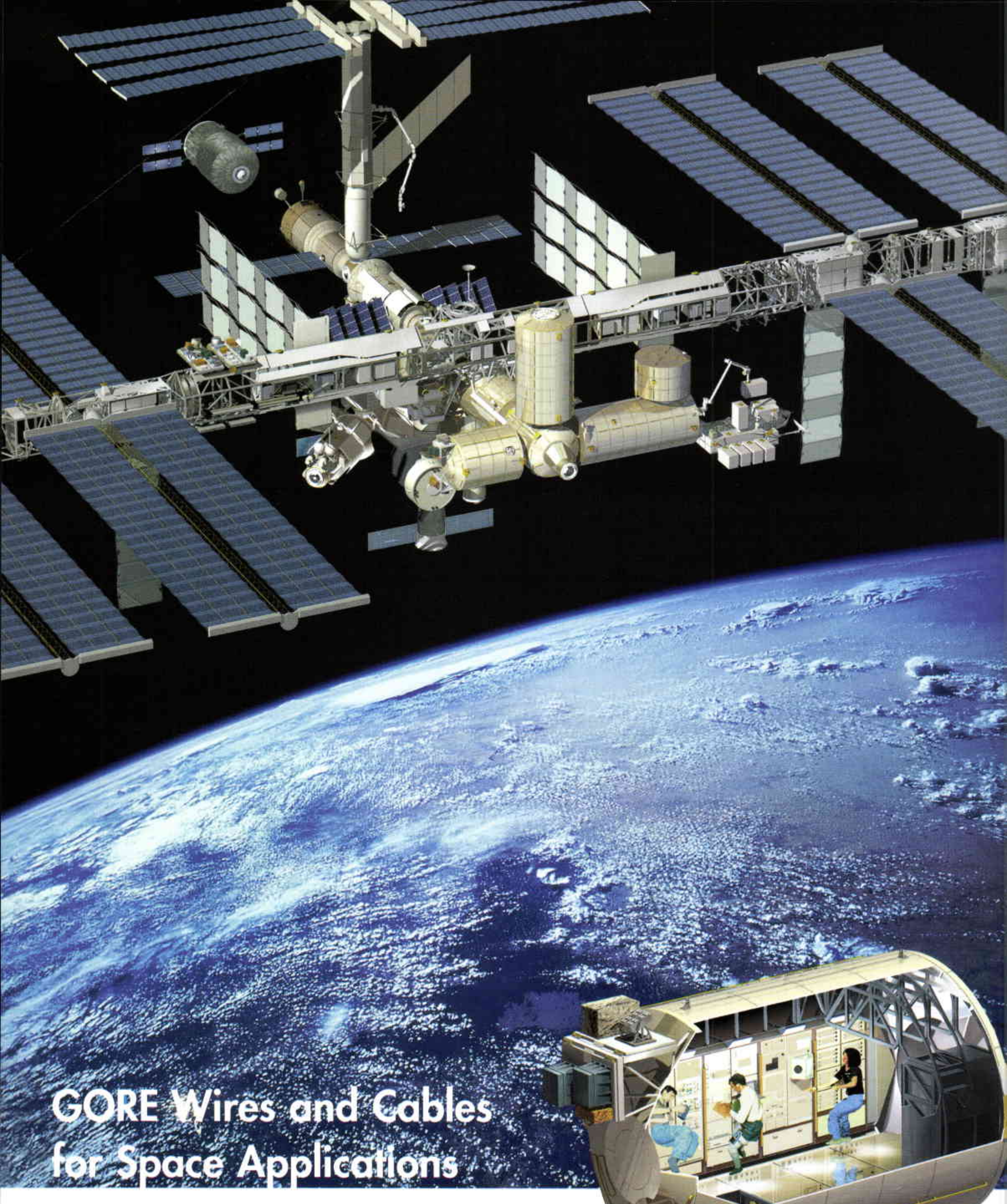
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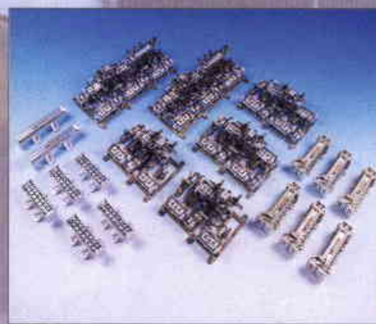

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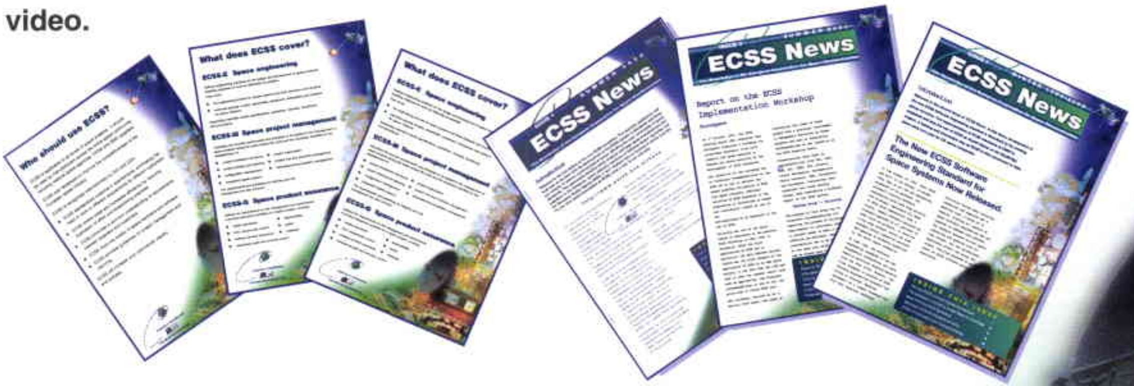

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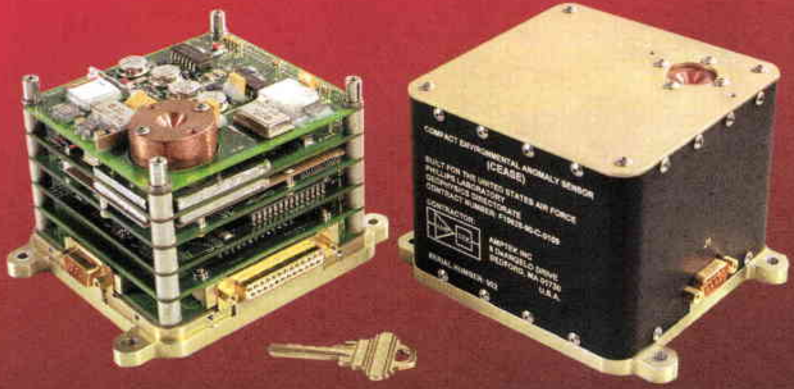

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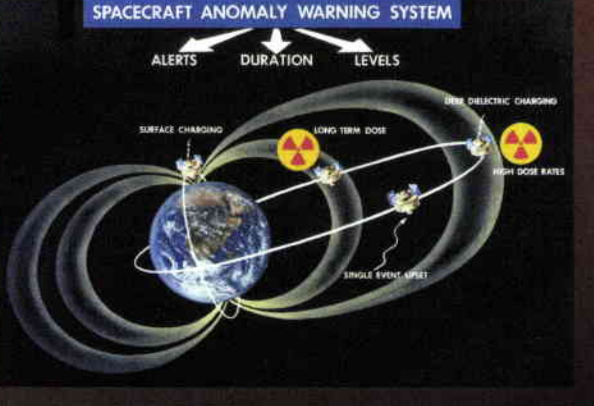

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AATSR: Global-Change and Surface-Temperature Measurements from Envisat

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The Advanced Along-Track Scanning Radiometer (AATSR) onboard ESA's Envisat spacecraft is designed to meet the challenging task of monitoring and detecting climate change. It builds on the success of its predecessor instruments on the ERS-1 and ERS-2 satellites, and will lead to a 15+ year record of precise and accurate global Sea-Surface Temperature (SST) measurements, thereby making a valuable contribution to the long-term climate record.

The exceptionally high radiometric accuracy and stability of AATSR data are achieved through a number of unique features. A comprehensive pre-launch calibration programme, combined with continuous in-flight calibration, ensures that the data are continually corrected for sensor drift and degradation. A further innovative feature providing substantial advantages over traditional nadir-viewing instruments is the use of a 'dual-view' technique offering improved atmospheric correction. The accuracies achieved with this configuration are further enhanced by using low-noise infrared detectors, cooled to their optimum operating temperature by a pair of Stirling-cycle coolers.

With its high-accuracy, high-quality imagery and channels in the visible, near-infrared and thermal wavelengths, AATSR data will support many applications in addition to oceanographic and climate research, including a wide range of land-surface, cryosphere and atmospheric studies.

Introduction

The monitoring and detection of global climate change is one of the great challenges for modern satellite observing systems. The Advanced Along-Track Scanning Radiometer (AATSR) is one of the Announcement of Opportunity (AO) instruments on ESA's Envisat platform due for launch in mid-2001. It is funded jointly by the UK Department of the Environment, Transport and the Regions (DETR), the Australian Department of Industry, Science and Resources (DISR), and the UK Natural Environment Research Council (NERC) and is the most recent in a series of instruments designed and developed to measure SST to the high levels of accuracy (better than 0.3K ±1 sigma limit) and precision required for monitoring climatic trends and for research into climate prediction.

The AATSR follows ATSR-1, launched on ESA's ERS-1 satellite in July 1991 and ATSR-2, launched on ERS-2 in April 1995. Together, this family of instruments will establish a unique fifteen-year record of global Sea-Surface Temperature (SST) at a level of accuracy previously unprecedented in this field.

As an imaging spectrometer, the (A)ATSR system builds on the multi-channel approach to SST retrieval developed from the NOAA Advanced Very-High-Resolution Radiometer (AVHRR) missions, but offers considerable advantages over other sensors in the form of the unique sensitivity and stability of its calibration. This is achieved through the use of several innovative features, including:

- An along-track scanning technique that provides observations of the same point on the Earth's surface from two different viewing angles, for improved atmospheric correction.
- Continuous onboard calibration of the thermal channels against two stable, high-accuracy black-body calibration targets.
- An onboard visible calibration system for the visible and near-infrared channels (first introduced on ATSR-2).
- Low-noise infrared detectors, cooled by a pair of Stirling-cycle coolers.
- A rigorous pre-launch calibration programme.

As with ATSR-1 and ATSR-2, AATSR has been designed primarily to provide data for the monitoring and investigation of global warming and climate change. However, it will also offer valuable data for a wide range of other applications in the fields of oceanography, land-surface studies and atmospheric science.

Heritage

The (A)ATSR series of instruments have shown a gradual progression from research tool to operational observing system. All of the instruments have a common heritage, although certain aspects of instrument design have evolved as more data bandwidth, mass and power have become available from the host satellite.

ATSR-1 was an experimental scientific instrument, developed by a consortium of research institutes in the UK and Australia. It offered three thermal and one near-infrared channel, and was aimed specifically at oceanographic and climatological research. ATSR-1 had a design life of two years, but was still capable of providing accurate SST measurements when the ERS-1 platform ceased to function in early March 2000.

ATSR-2 had similar specifications to ATSR-1, but was enhanced to include three visible and near-infrared channels, plus associated on-board calibration system, to extend the mission objectives to include land applications. The possibility of combining the data from these wavelengths with the original thermal channels also offered new opportunities for innovative studies of clouds and atmospheric particulates. ATSR-2 is still operational as of November 2000.

AATSR will provide continuity of the dataset established by ATSR-1 and ATSR-2. It will offer the same combination of visible, near-infrared and thermal channels as ATSR-2, with the added advantage that the improved data rates available on Envisat will provide global coverage at the highest (12-bit) digital resolution for all channels.

The ERS-1 and ERS-2 tandem mission in the period between the launch of ATSR-2 and the end of ATSR-1 operations provided valuable data for the cross-calibration of the two instruments. An overlap period between ERS-2 and Envisat will offer similar opportunities for cross-calibration.

Mission objectives

Global SST is a key geophysical parameter required for climate research and work in this field requires accurate long-term measurements of SST, to allow the detection of very small changes (typically 0.3 K) over large geographic scales.

The primary use for (A)ATSR data will be as input to climate models, with the overall objective of identifying and quantifying human influences on global climate change. The data will be particularly valuable for studying phenomena such as the El Niño Southern Oscillation, in monitoring global warming due to the greenhouse effect, and in the investigation of ocean–atmosphere heat transfer. The particular advantage offered by the (A)ATSR data set is the continuous provision of global, self-consistent SST measurements. Measurements from buoys and ships of opportunity provide similar surface observations, but can be sparsely distributed and are prone to measurement inconsistencies. The 'bulk' temperature measurements they provide can also differ by several tenths of a degree from the true 'skin' temperature. With the addition of the visible channels, the mission objectives have also been extended to include additional scientific goals in the areas of vegetation monitoring and cloud and aerosol studies.

The main objectives of the AATSR mission can be summarised as follows:

- To extend the precise, high-accuracy data set of global SST started by ATSR-1, and continued with ATSR-2.
- To provide high-quality images of Top-Of-the-Atmosphere (TOA) Brightness Temperature (BT), at 1 km resolution, covering all parts of the globe except the polar caps.
- To enable scientific studies of ocean dynamics, land-surface properties, and the properties of clouds to be carried out through the use of these data.

Scientific requirements

SST

Due to the very high level of accuracy and precision necessary for global climate-change detection and measurement, the AATSR instrument and ground processing system are required to produce SST retrievals routinely with an absolute accuracy of better than 0.3 K, globally, both for a single sample and when averaged over areas of 0.5° longitude by 0.5° latitude, under certain cloud-free conditions (i.e. >20% cloud-free samples within each area).

For a warming trend of 0.25 K per decade and an SST data set spanning at least 10 – 15 years, a stability of 0.1 K per decade is needed to be able to detect the change with any confidence. To be of maximum use in climate research, the AATSR SST data must therefore be quality-assessed and validated with ground measurements, both during instrument commissioning and on a routine basis, to prevent undetected instrument drift or changing atmospheric conditions from obscuring any climate drift.

These high-level scientific requirements give rise to a number of more detailed requirements dictating instrument design.

Primary sensing wavelengths
AATSR has thermal-infrared channels at 3.7, 11 and 12 micron. SST is calculated using the 11 and 12 micron channels during the day, and the 11, 12 and 3.7 micron channels during the night.

The ocean surface emits infrared radiation; the peak of the emission signal is at around 10 micron. The spectral region between 10 and 13 micron is a suitable window with both low atmospheric absorption and good radiance sensitivity to small changes in SST. The AATSR 11 and 12 micron channels were chosen to exploit these conditions. The 3.7 micron channel was selected to provide an additional channel at night. Measurements in the 3–5 micron window are affected by reflected solar radiation during the day, but show very high radiometric sensitivity at night.

Atmospheric correction
Atmospheric correction of remotely sensed upwelling radiances is a subject of great importance. Given the overall global SST accuracy requirement, it is important to account precisely for the contribution of atmospheric absorption and emission to the upwelling radiances.

It is recognised from work with AVHRR data that measurements of upwelling radiances in two thermal channels will allow an accurate assessment of atmospheric effects, as the two channels will be affected differently by the atmospheric effects. Consequently, AATSR provides corrections for the effects of the atmosphere on the SST retrievals through the use of multiple thermal channels in the retrieval. However, the strict demands placed on the accuracy of AATSR SST retrievals require further improvements to atmospheric correction. These can be made by making two observations of the same ocean surface through different atmospheric path lengths. As a result, AATSR employs a novel 'dual-view' technique to achieve the best possible atmospheric correction.

Cloud clearing
The key to meeting the overall SST accuracy requirements is effective cloud clearing. This can be achieved with reference to a visible channel during the daytime (when cloud will be bright compared to the sea surface) or at night by looking for large differences between different channel combinations, or in the properties of, and relationships between, measured Brightness Temperatures (BT's) expected for clear conditions. AATSR has a visible channel at 1.6 micron which is used primarily for cloud clearing. On ATSR-1 and -2, this was the only visible channel available, both day and night. For AATSR, any of the visible channels could be used, but the 1.6 micron channel is particularly good for phase discrimination between ice and water clouds.

Sampling distance and Instantaneous Field of View (IFOV)
The overall SST accuracy requirement has been set on the basis that 20% of samples need to be cloud-free over a 0.5° by 0.5° cell. For adequate noise reduction through averaging of individual sample values, a minimum of 500 samples should be cloud-free. In the limiting scenario of 80% cloud cover, this requires a total of 2500 samples, which for a 50 km x 50 km cell gives a sample size of 1 km. The AATSR sampling distance has therefore been set at 1 km at nadir. Research with previous sensors has also shown that 1 km is a reasonable compromise between data volume and spatial resolution for SST feature mapping. In terms of land applications, a 1 km sampling distance is good for mapping and monitoring on large scales, whilst providing adequate discrimination of land-surface types. To allow the cloud-clearing algorithms to work successfully at the edges of cloud masses, co-alignment of the AATSR channel IFOVs is also required to 0.1 of the sampling distance.

Calibration and characterisation requirements
To retrieve SST from the AATSR detector signals, the spectral response and IFOV of the channels need to be measured prior to launch. In order to meet the strict accuracy requirements, a pre-launch end-to-end radiometric calibration of the instrument has to be performed. In-orbit radiometric calibration will also play an important part in ensuring the long-term stability of AATSR SST measurements over the mission lifetime. To achieve this, the instrument carries two high-precision black-body targets, each of which is viewed during every scan to provide accurate in-orbit calibration of the thermal channels.

Land and atmospheric research
Work using Landsat and AVHRR data has shown the value of global monitoring of land, especially vegetation, at moderate resolution (i.e. ~1 to 4 km) and using certain combinations of bands. AATSR has three visible/near-infrared channels at 0.55, 0.67 and 0.87 micron, designed specifically for remote-sensing applications over land. However, an important instrument design requirement was that these channels be added in such a way as to avoid

compromising the primary SST measurement requirements. Whilst not originally designed for this purpose, the AATSR thermal channels complement these visible channels and have proved useful for land-based studies in such domains as improved global monitoring of burning vegetation and retrieval of Land Surface Temperature (LST).

In order to cope with all possible normal variations in brightness over the Earth's surface without saturation whilst maximising the precision of the measurements, the gain and offset of the visible channels are selectable in flight. These channels have a signal-to-noise ratio of 20:1 at 0.5% spectral albedo and measure top-of-the-atmosphere radiances to an absolute accuracy of 5% over the entire range.

The AATSR reflection channels also undergo a pre-launch calibration, including IFOV and spectral-response measurements. Nevertheless, for long-term monitoring of land parameters, it is important to have confidence in the stability of the sensing system. Thus, an in-orbit calibration system for the visible channels is also included.

The AATSR instrument

The AATSR Flight Model (FM) instrument is shown in Figure 1. Figure 2 shows the instrument with the main features highlighted. In operation, infrared and visible radiation is reflected from a scan mirror mounted on the scan mechanism, onto a paraboloid mirror. The beam is then focused and reflected into the infrared and visible Focal-Plane Assemblies (FPAs), where detectors convert the radiant energy into electrical signals. The low-level signals from the FPA are then amplified by a signal pre-amplifier, before being digitised and passed on to other systems on the satellite to transmit them back to the Earth.

The AATSR instrument consists of the following discrete items represented in the functional block diagram in Figure 3:

- The instrument itself, known as the Infrared-Visible Radiometer.
- The Instrument Electronics Unit, providing the signal channel processing function, the scan-mirror drive control and temperature-sensor conditioning. The Black-Body

Figure 1. The AATSR flight-model instrument

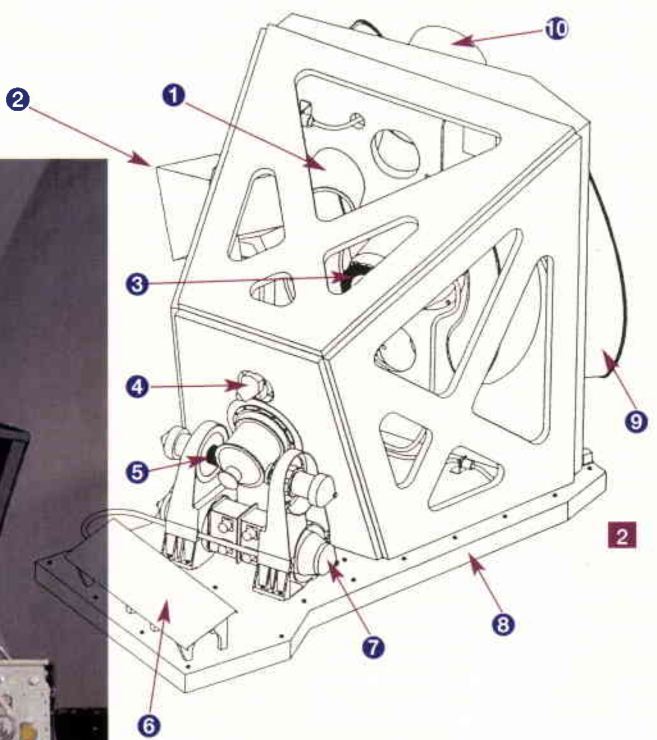

Figure 2. Main features of the AATSR instrument

Figure 3. AATSR functional block diagram

Figure 4. AATSR viewing geometry

Figure 5. Operation of the AATSR inclined-plane scan mirror to achieve two views of the Earth's surface

Electronics Unit is mounted on top, and provides the control of the black-body heaters and collects temperature-sensor data.
- The Cooler Control Unit, which provides the control function for the Stirling-cycle coolers.
- The Digital Electronics Unit (DEU) for instrument control and data-formatting functions.
- The Instrument Harness, which electrically connects the above items.

Spectral characteristics

The spectral channels offered by AATSR are summarised in Table 1. The selection of the thermal channels has been optimised to minimise the effect of the atmosphere on the observations. Their wavelengths are similar to those of AVHRR, which has provided operational values of SST, albeit at somewhat lower levels of accuracy, for nearly 30 years. However, unlike AVHRR, the AATSR thermal channels are supplemented by a channel at a wavelength of 1.6 micron, which was introduced for daytime cloud identification, but which also has the potential for water-ice discrimination in cloud fields.

Table 1. ATSR-2 and AATSR spectral channels (the first three channels listed were not present in ATSR-1)

Channel	Centre Wavelength	Bandwidth	Primary Application
0.55 µm	0.555 µm	20 nm	Chlorophyll
0.66 µm	0.659 µm	20 nm	Vegetation Index
0.87 µm	0.865 µm	20 nm	Vegetation Index
1.6 µm	1.61 µm	0.3 µm	Cloud Clearing
3.7 µm	3.70 µm	0.3 µm	SST
11 µm	10.85µm	1.0 µm	SST
12 µm	12.00 µm	1.0 µm	SST

Along-track scanning

The (A)ATSR instruments are unique in their use of along-track scanning to offer a dual view of the Earth's surface. The AATSR viewing geometry is shown in Figure 4. The dual view is achieved by rotating an inclined-plane scan mirror in front of a reflecting telescope, thus performing a conical scan of the instrument IFOV (Fig. 5). The resulting conical scan is arranged to view downwards and ahead in the along-track direction, allowing each point on the Earth's surface to be viewed in turn, first at an angle of 55° (the forward view) and then at

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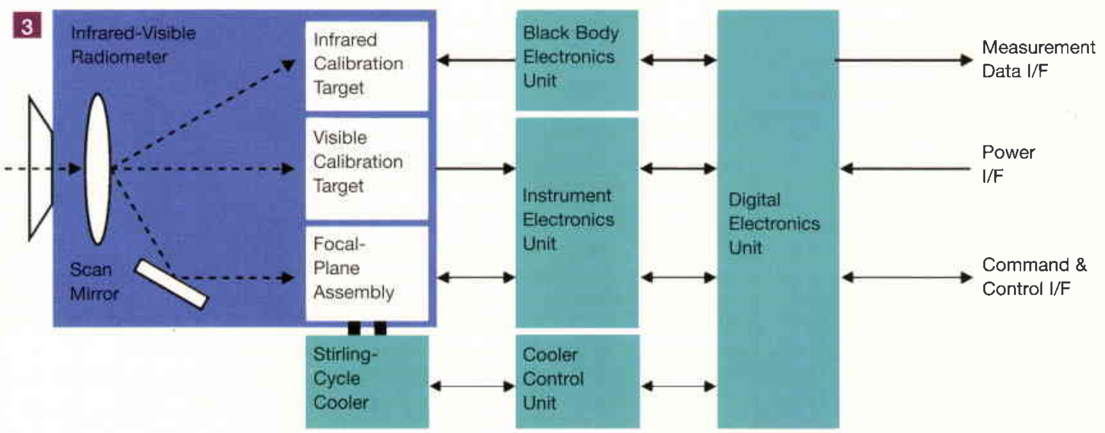

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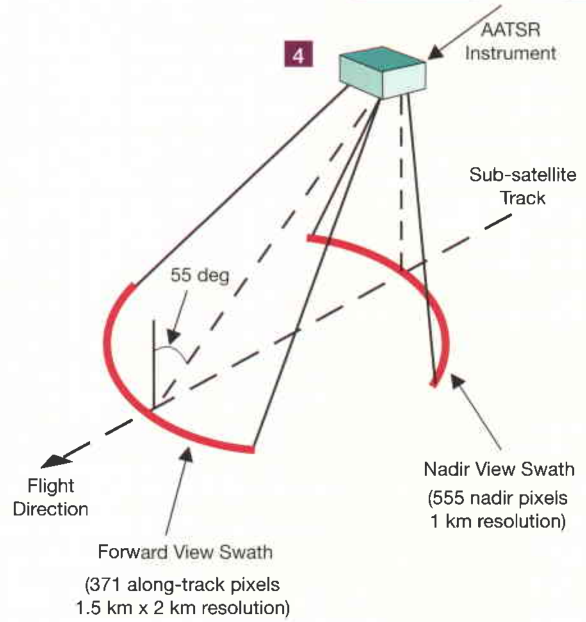

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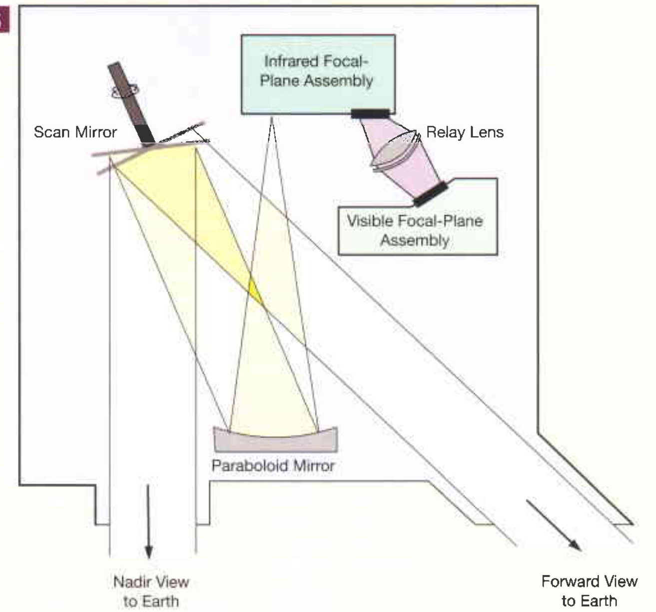


an angle close to vertical (the nadir view) as the satellite moves forward. These observations are separated in time by 150 sec, or approximately 1000 km on the ground, at the sub-satellite point.

The field of view comprises two 500 km-wide curved swaths, with 555 pixels across the nadir swath and 371 pixels across the forward swath. The nominal IFOV (pixel) size is 1 km^2 at the centre of the nadir swath and 1.5 km^2 at the centre of the forward swath. The scan cycle is repeated 6.6 times per second, and the sub-satellite point on the Earth's surface moves forward by 1 km (i.e. one pixel) during each scan cycle.

Coolers

Another unique feature of the (A)ATSR design is the use of closed-cycle mechanical coolers to maintain the thermal environment necessary for optimal operation of the infrared detectors. The FPA for the thermal- infrared wavelength region is cooled to about 80 K, whilst the other is maintained at ambient temperature. ATSR-1 was the first environmental sensor to carry such a cooler into space, and AATSR will include a commercial version of the cooler provided by the Prime Contractor, Astrium Ltd. (UK).

On-board calibration

The AATSR scan cycle allows the detectors to view a sequence of five elements, as shown in Figure 6. These are the along-track Earth view, a hot black-body target, the visible calibration unit, the nadir Earth view, and a cold black-body target. The two black-body calibration targets observed between the Earth-views are critical to the radiometric quality of the AATSR thermal data. These black bodies use a design concept specially developed for ATSR-1 and are basically cylindrical cavities with non-reflecting interior coatings, good insulation and a temperature monitoring system designed for high accuracy, high precision and low drift. The targets are designed to achieve exceptional stability and uniformity and are located in a thermal environment in which they provide extremely stable radiometer reference sources.

One black body is maintained at a temperature of about 305 K, just above the maximum temperature expected to be observed over marine scenes. The other is unheated and floats at a temperature close to the ambient temperature of the instrument enclosure (~256 K), just below the expected range of marine scene temperatures. The two black bodies therefore span the full range of expected SSTs. As a result, AATSR can be regarded as a near-ideal radiometer. The infrared calibration is applied automatically during the ground processing, so that users are provided with fully calibrated BTs or SSTs.

For the visible and near-infrared channels, a different calibration philosophy is adopted. Here AATSR employs a visible calibration system whereby once per orbit, as the satellite approaches sunrise, a brief view of the Sun is obtained, through a special aperture in the instrument. This illuminates a diffusing plate made of Russian opal tile, from which the scattered light enters the detector field of view at a suitable point in the scan cycle. Calibration of the visible channels will be performed automatically for AATSR, during ground processing. This is an improvement over ATSR-2, for which visible calibration coefficients were provided to users off-line.

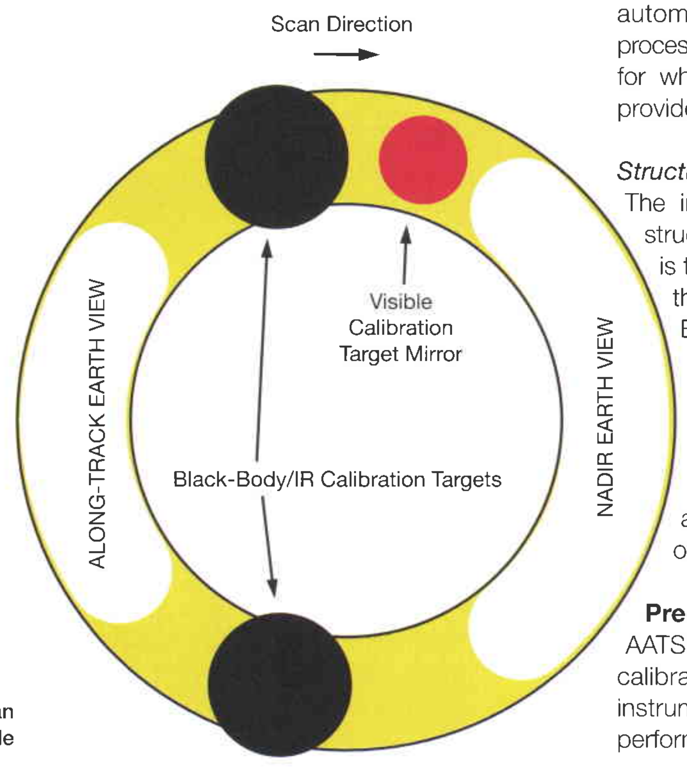


Figure 6. The AATSR scan cycle

Structure

The instrument is housed in a carbon-fibre structure and most of the instrument volume is taken up by the empty space required by the conical scanning geometry. The two Earth views, at different incidence angles, are defined by two large curved apertures in the Earth-facing side of the instrument. These are shielded by large baffles (Fig. 1), which prevent the entry of direct sunlight into the optical enclosure and are the most prominently visible parts of the instrument.

Pre-launch calibration

AATSR has undergone a rigorous pre-launch calibration programme to characterise the instrument and ensure that the very strict performance criteria are met. The calibration of the 12, 11 and 3.7 micron channels was verified using high-accuracy external black bodies, the characterisation of which can be traced back to international standards. Measurements were taken over a range of target temperatures from 210 to 315 K and corrections derived for detector non-linearity. Overall, the AATSR BTs were found to be within 30 mK of the target temperatures. The AATSR visible channels have also undergone a detailed laboratory calibration, to ensure that all instrument performance requirements are met.

Operations

Unlike ATSR-2, AATSR does not have special limited-sampling modes, which were necessary owing to data-rate restrictions on ERS-2. When in operation, data from all of AATSR's channels will be available all of the time at full 12-bit digitisation. The only routine interruption to the data flow will occur when the cooled detectors are warmed up to ambient temperature to remove any condensation that may have been deposited at low temperatures (a process known as outgassing). Calibration of the thermal channels is not affected by this condensation, as the view of the black bodies is subject to the same phenomenon, and so the effect is calibrated out.

Outgassing periods last about two days and occur at intervals of approximately three months. Information about such outgassing events is made available to users in advance. No useful thermal-channel data are collected during these periods. The operation of the visible and near-infrared detectors is unaffected by this warming, although consideration should be given to the accuracy of their calibration during this time.

Products and algorithms

Data from the Envisat low-bit-rate instruments, of which AATSR is one, will be acquired globally on a continuous basis and will be stored on-board for subsequent transmission to the ground. This will take place once per orbit, when the satellite is within range of selected ESA ground stations. Near Real Time (NRT) products will be generated at Payload Data-Handling Stations (PDHSs) co-located within the acquisition stations. The same data will also be sent to a dedicated Processing and Archiving Centre (PAC) for the archiving, processing and delivery of off-line products. The NRT processing will be exactly the same as the off-line processing, except for the quality of the auxiliary data files used.

The suite of AATSR products is summarised in Table 2. As for all Envisat instruments, the interface for browsing and ordering these products will be via the PDS User Service Facility (USF), accessible via the World Wide Web.

After reception on the ground, the stream of raw instrument source packets is converted into a Level-0 product. This consists of a chronological sequence of records, each containing a single instrument source packet, with each source packet representing one instrument scan. Associated header and quality information are also added to the product at this stage. From Level-0, the data processing is split into two further distinct steps, leading to the generation of first Level-1b (calibrated, geolocated radiances) and then Level-2 (single-pass geophysical quantities) products. It is these higher level products that will routinely be available to users.

Table 2. Summary of AATSR data products

Product ID	Name	Description	Approx. Size (Mbyte/orbit)
ATS_NL__0P	Level-0 Product	- Instrument source-packet data	490
ATS_TOA_1P	GBTR	- Full-resolution top of atmosphere BT/reflectance for all channels and both views - Product-quality data, geolocation data, solar angles and visible calibration coefficients	729
ATS_NR__2P	GST	- Full-resolution nadir-only and dual-view SST over sea - Full-resolution 11 µm BT and Normalised Difference Vegetation Index (NDVI) over land - Product-quality data, geolocation data and solar angles	126
ATS_AR__2P	AST	- Spatially averaged ocean, land and cloud parameters - Spatially averaged top-of-atmosphere BT/reflectance	63
ATS_MET_2P	Meteo. Product	- SST and averaged BT for all clear sea pixels, 10 arcmin cell, for meteo. users	5
ATS_AST_BP	Browse Product	- Three-band colour-composite browse image derived from Level-1b product, 4 km x 4 km sampling	4

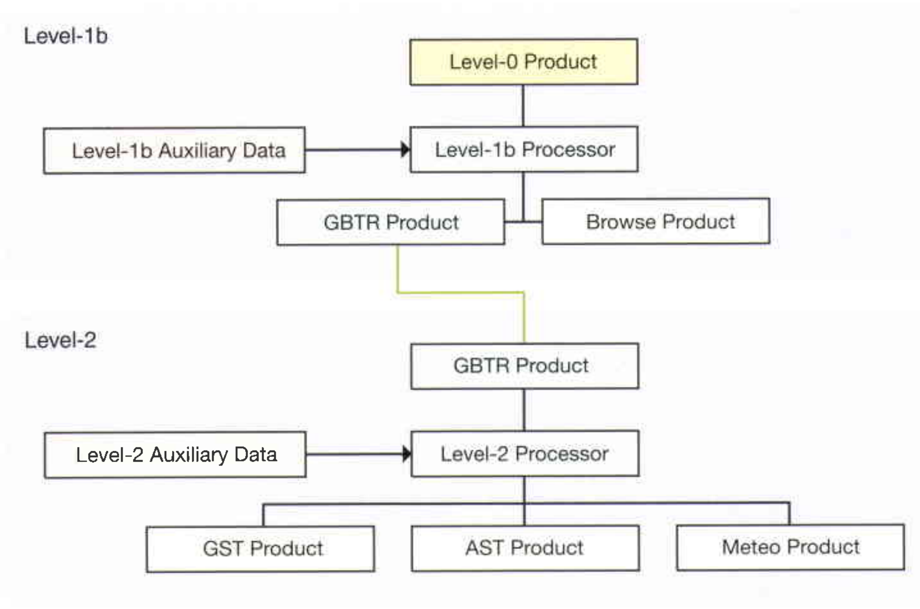


Figure 7. Relationship between the AATSR products and processing levels

Figure 7 summarises the relationship between the AATSR products and processing levels.

Level-1b products and processing

The Level-1b Gridded Brightness Temperature/ Reflectance (GBTR) comprises calibrated and geolocated images of BT for the three infrared channels, or reflectance for the near-infrared and visible channels, together with cloud and land identification. This is used as the starting point for processing to higher level geophysical products. The Level-1b processing steps are shown as a flow chart in Figure 8.

Following the unpacking and validation of the science and auxiliary data contained within the source packets, calibration parameters describing the relationship between pixel count and radiance for the three infrared channels are calculated. These are determined from the black-body pixel counts and the black-body temperatures within the auxiliary data. Look-up tables are used for the conversion of temperature to radiance. The calibration data for the visible channels, which are obtained once per orbit, are also unpacked and new calibration parameters for the visible channels are calculated and written out into an annotation data set.

Signal calibration uses the calibration coefficients to convert the science data in each channel to units of BT or reflectance, as appropriate. In the case of the infrared channels, look-up tables for the conversion of radiance to BT are used. For the visible channels, calibrated reflectances are calculated directly (the visible calibration parameters used are derived from an earlier orbit and found in an auxiliary data file).

Geolocation makes use of orbit-propagation software in conjunction with available satellite-orbit state vectors to determine the position on the Earth's surface of each instrument pixel. The data are then regridded onto a rectangular grid to correct for the curved lines of the AATSR conical scan, using the pixel co-ordinates derived at the geolocation stage. The same grid is used for both the nadir and forward-view images to achieve the colocation of the two images.

The regridding process may lead to gaps in the image, particularly in the forward view where the density of instrument pixels is lower than the density of points on the image grid; therefore, a cosmetic fill process is applied at this stage. Finally, land-flagging and cloud-clearing algorithms are applied to the images to distinguish between land and sea pixels, and to identify those regions of the image containing cloud.

Figure 9 indicates the wide variety of applications for which the AATSR Level-1b product can be used, including studies of the oceans, the land surface, the cryosphere, and the atmosphere.

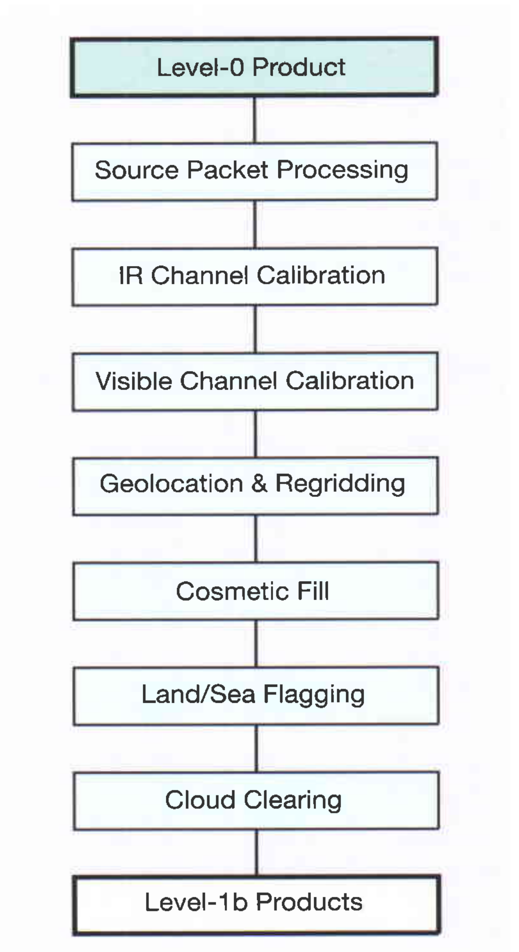
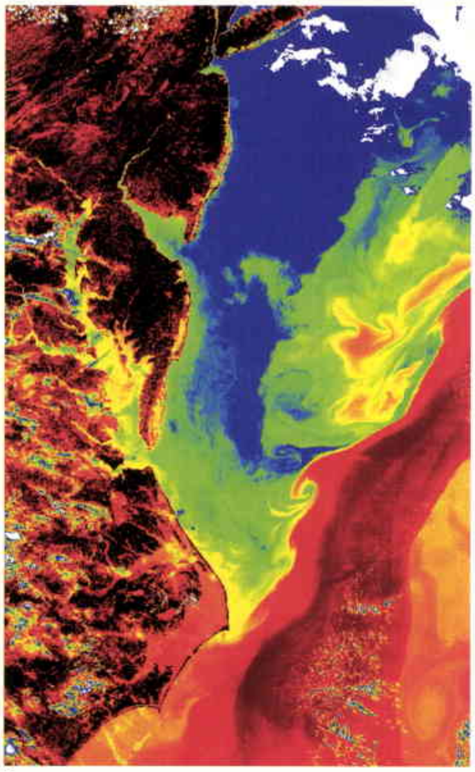


Figure 8. The AATSR Level-1b processing steps


a

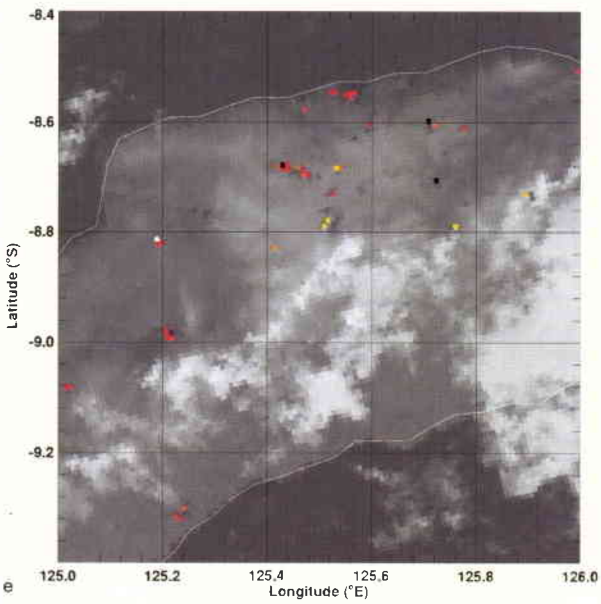

b


c


d

Figure 9 a to f. Applications of (A)ATSR Level-1b data

(a) A false-colour daytime ATSR-2 image (11 micron channel) of the US Eastern Seaboard, from New York, in the north to Pamlico Sound, North Carolina, in the south. Hot areas are black and red, while cool areas are white and blue. The Gulf Stream is clearly apparent at the bottom right. The image is a good example of structures on a wide range of spatial scales, and typifies the clarity and radiometric discrimination of ATSR imagery.
(b) A false-colour, daytime ATSR-2 image (0.55, 0.67 and 0.87 micron) showing Cyprus, Israel and the Sinai Peninsula. The border between Israel and the Sinai is visible due to changes in vegetation, resulting from differences in land-use patterns.
(c) A 12 micron ATSR-2 thermal image showing the break-up of the Ross Ice Shelf in the Antarctic. A large 300 km x 40 km iceberg can be seen breaking away from the main ice sheet.
(d) An image of the Malay Peninsula (1.6, 0.87 and 0.67 micron bands) showing a line of strong convection (across the centre of the image), and a gust-front.
(e) An ATSR near-real-time thermal image. Fires in the villages and towns of East Timor can be clearly identified.
(f) A daytime, 11 micron image of the Lascar volcano in northern Chile, showing two eruption columns. The ATSR stereo-view and atmospheric profile information can be used to calculate the heights of the columns. The insert shows an emplaced pyroclastic flow deposit, which saturates the 11micron channel. In this image, the coldest pixels appear white.



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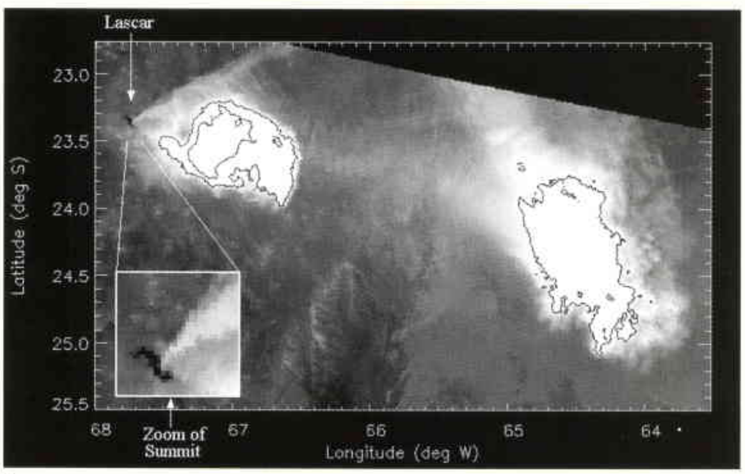

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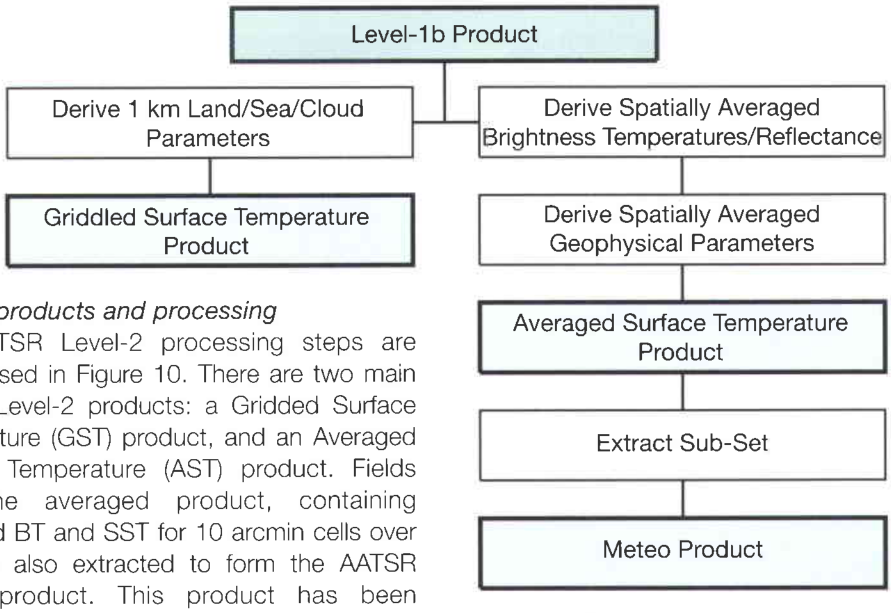

Figure 10. The AATSR Level-2 processing chain

Level-2 products and processing

The AATSR Level-2 processing steps are summarised in Figure 10. There are two main AATSR Level-2 products: a Gridded Surface Temperature (GST) product, and an Averaged Surface Temperature (AST) product. Fields from the averaged product, containing averaged BT and SST for 10 arcmin cells over sea, are also extracted to form the AATSR Meteo product. This product has been specifically designed for use by meteorological agencies in near-real-time.

Level-2 Gridded Surface Temperature

The GST product provides geophysical products over the ocean and land at 1 km resolution. This product is aimed at users interested in land and ocean applications requiring high-precision measurements at the full resolution, and will be available in multiples of the 512 km x 512 km minimum scene size, up to a maximum of one complete orbit.

SSTs are derived using the 11 and 12 micron channels for daytime data, and the 11, 12 and 3.7 micron channels for night-time data. For each pixel, two results are obtained whenever possible, one using the combined nadir and forward views and the other using the nadir view alone. The SSTs are calculated using a pre-defined set of retrieval coefficients. These are derived from a forward model representing a variety of different SSTs and atmospheric states.

Table 3. Contents of the AATSR AST product

- Averaged nadir-only and dual-view SST for cloud-free pixels over sea, plus associated parameters such as standard deviation of the mean and the number of pixels contributing to the average.
- Mean LST (currently the 11 micron BT) and NDVI for cloud-free pixels over land.
- Mean BT of the coldest 25% of cloudy pixels in the cell (as an estimate of CTT), and percentage cloud cover for each cell.
- Averaged BT/top-of-atmosphere reflectance in all channels for both cloudy and clear pixels over sea and land. (This will be particularly useful for users wishing to develop their own global algorithms and those wishing to reprocess global data sets.)

Currently, the 11 micron nadir-view BT is returned in the nadir-only field as an estimate of Land Surface Temperature (LST). A dedicated LST algorithm may be added in the future. Normalised Difference Vegetation Index (NDVI) values are calculated using the nadir 0.67 and 0.87 micron channels and returned in the combined view field. In cloudy conditions, the 11 micron BT is returned in the nadir field, as a placeholder for Cloud-Top Temperature (CTT). The combined field has been reserved for Cloud-Top Height (CTH), but this field is currently set to zero.

Level-2 Averaged Surface Temperature

The AST product contains spatially averaged SST, land and cloud parameters. Several different types of averaged measurement are offered within the same product (50 and 17 km^2 grid cells or half-degree and 10 arcmin cells) allowing users to select the most suitable data set for their needs.

The contents of the AST product include the fields listed in Table 3. The AST product will be disseminated on a full-orbit basis and is intended for global monitoring activities. Figure 11 shows spatially averaged, global SST imagery, derived from ATSR data.

It is important to note that the (A)ATSR instruments return SST measurements for the ocean's 'skin' (commonly taken to be the water layer within 0.1 mm of the surface). The AVHRR instruments also record emission from the skin, but the subsequent processing scheme uses a method of regressing the satellite observations to buoy measurements of 'bulk' SSTs, which can introduce a bias into this data set.

Algorithm heritage

ATSR-1 and ATSR-2 data are processed by the SADIST (Synthesis of ATSR Data Into Surface

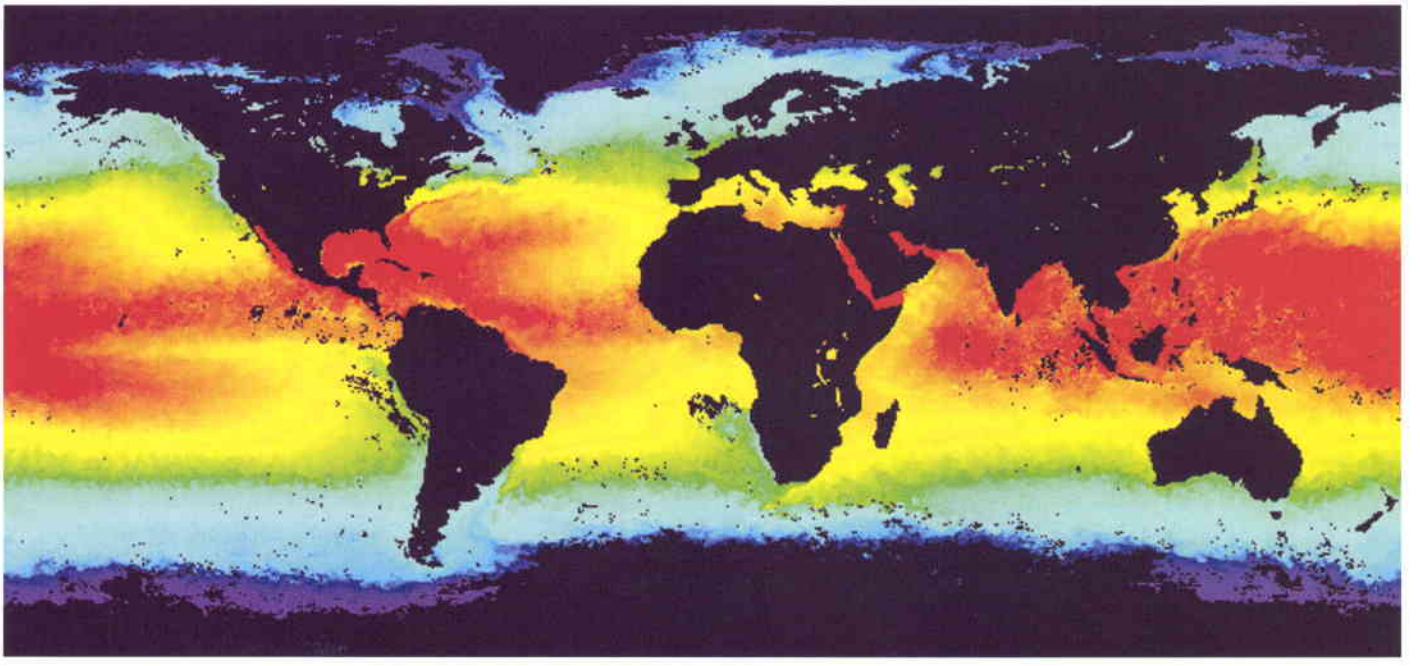

Figure 11. Spatially averaged, global SST imagery derived from ATSR data. The temperatures are represented on a scale from purple/blue (coldest) through green to red (warmest). To the east of the USA, a thin tongue of warm water can be seen stretching northwards, which is the Gulf Stream

Temperatures) processor developed by the Rutherford Appleton Laboratory (RAL). This software has been re-engineered for AATSR to allow it to be integrated within the wider Envisat PDS architecture. Algorithms from the SADIST processor have been re-used wherever possible to maintain consistency across the three missions, although AATSR products will also provide a number of enhancements. These include: the use of more accurate ellipsoidal, rather than spherical geometry within the regridding scheme; a change in the along-track sampling of the image grid from a fixed spacing of 1 km to sampling equally spaced in time; use of the Envisat tools for time correlation, orbit propagation and geolocation to ensure coherence between all Envisat instruments; operational calibration of the AATSR visible channels; the inclusion of a latitude and longitude topographic correction over land; and the introduction of NDVI over land.

Conclusions

As the third in the series of instruments, AATSR will fulfil an important scientific function within the Envisat mission. Its primary objective will be to provide continuity in the long-term data set of accurate global SST which, at the time of the Envisat launch, will be of nearly ten years' duration. It will also provide a rich source of thermal, visible and near-infrared imagery for other applications over oceans and land. As part of the wider Envisat payload, it will also offer unique opportunities for the synergistic use of AATSR data with other instruments, and particularly with the MERIS sensor.

AATSR offers the unique capabilities of continuous onboard calibration of both the infrared and visible channels, cooled detectors and along-track scanning, combined with rigorous pre-launch calibration and post-launch validation. These all combine to offer exceptionally high-quality data sets, not only over the ocean, but in all areas of environmental research.

AATSR also offers the advantage of being the third in a series of similar instruments. The length, consistency and accuracy of the SST data set, which only a series of instruments such as the ATSRs can offer, is of prime importance to climate-change research. In addition, considerable skill and expertise in instrument design, operations, data processing and data exploitation have been built up over the years in support of these missions. The AATSR programme has set itself an ambitious target of improving on a data set already in existence and of quite a high standard. Nevertheless, over the years the (A)ATSR instrument's position as the most accurate current measuring system for SST has strengthened with the improvements in both the instruments and the data-processing systems, long-term performance monitoring and comprehensive SST validation programmes.

Acknowledgements

The AATSR instrument has been developed by an international team led by Astrium (UK). The products and processing algorithms have been developed by the Rutherford Appleton Laboratory. The authors also acknowledge the assistance of: Gareth Davies of Vega, Gordon McFadyen of DETR, Phil Watts, Jo Murray and Nigel Houghton of RAL, Fred Prata and David Jupp of CSIRO; Steven Wilson of NERC, and Martin Wooster of Kings College London, in preparing this article.

Highlights of the ERS-Envisat Symposium 2000
– The Achievements of ESA's Earth Observation Programme

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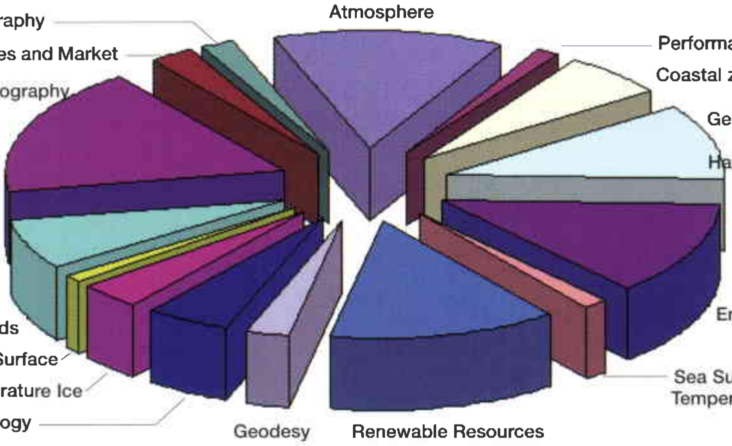
The ERS-Envisat Symposium 'Looking Down to Earth in the New Millennium' – organised by ESA and hosted by Chalmers University of Technology – took place in Gothenburg, Sweden, from 16 to 20 October 2000. This was the fourth ERS Symposium (after Cannes in 1992, Hamburg in 1993 and Florence in 1997) and the first Envisat Symposium, and it was open to all interested parties, from scientists to operational commercial users and service providers. It provided the 540 participants with an opportunity to familiarise themselves with the current status of ERS applications and the capabilities of the follow-on Envisat mission now being readied for launch in mid-2001, and to provide feedback from their own particular domains.

Introduction
The Gothenburg Symposium provided an ideal opportunity to review the European Remote Sensing Satellite (ERS) Programme's achievements in terms of both science and applications after close to ten years of satellite data exploitation. In addition, it provided a timely opportunity to review the imminent Envisat mission, its data products, and the approaches being applied to calibration and validation. The Symposium's Scientific Committee, composed of eminent scientists and ESA experts, had evaluated 460 submitted Abstracts in establishing the final programme. Following the themes of the Envisat Announcement of Opportunity, they grouped the accepted contributions into 42 Sessions (Figs. 1 and 2). Each session was chaired by a leading scientist in that particular field of application, and co-chaired by an ESA Earth-observation expert.

This article presents a summary of the highlights of the Symposium, grouped under the themes of Atmosphere, Land, Ocean and

Figure 1. Overview of the Symposium content



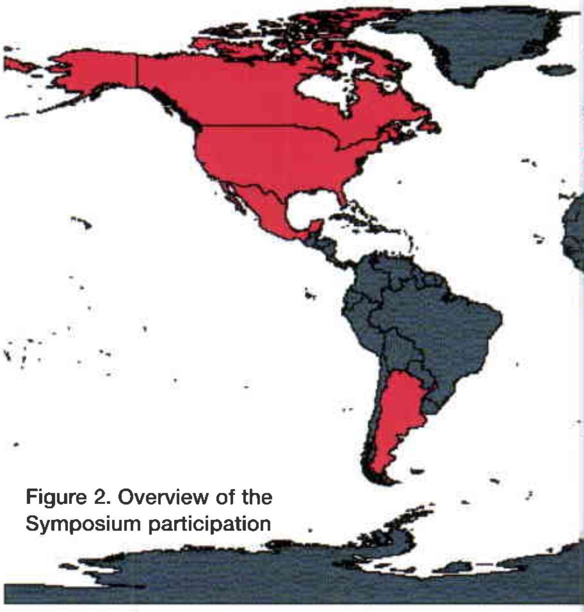


Figure 2. Overview of the Symposium participation

Envisat. The detailed summaries and recommendations prepared by the chairs and co-chairs of each Session are being published in the Symposium Proceedings (ESA SP-461, available from ESA Publications Division).

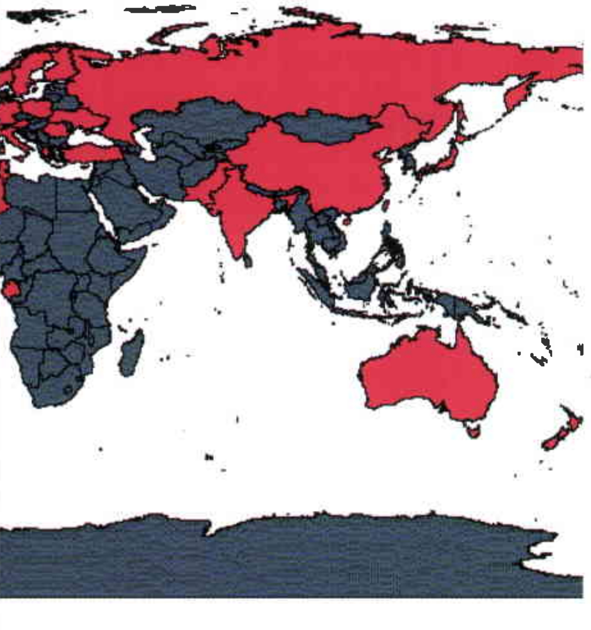
Highlights of the Atmosphere Session

"A Growing Community using GOME Data"

A total of 58 presentations (34 papers and 24 posters) were dedicated to the demonstration of scientific and application achievements by using the data from the ERS-2 Global Ozone Monitoring Experiment (GOME) instrument. GOME, a forerunner of future European atmospheric satellite instruments, is still the only spaceborne spectrometer capable of observing the entire spectral range from 240 to 790 nm with high spectral resolution. The presentations covered the retrieval of ozone, UV radiation, trace gases other than ozone, the characterisation of cloud and aerosol information, calibration and data assimilation techniques.

Ozone

GOME total ozone measurements were used to detect a mini ozone hole over northwestern Europe on 30 November 1999, and to observe the deepest ozone hole ever over Antarctica in the third quarter of 2000. Besides the total ozone, ozone profiles are derived from the GOME spectra to provide height-dependent ozone information down to the Earth's surface. Improved processing schemes have demonstrated the possibility to provide this information to users in near-real-time, so that it can be used to support measurement campaigns and for assimilating ozone data into numerical forecasting models (Fig. 3).



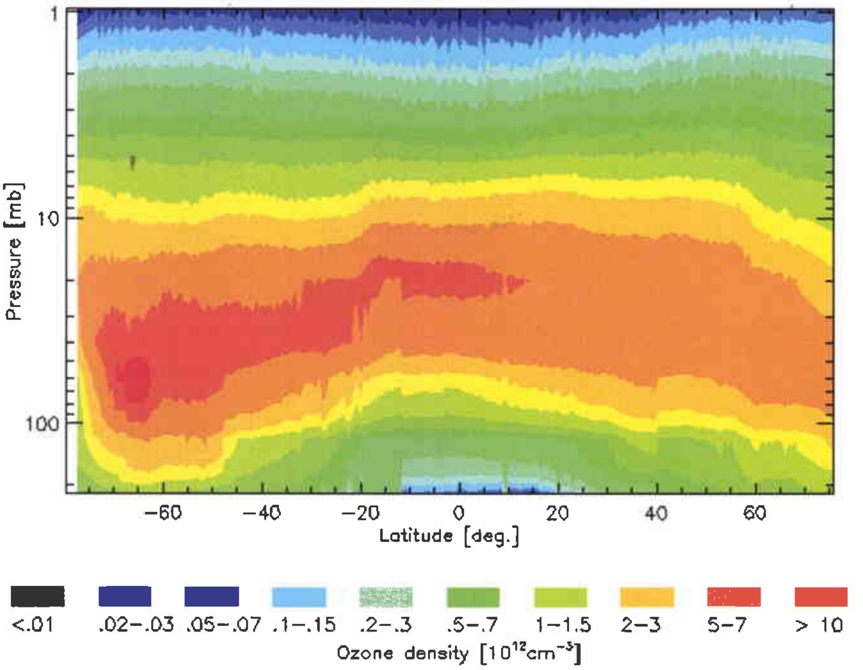


Figure 3. GOME ozone profiles retrieved within 3 h from one ERS orbit on 5 October 2000 (courtesy of Royal Netherlands Meteorological Institute)

Atmospheric constituents

Owing its nadir-viewing geometry, GOME provides the possibility to measure atmospheric constituents both in the troposphere and in the stratosphere. Formaldehyde (HCHO) in the troposphere could be retrieved for the first time on a global scale from space. The detection and the monitoring of SO_2 emissions due to volcanic events/industrial pollution and NO_2 emissions due to biomass burning/industrial pollution extracted from experimental retrieval algorithms down to the troposphere has been demonstrated. This newly-gained capability of observing tropospheric trace-gas distributions is a revolutionary step in terms of technical development and will lead to a significant enhancement of our ability to investigate the chemistry and physics of the troposphere (Fig. 4).

Minor trace gases, like BrO in the troposphere or OClO activation in the stratosphere, responsible for ozone depletion have been successfully retrieved from GOME measurements, providing greater insight into ozone chemistry (Fig. 5).

Global maps of the H_2O column above oceans and land have been retrieved. In the future, a tropospheric profile with limited spatial resolution will also be available. The feasibility of generating global and regional UV radiation maps was demonstrated. In combination with assimilation models, this will facilitate future UV forecasting services.

Algorithms for the retrieval of various types of cloud and aerosol information are increasingly based on instrument synergy. New cloud algorithms were presented for extracting cloud

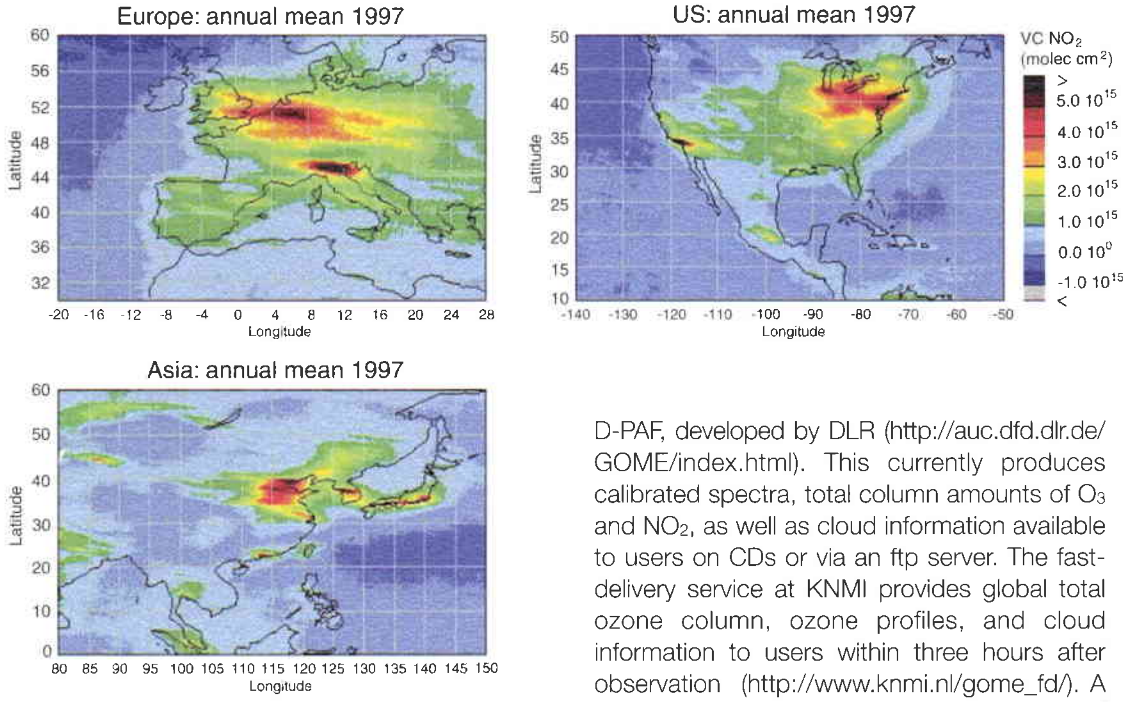


Figure 4. Regional yearly maps of nitrogen dioxide from GOME, showing air pollution from emissions over industrial areas (courtesy of Univ. of Bremen)

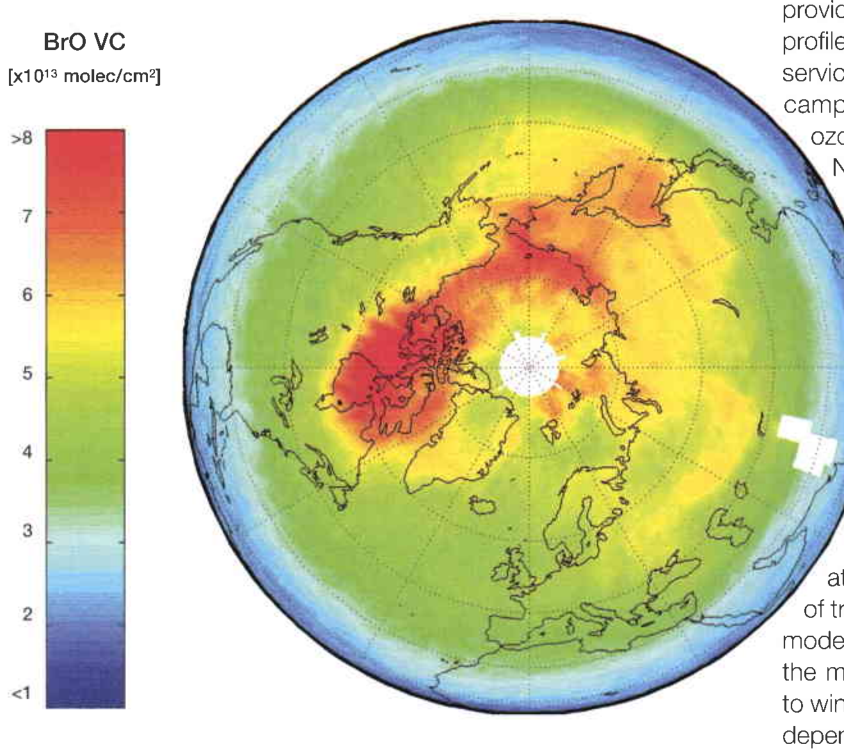


Figure 5. Monthly GOME bromine monoxide map over the North Pole for March 2000, showing tropospheric BrO plumes (courtesy of Belgian Institute for Space Aeronomy)

fraction and cloud-top height from GOME, Sciamachy and ATSR. Meteorological institutes have evaluated sample products. Further investigations will require the refinement of the definition of cloud parameters, and consolidation of libraries of aerosol classes, in order to simplify comparisons between different instruments and techniques

Services

An important issue has been the setting up of new data-delivery services in addition to the existing offline operational processing at the D-PAF, developed by DLR (http://auc.dfd.dlr.de/GOME/index.html). This currently produces calibrated spectra, total column amounts of O_3 and NO_2, as well as cloud information available to users on CDs or via an ftp server. The fast-delivery service at KNMI provides global total ozone column, ozone profiles, and cloud information to users within three hours after observation (http://www.knmi.nl/gome_fd/). A service has been set up by the University of Bremen (supported by ESA and DLR) to provide preliminary GOME data (e.g. ozone profiles, OClO, BrO, etc.) in near-real time. This service supports international measurement campaigns for investigating stratospheric ozone at mid- and high latitudes in the Northern Hemisphere in springtime (http://www. iup.physik.uni-bremen.de/gomenrt 2000/).

New radiative transfer models, generating simulated backscatter intensities and weighting functions, have been developed and applied to improve GOME retrieval algorithms (e.g. Air Mass Factor calculation).

GOME data assimilation

Owing to the high variability of the atmosphere, the generation of global maps of trace gases is not a trivial task. Assimilation models (e.g. 4-D VAR) are taking into account the movement of the measured trace gas due to wind fields related to different heights, and its dependence on the actual chemical state of the atmosphere. It was demonstrated that by using GOME ozone measurements such a tool is able to propagate information into regions where there are no measurements, thus producing a consistent picture of the entire globe. Furthermore, reliable ozone forecasting over a time period of about 5 days has been demonstrated.

All of the experience that has been gained in the exploitation of GOME data can be directly applied to the use of the future European atmospheric instruments on Envisat: GOMOS, MIPAS and Sciamachy.

Highlights of the Land Session

"A Wide Range of Land Applications"

The widespread use of space-based Earth observation over land – in particular the use of ERS SAR/InSAR data, – was demonstrated by the large number of presentations in this Session (131 papers). The tandem exploitation of the ERS-1 and ERS-2 satellites (1 day repeat cycle) has provided a unique data set for the development of the repeat-pass interferometry (InSAR) technique.

Seismic studies
SAR interferometry (InSAR) has allowed scientists to obtain surface-displacement maps and to construct complex fault models that could not be generated from seismological data and conventional geodetic techniques alone. SAR data have been a primary source of information after earthquakes in remote areas where little or no in-situ information was available, such as Western China, Iran and Tibet. Research is in progress to overcome the loss of coherence in the vicinity of the surface rupture. A major development has been the successful use of InSAR data to study interseismic deformation, the averaging of several interferograms allowing a detection level of better than 1 mm/year in line-of-sight change (Fig. 6).

Volcano monitoring
A number of attempts based on the processing of InSAR archived data have been made to monitor volcanic deformation. One of the examples, the computation of a series of differential interferograms has shown the deformation on the surfaces of four volcanoes in Alaska over several multi-year intervals in the 1990s.

Landslides
The Symposium also illustrated the state of art of SAR applications for landslide mapping and monitoring, focussing particularly on surface characterisation and the measurement of slow slope movements by means of SAR interferometry. ERS-1/ERS-2 tandem data sets, as well as 35-day repeat interferometric data sets, have helped to map landslides.

Land subsidence
The technique of SAR differential interferometry has been used for the monitoring of subsidence created by water/oil pumping, mining and excavation. Subsidence rates ranging from millimetres to more than 1 m per year have been observed. GPS measurements and mathematical models were used to validate the measurements. The results clearly show the considerable potential of remote sensing.

Some limitations of the SAR interferometric technique may be overcome by the emerging Permanent Scatterers technique pioneered by Politecnico di Milano, which is ready to be used in pre-operational applications where a long time-series of SAR images is available for the area of interest (Fig. 7).

Forest mapping
ERS InSAR (tandem coherence 1-day) products were shown to be an excellent Earth-observation product for forest/non-forest delineation. It was also shown that for some special meteorological conditions, ERS coherence is also correlated with the boreal forest stem volume. An extensive example was presented from the SIBERIA project (SAR Imaging for Boreal Ecology and Radar Interferometry Applications), which aimed to map the central-Siberian forest using three Earth-observation radar satellites. This was a joint effort by the German Aerospace Centre (DLR), ESA, and the Japanese Space Agency (NASDA) to collect ERS-1 and -2 and JERS-1 data via a mobile receiving station located in Mongolia. More than 550 ERS scenes and 890 JERS-1 scenes were used to demonstrate the semi-operational use of radar remote sensing for very-large-area forest mapping. The final results, derived from ERS-1/ERS-2 tandem coherence and JERS intensity, include geo-referenced maps with six land classes, three of which indicate different levels of timber volume (Fig. 8).

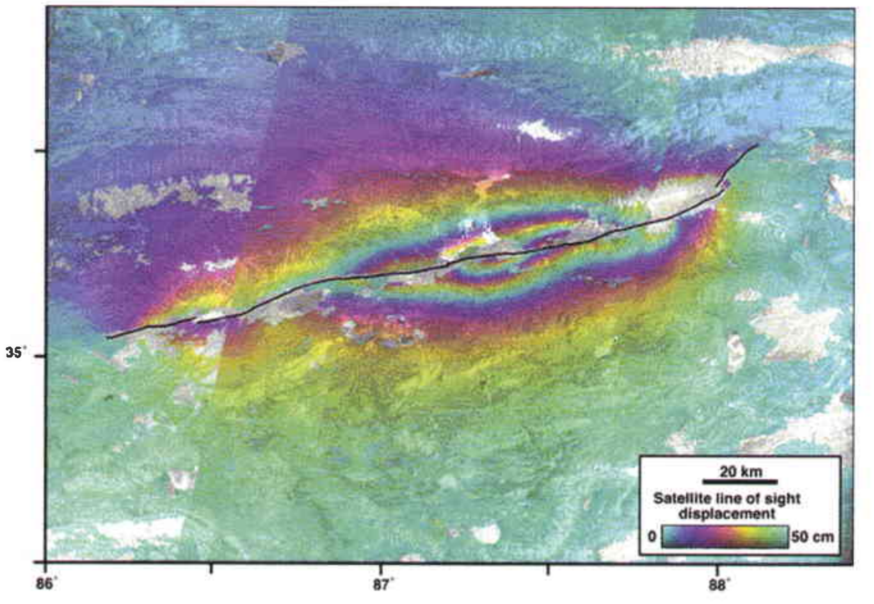


Figure 6. Three-track mosaic covering the 170 km-long section of the fault that ruptured during the Manyi earthquake (Tibet) on 8 November 1997 (courtesy of Jet Propulsion Laboratory)

Damage assessment
ERS coherence derived using the tandem data was revealed to be an excellent tool for

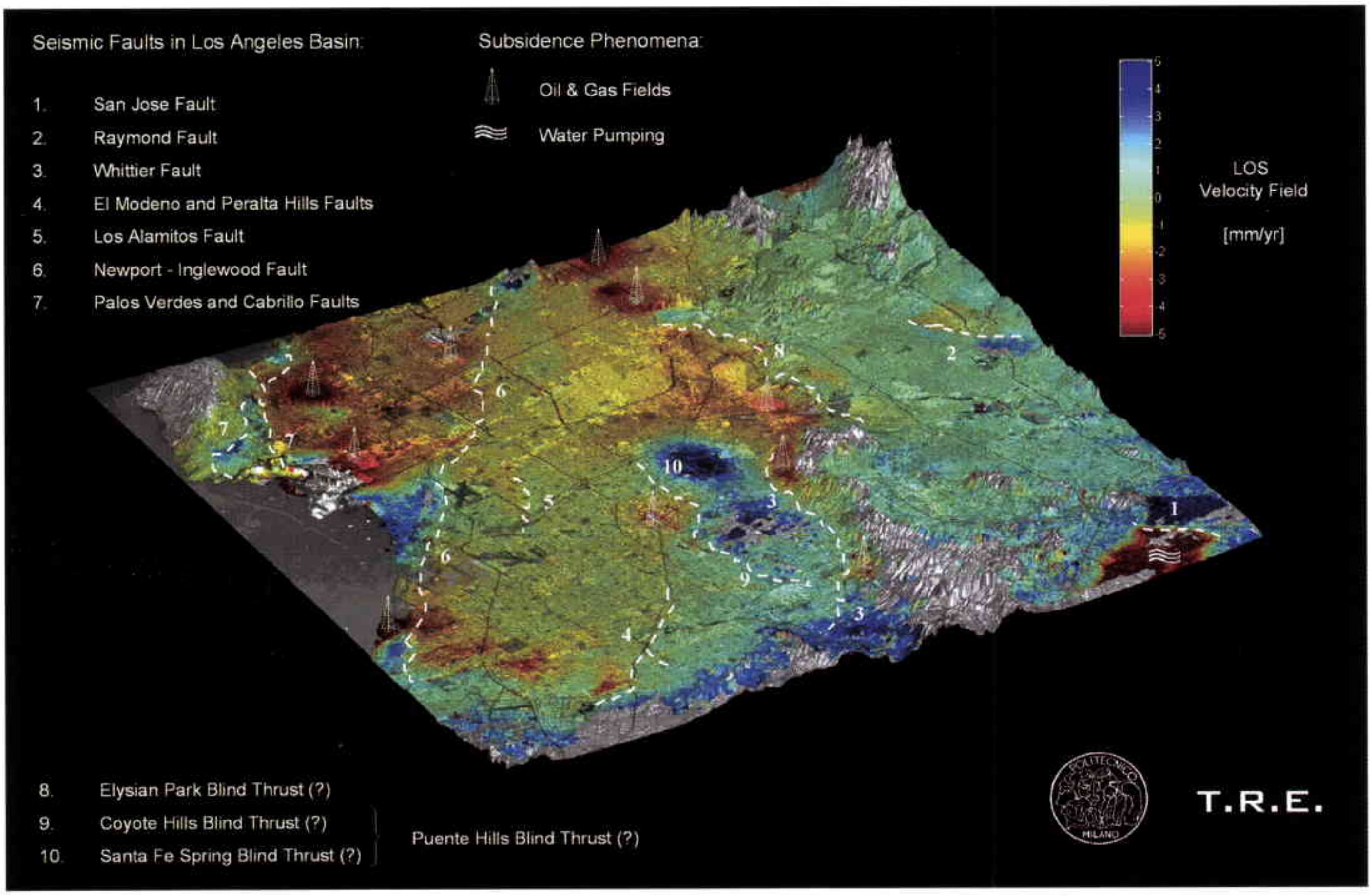


Figure 7. Subsidence map of the Los Angeles area obtained by applying the Permanent Scatterers technique to 56 ERS images. It shows the average subsidence rate, due mainly to oil/gas extraction, water pumping and seismicity, over the period 1992 to 1999. The colour scale indicates motion of up to 5mm/yr with an accuracy of better than 1mm/year (courtesy of Politecnico di Milano, TRE)

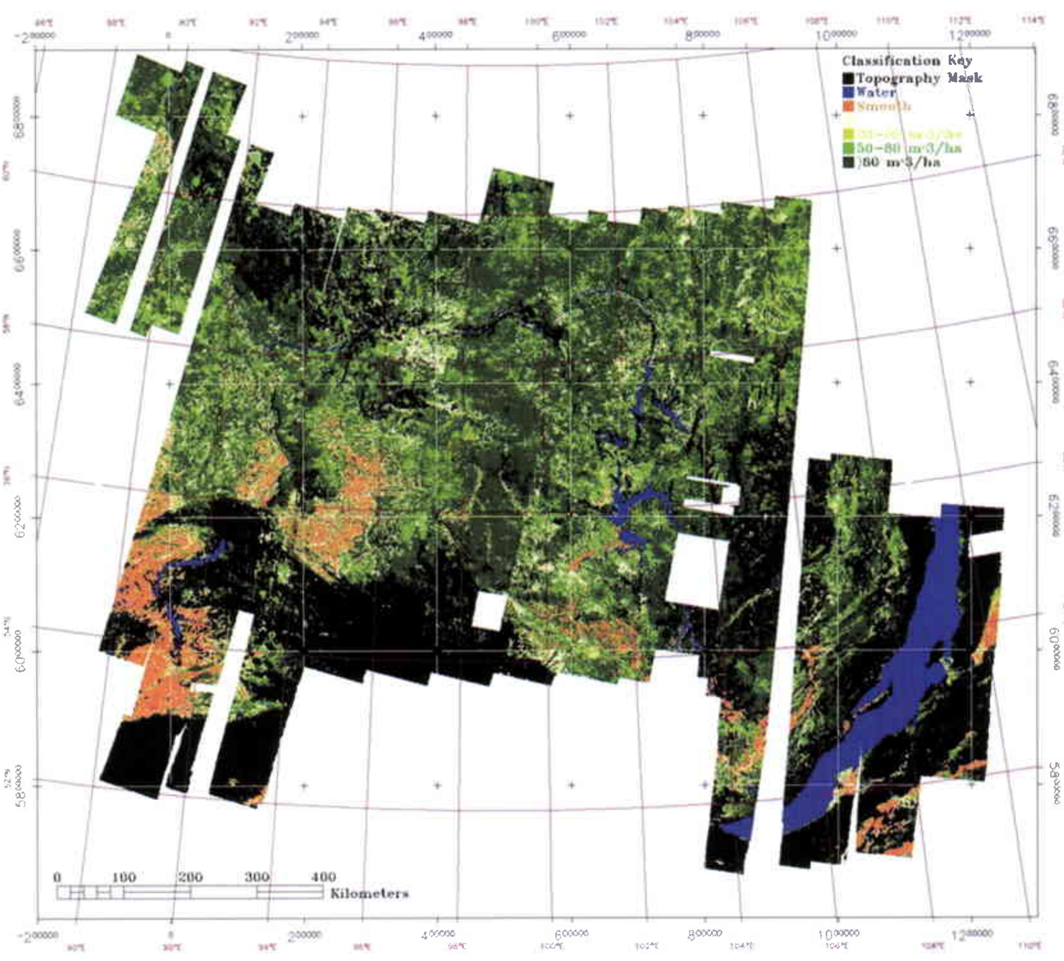


Figure 8. Mosaic image showing forest stem volume and land use in the Siberian forest, derived from ERS-1/ERS-2 tandem coherence and JERS intensity (courtesy of EU CEO Project, SIBERIA)

mapping burnt areas (Canada and Madagascar) and for assessing forest damage due to storms (Switzerland). The examples presented illustrated that this approach has potential for service development (Fig. 9).

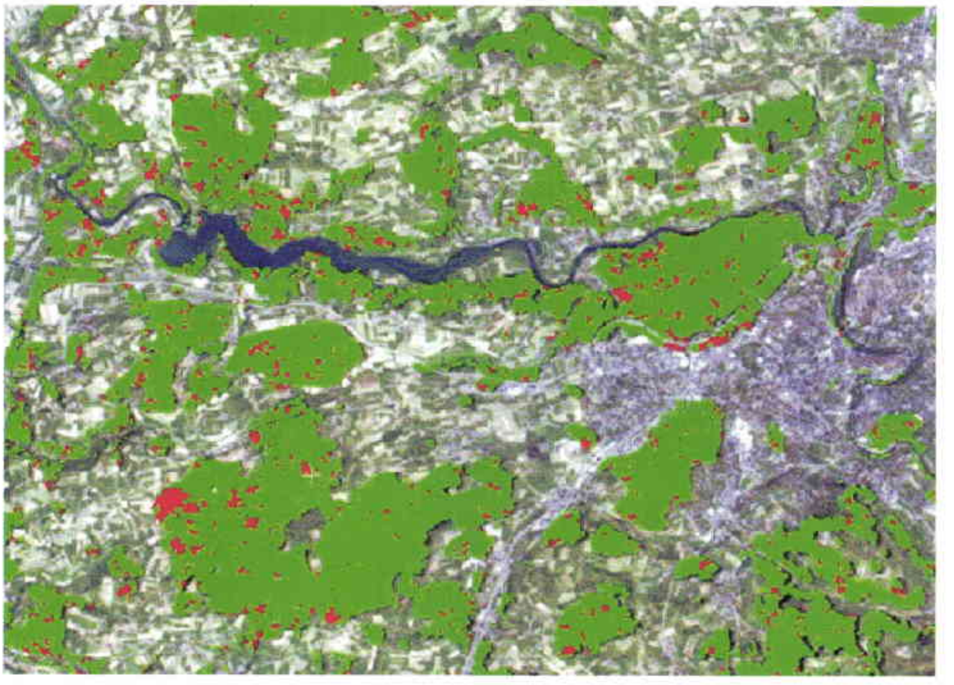


Figure 9. Storm-damage map of Switzerland, from winter 1999/2000, derived from ERS SAR tandem coherence combined with a Landsat TM image as background. Forested areas are in green and damaged forest areas are in red (courtesy of Gamma Remote Sensing, Spot Image, Swiss Federal Institute of Technology Zurich, and SERTIT)

Flood mapping and soil-parameter retrieval

The flood-application presentations demonstrated the contribution that ERS SAR data can make to the development of an operational flood-management information system. It has been shown that it is possible to produce SAR-based flood-extent maps. The synergy of using SAR-based flood-extent maps with Very High Resolution (VHR) optical data for the production of precise Land-Use Maps brings a significant improvement in terms of damage assessment and provides valuable information for the visualisation of the flood damage (Fig. 10). In addition, historical series of ERS SAR data are proving to be an essential information source for flood prevention and are serving as reference data for the elaboration of flood-prevention plans.

The use of multi-polarisation SAR data for soil-roughness assessment was presented, along with a promising technique for retrieving roughness from ASAR data. The use of spatial models of soil-vegetation-atmosphere (SVAT) processes, based on realistic-vegetation growth models, has been successfully applied for retrieving the soil moisture beneath vegetation.

Rice mapping and monitoring

Rice-crop mapping and monitoring appears to be one of the main agricultural applications for ERS SAR data. Its potential for this application had already been demonstrated in the past. A major step towards operational monitoring has been the development of user tools and the transfer of knowledge to users. Algorithms and processing chains have been set up for rice mapping and yield prediction. It is now possible to achieve mapping within a few days after satellite data acquisition. Future developments will focus on methodological refinements for large-scale mapping and data assimilation into crop-growth models.

Snow mapping and snow-melt runoff

Time sequences of ERS SAR data have been incorporated into an automatic classification algorithm to generate precise snow maps. These maps have then been applied successfully for accurate real-time forecasting of snow-melt run-off in mountainous areas, confirming the high operational potential of this technique (Fig. 11).

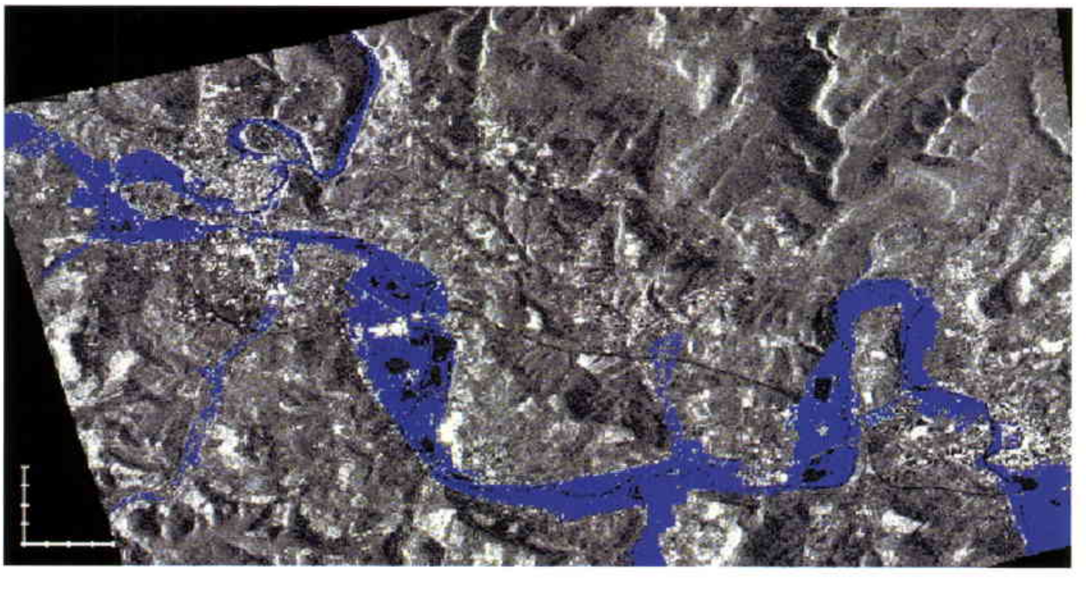


Figure 10. Flood-extension map of a portion of the River Meuse (F), which was subject to flooding in 1993/94 (blue) and 1995 (cyan). The map was generated from a multi-temporal combination of ERS SAR images (courtesy of SERTIT)

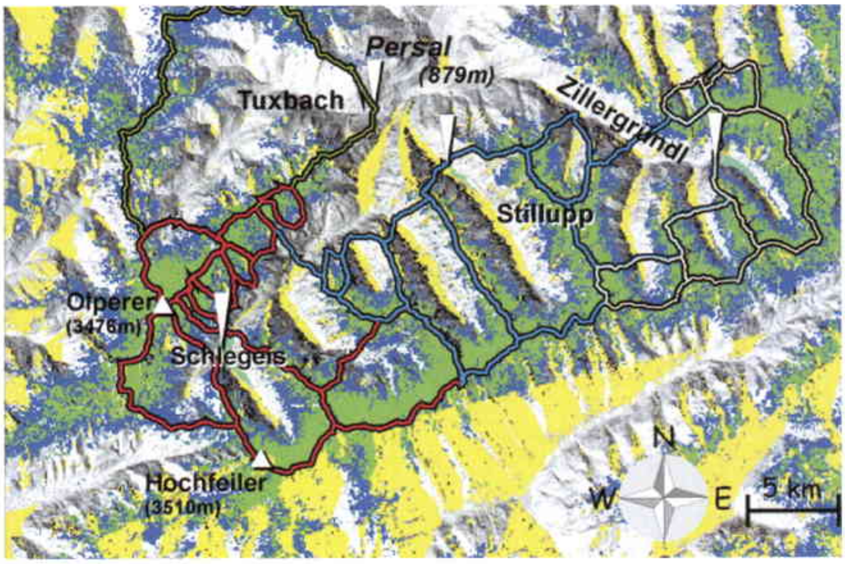


Figure 11. Snow map generated from ERS SAR ascending and descending images. The snow extent on 1 May 2000 is in blue and green, that on 6 June 2000 is in green, and areas where no information could be retrieved are in yellow (courtesy of Univ. of Innsbruck and SCEOS)

Ice mapping
Thanks to the combination of data from ERS's InSAR and Radar Altimeter, changes are being detected after several years of observation in the glaciers in West Antarctica. The benefit of reliable time series of data for monitoring the subtle changes occurring in the polar ice sheets has been amply demonstrated. An example was presented for Svalbard in Norway, where a sequence of interferograms over a glacier covering a period from 1992 to 1998 showed the complete cycle of a glacier surge, from initiation through fast flow to quiescence (Fig. 12).

Topography
The generation of accurate height measurements from both the Radar Altimeter and SAR for topography mapping continues to be demonstrated for large areas. ERS Radar Altimeter ice-mode data were shown to provide accurate terrain-height information (70% of cross-over measurements agree to < 5 m). A Digital Elevation Model has been generated for the whole of the British Isles, using ERS tandem interferometry. The DEM generation process itself is fully automatic and the model has been validated as having a typical accuracy of 8–14 m rms. The resulting DEM is being used successfully in both hydrological and geological applications.

ERS tandem data have also been used successfully to produce a wide-area DEM for the telecommunications sector in Switzerland. The customer has validated the product.

Highlights of the Ocean Session

"Development of New Services"

ESA Earth-observation data are being used operationally, and have been demonstrated to be a valuable source of information, for coastal-zone mapping and monitoring.

Service development
ERS SAR data have been used to update coastal maps for areas where SHOM (French Marine Mapping Agency) has mapping responsibility. As an example, a 1:50 000 map of the coastal region around Cayenne, in

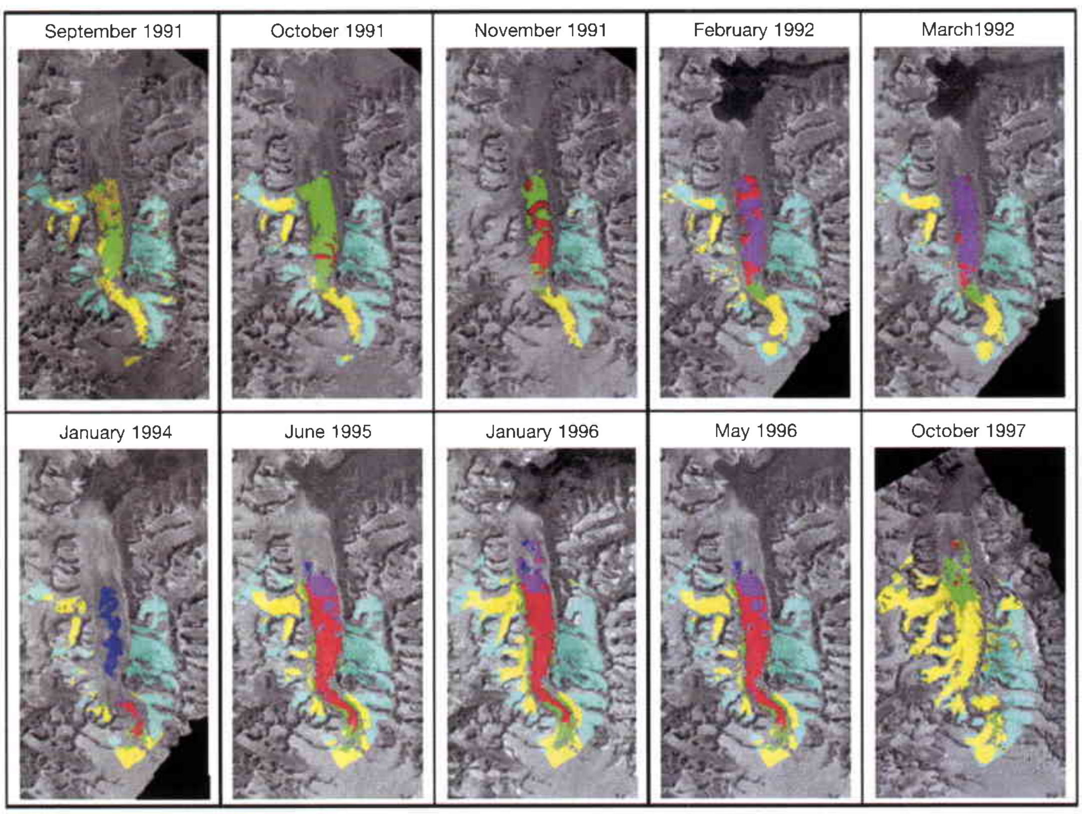


Figure 12. Temporal sequence of geocoded displacement maps of a glacier in Svalbard (24 km x 45 km). The magnitude d (in m/day) of the three-dimensional displacement rate is shown with the following colour scale: $d < 0.1$ cyan, $0.1 < d < 0.4$ yellow, $0.4 < d < 0.7$ green, $0.7 < d < 1$ red, $1 < d < 1.3$ violet, $d > 1.3$ blue (courtesy Univ. of Wales, Gamma Remote Sensing, Univ. of Leeds)

French Guiana, has already been issued by SHOM. Further work is in progress, including an analysis of the legal implications inherent in the use of Earth-observation data for chart and map updating (Fig. 13).

The Dutch company ARGOSS has applied the bathymetry assessment system based on the use of ERS SAR data in Indonesia. The average measurement error was found to be around 10–11 cm. Discussions with business partners are underway and it is expected to start full operations in 2001.

The Tromsø Satellite Station (TSS) in Norway provides an operational oil-spill detection service for customers from both government and offshore oil companies. This was developed using ERS and is based on joint use of Radarsat and ERS SAR imagery. The availability of Envisat is expected to make a significant contribution to the service's capability in terms of both update times and service area covered. A change in legislation, which requires oil companies to undertake environmental-monitoring activities, is expected to add to demand for this service.

NOAA is presently demonstrating near-real-time services to a range of government users in Alaska, including the Department of Fisheries and the National Weather Service. The present services cover coastal wind-field data and fishing-vessel surveillance based on Radarsat. It is planned to use ASAR data once Envisat is launched and to expand the service provided to include sea/river ice monitoring and oil-spill surveillance. About one year will be required to investigate the capabilities of ASAR before joint exploitation of ASAR and Radarsat is possible.

Ocean dynamics
The Ocean Dynamics session demonstrated that projects are moving from instrument-capability to application demonstration. Results were presented from a variety of missions (ERS, Topex Poseidon, GFO) as well as from different instruments on board ERS-2 (RA, ATSR, SAR), dealing with oceanographic phenomena at different spatial and temporal scales.

The continuing improvement in the ERS Altimeter data, both in terms of operational timeliness and ability to identify processes that would not have been possible even in the recent past, was highlighted by the ocean-dynamics community. A noteworthy illustration is the real-time monitoring of the tropical Pacific. Meanwhile, the 1997 El Niño data is still being used for research in this field (Fig. 14). There was also a presentation of a novel synergistic use of altimetry, sea-surface temperature, and ocean colour. A new automated method has been used to identify Rossby waves, a special class of planetary waves, and calculate their phase speed.

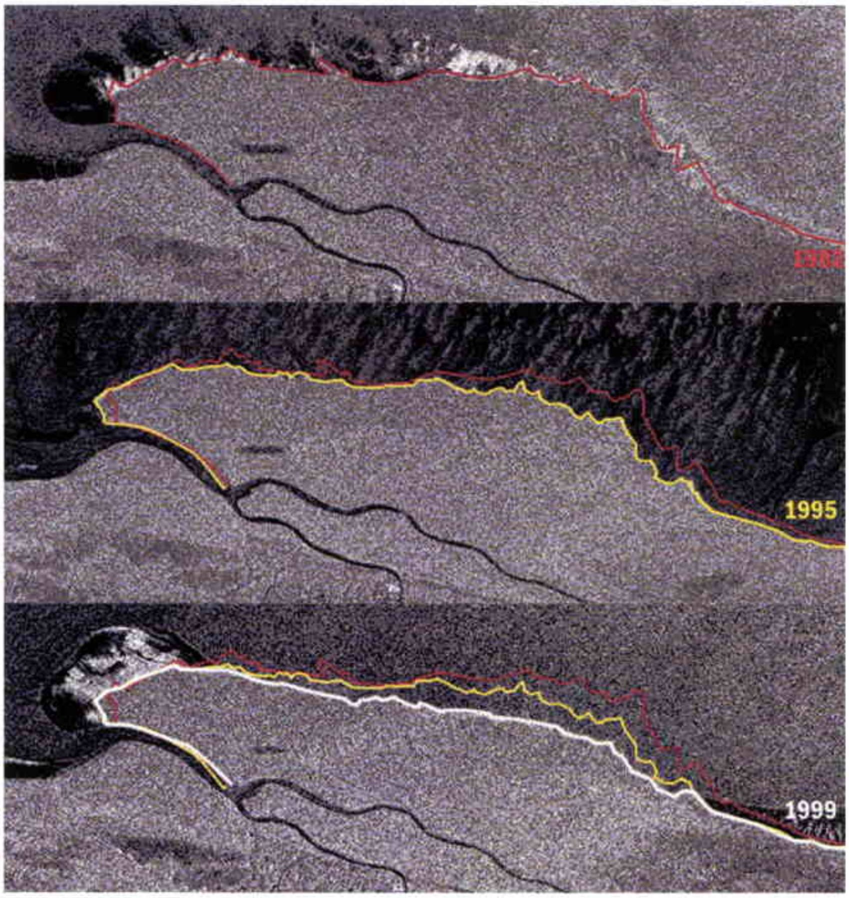


Figure 13. This sequence of ERS SAR images acquired between 1992 and 1999 shows the evolution of the coastline in French Guiana, with displacements ranging from hundreds of metres to several kilometres (courtesy of University of Marne La Vallée)

Significant progress has been made in the classification of different types of sea features commonly observed in SAR images (Fig. 15). The Norwegian Defence Research Establishment has been acquiring images along the coast of Northern Norway since the early days of the ERS-1 mission. The continuous and long-term nature of their SAR image analysis for the continental shelf gives the possibility to assess the signatures and observabilities of various features during the various seasons of the year. Quantitative information extraction is often dependent on multi-sensor approaches using SeaWiFS, AVHRR and/or combinations of SAR data with ocean models. Frequent coverage of selected sites should be pursued to learn more about the variability of the features and their signatures in SAR images.

Wind and waves
Scientific progress was demonstrated for wind- and wave-field retrieval from the three main sensors – altimeter, scatterometer and SAR – in both image and wave mode (Fig. 16). Altimeters have provided estimates of the wind speed and the significant wave height for potential operational services. The Ocean and Sea Ice Satellite Application Facility (OSI SAF

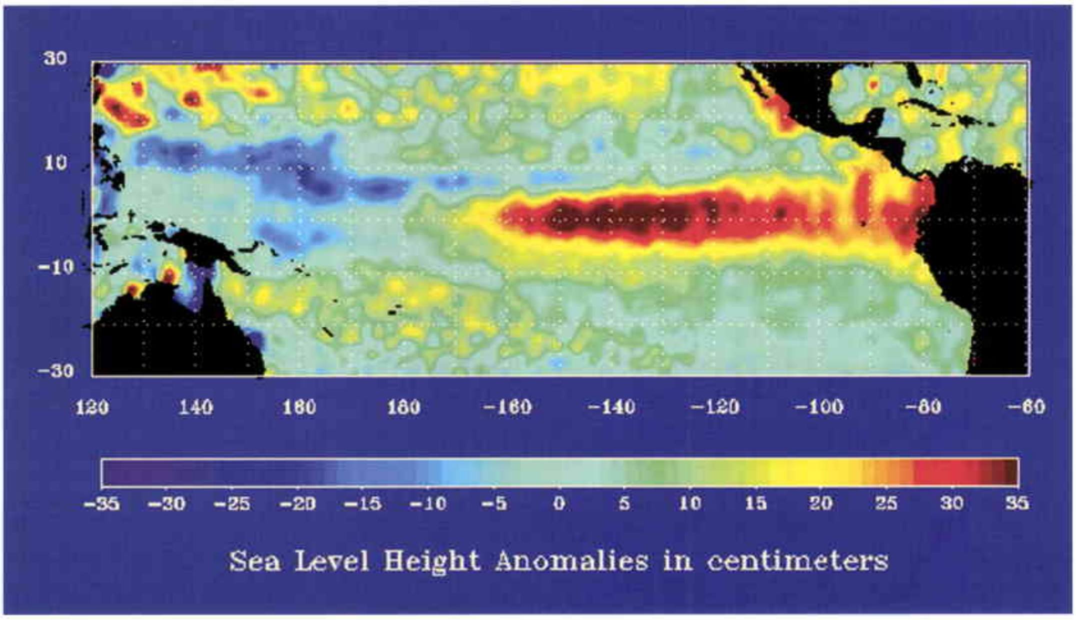


Figure 14. Sea-level elevation anomalies measured with the ERS-2 Radar Altimeter over the tropical Pacific during the last El Niño event. Sea-level anomalies are averaged over 7 days with 1 degree resolution. There is an abnormally high sea level near the West Coast of South America along the Equator (red, +35cm), which leads to the disappearance of fish and a radical switch in the regional climate in terms of rainfall. At the same time, the sea level drops in the Western Equatorial Pacific (deep blue, -20cm), where extreme droughts devastate crop yields and increase fire hazards (courtesy of DEOS, Delft University, and ESA/ESRIN)

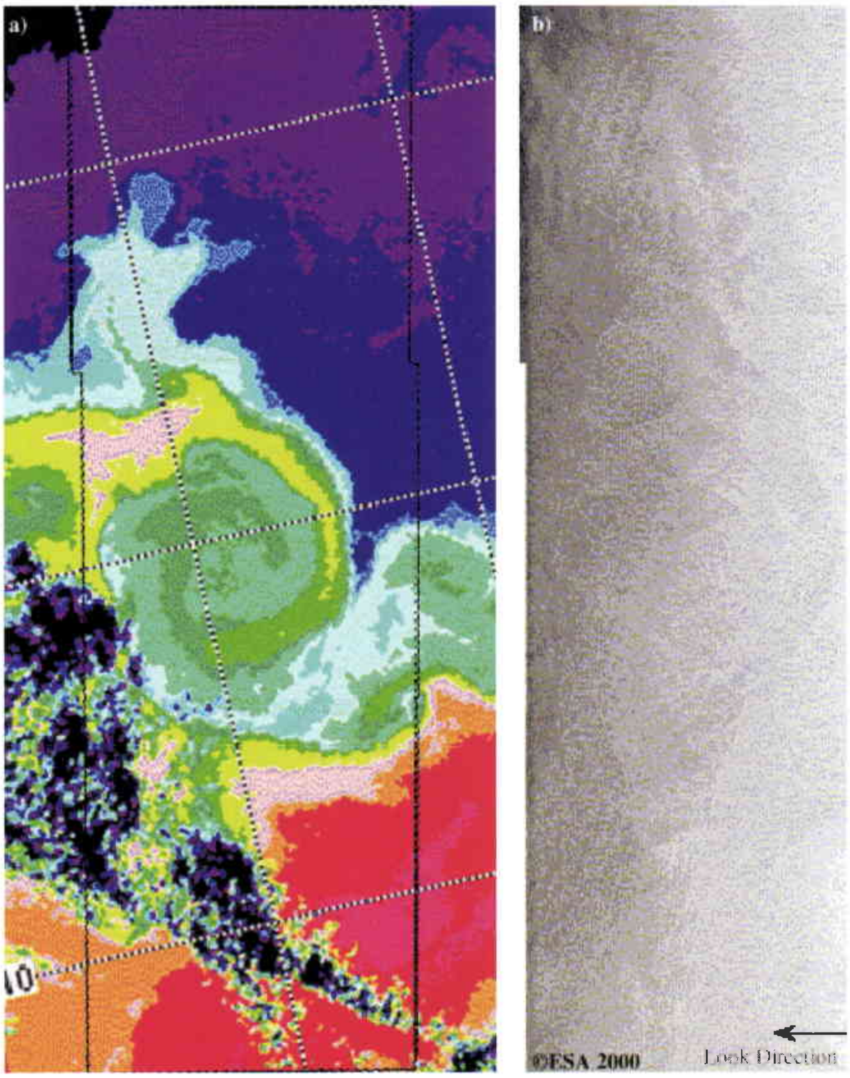


Figure 15. A NOAA-15 AVHRR thermal image and an ERS-2 SAR image acquired in February 2000. Both images show the features of mesoscale surface circulation in the northern portion of a subarctic front south of Vladivostok. Colour scale: violet: 0^0C, blue: 1°C, green: 2°C , yellow: 3°C, red: 4°C (courtesy of Pacific Oceanological Institute, Russian Academy of Sciences)

supported by Eumetsat and hosted by MeteoFrance) is preparing a pre-operational wind product based on ERS-2 scatterometer data. Preparatory work is in progress for the wind product from the ASCAT scatterometer to be flown on Metop. The potential of ERS SCAT fast-delivery products for detecting and monitoring cyclones has been demonstrated. 74% were retrieved with an average of two alarms per day.

Different methodologies have been applied in extracting wind and wave fields from image- and wave-mode data. Possibilities for the success-ful extraction of wind fields were shown for a grid of about 1 km x 1 km for wind direction and 0.1 km for wind speed. The Tromsø Satellite Station (TSS) provides an operational service for high-resolution wind-field observations based on cross-spectral analysis. Current numerical models provide wind information at a resolution of 25 km, while the new SAR wind service can provide information with 12 km resolution.

Operational use of ScanSAR Radarsat wind maps is in place at the Danish Meteorological Institute. A similar Envisat ASAR 500 km x 500 km wind product is required.

Sea ice

The Canadian Sea-Ice Service has demonstrated using ERS and Radarsat the importance of a fully operational end-to-end sea-ice information system. ASAR data from Envisat will provide a complementary source of data and bridge the gap to Radarsat-2. Scientific research for sea-ice thickness estimation is in progress using ERS Radar

Altimeter measurements as well as ERS SAR imagery. Use of ERS SAR and ATSR in combination has been shown to be successful in detecting sea-ice freezing, melting, evolution, and kinematics.

Sea-Surface Temperature (SST)

Responding to the primary objective of the ATSR mission, ATSR/SST is being used successfully to evaluate the long-term (1991–2000) change in Sea-Surface Temperature on a global scale. A clear warming is observed in the Western Pacific, whereas a cooling down is observed in the Eastern Pacific. The Atlantic is also warming up, but to a lesser degree. According to the results so far, the global SST is increasing by about 0.1 deg per year and the sea level is rising by about 0.1 cm per year.

Wind scatterometer

Global products are generated at CERSAT derived from the ERS AMI-Wind instrument, complemented by data from similar sensors on non-ESA platforms. In particular, a global-wind atlas and a sea-ice atlas have been produced and distributed worldwide as a major contribution to climate studies. In particular, the wind atlas, distributed to 1500 users, has been included in the WOCE dataset as a reference for wind measurement.

Geodesy

ERS Altimeter data, especially those from the geodetic mission, are being used to compute very detailed gravity-anomaly maps. Recent developments have shown improvements in coastal regions and extension towards the pole. A near-global gravity-anomaly field map is now available at 2'x2' resolution. Cross-validation against in-situ data indicate that the accuracy of the field is around 6 mgal even in shallow oceans and around topographic features. Work is in progress to improve resolution and accuracy, especially in areas with strong meandering currents. At the same time, mean sea-surface models are being produced and compared.

Highlights of the Envisat Session

"Getting Ready for Launch"

Gothenburg was the first combined ERS/Envisat Symposium. The Envisat Programme was therefore presented in the Plenary Session, and there was a special session devoted to the overall Envisat calibration/validation approach (15 papers). A full day was devoted to sessions on the opportunities for science and application development offered by the Envisat sensors (37 papers).

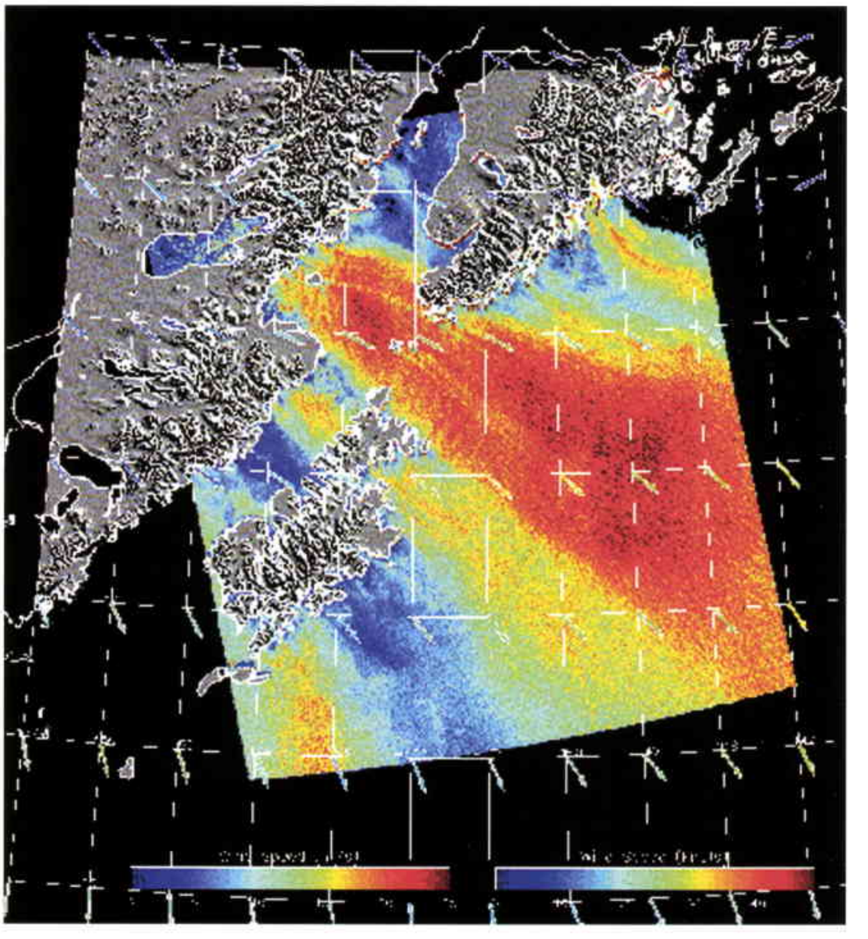


Figure 16. High-resolution SAR wind map of the Gulf of Alaska near Cook Inlet. This map was derived from a Radarsat wide-scan SAR scene collected on 24 December 1999 in preparation for the validation of Envisat ASAR wind fields. The arrows show the wind field predicted from the Global Atmospheric Prediction Model (NOGAPS) (courtesy of John Hopkins Univ. Applied Physics Laboratory)

In preparation for this new and challenging mission, a number of different actions were taken, ranging from public-relations activities (movie, pins, posters, stands, 1:10 scale-model display, etc.) to the distribution of technical documentation (leaflets, brochures, science reports for each Envisat instrument) and the opening of a web site for monitoring and reporting on the 674 projects selected in the framework of the Envisat Announcement of Opportunity.

A set of 10 CDs containing Envisat simulated products and a tool (called 'EnviView') designed to open, display and navigate the products, were distributed to each participant to help users familiarise themselves with the content and format of future Envisat data products. For ESA, this early distribution of EnviView was intended to promote feedback and recommendations on how to improve the tool's capabilities before the launch. EnviView will be maintained throughout the mission and will be offered free to all Envisat users (Fig. 17).

The special Envisat session was mainly devoted to the calibration and validation of the mission instruments and products. The number of instruments to be calibrated and the wide range of geophysical products to be validated make this task an unprecedented challenge. ESA is committed to delivering products to

Figure 17. A set of the Envisat Simulated Product CDs

the users starting 6 months after launch, which is currently scheduled for mid-2001. Within the first 6 months in orbit (so-called 'Commissioning Phase') and after a first few weeks dedicated to switch-on and data acquisition (so-called 'SODAP Phase'), a number of teams of experts will carry out the core calibration and validation programme, under ESA's responsibility and overall co-ordination. The aim is to achieve the release of good-quality products starting at the end of the Commissioning Phase. The detailed plan of action and the techniques and strategies that will be used were presented in detail by various speakers representing the calibration and validation teams.

ASAR

The ASAR calibration approach is based on the successful ERS approach. The challenge lies in the increased number of instrument modes and products that the ASAR on Envisat will deliver.

Already initiated calibration studies were reported, as well as results concerning the use of polarimetry for land-use classification. The use of airborne C-band and dual-polarisation data, experimented with in Denmark with the airborne EMISAR data, significantly improves crop-type classification, paving the way for a potentially successful Envisat application.

Important experiments will also be performed within the ASAR calibration/validation scheme, with the possibility of performing SAR interferometry using wide-swath-mode data and of performing interferometry between Envisat and ERS-2.

RA-2

RA-2 will be inter-calibrated with respect to several other altimeter systems, in particular ERS-2 and Jason-1. In addition, absolute range calibration will be carried out to the level of 1 cm residual inaccuracies, using the northwest Mediterranean Basin as a reference surface. For the first time, the sigma-zero absolute calibration will be attempted. A synthesis of methods and tools to cross-calibrate all geophysical parameters retrieved from altimeter data has already been initiated, as well as results from cross-calibrating ERS-2 and Topex-Poseidon. Another group involved in the absolute calibration campaign presented an indirect approach using tide gauges, together with a direct approach using GPS buoys. GPS buoys are also used for altimeter drift monitoring. Taking advantage of the two frequencies on RA-2, a new parameter is being estimated: the Ku-band backscatter attenuation; its definition and validation were also presented.

ESA presented the significant improvements in RA-2's capabilities over previous altimetric missions and the major conceptual evolution of the ground processing strategy. This evolution leads to highly enhanced data products, particularly in terms of the quality of the near-real-time data for supporting international climate-study programmes such as GODAE and GOOS.

AATSR

The calibration studies for the Envisat AATSR have demonstrated that the instrument satisfies the strict performance criteria required to meet its scientific goals: the global measurement of sea-surface temperatures to an accuracy of 0.3 K, the monitoring of global vegetation coverage, and the retrieval of cloud properties. The need for high-accuracy shipboard devices for a proper validation of AATSR sea-surface temperatures was highlighted. The development of an algorithm and the validation of the generated product for providing global LSTs were presented.

Sciamachy, GOMOS and MIPAS
As for Sciamachy, the GOMOS and MIPAS validations are carried out through a combination of balloon campaigns, high-altitude aircraft campaigns, model assimilation (both Numerical Weather Prediction Model and Chemical Transport Models), satellite inter-comparison, and ground-based measurements. The validation of the GOMOS, MIPAS and Sciamachy products is being co-ordinated by a single group, the Atmospheric Chemistry Validation Team.

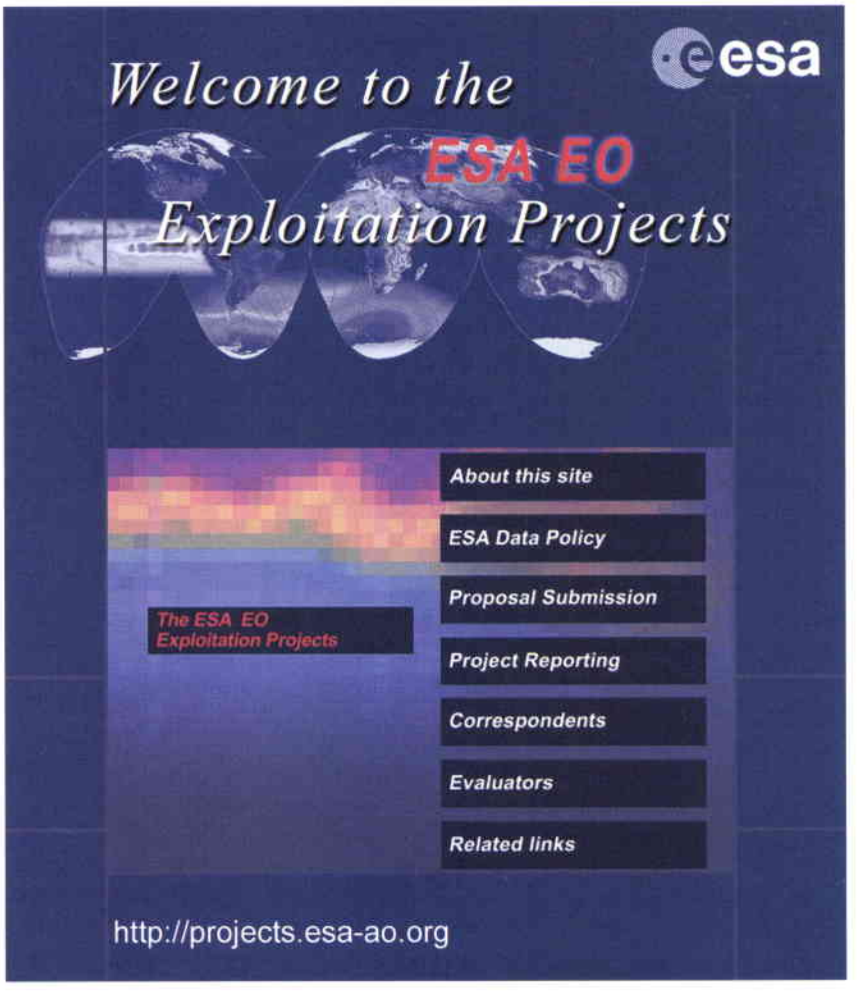
MERIS
The Medium Resolution Imaging Spectrometer (MERIS) is the first space-borne European optical sensor dedicated to the observation of ocean colour. It features 15 spectral bands, programmable in width and position, coupled with a resolution of 300 m that will provide data of outstanding radiometric precision and scientific interest. The in-flight instrument calibration of MERIS will use on-board sunlit calibration diffuser plates, which have been characterised to an absolute accuracy of 1%. The validation of Top Of the Atmosphere (TOA) radiance measured by MERIS will be achieved by comparison with TOA radiances derived from vicarious calibration methods. The ocean chlorophyll concentration will be validated using open-ocean dedicated ship campaigns in several coastal waters (mainly European) and long-term measurements from fixed buoys. The new water-vapour and cloud products will be validated through model assimilation and a dedicated helicopter campaign. The wide community of 322 Principal Investigators, selected via the Envisat Announcement of Opportunity, using MERIS data will contribute to the development of a variety of scientific and operational applications.

User recommendations and feedback
The Gothenburg Symposium provided the opportunity to capture the recommendations expressed by ERS/Envisat data users, both in the specialised sessions and during the final closing session.

Having noted that the algorithms have evolved and products have improved, users expressed the need for reprocessing of some ERS data sets such as the Radar Altimeter data from ERS-1. The ERS SAR tandem data archive remains a unique source of data for numerous applications presented at the Symposium, and use and exploitation of this archive is expected to continue to grow. The Envisat data will ensure ERS data continuity for a number of key applications, and for global-change monitoring in particular. The user needs for new products and services have been gathered, with many users stressing the development of new user tools and encouraging further development of on-line services. The need for continuous and timely access to data is a key factor for developing applications: Envisat will respond to this need thanks to the availability of onboard solid-state recorders and data relay through Artemis, and the near-real-time processing capability.

Every Symposium participant received a questionnaire aimed at soliciting their comments on ESA Earth-observation data exploitation and their expectations in terms of future ESA technical support. Some 180 responses were collected and the detailed results will be published in February 2001. The questionnaire also informed participants about the new Category-1 (CAT-1) Web site (Fig. 18), which under the new ERS-Envisat data policy

Figure 18. The ESA Earth Observation Exploitation Projects Web Site



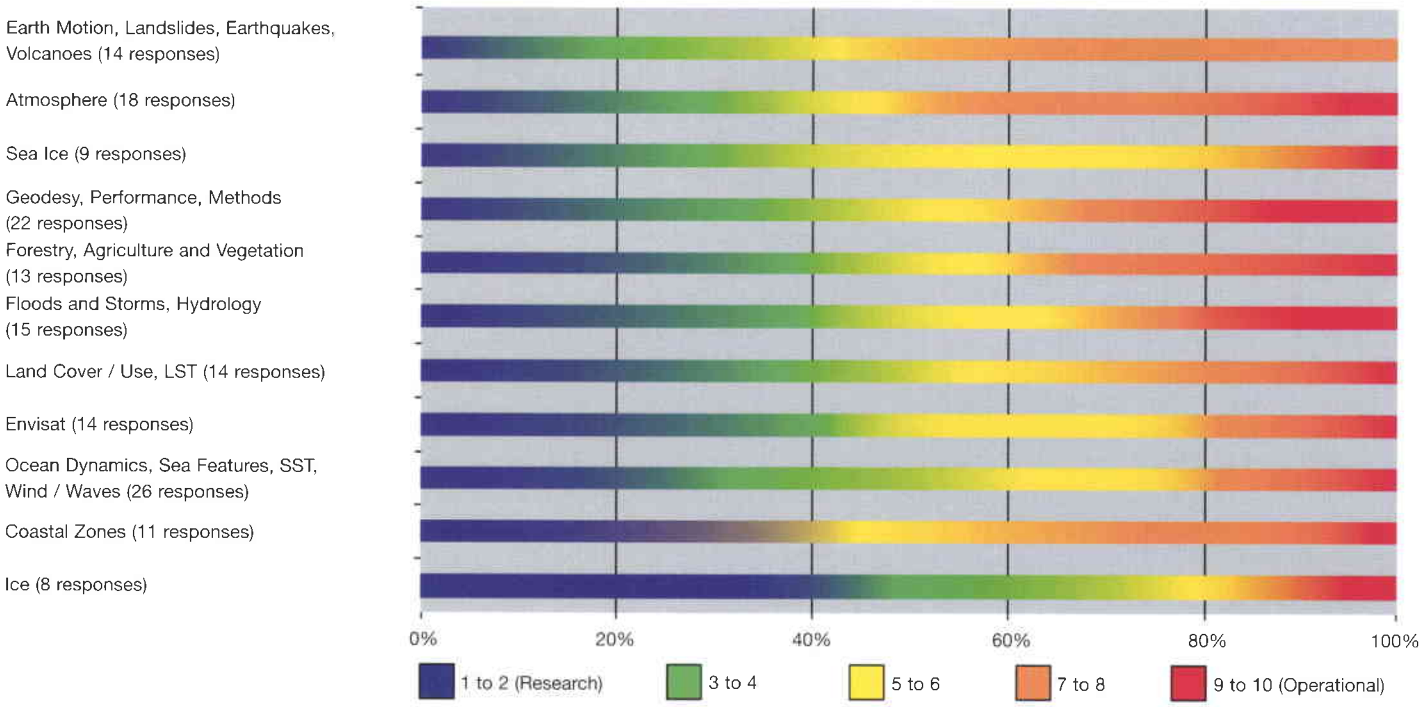


Figure 19. Evaluation by Principal Investigators of the status of their projects, classified by application theme. Blue and green refer to projects at the research stage, while yellow and orange indicate matured projects. Red indicates that Principal Investigators feel that their product, algorithm or service is ready for operational use

allows users to submit scientific project proposals at any time to ESA for use in research and application development in support of the mission objectives. The proposals are peer-reviewed by the Category-1 Advisory Group formed by external scientists (35 members) using web-based tools. The selected Principal Investigators (PIs) can get access, after signing ESA standard terms and conditions, at reproduction cost or even free of charge subject to the approval of the Earth Observation Programme Board.

The PIs were asked to evaluate the status of their projects with the following question: "On a scale of 1 (pure research), 5 (pilot project) to 10 (ready for market), how to operational do you think your project is?" Their responses are summarised, by application domain, in Figure 19. The graph shows that the ERS and Envisat AOs cover a wide spectrum, from pure research to applications development. The PIs expressed a need for continuous research. There is a clear indication that, in domains such as forest mapping, hazards, atmosphere, coastal zones, methods, floods and storms, a number of PIs felt their project had attained its research objectives. In the future, specific thematic workshops will be organised by ESA to support and foster science and application development where appropriate.

Conclusion

The ERS-Envisat Symposium provided a unique opportunity to demonstrate the contribution of the ERS-1 and ERS-2 missions to the monitoring of our environment and to the continual development of Earth-observation applications since 1991. The presentations made during the Symposium ranged from pure research, to the demonstration of applications and development of services and markets. The feedback collected from the Symposium attendees will be used to improve ESA's products and services.

The Envisat mission is now being readied for launch. It will ensure ERS data continuity and will enhance the European capability to monitor our environment. The new and improved Envisat sensors, algorithm and products will further develop the use and exploitation of Earth-observation data and will allow users to derive high-level information and products. ESA is preparing itself to work closely with the 674 Envisat Principal Investigators, with the support of its Earth-observation application engineers. The Envisat PI's reporting web site has already been opened for this purpose.

Acknowledgements

We would like to acknowledge the hospitality of the Chalmers University of Technology in hosting the Symposium, and the Scientific Committee, Chairs/Co-chairs for their work in supporting the programme preparation. Special thanks go to the Organising Committee for setting up a unique infrastructure, which greatly facilitated information exchange. We also acknowledge all attendees of and exhibitors at the Symposium for their presentations and feedback. We would also like to thank the ESA staff involved in the Symposium's organisation and in the preparation of the Proceedings.

EGNOS: The First Step in Europe's Contribution to the Global Navigation Satellite System

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The European Tripartite Group* - consisting of ESA, the European Commission and Eurocontrol - is implementing, via the EGNOS project, the European contribution to the Global Navigation Satellite System (GNSS-1), which will provide and guarantee the availability of navigation signals for aeronautical, maritime and land mobile trans-European network applications. On behalf of this Tripartite Group, ESA is responsible for the system design, development and qualification of an Advanced Operational Capability (AOC) of the EGNOS system.

EGNOS will significantly improve the accuracy of GPS, typically from 20 m to better than 5 m, will offer a service guarantee by means of the 'Integrity Signal', and will also provide additional ranging signals. It will operate on the GPS L1 frequency, and will thus be receivable with standard GPS front-ends. EGNOS is one of three inter-regional Satellite-Based Augmentation Services (SBAS) that complement GPS and GLONASS. The other two are the United States WAAS and the Japanese MSAS. The EGNOS coverage area will be the European Civil Aviation Conference area, but could be readily extended to include other regions within the broadcast area of the geostationary satellites, such as Africa, Eastern countries, and Russia. EGNOS will meet, in combination with GPS and GLONASS, many of the current positioning, velocity and timing requirements of the land, maritime and aeronautical modes of transport in the European region. It is the first element of the European satellite-navigation strategy and a major stepping stone towards Galileo, Europe's own global satellite navigation system for the future.

This article summarises the EGNOS system requirements, the overall system design, as well as the current status of the on-going development activities, including the EGNOS System Test Bed (ESTB).

* A formal agreement based on Article 228 of the EC Treaty was concluded on 18 June 1996 between the European Community, Eurocontrol and ESA, for the development of the European Contribution to the first-generation Global Navigation Satellite System (GNSS-1).

Introduction

The current capabilities of GPS and GLONASS, although very adequate for some user communities, present some shortfalls. The lack of civil international control represents a serious problem from the institutional point of view. In addition, there is a need for enhanced performance. In particular, the civil-aviation requirements for the precision and non-precision approach phases of flight cannot be met by GPS or GLONASS only. Marine and land users may also require some sort of augmentation for improving GPS/GLONASS performance.

The first-generation Global Navigation Satellite System, GNSS-1, as defined by the experts of the ICAO/GNSS Panel, includes the basic GPS and GLONASS constellations and any system augmentation needed to achieve the level of performance suitable for civil-aviation applications. EGNOS, which is a regional satellite-based augmentation equivalent to the American Wide-Area Augmentation System (WAAS) or the Japanese Multi-transport Satellite-based Augmentation System (MSAS), is the first European implementation for GNSS. EGNOS will become operational during early 2004. From 2006/2008 onwards, Europe should also have available the independent Galileo system, which will be compatible and interoperable with GPS/GLONASS/EGNOS.

The EGNOS mission

General objectives

The purpose of EGNOS is to implement a system that fulfils a range of user service requirements by means of an overlay augmentation to GPS and GLONASS, based on the broadcasting through geostationary satellites of GPS-like navigation signals containing integrity and differential-correction information applicable to the navigation signals of the GPS satellites, the GLONASS satellites, EGNOS's own GEO Overlay satellites and the signals of other GEO Overlay systems (provided they can be received by a GNSS-1 user located within the defined EGNOS service area). EGNOS will address the needs of all modes of transport, including civil aviation, maritime and land users.

Table 1. Aviation GNSS signal-in-space performance requirements

Typical operation(s)	Accuracy lateral/vertical 95%	Alert limit lateral/vertical	Integrity	Time to alert	Continuity	Availability	Associated RNP type(s)
En-route	2.0 NM/ N/A	4 NM/ N/A	10^{-7}/h	5 min	$1-10^{-4}$/h to $1-10^{-8}$/h	0.99 to 0.99999	20 to 10
En-route	0.4 NM/ N/A	2 NM/ N/A		15 s		0.999 to 0.99999	5 to 2
En-route, Terminal	0.4 NM/ N/A	1 NM/ N/A					1
Initial approach, NPA, Departure	220 m/ N/A	0.3 NM/ N/A		10 s		0.99 to 0.99999	0.5 to 0.3
APV-I	220 m/ 20 m	0.3 NM/ 50 m	$2x10^{-7}$ per approach		$1-8x10^{-6}$ in any 15 s		0.3/125
APV-II	16 m/ 8 m	40 m/ 20 m					0.03/50
Category-I	16.0 m/ 4-6 m	40 m/ 10-15 m		6 s			0.02/40

Aeronautical applications

The performance objectives for aeronautical applications are usually characterised by four main parameters: accuracy, integrity, availability and continuity of service. The values for these parameters are highly dependent on the phases of flight, typical requirements for which are included in Table 1. Neither GPS nor GLONASS can meet the required integrity, availability and continuity of service objectives without a system augmentation, although their performance in terms of accuracy alone could meet the requirements of en-route and terminal-area navigation and non-precision approaches. The actual requirements for Europe are currently being finalised by the International Civil Aviation Organisation (ICAO) in the form of SARPs (Standards and Recommended Practices).

Maritime applications

The performance objectives for maritime applications are generally broken down into ocean, coastal, inland-water and harbour navigation. Minimum performance requirements for these four generic cases have been quantified by the European Maritime Radio-Navigation Forum (see Table 2).

Table 2. Maritime GNSS typical performances

	System-level Parameters			
	Predictable Accuracy	Integrity		
	Horizontal (m)	Alert limit (m)	Time to alarm (s)	Integrity risk (/h)
Ocean	10	25	10	10^{-7}
Coastal	10	25	10	10^{-7}
Port approach and restricted waters	10	25	10	10^{-7}
Port	1	2.5	10	10^{-7}
Inland waterways	10	25	10	10^{-7}

Land applications

There are a large number of applications under development worldwide related to the use of satellite navigation and land mobile applications. These include: vehicle positioning, fleet management, position tracking, emergency services, theft protection, passenger information, road control, etc. Depending on the application, the accuracy needed for the various systems ranges from hundreds of metres to a few metres, requiring the use of differential corrections. Integrity is also required for some of these applications.

Other applications

Another important benefit of satellite navigation is the provision of a global time reference. EGNOS will provide a stable time reference to within a few nanoseconds of Universal Time

(UTC). Related applications include time synchronisation for cellular-phone networks, VSAT synchronisation, electric power synchronisation networks, Internet node synchronisation, etc. In addition, the combination of satellite navigation and mobile services will provide a wide range of new services.

Performance objectives for the EGNOS system

Of the three user communities, the civil-aviation requirements are the most stringent (in terms of integrity and continuity) and hence the EGNOS performance objectives are driven by those needs, whilst still covering the needs of the land and maritime user communities.

The coverage area serviced by EGNOS will be the European Civil Aviation Conference (ECAC) service Area (Fig. 1), comprising the Flight Instrument Regions (FIR) under the responsibility of ECAC member states (most European countries, Turkey, the North Sea, and the eastern part of the Atlantic Ocean).

The EGNOS AOC performance objectives are to provide a primary navigation service for all phases of flight, from en-route flying through to precision approaches within the ECAC area. In addition, EGNOS has the potential to also offer services over the full geostationary broadcast area, and discussions are being pursued with international partners to provide this capability in order to offer users a seamless global service.

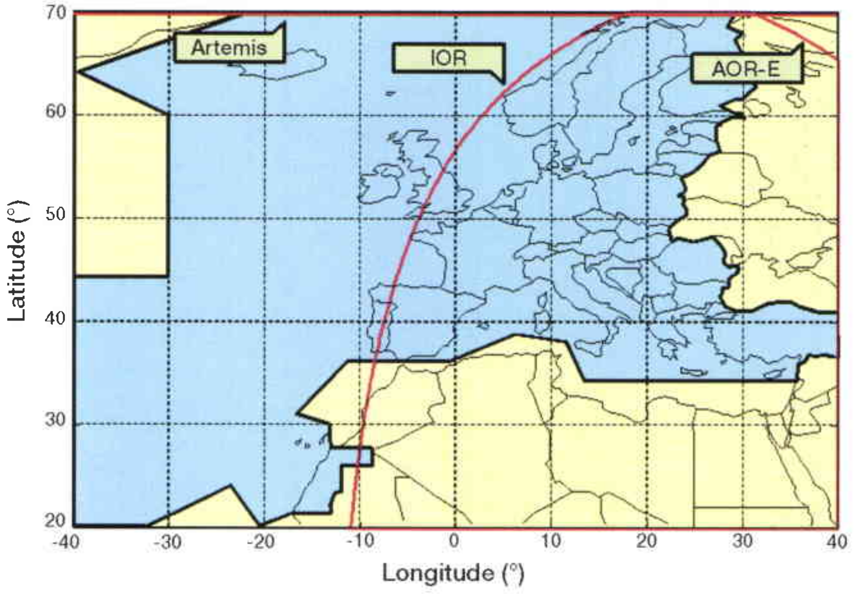


Figure 1. European Civil Aviation Conference (ECAC) approximate area coverage

The Main EGNOS Functionalities

- *GEO Ranging (R-GEO): Transmission of GPS-like signals from three GEO satellites (Inmarsat-3 AOR-E, Inmarsat-3 IOR, and ESA's Artemis satellite (Fig. 2) for the AOC phase), will augment the number of navigation satellites available to users.*
- *GNSS Integrity Channel (GIC): Broadcasting of integrity information will increase the availability of the GPS/GLONASS/EGNOS safe-navigation service to the level required for civil-aviation non-precision.*
- *Wide-Area Differential (WAD): Broadcasting of differential corrections will increase the GPS/GLONASS/EGNOS navigation service performance - mainly its accuracy - to the level required for precision approaches down to CAT-I landings.*

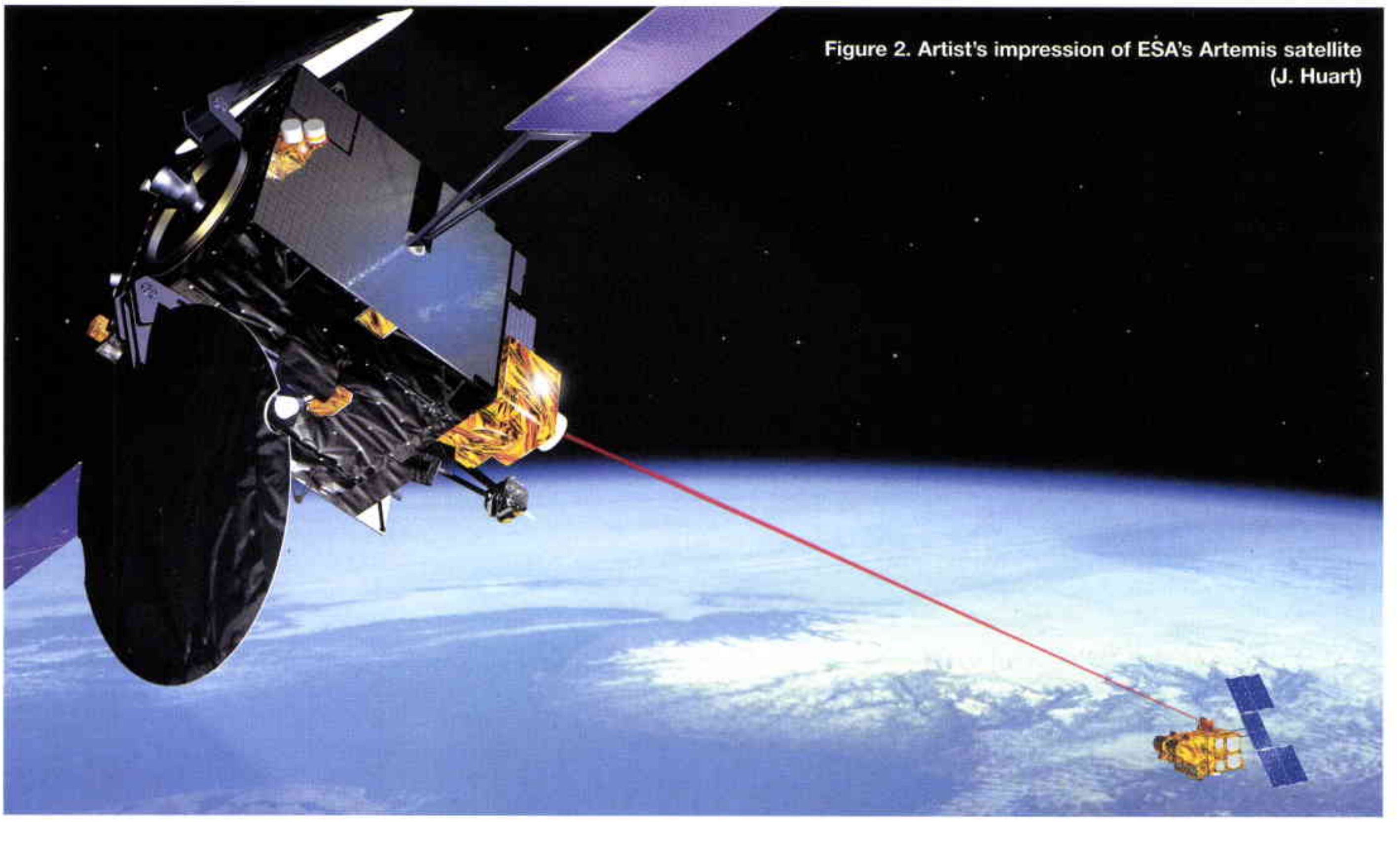


Figure 2. Artist's impression of ESA's Artemis satellite (J. Huart)

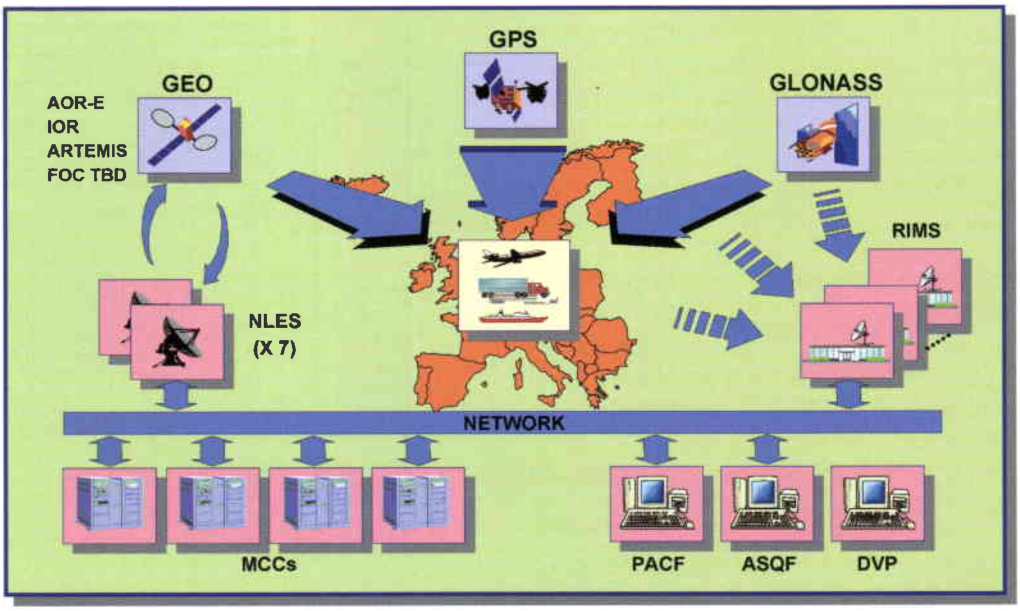


Figure 3. The EGNOS system architecture

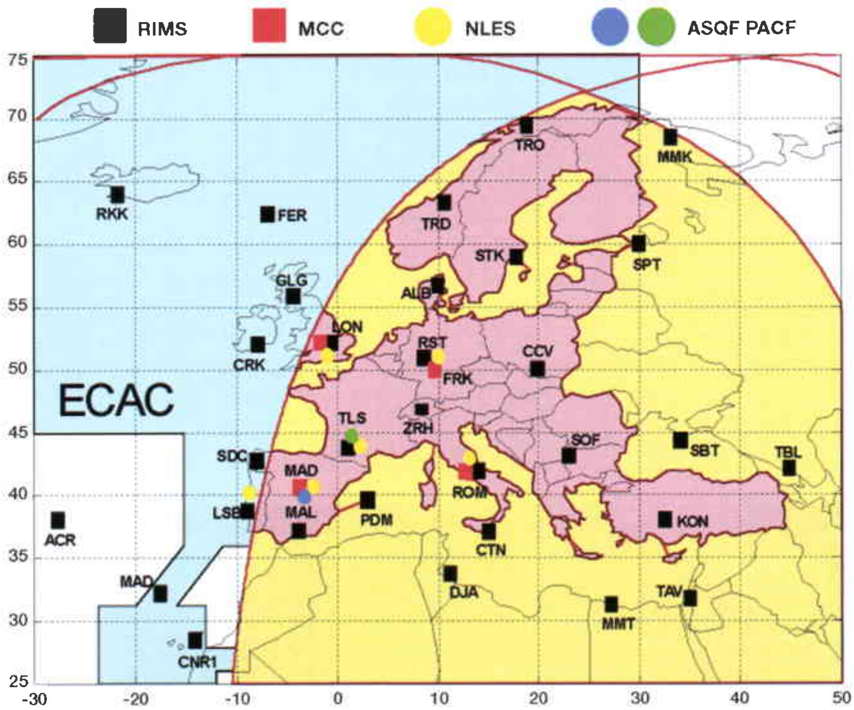


Figure 4. Planned sites for the various EGNOS Ground Segment elements

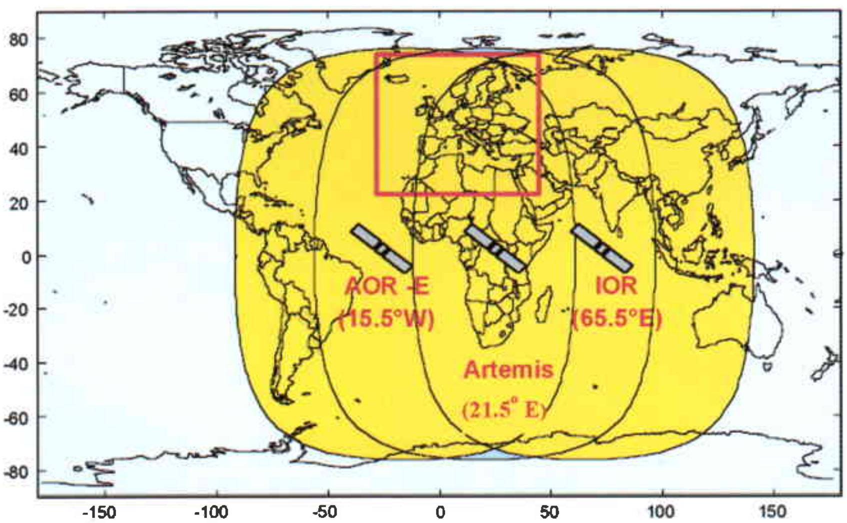


Figure 5. Inmarsat and Artemis EGNOS geostationary-satellite broadcast areas

The EGNOS architecture and system

The EGNOS reference architecture, depicted in Figure 3, is composed of four segments:

The *EGNOS Ground Segment* consists of GNSS (GPS, GLONASS, GEO) Ranging and Integrity Monitoring Stations (called RIMS), which are connected to a set of redundant control and processing facilities called Mission Control Centres (MCCs). The system will deploy 34 RIMS located mainly in Europe, and four MCCs located at Torrejon (E), Gatwick (UK), Langen (D) and Ciampino (I). The MCC determines the integrity, pseudo-range differential corrections for each monitored satellite, and ionospheric delays and generates the GEO satellite ephemeris. This information is sent in a message to the Navigation Land Earth Station (NLES), to be uplinked along with the GEO ranging signal to GEO satellites. The latter downlink this data on the GPS Link 1 (L1) frequency with a modulation and coding scheme similar to the GPS one. All ground-segment components are interconnected by the EGNOS Wide-Area Communications Network (EWAN). The system will deploy two NLESs (one primary and one back-up) per GEO navigation transponder and an NLES for test and validation purposes, located at Torrejon (E), Fucino (I), Aussaguel (F), Raisting (D), Goonhilly (UK), and Sintra (P), respectively. Figure 4 shows the planned sites for the various EGNOS ground-segment elements.

The *EGNOS Space Segment* is composed of geostationary transponders with global Earth coverage. The EGNOS AOC system is based on Inmarsat-3 AOR-E and IOR and the ESA Artemis navigation transponders (Fig. 5).

The *EGNOS User Segment* consists of an EGNOS standard receiver, to verify the signal-in-space (SIS) performance, and a set of prototype user equipment for civil-aviation, land and maritime applications. This prototype equipment will be used to validate and eventually certify EGNOS for the different applications being considered.

Last but not least, the *EGNOS Support Facilities* include the Development Verification Platform (DVP), the Application Specific Qualification Facility (ASQF) located in Torrejon (E), and the Performance Assessment and System Checkout Facility (PACF) located in Toulouse (F). These facilities are needed to support system development, operations and qualification.

The EGNOS AOC Pre-Operational Implementation involves the detailed design, development, deployment and verification of three elements:
- the EGNOS System Test Bed (ESTB)
- the EGNOS Advanced Operational Capability (AOC) System
- the AOC Complementary Activities.

The EGNOS System Test Bed (ESTB)
The ESTB, which became operational in January 2000, is a real-time prototype of EGNOS, providing the first continuous GPS augmentation service within Europe. It has been developed under ESA contract by an industrial consortium involving key European satellite-navigation companies such as Alcatel Space Industries, Astrium, GMV, Racal, Seatex and DLR. To optimise the overall ESTB effort, existing assets have been taken into account in building up the ESTB. These include the SATREF™ system from NMA (Norwegian Mapping Authority) and the EURIDIS ranging system from CNES. In early 2001, the ESTB will also be fully connected with the Italian Mediterranean Test Bed (MTB) being provided by ENAV (Italian Civil Aviation Authority).

The ESTB therefore constitutes a great step forward in terms of the European strategy for developing the future European EGNOS and Galileo satellite-navigation systems. The driving objectives in its development include:
- The support to EGNOS design: In particular, algorithm design benefits from the ESTB experience in both design and usage.
- The demonstration of the capabilities of the system to users: The ESTB constitutes a strategic tool for the European Tripartite Group (ETG). The ETG is promoting the use of EGNOS and analysing its capabilities for different applications. In particular, ESTB availability will allow Civil Aviation Authorities to adapt their infrastructure and operational procedures for future EGNOS use when it becomes operational. An ETG-sponsored workshop aimed at fostering the use of ESTB and analysing the needs of potential users was organised on 6/7 July 2000. The very large number of participants represented a wide variety of different users and countries worldwide.
- The analysis of future EGNOS upgrades.

The ESTB architecture (Fig. 6) is made up of a space segment comprising nominally two transponders onboard the Inmarsat-III Atlantic Ocean East and the Indian Ocean satellites, a ground segment comprising a number of reference stations spread across Europe and beyond, a processing centre and the Inmarsat uplink stations. Communication lines interconnect all stations. During the ESTB's development, the contributions from various providers have been integrated with the existing assets:
- a network of RIMS, consisting of eight in a first step, to be expandable in the near future, and which are permanently collecting GPS/GEO/GLONASS data
- a Central Processing Facility (CPF), generating the WAD (Wide Area Differential) user messages. The CPF is located in Hønefoss (N), and hosted by the SATREF™ platform
- one Navigation Land Earth Station (NLES), forming part of the EURIDIS ranging system, located at Aussaguel (F) and allowing access to the Inmarsat-III AOR-E satellite
- three EURIDIS RIMS for GEO ranging purposes. These RIMS are distributed on an intercontinental basis to provide a wide observation base for the geostationary orbit; they also collect GPS/GEO data
- a Processing Centre sited in Toulouse (France), devoted to the generation of the GEO ranging data, and which also acts as a node for the transmission of user messages
- a real-time communication network, allowing the transfer of the RIMS data to the CPF, and navigation messages from Hønefoss to the NLES.

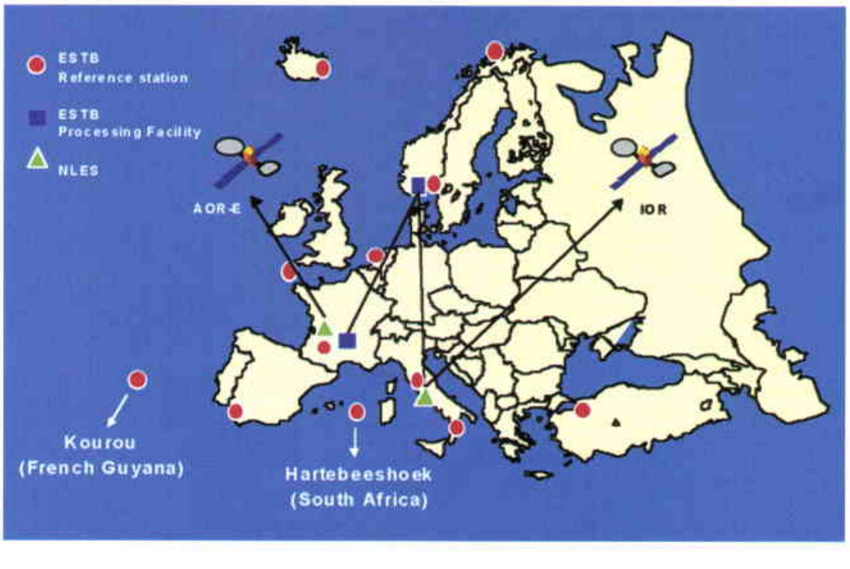


Figure 6. The EGNOS System Test Bed (ESTB) architecture

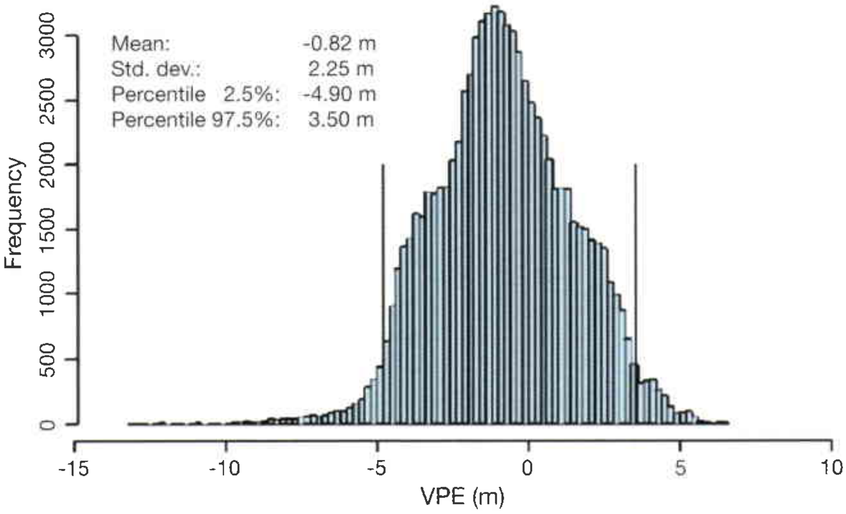


Figure 7. Typical ESTB vertical-error histogram

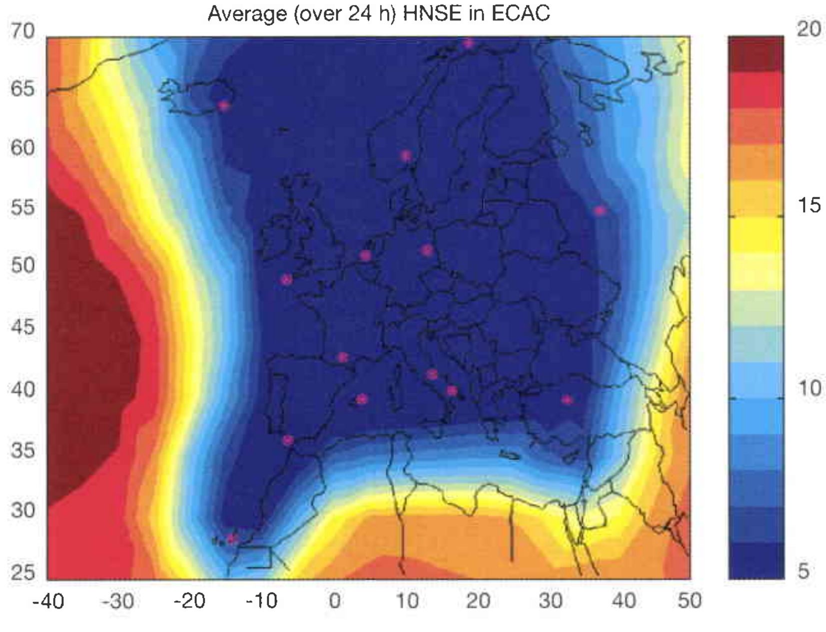


Figure 8. Estimated ESTB accuracy (2-sigma value) performances (including MTB)

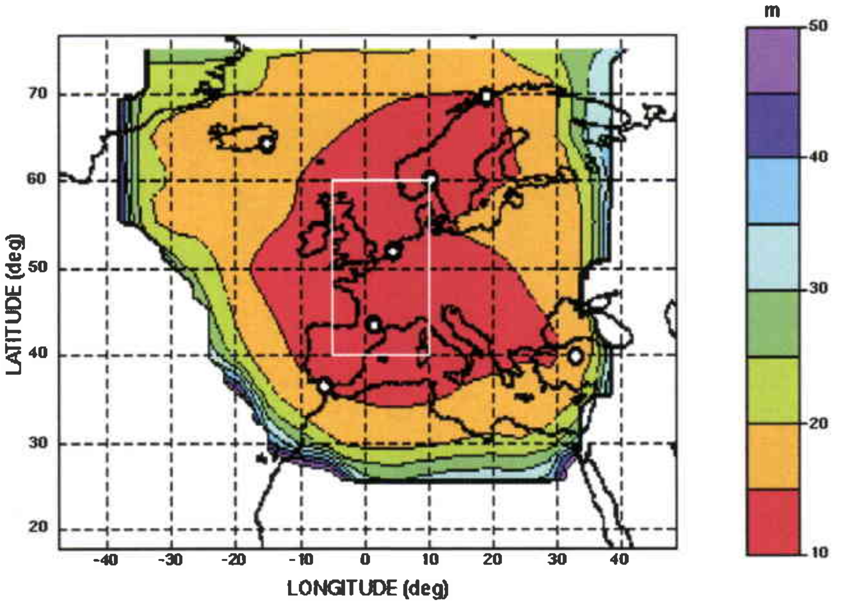


Figure 9. Typical vertical protection levels achieved by the ESTB

By using GPS and the ESTB Signal-In-Space, users within Europe can nowadays determine their positions with an error of less than 3 m horizontally and 5 m vertically, for 95% of the time. A typical ESTB vertical error distribution is represented in Figure 7, where the histogram of the errors is shown together with the associated statistical values (mean, standard deviation and 95th percentile). The area within which the test signal can be exploited is determined primarily by the locations of the reference stations. The present accuracy performances are illustrated in Figure 8.

The ESTB is also providing an integrity service, represented by the vertical and horizontal protection levels computed by the user with the ESTB information data, which are to bound with a probability of $2x10^{-7}$/150 sec the Alert limits associated with a particular operation. Figure 9 shows typical vertical protection levels (reflecting the guaranteed maximum error provided by the system ensuring the required level of safety) achieved throughout Europe through the ESTB. The values required for aircraft precision-approach landing are ensured across most of Europe. These results provide additional confidence in the current EGNOS design, especially given the reduced number of reference stations available and the current high solar activity.

The ESTB has already supported a number of application demonstrations during 2000. They included landing planes at several airports, guiding ships into harbours, but also navigating cars. The European Commission, national agencies and ESA are supporting such demonstration initiatives by European industry and operators in a number of ways.

The ESTB is still evolving to include the latest ICAO standards. Moreover, early in 2001 it will be operational 24 hours/day, 7 days/week, and will embrace capabilities for service expansion (outside Europe) and interoperability analysis (with other augmentation systems such as WAAS). In addition, the ESTB will be fully connected with the Italian Mediterranean Test Bed (MTB) being provided by ENAV (Italian CAA) and will incorporate additional reference stations provided in co-operation with AENA (Spanish CAA).

The ESTB Help Desk service can be reached via the E-mail address ESTB@esa.int. General information on ESTB scheduling, signal standards and the like can be found at: http://www.esa.int /navigation.

Interoperability of SBAS systems

In addition to EGNOS, there are currently two other Satellite-Based Augmentation Systems (SBASs) under development: the Wide-Area Augmentation System (WAAS) in the USA, and the multi-functional MTSAT-based augmentation system (MSAS) in Japan. Although all SBASs are currently defined as regional systems, it is commonly recognised that there is a need to establish adequate co-operation/co-ordination between the different systems so that their implementation becomes more effective and part of a seamless worldwide navigation system.

To guarantee a seamless worldwide service, it is essential that the three systems meet some common interoperability requirements. The service providers of those SBAS systems meet regularly in so-called 'Interoperability Working Group (IWG)' meetings to arrive at a precise understanding of the term interoperability, and to identify the necessary interfaces between SBASs. The EGNOS system includes specific requirements so that interoperability may indeed be achieved. In parallel, several initiatives are in progress for performing testbed interoperability demonstrations and flight trials in the near future.

In addition to interoperability, EGNOS has a built-in expansion capability to enable extension of the services over regions within the Geostationary Broadcast Areas of the GEO satellites used, such as Africa, Eastern countries, and Russia (Fig. 10). This combination of SBAS interoperability and expansion possibilities should allow the provision of a truly global and seamless worldwide navigation service (Fig. 11).

Current EGNOS programme status

The EGNOS programme comprises two different phases: the Initial Phase and the AOC Implementation Phase. The EGNOS Initial Phase was successfully concluded in November 1998 with the System Preliminary Design Review (PDR). The relevant ESA Programme Board approved full implementation of the EGNOS AOC System in December 1998, and the prime contract was signed with Alcatel Space Industries (F) on 16 June 1999 (Fig. 12).

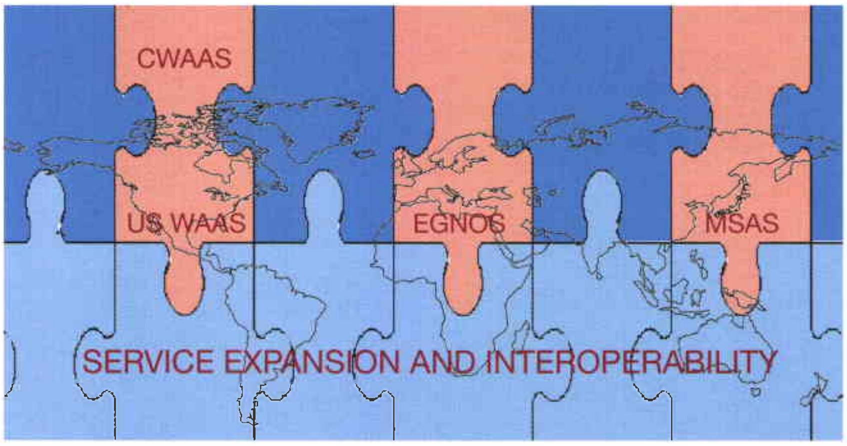


Figure 10. SBAS global interoperability and potential service expansion

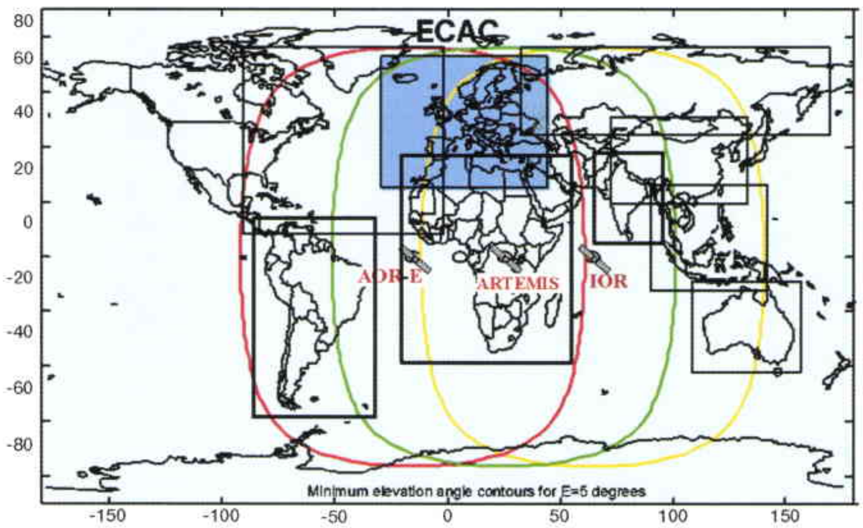
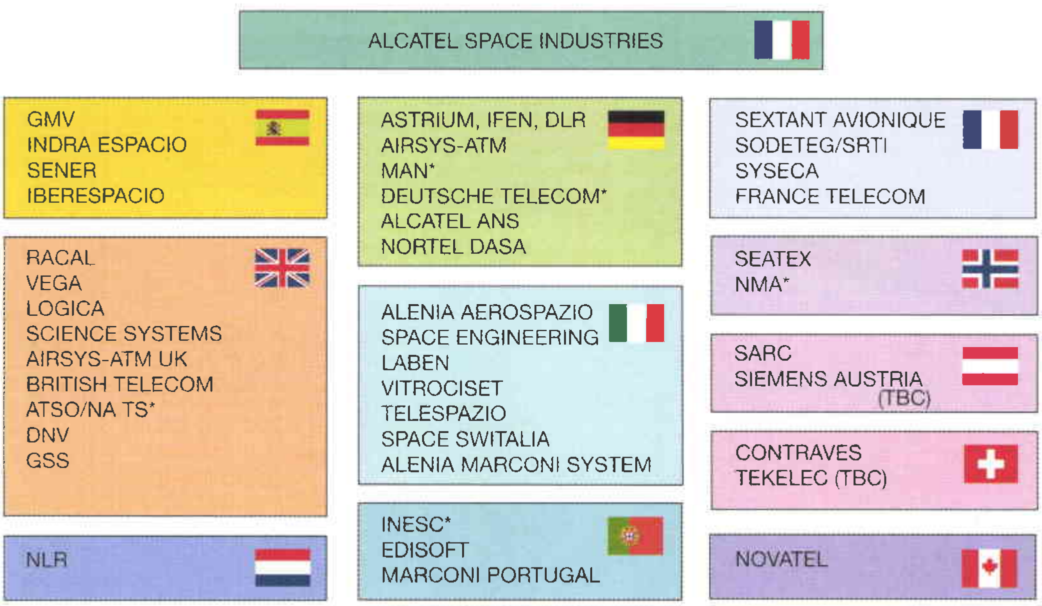


Figure 11. EGNOS AOC service broadcast areas



* Involvement in addition to EGNOS main development contract

Figure 12. The industrial team in charge of EGNOS AOC

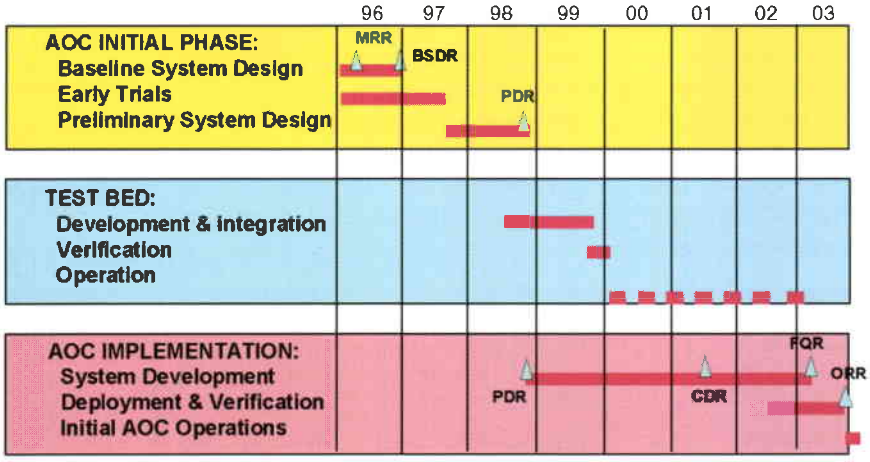


Figure 13. EGNOS AOC implementation schedule

Since then, all subsystem activities have been kicked-off and detailed design of those subsystems is currently in progress, after progressive completion of all subsystem PDRs during the course of 2000. The Operational Readiness Review is scheduled for December 2003.

The next milestones in the EGNOS AOC Implementation Phase (Fig. 13) are the System CDR in the second half of 2001, the System Factory Qualification Review (FQR) in early 2003, and the EGNOS AOC Operational Readiness Review (ORR) in December 2003.

The EGNOS project includes significant contributions from the French Space Agency (CNES), the Norwegian Mapping Authority (NMA), and the main European Air Traffic Management service providers such as AENA (E), NAV-EP (P), DFS (D), ENAV (I), DGAC (F), NATS (UK) and SwissControl (CH). Those partners will in particular provide ESA with in-kind deliveries, including the infrastructure to host a number of the necessary EGNOS ground stations. Some other hosting sites are being finalised by ESA via specific agreements with potential hosting entities. Site-survey activities started in mid-2000 and will last until mid-2001.

In parallel with those on-going development efforts, the actual integration of EGNOS into the Galileo mission is currently under detailed assessment. The results to date are very promising, and demonstrate that the EGNOS system can be used as a sound foundation on which the Galileo system architecture can capitalise.

Conclusion

EGNOS is the main European contribution to GNSS-1 to serve the needs of maritime, land transport and aeronautical applications in the European and neighbouring regions. For aviation, EGNOS AOC will be used in the ECAC Region as a primary means of navigation for all phases of flight down to CAT-I. EGNOS will be interoperable with equivalent US (WAAS) and Japanese (MSAS) SBAS systems, with the aim of contributing to a truly worldwide global navigation system.

The EGNOS Test Bed signal-in-space has been available since early 2000, and is being used to support demonstrations and trials in Europe, Africa and South America, and interoperability trials with Japan and the USA. The ESTB provides a unique opportunity for validating new application developments in a realistic environment, in preparation not only for the EGNOS operations, but also for future Galileo services.

EGNOS AOC development will be completed by the end of 2003, enabling operations to start in 2004.

Figure 14. Artist's impression of the Galileo satellite-navigation constellation (J. Huart)

The Selection of New Science Missions

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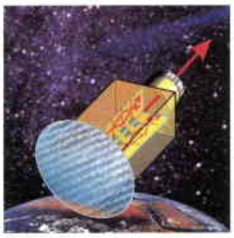
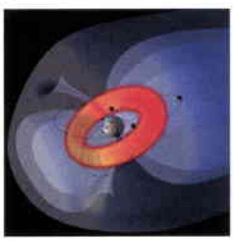
Eddington


Hyper


Master

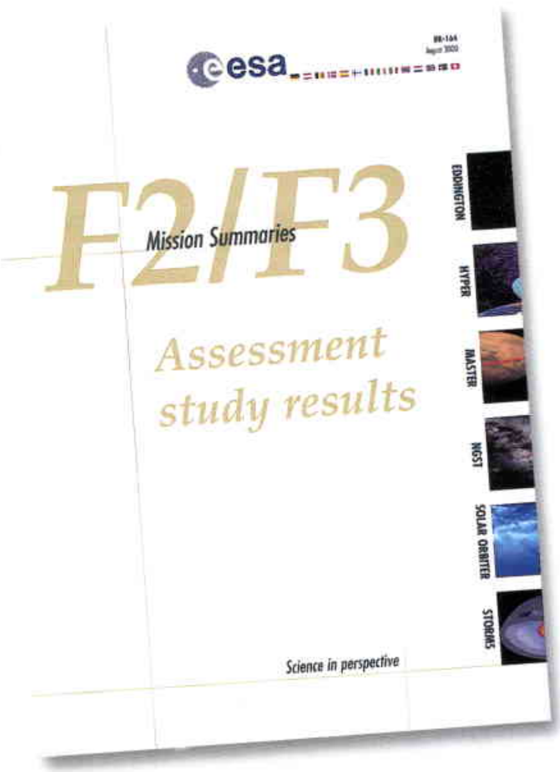

NGST


Solar Orbiter


Storms

In October 1999, ESA's Science Directorate issued a Call for Mission Proposals for the second and third Flexi-missions (F2 and F3) of the Horizons 2000 Scientific Programme. 49 proposals had been received from the European scientific community by the deadline of 31 January 2000.

Of these, six were selected by ESA's advisory bodies for an assessment study:
- Eddington (a stellar physics and planet finder explorer)
- Hyper (Hyper Precision Atom Interferometry in Space)
- Master (Mars and Asteroid Mission)
- NGST (Next-Generation Space Telescope)
- Solar Orbiter (a high-resolution mission to the Sun and inner heliosphere), and
- Storms (a three-spacecraft constellation for the study of magnetospheric storms).



The assessment studies, supported by the Concurrent Design Facility within the Directorate of Technical and Operational Support at ESTEC, were completed by mid-2000, and published as a series of reports to the ESA advisory bodies. An open presentation on the six study reports was made on 12 September 2000 at UNESCO in Paris.

On the next day, 13 September, the results of the four Cornerstone studies, which have been pursued over the last years following the recommendations of the Survey Committee in 1995, were also presented to the ESA advisory groups and Science Programme Committee (SPC) delegates. These Cornerstone programmes are:
- BepiColombo (Mercury orbiter and lander)
- GAIA (origin and evolution of our Galaxy through microarcsec astrometry to 20 ~mag)
- IRSI/Darwin (infrared space interferometer for the detection and spectroscopy of Earth-mass planets), and
- LISA (space interferometer for gravity-wave detection).

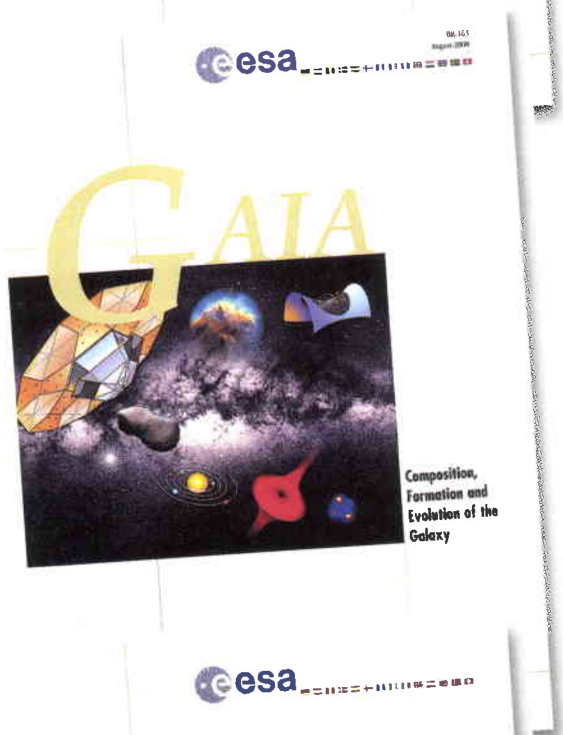
The Astronomy, the Solar System and the Fundamental Physics Working Groups met to review the results of these studies on 14 September, and the Space Science Advisory Committee (SSAC) met on 15 September to formulate their recommendations to the SPC. The outcome was that:
- BepiColombo should be selected as Cornerstone-5 (launch in 2009) and the GAIA mission as Cornerstone-6 (launch not later than 2012)
- LISA, the Fundamental Physics Cornerstone, should be implemented within a Flexi-mission envelope, in collaboration with NASA
- the European involvement in NGST should be pursued with the highest priority
- Solar Orbiter should be selected as a Flexi-mission, to be implemented after BepiColombo and capitalising on its technological development, with potential NASA cooperation

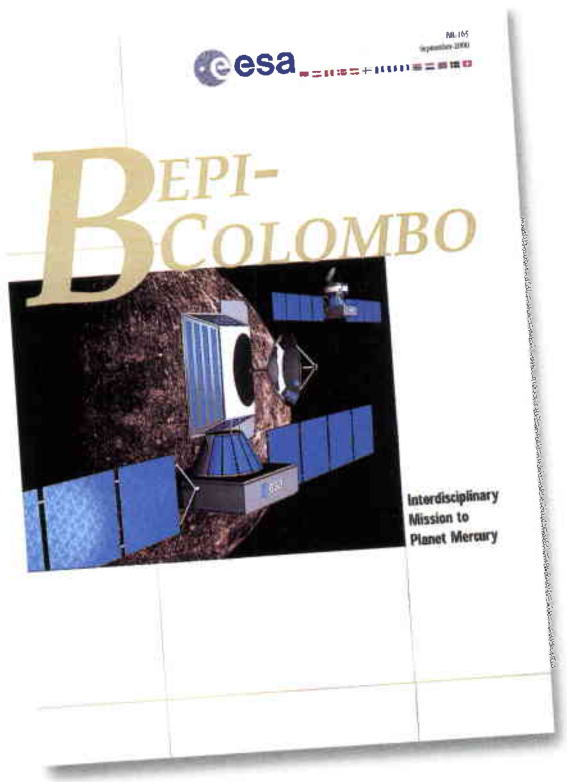
– Eddington should be selected as a 'reserve mission', which could be implemented depending on the NGST and LISA schedules or through the provision of further resources.

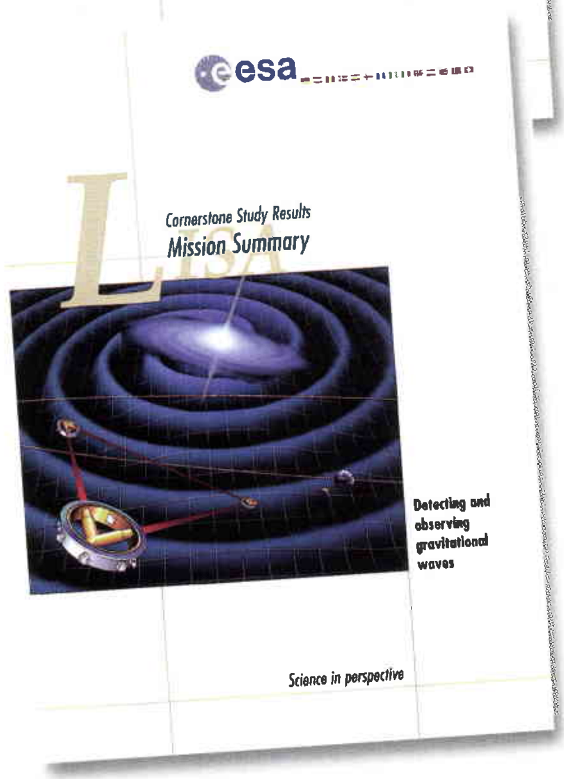
The SPC, at its meeting on 11-12 October, unanimously approved this package for the next phase of the Horizons 2000 Science Programme. The SPC noted the need to review the details of the implementation at each decision on the 'Level of Resources' and emphasised the need to maintain flexibility for new ideas and the earliest appropriate implementation of GAIA.

Further, the SPC approved a modest ESA participation in the Corot (astroseismology) and Microscope (test of the Equivalence Principle) missions in the French national programme, both of which had actually been proposed in response to the 1999 call for F2/F3missions.

While the four Cornerstone missions have been described earlier in the ESA Bulletin (No. 103, August 2000), presented here are six short articles on the F2 and F3 candidate missions, written by the study scientists from the Space Science Department and the study managers from the Future Projects Study and Technology Office. Due acknowledgements are made to the Science Teams of the candidate missions and other ESA staff involved, particularly in the Technical and Operational Support and the Science Directorates. esa







Eddington

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The quest for other 'worlds' in the Universe is one of mankind's oldest intellectual endeavours; while philosophers and scientists have speculated about the existence of other worlds already since antiquity, only now, at the beginning of the 21st century, has the technique needed to answer this question on a scientific basis become available. The Eddington mission is designed to finally answer the fundamental question: 'Are there other habitable planets?' Its design allows one to detect a significant number of habitable planets orbiting other stars, and to determine how common they are, as well as to establish their key characteristics.

The other key scientific goal of Eddington is to understand the structure and evolution of stars. Stars are the building blocks of the Universe, the key component of galaxies and, as chemical elements are created inside them, the seat of all chemical evolution in the Universe. Yet our understanding of the interior structure of stars is still very limited, especially for some of the critical stages in stellar evolution. Stars are also the clock with which the age of galaxies, and thus of the Universe, is measured. Yet an accurate and reliable calibration of this clock is still missing. To understand stars and their evolution, one needs to look 'inside' them. Of course stars are opaque, and no photons ever escape directly from their interiors. They are, however, transparent to sound waves, and thus seismic techniques can actually 'look' inside stars at a very accurate level of detail. These techniques have, of course, been used successfully on Earth (by studying the propagation of seismic waves), but also on the Sun, for example by the very successful ESA/NASA SOHO mission.

Both of these crucial scientific enterprises can be achieved with the same simple technique, namely high-precision, space-based, wide-field photometry. The only technique available today for finding terrestrial planets is to look for the minute decrease in the light of the parent star when the planet transits in front of it. While small (about 1 part in 10 000), the dip in the stellar light is easily measurable from space with an adequate, purpose-built photometer. Indeed, the feasibility of the approach has recently been demonstrated by the detection, from the Hubble Space Telescope (HST), of the transit of a giant (Jupiter-sized) planet in front of another star. However, HST has a very small field of view and thus can only observe one star at a time (the planet was already known to exist around the star shown in Fig. 1). On the other hand, Eddington's wide field of view will allow us to survey the large number of stars (hundreds of thousands) necessary to find other rocky planets similar to the Earth, i.e. of similar size and with a similar surface temperature.

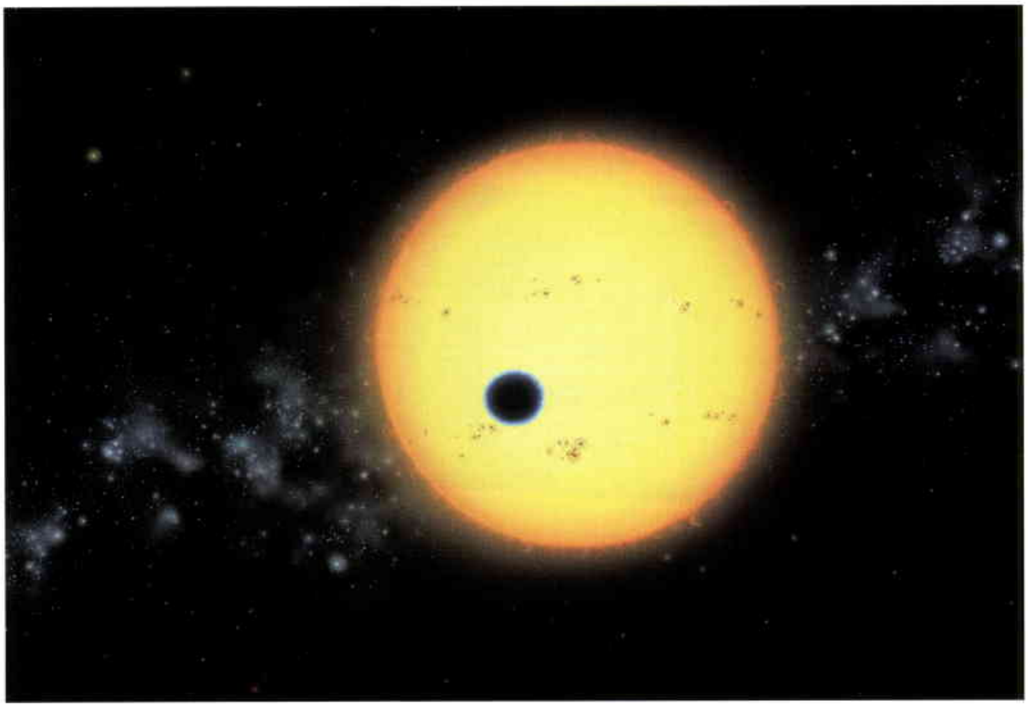
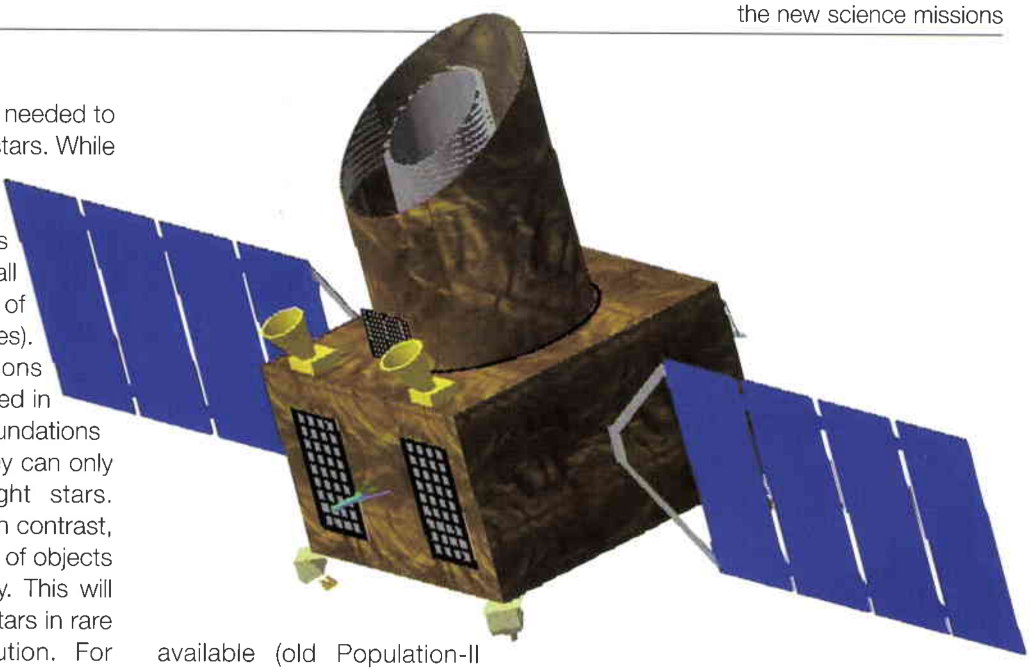


Figure 1. Artist's impression (approximately to scale) of the recently observed transit of the giant planet in front of the star HD 209458 (Copyright L. Cook)



Accurate photometry is also the tool needed to detect seismic oscillations on other stars. While this is now routinely achieved on the Sun, e.g. with SOHO, Eddington will do the same for a large number (tens of thousands) of stars spanning all interesting stellar types (in terms of mass, chemical composition and ages). While some small national missions (Most, Corot and Mons) are scheduled in the next few years to lay the initial foundations of asteroseismology from space, they can only observe a small number of bright stars. Eddington's observing programme, in contrast, is characterised by the large number of objects spanning a wide range in luminosity. This will give it the unique ability to observe stars in rare but crucial stages of their evolution. For example, Eddington will study with a high level of detail key stellar types such as the precursors to type-II supernovae, the stellar 'chemical factories' where most of the elements that are present in the Universe are manufactured. Eddington will also be able to 'observe' the interior of the oldest known stars available (old Population-II stars), whose age sets an important limit to the age of the Universe (according to current knowledge, some old stars appear to have been born before the Big Bang, which is a paradox that Eddington will address). The wide range of stellar types that Eddington will observe is shown in Figure 2.

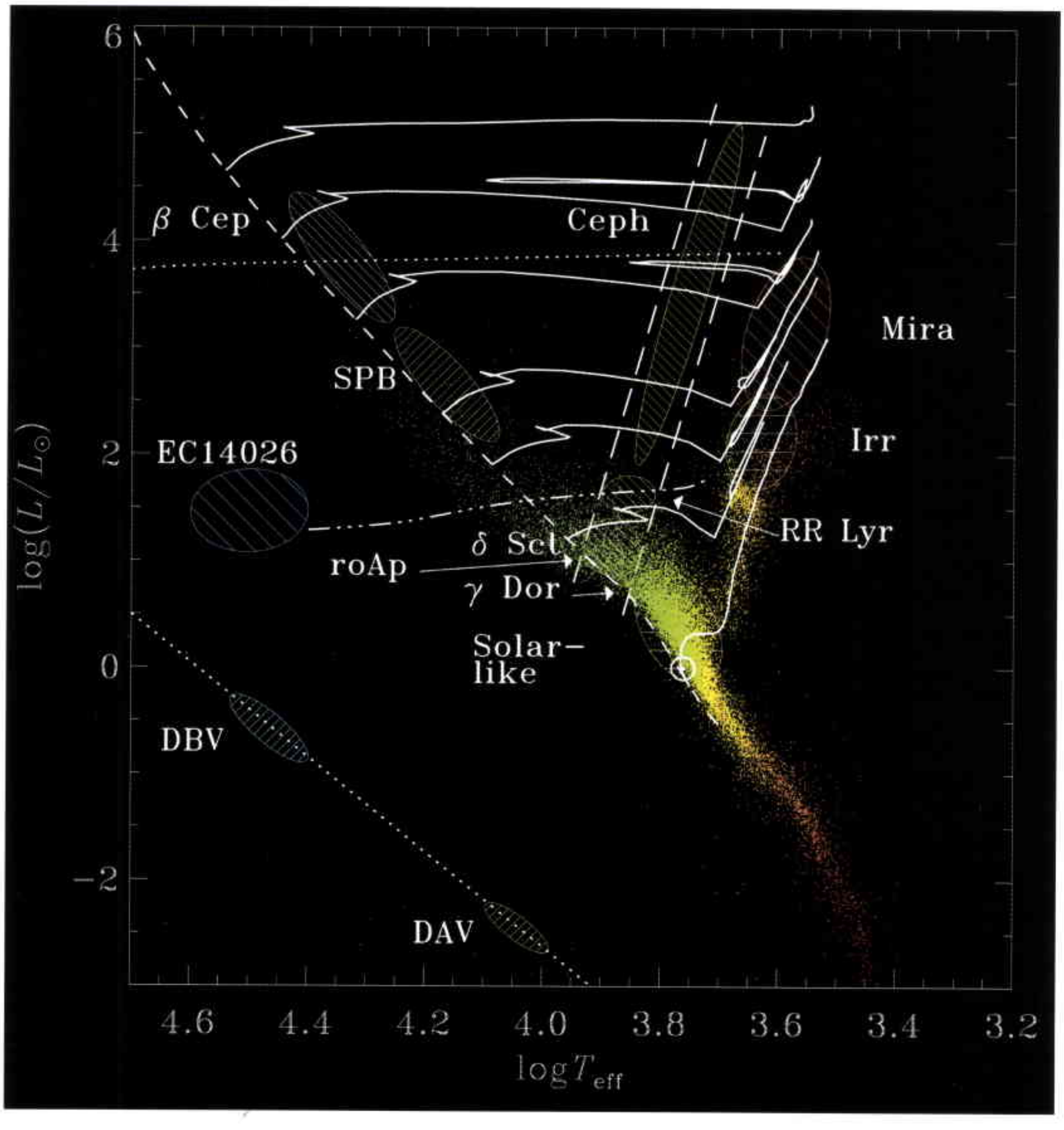


Figure 2. Schematic locations of various classes of oscillating stars in the Hertzsprung-Russell diagram, together with actual Hipparcos observations of stars in the solar neighbourhood. All of the stellar types shown here will be observed in detail by Eddington

How our Solar System formed is still an open question. Existing theories about its origin did not predict the existence of giant planets in close orbits, yet since the discovery of the first extra-solar planet in 1995 these have been shown to be common. However, ground-based techniques are intrinsically limited in terms of the discovery of giant planets, and therefore give only a partial view of the state of planetary systems around other stars. Observation of a large number of planetary systems spanning a wide range of planet masses is needed to understand their formation, and thus ultimately the formation of our own Solar System. Eddington is designed to supply the observational data needed.

At the same time Eddington will enable us to understand, in detail, stars with the same mass and composition as our Sun, but in different stages of their evolution. In particular, young Suns will be studied, providing a detailed understanding of the conditions in the early Solar System, at the times at which life must have started to form. Thus, while yielding fundamental insights into the evolution of stars and planets elsewhere in our Galaxy (and ultimately in the Universe at large), closer to home Eddington will lead to a fundamental advance in our understanding of our own Solar System.

In addition to its the key science goals (stellar structure and evolution, and habitable planet finding), the long, wide-field observations performed by the Eddington telescope will allow a variety of additional, 'parallel' science goals to be addressed. In the initial study, several activities were identified, i.e. the study of variability from QSOs, the study of the faint halos from galaxies, as well as several additional scientific projects deriving from the accurate measurement of stellar variability (e.g. eclipsing binaries, stellar activity, etc.).

Allocation of most of Eddington's observing time will take place through an open Announcement of Opportunity, so that the whole European astronomical community will be able to participate in its science. This applies to both the core scientific goals as well as the parallel science.

Neither of Eddington's key scientific enterprises can be carried out from the ground, as the Earth's atmosphere perturbs the starlight through the well-known – but unavoidable – phenomenon of 'scintillation' (which makes stars twinkle). This introduces noise into the photometric measurements, which obscures any signal either from transiting terrestrial planets or from low-amplitude stellar oscillations. At the same time, however, space offers an ideal environment in which to perform such measurements: outside the Earth's atmosphere, the dip in stellar light caused by a transiting planet will be immediately recognisable with a modest-sized telescope and a simple CCD camera. Indeed, Eddington's telescope is very simple, and relies on technology available today, with similar telescopes already operational on Earth.

More generally, Eddington can be realised with simple, already-available technology, and its payload can make use of different existing spacecraft, such as the Mars Express or the Prima multi-purpose bus. The mission is designed to be launched to an L2 orbit, which offers the benefit of a very quiet environment and permits the long, undisturbed observations that are crucial to the achievement of Eddington's goals.

The direct observation of habitable planets, and the determination of whether they are life-supporting, is part of ESA's long-term programme, with the IRSI-Darwin mission set to actually study the composition of the atmospheres of such planets. This is an extremely ambitious programme requiring challenging, yet to be developed technologies. The Eddington mission, by detecting the first habitable planets, will act as a key precursor of the IRSI-Darwin programme: it will prove the existence of habitable planets, and it will provide a direct measurement of their frequency around different types of stars, thus providing key knowledge to steer the construction and the exploitation of such a challenging programme.

At the same time, Eddington's science in the field of stellar structure and evolution is key to the achievement of the ambitious scientific goals of GAIA, one of ESA's Cornerstone missions: GAIA will trace the history of our Galaxy back in time, by mapping in detail the positions and orbits of a significant fraction of its stars. Eddington will provide the accurate clock (currently lacking) with which the age of these stars can be precisely determined. esa

Hyper

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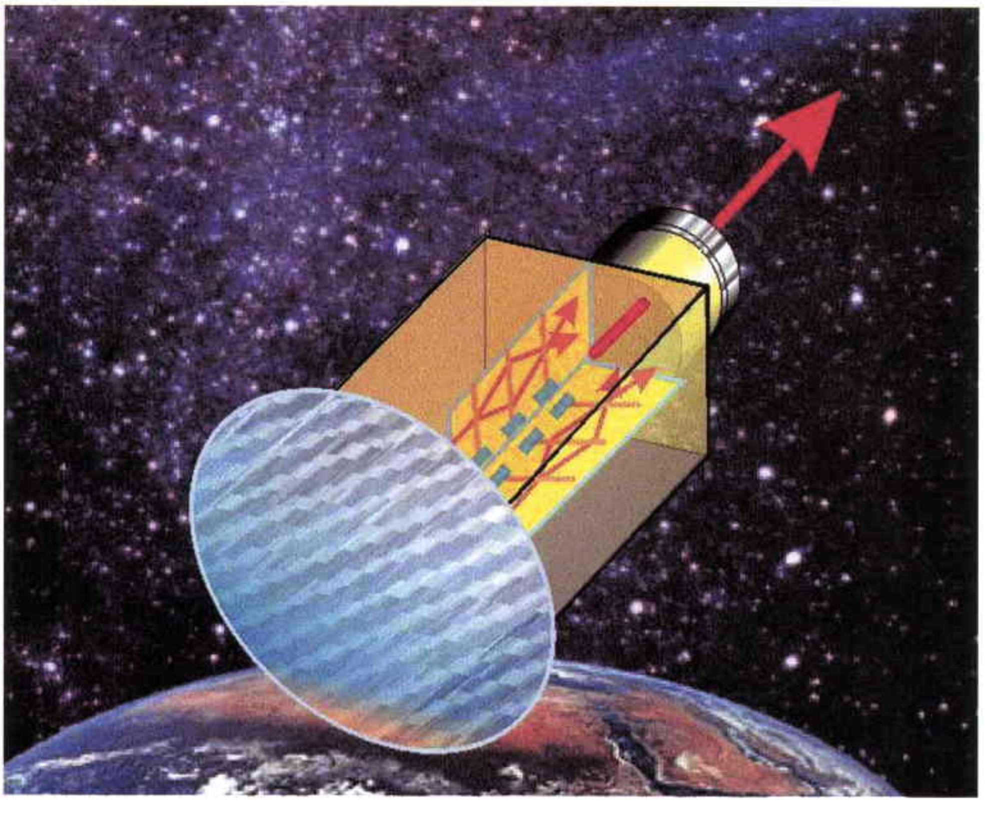
Atom interferometers are versatile sensors, which can be employed for many different purposes depending on the interferometer design selected. The Hyper mission has been designed to realise two different types of sensors based on atom interferometers, each optimised for a specific scientific objective: a Mach-Zehnder interferometer used as an atomic gyroscope, and a frequency-sensitive Ramsey-Bordé interferometer.



In a Mach-Zehnder interferometer, slowly drifting atoms are coherently split, re-directed and re-combined such that the atomic trajectories enclose as large a surface as possible. Beam splitting is achieved by atom–light interaction. During each interaction sequence, the atoms cross two counter-propagating laser beams. An atom absorbs a photon from one laser beam and is stimulated by the other laser beam to re-emit the photon. In this way, twice the recoil of a photon is transferred coherently to the atomic wave (rather than atoms), such that the atomic wave is either equally split, deflected or re-combined. The Mach-Zehnder interferometer senses both rotations and accelerations in only one particular direction. Two interferometers with counter-propagating atoms are required to discriminate between the two kinds of motion. This combination of two interferometers is called an Atomic Sagnac Unit (ASU).

Unlike the Mach-Zehnder interferometer, the Ramsey-Bordé configuration is designed to measure frequencies. It is based on atoms at rest, which are split by a temporal sequence of four laser pulses retro-reflected on one mirror such that two atom interferometers are formed. The frequency sensitivity is due to the asymmetry of the beam splitting. The part of the matter wave that is split off gets excited and experiences the recoil shift, while the other part of the matter wave remains unaffected. In the two interferometers, the frequency shifts have opposite signs, because the roles of the ground and excited state are reversed.

Hyper carries four cold-atom interferometers, which can be operated in either Mach-Zehnder or Ramsey-Bordé mode. For measuring the gravitomagnetic effect of the Earth, the four atom interferometers are used in Mach-Zehnder mode, while for the measurement of the fine-structure constant they are used in Ramsey-Bordé mode. In space, the drift velocity of the atoms can be reduced to 20 cm/s, which gives 3 s of drift time in a 60 cm enclosure. The temperature of the atoms is 1 μK, corresponding to a thermal velocity of ~1 cm/s.

The primary scientific objectives of the Hyper mission are:

- *To test General Relativity by mapping the spatial (latitudinal) structure (magnitude and sign) of the gravitomagnetic (frame-dragging or Lense-Thirring) effect of the Earth for the first time, with about 3-5% precision.*

Gravitomagnetism describes the general relativistic modification of the metric of spacetime around rotating massive bodies, such as the Earth. Hyper will make the first map of the spatial contour of the gravitomagnetic effect close to the Earth. It will achieve a precision of 3 - 5% in one year of accumulated measurement time (continuous measurements are not required). As they move in their orbit, atom gyroscopes with high rotation-rate sensitivity (10^{-12} rad/s at 1 Hz) will trace the latitudinal variation of the Earth's drag with respect to an inertial reference provided by a guide star monitored by a high-performance star tracker. In an atom interferometer, the Earth's rotation affects the trajectories of the coherently split matter waves differently and thus causes a Sagnac-like phase shift at the exit ports of the interferometer. Proposals to track satellites precisely with lasers such as the Lageos project, or the even more ambitious Gravity Probe B measuring the precessions of free-falling gyroscopes without any interruptions over one year, will only be sensitive to the mean effect and cannot resolve the latitudinal shape of the gravitomagnetic effect.

- *To determine independently from Quantum Electrodynamics (QED) theories the fine-structure constant by measuring the ratio of Planck's constant to the atomic mass one to two orders of magnitude more precisely than present knowledge.*

The fine-structure constant α is a measure of the strength of the electromagnetic interaction, and hence plays an important role in Grand Unification Theories (GUT). Presently, the most precise value of α is inferred from the anomaly of the magnetic moment of the electron relying on QED. In contrast to this measurement, the route chosen by Hyper to determine α does not rely on QED and, thus, represents an independent test for

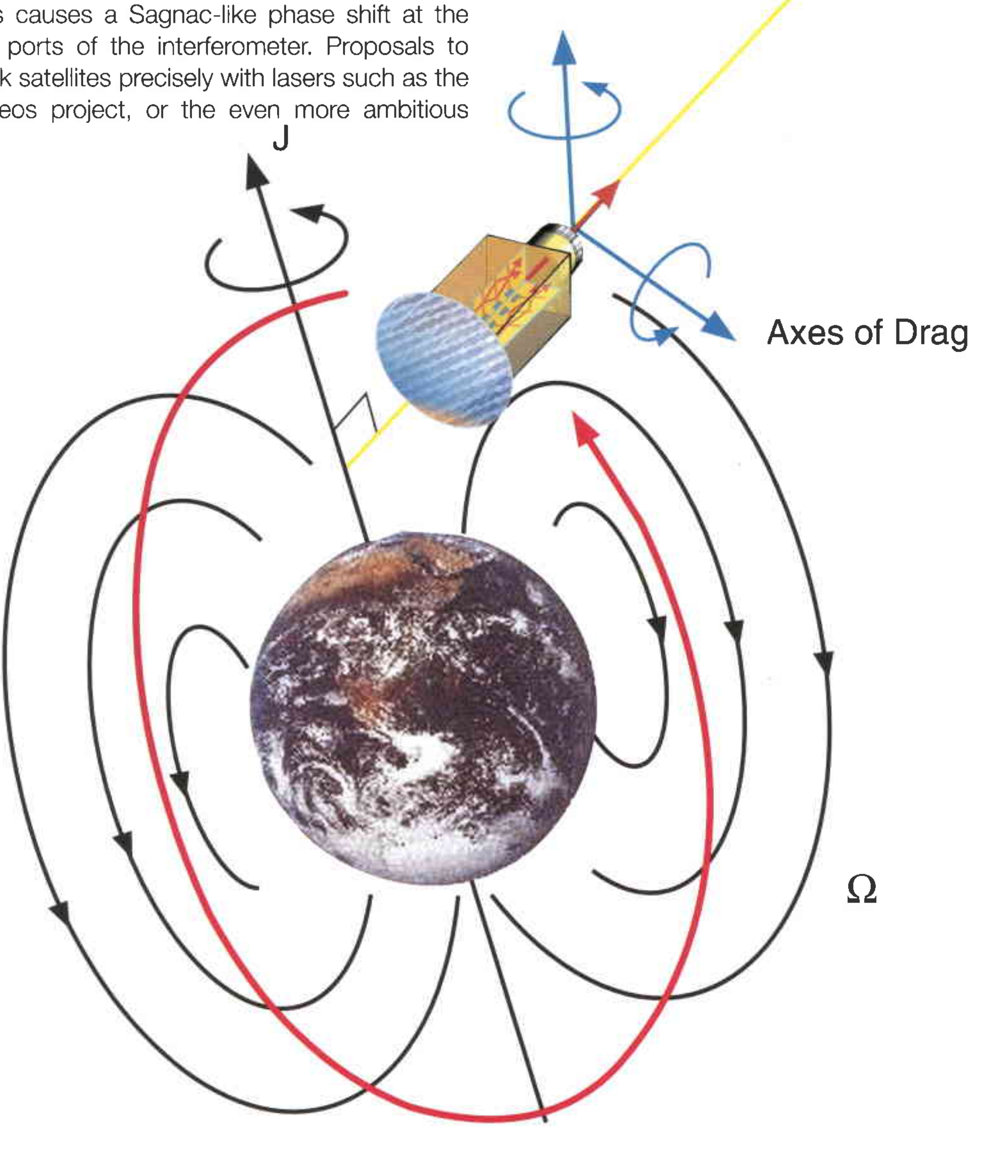


Figure 1. The gravitometric effect. The Earth's rotation J leads to a drag (black field lines) varying over the satellite's orbit (red). The contour of the vector field of the Earth's drag resembles the magnetic field of a dipole – hence the term 'gravitomagnetic'

this kind of theory. The measurements performed by Hyper will help to resolve the disagreement between the results obtained by measuring α in several different ways. One of these methods determines it by measuring the ratio of Planck's constant to the atomic mass (caesium or rubidium). In the absence of gravity, Hyper will improve the precision of this measurement by one to two orders of magnitude. Apart from the significance for QED theories, the fine-structure constant plays an important role in metrology and spectroscopy, linking together three other fundamental physical constants: the speed of light, Planck's constant and the electric charge of an electron.

– *To investigate various distinct sources of matter-wave decoherence as required for an upper bound to quantum gravity effects.*

Hyper will investigate the decoherence of matter waves in an undisturbed environment. Besides technical noise, decoherence results from many distinct kinds of interaction between the atoms and the environment, for instance with black-body radiation. New theories have been developed predicting changes in the first-order correlation function of matter waves due to spacetime granularity. One of the biggest unsolved problems in fundamental physics is the unification of quantum mechanics and gravity. A consequence of the unification could be the existence of incoherent conformal waves in gravitational fields due to quantum mechanical zero-point fluctuations. The outstanding performance of the atom interferometers on Hyper and a detailed study of possible sources of decoherence will set an upper boundary for these predictions, and thus will have a strong impact on this new quantum-gravity field.

Moreover, Hyper will be the first spacecraft to be controlled by atom interferometers acting as sensors for rotations and accelerations. The four atom interferometers carried can be combined to form two atomic Sagnac units to measure rotations and accelerations in two orthogonal directions. The Sagnac units can work in two different modes, for coarse (sensitivity 10^{-9} rad/s) and fine sensing (sensitivity 10^{-12} rad/s), depending on the atomic velocity, which is adjusted by lasers. While the fine-sensing gyroscope measures the gravitomagnetic effect, the coarse-sensing gyroscope will support the attitude and orbit control system and keep the star tracker directed to the guide star. Hyper will therefore pave the way to a novel generation of inertial sensors and gyroscopes, which will be needed, for example, for future gravitational-wave missions.

The Payload Module, with a mass of 240 kg and a power consumption of 200 W, consists essentially of the *Optical Bench*, carrying:
- the optical elements for coherent atom manipulation
- the high-precision star tracker (200 mm-diameter Cassegrain telescope, pointing accuracy 10^{-7} rad at 10 Hz readout frequency)
- the two drag-free proof masses

the *Atom Preparation Bench*, carrying:
- the four atom interferometers based on caesium or rubidium and accommodated in two magnetically shielded vacuum chambers
- the optics for atom preparation and detection

the *Laser Bench*, carrying:
- the laser for atom interferometry, preparation (e.g. trapping, cooling) and detection of the atoms
- the high-precision microwave synthesiser for the hyperfine transitions of caesium or rubidium.

The Payload Module, a cylinder 0.9 m in diameter and 1.3 m high, is accommodated in the centre of the box-shaped Service Module. Together they constitute the 'spacecraft', which has a launch mass of 770 kg. It will be launched by a Rockot vehicle from Plesetsk Cosmodrome into a circular, 700 km Sun-synchronous orbit. Drag-free performance to a level of 2 x 10^{-11} g (at 0.3 – 3 Hz) is achieved by a drag-free control system, comprising two drag-free proof masses and their capacitive sensors, and 16 proportional Field-Emission Electric Propulsion (FEEP) thrusters mounted externally on the spacecraft, each with a thrust capability of 500 μN.

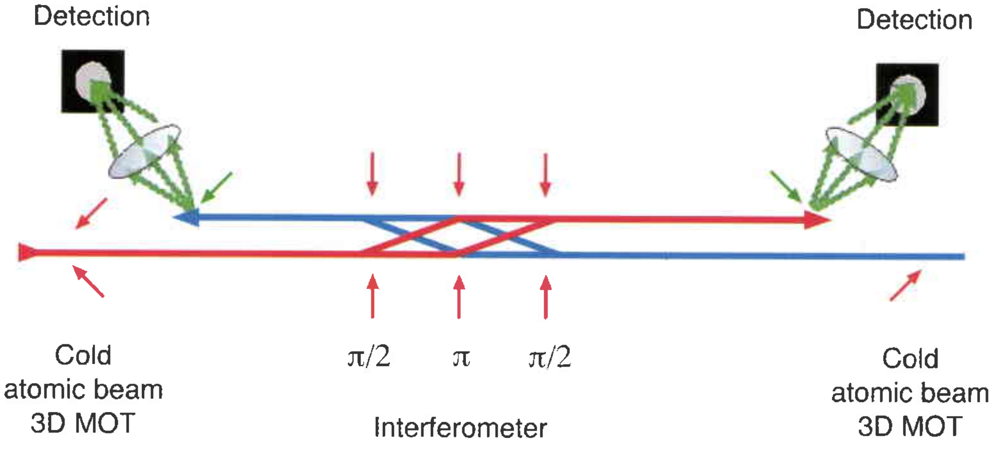


Figure 2. The Atomic Sagnac Unit (ASU). The two counter-propagating atom interferometers (red and blue) discriminate between rotations and accelerations. The ASU is sensitive only to one axis for both accelerations and rotations

Master

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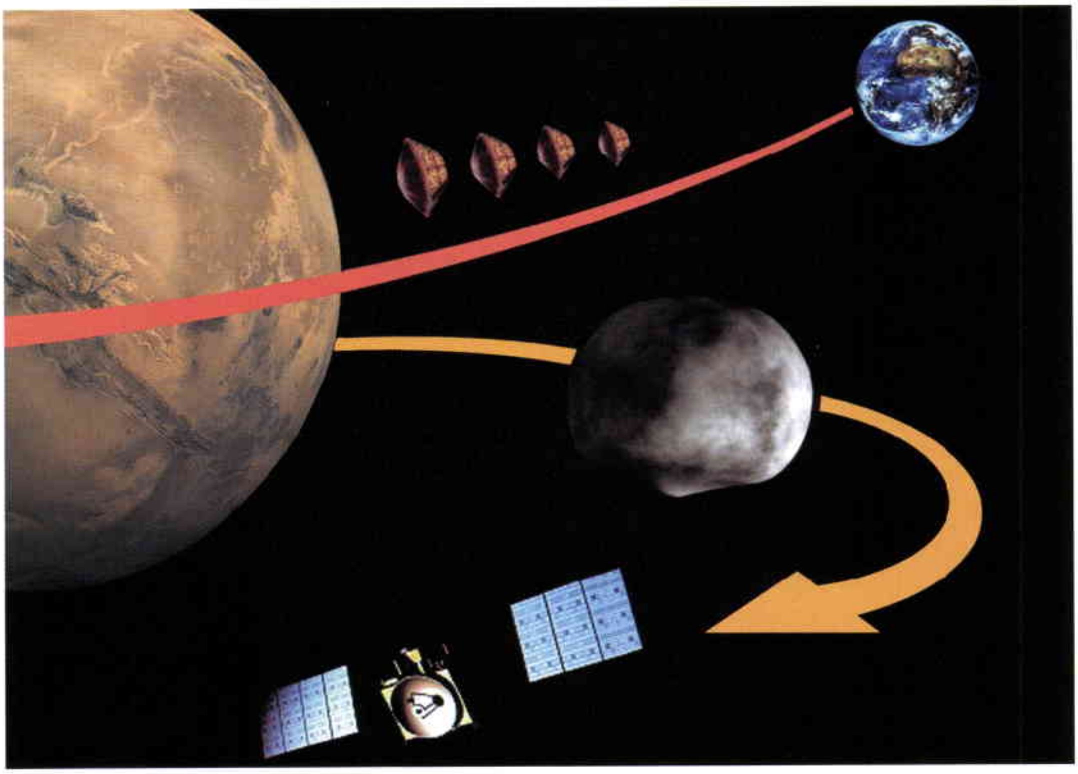


Figure 1. The trajectory of the Master spacecraft joins three milestones in the history of the Solar System: the Earth with its complex ecosystem, Mars which possibly sustained primitive life forms, and the large asteroid 4 Vesta, whose basaltic surface retains the record of ancient volcanic activity (graphics by E. Perozzi)

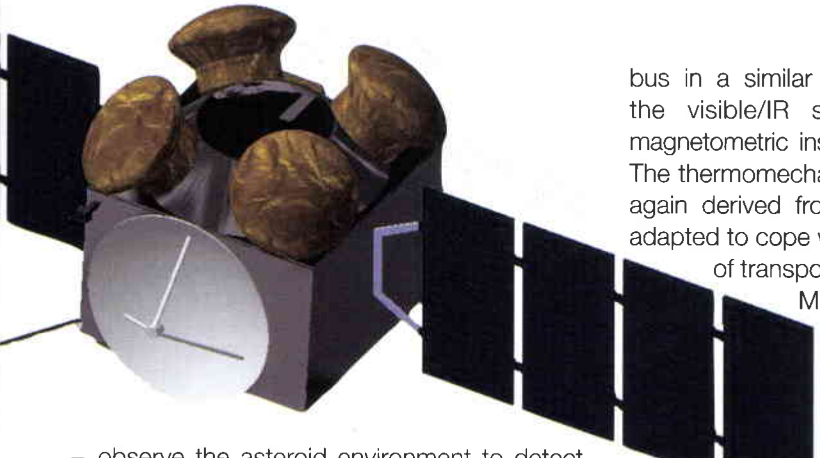
The Master (Mars + Asteroid) mission comprises Mars and Asteroid flybys and was intended to make use of the Mars Express spacecraft bus to the maximum practicable extent. The Mars flyby, needed to gain delta-V to reach the Asteroid Main Belt, offers a unique opportunity to carry out remote observations and to deploy landers on the martian surface. The asteroidal part of the mission starts after the Mars flyby, when the Master spacecraft is inserted into a trajectory that can lead to flybys of one or more asteroids. Several asteroids were considered in the course of the study, each of them producing different mission scenarios. However, Vesta is by far the most appealing among the inner main belt objects.

Vesta is the third largest known asteroid, orbiting the Sun at 2.4 AU. Its spectral characteristics are unique in the asteroidal belt and this leads us to believe that Vesta may be the parent body of some basaltic achondrite meteorites (howardites, eucrite, and diogenites, the HED group). Its albedo of 0.42 is one of the highest among the asteroids and its surface has a non-uniform appearance. Indeed, HST observations discovered the presence of what appears to be a 460 km impact basin. Vesta would therefore represent one of only three known extraterrestrial Solar System bodies for which actual rock samples are available in terrestrial laboratories.

In summary, therefore, Vesta is a small planetary world frozen in time at a unique and unexplored epoch of the early Solar System's formation and evolution. Because it is the smallest surviving body to have undergone terrestrial processes such as heating, melting and differentiation, the space-borne exploration of Vesta will reveal unique clues about the early planetary evolution of the Earth, Moon, Mars, Venus and Mercury.

The relatively low flyby velocity of Master at Vesta – less than 4 km/s – enables it to achieve numerous scientific goals. The determination of the asteroid's size, shape, mass, density, rotation speed, pole orientation and magnetic environment would provide a physical characterisation of Vesta. A medium-angle camera, a flux-gate magnetometer, a plasma package and radio science address these objectives. The surface can be studied morphologically with a resolution of <50 m/pixel, as well as mineralogically and chemically using a visible/infrared imaging spectrometer and an X-ray spectrometer. The internal structure of the asteroid can be investigated using radio-science techniques with the aim of establishing the presence and size of a core.

Master would allow high-precision determination of the global and local properties of Vesta. Primary objectives for asteroid science are to:
– characterise the global physical properties of the asteroid: size, shape, volume, density, rotation and pole orientation



- observe the asteroid environment to detect the presence of satellite(s) and dust
- reveal the surface record of collisional processes over the age of the Solar System
- detect the presence of a magnetic-field and plasma signatures of the asteroid's interaction with the solar wind
- study the morphology (local features, crater distribution and evidence of possible regolith), texture and composition of the surface layers to infer some of its bulk physical and chemical properties
- draw physiographic maps in order to define a relative time sequence for the major events that affected the object's history
- investigate the nature of early protoplanetary heating, melting, and differentiation processes
- study the nature of surface evolutionary processes during the first few million years of the Solar System's lifetime
- determine the spatial distribution of the various mineralogical types and their mixtures
- investigate the global elemental composition and establish possible differentiation
- establish the element abundances and mineralogy sufficiently to identify the source of meteorites recovered on Earth.

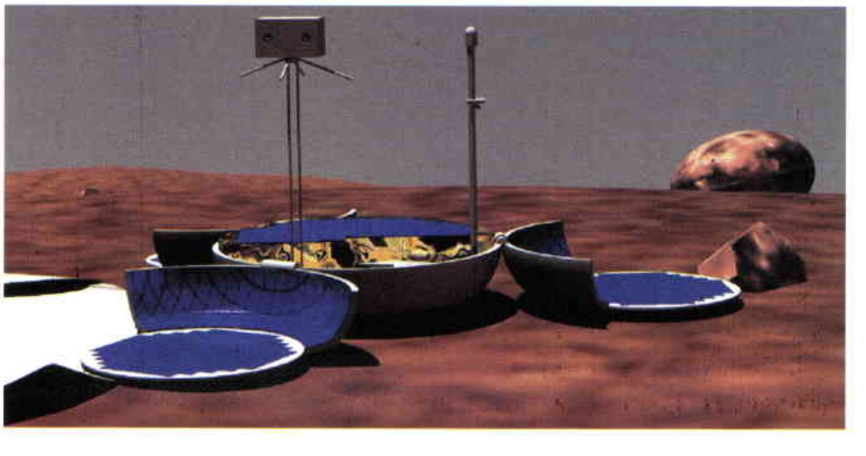
Master also provides an excellent opportunity for the exploration of Mars, not only by observing its surface and atmosphere with a state-of-the-art payload during two flybys, but also by carrying and deploying the four NetLander probes to the surface of the red planet. A European Consortium formed by a large number of ESA Member States would provide the network of landers, which are designed to carry out geophysical, meteorological and mineralogical investigations of Mars.

The complementary nature of the Mars and Vesta-related science objectives of Master are reflected in its system configuration. The selected spacecraft bus design is conceptually the same as for Mars Express. This allows re-use of the whole suite of electrical systems with minimum modifications related to off-the-shelf equipment availability in the time frame of relevance. The remote-sensing payload is partially accommodated inside the spacecraft bus in a similar way to Mars Express, with the visible/IR spectrometer and plasma/magnetometric instruments mounted externally. The thermomechanical architecture of the bus, again derived from Mars Express, has been adapted to cope with the specific requirements of transporting and delivering landers to Mars, and of surviving the cooler asteroid-belt environment between 2 and 3 AU from the Sun. The 2007 launch opportunity to Vesta allows a full complement of four landers (of the NetLander class) to be delivered to Mars, requiring a purpose-built jettisonable support structure.

In the Master baseline mission, the 1500 kg spacecraft would be launched from Baikonur on a Soyuz/Fregat booster (with the same performance as expected for the 2003 launch of Mars Express) during a month-wide window in September 2007. The spacecraft then fires its own 400 N engine to reach the required hyperbolic excess velocity of 3.6 km/s. Vesta is reached by a combination of two Mars gravity-assists and propulsive manoeuvres. The first Mars flyby then occurs in October 2008, at which time the four landers are individually released between 30 and 10 days before closest approach, and start their autonomous mission. Lander release parameters match those already used for the NetLander design as part of the Mars Sample Return Orbiter mission.

The Master on-board payload is operated during the Mars flybys for remote sensing of either the martian surface and atmosphere, or the moons. After a second Mars flyby in August 2009 and a main mid-course propulsive manoeuvre, Master would reach Vesta in March 2011. Science data (in the order of 40 Gbit) would be gathered during flybys, stored on board, and downlinked to Earth after the completion of each pass. esa

Figure 2. A NetLander probe deployed on Mars' surface



NGST

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Few will dispute that the NASA/ESA Hubble Space Telescope (HST) has been one of the most successful astronomical space projects ever undertaken. The equal access to the HST observatory gained through ESA's active participation in the HST mission from its very beginning has not only been hugely beneficial scientifically to the European astronomical community, but has also contributed towards promoting competitiveness and cross-border collaboration within European science as a whole. NASA and ESA — joined by the Canadian Space Agency (CSA) — have collaborated since 1996 in the definition of a worthy successor to HST, the Next-Generation Space Telescope (NGST). By participating in NGST at the financial level of a Flexi-mission, ESA stands to gain a ~15% partnership in the observatory, as well as a continuation of the existing HST Memorandum of Understanding (which expires in 2001) to the end of that observatory's operational life, expected in 2010.

As presently envisaged, NGST is to consist of a passively cooled, 6 m-class telescope, optimised for diffraction-limited performance in the near-infrared (1 – 5 micron) region, but with extensions to either side into the visible (0.6 – 1 micron) and mid-infrared (5 – 28 micron) regions.

Figure 1. Light from faint background galaxies is bent by the lensing effect created by the gravitation of the large Abell 2218 cluster of galaxies. The unprecedented high angular resolution and sensitivity of HST make study of the fine structure in the arcs possible, as well as providing important cosmological clues. NGST will push such observations to far greater distances

The large aperture and shift to the infrared embodied by NGST is first and foremost driven scientifically by the desire to follow the contents of the faint extragalactic Universe back in time and redshift to the epoch of 'first light' and the ignition of the very first stars. Nonetheless, like its predecessor, NGST will be a general-purpose observatory capable of addressing a very broad spectrum of outstanding problems in galactic and extragalactic astronomy.

The scientific case for NGST is documented in considerable detail in the form of the so-called 'Design Reference Mission' (available at http://www.ngst.stsci.edu/drm/programs.html). The DRM represents a nominal observing plan for NGST covering the first 2.5 years of the mission. Its 23 programmes can be grouped into the following broad categories touching upon nearly all areas of modern astrophysics:
- cosmology and structure of the Universe (21%)
- origin and evolution of galaxies (33%)
- history of the Milky Way and its neighbours (15%)
- the birth and evolution of stars (16%)
- origins and evolution of planetary systems (15%).

The scientific objectives of the DRM are to be achieved with an instrument complement consisting of:
- a Near-IR Wide-Field Camera covering the 0.6 – 5 micron band
- a Near-IR Multi-Object Spectrograph covering the 1 – 5 micron band, and
- a Mid-IR combined Camera/Spectrograph covering the 5 – 28 micron band.

In contrast to HST, NGST will be placed into a Sun–Earth L2 halo orbit and will not be serviceable after launch. It will therefore not be possible to repair or replace these instruments over the lifetime of the observatory.

The NGST telescope proper and its three instruments are to be cooled in bulk to <50 K, a temperature determined by the operating temperature of the (InSb and HgCdTe) detector arrays covering the prime near-IR 1–5 micron range. Cooling is to be achieved by passive means by placing the observatory at the second Lagrangian point (L2) and keeping the telescope proper and its instrumentation in perpetual shadow by means of a large deployable sunshade.

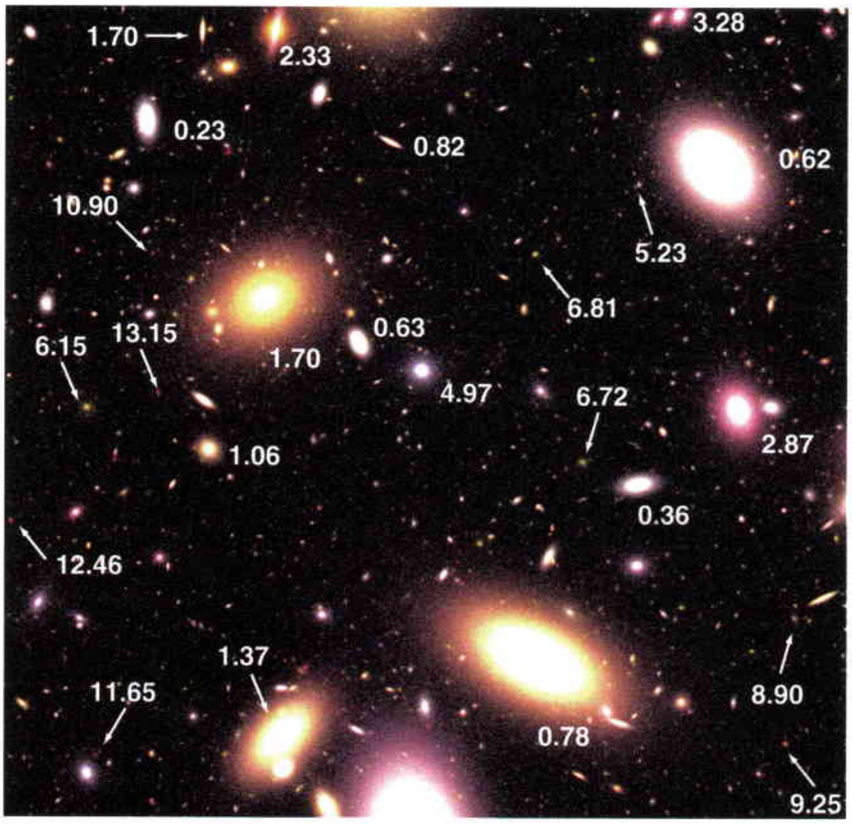
The NGST telescope is specified to yield diffraction-limited performance at a wavelength of 2 μm in the near-IR. In order to fit into the shrouds of suitable launchers (EELV, Atlas or Ariane-5), it is necessary that the primary mirror be folded during launch. The fine pointing required to exploit this spatial resolution will be achieved by deflecting the telescope image by means of a fast-steering mirror controlled by a fine guidance sensor located in the telescope focal plane.

The short 0.6 micron visible-wavelength limit of the NGST observatory allows for the likely use of gold as the reflecting coating in the telescope and instrument optics. At the other end of the wavelength coverage, the (Si:As) detector arrays needed to reach wavelengths beyond 5 micron require an operating temperature of ~8 K, which is significantly below the 30–50 K ambient environment of the observatory. Active cooling is therefore called for as part of the NGST mid-IR instrument, in the form of a solid hydrogen cryostat or a mechanical cooler of some description.

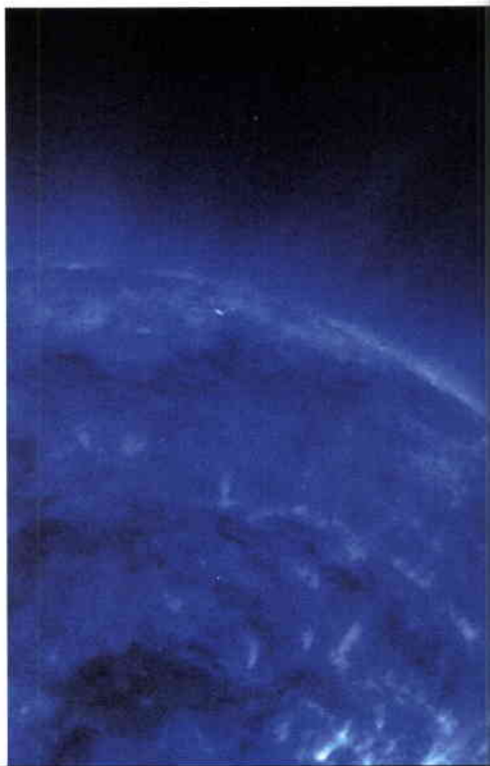
ESA's participation in NGST will follow closely the successful HST model, and consist of three main elements:
- ESA will be responsible for procuring approximately half of the NGST payload. It will provide the Near-IR Multi-Object Spectrometer. In addition, through special contributions from its Member States, ESA will provide a major (40–50%) contribution to the Mid-IR Camera/Spectrograph to be developed jointly by NASA, ESA and CSA.
- ESA will also provide the spacecraft Service Module for NGST (assumed to be a derivative of the FIRST spacecraft bus), or alternatively, in the event that this proves impractical, subsystems of the Service Module plus some amount of optical figuring and polishing of the telescope mirrors.
- Thirdly, ESA will participate in NGST operations at a similar level to that provided for HST.

Through these contributions, ESA will secure astronomers from its Member States full access to the NGST observatory on identical terms to those enjoyed today on HST; i.e. they will have representation on all advisory bodies of the project and will win observing time on NGST through a joint peer-review process, backed by a guarantee of a minimum ESA share of 15%.

Figure 2. A simulated NGST image with redshifts for selected objects. NGST could detect approximately 100 galaxies with redshift larger than 5 in this small fraction (less than 1 percent) of the camera field of view (courtesy of Myungshin Im, Space Telescope Science Institute)



Solar Orbiter



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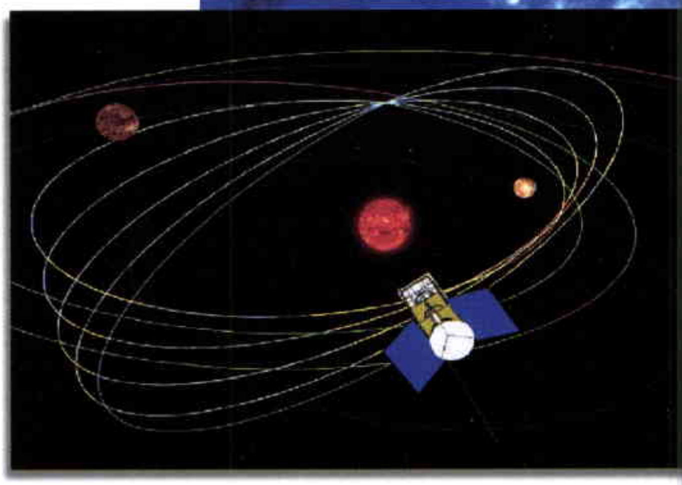
The Sun's atmosphere and the heliosphere represent uniquely accessible domains of space, in which fundamental physical processes common to solar, astrophysical and laboratory plasmas can be studied in detail and under conditions that are impossible to reproduce on Earth or to study from astronomical distances. The results from missions such as Helios, Ulysses, Yohkoh, Soho and Trace have enormously advanced our understanding of the solar corona, the associated solar wind and the three-dimensional heliosphere. However, we have reached the point where further in-situ measurements, now much closer to the Sun, together with high-resolution imaging and spectroscopy from a near-Sun and out-of-ecliptic perspective, promise to bring about major breakthroughs in solar and heliospheric physics. The Solar Orbiter will, through a novel orbital design and its state-of the-art instruments, provide exactly the observations required.

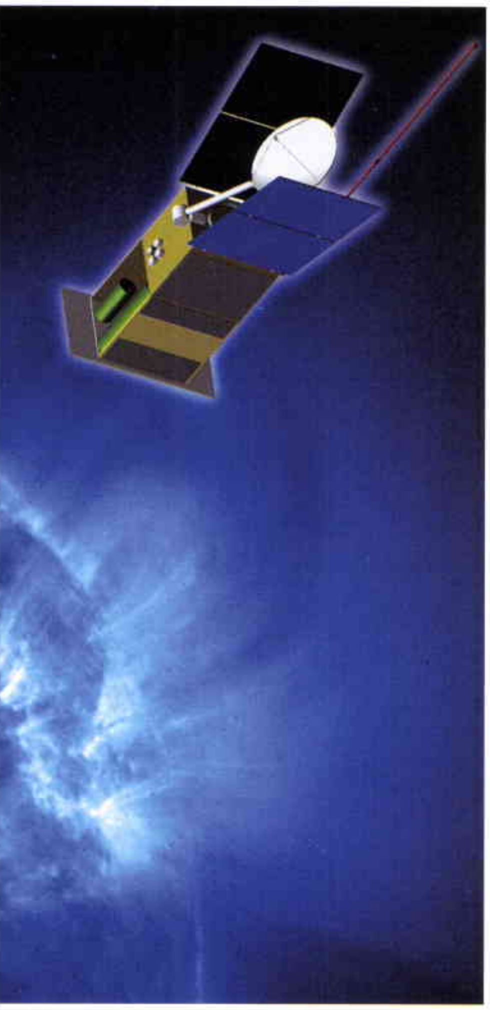


The scientific goals of the Solar Orbiter are to:
- determine in-situ the properties and dynamics of plasma, fields and particles in the near-Sun heliosphere
- investigate the fine-scale structure and dynamics of the Sun's magnetised atmosphere, using close-up, high-resolution remote sensing
- identify the links between activity on the Sun's surface and the resulting evolution of the corona and inner heliosphere, using solar co-rotation passes
- observe and fully characterise the Sun's polar regions and equatorial corona from high latitudes.

The underlying basic questions that are relevant to astrophysics in general are:
- Why does the Sun vary and how does the solar dynamo work?
- What are the fundamental physical processes at work in the solar atmosphere and in the heliosphere?
- What are the links between the magnetic-field-dominated regime in the solar corona and the particle-dominated regime in the heliosphere?

In particular, the data obtained by the Solar Orbiter will be used to:
- unravel the detailed working of the solar magnetic field as a key to understanding stellar magnetism and variability
- map and describe the rotation, meridional flows, and magnetic topology near the Sun's poles, in order to understand the solar dynamo
- investigate the variability of the solar radiation from the far side of the Sun and over the poles
- reveal the flow of energy through the coupled layers of the solar atmosphere, e.g. to identify the small-scale sources of coronal heating and solar-wind acceleration
- analyse fluctuations and wave–particle interactions in the solar wind, in order to understand the fundamental processes related to turbulence at all relevant scales in a tenuous magnetofluid

* Based at NASA/GSFC, Greenbelt, Maryland, USA



- understand the Sun as a prolific and variable particle accelerator
- study the nature and the global dynamics of solar eruptive events (flares, coronal mass ejections, etc.) and their effects on the heliosphere ('space weather and space climate').

The near-Sun interplanetary measurements (together with simultaneous remote-sensing observations of the Sun) will be used to disentangle spatial and temporal variations during the co-rotational phases. Characteristics of the solar wind and energetic particles will be studied in close linkage with the plasma conditions in their source regions on the Sun. By approaching as close as 45 solar radii, the Solar Orbiter will view the solar atmosphere with unprecedented spatial resolution (35 km pixel size, equivalent to 0.05 arcsec from Earth). Over extended periods, the Solar Orbiter will deliver images and data from the polar regions and the side of the Sun not visible from Earth.

The Solar Orbiter will achieve its wide-ranging aims with a suite of sophisticated instruments. The payload (mass 130 kg; power 125 W; telemetry 75 kbps) includes two instrument packages, optimised to meet the solar and heliospheric science objectives:

- *Heliospheric in-situ instruments:* solar-wind analyser, radio- and plasma-wave analyser, magnetometer, energetic-particle detectors, interplanetary-dust detector, neutral-particle detector, solar-neutron detector.
- *Solar remote-sensing instruments:* EUV full-Sun and high-resolution imager, high-resolution EUV spectrometer, high-resolution visible-light telescope and magnetograph, EUV and visible-light coronagraph, radiometer.

The Solar Orbiter will benefit from technology developed for the BepiColombo Cornerstone project. Using Solar Electric Propulsion (SEP) in conjunction with multiple planetary swing-by manoeuvres, it will take the Solar Orbiter only two years to reach a perihelion of 45 solar radii at an orbital period of 149 days. Within the nominal 5-year mission phase, the Solar Orbiter will perform several swing-by manoeuvres at Venus, in order to increase the inclination of the orbital plane to 30° with respect to the solar equator. During an extended mission phase of about two years, the inclination will be further increased to 38°.

The spacecraft will be three-axis-stabilised and always Sun-pointed. Given the extreme thermal conditions at 45 solar radii (25 solar constants), the spacecraft's thermal design has been examined in detail during the assessment study and viable solutions have been identified. Telemetry will be handled via X-band low-gain antennas, and by a two-axis steerable Ka-band high-gain antenna. The total mass of the Solar Orbiter (1308 kg) is compatible with a Soyuz-Fregat launch from Baikonur.

Figure 1. Artist's impression of the Solar Orbiter mission

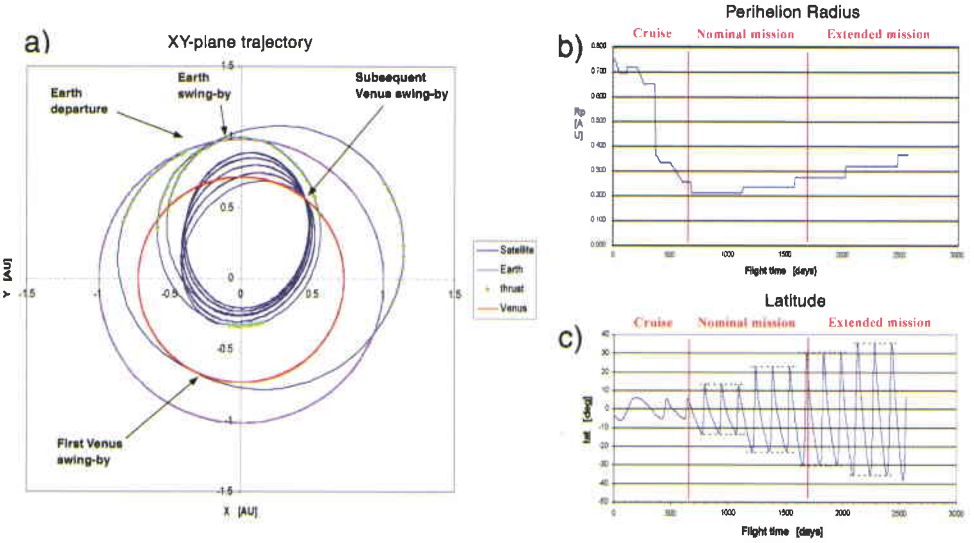


Figure 2. (a) Ecliptic projection of the Solar Orbiter's trajectory. Blue: Solar Orbiter. Pink: Earth orbit. Red: Venus orbit. Green: SEP thruster firings. (b) Perihelion distance of the Solar Orbiter as a function of time. (c) Spacecraft latitude with respect to the Sun's equator as a function of time

Storms

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The three-spacecraft constellation Storms is a mission to study magnetic storms and the inner magnetosphere. The disturbances that cause magnetic storms originate in active processes on the Sun, in particular as Coronal Mass Ejections (CMEs), and are carried to the Earth by the solar wind. The terrestrial magnetosphere responds to these perturbations in many different ways, and on many time scales. The effects of the storms are detectable throughout the magnetosphere and also on the surface of the Earth. In fact, the average progress of a magnetic storm is traditionally determined by ground-based magnetometers, which measure the magnetic perturbations caused by the ring current composed of energetic ions encircling the Earth at altitudes of several Earth radii.

Among the most important scientific problems to be studied by the Storms spacecraft are:
- growth and decay of the ring current and the role of ionospheric oxygen
- contributions of different current systems to the ground-based determination of storms
- storm–substorm relationships
- physical mechanisms for the injection of particles into the radiation belts
- forecasting of storms for space-weather purposes.

Considering the present and planned satellite missions worldwide, these problems will be highly relevant in the time frame of F2/F3 missions.

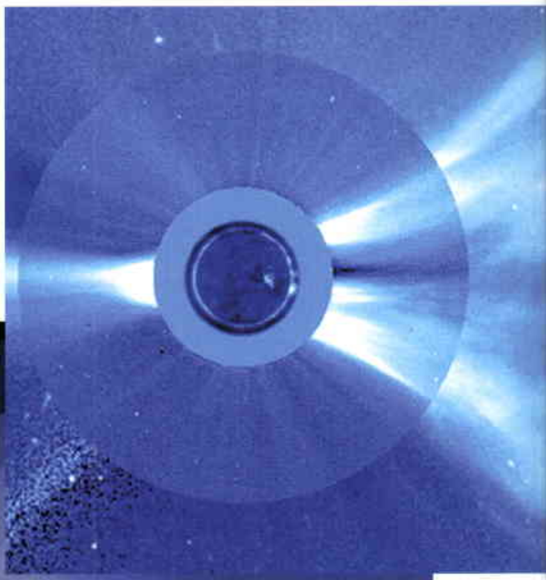
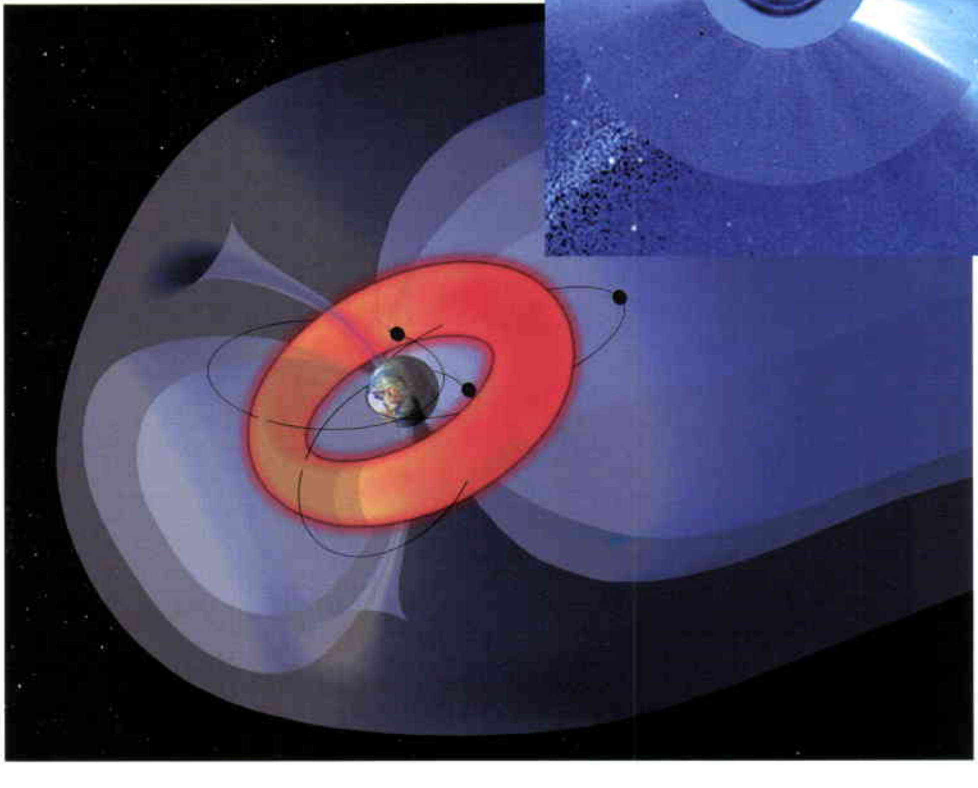


Figure 1. A typical Coronal Mass Ejection (CME) seen at the Sun, which is the cause of a magnetic storm



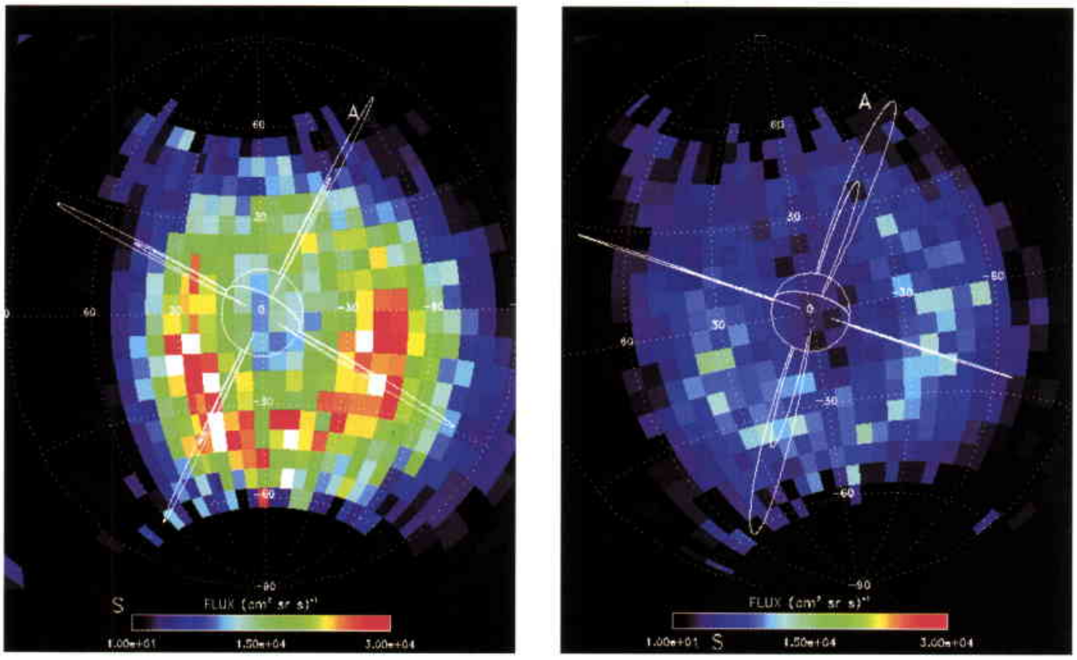


Figure 2. Energetic Neutral Atom (ENA) images of the Earth's magnetosphere taken during the main phase (left) and the recovery phase (right) of a magnetic storm (courtesy of D. Mitchell, APL)

With Storms, ESA will not only achieve a leading role in the scientific research into magnetospheric storms, but will also acquire an excellent tool for practically real-time monitoring of storm development and detailed observations of the most hazardous particle populations.

The relevance of the Storms mission to space weather will also provide unique possibilities for education and outreach. Its results can be used to illustrate the harshness of the space environment and the relationships between basic space science and technology. Moreover, its ability to image Energetic Neutral Atoms (ENAs) arising from the charge-exchange processes between the terrestrial exosphere and the ring current will make space and its dynamics visible in a much more concrete way than ever before. Up-to-date information on space storms can be transmitted, for example via the Internet, to science centres, classrooms and news rooms.

The most important features of the Storms mission are the three-satellite constellation and the scientific instrumentation, both of which are carefully designed to satisfy the scientific objectives listed above. In particular, the three-spacecraft approach will allow Storms to investigate the spatial asymmetries of storm development in an unprecedented way.

The original goal was to have the orbits of the three spacecraft in the equatorial plane with an apogee at 8 Earth radii (geocentric), a low-altitude perigee, and the lines-of-apsides separated by 120° ± 20° from each other. The assessment study resulted in two options: the original equatorial orbit or, alternatively, an orbit with an inclination of 63°, but keeping the line-of-apsides in the equatorial plane. Both of these options have their merits and were found to be feasible.

The strategy for the model payload is based on demonstrated feasibility, good coverage of essential observables, as well as simplicity that favours the equipping of all three spacecraft with identical instruments. It is essential to cover charged particles from thermal energies up to relativistic particles in the radiation belts. Magnetic and electric fields have to be measured as comprehensively as possible within the weight constraints of small spacecraft. A wave instrument is needed for studies of the particle energisation and decay processes of ring current and radiation belts. The only relatively new component is the ENA instrument, which will provide an unprecedented view of the inner magnetosphere.

In summary, Storms will address the following scientific questions:
- Growth and decay of the ring current.
- Effects of different current systems on ground determinations of storms.
- Storm–substorm relationships.
- Particle injection and acceleration mechanisms.
- Radiation-belt dynamics.
- Plasma sheet and substorms.
- Forecasting of storms (space weather).

esa

IRSI/Darwin: Peering Through the Interplanetary Dust Cloud

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ESA has identified interferometry as one of the major goals of the Horizon 2000+ Programme. Infrared interferometers are highly sensitive astronomical instruments that enable us to observe terrestrial planets around nearby stars. It is in this context that the infrared space-interferometry mission IRSI/Darwin is being studied. The current design calls for a constellation of six free-flying telescopes using 1.5 metre mirrors, plus one hub and one master spacecraft. As the baseline trajectory, an orbit about the second colinear libration point of the Earth–Sun system has been selected.

The thermal radiation from the interplanetary dust cloud that surrounds the Sun, the so-called 'zodiacal infrared foreground', is a major concern for any high-sensitivity infrared mission. The most reliable information about this radiation comes from the measurements made by the Cosmic Background Explorer (COBE) mission. There are various ways to detect faint terrestrial planets despite the bright foreground. We find that, using integration times in the order of 30 h, the baseline mission scenario is capable of detecting Earth-sized exo-planets out to 11 pc. Increasing the heliocentric distance of the instrument would make the observing conditions even better. A dust model that was fitted to the COBE measurements shows that an observing location for Darwin in the outer Solar System would potentially reduce the zodiacal foreground by a factor of 100, effectively increasing the number of potential target stars by almost a factor of 30.

Introduction

Since the mid-1990s the search for extra-solar, terrestrial planets (called 'exo-planets' hereafter for brevity), and the possibility of life on them has received much attention. Both ESA and NASA are studying space-based telescopes that will enable the scientific community to conduct such a search. The most promising technology that will allow the detection of exo-planets and the search for biologic activity on their surface is space-based infrared nulling interferometry. Nulling interferometry allows one to superimpose the light from a star seen from slightly different angles so that the starlight is reduced, but light from sources close to the star is enhanced. ESA is studying the Darwin infrared interferometer as a candidate Cornerstone mission. The NASA mission proposal is called the Terrestrial Planet Finder (TPF). In addition to the search for exo-planets, such interferometers could also be used for general-purpose astronomical imaging and spectroscopy with extremely high spatial resolution.

One of the main problems for the detection and analysis of Earth-sized exo-planets using an infrared telescope is the cloud of cosmic dust particles that surrounds the Sun. These dust particles are heated by the Sun and thus emit thermal radiation, called the 'zodiacal infrared radiation'. Darwin has to look through the Solar System dust cloud. Since we are looking for a planet with a peak of emission at a wavelength near the maximum of the local zodiacal foreground, we will see a considerable amount of foreground radiation. In analogy with the 'atmospheric seeing' for ground-based telescopes, which is caused by fluctuations in the Earth's atmosphere, the infrared foreground in the Solar System causes an 'interplanetary seeing'. While a constant foreground brightness can easily be subtracted from the observations, the photon noise that is generated by all light sources is a random, unpredictable brightness fluctuation. This fluctuation is proportional to the square root of the number of photons from the source. If the number of observed photons from the target exo-planet is in the order of the square root of the number of photons from the foreground, the planet's signal can no longer be clearly detected. In order to minimise the foreground, Darwin will observe mainly in the anti-Sun direction, where the zodiacal foreground is less prominent.

As a baseline, Darwin's observation window is defined to include directions less than 45° off the anti-Sun direction. But even in the anti-Sun direction, the zodiacal foreground is much brighter than an exo-planet. Since the number of collected photons increases with time, the ratio of the planet's signal to the photon noise (signal-to-noise ratio, or SNR) is proportional to the square root of the observation time. Thus, the easiest way to detect a planet behind a bright foreground is long-duration observation. Since observation time is a precious resource for a space telescope, a trade-off between observation time and other possibilities to improve the interplanetary seeing has to be made. One option is to increase the telescope's diameter. With a larger diameter the same foreground brightness is still observed, but the planet's signal is increased proportional to the area of the light-collecting surface.

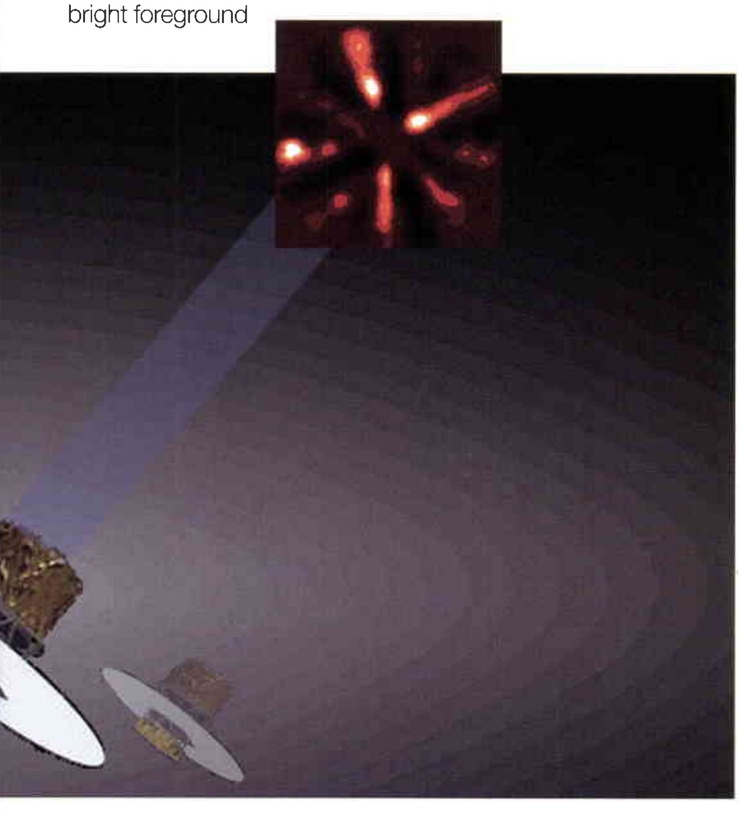

Figure 1. Darwin is surrounded by a cloud of dust that shines much brighter at infrared wavelengths than the extra-solar planets it is designed to look for

Alternatively, the telescope can be placed at a larger heliocentric distance, where the infrared radiation from the dust is reduced owing to the lower interplanetary dust density and lower dust temperatures. The current baseline mission design calls for an observing location at the second co-linear Lagrangian point of the Earth–Sun system. At this point, called L2, the Earth's and the Sun's gravity plus the centrifugal force caused by the Earth's orbital motion cancel each other out. A spacecraft placed at this point will be in unstable equilibrium, i.e. it will stay there for a long time with minimum control. The advantage of putting Darwin at L2 is the relatively short distance to Earth (roughly 1.5 million km), the stable thermal environment, and the abundant availability of solar power. The zodiacal infrared foreground at 1 AU*, however, is a drawback for any highly sensitive infrared observatory at L2. It is believed that at a distance of 5 AU the interplanetary infrared foreground is less strong and becomes comparable to other sources of noise, such as light from the central star that is not perfectly cancelled.

Because dust in the Solar System is mainly concentrated close to the ecliptic plane of the planets, still another possibility to reduce the infrared foreground is to put the telescope in an orbit that is inclined with respect to the ecliptic plane. In such an orbit, the telescope would cross the ecliptic plane twice and reach the maximum separation from the ecliptic plane for a short time a quarter of a revolution later. The propellant allocation needed for a change in the orbital inclination is, however, quite substantial.

How much foreground radiation is expected for observations at larger distances from the Sun or with inclined orbits? So far, infrared observations have only been performed close to the Earth. The most complete and accurate survey of the sky at infrared wavelengths between 1.25 and 240 micron has been performed by the Cosmic Background Explorer (COBE) satellite. Using the data obtained by COBE, a model of the zodiacal infrared radiation has been developed that allows one to extrapolate the expected foreground radiation to larger distances and inclined orbits. One has to be careful, however, in using such an extrapolation, because it is only well constrained close to the observing location of COBE, i.e. at 1 AU distance from the Sun and in the ecliptic plane. To acquire more accurate information on the zodiacal foreground, *in-situ* measurements of the infrared radiation should be performed. Lacking data from other observing locations, we can use the extrapolation of the COBE data to estimate how much foreground radiation can be expected if Darwin is placed at solar

* 1 Astronomical Unit (AU) is equal to the distance from the Earth to the Sun

distances of 1, 3 or 5 AU, or in orbits with 30° or 60° inclination with respect to the ecliptic plane.

Interplanetary seeing as a function of selected orbit

The amount of foreground radiation received by an instrument at a given observing location depends on the direction in which the instrument is pointing. The foreground brightness measured for a given pointing direction is the sum of the emission from all dust grains that are located in the line of sight. For a pointing direction close to the Sun, for example, a strong foreground is expected, because parts of the line of sight lie within regions where the dust density as well as the dust temperature is high. The model calculations allow us to determine the expected brightness for any pointing direction, which can be expressed using two angles: the ecliptic latitude β_{ECL}, which is equal to 0° for a pointing in the ecliptic plane, and the difference of the ecliptic pointing longitude and the ecliptic longitude of the Sun position $\lambda_{ECL} - \lambda_{ECL,sun}$. On a map in the ($\lambda_{ECL} - \lambda_{ECL,sun}$, β_{ECL}) coordinate system, the Sun is located at (0°, - $\beta_{ECL,s/c}$), where $\beta_{ECL,s/c}$ is the ecliptic latitude of the observing location.

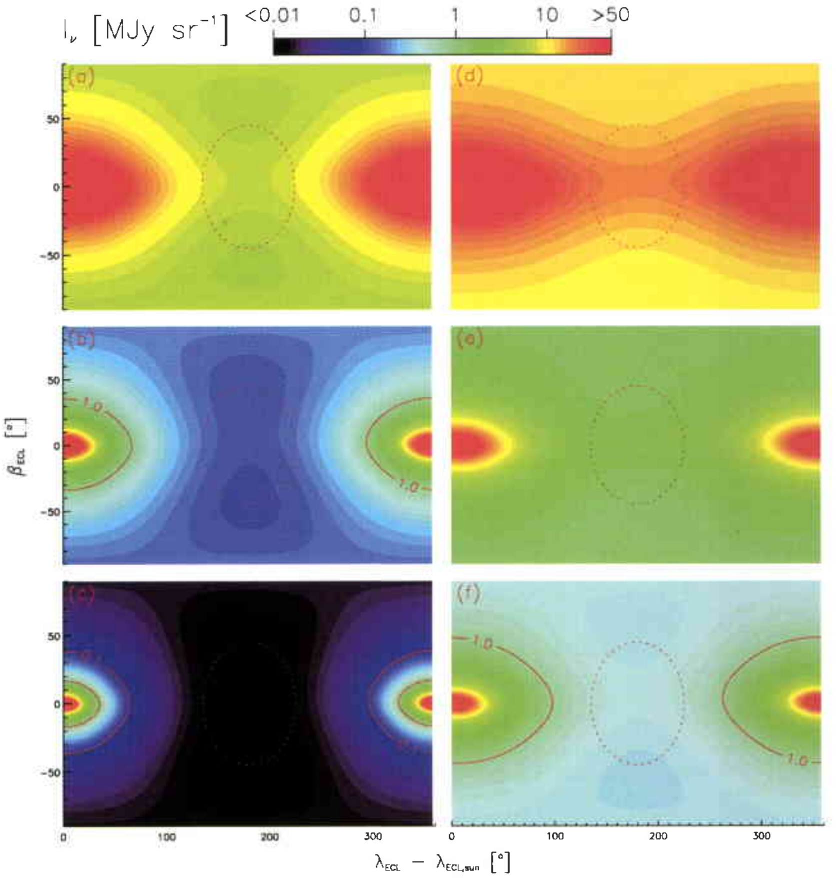

Figure 2. Sky maps of the infrared surface brightness of the interplanetary infrared foreground at wavelengths of 10 micron (a), (b), (c), and 20 micron (d), (e), (f). Panels (a) and (d) show the brightness at an in-ecliptic observing location at 1 AU, while in (b) and (e) the observation is made at a heliocentric distance of 3 AU, and panels (c) and (f) show the brightness at 5 AU. The contour lines show limiting foreground brightnesses of 0.1 and 1 MJy sr^{-1}. The dotted circle indicates Darwin's observation window within 45 deg of the anti-Sun direction

The maps of the infrared sky at wavelengths of 10 and 20 micron are shown in Figure 2, for observing locations in the plane of the ecliptic at solar distances of 1, 3, and 5 AU. It is evident from these maps that the further the telescope is located from the Sun, the *colder* the sky gets. At Earth's distance (1 AU), all of the sky is brighter than 1 MJy sr^{-1}. An improvement can be observed at 3 AU, where 84% of the sky is darker than 1.0 MJy sr^{-1} at a wavelength of 10 micron. At 20 micron, however, the whole sky is still bright. A much improved situation can be seen at a distance of 5 AU from the Sun; at the 10 micron wavelength, 96% of the sky is darker than 1.0 MJy sr^{-1}, and 83% is even darker than 0.1 MJy sr^{-1}. Also at the longer wavelength of 20 micron the foreground is reduced; 70% of the sky is darker than 1.0 MJy sr^{-1}.

It can be seen from the in-ecliptic sky maps that the infrared brightness is concentrated around the plane of the ecliptic, i.e. $\beta_{ECL} = 0$. Can the foreground be reduced by putting the telescope into an orbit that is inclined with respect to the ecliptic plane? Figure 3 shows sky maps of the expected foreground infrared brightness as seen from observing locations 30° and 60° above the plane of the ecliptic. At +30° above the ecliptic, the Sun appears at a pointing direction of β_{ECL} = -30°, as can be seen from the brightest spot in Figures 3 (a) and (c). From the maps, it is evident that at 30° the foreground is not reduced below 1.0 MJy sr^{-1} at any spot on the sky. Only at 60° above the ecliptic is the foreground reduced below 1.0 MJy sr^{-1} for 38% of the sky at a wavelength of 10 micron. Still, the sky is everywhere brighter than 0.1 MJy sr^{-1}.

Discussion and conclusion

How do we see through the interplanetary dust cloud? There is no unique answer to this question, but there are a number of options. In general the avoidance of a high foreground radiation level caused by the cloud has to be traded-off against more difficult operations, less available power, and longer transfer time to the observing location. In the current baseline mission scenario for Darwin, the zodiacal foreground is the dominant source of noise. Sufficiently long integrated observation times allow one to increase the SNR to any level required for planet detection or spectroscopy. Long observation times, however, limit the number of observations that can be performed during the mission. The advantages of the current mission design are the short transfer to the observing location (about 100 days), the spacecraft operations are straightforward, and solar power is abundantly available. The number of target stars that can be observed within the mission duration can be increased by increasing the diameter of the telescope mirrors. We find from extrapolation of the COBE results that another way to increase the number of potential targets is to increase the heliocentric distance of the instrument. While increasing the operational and transfer demands, this option would reduce the foreground level by up to three orders of magnitude. The maximum target distances for various observing locations are summarised in Table 1.

To assess quantitatively the reduction in infrared foreground for Darwin at the different observing locations, we determine the brightness $I_\upsilon^{(max)}$ of the brightest spot in Darwin's observation window (within 45° of the anti-Sun direction). As a worst-case scenario, we assume that this brightness is the infrared foreground for all observations. The results given in Table 1 have been calculated assuming a telescope diameter of 1.5 m, an Earth-sized exo-planet at 1 AU from its Sun-like central star, an observing wavelength of λ = 10 micron, an interferometric transmission of 20%, and a telescope field of view of 1.096 λ^2. Also, three different observation requirements have been considered: (a) detection of an exo-planet requires a spectral resolution of $\lambda/\Delta\lambda$ = 2 and SNR = 10, (b) spectroscopy of CO_2 features requires $\lambda/\Delta\lambda$ = 6 and an SNR = 25, and (c) spectroscopy of O_3 features requires $\lambda/\Delta\lambda$ = 20 and an SNR = 40. Requirements (a), (b), and (c) have been abbreviated as 'det.', 'CO_2', and 'O_3' in the table, respectively. For each observation requirement, we have calculated the maximum target distance for an observation time of 30 h.

From Table 1, it is evident that the baseline mission scenario is capable of exo-planet detection as well as spectroscopy of atmospheric CO_2 and O_3. Bearing in mind that already within 6.5 pc one can find more than 100 stars, it is obvious that Darwin will have a adequate number of potential targets. It is clear that the observation conditions get even better if the instrument is moved to larger distances from the Sun. Already at 3 AU, the maximum observation distance increases by a factor of three. Since the number of stars increases with the third power of the maximum observation distance, this translates into an increase in the number of potential targets by a factor of 27 ! At 5 AU, the maximum observation distance theoretically increases by another factor of 2. However, at such low zodiacal foreground levels, probably other sources of noise, like light from the central star that is not perfectly cancelled or detector noise, dominate the zodiacal foreground noise. If the zodiacal foreground was the only source of noise, O_3 spectroscopy would be possible for a target planet 25 pc away. While increasing the instrument's distance from the Sun to 3 or 5 AU would reduce the infrared foreground by more than 2 or 3 orders of magnitude, respectively, increasing the inclination of the instrument's orbit to 60 ° leads to an improvement by one order of magnitude only. Furthermore, an orbit inclination change requires more propellant than an increase in the orbit's size, effectively reducing the available payload mass. It is obviously more advantageous to increase the solar distance than the vertical distance from the ecliptic plane.

Table 1. Summary of maximum target distances for an observing time of 30 h

Distance [AU]	i	$I_v^{(max)}$ [MJy sr^{-1}]	Max. distance [pc] det.	CO_2	O_3
1	0°	12	11	5.0	3.2
3	0°	0.17	33	16	9.3
5	0°	0.013	63	30	18
1	30°	5.1	14	6.8	4.0
1	60°	0.85	22	11	6.2

The uncertainty in the modelling of the interplanetary infrared foreground has been discussed in the introduction. The results presented here rely on a model of the interplanetary dust and temperature distribution that is constrained only near the Earth's orbit. A better understanding of the zodiacal foreground for Darwin is only possible if the infrared brightness is directly measured from the proposed observing locations. The advances in detector technology that allow passive cooling systems to be employed, as well as electric propulsion systems that will be flight-tested in 2002/2003 on the Smart-1 spacecraft, make a small-satellite mission equipped with an infrared camera to explore the infrared environment at 5 AU feasible. Such a precursor mission would serve two purposes: (i) it would help to make a good decision about where to put the Darwin instrument, and (ii) it would map the distribution of interplanetary dust, and thus improve our understanding of pristine Solar System material.

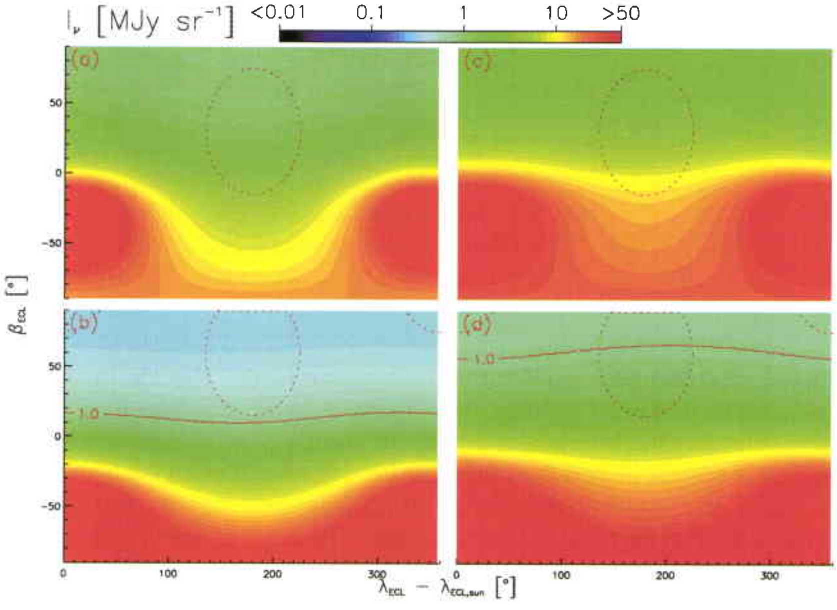

Figure 3. Sky maps of the foreground brightness of the zodiacal foreground at 10 micron (a), (b), and 20 micron (c), (d). Panels (a) and (c) show the brightness on an heliocentric orbit with 30° at a distance of 1 AU, and panels (b) and (d) show the brightness from a 60° inclined orbit also at 1 AU. The contour lines show limiting foreground brightnesses of 0.1 and 1 MJy sr^{-1}. The dotted circle indicates Darwin's observation window within 45° of the anti-Sun direction

The Code of Conduct for International Space Station Crews

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On 15 September 2000 in Washington DC, the Multilateral Coordination Board (MCB), the highest-level cooperative body established by the Memoranda of Understanding (MOUs) pertaining to the International Space Station (ISS) Programme signed early in 1998 by NASA and each of the Cooperating Agencies designated by the other ISS Partners (i.e. the Russian Space Agency, ESA, the Government of Japan and the Canadian Space Agency), approved the Code of Conduct for International Space Station Crews. This document contains a set of standards agreed by all Partners to govern the conduct of ISS crew members, starting with the first expedition crew launched from Baikonur in Kazakhstan on 31 October 2000. These standards had been developed over the previous six months by teams of Agency officials, working in close consultation with the competent authorities of the Partner States.

Introduction

A broad outline of the Code was already contained in Article 11 of the four above-mentioned MOUs and therefore the drafters had their work mapped out in advance. The Code had to establish a clear chain of command and relationship between ground and on-orbit management, standards for work, responsibilities with respect to elements and equipment, disciplinary regulations, together with physical and information security guidelines. It also had to define the ISS Commander's authority and responsibility to enforce safety procedures, physical and information security procedures and crew-rescue procedures for the ISS. As far as the US Space Shuttle is concerned, these matters are covered by regulations adopted under the authority of the legislation that established NASA. Similarly, specific Russian regulatory provisions apply to crew members while being launched or returned on Russian space vehicles or conducting their activities on board the Mir Space Station.

Because of the genuine partnership entailed by Space Station cooperation pursuant to the corresponding Inter-Governmental Agreement (the IGA), it was necessary to develop a Code that could be applied on the various parts of the Station, bearing in mind that the Partners retain their jurisdiction and control over the flight elements they themselves provide, and over personnel who are their nationals. The negotiations on the Code developed rapidly into a genuine inter-cultural exercise, based not only on the solid experience of human space-flight built up over the last forty years by both the Russian and US Partners, but also on the valuable contributions of the other Partners, which had gained their experience through numerous flight opportunities offered by Russia and the United States in the last fifteen years. In this exercise, an appropriate balance had to be struck between features originating from the military heritage of the USA and Russian astronaut programmes and those needed to firmly establish the civilian and multi-national character of the ISS.

The closest approximation to this Code until then was a 'Standards of Conduct Agreement', which a mission specialist sent by a foreign organisation such as ESA for training in the United States was required to sign before being assigned to a specific US Space Shuttle flight. The main purposes of this document are to obtain the person's consent to be subject to the authority, orders and direction of the Commander, to limit the disclosure of data which are protected, and to refrain from using his or her position or information obtained in the course of the mission for personal gain.

Noteworthy issues covered by the Code

Legal requirements imposed on ISS crew

When reading the Code, one may be surprised by the number and scope of the various sets of regulations that will apply specifically to ISS crew, bearing in mind that a number of provisions of the IGA and MOUs are also directly relevant to astronaut activities. In addition to the Code itself and the related disciplinary policy, a crew member is subject to the provisions of the ISS Flight Rules and the other requirements imposed by the Cooperating Agency providing him or her, those relating to the Earth to Orbit Vehicle (ETOV) being used for the mission, those defined by the various ISS cooperation bodies listed in Article 11 of the MOUs dealing with various aspects of astronaut matters and, finally, to the requirements contained in the rules of the various institutions hosting the training. It is therefore normal that the Code specifies that the ISS crew member has a right to know about these requirements, and that he or she will be educated as to the applicable rules by the Cooperating Agency providing him or her, through the crew training curriculum and normal programme operations.

The disciplinary policy for ISS crew has been developed by the Multilateral Crew Operations Panel (MCOP), a cooperative body established through Article 11 of the MOUs, and approved at the above-mentioned MCB meeting of 15 September 2000. This policy will be further expanded through detailed documentation being established on the various steps it outlines. It covers matters on which the MCOP will exercise a central role, such as the procedure required for submitting a statement asserting violation of a prescription of the Code by a crew member, examining and making determination on this statement, the manner in which a decision may be revised, and the type of disciplinary measures that could be imposed depending on whether the violation occurred on Earth or during flight, etc. The interest of this disciplinary policy lies in the implicit recognition by the Cooperating Agencies that their astronauts' behaviour may be subject to a process that is administered not only on the basis of their own personnel policy, but also of rules developed by the ISS partnership.

Issues affecting a crew member as an individual

The prescriptions of the Code apply to an ISS crew member from the time he or she is assigned to a specific ISS expedition until completion of post-flight activities. Some of the provisions, for example those outlining the responsibilities of the Commander on board the ISS, are obviously not relevant to the activities of the astronaut while on the ground, training for the flight, or conducting activities on return from the ISS, although the Commander at these stages is still 'directing the activities of the ISS Crew Members as a single integrated team to ensure the successful completion of the mission'. As mentioned above, the requirements outlined in regulations pertaining to the space vehicle used by the crew member must also be observed. The Code applies to visiting crew members who will be staying on the ISS for only a few days: the basic idea is that, while on board for a visit or a full stay, all crew members are covered by the same legal prescriptions and are subject to the authority of the ISS Commander.

Although the Space Station is in the early stages of construction, it is already permanently occupied

The Code stipulates that a crew member must refrain from any use of that status motivated by private gain. This requirement is not limited in time, but it is understood that each Agency will have to deal with the conditions applicable to post-employment activities of astronauts and determine what is acceptable in terms of compensation, in the form of bonuses, special remuneration for non-government agents, etc. Making a distinction between personal effects and mementos that could be carried on board by the crew members, the Agencies agreed that constraints of manifest, safety and stowage allocation were already sufficient and that there was no need for the Code to spell out the discretion exercisable by an Agency in this regard.

The Station's long-stay crews (blue coveralls) sometimes play host to visiting Shuttle crews

Harassment

One of the Agencies was adamant that 'zero tolerance' must be enforced in or on the ISS for interpersonal or group harassment, as an express provision of the Code. The discussion showed the difficulty of harmonising the Partners' respective legal concepts of harassment in a multi-national environment. In order to accommodate the multiplicity of views, it was decided to repeat in the general rules of conduct for the crew member outlined in Section II of the Code, a sentence originally drafted for the next section pertaining to the Commander's responsibilities. This sentence calls for the need to 'maintain a harmonious and cohesive relationship among the crew and assure an appropriate level of mutual confidence and respect'. In other words, the Agencies recognised that such language would make the application of sanctions possible in a case where the MCOP determined that harassment had taken place.

Authority of the Commander over payloads

An issue discussed during the negotiations was whether or not the authority of the ISS Commander should extend to payloads. One argument advanced was that such an extension could jeopardise the understanding, apparently reached bilaterally between NASA and the RSA and reported in the press a number of years ago, according to which any crew member, whether an American or Russian national, could be designated to be an ISS Commander. One Agency contended that if NASA considered that specific payloads would be particularly sensitive during a mission, NASA could object to the designation of a non-American ISS Commander. This matter was settled by the addition of an explicit interpretative sentence stating that nothing in the relevant section of the Code would affect the designation by the MCOP of an individual of any Partner State to be an ISS Commander. This addition has the double advantage of the first recognition in writing at such a high level of the 'rotation' principle (i.e. a national of any Partner State) for designation of the Commander and the fact that no national of a non-Partner State can become ISS Commander.

In this connection, the discussion developed further because of the insistence of one Agency that the authority of the ISS Commander over the payloads must be put in the appropriate framework, i.e. strictly in relation with the Commander's responsibility to preserve the safety of the crew and the ISS. The Agency in question wanted to make sure in the drafting of the Code that the authority of the ISS Commander over payloads would not extend to the right of disposal, for whatever reason, over the other Partners' elements and equipment. This could lead, admittedly in the worst-case scenario, to a situation in which the ISS Commander orders the destruction of payloads that would not be in the commercial interest of its own cooperating Agency. It was stressed strongly that such a far-fetched scenario could simply not be envisaged under the IGA, the MOUs and the Code.

Use of force on board the ISS

Two of the Partners argued strongly against any explicit reference in the Code to the possibility of the ISS Commander making some 'use of force', contending that the reference to the right of the ISS Commander to use 'reasonable and necessary means' to discharge his or her responsibilities was sufficient. One of the other

Agencies expressed a concern that not mentioning 'use of force' in the Code would preclude the use of force or physical restraint of any kind in or on the ISS in the future. After a long discussion, it was agreed that the minutes of the MCB meeting dedicated to Code approval would contain the following interpretative statement: 'In cases where necessary to ensure the immediate safety of the Crew Members of the ISS, reasonable and necessary means may include the use by the ISS Commander of proportional physical force or restraint'. It is the Cooperating Agencies' understanding that force may be used only when immediate safety is jeopardised and after exhaustion of other possibilities. It should be noted that it was not considered necessary to make any explicit reference to the possibility that any crew member other than the ISS Commander may need to use force against another.

Proprietary and export-controlled data generated in or on the ISS

Tackling the issue of 'Physical and Information Security Guidelines' in Section V of the Code, the Agencies examined the need to protect data generated by activities conducted in or on the ISS when such data could be considered to be 'proprietary' or 'export-controlled'. Because protection of the corresponding data pursuant to Article 19 of the IGA is linked to the fact that they are marked with an appropriate notice or otherwise identified, the discussion focussed on the need to mark or otherwise identify the new data as soon as they are generated through the conduct of experiments on board the ISS. Through these provisions, the Agencies have excluded data that do not require protection for reasons other than those stated above, thus leaving the astronauts with a significant amount of data – even those not generally available to persons outside the ISS programme – to be exploited without particular restriction, for example for the purpose of writing articles or books.

The Agencies agreed that it is up to the Cooperating Agencies or the data owner or provider to give instructions for the marking of data generated on board the Station, because leaving this matter to the discretion of the astronauts themselves would impose an undue burden on them. As for the duration of the protection conferred to the data by the marking, which entails an obligation to seek permission from the owner before divulging data to a third party, the point was made that this protection was a 'continuing obligation' that would apply in certain instances even after an astronaut had ceased to be subject to the Code. Finally, because of these new rules in the Code, the Partners were for all practical purposes extending the marking obligation outlined in Article 19 of the IGA to data that were not necessarily to be exported or otherwise transferred to another Cooperating Agency. Such an extension of the original obligation, which could be justified by the 'safety of information' clause contained in paragraph 8 of Article 19, was necessary because of the presence of crew members of more than one Partner on board the ISS.

Implementation of the Code in the Partners' internal legal systems

The Agencies have been interested by the steps to be taken on a solid legal basis in order to persuade astronauts to abide by the rules outlined in the Code, albeit on a voluntary basis, as part of additional terms and conditions enabling them to pursue astronaut activities as employees of a Cooperating Agency. These steps are necessary to eliminate doubt as to the right of an Agency to require an astronaut to abide by these rules when assigned to an ISS expedition, or possibly face the prescribed sanction in case of violation of them.

Station crew size is limited to three until the 7-man Crew Return Vehicle becomes available in about 5 years' time

A question considered by the European Partner States was whether there was a need for some government-level involvement in the finalisation of the Code because of the nature of the issues it covered, bearing in mind that the IGA stipulates that each State retains jurisdiction and control over personnel who are its nationals. They concluded that the matters dealt with in the Code were within the scope of the powers delegated by the IGA to the Cooperating Agency of the European Partner, and that ESA could therefore take the appropriate measures, including through the Agency's delegate bodies. Also, because the European astronauts are all members of the European Astronaut Corps and, as such, ESA staff members, the ESA Staff Regulations were deemed applicable in the circumstances.

A second question was whether there would be a need for some ratification-type procedure at government level in any of the European Partner States to confirm that the Code was 'accepted' by the European Partner as prescribed in Article 11 of the IGA. Finally, it was decided that explicit acceptance of the Code by the European Partner will be made in a letter addressed to the ESA Director General by the competent authorities of each European Partner State, thus enabling the Director General to confirm acceptance of the Code on behalf of the European Partners as a whole. Before writing their letter of acceptance, the government representatives, generally the legal service of the Foreign Ministry, had to check whether their internal legal system enabled their authorities to abide, albeit through ESA, by the commitment spelt out in Article 5 on the exercise of jurisdiction and control over their nationals and in Article 11.2 of the IGA to the effect that: 'Each Partner, in exercising its right to provide crew, shall ensure that its crew members observe the Code of Conduct'.

All crew members, of any nationality, are subject to the authority of the ISS Commander

As a result of the above procedure, the Code has been implemented in Europe through a directive of the ESA Director General addressed individually to members of the European Astronaut Corps (EAC), in which they are invited to agree in writing to the terms and conditions in the Code, a process that is consistent with the ESA Staff Regulations and the decision taken in March 1998 by the ESA Council on the modalities for building up the EAC.

In the United States, the Code has become part of the US astronauts' terms and conditions of employment through the adoption on 1 October 2000 of corresponding regulations under NASA's existing legislation (14 CFR Part 1214). In Japan, the Code will be incorporated into regulations consistent with the terms of the legislation that established the National Space Development Agency (NASDA) and Japanese astronauts, as employees of NASDA, will be invited to sign up to the terms of the Code. Similarly in Russia, the cosmonauts will be invited to sign up individually to the terms of the Code once it becomes part of the regulations and policies applicable to the Russian Aviation and Space Agency (RSA). In Canada, where astronauts are appointed by decision of the Cabinet, the Code will become part of the terms and conditions of astronauts' employment in the same manner, i.e. through an Order in Council issued by the Cabinet.

Conclusion

Adoption of the Code was clearly a milestone in ISS cooperation. However, a number of issues affecting ISS astronauts remain to be addressed by the Cooperating Agencies and may test the Code's flexibility and adaptability. For example, over the next few months, the Agencies have to examine all of implications of participation in ISS cooperation by States other than the 15 Partner States. Nationals of non-Partner States may be acquiring flight opportunities from the Partners, either on the basis of cooperation between space agencies or privately, through a commercial venture. At this stage, no distinction is made in the applicable legal texts between a career astronaut hired by an ISS Cooperating Agency, and an individual flying to and from the ISS for only few days on a fare-paying basis, although the actual requirements in terms of training, proficiency and performance and long-term commitment would vary significantly. The Partners still have to examine the implications, and agree on the applicable rules and procedures for enabling nationals of non-Partner States to become ISS crew members, primarily as visiting crew, since Article 5 of the IGA prescribes that it is the Partner State that retains jurisdiction and control over personnel who are its nationals, and Article 22 of the IGA constitutes the basis for a Partner State to prosecute an 'alleged perpetrator' of a crime committed on board the ISS, but only when that person is a national of that State. Commercialisation of ISS utilisation will also bring opportunities for advertising, merchandising and sponsoring, which may raise some concerns for astronauts and their Cooperating Agencies. All of these issues need to be addressed and resolved in good time and to the satisfaction of the Cooperating Agencies and their astronauts.

Aerothermodynamic Analysis of Space-Vehicle Phenomena

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Aerothermodynamics is a key technology for the design and optimisation of space vehicles because it provides the necessary databases for, for example, the choice of trajectory, for guidance, navigation and control, as well as for the thermal-protection and propulsion systems. Computational aerothermodynamics, in particular, has become a powerful tool for improving our understanding of the physical phenomena that are at work. This article presents its current capabilities with respect to flow phenomena. Examples are presented of external flows past re-entry-vehicle demonstrators and launchers. Internal flow problems associated with propulsion and the interactions with external flow are also presented.

The future work requirements for further strengthening the computational and testing capabilities in Europe are identified. These objectives would be facilitated by bringing together a European network of industry, research organisations and universities. The need to verify ground-based tests with in-flight experiments, i.e. vehicle demonstrators, is also addressed.

Introduction

By adding thermodynamics to aerodynamics, one arrives at the notion of 'aerothermodynamics', in which those flow fields are considered, the analysis of which requires - beyond its use in classical aerodynamics - the consideration of special thermodynamic relations. Well-known examples are the high-temperature flows past re-entry vehicles, and flows in combustion chambers and in the nozzles of propulsion systems.

The development of aerothermodynamics in Europe experienced a substantial boost in the mid-eighties within the framework of ESA's development efforts for the Manned Spaceflight Programmes, such as Hermes, and later in the framework of the follow-up Technology Programmes. This was especially true of the development of the hypersonic high-enthalpy facilities, as well as for computational aerothermodynamics. Since then, aerothermodynamics has evolved to cover a wide field of applications and its use is becoming increasingly multidisciplinary.

The design of space vehicles depends crucially upon databases providing the forces, moments, temperatures and heat fluxes along the chosen trajectories. These databases can be established for given shape and control surfaces, for an assumed centre of gravity, where the shape and control surfaces of the space vehicle need to be determined in an iterative manner until stable and controllable flight is achieved. If the thermal-protection system chosen does not tolerate the loads encountered along the trajectory, the latter has to be adapted such that the flight remains controllable, by changing the space vehicle's shape and/or its control surfaces. In such multidisciplinary iterations, the available databases play a key role. The problem becomes more complex if the aeroelastic effects are considered and integration of the propulsion system is required, the latter being most important for future launchers. Figure 1 indicates the strong interaction between aerothermodynamics and other disciplines.

Aerothermodynamic tools for design purposes

Aerothermodynamic design issues can be addressed using advanced analysis methods, ground-based facilities, and flight testing. In a classical approach, the design of space vehicles (e.g. the Space Shuttle) depends heavily on experimental data. Owing to the inherent limitations of similarity laws, ground-based facilities cannot simulate fully the physical flows around space vehicles during reentry. In the USA, therefore, data obtained from in-flight experiments, particularly with the X-vehicles, have been used to complement the test data obtained from ground-based facilities. The latter contribute to the data required for design work up to Mach 10. These so-called 'cold' wind-tunnel data provide the 'anchor' points for the extrapolation to flight conditions. In the Hermes era, Europe chose to complement the knowledge available from the cold wind tunnels, which are not able to model

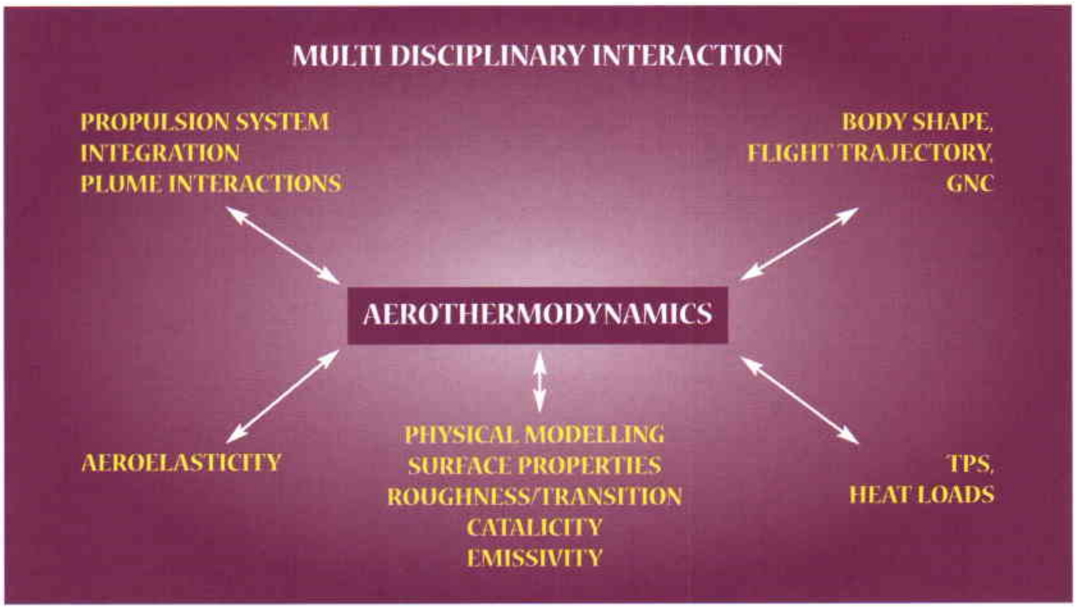


Figure 1. Interactions between aerothermodynamics and other disciplines

the high-temperature effects typical for higher speeds and altitudes, by means of high-enthalpy or hot-flow facilities. ESA has supported the modernisation of existing cold wind tunnels, and also the construction of facilities with new capabilities.

Facilities that were initiated during the Hermes Programme and completed or upgraded during the follow-up Manned Spaceflight and Technology Programmes include:

- Two high-enthalpy facilities, which are mutually complementary, for the study of high-temperature effects on controllability and heating: the 'hot shot' facility F4 at ONERA Le Fauga, and the piston-driven 'shock tube' HEG at DLR Goettingen.
- Three plasma facilities, also mutually complementary, to investigate the heat load and gas surface interaction on materials and structures: the segmented arc-jet-heated L3K facility at DLR Cologne (max. power 6 MW), more recently the larger Scirocco facility at CIRA Capua (max. power 70 MW), as well as the recently commissioned plasmatron facility at VKI Brussels (max. power 1.2 MW).

The Scirocco facility is still in the commissioning phase, but should be operational in 2001; the other facilities are already in full operation.

In 1997, Europe decided to carry out full-scale free-flight experiments and embarked on the Atmospheric Re-entry Demonstrator (ARD) capsule. The corresponding post-flight analysis has recently been completed. A lifting-body re-entry demonstrator (X-38) will be flown in 2002 based on a close partnership with NASA, where ESA's and the German TETRA programme have joined forces. In February 2000, a low-cost flight experiment based on Inflatable Re-entry and Descent Technology (IRDT) from Russia, initially foreseen for a Mars lander, was carried out. This flight experiment is being repeated in 2001 to evaluate its potential as an independent, low-cost Space-Station payload return vehicle in greater detail. In addition to ground-based facilities and the little available flight testing so far, the tool that has been developed most since the Hermes era is Computational Fluid Dynamics (CFD). CFD is being used to gain greater insight into the physical phenomena and to help to accelerate and improve the design processes.

CFD has become a powerful tool in classical aerodynamics, but its usefulness relies on input from appropriate physical modelling, for example transition and turbulence for the numerical integration of the flow governing Reynolds averaged Navier-Stokes equations. Hence, measurements in ground-based facilities provide the skeleton or anchor points for the database below Mach 10. The corresponding 'interpolation' is performed with the results of validated CFD solvers. Above Mach 10, where in particular high-temperature effects dominate the flow, CFD must be used. The appropriate validation of CFD is therefore of great concern. It is achieved by comparing data measured in, for example, the above-mentioned high-temperature facilities with those obtained by numerical prediction. In many cases the use of CFD goes hand in hand with the definition of the test cases and interpretation of the data. In this context, ESA/ESTEC and others have organised a number of workshops in the past. CFD is subsequently being used for flight simulations above Mach 10. This 'extrapolation method' assumes, however, that the physical models that enable good results for the simulation of the experimental test case, will provide good results also for free flight. Therefore, free-flight data are urgently required to remove any doubts about the validity and accuracy of the CFD predictions and to confirm the extrapolation methodology. This is particularly important for man-rated vehicles.

Today's aerothermodynamic issues are discussed below in the context of examples from the different ESA Directorates.

Aerothermodynamic applications in the ESA Manned Spaceflight and Microgravity Programme

Thanks to ESA's Manned Space and Technology Research Programmes, European expertise in aerothermodynamics has been advanced considerably in recent years. The flight of the Atmospheric Re-entry Demonstrator (ARD), and the challenging participation in NASA's Crew Return Vehicle (X-38/CRV) programme with substantial European hardware and software contributions, represent major steps in this respect.

ARD

ARD was flown successfully on Ariane-503 in October 1998. The objective was to test and qualify re-entry technologies and flight-control algorithms under real flight conditions, to achieve in-flight validation of design concepts, hardware and system capability, to validate aerothermodynamic prediction tools, to qualify the thermal-protection system, to assess guidance, navigation and control laws, to assess parachute and recovery-system performance, and to study radio-communication links during re-entry.

The ARD flight was a major achievement for Europe. It provided real flight data and enabled comparison with experimental and numerical design tools used for all flight phases. Data were recorded from the de-orbiting, throughout the high-speed portion of the flight, until parachute deployment and splashdown. Reaction and control system efficiencies, local heating, blackout, transition phenomena and dynamic and static stability data were all measured. The splashdown in the Pacific occurred less than 5 km from the expected position. The ARD's angle of attack and flight-path angle differed only slightly from the prediction (around 2 deg for trim and 0.5 deg for side-slip angle). Four angle-of-attack manoeuvres were successfully executed to study pitch damping. A detailed post-flight analysis has just been completed with new experiments and computations to check the databases. Figure 2 shows an example of a Schlieren picture in the S4 ONERA Modane facility at Mach 10, together with corresponding predictions using the in-house-developed Lore code. Figure 3 compares experimentally obtained oil-flow patterns with predicted skin friction lines for the study of the local heating, using the same facility.

The ARD flight not only allowed the verification of the use of ground-based facilities and the use of CFD for databasing and design, but also highlighted some critical issues requiring further study and improvement, such as flight heat-flux gauge integration and high-enthalpy wind-tunnel pressure and heat-flux data accuracy improvement.

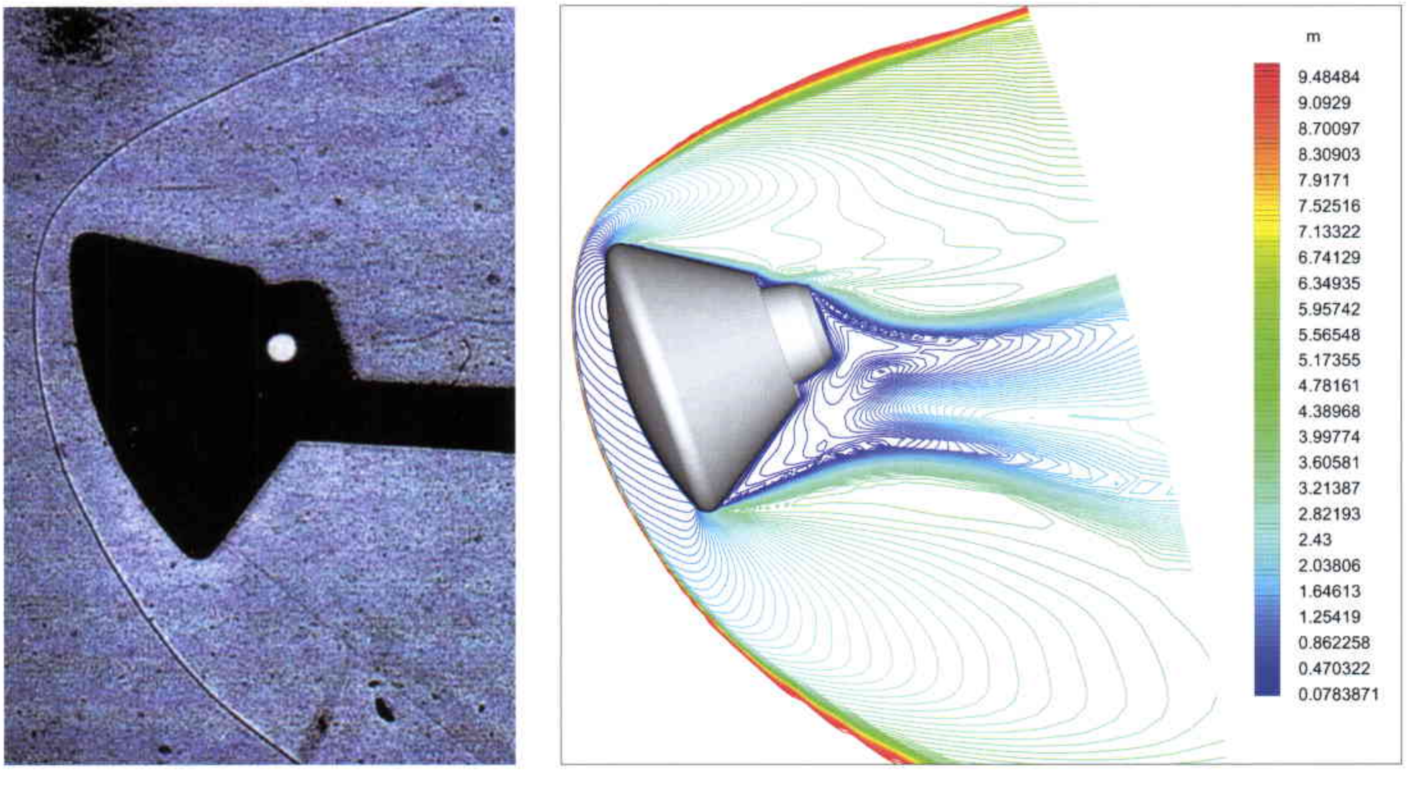


Figure 2. ARD Schlieren photograph taken in the ONERA S4 facility at Mach 10 (incidence angle 20 deg) and the corresponding computed iso Mach lines

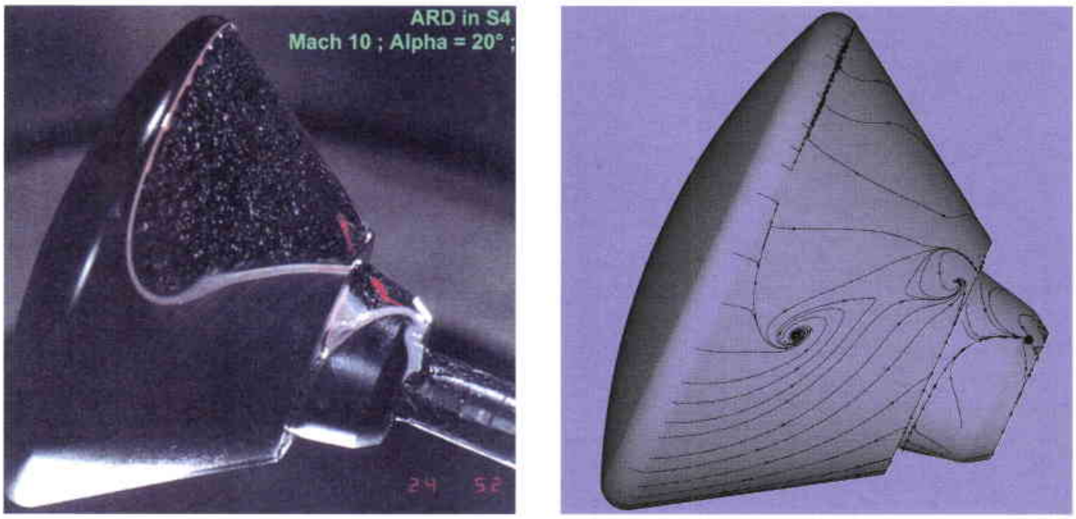


Figure 3. ARD oil flow patterns in the ONERA S4 facility at Mach 10 (incidence angle 20 deg) and the corresponding computed skin friction lines

X-38/CRV

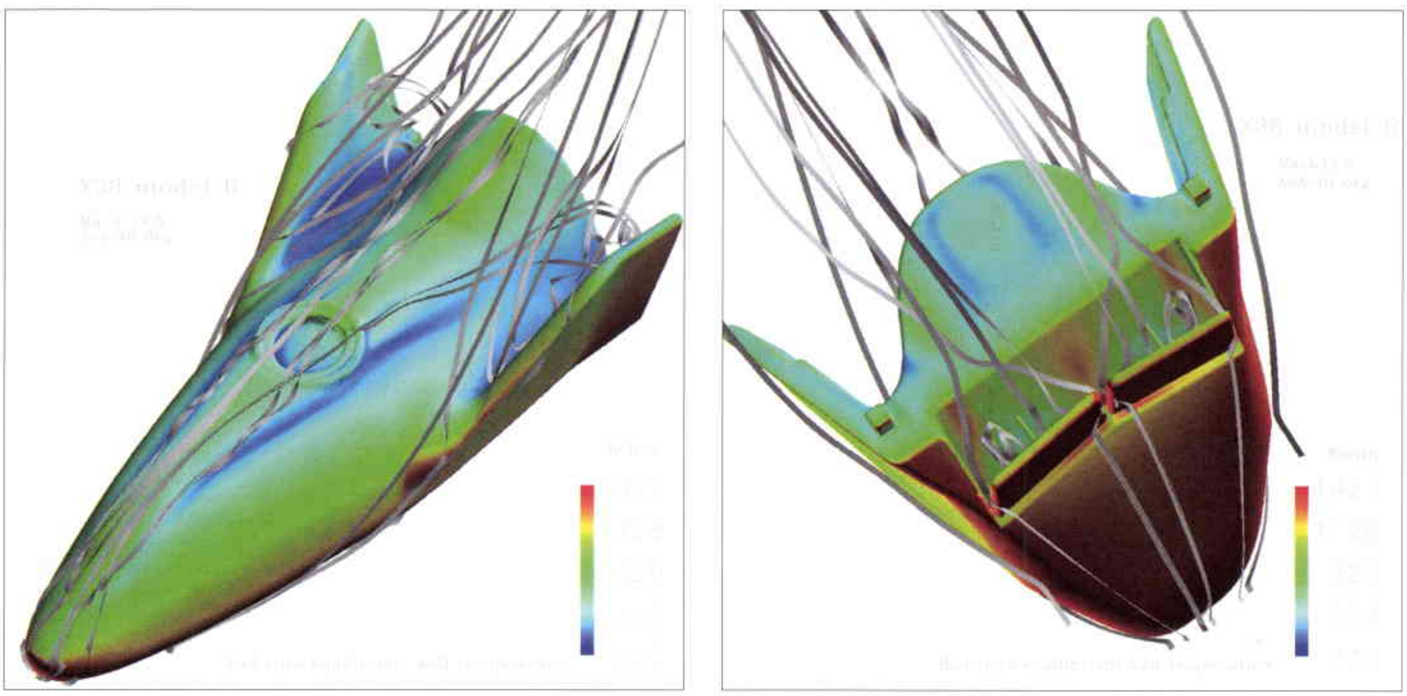
The joint NASA/ESA/DLR X-38 project includes the demonstrator V201 being assembled for a Shuttle-carried hypersonic re-entry flight planned for 2002. This partnership with NASA will be carried over to the production of the operational man-rated Crew Return Vehicle (CRV) for the International Space Station in collaboration with American industry as prime.

Some of the aerothermodynamic issues for the X-38 design are:
- Stability and trimming: the influence of real gas and viscous interaction effects on control-flap efficiency and heating.
- Roughness-induced boundary-layer transition, flap shear-layer transition and its influence on local heating.
- Micro-aerothermodynamic effects due to flow through hinges and gaps in rudders and flaps.
- Qualification testing of the thermal-protection system in ground-based facilities and extrapolation to flight.
- Wall catalysis and radiation influencing heating rates.
- Transonic dynamic derivatives for stability control.
- Flight measurement techniques, including air data system.
- Reaction and control system efficiencies.

To assess these issues, CFD is being heavily used in defining wind-tunnel test conditions, in interpreting the measured data, and finally for the flight extrapolation.

Figure 4 shows some interesting flow patterns on the windward and lee sides of the X-38 vehicle at Mach 17.5 and 40 deg incidence. It confirms the predicted (Lore) increased radiation equilibrium temperatures at the leading edges and at the flap corners, especially between the body flaps and at the base end behind the control flaps. Figure 5 shows the effect that the boundary layer has when it transitions from laminar to turbulent

Figure 4. Predicted X-38 flow streamlines at Mach 17.5 (incidence angle 40 deg) combined with the equilibrium radiative wall-temperature distribution



flow on the flap. A comparison is presented with experiments performed in the NASA LARC 20-inch Mach 6 facility. The complexity and multidisciplinary nature of the interactions involved in the body-flap design are shown in Figure 6. Extensive testing is being conducted within the German TETRA programme using the L3K plasma facility at DLR in Cologne. Figure 7 shows a model set-up as tested under high-enthalpy conditions. Here again CFD is required for flight extrapolation, as the local conditions in the wind tunnel only partially duplicate those in flight.

The collaboration with NASA's Johnson Space Center has helped Europe to improve the understanding of such phenomena as windward roughness-induced transition, based on Shuttle lessons-learnt and extensive testing in NASA's LARC Mach 6 facility. Roughness-induced transition correlations were developed and validated by properly designing these roughness distributions on the windward side such that the transition encountered in the wind tunnel corresponds to that in flight. This European collaboration with NASA is unique and all partners are looking forward to strengthening the relationship through the

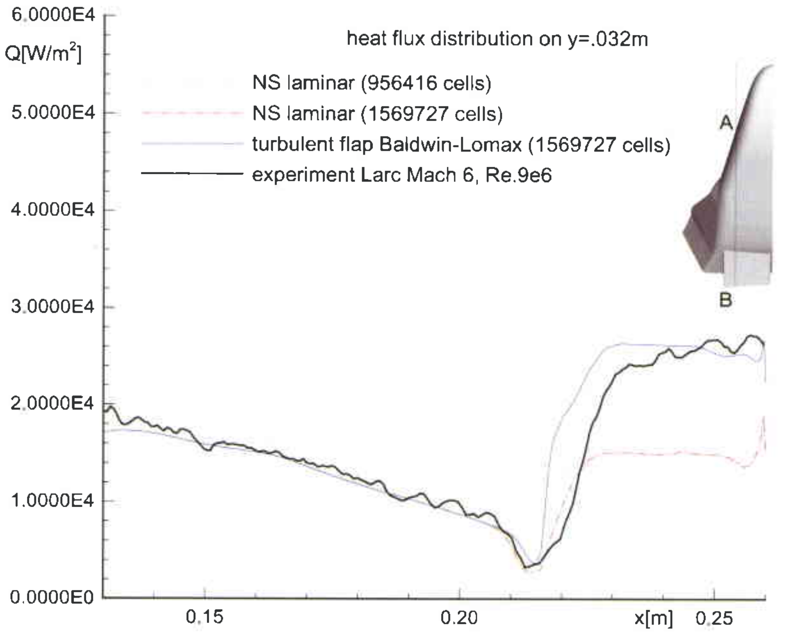


Figure 5. Predicted laminar and turbulent heat-flux distribution along the X-38's deflected body flap and a comparison with NASA LARC Mach 6 experiments

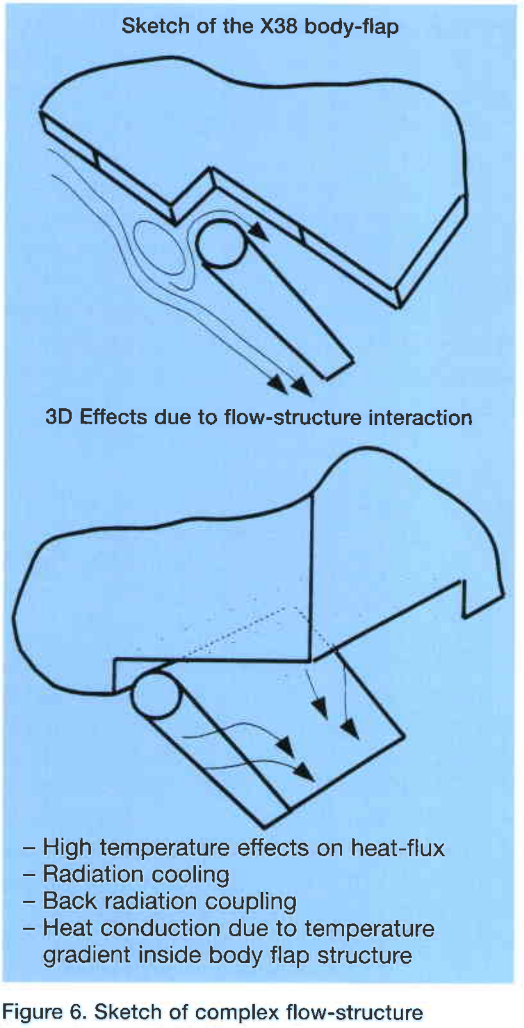


Figure 6. Sketch of complex flow-structure interaction on the X-38 body flap

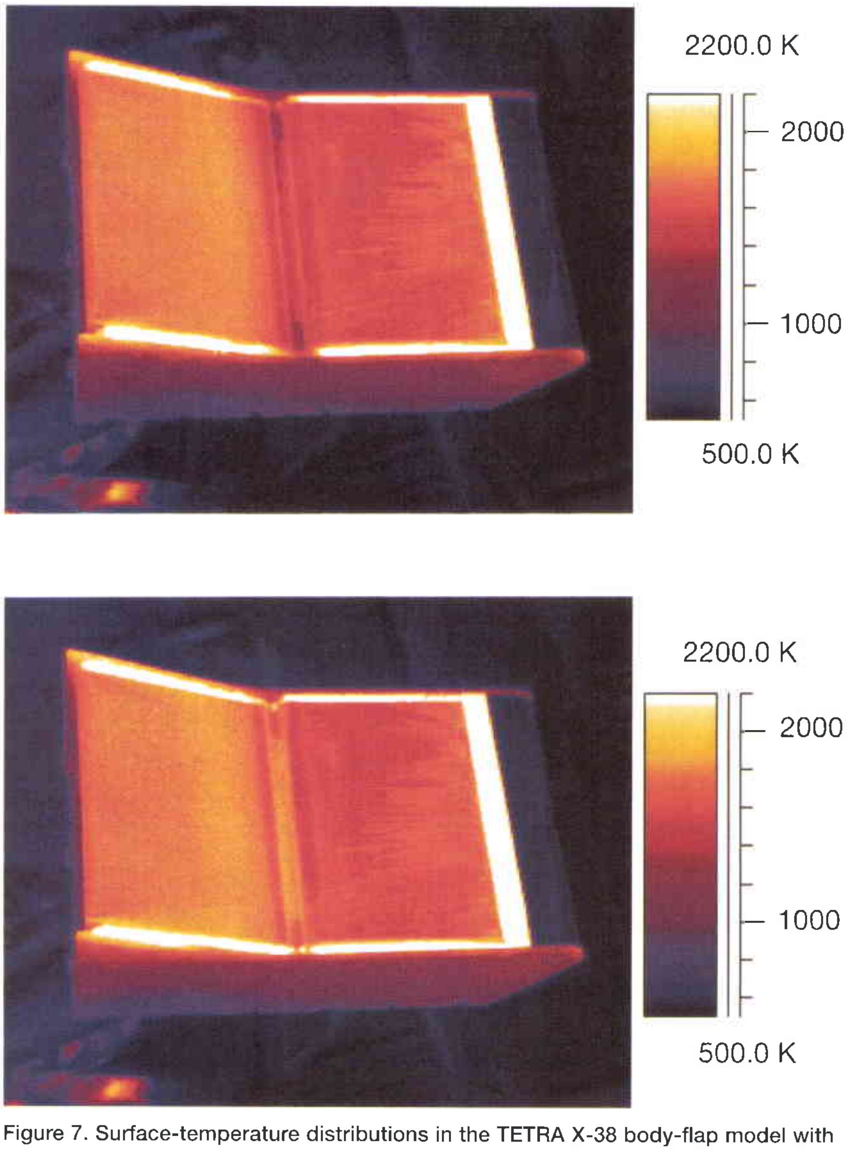


Figure 7. Surface-temperature distributions in the TETRA X-38 body-flap model with closed and open gaps in the L3K facility at DLR in Cologne

upcoming X-38/V201 hypersonic flight and the CRV programme.

Aerothermodynamic applications in ESA Science Programmes

One of the aerothermodynamic issues associated with satellites is plume impingement due to the interaction of the propulsion system with the spacecraft's surfaces. Improperly engineered plumes not only produce pressure and frictional forces, but may also cause contamination or unacceptable heat loads. To assess this computationally, a combination of different numerical methods is used: Navier-Stokes solvers for the continuum flow in the thruster nozzle, a Monte-Carlo direct simulation method for the near-transitional flow field, and free-molecular-flow tools for the far field. For routine project design work, industry uses quick empirical models. Such models for plume/surface interaction are currently being improved using data obtained in the unique, ESTEC-supported STG simulation facility at DLR in Goettingen, which produces roughly 10 m^3 of 'real space conditions'. The interaction of the rarefied flow with the surfaces requires separate modelling.

Planetary-science missions with capsule planetary entry or Earth sample-return scenarios involve critical aerothermodynamic phenomena:

- Direct entry using aerocapturing or aerobraking techniques involves improved knowledge of the reaction and control system interactions with the flow in transitional and continuum regimes.
- Thermochemical effects and radiation play a dominant role in the shock layer and in the wake of capsules for TPS design. Entering atmospheres of which the composition is not well known makes the assessment even more complex.
- Wake-flow stability and wake-flow transition effects influence the payload shield design for the capsule.
- For the higher capsule entry speeds, more complex phenomena have to be considered in the layer between the bow-shock wave and thermal-protection system, such as radiation and ionisation including gas/surface interactions, requiring knowledge of the appropriate material properties.
- The qualification of thermal-protection systems in plasma facilities using gases other than air is non-trivial. In addition, in many cases the thermodynamic and chemistry databases are incomplete or even non-existant.

Here also, CFD plays a major role in the design process. The validation is complex and requires dedicated tests in shock tubes, shock tunnels and plasma facilities using sophisticated instrumentation. These only provide the database for partial validation, because the facilities cannot completely simulate the free-flight flow field around the capsules. Again, the validity of the CFD-based extrapolation needs to be checked against actual in-flight measured data.

Aerothermodynamic applications in ESA Launcher Programmes

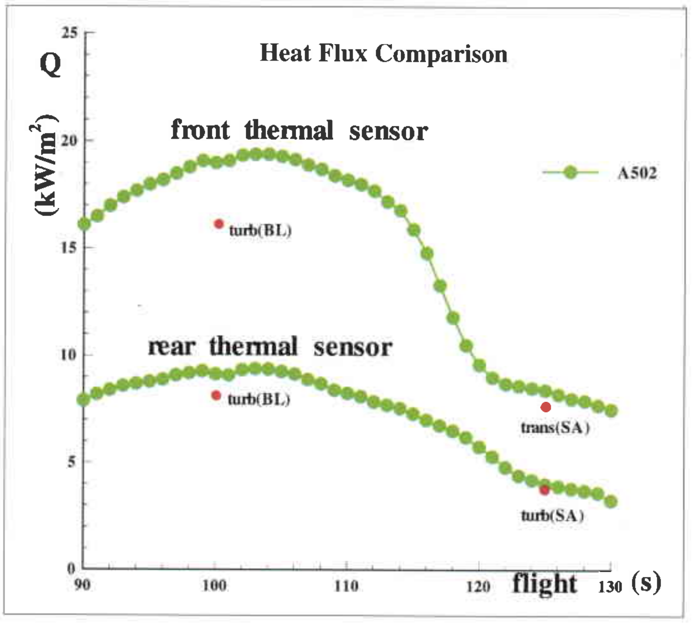
The aerothermodynamic issues for launchers differ significantly from those for blunt-body re-entry vehicles. In general, Mach number (compressibility) and Reynolds number effects (viscous forces) are important parameters for ascent-type vehicles, whereas high-temperature effects and pressure forces are dominant for re-entry vehicles.

Ariane-5

The aerothermodynamic activities involved in designing a launcher like Ariane-5 touch upon many areas: overall drag assessment during take-off, unsteady buffeting loads assessment at transonic speed, maximum steady-state load estimations around Mach 2, booster separation and jet impact during staging, solid booster radiation, local aerothermodynamics such as local heating at high Mach number around the booster attachment bars, attitude-control-system plume contamination and performance, nozzle-induced side loads at start-up and sloshing in tanks during staging or payload separation.

Only a limited subset of the many interesting fluid-dynamics issues will be touched upon here:

- *Performance of the attitude control system:* Its qualification involved hydrazine tests at ONERA Le Fauga for the verification of possible vaporisation inside the pipes. Because the test could not simulate vacuum conditions, CFD was used to extrapolate to flight conditions.
- *Explaining peculiar measurements with the help of computational simulations:* An overshoot in heat flux measured in flight proved to be due to the sharp drop in the wall temperature at the locations of the heat sensors. Figure 8 shows the locations of the thermocouples on the Ariane-5 fairing, and the temperature and corresponding heat flux distributions at those locations for two sets of flight conditions during ascent: those corresponding to Mach 3.7 and an altitude of 29 km, and those for Mach 5.8 at an altitude of 49 km. The predictions were made using the in-house-developed Sesmans code.
- *The magnitudes of the buffeting loads in the base region of the cryogenic tank (EPC) and on the Vulcain nozzle are a major concern.* Unsteady, separated flow emanating from



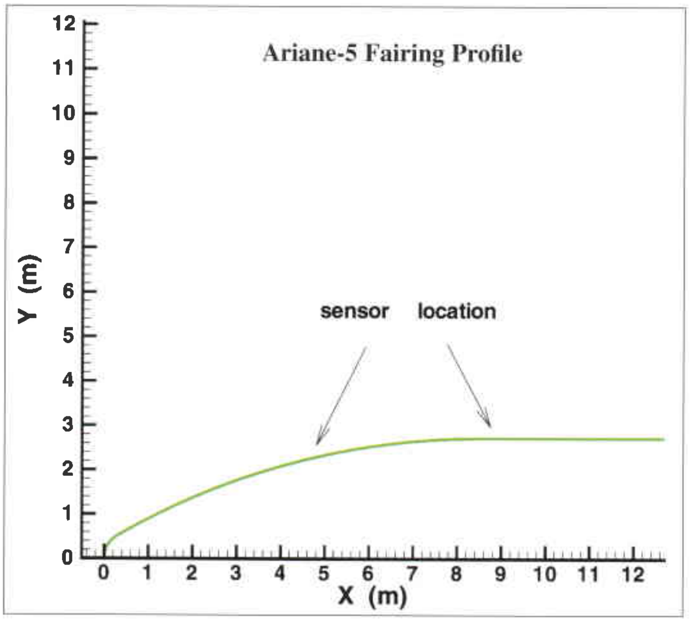


Figure 8. Comparison of computed and in-flight-measured heat flux on the Ariane-502 nose cone

the central core creates unsteady forces on the Vulcain nozzle. The magnitude and direction of these forces are influenced by 3D effects originating from the protuberances, as well as from the solid boosters. Extensive experimental campaigns involving large-model testing in transonic facilities with and without plume simulation were carried out. The analysis has recently been augmented with experimental activities for the study of possible coupling between external flow and shock-separated flow in the nozzle (all experiments in the transonic facilities are carried out with cold jets, and extrapolation to flight involves an assessment of the influence of hot jets on the buffeting interaction). Figure 9 shows the predicted unsteady velocity vectors using the ESA-funded Euranus code, highlighting the complexity of the flow. Figure 10 shows the Ariane-5 model in the FFA transonic/supersonic facility (S4). It is believed that the use of Large Eddy Simulations (LES) or eventually of Direct Numerical Simulation (DNS) will improve our understanding by enhancing the analysis of the influence of the hot plumes.

- *Ariane-5 loads:* CFD can be used to assess the pressure and heat loads and to update the launcher specification to reduce the structural and thermal-protection-system mass. To this end, CFD wind-tunnel flow simulations are carried out to build up confidence for flight computations. In-flight results from several sensors at specific locations provide the real flight data which, when used in combination with CFD results, allow the assessment of pressure and heat load. Figure 11 shows a typical 3D grid and preliminary computational results (Lore) for Mach 0.7 conditions in NLR's transonic facility (HST). The distribution of 3D pressure load in the base region is shown.

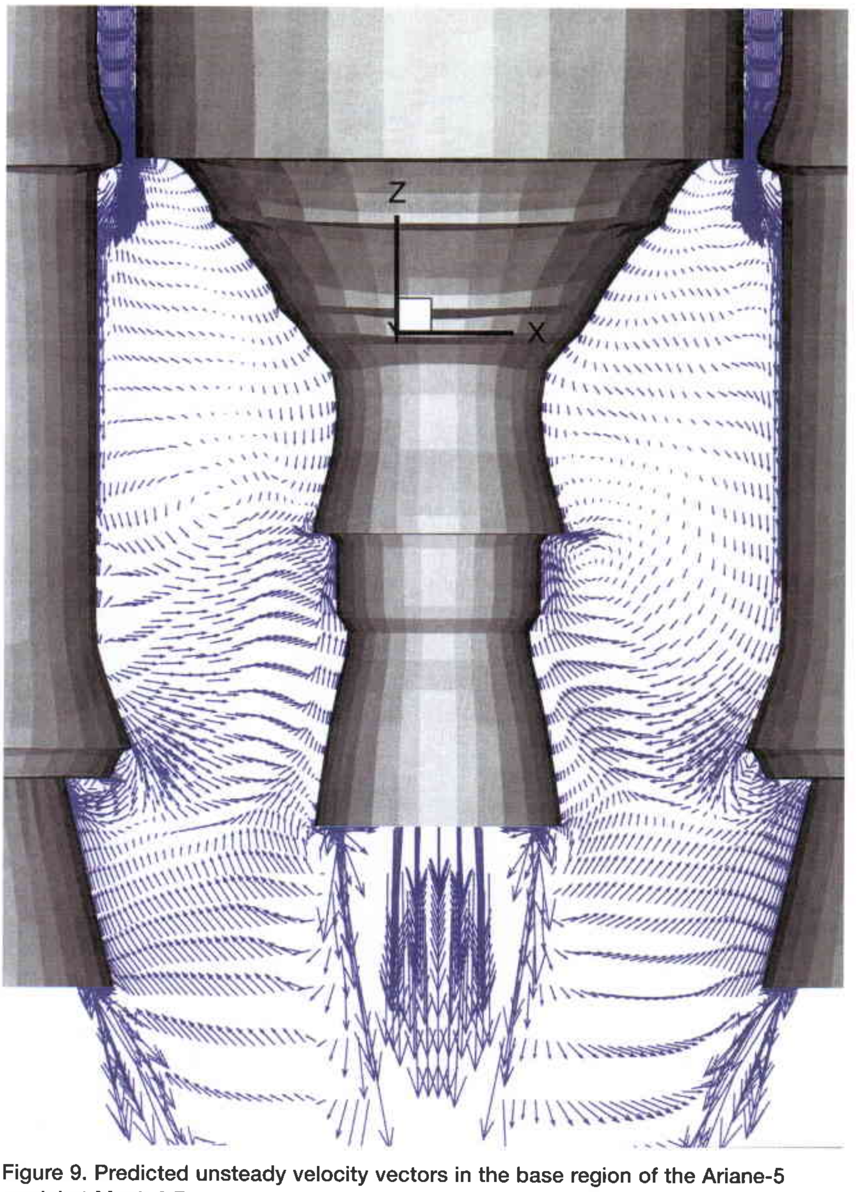


Figure 9. Predicted unsteady velocity vectors in the base region of the Ariane-5 model at Mach 0.7

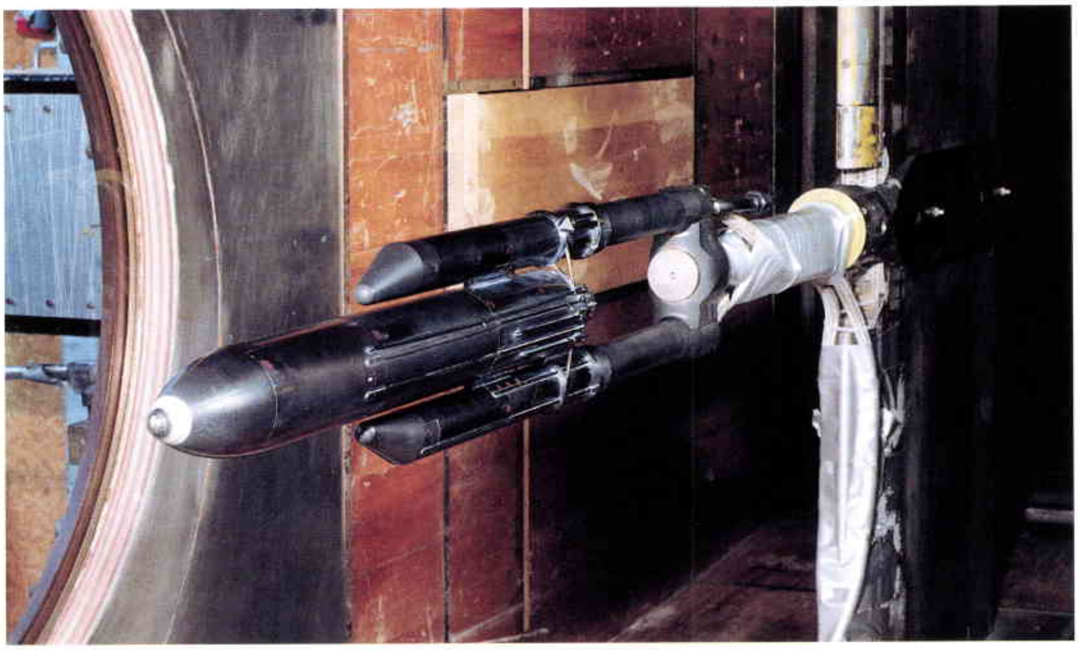


Figure 10. The Ariane-5 model in the supersonic S4 tunnel at FFA

– *Vulcain-2 performance analysis:* CFD was used to analyse the boundary-layer separation and shock pattern during the flow start-up process in the nozzle. The challenge here is to include in the simulation the correct representation of turbine exhaust gas (TEG) re-injection and the hydrogen dump cooling. The results explained the 3D heating patterns observed in a series of hot-flow experiments conducted at DLR in Lampoldshausen. Figure 12 shows the iso Mach contours (Lore) in the Vulcain-2 nozzle, the details of the flow structure near TEG injection and the H_2 dump location, and the shock-induced boundary-layer separation at the nozzle exit.

FESTIP

Within ESA's FESTIP Technology Programme, aerothermodynamic research has been performed in three main areas:

– *Configuration analysis:* Analysis of aerodynamic coefficients was carried out on generic shapes using numerical tools with different levels of sophistication, taking the Experimental Test Vehicle (EXTV) as the reference configuration. Force and moment bookkeeping data in the S4 FFA for the low-attack-angle ascent phase, with and without twin plume interaction, were analysed. Pressure-Sensitive Paint (PSP) data were recorded for comparison with CFD. Figures 13 and 14 show some typical experimental results with jets. The oil-flow picture shows the complex interactions to the lee side of the body flaps induced by the jets. The Schlieren photograph shows the embedded shock patterns at the location of the flap hinge influencing the overall trimming of the vehicle.

– *Critical-point analysis:* Roughness-induced-transition experiments were conducted on a

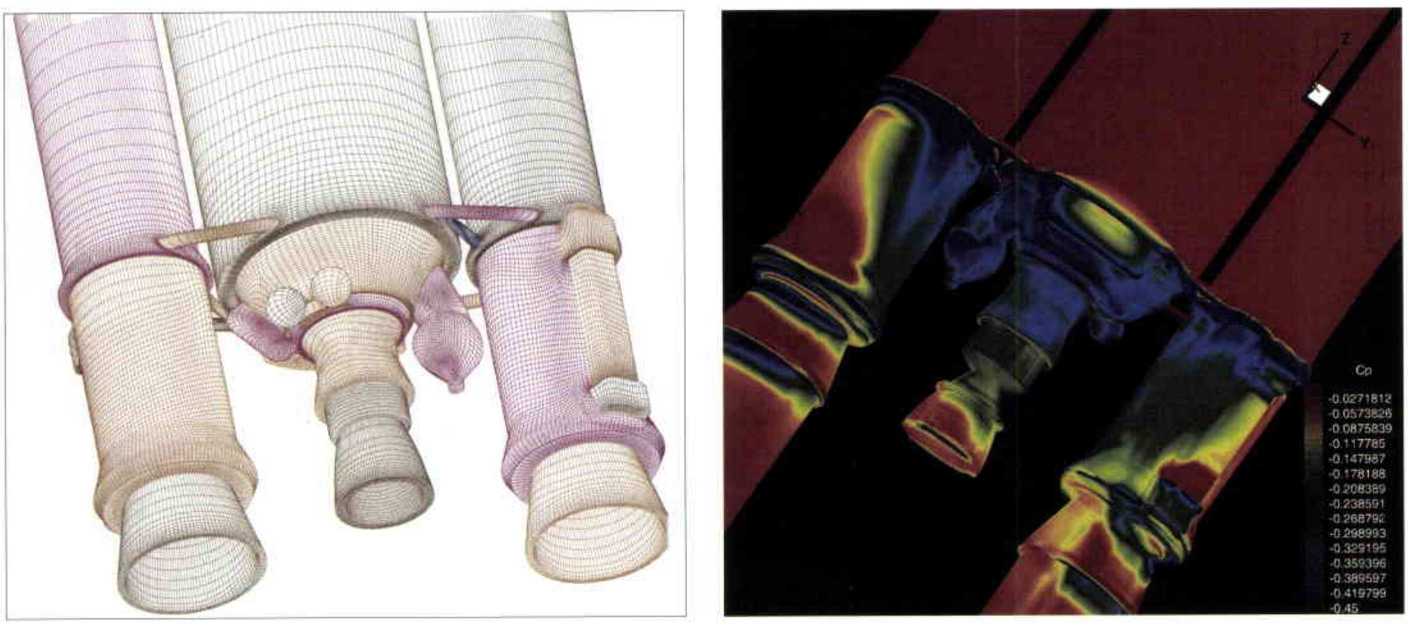


Figure 11. Surface mesh and preliminary predicted pressure distributions around an Ariane-5 model in NLR's HST facility for Mach 0.7 conditions

generic configuration and compared with existing correlations. Shock-wave boundary-layer interactions were studied for ramp flows, and CFD was used to study scaling effects, where in particular wall-temperature effects were addressed. As part of this programme, base flow plume-interaction experiments were also conducted at TU Delft and FFA for validation purposes. The importance of strut effects and the need for improved, time-accurate turbulence models were stressed.
- *Flight measurement techniques and flight-test analysis:* The activities here focussed on the definition of requirements for air data systems for the Raduga D2 configuration and on the MIRKA flight analysis. New experiments in the plasma facilities at IRS (Univ. of Stuttgart) as well as in the Ludwieg Tube at HTG (Hypersonic Technology Goettingen) were performed with a MIRKA configuration for the study of catalycity and of the influence of real gas on shock stand-off distance. Numerical results in the wind tunnel as well as under flight conditions were derived for MIRKA. These confirmed that in-flight catalytic experiments are feasible on simple ballistic configurations.

FLTP

To improve understanding of the issues related to launch-vehicle reusability and to enhance European technology in this field, the Future Launchers Technologies Programme (FLTP) was initiated as an ESA optional programme. Here we are focussing on the critical points from previous programmes that have not yet been completely solved:
- Increased heating due to roughness-induced boundary-layer transition will be investigated and shear-layer transition validation experiments will be carried out. CFD will be used to study scaling issues and hot-wall effects.
- Plasmatron experiments will be carried out to study the catalycity and compared with laboratory-obtained O_2, NO and N_2 catalytic recombination reactions. CFD will be used to bridge the gap and to report on the accuracy of the semi-numerical methods as presently used in the plasmatron.

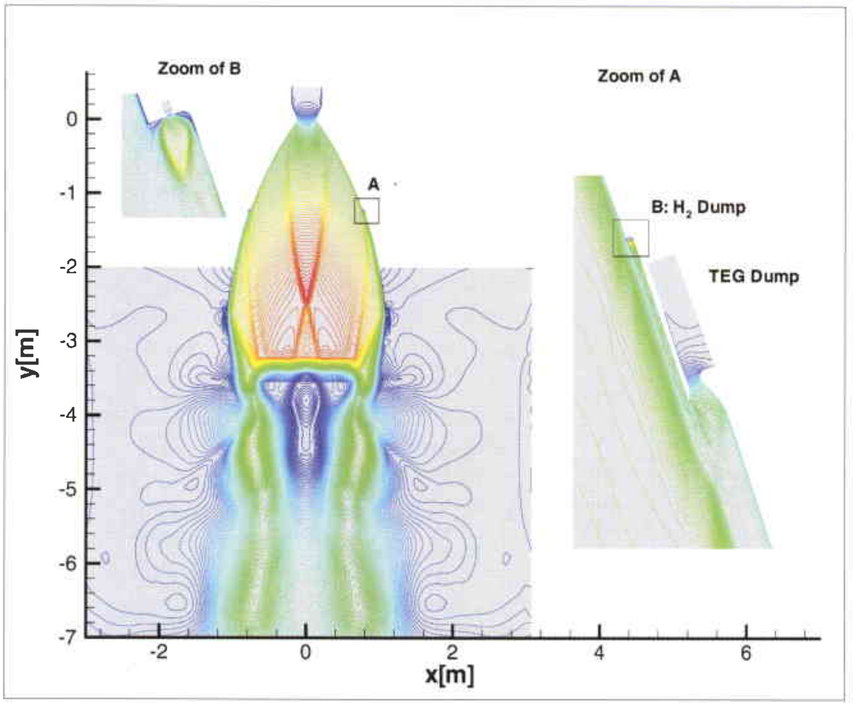


Figure 12. Predicted iso Mach lines for Vulcain 2 at design point at 115 bar with zoom of turbine exhaust gas section and hydrogen dump slot

Figure 13. Schlieren picture of EXTV in the S4 FFA facility at Mach 0.9, incidence angle 0 deg, nozzle pressure ratio 10

Figure 14. Oil-flow visualisation on EXTV in the S4 FFA facility at Mach 0.9, incidence angle 10 deg, nozzle pressure ratio 10

- Local aerothermodynamics effects will be investigated such as flap/gap flow, with the emphasis on scaling.
- Base flow experiments, with and without jet interaction, will be performed, with the emphasis on hot-plume effects. Understanding hot-plume effects is crucial not only for base flow pressure recovery and heating, but also for unsteady buffeting effects and nozzle flow separation/external flow interaction assessment.

Aerothermodynamics in ESA Application Programmes

A typical example of plume-impingement analysis for an Application Programme is shown in Figure 15, for the MSG mission. The back flow emanating from the main 400 N rocket-engine nozzles impinges on the satellite's external ring and on its base. The heat shields around each of the two nozzles protect the satellite base region against radiation and against convective heating. A coupled Navier-Stokes (in-house-developed YPANS code) and Direct Simulation Monte Carlo solver (ITAM/ Smile code) has been used to compute the total energy flux at critical locations. This analysis involved axisymmetric computations; 3D computations are planned to predict the heat flux to be measured in flight.

Aerothermodynamic research activities in ESA

The Agency has set up Technology Programmes (GSP, TRP, GSTP) in order to initiate novel developments and to assure knowhow continuity, and to advance analysis and experimental capabilities. These activities are intended to prepare to meet the technology needs for future programmes and advance our capabilities to allow industry to stay at the cutting edge of technology. The (non-exhaustive) list of aerothermodynamic research activities includes:

- *Gap heating, using data from the Japanese suborbital re-entry demonstrator Hyflex:* A combined numerical and experimental activity has been set up using the DLR L3K facility, where a set of instrumented tiles are being tested which are identical to those used in flight (Fig. 16). The objective is to achieve wind-tunnel conditions such that the local convective and radiative heat fluxes in the gaps are as close as possible to those in flight. Wind-tunnel and flight flow fields are being predicted with CFD, taking into account the 3D effects in the gaps as well as the heat conduction into the material. The results obtained from the analyses will identify where further investigations in the flow /material-interaction area are needed.
- *Plasmatron measurement techniques:* Non-intrusive measurements will be developed and calibrated to provide a direct means of measuring the species concentrations in the boundary layer in front of a model. This method will be compared with the semi-numerical methods currently being used in plasmatron applications to assess recombination coefficients.
- *Hot-plume testing:* Retrofitting of an existing H_2/O_2 propulsion stand is planned to study the influence of hot plumes on the base pressure and heating of launchers.
- *Buffeting:* Experimental and numerical studies of base-flow buffeting on simple and complex Ariane-5 models are planned, including cold-jet effects.
- *Nozzle flow-separation control device:* Experimental and numerical flow-separation studies will be conducted on different nozzle

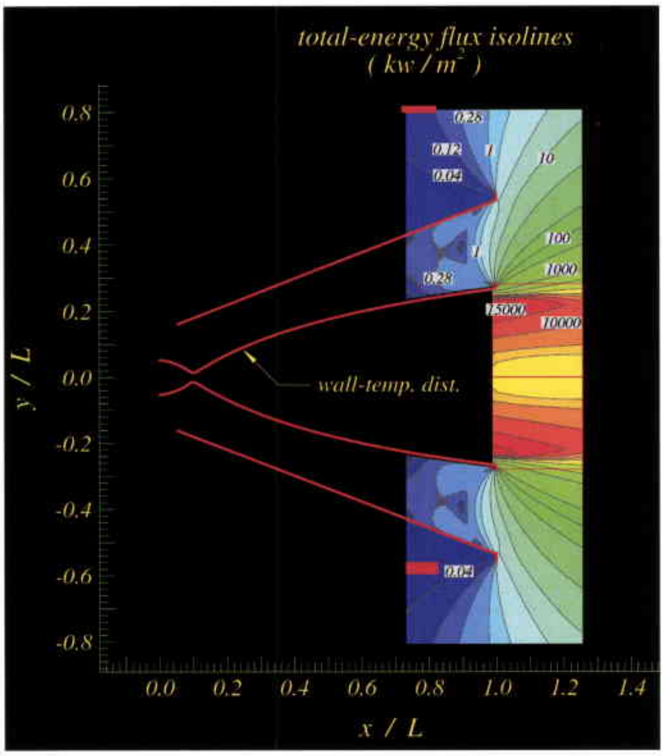
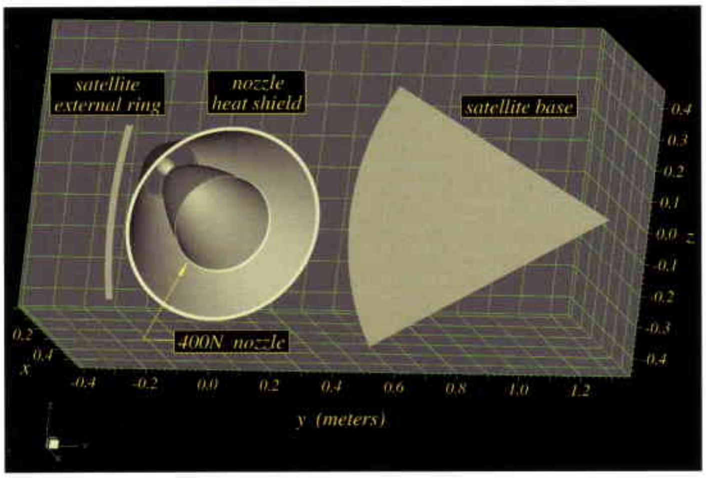


Figure 15. Meteosat Second Generation (MSG) plume-impingement numerical analysis using Navier Stokes predictions for the nozzle and Monte Carlo simulations for the plume flow



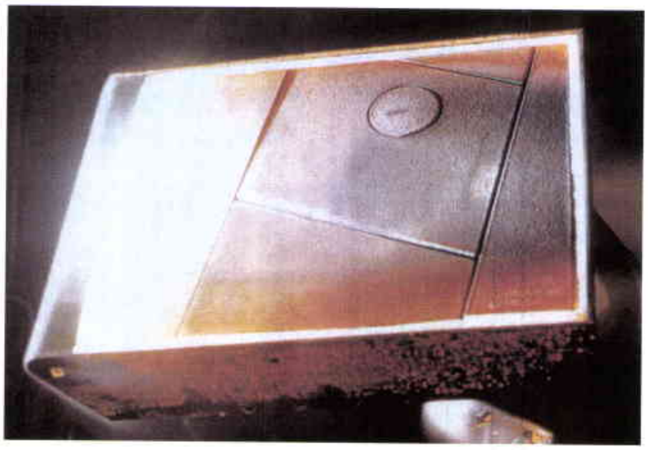


Figure 16. Hyflex tiles instrumented with as-flown sensors tested in the L3K DLR facility in Cologne

shapes such as the classical bell-type, dual-bell, extendable and external-expansion nozzles in order to understand and control nozzle flow separation.

- *In-flight research:* The objective is to perform a feasibility study for in-flight research using generic configurations to study transition, catalycity and shock boundary-layer interaction. The study will also focus on the corresponding wind-tunnel tests to represent flight, and on improvement of the accuracy of flight measurement techniques and their integration into the thermal-protection system.
- *Inflatable Re-entry and Descent Technology (IRDT):* A flight experiment was performed in 2000, which was supported by the European Commission through the ISTC programme. Astrium carried out this programme in close collaboration with Babakin Space Centre (Lavochkin). One of the objectives was to evaluate IRDT's potential as an independent, low-cost payload-return capability for experiments conducted on the International Space Station (ISS). The successful suborbital flight in February 2000 confirmed the technology's potential (Fig. 17; see also ESA Bulletin No. 103, August 2000). Another flight, initiated by the Directorate of Manned Spaceflight and Microgravity, and a precursor flight are planned for March and August 2001, respectively. Near-orbital entry conditions will be achieved for full validation of the concept.

Conclusions

This article has discussed some of the critical aerothermodynamic issues inherent in the design of re-entry space vehicles and launchers, as well as reviewing the analysis and test results obtained to date. The importance of flight-testing for the validation of methods and procedures for the extrapolation of results obtained from ground-based facilities has been highlighted. In particular, such flight data are needed to establish real confidence both in the computational fluid dynamics and the underlying physical modelling.

Aerothermodynamics has emerged as a key discipline for the design and qualification of advanced launchers, re-entry vehicles, and planetary probes. It requires enhancements in multidisciplinary techniques which, thanks to the rapid growth in computing power, will be increasingly used in the future. The Agency is working towards continued and well-directed research with flight demonstrators to advance Europe's computational and experimental capabilities for future space programmes. Continuation of such activities in Europe is essential to remain at the cutting edge of technology for space transportation.

Figure 17. The IRDT reentry configuration

These efforts will be supported by co-ordinating European activities and promoting closer collaboration between universities, research establishments and industry. The success of this challenging undertaking depends upon support from all of the nations involved. Continued international cooperation, such as the partnership with NASA in the CRV Programme, will only be possible if Europe continues to enhance its aerothermodynamic knowhow and expertise, which includes the availability of verification facilities and flight demonstrators.

Acknowledgement

The authors are grateful to C. Stavrinidis for reviewing this article; to J. Steelant for his in-depth contributions to the Vulcain analysis; to G. Markelov for his substantial contributions to the DSMC analysis for MSG; and to G. Tumino for his work associated with the Scirocco project. They thank R. Molina (X38), M. Steinkoph (ARD) and M. Toussaint for permission to show the 'project support' figures. Thanks also go to E. Luparini for his assistance in preparing the figures.

The ECSS-E-30 Mechanical Engineering Standard

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Introduction

The disciplines and major topics addressed by the various volumes of ECSS-E-30, produced and issued by the European Cooperation for Space Standardization (ECSS), are:

- thermal control
- structures
- mechanisms
- environmental control and life support
- propulsion
- pyrotechnics
- mechanical parts
- materials.

The ECSS-E-30 standard defines the high-level rules, the overall principles and the requirements to be applied to all mechanical-engineering activities performed for the establishment of requirements and for the definition, development, production, operation, and eventual disposal of mechanical space products. The standard takes into account both the engineering processes and the technical aspects of products in accordance with system-engineering approaches and practices as described in ECSS-E-00 and ECSS-E-10, respectively. It applies to all space-product types defined in ECSS-E-00 (e.g. spacecraft or launchers) and their associated equipment.

The standards define the activities and requirements that are relevant for all areas of mechanical engineering. They also identify the critical points that need to be assessed during the design, development and verification phases, plus their associated requirements. The mechanical-parts standard and the materials standard also define requirements for hardware rather than purely mechanical-engineering activities. This is addressed in terms of requirements for the process of selecting parts (in the case of the mechanical-parts standard) and the requirements for selecting and verifying the use of materials employed in products for space applications (in the case of the materials standard).

Within each of the respective disciplines, the standards define the scope of the discipline and the terminology for all activities within it. Also defined are the respective topics and activities that need to be considered to ensure proper engineering. The interfaces of the discipline and related activities within them are defined. The other disciplines and interfaces with the domains of management and product assurance are as defined in ECSS-E-00.

Tailoring

Since it cannot be divorced from the customer-supplier and product-type aspects, the ECSS-E-30 standard does not include general rules. Instead, guidelines with respect to technical aspects of tailoring have been identified for the respective engineering disciplines, where deemed possible, and these are included within the discipline standards.

Structure

ECSS-E-30 consists of a coherent set of eight engineering level-2 standards. This reduces the number of standards that need to be considered by industry within Invitations to Tender (ITTs) or projects. The standard was developed from scratch between 1996 and 1998 by a working group of more than 70 people (70% from industry, 30% from agencies) split into eight discipline teams and led by one convenor. This division of responsibilities ensured that the capture and usage of requirements was in a form that was clearly understandable by all parties. It also ensured flexibility with respect to projects and products via tailoring, and guaranteed ECSS compatibility.

The maximum direct benefit of the ECSS-E-30 standard is expected to come from the improved interface between small- and medium-sized enterprises, sub-contractors and their primes, where excessive time to track requirements or differences in understanding of requirements have the greatest detrimental effect.

Table 1. Summary guide to ECSS-E-30

Standard	Title	Information
ECSS-E-30 Part 1	Thermal Control	• Set of engineering processes and products that enable temperature variations to be constrained in a specific range. • Thermal-control discipline definitions. • Requirements for thermal activities related to: mission, performance, interface, design, verification, production, integration, in-service activities. • Uncertainty and margin approach. • Analysis approach. • TCS development philosophy.
ECSS-E-30 Part 2	Structural	• Set of engineering processes and products that ensure that structures are able to withstand specified loads and meet mission requirements (e.g. stability). • Basic requirements for structures used on space missions, including definition, analysis, development, production, test verification, in-orbit operation and disposal. • Mechanical analysis, design and verification of structures. • Static, dynamic, thermal, acoustic and shock loads. • Fracture control. • Design concepts. • Assembly techniques and alignment.
ECSS-E-30 Part 3	Mechanisms	• Basic requirements for mechanisms used on space missions, including definition, analysis, development, production, test verification, in-orbit operation and disposal. • General, thermal and mechanical design. • Lubrication engineering. • Electrical power and control. • Alignment, bias and stability. • Functional performance tests.
ECSS-E-30 Part 4	Environmental Control and Life Support	• Set of engineering processes and products to ensure a safe and comfortable environment for manned space missions. • Analysis, design and verification for the provision of safe and comfortable environment for crew and equipment in manned spaceflight. Includes: - atmosphere management - water management - food management - waste management.
ECSS-E-30 Part 5	Propulsion	• Set of engineering processes and products required to ensure the motion of a spacecraft through thermodynamic means. • Special rules and guidelines applicable for the design and development of propulsion systems, covering interaction between various disciplines (materials, thermal, structure) and practices proven by experience in the field of development and design process. • Launcher and spacecraft aspects are addressed. • Solid-, liquid- and electric-propulsion technologies addressed.
ECSS-E-30 Part 6	Pyrotechnics	• Set of engineering processes and products developed for the use of energy released by explosive substances and its conversion into useful mechanical work. • Subsystem definition. • Component definition. • Technical and product-assurance requirements for design, procurement, integration and verification at component and subsystem levels.
ECSS-E-30 Part 7	Mechanical Parts	• Characterisation, selection, procurement, verification and control of mechanical parts considering the environments experienced during their application life in space products. • Basic requirements for the selection of mechanical parts to be used for space missions. • This applies to any type of mechanical part, such as: - assembly parts: bolts, washers, inserts, rivets and spacers - thermal parts: heaters and thermocouples - bearing parts - separation parts: springs, cutters.
ECSS-E-30 Part 8	Materials	• Characterisation, selection, procurement, verification and control of materials considering the environments experienced during their application life in space products. • Basic requirements for the establishment of mechanical and physical properties of materials to be used for space missions. • Includes: - mechanical and physical requirements - environmental constraints - manned environment - interface requirements (coatings/layers, joining) - material design allowables (metals/composites) - composite sandwich constructions - ceramic matrix composites - polymers (thermosets/thermoplastics) - mechanical and physical test methods - non-destructive inspection - procurement, production, verification - maintenance, inspection, repair.

EMITS: Improving Communication between ESA and Industry

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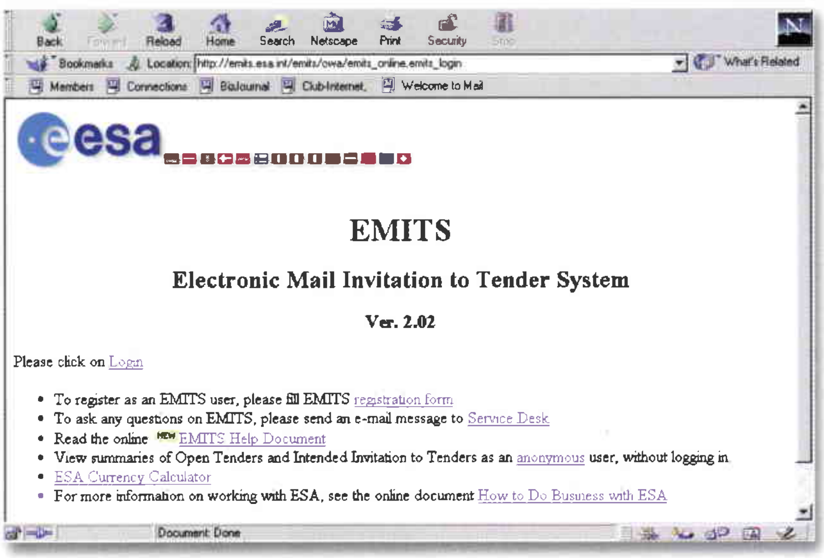
ESA works in co-operation with industry and R&D organisations throughout Europe and Canada. All Invitations to Tender issued in open competition by the Agency are channelled through the Electronic Mail Invitation to Tender System (EMITS). EMITS is a web application that allows industry and R&D entities to access the Invitation to Tender documentation and other relevant information, to express their interest in participating in the various procurements and making that interest known to ESA and other potential partners.

This article provides a brief review of the EMITS system and highlights the most important features of interest for industry, R&D entities and national delegations, as well as the further developments to be expected in the short term.

Introduction

Originally conceived as a system limited to the electronic delivery of ESA Invitations to Tender (ITTs), EMITS has evolved drastically during the last two years to become a real line of communication between ESA and industry, and between industries. The catalyst for this evolution was the request by the ESA Council at Ministerial Level to grant a special place to Small and Medium Enterprises (SMEs) in the Agency's system. One of the most constraining limitations for SMEs was identified as access to information and the difficulties in finding suitable industrial partners. EMITS was immediately identified as a key tool with enormous potential in this respect.



After two years of continuous improvement, access by industrial and other organisations to the ESA procurement system has become easier and more user friendly. The possibilities for them to establish fruitful co-operations and increase their mutual knowledge have been considerably expanded. It is a good example of how a measure that was triggered by a clear need on the part of SMEs has benefitted all of the industrial and R&D chain.

Origin of the EMITS system

During the eighties, the Agency decided to embark on the development of a system of electronic distribution that would replace the sending of ESA ITTs by surface mail to all interested companies, research entities and national delegations. The idea was to reduce drastically the costs and manpower required for reproducing, printing and posting the ITTs, as well as to minimise the delays in that process. Development of the EMITS system was formally proposed to the 71st meeting of ESA's Industrial Policy Committee on 4 October 1984. The first operational system was deployed in 1987. In 1995, keeping the same overall concept, the system was moved to the Internet.

Some statistics

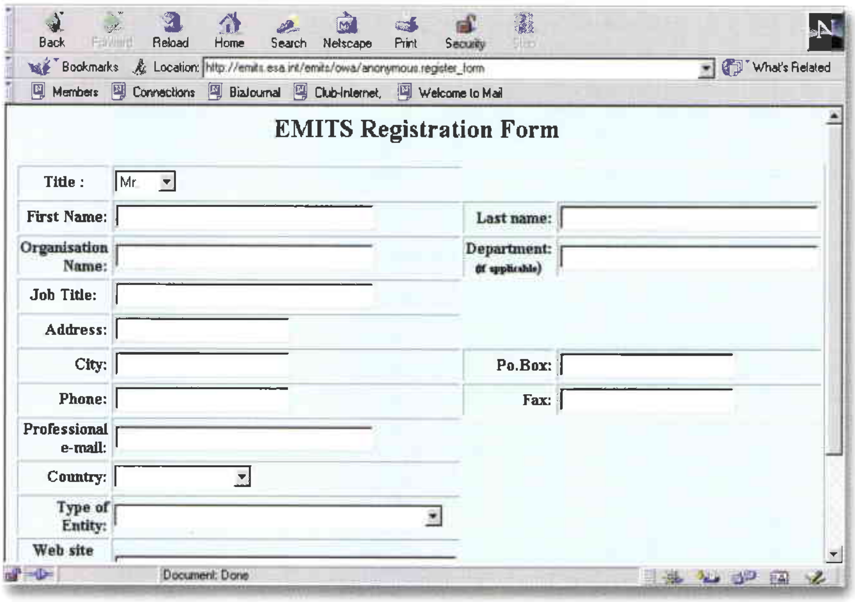
The total number of active EMITS users from industry and R&D entities is around 3000. In addition, Delegations and many ESA staff are users of the system, bringing the total number of registered users to around 4000. An average of 57 000 EMITS session are recorded each year.

The continuous improvement of the system and the services that it provides has resulted in a substantial increase in utilisation. From 1999 to 2000, the use of EMITS by the 100 most active users increased by 11.3%, from 28 094 to 31 278 sessions, which is equivalent to one session per working day per user, on average. This statistic confirms EMITS's role as a communications hotline between ESA and industry.

Who can access EMITS?

Staff belonging to entities qualified as ESA potential bidders (i.e. having an ESABD code) can get access to EMITS, in addition to ESA staff and national Delegations.

Interested users can directly request access to the application by completing the questionnaire available via the EMITS access page at http://emits.esa.int. This allows the EMITS help desk to check whether a valid ESABD exists already for their company or organisation. If this is the case, they will obtain immediate access; otherwise, they will be invited to provide the Industrial Relations Service at the Agency's Headquarters in Paris (SME-Unit@hq.esa.fr) with the information necessary to become a potential ESA bidder.



Main functionalities

Through EMITS, industry has access to the following information:

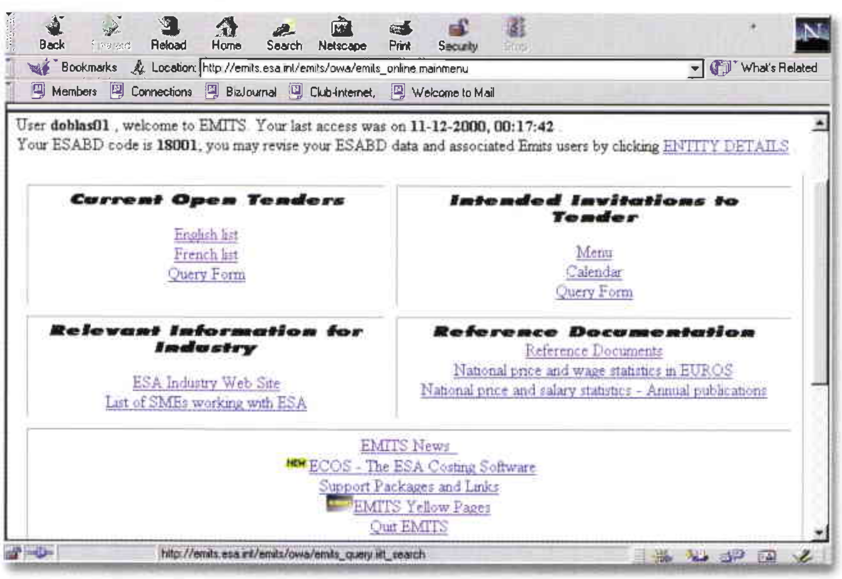
- All *Open Invitations to Tender* published by ESA. The different elements of the tender – letter of invitation, special tender conditions, special contract conditions and Statement of Work – can all be downloaded. Clarifications as a result of questions raised by industry are also published via EMITS, in order to provide all potential bidders with the same information.
- All *Intended Invitations to Tender*, during the preparation of the corresponding open Invitations to Tender. Through EMITS, industry can obtain early information about the scope of the intended procurements, the intended publication date for the open Invitation to Tender, budget, programme, participating States, etc.
- *Relevant Information for Industry.* The most relevant information is provided through a link to the ESA industry web portal, where industry can gain access to standards, news relevant to industry, links to selected programmatic information, ESA laboratories, final reports of contracts, etc.
- *Reference documentation.* These are essential documents forming an integral part of any procurement action (basically, the General Conditions of Tender for ESA contracts, including the costing forms and the General Clauses and Conditions for ESA contracts) and the technical standards (through a link to the ESA industry portal).
- *News.* EMITS users are also provided with relevant information not generally related to a particular procurement (Announcements of Opportunity, Calls for Ideas, information of interest for industry, etc.).

In what follows, we will concentrate on those EMITS services that are having a major impact on improving the mutual knowledge base of industry and other organisations and hence on the establishment of fruitful industrial relations, i.e.:

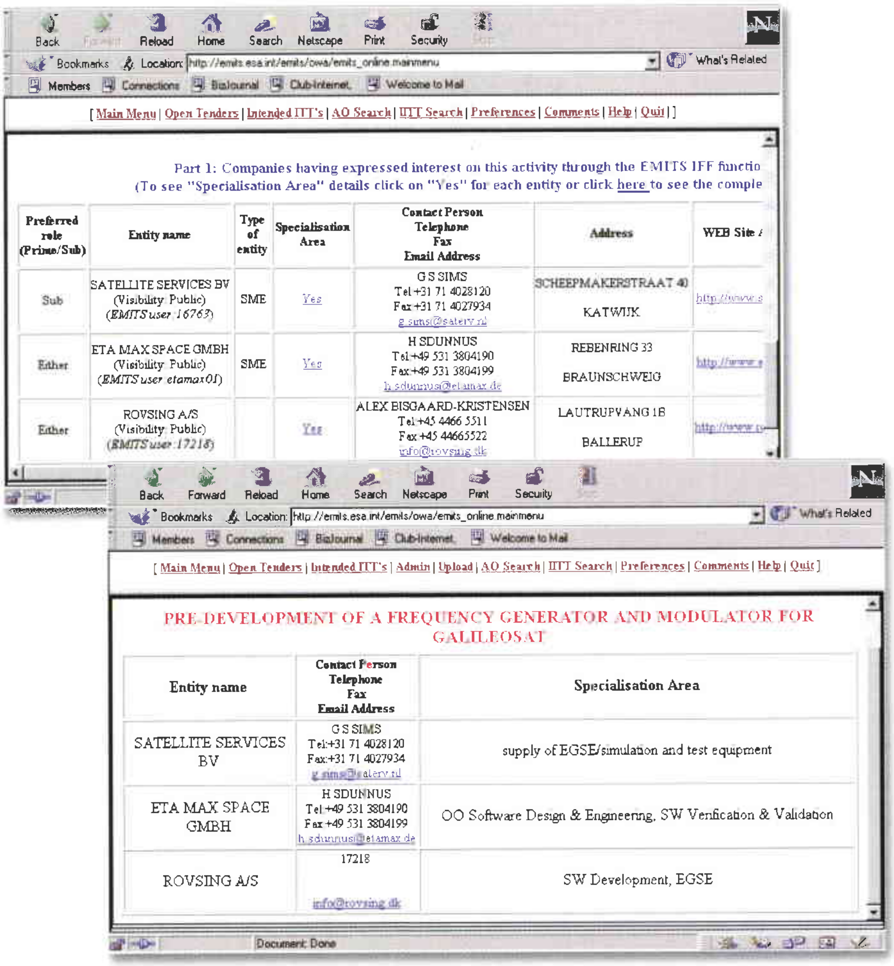
- The expression of interest in Open Tenders and Intended Invitations to Tender.
- The availability, through EMITS, of the web sites of the participating companies and organisations.
- The access, through EMITS, to the European Space Industry Directory.
- The EMITS 'Yellow Pages'.

Expression of interest: a fundamental tool for fostering industrial co-operation and innovation

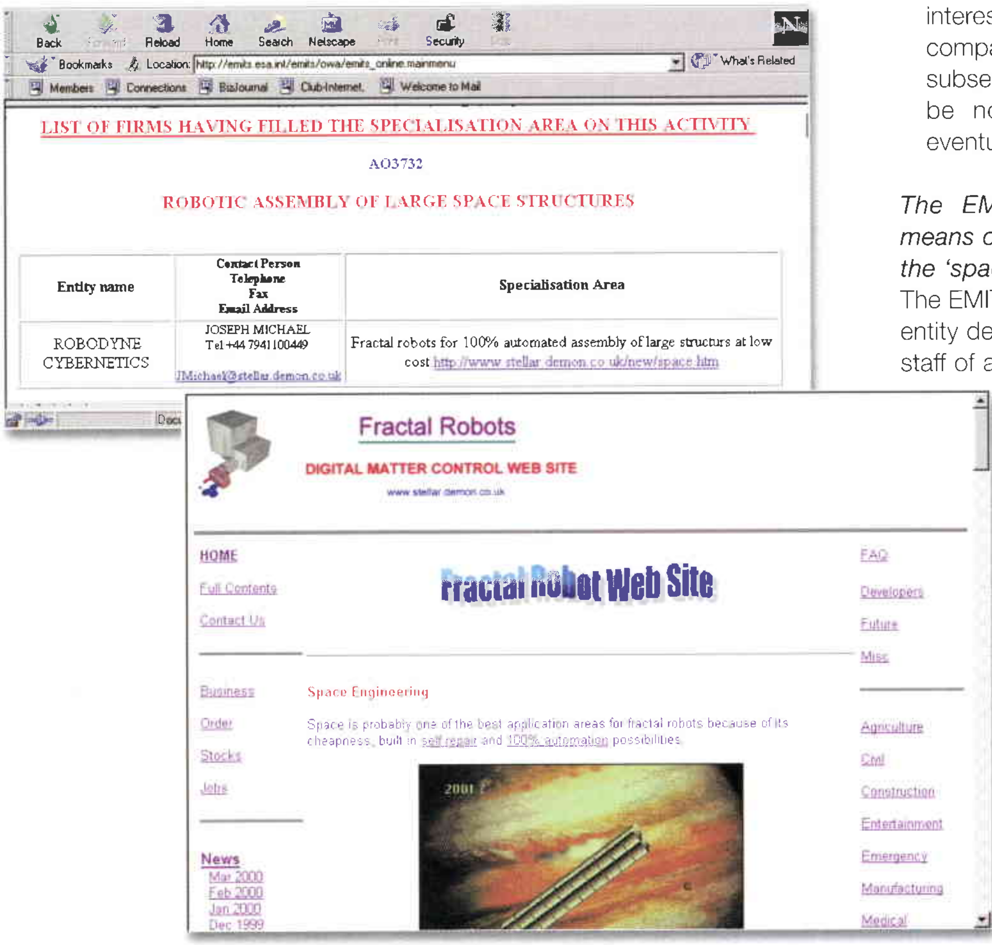
EMITS incorporates an 'Express Interest' function that enables users to make known to ESA and the other industries and organisations their interest in bidding against a given Invitation to Tender. Interest can be expressed as soon as an Intended Invitation to Tender (IITT) is published and can be confirmed/revoked when the formal Invitation to Tender (ITT/AO) is eventually published.



Examples of Expressions of Interest



Use of hyperlinks in the "Specialisation" field



When expressing their interest in bidding for a particular tender, EMITS users are asked to indicate whether they:

– Intend to bid as a Prime or as a Subcontractor, or either (i.e. their role).
– Accept that their interest is made visible to other companies, or request that it is limited only to ESA. It is worth mentioning that the vast majority of users choose the full-visibility option, thereby taking full advantage of the philosophy and potential of EMITS.
– Want to include their 'field of specialisation'. These are details of areas of speciality, products, services, capabilities, etc. that the user considers he could satisfactorily provide in reply to the specific Invitation to Tender. In the 'specialisation field' box, bidders can insert Internet addresses corresponding, for instance, to a particular area of their company or institution web site where more information can be found about related capabilities, products, projects, etc., or even to File Transfer Protocol (FTP) servers where related reports can be obtained. The URL then becomes active to other EMITS users, who can click directly on the link and access that targeted information. This function has enormous potential as it gives EMITS users the ability to obtain very good information about possible partners.

All this information goes into the 'List of Firms', which logs all companies that have expressed interest in a given tender. It allows those companies to be directly informed of any subsequent modification in the tender and to be notified by e-mail when the ITT is eventually issued, among other things.

The EMITS Yellow Pages: an additional means of improving the mutual knowledge of the 'space family' at working level

The EMITS Yellow Pages provide access to the entity details as well as the co-ordinates of key staff of all companies and organisations doing, or willing to do, business with ESA. They allow the user to search for and display bidders based on selected criteria, such as bidder code, country, entity name, type of entity or any combination of these criteria.

The EMITS Yellow Pages constitute the most accurate and targetted contacts database of space industry and space organisations in Europe, including information on key staff for the procurement process. This represents a fundamental step towards fostering industrial co-operation.

The web sites of space industry and organisations available through EMITS: a unique opportunity to reach a targetted community

EMITS provides industry and other organisations with direct access to each other's web sites. This functionality was added to provide a common platform for improving their mutual knowledge base, and therefore for enhancing the possibilities for fruitful co-operation.

EMITS users are invited to provide their web site address in their user preferences profile. Thereafter, the entity's web site will be prompted in EMITS wherever the company name appears (in the Yellow Pages, in the List of Firms having expressed interest in an ITT, etc.). The percentage of web site addresses included in the system is very high, reflecting the importance that EMITS users attach to this function.

The European Space Industry Directory: an interactive reservoir of all actors, products and capabilities in the European space sector

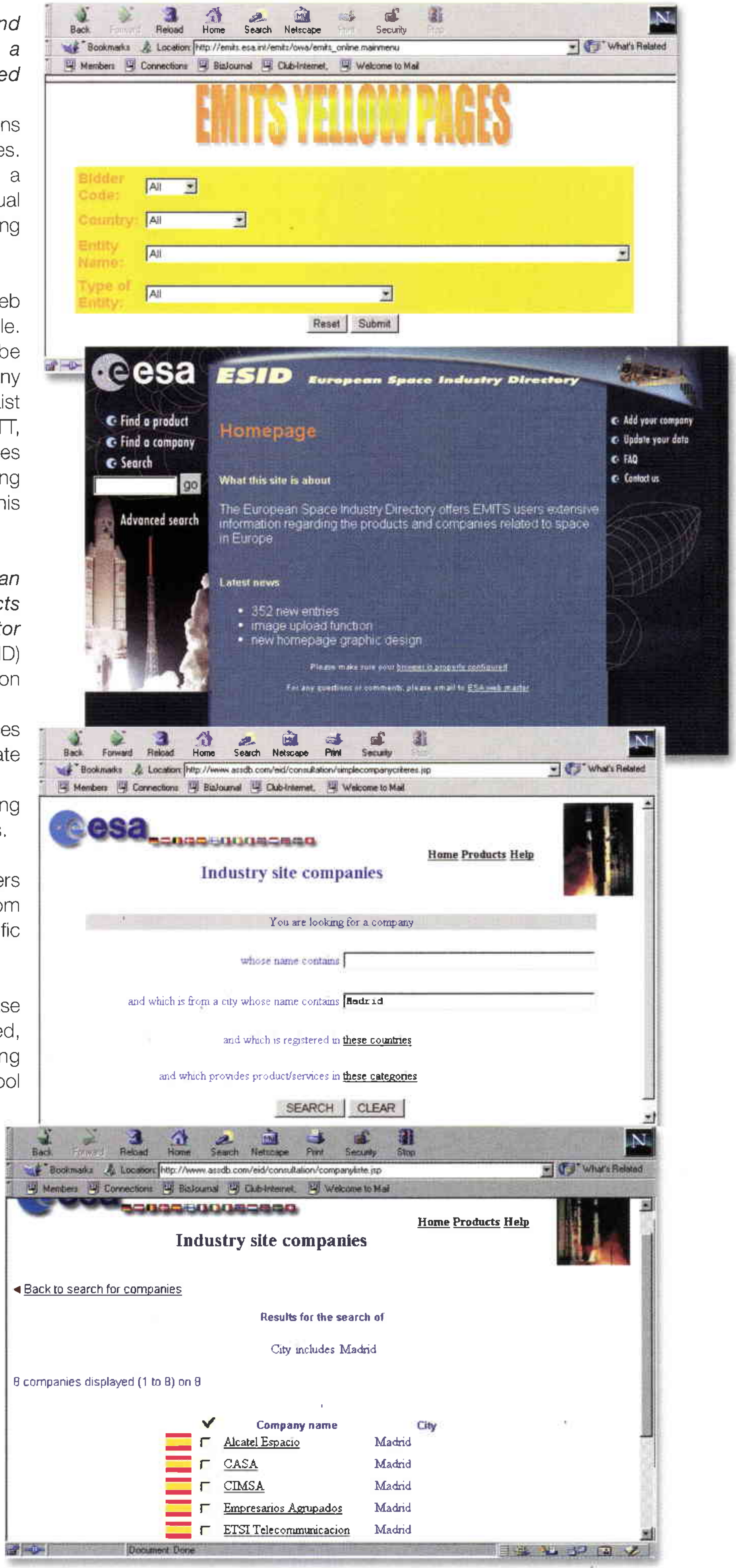
The European Space Industry Directory (ESID) is an on-line database containing information about:

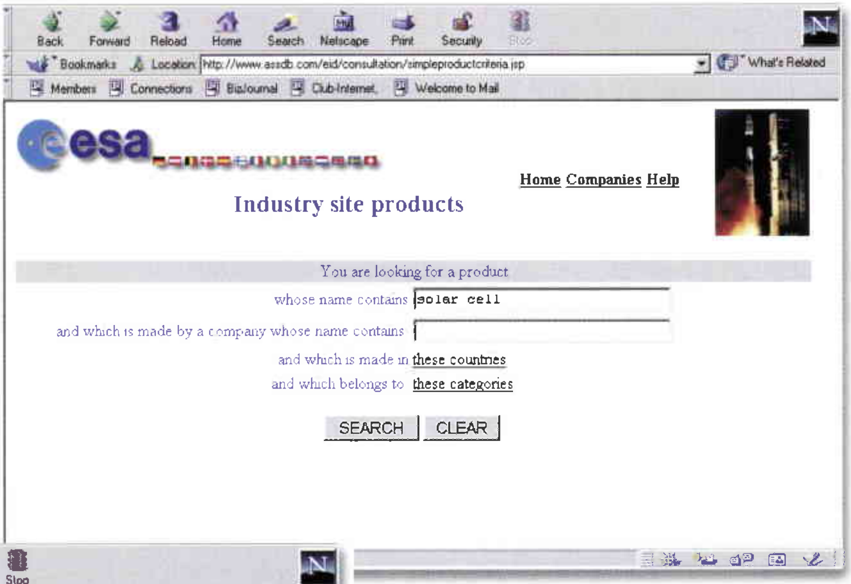
- the space products, technologies and services developed within the Member and Associate Member States of ESA
- the companies and organisations developing these products, technologies and services.

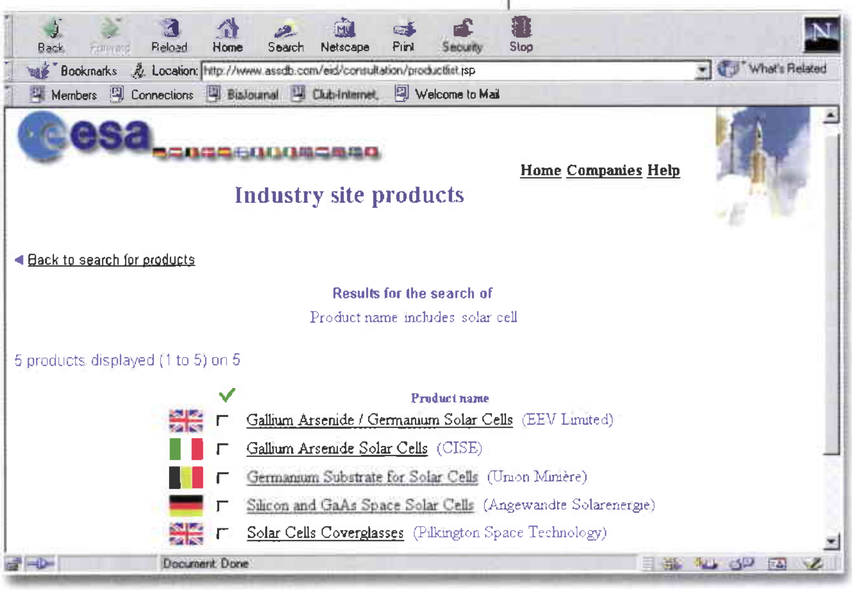
The ESID keeps growing steadily and covers the full spectrum of space activities, from ground segment to payloads, from scientific laboratories to worldwide corporations.

The Directory relies on an Oracle database where all products and companies are stored, and has powerful search and reporting capabilities. It is intended as a practical tool allowing industry to find the right partners for their space activities in ESA, national and commercial programmes.

The information within the ESID database is provided by the companies themselves, on a voluntary basis. To be included in the Directory, companies must be involved in activities specific or closely related to space (aviation activities are not eligible) and a significant presence in at least one of the ESA Member and Associate Member States. Only entities that have qualified as potential ESA bidders and have an ESABD code can appear in the ESID. The EMITS system also provides them with the possibility to update their data interactively and include additional products.







Major expected evolution in the short term: EMITS for external entities

The above improvements to the EMITS system have had an immediate repercussion in terms of the scope of the application. It has been decided to expand EMITS to also cover the Invitations to Tender issued by space prime contractors to select their subcontractors and equipment suppliers for major satellite projects. ESA's scientific project Herschel/Planck will be the first where the EMITS system will be used in this way. The selected prime contractor will publish his Invitations to Tender for the project conducted in open competition in a dedicated area of EMITS. This will greatly improve the transparency and fairness of the procurement process, as well as the efficiency of the overall procurement system.

Moreover, the French national space agency CNES has expressed interest in using the functionalities of EMITS for its national programme in order to ensure that selected procurements reach all European space industry and organisations in an effective way. This CNES initiative could also be followed by the other national space agencies. Adaptation of EMITS to cope with this requirement is under development.

Conclusion

The EMITS system, together with the elements built around it (Industry Web Site, Industry Directories, etc.), represent a new way for the Agency to interact with industry and R&D organisations, where emphasis is put, in particular, on the following issues:

- Fairness in the procurement process.
- Transparency.
- Equal access to information.
- Supply-chain improvements, industry net-working.
- Opening possibilities for innovative companies and R&D entities to 'penetrate' the system.
- Support to qualitative industrial-policy measures (policies encouraging, for instance, the participation/cooperation of SMEs, of equipment suppliers, of R&D entities, etc.).

The new EMITS has been deployed at a key moment, when industry is confronted with a process of consolidation at prime-contractor level, when the need to safeguard fairness and the interests of equipment suppliers and non-primes is essential, and when the need to foster innovation is more important than ever. The impact of the new system will depend fundamentally on the use that industry makes of it. We are confident that the user friendliness of the system and the many benefits it provides, to industry and to ESA, will ensure that its potential is exploited to the full, for the benefit of space.

* A pilot version of the ESID database can be accessed at: http://www.assdb.com/eid/consultation/index.html

A New Force Measurement Device for Spacecraft Testing

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A new Force Measurement Device (FMD) has been used during the sine-vibration testing of ESA's Rosetta spacecraft, to measure directly the forces and moments at the spacecraft/launch-vehicle interface. It proved extremely useful in ensuring that the test levels required by the launcher authorities were strictly applied, and that the tests were executed safely. The FMD's output was also valuable for the validation of the finite-element model. The use of this new device, which is simple to set up and requires just six instrumentation channels, is therefore highly recommended in conducting future spacecraft qualification and acceptance vibration tests.

Introduction

The Structural and Thermal Model (STM) of the Rosetta scientific spacecraft was successfully tested at ESTEC in Noordwijk (NL) between December 1999 and May 2000. During the sine vibration tests, a technique known as 'primary notching' was applied, which involves reducing the input level so that the dynamic interface forces do not exceed the static interface forces corresponding to the quasi-static design loads defined by the launcher authorities. This, by definition, is a very delicate operation: on the one hand, any structural failure must be avoided, but on the other adequate qualification must be achieved in order to be acceptable to the launcher authorities.

Generally, the level of notching is determined by a combination of test results and analysis predictions. This method has two major drawbacks, because it relies on a finite-element model (FEM):

- The accuracy of the interface forces depends on the quality of the model and on the measurement-point plan: a poorly representative FEM, inadequate instrumentation or an error in the methodology can result in a wrong estimate of the interface forces and thus in a wrong notched input, which could lead to structural damage or to a too low, and thus inadequate, qualification input.
- The final acceptance of the qualification has to be confirmed once the FEM is correlated, which means well after the qualification test campaign.

In Rosetta's case, a new Force Measurement Device (FMD) was used, which measures the forces and moments directly at the test-specimen interface. This allows the primary notching to be performed with very good safety, and also allows one to be sure that adequate loads have been applied during the qualification campaign.

The Force Measurement Device (FMD)

The FMD has been developed for ESA by Ingemansson Technology AB (Sweden) under an ESTEC contract. It consists of two rings connected by eight piezoelectric Kistler Z14976 force links, as shown in Figure 1. Each force link measures the dynamic forces in the three directions (Fig. 2), and the two rings correspond to a 1194mm-diameter spacecraft interface.

The measured values are weighed, combined, and reduced to three forces and three moments in an electronic circuit contained in the Signal Processing Unit (SPU). These six output channels are available for either data acquisition or for vibration level control.

Apart from the functioning of the system itself, the stiffness of the device is of particular concern since the impact of its presence on the test specimen needs to be as small as possible. The FMD's stiffness was first assessed by finite-element analysis, and then tests were performed on a single transducer. Finally, the complete device was tested at ESTEC with the structural and thermal model of the Olympus spacecraft (mass 1200 kg and centre of gravity at ~1.7 m) in early 1996 (Fig. 3).

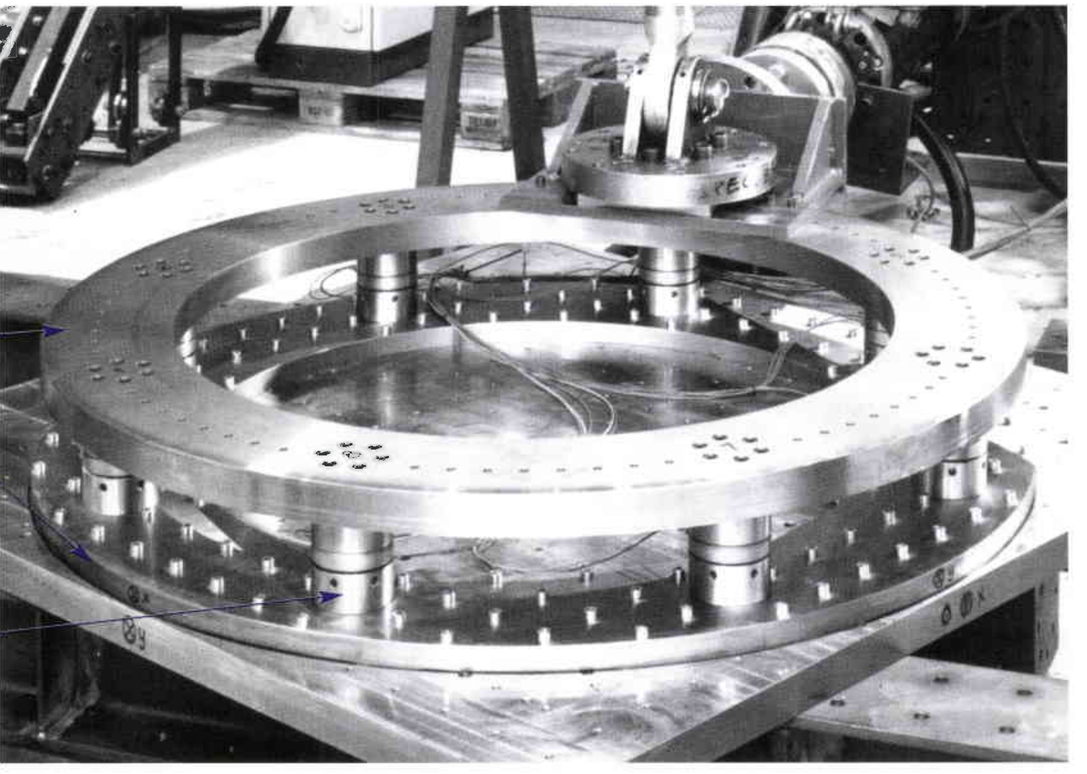

Figure 1. The new Force Measurement Device (FMD)

The main characteristics of the FMD:

Frequency measurement range:	up to 100 Hz at high level and ~300 Hz at low level
Force measurement range:	up to 800 kN axially and up to 200 kN laterally
Moment measurement range:	up to 260 kNm in bending and up to 130 kNm in torsion
Typical measurement error:	1 to 4%
Axial stiffness:	9.55 x 10^9 N/m
Bending stiffness	2.73 x 10^9 Nm/rad
Overall mass:	494 kg.

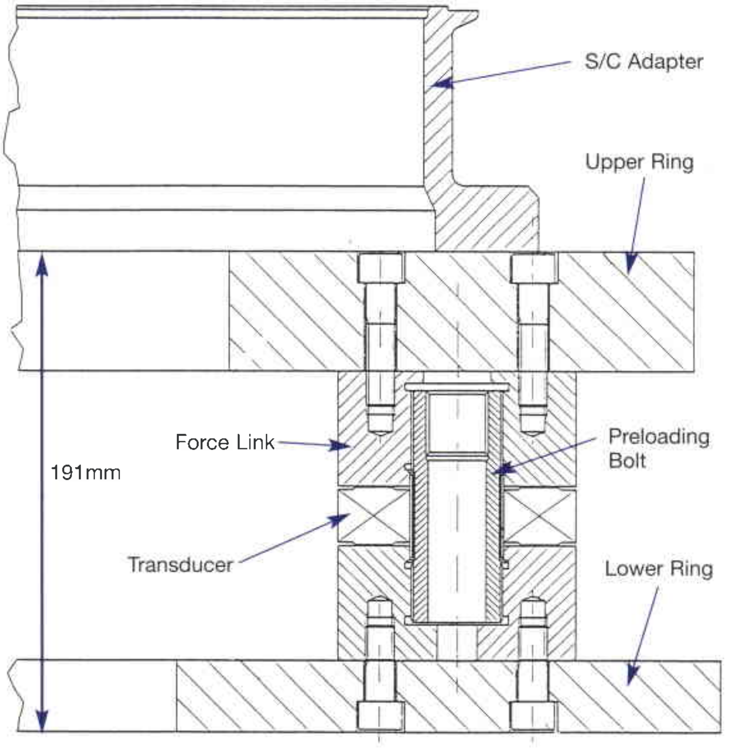

Figure 2. Cutaway of the force link

The Olympus spacecraft was submitted to low-level sweeps up to 2000 Hz and to high sine-vibration levels up to 100 Hz, with and without the FMD. Comparison of the low-level runs showed that the axial fundamental frequency shifted from 46.2 to 45.9 Hz (-0.5%), and the lateral one from 14.7 to 14.6 Hz (-0.6%). For other modes, the frequency shift was less than 3%.

The FMD has subsequently been made available as a regular testing tool at the ESTEC Test Centre.

FMD's application in the Rosetta STM test campaign

Before starting the qualification of the Rosetta STM, the multi-shaker table was submitted to an acceptance test, which also provided the opportunity to verify the good functioning of the FMD. The test set-up consisted of the slip-table, FMD, load spreader, and a 2085 kg dummy specimen. The aim with the load spreader was to increase the load capability of the slip-table. The interface forces and moments were measured with the FMD, as well as computed.

The FMD measurements and the calculations matched very well. For the first resonance, the measured and calculated bending moments agreed to within 1%, and the measured lateral force at low frequency corresponded to the rigid body mass above the FMD times the acceleration input also to within 1%. The cross-talk appeared to be very small, being typically less than 4%. Finally, a maximum overturning moment of 203 kN.m was applied to the table. The FMD was submitted to a maximum bending moment of 183 kN.m and a maximum lateral force of 47 kN.

Before performing the Rosetta test campaign, the effects of the FMD's flexibility were analysed. As the frequency shift proved acceptable, it was decided to use this device. For the lateral excitation, the configuration was very similar to that used with the dummy spacecraft, with load spreader, FMD and the Rosetta adaptor. In the axial direction, the load spreader was no longer needed and was therefore removed, as shown in Figure 4.

Figure 3. The Olympus STM mounted on the Force Measurement Device (FMD)

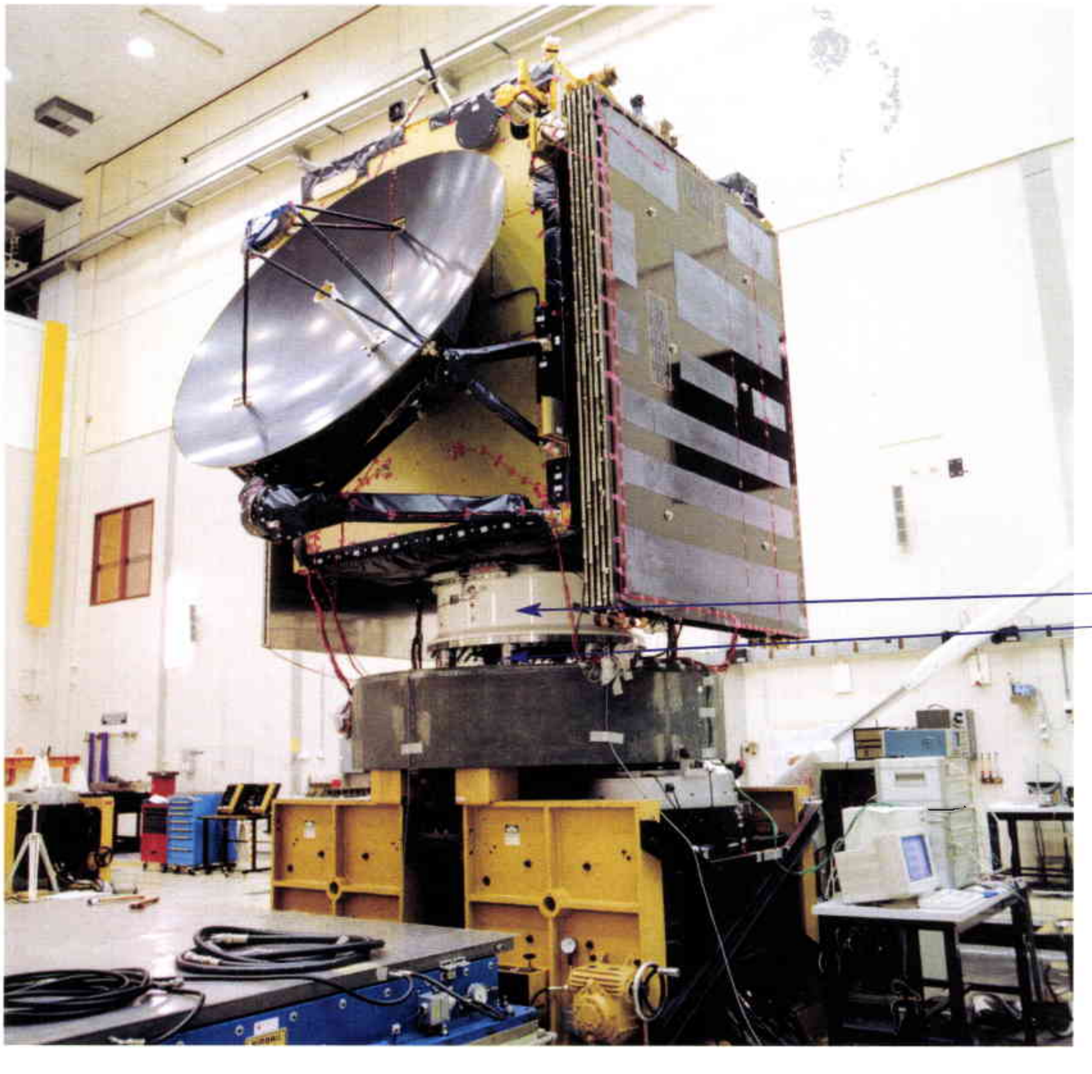

Figure 4. Rosetta STM mounted on the Force Measurement Device (FMD) for axial sine vibration testing

The mass and dynamic properties of the Rosetta STM were as follows:

Mass:	3058 kg
CoG:	1.18 m
1st bending modes:	16.3 Hz in X and 16.5 Hz in Y
2nd bending modes:	32.5 Hz in X and 31.8 Hz in Y
1st axial modes:	37.1 Hz and 40.4 Hz in Z.

The FMD was used during the sine vibration tests to measure the interface forces and moments. An automatic notching procedure was established, comparing the FMD outputs directly to the thresholds. The shaker control system accepted this unusual input without problems. The target levels were met with a limited error of typically 6%. The FMD-achieved auto-notched levels were in good agreement with those estimated by more traditional methods, i.e. use of strain gauges and accelerometer measurements in combination with model predictions. The final notched input was always based on the FMD data, since it was considered more accurate and more reliable. The FMD was also used for secondary notching of response levels on the lower tank.

Low-level sine sweeps were performed up to 200 Hz. The FMD did not show any disturbing resonances in this frequency band. The maximum bending moment applied at FMD level was 125 kN.m, the maximum axial force 106 kN, and the maximum lateral force 65 kN, which is at least a factor 2 below the FMD's limit. The outputs of the FMD were of particular interest because the shaker had difficulty in applying a smooth input at the main resonances. The spiky readout would have made determination of the resulting interface forces very difficult without the actual FMD measurements.

The FMD also provided very valuable data for the finite-element-model correlation, in two respects:
- to tune the major modes dictated by the primary structure, without being disturbed by the local modes that often affect the calculation of modal masses and of model correlation criteria
- to determine that the FEM used for the Launcher Coupled Dynamic Analysis (LCDA) is representative at the spacecraft/launcher vehicle interface, thereby increasing confidence in the LCDA predictions; moreover, this can easily be done without the use of such model correlation criteria as the Modal Acceptance Criterion (MAC) or Cross-Orthogonality Check (CoC).

Conclusions

The Force Measurement Device was used for the first time in the qualification testing of the Rosetta spacecraft. Its major advantages can be summarised as follows:
- Direct measurement of interface forces and moments.
- Immediately validates the qualification of the main modes, whatever the quality of the FEM.
- High accuracy of the interface-force measurements.
- High stiffness resulting in limited frequency shift.
- Can be used for auto-notching.
- Provides useful data for the FEM correlation.
- Very good linearity and low cross-talk.
- Uses only six measurement channels.
- Easy to implement in a test set-up.

Some points worthy of attention were also highlighted during the Rosetta test campaign:
- In general, an extra load spreader is required between the slip-table and the FMD (depends on the particular slip-table).
- The use of an additional load spreader and of the FMD increases the overturning moment on the slip-table (additional mass and higher CoG).
- Currently only available for a 1194 mm diameter spacecraft interface, but the technology can easily be applied to other interface diameters.

All in all, the new Force Measurement Device has been demonstrated to be useful, reliable, and practical:
- Useful, because the notched levels could be determined and applied with good confidence so as to ensure adequate safety during testing, and because it was also possible to confirm to the launcher authorities that the qualification loads were indeed reached during these tests. Moreover, the data are valuable for the test validation of mathematical models.
- Reliable, because high stiffness and accuracy have been shown.
- Practical, because its implementation in the test set-up is simple, and because it requires only six measurement channels.

The use of the FMD device is therefore highly recommended in the vibration qualification and acceptance testing of all spacecraft.

Acknowledgement

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The Third ESA Student Parabolic-Flight Campaign

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Today's students will become tomorrow's workforce and hence they should be involved in the global space programme as early as possible so that they will be motivated to follow space careers and create a space-educated next generation for working within the space domain. Getting students involved in today's space programmes is important not only for the space industry in terms of providing a talented workforce for the future, but also for the general public who will be the future voters and potential political supporters of future European space activities. With this in mind, ESA's Office for Education and Outreach organises and runs many space-related activities for young people in order to stimulate their interest in space in particular and in science in general. One of these activities is the 'Student Parabolic-Flight Campaign'.

Introduction

After the successful Student Parabolic-Flight Campaigns conducted in 1994 and 1995, ESA has now resumed their organisation on an annual basis. The Third Campaign was held in Bordeaux, France from 16 to 27 October 2000. The flights were conducted at Novespace's facilities at Bordeaux-Merignac airport, which is home to the Airbus A300 Zero-g aircraft. Novespace operates and manages the A300, which is specially adapted for microgravity experimentation. The aircraft is maintained by Sogerma and operated in flight by the Centre d'Essais en Vol (Flight Test Centre).

Figure 1. The Airbus A300 Zero-g aircraft (courtesy A. v.d. Geest)

From the 150 applications received for this Third Campaign, a total of 31 experiments were selected using the criteria of originality, demonstration of 0g, technical complexity and outreach performed by the team. Each experiment team consisted of four students, whereby each experiment was flown twice accompanied by two students each time. (The list of experiments, along with short descriptions and preliminary results, can be found in Table 2).

The flights took place over four days, and a total of 122 students from 11 countries (Table 1) were able to experience weightlessness first hand.

Table 1. Numbers of student teams participating in the Third Campaign

Belgium	5
Finland	3
France	6
Germany	2
Italy	6
Netherlands	1
Portugal	1
Spain	1
Sweden	1
Switzerland	1
United Kingdom	3
International Teams	1
Total	31

Students were asked to address outreach as part of the selection process and several student groups brought along their own journalists, who followed their progress throughout the application and selection processes, and eventually got to fly with their chosen group. Other outreach activities conducted by the students included creating their own web pages, giving talks to local schools, and publishing newspaper reports and articles in scientific magazines.


Figure 2. A free-floating journalist

Approximately 30 European journalists covered the campaign, with 18 of them actually participating in the flights.

The following TV broadcasters participated in the campaign:

- DRTV, Denmark
- MTV 3, Finland
- France 3, France
- TF1, France
- Spiegel Magazine/ TV, Germany
- Deutsche Welle, global
- Canal 24 Horas, global (in absentia)
- RAI Leonardo, Italy
- RAI SAT, Italy (on the ground)
- RTP, Portugal (on the ground)
- Antena 3, Spain
- SVT Nova, Sweden
- TROS, The Netherlands
- BBC 1, United Kingdom
- BBC 2, United Kingdom (in absentia).

The following press/radio reporters participated in the campaign:

- Le Soir, Belgium
- Tahdet ja avaruus Journal, Finland
- EADS Magazine, France
- Newton Magazine, Italy
- Volare, Italy
- RDS, Italy
- Kijk Magazine, The Netherlands.

A representative of the Italian Space Agency (ASI) was also included on one flight in recognition of the funding and support that ASI gave to three of the Italian experiments.

Flight-week activities

During the first week of the campaign, the students arrived in Bordeaux with their experiments and took up residence in the specially constructed marquee in Novespace's grounds to prepare their experiments. Last-minute modifications were carried out in order to pass the security tests performed by the Centre d'Essais de Vol (CEV). Once they were cleared, the experiments were loaded into the Zero-g aircraft, ready for the flight.

The four flights were performed as planned during the second week of the campaign, with each flight accommodating approximately 50 passengers: 30 students, an average of 5 journalists, the ESA photographer, Novespace and ESA representatives and a cabin crew of 5 CEV safety personnel.

Figure 3. The A300 Zero-g during the injection phase before a parabola (courtesy of Novespace)

On each flight, 30 parabolas were performed and the quality of the microgravity generated was found to be very good, with an average level of between 10^{-3} and 10^{-4} g being generated.

A quick turnaround between the two groups occurred on Tuesday afternoon and Wednesday, when all Group 1 experiments had to be unloaded and the new Group 2 experiments loaded into the A300.

Despite such difficulties, all of the experiments and the participating students were flown, which led to many CEV records being broken, including those of the most experiments ever flown and the most parabolas/flights performed in one week.

Table 2. The experiments in the Third ESA Student Parabolic-Flight Campaign

Material Science/Material Processing

Experiment name: **Foam** *From:* Cambridge University, UK

Description: Creating Structural Foams: an investigation into the isotropic properties of plastic foams formed in microgravity.

Results: Optical microscopy showed little geometric difference between the vertical and horizontal zero-g cores, as predicted. However, unexpectedly, the zero-g samples showed a mass distribution with a minimum in the centre of the sample. The bubble structure also caused surprises with an angular structure being preferred over the expected spherical form.

Experiment name: **Eutectic** *From:* University of Technology, Tampere, Finland

Description: Producing samples of eutectic and other alloys under microgravity conditions.

Results: Pending

Experiment name: **Welding** *From:* University of Bologna, Italy

Description: Observing how microgravity affects the phenomena related to the solidification of an aluminium alloy, which will be melted during a welding process.

Results: Weld beads were obtained in 0g, 1g and 2g environments. Polishing and chemical attack in 0g: The top of the weld bead was flat and bright whereas the bottom had a lack of metal due to cooling. Different (round) phases were observed in the bead, indicating a bad mixture and poor convection and heat diffusion. This is due to the dynamic Marangoni effect. The structure has local orientation and is globally irregular. In 2g there was good heat diffusion and the phases were more extended along the thermal flow direction. The structure was globally oriented. Stereomicroscopic imaging revealed that the flux lines in the molten material inside the welding bead radically change from 0g to 2g. Further analysis will include XRD X-ray diffraction, tensile tests and wrinkle profiling.

Experiment name: **Poly** *From:* University of Parma, Italy

Description: Production of low-density expanded polyurethane under microgravity conditions and comparison with 1g-produced polyurethane.

Results: The static mixer system was found not to be a good system for creating foam in 0g due to the fact the reaction time was not quick enough. This led to the foam being non-uniform and full of veins and streaks. In spite of this, the following tests were made on the18 polyurethane foam samples produced:

- The compression test: due to the non-uniformity of the samples the test calculated different resistance coefficients depending on the direction of compression.
- The optical test: it revealed more spherical cells in 0g than in 1g.

Fluid Physics

Experiment name: **Beer** *From:* Technological University of Delft, Netherlands

Description: Studying the behaviour of gaseous and non-gaseous fluids in microgravity, including the tapping of beer.

Results: Beer tapping: The modified beer barrel was declared perfect for use in space, enabling the beer to be tapped without spluttering. However, no foam head was created; instead the CO_2 bubbles spread out homogeneously in the liquid, resulting in a grey-brown turbulent liquid.

Amongst many other fluid-physics experiments conducted, the contact surfaces between different liquids were observed:

- water-glycerine: this created a curving surface – are non-viscous fluids therefore more sensitive to 0g than viscous fluids?
- acetone-oil: surface became very faint – good mixability of acetone in oil in zero-gravity
- water-air: most unexpected result – surface was undisturbed! Surface tension on water surface is strong enough to keep the surface intact and avoid 'curling'.

Experiment name: **Mix** *From:* Imperial College, London, UK

Description: Studying the immiscibility of fluids (water and silicon oil) under standard and microgravity conditions.

Results: Many different behaviours were observed, some expected and others not. The latter could be due to the fact that an air bubble and impurities were present in the fluids, and also the discrete fluctuations in the g-field. Particular examples include: spherical bubble formation occurred throughout the experiment, as expected, but these were of water and not oil, due to the higher surface tension of water. These spherical bubbles were deformed by adhesive forces when they came into contact with any of the solid surfaces present. Cohesive forces were only visible through the smaller water molecules and the air bubble.

Experiment name: **Phase** *From:* Imperial College, London, UK

Description: Investigating the effects of microgravity on two-phase flow.

Results: After an initial leak in one of the connections was repaired, many interesting observations were noted, including the fact that colliding air-bubbles underwent elastic collisions and different flow patterns were observed in 0g than in 1g, which depended on the amount of air present.

Experiment name: **Marangoni** *From:* **Catholic University of Louvain, Belgium**

Description: Investigating the induction-driven Marangoni effect

Results: Pending

Experiment name: **Fluid Disc** *From:* University Frederico II, Naples, Italy

Description: Creating a fluid disc and studying fluid jets

Results: Due to technical problems, the disc formed only for a few seconds during each parabola. After that the water floated into the cell, which led the pump to drain air and hence broke the disc into droplets. Horizontal ejection did not seem to be optimal.

Experiment name: **Bubbling** *From:* ETSI, Madrid, Spain

Description: Studying bubble behaviour and effervescence in microgravity

Results: Pending

Experiment name: **BlobTrap** *From:* University of Oulu, Finland

Description: Studying how liquids of different viscosities can be handled in the microgravity environment without physical contact

Results: Successful liquid injection was achieved and liquid blobs were seen moving slowly through the experiment tube. However, no difference was observed between the oil and water blobs, perhaps because of the air stream being too powerful.

Experiment name: **SOAP** *From:* University of Liege, Belgium

Description: Studying the creation and evolution of bubbles in a liquid and investigating the drainage and wetting of foams.

Results: 2D Foams: In the Hele-Shaw cells, the zero-gravity stage induced a fast wetting of the foam and the creation of spherical bubbles - microbubbles being transported upward and large bubbles moving downwards.
3D foams: In zero gravity, the wetting of the foam in the HS cells was first of all observed and then when sufficiently wet, the foam started to flow along the walls of the cylinder, finally surrendering the large air bubble located at the centre of the cylinder.

Biology

Experiment name: **Fruit Fly** *From:* University of Trieste, Italy

Description: Studying the behaviour of Drosophila flight in different gravity and lighting conditions

Results: Pending

Experiment name: **Plant** *From:* ENSIA, Nancy, France

Description: Studying the influence of microgravity stress on maize exudation and on the colonisation of the rhizosphere by the bacteria communities.

Results: At the time of writing, analysis of the 750 bacteria and root samples obtained was just getting underway, with results expected in a couple of months.

Experiment name: **Catch** *From:* Santa Anna's School, Pisa, Italy

Description: Evaluating the behaviour of the upper limb during grasp in zero-g and hypergravity conditions.

Results: Preliminary results focus on the two degrees of freedom of the index finger only. By plotting time versus channel value, the graphs clearly show the difference between the behaviour of the middle finger in 0g and 1g. The constant repetition of the same phalanx movement during the parabolas can be seen, as can the large gap between the 0g data compared with the data obtained in 1g.

Experiment name: **Fish** *From:* University of Oulu, Finland

Description: Monitoring the changes in behaviour and orientation of a shoal of fish in different environments

Results: The fish reacted to the different gravity conditions individually rather than as a shoal. Each fish started behaving nervously and looping during different parabolas. Group formation was only intact during the 1g and 2g environments. The different lighting conditions had no effect on their behaviour or orientation.

Experiment name: **Orientation** *From:* University Joseph Fourier, Grenoble, France

Description: Studying the kinematics and accuracy of pointing movements without visual feedback towards the subjective horizon, when applying pressure and contact cues on different parts of the subject's body.

Results: Subjects 1, 2 and 3: During the parabolas the pointing movements towards the horizontal were considerably lower than the absolute horizontal reference. The subjects also showed an 'order effect', whereby there was an increasing gap between the motor response and the reference during the parabola. Only subject 2 showed any signs of adaptation between parabolas. Subject 4 had a lot of experience in 0g and his pointing measurements were no different in 0g than 1g and remained the same throughout the flight. However, he was the only subject to show an effect due to pressure simulation; foot pressure made him point too high and head pressure made him point too low.

Experiment name: **Centrifuge** *From:* University of Lausanne, Switzerland

Description: Developing an easy to use, small and light centrifuge capable of achieving 50 000g and using it to test the effects of gravity on the reorganisation of prokaryotic nucleosome and eurcaryoitc nucleus after centrifuging.

Results: Both centrifuges worked perfectly during both flights. Of the three species of cells (bacteria, cyanobacteria and yeast) fixed in microgravity, only one (bacteria Bacillus megaterrium) showed a different DNA repartition in 0g than with fixation in 1g. Big globules were observed in the cytoplasm of Bacillus megaterrium when the cells were fixed in microgravity. The size and repartition of these globules are different from the cells manipulated in normal gravity. This leads to the conclusion that there is a mechanism of internal arrangement present in the bacteria which depends on the gravity level.

General Physics

Experiment name: **Strain** *From:* ENSMA, Poitiers, France

Description: Studying the behaviour of different materials (Teflon, PVC and steel) and their state of strain in microgravity

Results: The Teflon behaved as expected, with the length variations following the acceleration without any reaction time. However, the results from the PVC and steel were very surprising; at the end of the 0-g phase, the sample first returned to its original length then continued to shrink during the hypergravity phase. This will require further study!

Experiment name: **Detector** *From:* Catholic University of Louvain, Belgium

Description: Developing a new generation of particle detector; preparing a stable mixture in which the freon is uniformly spread out as tiny droplets.

Results: In spite of technical problems during the second flight, 34 samples were prepared and the six parameters below changed to find out their influence on the polymerisation:

1. Changing the diameter of the samples: the larger diameter samples were not polymerised across the entire section, leading to the conclusion that the mixing in 0g made the gel less transparent to UV light.
2. The concentration of Solkane did not seem to influence the curing of the gel.
3. Too strong a concentration (20%) of KCL generated a rapid autopolymerisation. A reasonable concentration of KCL in order to produce a homogeneous polymerisation was 9.1%.
4. 24% of $BaCL_2$ seemed to be the appropriate value for proper polymerisation.
5. It was also found that it was imperative to polymerise the entire sample in microgravity.
6. Dishwasher soap (5%) was found to improve the mixing of the two components by decreasing the surface tension.

Experiment name: **Dustgun** *From:* Technical University of Braunschweig, Germany

Description: Conducting dust-aggregation experiments with magnetised and non-magnetised dust grains in order to study the effects of magnetisation of pre-planetary grain growth

Results: SEM imaging revealed that the purely magnetic samples favoured chain-like particle growth as expected. However, the mixture of magnetic and neutral (spherical) particles showed a much more surprising result - the spherical particles appeared to be caught in complicated web-like structures of almost linear dimensions. Dust aggregation in-situ was also observed using a CCD camera and long-range microscope. Initial analysis shows that a few, rare grain-grain collisions may have even been captured on film. Further analysis of individual aggregates using X-ray spectrometry will also be conducted to clarify the role of the individual grain types in the dust-growth process.

Experiment name: **Magnetism** *From:* University of Orleans, France

Description: Studying the effect of diamagnetism and deducing the atomic radius of different materials

Results: Pending

Experiment name: **Convection** *From:* Polytechnic of Milan, Italy

Description: Studying temperature changes due to microgravity effects in free and forced convection between two co-axial cylinders of different diameters, the inner one being heated by resistors.

Results: Major changes in temperatures were noted due to macro- and microgravity conditions when the fan was off and the lid closed, and when the lid was open. No changes in temperature were noted, however, due to macro- and microgravity conditions when the fan was on, at both voltage levels. These tests showed important phenomena that could cause problems during the thermal modelling of space instruments.

Mechanics

Experiment name: **Lubricate** *From:* INSA, Toulouse, France

Description: Studying the lubricating power and the kinematic behaviour of oil in zero gravity in transmission gears.

Results: The amount of oil was changed between the two flights (first flight – normal amount, second flight – excess oil) and the rotation speed of the gears was changed between parabolas. Using a normal amount of oil, it lost contact with the gears during zero-gravity and was ejected onto the container walls, at all rotation speeds, although the effect was more dramatic at high speeds. Only when excess oil was added did it pass through the gears, but at high speeds it still did not lubricate them correctly, due to the amount of air bubbles produced and cavitation phenomena.

Combustion

Experiment name: **COSMIC** *From:* Ecole Centrale de Paris, France

Description: Studying the combustion around a porous sphere

Results: The experiment worked perfectly during 51 parabolas and 42 successful ignitions were completed. In 0g the flame took on a spherical shape as predicted. However, the diameter of the flame was three times as big as in 1g. Fluctuations in the shape of the flame occurred and were probably due to the small fluctuations in the g-level from perfect zero-gravity. In hypergravity, the flame was much brighter and formed an even more cylindrical shape than in 1g. More soot was also produced. The relationship between fuel flow and flame diameter was also studied and it was found that as the flow rate increased, the flame diameter decreased. Many more post-analysis tasks are now scheduled, including a study of the soot formation and flame extinction.

Experiment name: **Burning Particles** *From:* Free University of Brussels, Belgium

Description: Estimation of the influence of particle burning on their motion

Results: Pending

Robotics and Technology Demonstration

Experiment name: **CRV** *From:* University of Lund, Sweden

Description: Investigating the ergonomics of the Crew Return Vehicle (CRV)

Results: All predefined procedures were executed by the end of the second flight, leading to many recommendations being put forward regarding all aspects of the ergonomics of the CRV, specific examples being seat design and ingress manoeuvres. A new design proposal will now be made for the interior of the CRV, taking into account the experiences of the team.

Experiment name: **Robot** *From:* University Nova de Lisbon, Portugal

Description: Testing the navigation and dynamics of the robot and its ability to use different radiation and magnetic sensors in microgravity.

Results: Although the robot experienced some problems due to the extra tension generated by the imposed safety straps/wires, the robot was successfully controlled using four motors in composed movements only, such as 'X and Y' and 'X and Z'.

Experiment name: **LEGO** *From:* University of Glasgow, UK

Description: Testing the GUST (Glasgow University attitude Stabilisation Tool) in microgravity conditions

Results: After some initial problems, the robot was able to track a moving source whilst maintaining continual line-of-sight with the source, hence proving the viability of using small reaction wheels for attitude stabilisation on an autonomous micro-robot.

Conclusions

The Third ESA Student Parabolic-Flight Campaign was a very successful one in terms of the numbers of students and microgravity experiments flown, the performance and quality of the experiments, and the media interest that was generated in the campaign and ESA as a result.

Once again, the students proved to be hard-working and adaptable, having invented and produced a series of very good microgravity experiments. Two of the very best experiments will now be chosen to participate in ESA's professional parabolic campaign in May 2001, in keeping with a new agreement that provides the possibility for exceptional student parabolic experiments to be up-graded for flight on a professional parabolic-flight campaign.

Next year's Student Parabolic-Flight Campaign will take place from 16 to 27 July 2001. It will have a slightly different flavour from usual due to the availability of a new Foton flight opportunity. For the first time, ESA has offered 7 kg of payload on the Russian retrievable satellite Foton to students. A parallel Announcement of Opportunity has been launched with the 4th PFC, enabling students to either propose a traditional parabolic experiment or a suitable Foton experiment. Students will need to chose carefully because parabolic-flight experiments are normally large and bulky, weighing up to 150 kg, whereas the Foton experiments will have to be autonomous, weigh less than 3 kg each and be made to fit within the special boxes provided.

Keeping the very best news until last, the budget has been allocated to allow the ESA Student Parabolic-Flight Campaign to be conducted once a year for the next five years.

Acknowledgements

We would like to thank the following people for their support during the campaign: Novespace, CEV, Medialink, Vladimir Pletser, ASI for their sponsorship and support of three of the Italian experiments and our own team which, in addition to the authors, included Martin Houston and Eric Trottemant.

More information on the Foton opportunity is available on the dedicated web page:
http://www.estec.esa.nl/outreach/pfc/Default.htm

More information on the 2001 Student Parabolic-Flight opportunity is available on the dedicated web page:
http://www.estec.esa.nl/outreach/pfc/

Figure 9. The Participants in the Third ESA Student Parabolic-Flight Campaign

The DAISEX Campaigns in Support of a Future Land-Surface-Processes Mission

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In the last ten years, the retrieval of geo-/biophysical parameters from airborne imaging-spectrometer data has made significant progress. ESA therefore decided to investigate the feasibility of quantitatively retrieving geo-/biophysical variables as the requisite inputs for process models. For three years in succession (1998 to 2000), therefore, the Agency has conducted an airborne imaging-spectrometer campaign called 'The Digital Airborne Imaging Spectrometer Experiment (DAISEX)' in support of a possible future spaceborne mission. The instruments flown included DAIS 7915, HYMAP, ROSIS, POLDER and LEANDRE.

This article describes the state of the art in retrieving variables relevant to land-surface processes from hyperspectral data cubes, outlines the scientific objectives, and demonstrates the first results of the DAISEX campaigns.

Introduction

Part of ESA's Earth Observation Envelope Programme (EOEP) is intended to advance our understanding of the various processes occurring in the Earth's biosphere/geosphere, and their interactions with the atmosphere. Thus, the Programme's 'Theme 3: Geosphere/Biosphere' focusses on the modelling and monitoring of land-surface processes, the study of interactions, and the analysis of climate impacts on the biosphere, with the objective of enhancing our skills in predicting the evolution of the Earth system.

Real-life applications such as weather forecasting, crop-yield estimation, precision farming, the management of renewable and non-renewable resources, as well as environmental-hazard monitoring/forecasting, would all benefit from improved process model descriptions.

A spaceborne scientific mission addressing the provision of information on geospheric/biospheric processes and their interactions with the atmosphere is currently being formulated. This mission implies the need for an instrument with high spectral and angular resolution and a very high radiometric performance, operating in the reflective and thermal parts of the spectrum, not only to identify but also to quantify the key variables driving the processes.

Background

The Earth's environment is a complex system that couples, on various temporal and spatial scales, the atmosphere, the oceans, the land and the cryosphere. Many aspects of the functioning of the Earth system are still not fully understood. In order to enhance still further our capacity to predict the evolution of the Earth's environment under the influence of both natural variability and human activities, the provision of data and their integration into appropriate models is of paramount importance. To better understand and predict processes occurring in the different ecosystems, estimates of 'process-driving' variables are needed. The capability to observe the Earth with a range of instruments providing different spatial, radiometric, temporal and angular resolutions is expected to result in major advances in process monitoring and management. Such considerations underlie the formulation of ESA's Earth Observation Envelope Programme.

For this Programme, two classes of Earth Observation missions have been identified for the post-2000 time frame: the *Earth Watch and the Earth Explorer missions*. Earth Watch missions are pre-operational missions concerned with operational needs requiring continuous data provision. Earth Explorer missions are focussed on research and demonstration. They are further subdivided into Earth Explorer Core Missions, which are larger missions led by ESA, and Earth Explorer Opportunity Missions, which are smaller and more flexible missions, not necessarily led by ESA.

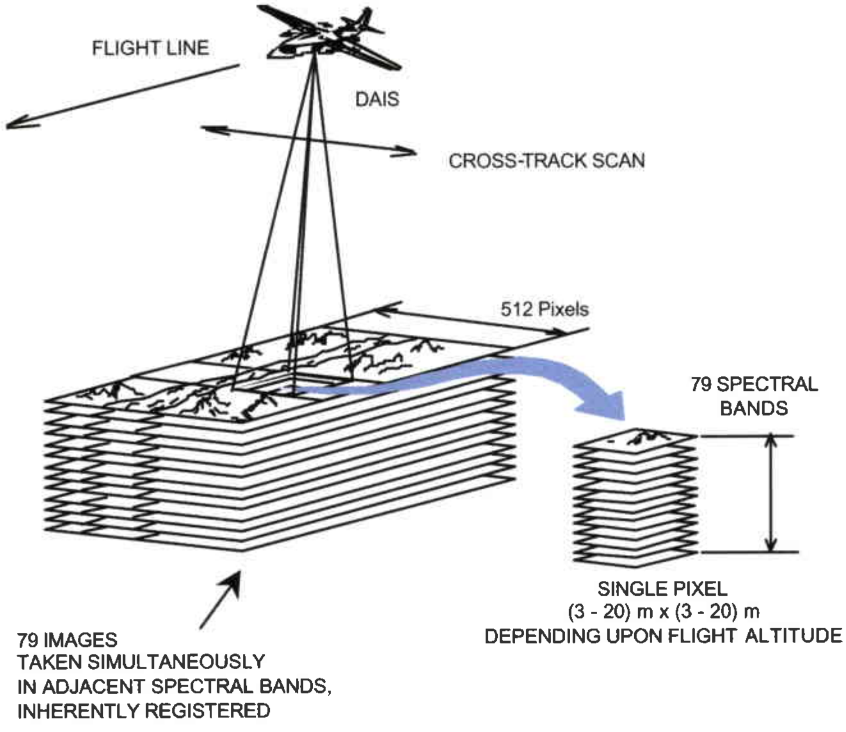
One of the first set of Earth Explorer Core Missions, which were the subject of Phase-A studies, was the Land-Surface Processes and Interaction Mission (LSPIM). This mission's core instrument was a hyper-spectral imager covering the visible, near-infrared, shortwave-infrared and thermal-infrared spectral ranges.

Following the User Consultation Meeting in Granada (Spain) in October 1999, LSPIM was not selected, but was assessed as being of high scientific merit. SPECTRA – a mission with similar but more focussed and refined objectives – was proposed to the Agency in response to the Call for Ideas for the next Earth Explorer Core Missions. Its scientific objectives and technical and programmatic feasibility are currently under evaluation.

Within the framework of the Earth Observation Preparatory Programme (EOPP), ESA carries out various airborne campaigns to support the development of geo-/biophysical retrieval algorithms, calibration and validation and simulation for future spaceborne Earth Observation missions. It was within this framework that the DAISEX campaigns were organised in 1998, 1999 and 2000, involving test sites in Spain, France and Germany and exploiting a range of airborne instruments. The overflights were accompanied by an intensive field-measurement programme.

DAISEX is intended to provide airborne hyperspectral measurements over land, to demonstrate the retrieval of variables as required for future land-surface-process missions.

Figure 1. Illustration of hyperspectral data cube acquisition



Information gathering

Passive optical sensors operate in the reflective and thermal parts of the electromagnetic spectrum. The sources of information they observe are the radiance fields emitted or reflected from the Earth's surface. On its path through the atmosphere, the irradiance interacts with the atmospheric particles and gases before reaching the sensor. Assuming that all interactions caused by the atmosphere can be accounted for, information on the surface should be retrievable. These 'disturbing interactions' caused by the atmospheric constituents (gaseous molecules and aerosols) contain information useful for atmospheric research.

The chemical and physical condition of the surface defines the intrinsic information in the reflected or emitted radiance field. Its retrievability depends on the spatial, spectral, angular and radiometric resolution of the observing instrument.

The basic concept of an imaging spectrometer is shown in Figure 1. The sensor scans the top-of-the-atmosphere radiance within its instantaneous field of view (IFOV). The flight altitude and the IFOV define the footprint size of each pixel, often referred to as the ground instantaneous field of view (GIFOV). The incoming radiance is dispersed into its spectral components by a spectrometer. As the instrument moves forward it records line-by-line, building up an image data cube.

As already mentioned, the chemical and physical condition of the surface defines the information intrinsic in hyperspectral data cubes. Generally, the reflectance (ρ) can be described as a function of the wavelength (λ), the location ($\vec{r}$), the time of observation (t), the viewing direction (ϑ) and the polarisation (p), such that

$$\rho = f(\lambda, \vec{r}, t, \vartheta, p)$$

Polarisation plays an important role for atmospheric scattering, but is of minor influence for natural surfaces and thus can be neglected.

The viewing direction and the directional anisotropy behaviour of different surfaces were only marginally addressed in the early days of remote sensing due to lack of data, but are currently the subject of much on-going research. Sensors like MISR and POLDER foster these research topics by providing multi-angular and multi-spectral data sets.

Anisotropic reflectance is caused by multiple scattering within the surface (e.g. canopy) and is thus a function of the structure of the interacting media. It may contain meaningful information about, for example, the number and size of the leaves (Leaf Area Index – LAI), their orientation (Leaf Inclination Distribution Function – LIDF), and the height of the canopy. It may therefore be able to provide indicators of the condition of the vegetation. A prominent feature of the directional anisotropy effect is called the 'hot spot', which is the increased reflectance when the surface is viewed in the same direction as it is illuminated by the Sun (same line of sight). Recent research showed that the half-width of the hot spot contains useful information about the condition of the vegetation. Usually, there is a parameter 'q' associated with the hot spot, defined as its width/height ratio. In order to get a good estimate of q, one of the aims is to observe from as many different viewing directions as close to the hot spot as possible.

Anisotropic effects can be assessed via the experimental Bidirectional Reflectance Factor (BRF), which is the ratio of the directionally reflected radiance from the surface target and the nadir radiance of a Lambertian-scattering reference target. The Bidirectional Reflectance Distribution Function (BRDF) describes the angular behaviour of the surfaces, and it can be assessed by measuring the BRF.

Compared with the limited angular range of airborne and spaceborne data sets, experimental directional reflectance factors (acquired with field goniometers) are quite plentiful and enable us to determine the BRDFs of the objects for quite a number of viewing and illumination geometries.

Figures 2 and 3 show two examples of experimental directional reflectance factors, namely those for bare soil and for alfalfa acquired during DAISEX '99 with the Swiss field goniometer. Note that the highest reflectance, which forms the peak of the hot spot, cannot be measured with the field goniometer due to the shading of the target by the instrument.

Diurnal directional measurements show the variability of the reflectance factors due to changing illumination geometry, i.e. changing solar zenith angle.

The spectral effects of the anisotropy can be analysed by normalising the BRF with a

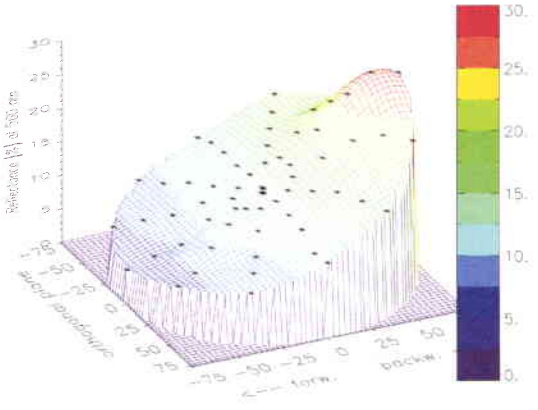


Figure 2. Bidirectional Reflectance Factors (BRFs) of bare soil for 65 different viewing angles at 560 nm (Sun azimuth 94° and zenith angle 49°; symbols indicate measured data points)

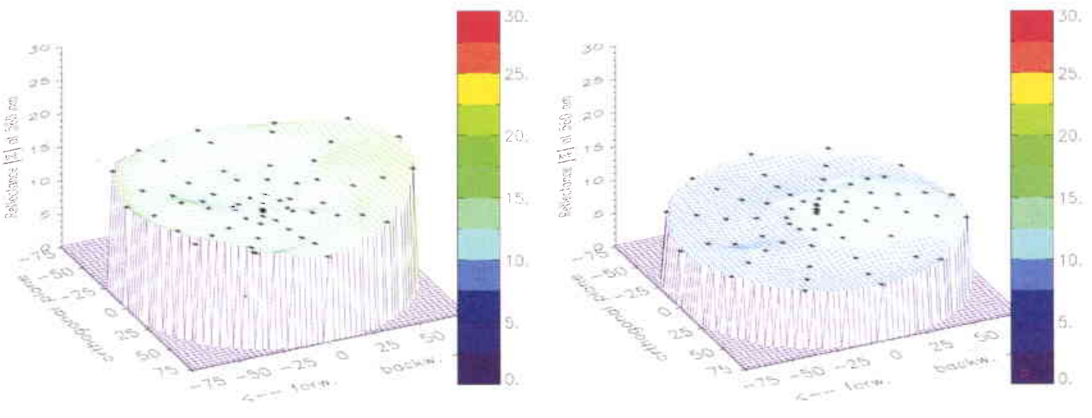


Figure 3. Bidirectional Reflectance Factors of a dense alfalfa canopy for two different illumination angles at 560 nm (left: Sun azimuth 90°, zenith 53°; right: Sun azimuth 182°, zenith 17°)

representative spectrum of the object (e.g. a nadir-view spectral signature or the spectral hemispherical albedo derived from the BRF measurements). Figure 4 shows an example of the spectral dependence of anisotropic effects for the measured alfalfa canopy with different solar zenith angles.

One of the objectives of DAISEX was to assess the use of multi-angular-hyperspectral data to enhance the retrieval of structural biophysical variables such as the LAI.

Information retrieval

Basically, three different types of retrievals can be distinguished:

1. Classical retrievals

Classical retrievals use system, atmospherically and geometrically corrected data sets as input data. Each pixel represents the reflectance on the ground within the footprint of the sensor. Different correction schemes are used to atmospherically correct the data. Semi-empirical methods are mainly used to correct for atmospheric scattering effects. These techniques are considered sufficient for broad-band sensors, which are affected to only a minor extent by atmospheric gaseous absorption features. More sophisticated techniques are required for the narrow-band hyperspectral data sets. For these data, atmospheric radiative transfer models, constrained by radiosonde measurements or the use of standard atmospheric profiles, are used. High calibration accuracy is a prerequisite. Calibrations are performed to convert the recorded digital counts into radiance values. The latest developments in the atmospheric-correction schemes consider the different viewing directions within one scanning line, as well as the topography of the terrain. On-going research focusses on the inclusion of the anisotropic reflectance effects of different surface types.

The derived reflectance values are used to produce higher-level products (Level-2), which may in turn be used to derive further products (Level-3), for instance estimating LAI from vegetation indices. The latter were derived by relating the increased reflectance values of vegetation in the near-infrared to the reflectance of vegetation in the visible red (red edge), and using an established empirical relationship between the indices and LAI. Another technique fits the red edge to a Gaussian function, the coefficients of which are then related to vegetation variables in a semi-empirical way.

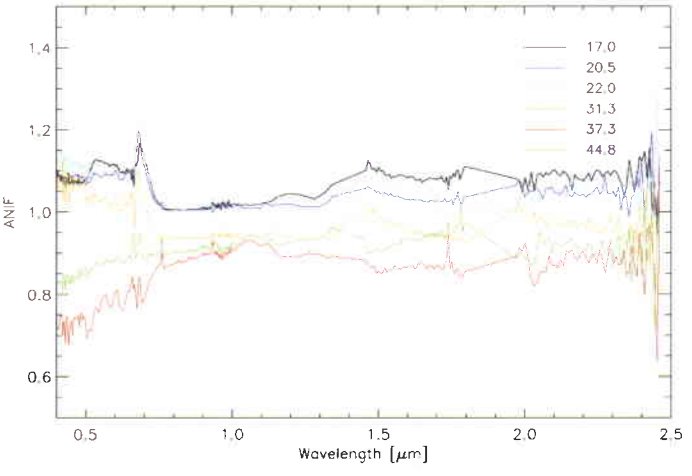


Figure 4. Comparison of alfalfa nadir reflectances ratioed with the spectral albedo for six different solar zenith angles

Currently, the most commonly used techniques for quantitatively retrieving variables from hyperspectral data are un-mixing and differential absorption techniques. The latter use the fact that the depth of the absorption is correlated with the weight percentage of the material observed. Thus, absorption depths in specific spectral bands can be used to quantify the amount of the material present. For this technique, the absorption feature needs to be fully observed, including both of the inflection points left and right of the absorption feature. Un-mixing techniques assume that the observed spectrum within the footprint of the sensor is a combination of the spectra of all pure spectral end-members (spectrally 'pure' material) within this footprint. Even though the combination is unlikely to be linear, it has been proved that the assumption of a linear combination (as often applied) gives reasonably good results. End-members can be selected from the data set itself by identifying 'pure' pixels within the scene, or using spectral libraries.

It should be noted here that spectral libraries are also being used to train 'classifiers', e.g. neural networks. In this case it is the image that is classified rather than variables quantitatively retrieved. Another technique that falls into this category is the Spectral Angle Mapper (SAM). This method determines the similarity of each pixel in the image to known library spectra by computing their angle within the spectral space, where the number of spectral bands defines the dimension of the latter.

2. Inversion of coupled radiative transfer models

Intensive research is currently in progress in this area and major advances have been achieved during the past few years. Instead of using a radiative transfer model only for the atmospheric correction, radiative transfer models are developed to describe the optical properties of vegetation and soils. These models are coupled with the atmospheric transfer models, resulting in complete radiative transfer codes describing the interactions over the entire path of the radiation from the emitted solar irradiance to the Top of the Atmosphere (TOA) radiance recorded by satellite sensors. Variables can then be retrieved by model inversion constrained by ancillary data (e.g. atmospheric profiles measured by a radio-sonde, *in-situ* measured micro-climatic data, a-priori knowledge of some of the canopy and soil variables, e.g. gathered by campaign activities). Moreover, comparison of the modelled TOA radiances constrained by ancillary data with the observed TOA radiances makes it possible to analyse and further improve the models.

TOA radiances are used as inputs in the inversion process. Different approaches are proposed for the inversion, such as look-up tables, neural networks, golden-section 3D and Gauss-Newton techniques.

It should be noted that the models also consider illumination- and viewing-angle-dependent effects. This means that the inversion process is further constrained by feeding in additional angular observations. This in turn reduces the number of degrees of freedom available during the inversion, and may enhance the accuracy of the retrieved variables. The latter will then be used as inputs to surface-process models to derive variables of interest to researchers, such as canopy state, fluxes, crop production, etc. These models can be used both for monitoring and fore-casting the state of the ecosystem.

3. Assimilation of remote-sensing data into radiative transfer and canopy or soil functioning coupled models

A further development of the technique discussed above is the coupling of the complete radiative transfer models with the surface-process models themselves (canopy and soil functioning models) and assimilating the remote-sensing observations from different sources (optical and SAR data with different spectral and spatial resolutions) in a multi-temporal manner.

Assimilation involves tuning (by means of a cost function) some of parameters of the coupled models so that the simulation matches the observations as closely as possible. This facilitates optimum exploitation of the complementary features of the different sensors. This technique is potentially the most promising because it makes best use of available information, both on the physical or biological processes and any ancillary data.

This technique follows a new philosophy. Instead of retrieving variables directly, it rather aims at stabilising the coupled process models by adjusting variables within the models, making use of assimilation techniques. The stabilised models make it possible to predict the future state of the ecosystem more accurately. The frequent feeding of the models with remote-sensing data accounts for unforeseen events such as hailstorms or other natural hazards, thereby ensuring that the model remains 'on-track'.

This, of course, is a rather ambitious and challenging idea and many scientific questions still remain unanswered. These include the refinements to be introduced into the models, the non-linearity of model scales and the related optimum spatial resolutions, the optimum temporal coverage of the different sensors, the optimum spectral resolution, the optimum number of viewing directions and the required spectral resolution of angular observations, the optimum SAR (band, polarisations and incident angle), etc. Some of these questions were already addressed within the framework of the LSPIM Phase-A.

ESA plans to investigate these questions further through dedicated study activities. The DAISEX campaigns provided suitable data to start addressing some of these questions. A future land-surface-processes mission will certainly help in refining these ideas. Programmes like APEX and CHRIS/PROBA will be useful assets.

The DAISEX campaigns

The main scientific objective of the DAISEX campaigns was to demonstrate the feasibility of quantitatively retrieving geo-/biophysical variables by accounting for atmospheric effects, whilst at the same time analysing the data for possible additional information on directional anisotropy. Bio-/geophysical variables included the leaf area index, biomass, leaf water content, canopy height, chlorophyll content, surface temperatures and emissivity. Since accurate calibration and atmospheric corrections are essential to quantitatively retrieve these variables, in-situ atmospheric measurements (needed to derive the atmospheric corrections) were performed in addition to the field measurements for validating calibration and retrieval. The atmospheric modelling for airborne hyper-spectral sensors was carried out based on the ATCOR model. Three airborne campaigns were organised over test sites in Spain, France and Germany, in 1998, 1999 and 2000, exploiting a range of different airborne instruments.

DAISEX Test Sites and Teams

The Barrax Site

The Barrax test site is a well-described agricultural site close to the town of Albacete in Spain. It was formerly used in such international programmes as EFEDA, RESRAPS, RESMEDES, RESYSMED, RISMOP and STAAARTE, which included the exploitation of a range of airborne instruments, e.g. AVIRIS, DAEDALUS, TMS, and AIRSAR. Data from SIR-C/X-SAR as well as operational sensors such as ERS-SAR, Landsat-TM, SPOT-HRV, NOAA-AVHRR, and Meteosat are available. Detailed thematic maps and long-term data records exist. In addition, there are two permanent meteorological stations in the area continuously recording the energy and water fluxes. The School of Agronomical Engineering of the University of Castilla-LaMancha permanently monitors the fields. An additional advantage of the Barrax site is its topography and geomorphology. It is relatively flat, which eases the pre-processing required to correct for geometric and radiometric distortions (needed for the analysis of multi-angular observations).

The Colmar and Harheim Sites

The Colmar site is an agricultural one operated by the Institute National de Recherches Agronomiques (INRA), located south of the city of Colmar in France. The Hartheim site is about 20 km southwest of Freiburg in Germany, and is directly adjacent to the Colmar site. During DAISEX, both sites were referred to collectively as the DAISEX 'Upper Rhine Super Site (URSS)'. The URSS is located in the southern part of the Upper Rhine Valley, extending from Karlsruhe to Basel, and from the Vosges to the Black Forest.

The area is a highly uniform flood plain, lying about 200 m above sea level. Much information has been collected on the atmosphere, soil, hydrology, radiation, land occupation and use, and air quality over the years. Remote sensing has been used over the last 15 years (Landsat-TM, SPOT-HRV, NOAA-AVHRR, Meteosat, ERS-SAR). It has been an important area for both national and international research programmes, such as the Regio Klima Project (REKLIP).

The Colmar site includes experimental test fields producing a variety of crops, and experimental vineyards. The site is well-characterised in terms of the physical and chemical properties of its soil and its hydrology, and it includes meteorological stations.

Hartheim is a coniferous forest site (pinus sylvestris, about 40 years old) run by the Meteorological Institute of the University of Freiburg. It is about 10 km in extent north-south, and about 1.5 km east-west. Intensive measurements have been conducted since 1970, including tree-characterisation (height, density, etc.) and flux measurements. Two towers (30 m and 15 m high) within the site are instrumented with radiometers, ultrasonic anemometer thermometers and fast hygrometers, enabling mass- and energy-flux estimates to be derived. Hartheim has been used for both national and international research programmes such as REKLIP.

Teams Involved in the Campaigns

ESA Earth Sciences Division:
Campaign Unit (APP-FSS): Overall management
Land Unit (APP-FSL): Scientific support

DLR, Oberpfaffenhofen:
Flight operation of DAIS 7915, HYMAP and ROSIS. Pre-flight and in-flight calibration of airborne instruments. Radiometric, geometric and atmospheric corrections of DAIS 7915, HYMAP and ROSIS data.

University of Valencia:
Management of ground measurement programme in Barrax, Spain. Data analysis, including data-quality assessment and algorithm validation.

University of Strasbourg:
Management of ground measurement programme in Colmar and Hartheim. Data analysis including quality assessment and algorithm validation.

University of Zurich:
Goniometer measurements in Barrax and Colmar. Analysis of goniometer measurements.

CESBIO:
Flight operation of POLDER. Radiometric, geometeric and atmospheric correction of POLDER data.

Airborne sensors, flight patterns and acquired data sets

The core instruments used in the DAISEX campaigns were the Digital Airborne Imaging Spectrometer (DAIS 7915), the High-Resolution Imaging Spectrometer (HYMAP), the Reflective Optics System Imaging Spectrometer (ROSIS), and the Polarisation and Directionality of the Earth's Reflectance (POLDER) airborne instrument.

DAIS 7915 is a 79-channel imaging spectrometer operating in the 0.5 to 12.5 μm wavelength range with four grating spectrometers. With the exception of the 1.05 – 1.4 μm region, all atmospheric windows are covered, which is a unique feature of this system. The instrument, purchased from GER Corporation (USA) jointly by the EC Joint Research Centre (JRC) and DLR, has already been flown in Europe since 1995 for a number of different research and commercial projects.

HYMAP is an Australian instrument, built by Integrated Spectronics Pty. Ltd. The sensor provides 126 bands across the reflective solar wavelength region (0.45–2.5 μm) with contiguous spectral coverage (except in the atmospheric water-vapour bands) and bandwidths of 15 – 20 nm. The system operates on a three-axis-stabilised platform to minimise image distortion due to aircraft motion. It provides a high signal-to-noise ratio (>500:1) and thus an industry-standard-setting image quality. Laboratory calibration and operational system monitoring ensure the radiometric performance required for demanding spectral mapping tasks.

ROSIS is a compact airborne imaging spectrometer developed jointly by German industry and research organisations. It provides 115 spectral bands in the spectral range 430 – 860 nm, with 4 nm spectral sampling. It was recently redesigned to provide greater radiometric and spectral stability.

POLDER is a wide field of view radiometer equipped with a 2D CCD array and a filter wheel providing eight spectral bands from 443 to 865 nm. The airborne version has a similar concept to the spaceborne version, but a different spectral band configuration. A given pixel on the ground is projected to different locations on the 2D CCD array, and therefore has different view-angles in successive images. With a specific flight pattern such as that operated by ARAT during DAISEX '99, up to 50 view directions are acquired per pixel. After pre-processing, the BRDF of every pixel is reconstructed up to a 60° viewing angle at 20 m spatial resolution of an area of typically 3 km x 3 km.

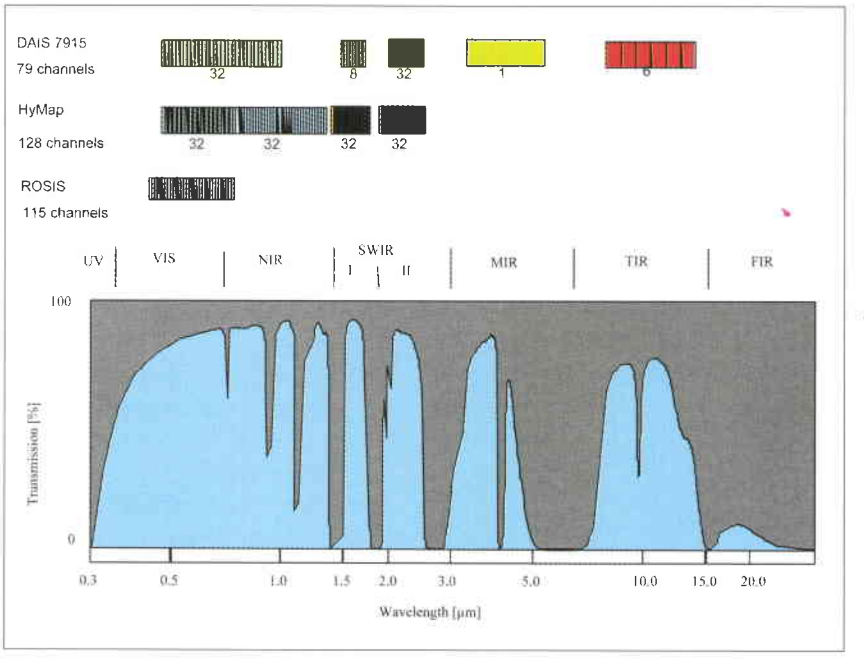


Figure 5. Atmospheric transmission and spectral layout of DAIS 7915, HYMAP and ROSIS

The complementary nature of the various instruments is illustrated in Figure 5, which shows their different spectral layouts in the context of atmospheric transmission.

Data have been acquired under different observation geometries by using crossing flight paths, as illustrated in Figure 6. In particular, the 1999 campaign focussed on the acquisition of multi-angular data, by using three pairs of crossing flight paths – one in the morning, one at midday, and one in the afternoon – over the Barrax site for HYMAP and DAIS 7915. This provided a total of six different view-illumination angles for each pixel in the overlapping area of the flight paths. Observation of the hot spot was assured by the east-west flight line at noon. Table 1 summarises the data acquired by each sensor during the three campaigns.

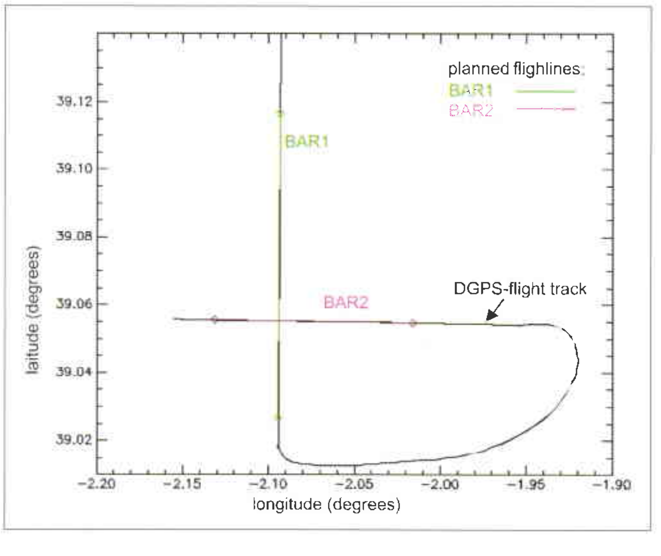


Figure 6. Flight pattern used during DAISEX '98 over the Barrax test site

Table 1. Airborne data acquired during DAISEX campaigns

- DAIS 7915
- HYMAP
- POLDER
- ROSIS

Year	Barrax, Spain				Colmar, France				Hartheim, Germany			
	D	H	P	R	D	H	P	R	D	H	P	R
1998	■											
1999	■	■	■		■	■			■	■		
2000	■	■		■								

The most complete data set was acquired over the Spanish test site. Thanks to an EC-funded project, the French ARAT aircraft, equipped with the LEANDRE atmospheric-measurement instrument, could be operated simultaneously with DAIS and HYMAP over the Spanish site in 1999. This allowed the acquisition of a complimentary data set, something that had never been done before. The combination of HYMAP (VNIR, SWIR component), DAIS (VNIR, SWIR, TIR component) and POLDER (angular component) data enabled us to simulate the instrument as it was proposed by LSPIM. The ARAT instrument provided a 3D characterisation of the atmosphere at the time of the overflight.

Ground measurements
The field measurements involved a suite of instruments operated by the various research teams. The direct and diffuse solar irradiation was measured with high spectral resolution (6 nm) for atmospheric characterisation. In-situ aerosol characterisation was also performed by a particle counter and nephelometer on ARAT, enabling us to estimate aerosol extinction profiles. Ground-based reflectance measurements were mainly acquired for two reasons: (a) those of relatively homogeneous targets for system-calibration purposes, and (b) those to radiometrically characterise principal soils and vegetation. The latter were also performed under different viewing geometries exploiting a field goniometer. Figure 7 shows the Swiss goniometer for BRDF measurements as operated during the DAISEX '99 campaign. All field measurements were geo-referenced using GPS for later integration of the data into Geographical Information Systems (GIS).

Detailed mapping included crop identification, phenological state description and soil-roughness measurements. Soil and crop samples were collected for later laboratory analysis of the soil's mineral composition and the biochemical contents. Validation measurements included LAI, fPAR, chlorophyll content, surface temperature, surface emissivity and evapotranspiration.

At the URSS* particular attention was paid to measurement of the radiative-balance, energy-flux and directional TIR-radiance components for modelling and evaluating the surface energy balance. In-situ radiosonde measurements were made to obtain temperature, ozone, pressure and humidity profiles up to an altitude of 30 km. These measurements are used to constrain the atmospheric transfer codes used for atmospheric corrections. Radio sounding was supported by the Spanish National Institute of Meteorology and Meteo France.

Preliminary results
Pre-processing of DAIS 7915, HYMAP and ROSIS data included radiometric, geometric and atmospheric corrections, carried out by

* URSS = the DAISEX Upper Rhine Super Site

Figure 7. The Swiss goniometer at the Barrax site

DLR. First results are presented in Figure 8, where HYMAP data with a spatial resolution of about 6 m x 6 m, acquired over Barrax during DAISEX '99, are shown. The image is a 'true-colour' composite using bands 18,9,3 (0.685, 0.549, 0.457 µm) for red, green and blue, respectively. For visualisation purposes, the image was enhanced using standard image-processing tools. Irrigated field patterns of different sizes (circled objects) are shown. Different shades of green indicate different types and growing stages of vegetation and crops. Brownish to greyish colours show fields with sparse vegetation and bare soil; gravel roads appear as white lineaments.

Data acquired during the DAISEX '99 campaign show the 'hot spot' in hyper-spectral data cubes for the first time; it appears as a bright horizontal line in the upper part of the image.

POLDER images of the 3 km x 3 km Barrax area at 865 nm for three positions of the plane (along the same flight line, within a time interval of a few seconds) are presented in Figure 9.

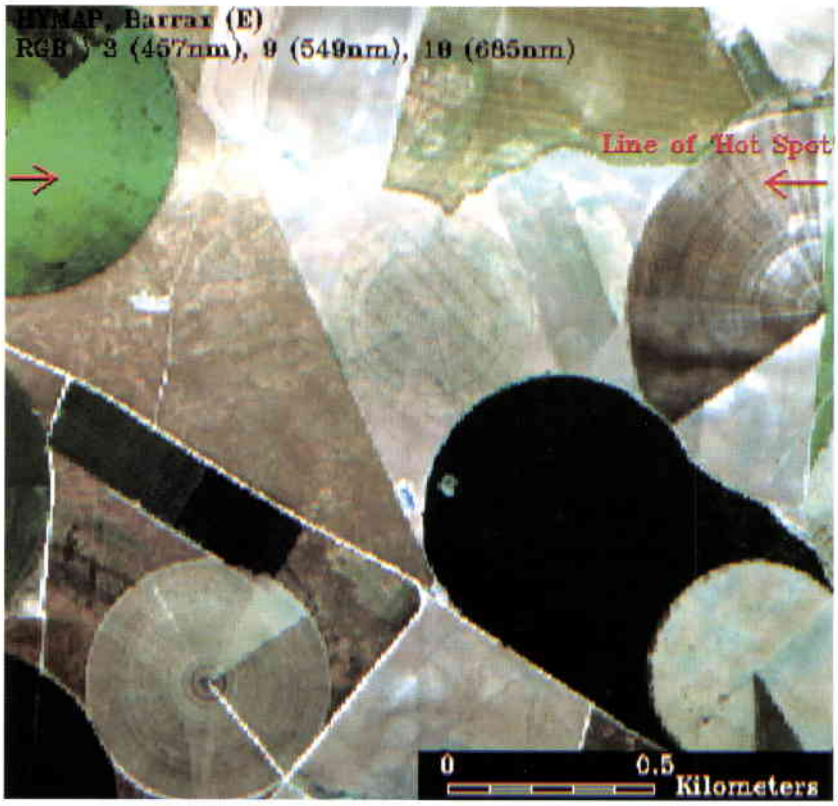


Figure 8. HYMAP data acquired over Barrax

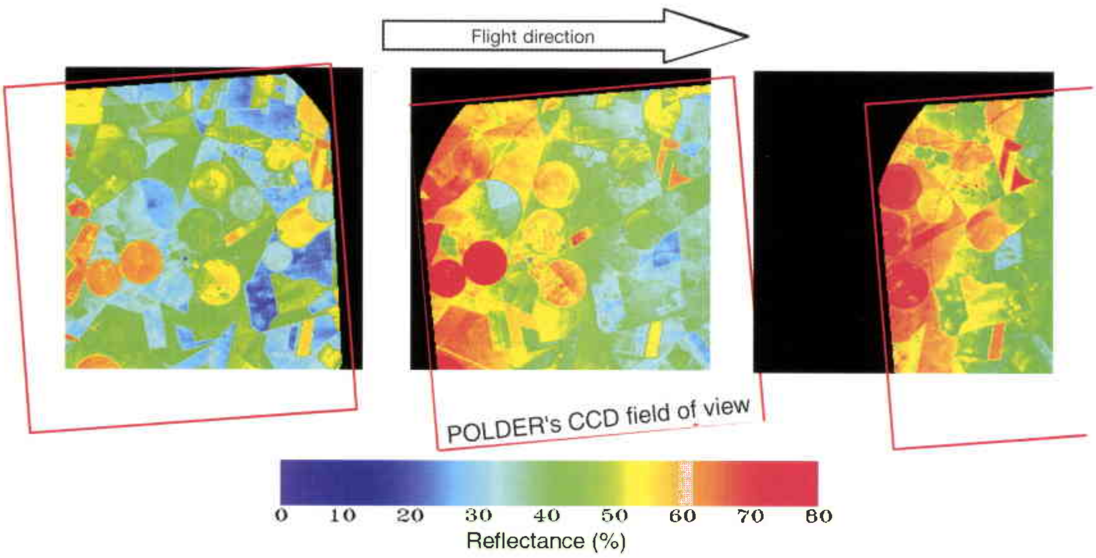


Figure 9. POLDER images of the 3 km x 3 km Barrax area at 865 nm for three positions of the viewing plane (courtesy of Luis Alonso, Univ. of Valencia)

The different aspects of the three images are due to the different view-target-Sun configurations (the Sun is located to the bottom-right of the images). The image sequence shows the hot spot, characterised by a sharp increase in surface directional reflectance when illumination and viewing geometry are in coincidence. The processing of all images acquired during the flight permits the full BRDF of every 20 m pixel of the area to be reconstructed.

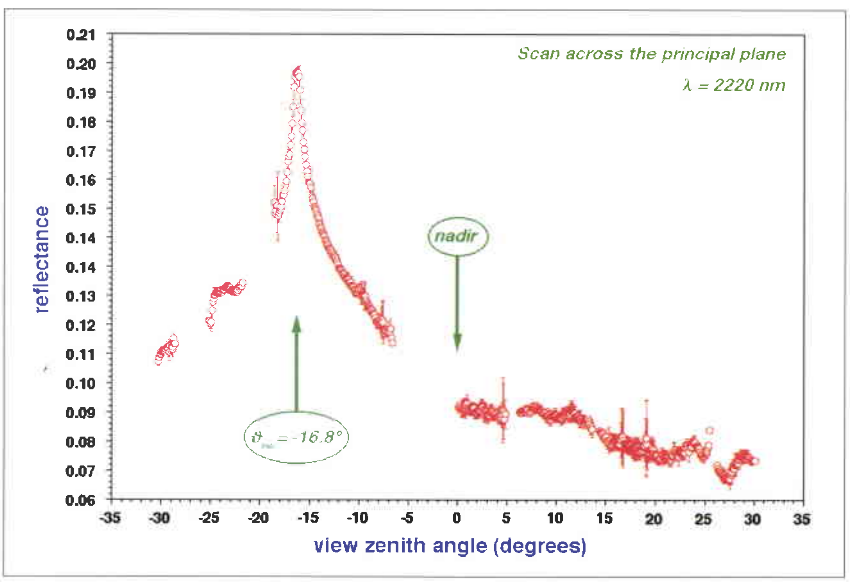


Figure 10. Reflectance of alfalfa at 2200 nm for different view zenith angles extracted from HYMAP data

Figure 10 shows the reflectance at 2200 nm (SWIR-II) extracted from the HYMAP image for different viewing zenith angles. Several fields with the same vegetation coverage were used for this purpose. The hot spot is clearly visible at a view zenith angle of 16.8°, also in the

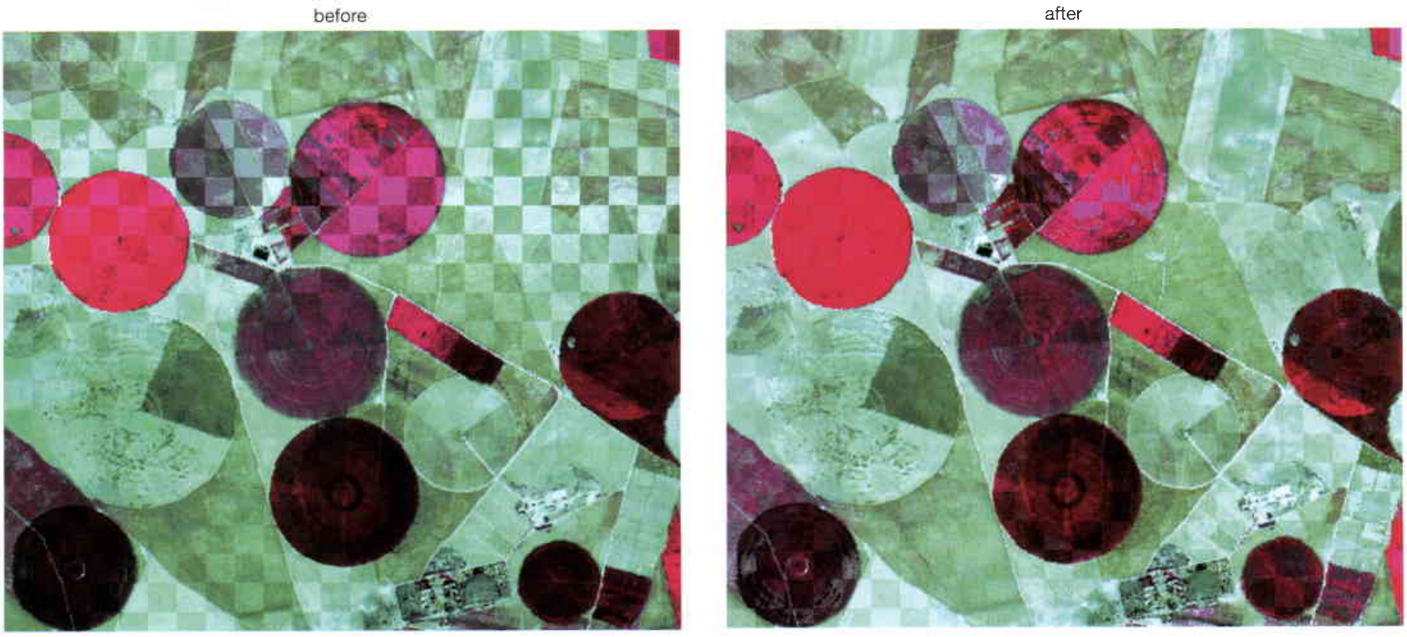


Figure 11 a,b. BRDF correction with a class-specific Ambral Model fit

SWIR-II, which proves the good radiometric performance of the HYMAP sensor. Note that the image was acquired on 4 April, when the Sun was close to latitude 20°N, which with the observed hot spot at 16.8° adds up to about 37°, which is the latitude of the test site.

Figure 11a shows a cross-section of two geocoded, atmospherically corrected, and co-registered HYMAP data acquisitions in Barrax. The chess-board-like pattern in the overlapping area is obtained by alternating squares in the north-south image, which is superimposed on top of the east-west image. Both images have been processed in the same way (calibration, geocoding/correction, atmospheric correction, image processing), and the differences are due solely to angular effects.

The angular effects are most pronounced in the hot-spot region (a bright horizontal band in the upper third of the image) and disappear in the nadir viewing direction (slightly below image centre). Images without any directional components would not exhibit any pattern-like structure. In this case, the hot spot in the east-west direction is not present in the north-south image. Also, no pattern-like structure can be observed close to nadir in the centre of the image.

Figure 11b is an example of a new method for normalising hyperspectral images to a single viewing geometry (BRDF correction). The BRDF correction takes place after geo- and atmospheric correction and a statistical method is used to extract BRF measurements for each surface type. The Ambrals Model is applied to the data and correction factors are calculated. The procedure currently requires user supervision, but has the potential to be automated in the future.

As a result, most of the differences disappear in the right-hand image (Fig. 11b). Only some vegetated areas show residual differences, which are smaller than the original ones. These classes have a large internal reflectance variation. Improving the classification will reduce the errors. A prerequisite for separating a class is to have enough occurrences at different viewing angles within the image.

The ability to discriminate between green vegetation (Fig. 12a), senescent vegetation (Fig. 12b), and soil background is essential

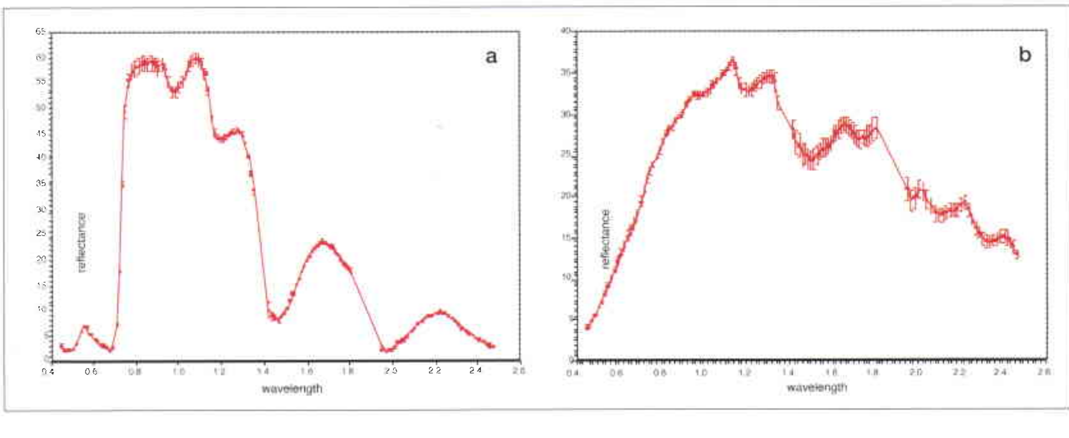


Figure 12a,b. Spectral response of the HYMAP sensor for (a) green vegetation, and (b) senescent vegetation, for the Barrax study area during DAISEX '99 not only to retrieve critical biophysical parameters, but also for the assimilation of data into models describing the terrestrial carbon cycle, where the different roles of the green (photosynthetically active) vegetation, the senescent vegetation (carbon assimilation) and soil (mostly for soil respiration) must be properly accounted for.

Figure 13 compares actual HYMAP reflectance data, derived from raw data after calibration and atmospheric correction, and simulated reflectance data, by means of a theoretical radiative transfer code driven by elementary inputs describing the leaves, the soil background and the canopy structure. The good fit that has been obtained is an indication both of the accurate radiometric calibration and atmospheric correction of the HYMAP data, and the stability achieved across the whole spectral range. The fit also illustrates our present capabilities for modelling hyperspectral data by means of radiative transfer codes. The code is based on the scattering and absorption properties of elementary leaf constituents. The combined soil-canopy response is obtained by modelling the transport of photons across the medium. Any deficiency in the theoretical modelling and/or the calibration of HYMAP data would show up in this plot.

The ability to understand the theory behind the role of each individual variable in the combined spectral response finally measured by the sensor is important for retrievals of bio-/geo-chemical parameters and for assimilating hyperspectral data into models of land-surface processes.

Outlook

Data acquired during the DAISEX campaigns are currently being further analysed and validated. In particular, validation of higher-level products accounting for different viewing and illumination geometries will be analysed, by comparing measured and modelled BRDFs and by inverting a full radiative transfer code.

Results of the campaigns will be aggregated into process models describing the vegetation growth and energy/water balance over time. This will further demonstrate the feasibility of a future land mission aimed at advancing our knowledge of land-surface processes and interactions with the atmosphere.

A Workshop summarising the results is planned for the beginning of 2001. In addition, ESA plans to fund dedicated studies addressing some of the open questions discussed in this article by exploiting the data acquired during the DAISEX campaigns.

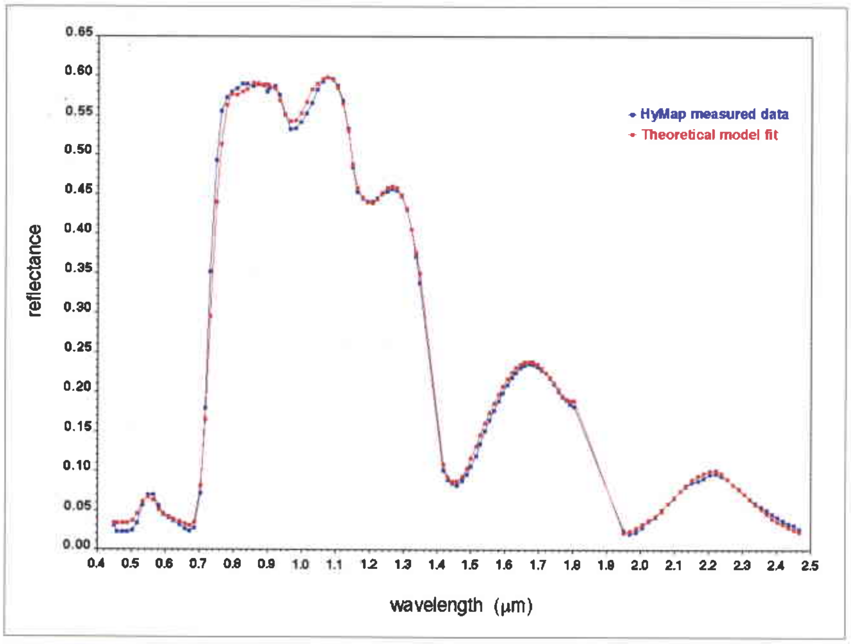


Figure 13. Comparison between actual HYMAP reflectance data, after calibration and atmospheric correction, and simulated reflectance data by means of a theoretical radiative transfer code

Acknowledgment

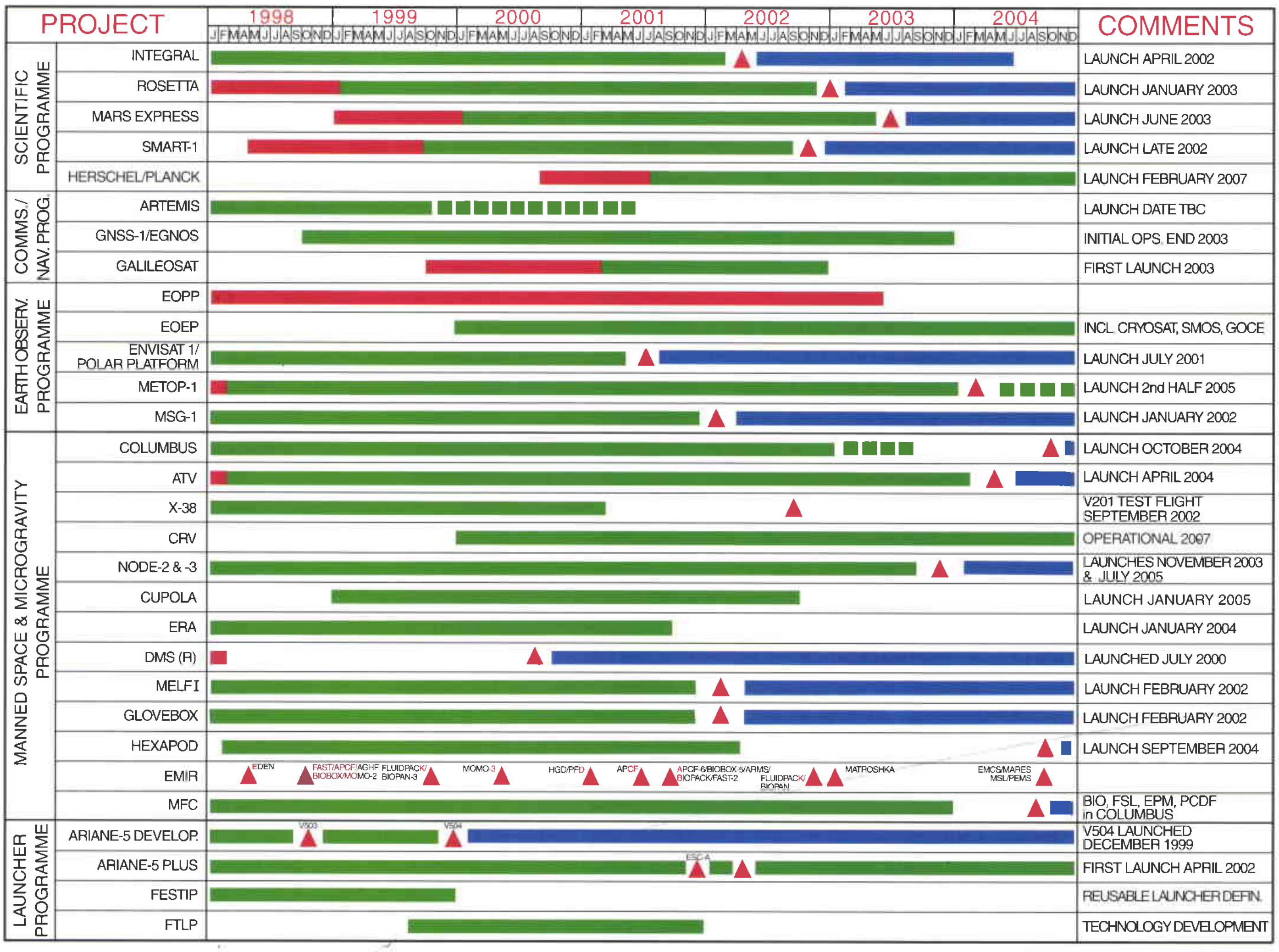
The authors wish to acknowledge the work of all team members involved in the DAISEX campaigns. The cooperation of the Institute for Regional Development at Albacete and the Agricultural Research Centre in Barrax were essential to campaign success. We are also grateful to the Spanish Air Force authorities, in particular the commander and personnel of the Military Airfield at Albacete, to the DLR flight operations manager Heinz Finkenzeller, to Christian Tardieu (IGN) and Christian Allet (INSU) for the operation of ARAT, to Jean-Yves Balois (LOA, Lille) for the installation and calibration of POLDER, to Meteo France, to the Spanish National Institute of Meteorology (which contributed the local radio soundings), and to the Remote Sensing Laboratory of Zurich University for their support.

The ARAT/LEANDRE flights over Barrax were supported by the European Commission's STAAARTE project, funded by the Fourth Framework Research Programme. The DAISEX experiment in Barrax was also supported by a Fulbright project of the Commission for Cultural, Educational and Scientific exchange between the USA and Spain. The US contribution was partially supported by a grant from the US Department of Agriculture.

Programmes under Development and Operations
(status end-December 2000)

In Orbit / En orbite

Under Development / En cours de réalisation



DEFINITION PHASE — MAIN DEVELOPMENT PHASE — ▲ LAUNCH/READY FOR LAUNCH

OPERATIONS — ADDITIONAL LIFE POSSIBLE — ▼ RETRIEVAL — STORAGE

XMM-Newton

The first public data from the XMM-Newton observatory have been made available on the World Wide Web, together with the associated analysis software (see: http://xmm.vilspa.esa.es/public/xmm_sas_sv_top.html). The software was developed jointly by the XMM-Newton Science Operations Centre (SOC) and the Survey Science Centre (SSC), a consortium, led by Dr. Mike Watson of Leicester University (UK), selected to routinely process all XMM-Newton data.

A Workshop on the radiation effects experienced by ESA's XMM-Newton and NASA's Chandra missions was held at ESA's Vilspa station, near Madrid (E), on 29 November (see http://sci.esa.int/xmm).

XMM-Newton's instruments are performing nominally, with no further problems being encountered. The ground segment has continued preparations for the inclusion of a third antenna (in Santiago, Chile) in the mission's day-to-day operations. This additional antenna will close an existing gap in data reception around spacecraft apogee.

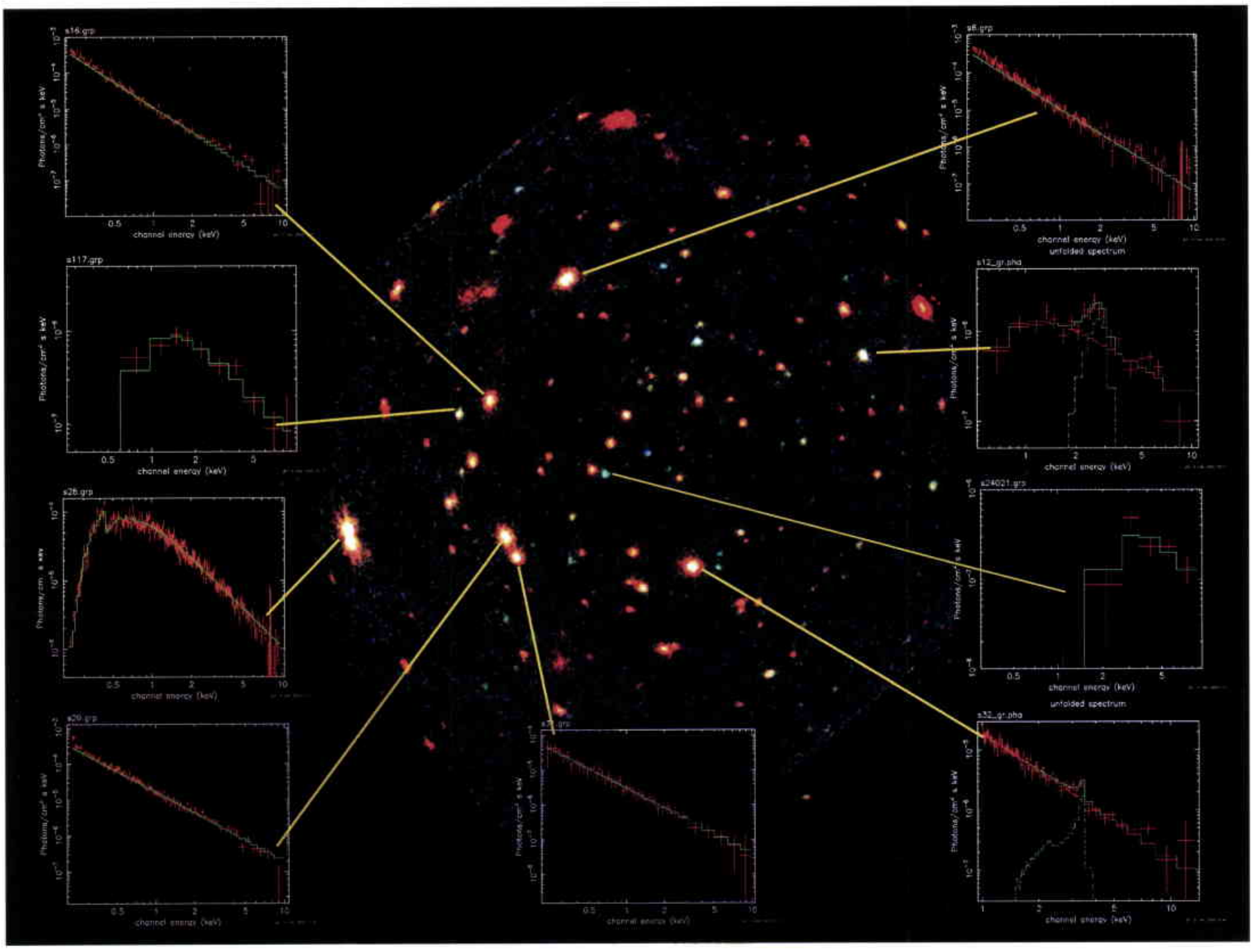
A special issue of Astronomy and Astrophysics magazine containing 56 high-quality papers based on XMM-Newton data has been published, and another similar special issue is already planned.

One of the highlights of the XMM-Newton mission is the combination of high-throughput and imaging X-ray spectroscopic capabilities. The accompanying image is from a 100 ksec observation of an area called the 'Lockman Hole'. This false-colour X-ray image shows hundreds of so-called 'serendipitous sources', and the overlaid X-ray spectra illustrate the quality and capabilities of XMM-Newton in this field for a few randomly selected sources. Regular updates on the most striking results obtained by the XMM-Newton observatory can be found at http://sci.esa.int/xmm.

Cluster

The Cluster quartet successfully completed the instrument-interference campaign on 22 December. It involved two weeks of intensive checks to ensure that the 11 scientific instruments on each spacecraft do not adversely affect each other's measurements. A few minor difficulties involving one or two instruments have been experienced, as expected, but by no means can they be considered show-stoppers.

The potential operational conflict is largely due to the complexity of the instrument



XMM-Newton false-colour X-ray image of a 100 000 sec observation of the Lockman Hole. Colour indicates temperature, with red being cold (around 1 million K) and blue being hot (a few million K) objects. The overlays show X-ray spectra (decomposition of X-ray light into its constituent 'colours'; as with a prism for visible light) for a limited number of randomly selected sources in the image. This clearly illustrates that XMM-Newton can routinely derive detailed information for many sources within its field-of-view (courtesy of Prof. G. Hasinger, AIP/MPE) set on each spacecraft. Most experiments are 'passive' and simply measure the space environment through which the spacecraft is passing, but some experiments (EDI, WHISPER, EFW, ASPOC) actively probe near-Earth space. All of these active instruments were designed to be compatible with their neighbours. It was not possible, however, to precisely forecast, or test for, all of the possible interference effects until the spacecraft were actually in orbit and the experiments had been commissioned. During the interference campaign, the scientists investigated 'worst-case scenarios' by looking for any unforeseen effects that could perturb the space plasma and so adversely affect the rest of the science payload. Once these were found, the challenge was to determine how to operate the instruments in question successfully whilst limiting the impact on the overall science data return. Careful global scheduling of the scientific measurements ensured that the Cluster science programme could be started in early January and that it will produce top-quality scientific data.

Meanwhile, after some small 'constellation manoeuvres', the Cluster quartet are now in the correct orbits to form a perfect tetrahedron for the cusp crossings next February. At that time, the spacecraft will be almost exactly 600 km apart. Taking advantage of this spatial spread, the suite of instruments on each satellite will gather a unique three-dimensional set of data as they sweep through the cusp regions over the Earth's magnetic poles.

Integral

The flight model of the Integral Service Module is now practically completed. A significant milestone was achieved with the delivery last October of the Optical Monitoring Camera (OMC), which was the first flight-model scientific instrument to be delivered and integrated on the spacecraft.

The current project-completion schedule remains extremely tight due to the technology-development difficulties that some instrument teams have recently encountered. The plan is to integrate the remaining flight-model instruments into the spacecraft during the first half of 2001 at Alenia Spazio's facilities in Turin (I). The environmental test campaign at ESTEC (NL) will follow immediately thereafter, allowing the Flight-Acceptance Review to be held in early 2002.

The third round of System Validation Tests (SVT-C) was successfully completed in December and included the verification of spacecraft contingency recovery and instrument flight-operations procedures. The ground-segment activities are progressing according to plan.

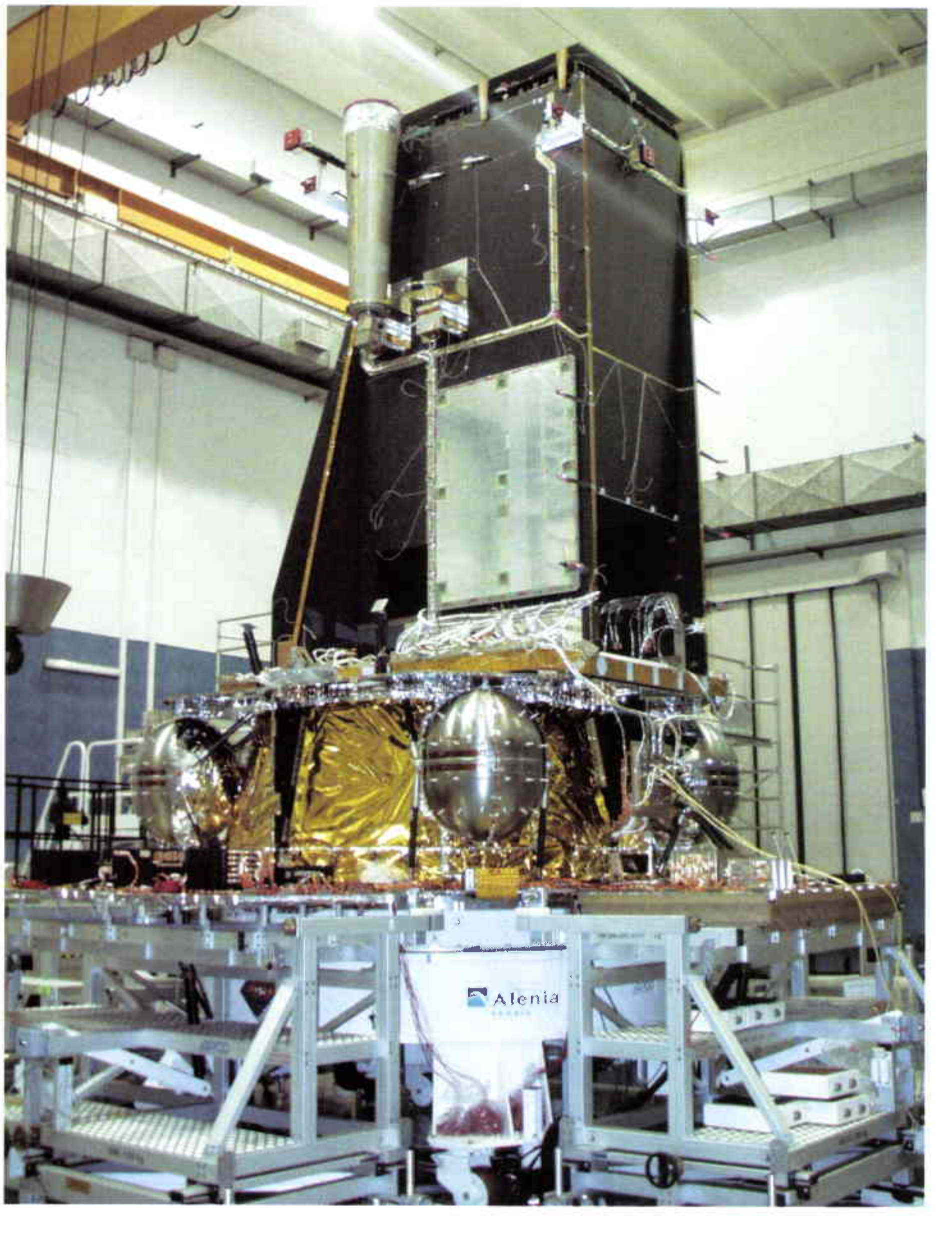
There have been some delays in adapting the design of the Proton launch vehicle and facilities, but overall progress is presently sufficient to allow launch according to the current schedule in April 2002 from the Baikonur Cosmodrome in Kazakhstan. The next major launch-related milestone is the Mission Critical Design Review (MCDR), planned for April 2001.

Rosetta

The Electrical Qualification Model (EQM) continues its testing at Alenia in Turin (I). All of the payload units have been integrated and the bus and payload modules have been mated. The integrated system tests have been performed on the power and data-handling subsystems, as well as for most of the experiments. The first phase of EQM testing is still foreseen to be completed by the end of March 2001.

The spacecraft Proto-Flight Model (PFM) programme has also just started. The structure, propulsion and thermal subsystems have been delivered and mechanical integration has commenced.

The Integral flight model ready for payload integration



There is still some concern regarding the delivery schedule for the flight models of some critical equipment items (star tracker and transponder), owing to their development programmes running late due to technical problems. The engineering model programmes for these items have, however, been brought to a successful conclusion, demonstrating that these problems are now under control. The complex nature of the software has also given rise to development problems. An incremental delivery approach compatible with the system test requirements has now been agreed with all parties.

The Experiment Final Design Reviews (EFDRs) have all taken place successfully, with no show-stoppers being identified. The payload institutes are now busy integrating and calibrating their experiment flight models for delivery in the second quarter of 2001. For most, the schedule is still very critical, particularly for the scientific camera (Osiris).

The EQM lander has also been integrated on the EQM spacecraft and compatibility testing successfully performed. Assembly of the flight-model lander has also started, but there are still some critical units, in particular the landing gear and some experiments,.which are receiving maximum attention in order to ensure timely delivery.

The development of the ground segment is proceeding according to plan. The pedestal for the new 35 m antenna in New Norcia, Australia, has now been completed, and the complete ground station should be ready in early 2002, which is compatible with the mission requirements.

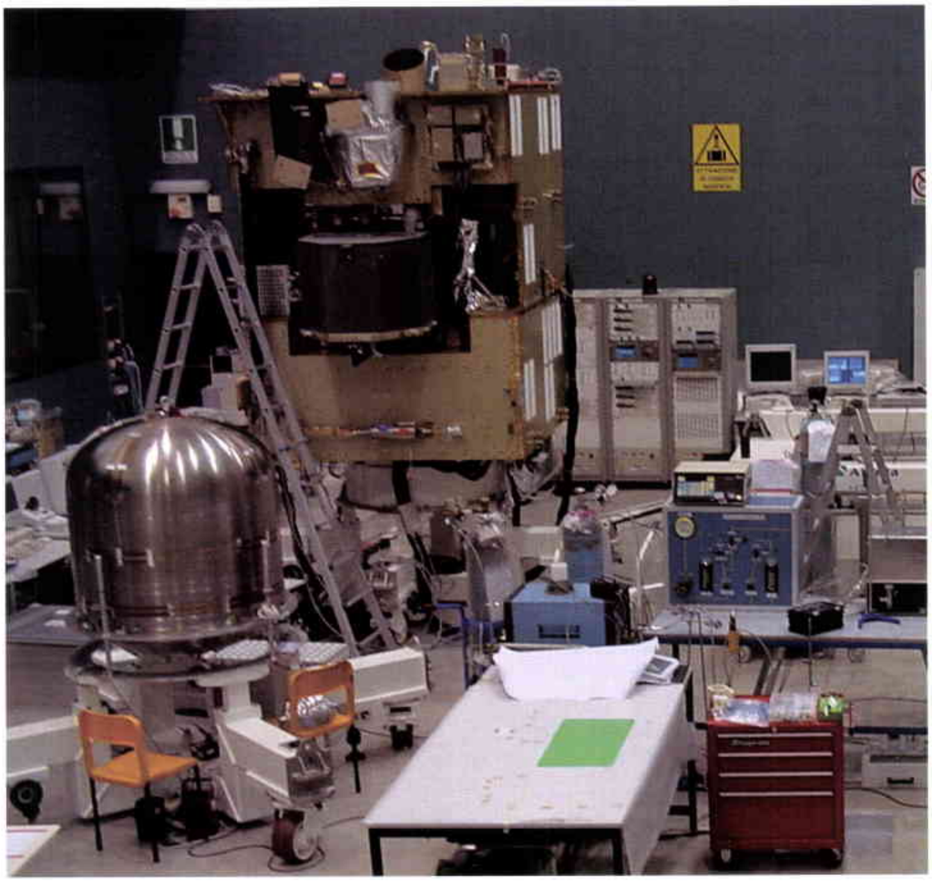
Mars Express

The spacecraft programme continues to progress according to plan, and the overall workload is currently reaching its peak. Engineering-model testing is in progress at Astrium SAS in Toulouse (F). Production of the flight-model structure is nearing completion at Contraves in Zurich (CH) and qualification testing will follow.

The Critical Design Reviews of the scientific instruments have started, as has delivery of the instrument engineering models. The first instrument delivery to Astrium's site took place just before Christmas.

Beagle-2, the Mars Express lander, has been reviewed by an independent group of experts, led by J. Casani, a former NASA/JPL project manager. It concluded that the Beagle-2 project is 'eminently doable', but certain activities require more attention than initially planned. The review group's conclusion led the United Kingdom to formally request ESA's Science Programme Committee (SPC) to support the Beagle-2 project. During its November meeting, the SPC approved 16 MEuro for ESA participation in the Beagle-2 consortium. ESA will primarily be involved with the entry, descent and landing system, and will participate in the lander's assembly, integration and verification (AIV) programme. In addition, ESA will procure the lander/orbiter relay system, and will provide access to its expertise and facilities.

The Ground-Segment Design Review was completed successfully on 31 October. The Fifth Meeting of the Mars Express Science Working Group took place in December. Discussions focussed extensively on the scientific aspects of mission operations, and data analysis and archiving.



The Rosetta Electrical Qualification Model at Alenia in Turin (I)

Smart-1

Since the start of the main development phase (Phase-C/D) in November 1999, work has proceeded on all mission elements: spacecraft, payload instruments, electric-propulsion subsystem, and ground segment.

The spacecraft, under the responsibility of the Swedish Space Corporation (SSC) and its industrial consortium, has been designed according to the system requirements down to subsystem and equipment level. All of the subsystem and equipment Preliminary Design Reviews (PDRs) have been successfully closed. A few subsystems - primary structure, some mechanisms, solar arrays, transponder, star tracker - have already undergone their Critical Design Reviews, allowing flight-model production to start. The electrical tests on breadboard and engineering-model units started towards the end of 2000 and will continue throughout 2001. The On-board Software contract has recently been awarded and the Architectural Design Review is planned for February 2001.

The six payload instruments are being developed in parallel by various European institutes and industries. Four of them – the Electric-Propulsion Diagnostic Package (EPDP), the Smart-1 Infrared Spectrometer (SIR), the Demonstration of Compact X-ray Spectrometer (D-CIXS) and the X/Ka-band Transponder Experiment (KaTE) – are being developed under ESA TRP contracts, whilst the other two – the Asteroid and Moon Imaging Experiment (AMIE) and the Spacecraft Potential Electron and Dust Experiment (SPEDE) – are nationally funded. All instruments have undergone their PDRs successfully. The Critical Design Reviews (CDRs) are planned for April 2001. The structural and the electrical models will be delivered for integration into the spacecraft models in the February-March time frame.

The electric-propulsion subsystem is being procured separately directly by ESA from SNECMA and its subcontractors, and will be delivered to the SSC as customer-furnished equipment. The CDR was held in December and close-out of all open actions is expected by March 2001. A complementary engine-lifetime qualification test will start in January.

The ground segment is being designed and built by ESOC, based on the existing infrastructure and facilities. The mission-control system is based on the SCOS-2000 (Spacecraft Control Operating System) kernel, the dedicated control room is shared with the Huygens mission, and the ESA ground stations will be used on a time-availability basis. Extensive work has been done on optimising the low-thrust trajectory to the Moon, to cope with Arianespace's launch-window requirements for an auxiliary payload like Smart-1.

The Science and Technology Operation Coordination will take place from ESTEC and will include the science and technology operation planning, technology data distribution and exploitation, and data archiving. This will ensure that the results of this preparatory mission will be directly transferred to the technology and project offices of the future science missions, such as BepiColombo.

Herschel/Planck

The Far-Infrared and Submillimetre Telescope (FIRST) mission was renamed the 'Herschel Space Observatory' at the end of last year, in honour of William Herschel, the famous Anglo-German astronomer who discovered infrared light exactly 200 years ago, in 1800.

The industrial Invitation to Tender (ITT) for the Herschel/Planck mission had been issued to European industry by 1 September 2000 as planned, and the proposals were received in early December. Evaluation of those offers is underway. The start of development activities (Phase-B) with industry is planned for June 2001, which is in line with the foreseen launch of the two spacecraft in February 2007.

The development of the three Herschel instruments and the two Planck instruments is proceeding according to plan. A major instrument-development milestone is the second formal Instrument Design Review. A first review meeting for the Herschel SPIRE instrument took place in November. The next review meetings, for Planck's LFI and HFI instruments, will take place in February 2001.

The co-ordinated parts procurement that has been initiated to support scientific-instrument development is progressing nominally. The activities together with the Danish Space Research Institute for preparing the Invitation to Tender (ITT) for the Planck telescope's reflectors are also progressing. Release of the ITT to European industry is planned for early 2001.

Earth Observation Envelope Programme (EOEP)

The Cryosat Phase-B activities are proceeding nominally; all Invitations to Tender (ITTs) relating to the procurement of the various spacecraft equipment items have been issued. Evaluation of the offers received will take place early in 2001.

Negotiation of the GOCE space-segment Phase-B/C/D/E1 industrial proposal has been successfully completed. The GOCE Phase-B activities were kicked-off on 19 December under a Preliminary Authorisation to Proceed (PATP). Completion of the GOCE Phase-B is expected by the end of 2001.

The detailed design of the ALADIN instrument for the ADM/Aeolus mission is nearing completion. The ITT package for the second phase of the predevelopment programme (hardware manufacturing) is being prepared.

The ITT package for the Prodex-funded instrument Phase-C/D is in preparation. Finalisation of the specifications is being supported by a scientific study. The procurement proposal for the provision, under EOEP funding, of short-wave infra-red (SWIR) focal planes to APEX has been approved by ESA's Industrial Policy Committee (IPC). The relevant contractual actions have been initiated.

In the market-development area, 14 short-term contracts have been started. Six proposals for longer-term contracts are under evaluation, with the objective of selecting two or three for a start in the first quarter of 2001.

ESA's plans for Earth Watch's ORSA-3, including preparatory activities under EOEP, have been fully aligned with Eumetsat's post-MSG/EPS plans.

Earth Observation Preparatory Programme (EOPP)

From the ten proposals received in response to the Call for Mission Ideas for the second cycle of Earth-Explorer Core Missions, five missions were selected for further assessment: ACE, EarthCARE, SPECTRA, WALES and WATS. This selection was endorsed by the Earth-Observation Programme Board (PB-EO) in November. The proposals for pre-Phase-A studies of these missions are currently being evaluated, and these studies are expected to be kicked-off early in the first quarter of 2001.

The 'End-to-end Mission Performance Simulation' study for SMOS has been kicked-off.

Meetings were held with NASDA on the potential joint EarthCARE Earth-Explorer core mission, ESA's possible participation in the NASDA/NASA Global Precipitation Mission (GPM), and implementation of ESA's SWIFT Earth-Explorer Opportunity Mission on the Japanese GCOM mission.

Intensive work within the Agency and consultations with Delegations are taking place in the framework of the Earth-Watch Task Force, created at the PB-EO's November meeting. The objective is to arrive at a consolidated proposal for future Earth-Watch programmes.

Meteosat Second Generation (MSG)

The MSG-1 launch delay from October 2000 to January 2002 announced by Eumetsat means that all of the spacecraft – MSG-1, EM, MSG-2 and MSG-3 – will now have to be stored for in the order of 15 to 21 months. The revised and extended MSG programme planning is under review in order to minimise the resulting costs.

The Pre-Storage Review (PSR) for MSG-1 took place as planned at the end of 2000, and a PSR Board meeting is planned in the March 2001 time frame.

The need to add a shock-test programme in order to qualify MSG-2, MSG-3 and follow-on models for an Ariane-5 launch is still under investigation.

MetOp

An important milestone was achieved with the completion and delivery of the Advanced Scatterometer instrument (ASCAT) and the GPS Receiver for Atmospheric Sounding (GRAS) for the engineering-model Payload Module (PLM). With these instruments now successfully integrated, the EM PLM is complete, and has started its system-level testing. The thermal-balance/thermal-vacuum test in ESTEC's Large Space Simulator (LSS) is planned for the second quarter of 2001.

A major change is now being discussed with industry, to re-align the assembly, integration and verification (AIV) programme for MetOp-1, -2 and -3 to be in line with the delivery schedule for customer-furnished instruments, specifically IASI, A-DCS and SARP. This re-alignment results in a thinning out of activities in 2001 (reduced parallel working on the EM PLM and MetOp-1 PLM) and an interleaving of work on MetOp-1, -2 and -3 thereafter. Work is continuing on the MetOp-1 PLM, but at a somewhat reduced pace, with the first instrument integration starting in February.

In the meantime, the elements of the MetOp structural model have been delivered to ESTEC for final integration and then vibration/acoustic testing.

Eumetsat has finalised its approval procedures for the core ground segment, allowing the kick-off with Alcatel (F) to take place in January 2001. Eumetsat was also able to finalise the contract with Starsem for the provision of the Soyuz-ST launch vehicle, which is now the baseline for MetOp. Negotiations for this change are underway with the MetOp industrial partners.

Following a programmatic review, Eumetsat has determined that ground-segment system readiness will not be achieved before the second half of 2005, and so the launch of the MetOp satellites would be correspondingly delayed. Under the realigned AIV programme, the first MetOp satellite will be ready at the

The MSG-1 SEVIRI optical instrument during integration at Astrium in Toulouse (F)

The integrated MetOp structural model at ESTEC in Noordwijk beginning of 2004. The consequences of this launch delay are being assessed in the context of the ESA/Eumetsat Co-operation Agreement.

Envisat

System

The system activities have focussed on:

- preparing and conducting the satellite functional tests and analysing the results
- progressing the Ground Segment Overall Verification (GSOV) tests
- defining the LEOP nominal and contingency procedures
- progressing the Commissioning Phase preparations with the calibration/ validation teams, and performing a data-circulation rehearsal involving all of the main players
- preparation of the Flight-Acceptance Review (FAR) and the Ground-Segment Readiness Review (GSRR).

Satellite and payload

All of the flight-model satellite-verification-programme goals set in February 2000 have been met. Following the successful environmental tests carried during the summer, deployments of the solar array and of the ASAR antenna were performed and confirmed the good health of these two subsystems. Retrofitting of the ASAR antenna was then undertaken. The six repaired transmit/receive tiles were integrated and an overall antenna-operation and performance-stability verification was performed, confirming overall antenna integrity with respect to reference data sets. The ASAR Central Electronics (CESA) was also retrofitted with flight PROMs carrying the updated flight software and antenna coefficients. Functional tests demonstrated the integrity of this subsystem. The second solid-state recorder was successfully integrated. Special Performance Tests (SPTs) specific to each instrument, and designed to verify the instrument's functionality and performance stability, were successfully performed.

The satellite functional tests, including the Integrated Satellite Tests (ISTs) and System Verification Tests (SVTs), constituted the most critical activities in the last quarter of 2000. Thanks to the very good progress achieved with Payload Module Computer (PMC) software validation, the full suite of ISTs and SVTs was successfully completed before Christmas, allowing preparations for the last major testing exercise, namely the Radio-Frequency Compatibility (RFC) tests, to start.

During the SVTs, the satellite was controlled from the Flight Operations Control Centre (FOCC) at ESOC in Darmstadt (NL). Sustained satellite and payload operations generated by the

The Envisat Radio-Frequency Compatibility (RFC) test configuration

ESOC mission-planning system were successfully commanded and executed for two eight-consecutive-hour periods. These tests provided very good confidence in the satellite software, particularly in terms of validation of the on-board PMC software, which had been schedule-critical, as well as enhancing confidence in the validation of the FOCC and mission planning at ESOC.

The configuring of the satellite for the RFC tests is presently in progress, including the installation of a specially built RF protective enclosure around the spacecraft. These tests, due to start at the end of January 2001, will verify electromagnetic and radio-frequency compatibility between all payload instruments and service subsystems. For this test, the complete flight model satellite, with antennas deployed, is nominally operated with the ASAR and RA-2 radars radiating, telemetry/telecommand links operating, and radiometer/spectrometer instruments in their operational receiving modes.

The AIT programme is on schedule and the Envisat launch has been confirmed for the second half of July 2001. The Ground-Segment Readiness Review (GSRR) and the satellite Flight-Acceptance Review (FAR) are scheduled for the first quarter of 2001 to allow shipment of the satellite to Kourou (Fr. Guiana) for the launch campaign by April 2001.

Ground segment
The FOS part of the ground segment is nominally on schedule and the latest SVT test results are providing high confidence in its validation. Production of the Flight Operation Procedures (FOP) has progressed well and the simulation campaigns, to train operators and to verify the correctness and completeness of the procedures, will start by early February 2001.

As far as the Payload Data Segment is concerned, version V3 integration is in progress. The ESRIN Payload Data Handling Station's formal acceptance testing is in progress. PDS version V3 is currently also being installed at the Kiruna station.

The integration of the Payload Data Control Centre (PDCC) is being finalised, with acceptance testing planned to start in January 2001.

Ground Segment Overall Validation (GSOV) is currently focusing on the validation of the mission-planning interfaces between FOS and PDS, using realistic operational scenarios to exercise the various functions.

Most of the Processing and Archiving Centres (PACs) are preparing for compatibility testing with the ESA PDS, which is due to start in May 2001.

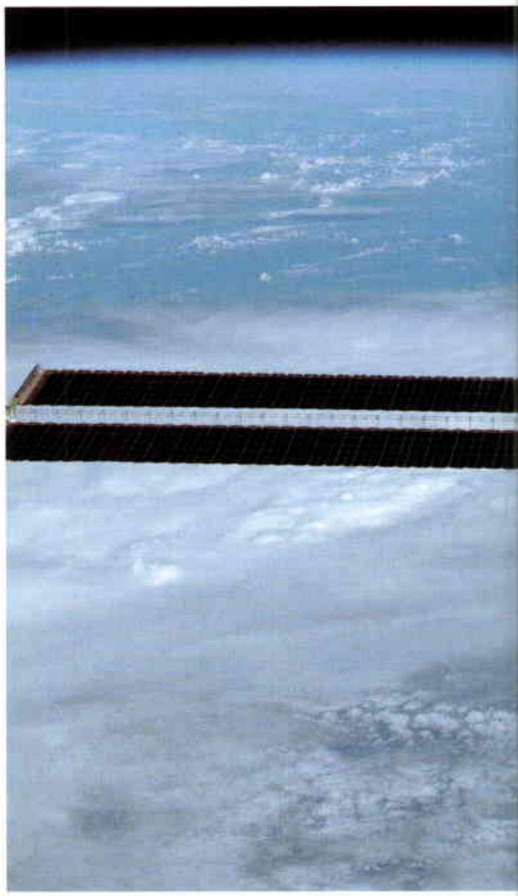
The calibration and validation groups have been very active during the latter part of 2000, and a rehearsal data-circulation campaign, involving use of the Envisat User Service Facilities, has been performed. Based on these test results and the comments received from the participants, the necessary modifications are being implemented. Workshops are being planned for spring 2001 to present and review the calibration/validation plans with participants outside the calibration/validation teams proper.

International Space Station

ISS Overall Assembly Sequence
During the reporting period there were three flights to the ISS. Two were primarily assembly flights, but the third flight, on 31October carrying the 1st ISS Expedition crew (Shepherd, Krikalev and Gidzenko), marked the beginning of a permanent human presence on the Station. The mission objectives set for each of these flights were fully achieved.

On 16 November, the Government of the Russian Federation formally decided to implement controlled de-orbiting of the Mir space station at the end of February 2001.

Columbus Laboratory
The system Critical Design Review (CDR) is underway as planned and will be completed by a Final ESA/NASA Joint Board in mid-January 2001. In parallel, independent NASA Safety Review II has been conducted. No showstoppers have been discovered, although many action items have been generated as a result of the reviews. Following successful completion of the launch and on-orbit Modal Survey Tests on the flight model, the test configuration has been disassembled and integration of the flight harnesses, ducting and plumbing has started.

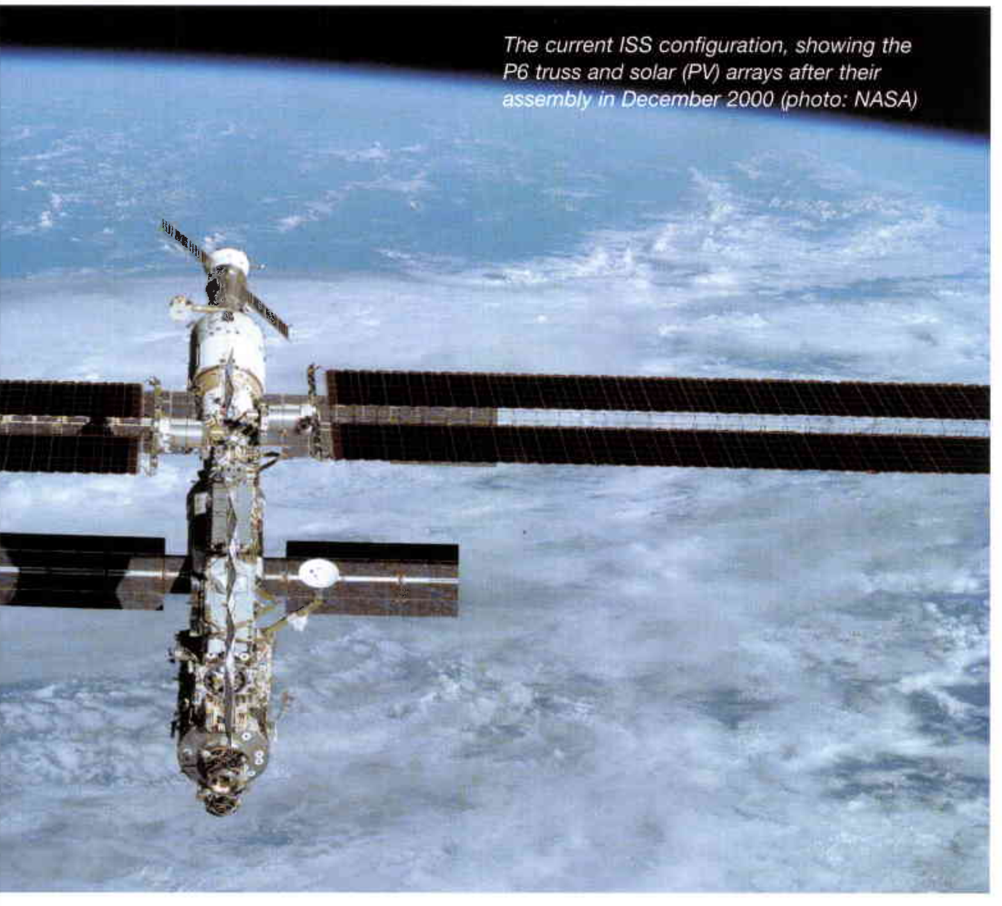


Columbus Launch Barter
Nodes-2 and -3
Pressure testing on the Structural Test Article (covering ultimate pressure and leak tests) has been successfully completed, and the Modal Survey Test campaign has been initiated.

Crew Refrigerator / Freezer (RFR)
A consolidated set of requirements for accommodation of the RFR in the NASA Habitation Module has been agreed, and industry has been authorised to proceed with Phase-B/C0, covering the detailed design, manufacture and qualification of the first RFR.

Cupola
The Cupola Structural Test Article (STA) dome and ring forgings machining has been completed and the two parts successfully welded together. Pressure testing on the STA is imminent.

Automated Transfer Vehicle (ATV)
Industry has completed an internal evaluation/recovery plan for the ATV project. Technical teams have closed various issues identified in the Preliminary Design Review (PDR) Recovery Plan and the PDR Board endorsed the results in December. An overall schedule review has been performed to successfully establish



The current ISS configuration, showing the P6 truss and solar (PV) arrays after their assembly in December 2000 (photo: NASA)

top-level planning compatible with the April 2004 launch date, and work is underway to ensure that the 'bottom up' planning is compatible with this top-level schedule. Assembly of the Dynamic Test Article is well advanced.

X-38/CRV and Applied Re-entry Technology (ART)

The first V131R drop test was completed. Owing to some failures in the control system, the vehicle did not drop as predicted and the parafoil did not fully deploy as planned. Thanks in part to the ESA Parafoil Guidance, Navigation and Control (GN&C) system, vehicle control was recovered and the flight ended successfully, albeit with quite a high landing speed but little/no resulting damage. Wind-tunnel tests are underway to determine the cause of the unpredicted behaviour.

The CRV Phase-1 Request for Quotation (RFQ) has been released to industry and the proposal has been received and is under evaluation.

Ground-segment development and operations preparation

Preparation of the Columbus (COL-CC) and ATV Control Centre (ATV-CC) System Requirements Reviews (SRR) planned for February to April 2001 has continued, as have preparation activities to support the ESA payload on Zvezda, the Global Timing System (GTS).

Utilisation

Promotion

Preparations for the global Space-Station utilisation conference 'ISS Forum 2001', to be held in Berlin in June 2001, are continuing. A workshop on the European Research Strategy for Life and Physical Sciences in Space, organised by the European Science Foundation (ESF) from 28 to 30 November, was attended by some 50 participants from both space and non-space disciplines.

Two Announcements of Opportunity (AOs) have been released, one in the area of physical sciences and the other specific to exobiology and exposure experiments for the flight of the Biopan and Stone facilities on the next Russian Foton flight.

Most of the 24 projects in the first batch for the Microgravity Applications Promotion programme have been, or are about to be, kicked-off. In parallel, activities have already been initiated for a further batch of 20 projects, finalisation of which is planned during 2001.

X-38 Vehicle V131R in free flight

Hardware development
Both the Phase-C/D contract for the European Drawer Rack and the Columbus Payload Integration contract have been negotiated, and the Phase-C/D contract for the Coarse Pointing Device was signed in October. The Bridging Phase of the European Technology Exposure Facility (EuTeF) has been closed, and the PDR-2 was successfully completed. However, the start of Phase-C/D has been put on hold due to uncertainties regarding the Express Pallet Programme.

Astronaut activities
In October, a 'Delta' Basic Training Course was started at the European Astronaut Centre (EAC) in Cologne-Porz (D) to provide updated ISS System training to experienced ESA astronauts. This is necessary to meet the certification requirements of International Space Station Basic Training.

Astronaut Claudie André-Deshays and the Head of EAC's Astronaut Division, Jean-Pierre Haigneré, were both decorated in October by the President of the Russian Federation, Mr Putin, receiving the Ordre de Courage.

Mission-preparation support is being provided at Johnson Space Center (JSC) for the STS-100/MPLM flight, scheduled for April 2001, with ESA astronaut U. Guidoni. A new flight opportunity involving member of the European Astronaut Corps – Claudie André-Deshays – has been identified on the CNES-sponsored so-called 'Taxi Flight', using the Russian Soyuz/Progress complex, to the Space Station in October 2001. Mrs André-Deshays will start astronaut training at Star City early in 2001 to prepare for this flight.

Early deliveries
MPLM Environmental Control and Life-Support Subsystem (ECLSS)
The contract with industry has been closed following the successful completion of all activities.

Data-Management System for the Russian Service Module (DMS-R)
The fault-tolerant computer complex installed in the Russian Service Module (Zvezda) has continued to perform nominally since its launch on 12 July, except for a few anomalies caused by a problem in the RSC-Energia application software. The problem, which is not mission-critical, will be fixed together with the planned software update associated with the US Lab launch and docking.

The Control Post Computer (CPC) and laptop computers were unpacked, installed and activated by the Station's first crew on 3 November. Although the CPC has operated flawlessly, some difficulties, now under investigation by RSC-Energia, have been encountered with the two laptops.

European Robotic Arm (ERA)
The ERA flight model has undergone environmental qualification testing (EMC and structural) in the ESTEC facilities. The EMC test was successfully completed and structural qualification has been partly achieved, with some static load tests still outstanding. The flight model has been re-integrated on the Flat Floor and will be used together with the engineering qualification model to continue the functional test programme. Many of ERA's subsystems have been successfully qualified; the remainder will undergo qualification reviews early in 2001. The ERA flight model will be ready for delivery to Russia towards the end of 2001, which is still consistent with the delayed Russian Scientific Power Platform (SPP) schedule.

Laboratory Support Equipment (LSE)
Hardware for the –80 degC Freezer (MELFI) has been pre-accepted for integration into the first MELFI flight unit, and agreement has been reached with NASA for the delivery of MELFI integration products. Agreement has also been reached with NASA for the Microgravity Science Glovebox (MSG) to be carried on Space Shuttle flight UF-2 in February 2002. The Hexapod Critical Design Review (CDR) has taken place successfully.

ISS Exploitation Programme
The Operations Preparation Detailed Definition Study has been kicked-off with industry, and an engineering change request for the Exploitation Programme Early Activities has also been released to industry. The evaluation and negotiation of the proposal that was subsequently received is complicated by the revised Manufacturing, Assembly, Integration and Test (MAIT) concept of the ATV development programme, which requires early procurement of a first production model. Preparation of the Request for Quotation (RFQ) for the Exploitation Programme Operations Contract has continued and it is intended to release it to industry early in 2001.

The ISS image-promotion concept has been defined, identifying target segments and phasing of promotion campaigns and Pathfinder projects for commercial utilisation have been evaluated and are close to commitment. Co-ordination with the International Partners has continued specifically in the areas of sponsorship, merchandising and advertising, and ESA's Council has approved the approach to the implementation of commercial utilisation.

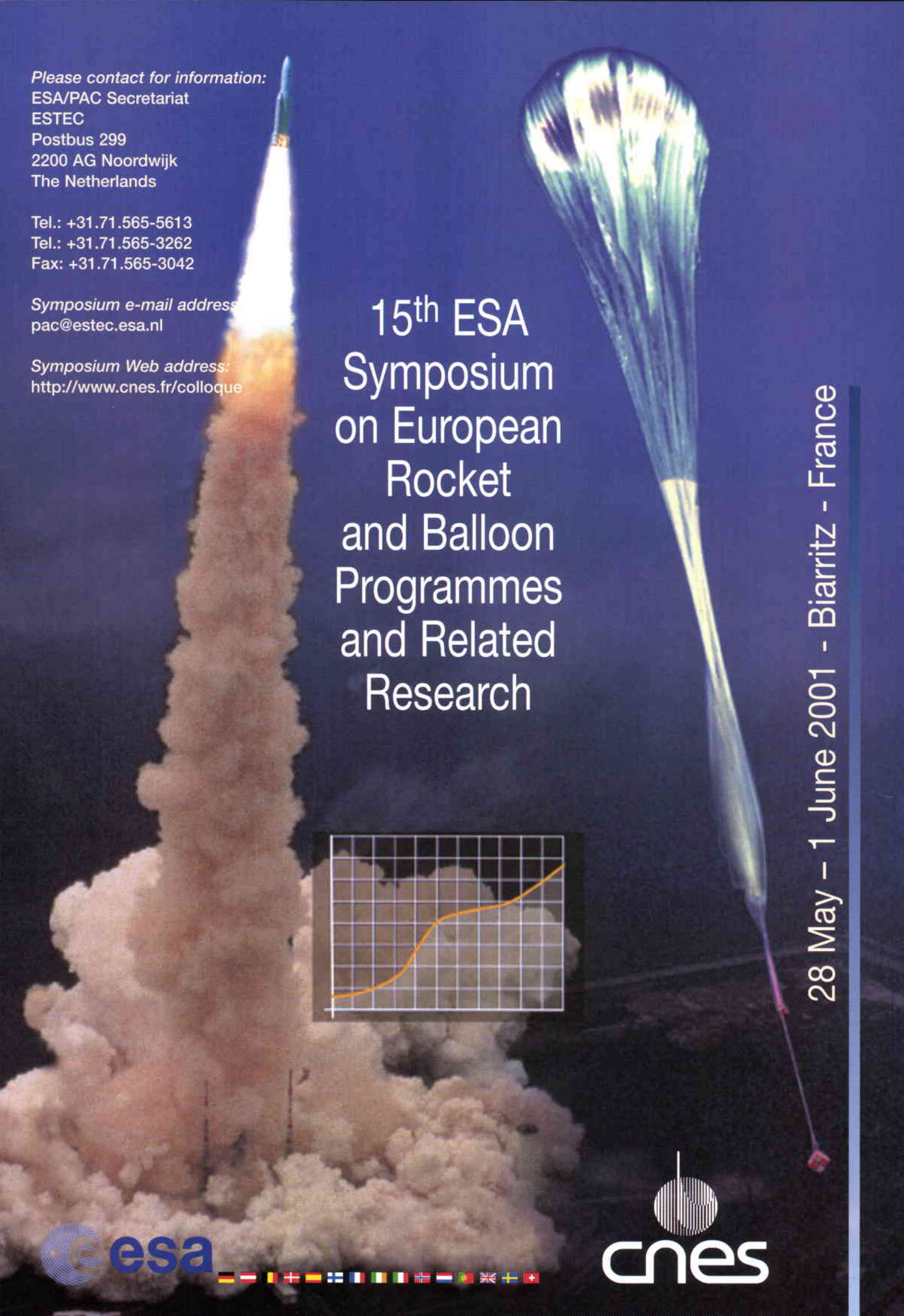
Microgravity

EMIR programmes
The 29th parabolic-flight campaign took place from 20 to 24 November 2000. A mixed payload of physical- and life-sciences and student experiments was successfully completed. The 30th ESA campaign is planned for mid-May 2001, with both physical- and life-sciences experiments onboard.

Preparations continue for Shuttle/Spacehab mission STS-107, for which ESA has a number of multi-user facilities designated for flight covering both the life- and physical-sciences. That mission is scheduled for August 2001.

Microgravity Facilities for Columbus (MFC)
Testing of the Biolab engineering model started in December, and manufacture of the flight model will start in May 2001. Some delays have occurred in Materials-Science Laboratory (MSL) and Fluid-Science Laboratory (FSL) subsystem manufacturing. Their Critical Design Reviews will be completed by end-April 2001. The MSL using Electro-Magnetic Levitator (MSL-EML) technology Phase-A/B will start early in 2001.

An agreement with the Canadian Space Agency (CSA) for the provision of the Microgravity Vibration Isolation System (MVIS) for the Fluid-Science Laboratory (FSL) has been concluded, and the provision of Cardiolab by CNES/DLR for the European Physiology Module (EPM) has been approved.



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15th ESA Symposium on European Rocket and Balloon Programmes and Related Research

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In Brief

ESA's Evolution as Envisaged by The Three 'Wise Men'

As reported in ESA Bulletin No. 103 (August 2000 issue), in March 2000 ESA's Director General, Antonio Rodotà, asked a committee of three 'Wise Men' to provide him with an independent assessment of the future evolution of the Agency. The committee was made up of Carl Bildt (Chairman), former Swedish Prime Minister and UN Envoy to the Balkans, Jean Peyrelevade, President of Crédit Lyonnais, and Lothar Späth, Chief Executive Officer of Jenoptik, together representing a formidable combination of high-level political, economic and industrial expertise.

From left to right at the Paris Press Conference: Lothar Späth, Jean Peyrelevade, Carl Bildt, Antonio Rodotà and Jean-Jacques Dordain

The three examined the organisation of the public space sector in Europe and the role of ESA in that sector, the institutional relationship between ESA and the European Union, and the associated potential for synergies between civil and defence programmes. They also analysed the potential for enlargement of ESA to include more countries, and the market opportunities available to ESA Member States in the space domain.

On 9 November, commensurate with the calendar for the European space strategy being prepared jointly by ESA and the European Union, the Wise Men presented their recommendations at a Press Conference at the Agency's Headquarters in Paris, hosted by Antonio Rodotà and Jean-Jacques Dordain, ESA's Director of Strategy and Technical Assessment.

ESA and the European Union Adopt a Common Space Strategy

On 16 November, Ministers representing the 15 ESA Member States, gathered in Brussels for an Extraordinary Meeting of the ESA Council, adopted a Resolution that accompanies a joint ESA/EC document on a European Strategy for Space (the Wise Men's Report – see previous news item). A parallel Resolution, based on the same document, was also endorsed by the European Research Council in Brussels on the same day.

This was the first time that the Councils of ESA and the European Union had met on the same date and in the same place to adopt Resolutions that will constitute a common framework within which all European players involved in space activities will develop their respective plans of action.

Further information on the content and availability of the Report can be obtained from:
ESA Communication Department
Tel: +33 (0) 1 53 69 7155
Fax: + 33 (0) 1 53 69 7690

⇨*"Through these resolutions, European space policy takes a first step into a new phase in which space systems become an integral part of the overall political and economic efforts of European States – whether members of ESA or the EU – to promote the interests of European citizens"*, said ESA's Director General, Antonio Rodotà.

The European Strategy for Space identifies three lines of action:
a. strengthening the foundations for space activities
b. enhancing scientific knowledge
c. reaping the benefits for society and markets.

The first line encompasses broadening space technology and guaranteeing access to space through a family of launch vehicles. The second sees Europe continuing to pursue cutting-edge themes in space science and space contributions to the understanding of our planet's climate. It includes human spaceflight and optimisation of the use of the International Space Station as an infrastructure for European research in all disciplines of space science. The third line of action has the objectives of seizing market opportunities and meeting the new demands of our society. It has a bearing on satellite communications and the information-technology sector, satellite navigation and positioning (Galileo), and systems monitoring the Earth for environmental and security purposes. This is where close cooperation between ESA and the EC will be most instrumental in putting space systems at the service of European policies responding to citizen's expectations.

The European Space Strategy also covers industrial aspects and pays specific attention to Small and Medium-sized Enterprises (SMEs). In the document, public/private partnerships are seen as a model for committing the public sector, along with the complete industrial chain, to an operational project.

The two Resolutions adopted on 16 November endorse the setting up of a cooperative structure that will bring together the ESA Executive and the European Commission. An interim high-level joint Task Force is being set up to make proposals for the continuing development of the European Space Strategy and its implementation.

In addition to being a partner in the setting up of joint programmes responding to political initiatives of the European Union, ESA will act as the implementing organisation for the development and procurement of the space and ground segments associated with such initiatives.

The Ministers invited ESA's Director General to prepare Programme Proposals on the basis of this strategy and to submit them to the ESA Council Meeting at Ministerial Level scheduled for November 2001.

Ariane-4 – 100 Launches and Counting!

Not so much an anniversary, more a consecration. On 29 October Ariane-4 carried the Europe*Star-1 communications satellite safely into Geostationary Transfer Orbit (GTO) with the precision that has become Ariane's hallmark. So much so in fact that the lift-off could have gone almost unnoticed, but for the fact that this was the 100th launch of the Ariane-4 generation of vehicles. For this particular launch (V134), the Ariane-44LP was equipped with two solid-propellant and two liquid-propellant strap-on boosters.

Just two weeks later, on 15 November, Ariane was at work again, lifting off from the Guiana Space Centre in Kourou, French Guiana, to put the PAS-1R telecommunications satellite into GTO, together with a radio-amateur satellite, AMSAT P-3D, and two technology microsatellites. On this flight (V135), however, it was an Ariane-5 launcher providing the ride.

The 136th Ariane launch (V136) took place successfully less than a week later on 22 November 2000. This time another Ariane-4 – a 44L fitted with four liquid-propellant strap-on boosters – put the Anik-F1 telecommunications satellite into GTO for Canadian operator Telesat.


V134 Ariane-4 No. 100

The next Ariane-4 launch (V137), originally scheduled to lift the Eurasiasat-1 telecommunications satellite for Turkey into orbit on 8 December, was subsequently postponed until the new year.

The 138th Ariane launch (V138) took place successfully on 20 December. This time, another Ariane-5 launcher (V508) placed the Astra-2D and GE-8/Aurora-III telecommunications satellites safely into orbit for GE Americom (USA), along with the LDREX experimental payload belonging to the Japanese Space Agency (NASDA).

Ariane-4 was in action again on 8 February (V139). This time an Ariane-44L equipped with four liquid strap-on boosters lifted-off from Kourou to launch two European military communications spacecraft into GTO – Sicral for Italy and Skynet-4F for the UK.

The next Ariane launch, an Ariane-5, is currently scheduled for Friday 2 March, carrying two more telecommunications satellites, Eurobird and BSAT-2A.

Portugal Officially Fifteenth ESA Member State

On 14 November 2000, Portugal deposited its instrument of accession to the ESA Convention with the French Government, thereby completing the legal formalities making it the fifteenth Member State of the European Space Agency.

Memorial Symposium in Honour of Prof. Henk van de Hulst

Professor Henk van de Hulst, who died on 21 July 2000 at the age of 81, was not only one the greatest Dutch astronomers of the last 150 years, but also one of the founding fathers of ESA – and indeed in no small way responsible for ESTEC being situated in Noordwijk (NL). To mark his contribution to ESA and ESTEC, the ESA Science Directorate organised a Memorial Symposium in his honour at ESTEC on 6 November, which was attended by many eminent Dutch and international scientists, as well as Prof. van de Hulst's widow and family.

The afternoon began with the planting of a chestnut tree just outside the ESCAPE building by Mrs van de Hulst. Henk Olthof (ESA) explained that once the roots of the tree are firmly settled, a bench will be built around it so that the staff at ESTEC can enjoy its shade – something Henk van de Hulst himself would certainly have approved of.

The Symposium proper was held in the ESTEC Conference Centre with Prof. van de Hulst's central role in the setting up of ESRO and ESA as the theme. Prof. Harm Habing from Leiden University gave the opening talk on 'The Self-evident Importance of Quality: Some Remarks on the Life of Henk van de Hulst'. In 1958, Prof. van de Hulst became the first President of COSPAR, then a new international organisation for the peaceful exploration of the Universe, out of which came the European Space Research Organisation (ESRO), and later ESA. This was reflected in the talk given by Prof. Reimar Lüst on 'Henk van de Hulst and the Build-up of European Co-operation in Space Research'. Prof. Sir Hermann Bondi spoke on the 'Changes in Governmental Attitudes to Space' during this period.

The emphasis then moved to Prof. van de Hulst's scientific work with ESRO and ESA – Prof. Livio Scarsi (Palermo) explained the pivotal role played by Henk van de Hulst in the Cos-B project, and Prof. Malcolm Longair (Cambridge) discussed Prof. van de Hulst's work on the Hubble Space Telescope.

The day was rounded off with a dinner in the ESTEC Restaurant, where Prof. Roger Bonnet, ESA Director of Scientific Programmes, gave the After-Dinner Speech, reflecting on how Prof. van de Hulst's work has paved the way for a number of the Science Directorate's future programmes.

Mrs van de Hulst planting the chestnut tree outside ESCAPE

Prof. Reimar Lüst addressing the family and assembled guests

Agreement Signed with Greece

On 17 January, ESA's Director General, Antonio Rodotà, signed a framework Cooperation Agreement with the Greek Minister for Development, Mr Nikos Christodoulakis, in Athens. The areas considered as offering potential for future cooperation include: space science, Earth-observation research and applications, telecommunications, satellite navigation, microgravity research, and ground-segment engineering and utilisation. In the next phase, projects of mutual interest will be identified and they will be defined in specific implementing arrangements once the Cooperation Agreement enters into force.

Green Light for Small Launcher and Advanced Solid Booster

The Vega Small-Launcher Development Programme and the P80 Advanced Solid Propulsion Stage Demonstrator Programme were formally approved on 15 December by the Participating States. Belgium, Italy, the Netherlands, Sweden and Switzerland decided (with Spain's decision still pending) to proceed with full development of the Vega small launcher.

Developed and manufactured by European industry, Vega will complete the range of European launch services by offering on the international market a competitive vehicle for small payloads of up to 1500 kg (primarily polar Earth-orbiting missions at around 700 km altitude).

Belgium, France, Italy and the Netherlands also decided to finance the P80 Advanced Solid Propulsion Stage demonstrator. This development programme is designed to:
- demonstrate most of the technologies required to improve Ariane-5 solid-propellant booster performance and competitiveness
- develop and ground-qualify an advanced-technology first stage for the Vega launcher.

The development milestones for the P80 are consistent with the schedule for developing Vega, whose maiden flight is planned for end-2005.

Envisat Nearing Launch

A Media Information Day at ESTEC in Noordwijk (NL) on 1 February provided the last opportunity for the press and media to take a look at the impressive 10 metre-tall Envisat Earth-observation spacecraft before launch. All ten instruments were installed on the spacecraft and the large Advanced Synthetic Aperture Radar (ASAR) antenna was deployed.

The leading international scientists involved in the design of Envisat's instruments, top managers from the Astrium industrial consortium that has built the spacecraft, and the ESA Project Team that has managed the satellite's design and construction, gave comprehensive background briefings on the mission objectives for this unique spacecraft, its sophisticated instruments, and the work scheduled between now and the start of its operational life in polar orbit.

Envisat, the largest and the most sophisticated European Earth-observation satellite ever built, will complete its final test sequences at the ESTEC Test Centre over the coming weeks before being shipped to Kourou in French Guiana for the three-month campaign leading up to its planned Ariane-5 launch in the second half of July.

The next issue of the ESA Bulletin – No. 106, May 2001 issue – will be dedicated to the Envisat mission.

ESA Satellite Supports Rescue Efforts in El Salvador

Responding quickly to support rescue efforts converging on El Salvador, member space agencies of the International Charter on Space and Major Disasters dispatched their Earth-observation satellites to capture images of the devastation caused by the mid-January earthquake. The satellites involved were ESA's ERS-2 radar satellite, Canada's Radarsat-1 satellite, and France's SPOT optical series, and together they provided the emergency rescue crews with support based on images captured day and night and in all weather conditions after the quake. Up-to-date maps and information obtained from these specially acquired images and existing archived images were forwarded to the rescue authorities as soon as they were available. Satellite positioning and operation and image capture were coordinated by the International Charter partners.

ERS-2 circles the Earth at a height of 800 km and completes an orbit every 100 minutes, crossing both poles and covering the entire globe in just three days. It will be followed this year by ESA's new-generation environmental satellite, Envisat, due to be launched in July.

The International Charter on Space and Major Disasters is the expression of a collective resolve to put space technology at the service of rescue authorities in the event of major disasters. Its current signatories are ESA, the French space agency (CNES) and the Canadian Space Agency (CSA). The Charter, set up in the context of the United Nations UNISPACE III Conference in 1999 and in force since 1 November 2000, remains open for signature by other space agencies and satellite operators anywhere in the world.

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ESA Takes Further Steps in Caring for the Earth

At the end of November, the Agency took further steps to enhance Europe's capacity to predict the evolution of the Earth's environment, under the influence of both natural variability and man's activities: it selected five new candidate Earth-observation space missions to undergo preliminary feasibility studies. This move reflects the importance of Earth observation from space in providing the globally coherent data that are the essential complement to ground-based, airborne and shipborne measurements.

To be at the forefront of these activities, in 1999 ESA launched the Living Planet Programme, which funds many of the Agency's Earth-observation activities, including the Earth Explorer missions. These are research/demonstration missions intended to advance our understanding of the Earth's environment, which can also be used to demonstrate new observing techniques. There are two complementary types of Earth Explorer Mission:

- *Earth Explorer Core Missions*, which are large ESA-led research/demonstration missions
- *Earth Explorer Opportunity Missions*, which are smaller research/ demonstration missions that are not necessarily ESA-led.

In June 2000, ESA issued a Call for Ideas for the next Earth Explorer Core Missions. Ten proposals were received, spanning the interests of the whole Earth-science community and involving some 180 scientists from ESA Member States and Canada, plus countries such as Japan and the USA. The ten missions proposed were:

- ACE – atmospheric chemistry explorer
- CARBOSAT – a mission dedicated to monitoring the carbon cycle
- CLOUDS – a cloud, aerosol, radiation and precipitation explorer
- EarthCARE – Earth clouds aerosol and radiation explorer
- GeoSCIA++ – a passive remote-sensing experiment assessing the impact of regional tropospheric pollution on global change
- LICODY – laser interferometry experiment for core and ocean dynamics
- SPECTRA – surface processes and ecosystem changes through response analysis
- WALES – water-vapour lidar experiment in space
- WATS – water vapour and wind in atmospheric troposphere and stratosphere
- W_WISE – atmospheric windows and clouds, water vapour, ozone, carbon dioxide, infrared spectral radiation explorer.

The ten proposals were evaluated by the Earth Sciences Advisory Committee, who assessed them and selected five for preliminary studies, but also made specific recommendations to ESA for furthering all ten missions. The five proposals retained were (in alphabetical order): ACE, EarthCARE, SPECTRA, WALES and WATS.

On 20 November 2000, ESA accepted the recommendations of the Earth Sciences Advisory Committee and work has now started on all five missions in anticipation of a Workshop to be held in Granada (E) in October 2001. During that meeting all five missions will be presented to the user community for comment and reaction as a prelude to their further assessment, to decide which should go forward for further studies and implementation.

These proposals follow four other studies that were completed in late 1999 and led to the selection of the first two Earth Explorer Core Missions to be implemented: the Gravity Field and Steady-State Ocean Circulation Mission, which will help to advance knowledge of the Earth's interior structure and provide a much better reference for oceanographic and climate studies, and the Atmospheric Dynamics Mission, which will provide the first direct observations on a global scale of atmospheric wind profiles over the depth of the atmosphere.

In parallel with its work on the Earth Explorer Core Missions, ESA has also initiated considerable activity on the Earth Explorer Opportunity Missions front. A Call for Proposals in July 1998 resulted in 27 proposals, which were subjected to peer review by the Earth Sciences Advisory Committee and consideration by the Earth Observation Programme Board.

The first Earth Explorer Opportunity Mission selected for launch is Cryosat in 2003, to be followed by SMOS 2005. Cryosat will measure the variations in the thickness of the polar ice sheets and the thickness of floating sea ice. Its data will be used to study the mass balances of the Antarctic and Greenland ice sheets, to investigate the influence of the cryosphere on global sea-level rise and to provide important observations of sea ice thickness for use in Arctic and global climate studies. Cryosat is scheduled for launch in 2003. SMOS is intended to demonstrate the observation of two key Earth-system variables, namely soil moisture over land and salinity over oceans, to advance the development of climatological, meteorological and hydrological models. It should also provide new insights into snow and ice structure, so helping to advance our understanding of the cryosphere. esa

Compatibility Testing of ATV Transponders Successfully Achieved

An important milestone in the development of the communications system for ESA's Automated Transfer Vehicle (ATV) was achieved at the end of 1999 with the successful compatibility testing of the Vehicle's S-band transponders by Alcatel Espacio (E). The objective of this test, performed with the participation of ESA, NASA and Astrium SAS representatives, was to verify the transponder's ability to communicate with the Ground Control Station via the TDRSS data-relay satellite network.

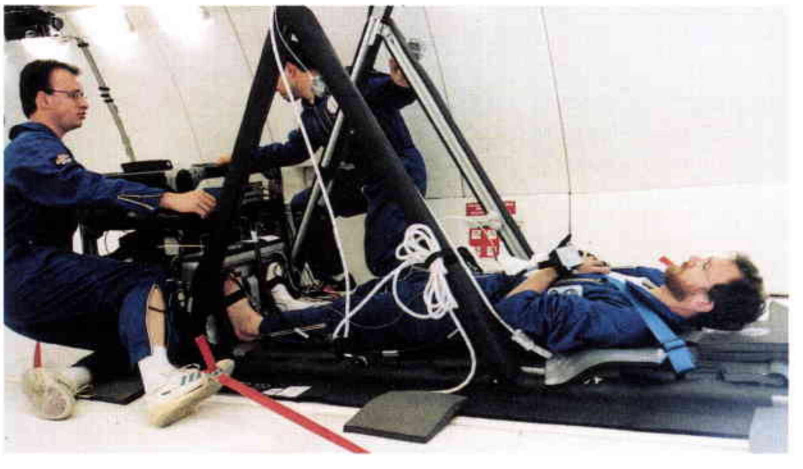
The test involved sending data and ranging information from the TDRSS transponder located at Alcatel Espacio's laboratory in Madrid, via the TDRSS satellites, to the Ground Control Station located in White Sands (USA), and vice-versa. All of the tests were made simulating normal operational modes, making it possible to check and confirm that the TDRSS transponder receives and demodulates the signals as required, as well as that the signals sent by it are properly received at the Control Station.

The work performed under ESA contract by Alcatel Espacio in the design, development, manufacture and testing of this new equipment has positioned the company as the sole European supplier for TDRSS S-band-compatible transponders. esa

Scientists, School Teachers and Students Conduct Physical- and Life-Sciences Studies on ESA Parabolic Flights

ESA's 29th Parabolic-Flight Campaign was conducted from Bordeaux-Mérignac airport in France, from 21 to 23 November, using the specially adapted 'Zero-g' Airbus A300. This particular campaign included 11 different experiments: four in physical sciences, four in life sciences, two experiments proposed by students and one serving educational purposes for the general public. 30 microgravity-simulating parabolas were flown by the A300 on each of the three days.

Parabolic flights are practically the only means on Earth of reproducing weightlessness with human operators on board. During a parabolic flight, the Airbus pilot – flying at an altitude of approximately 6000 m, usually in a specially reserved air-corridor above the Gulf of Gascogne – first performs a nose-up manoeuvre to put the aircraft into a steep climb (7600 m). This generates an acceleration of 1.8g (1.8 times the acceleration due to gravity on the ground) for about 20 sec. Then, the pilot throttles back to inject the aircraft onto a parabolic flight path. The plane continues to climb until it reaches the apex of the parabola (8500 m) and then starts descending. This condition lasts for about 20 sec, during which time the passengers in the cabin float in the weightlessness resulting from the aircraft's free fall. When the angle below the horizontal reaches 45°, the pilot opens the throttles again and pulls the aircraft up to return to steady horizontal flight. These manoeuvres are repeated 30 times per flight.



With Europe and its international partners now building the International Space Station, on which research and experiments will be carried out for the next 15 years, parabolic flights are crucial to the preparation of experiments, equipment and astronauts, and allow scientists to have their experiments tested before they are actually flown on a space mission.

The four physical-sciences experiments were related to fluid physics and investigated electrostatic effects in boiling liquids, particle motion in aerosols, annular liquid flows and plasma states:

- Study of the effect of an imposed electrostatic field on pool boiling heat transfer and fluids management, provided by Prof. W. Grassi and Dr P. Di Marco (Univ. of Pisa, I).
- Three-dimensional tracking by digital holography of particle motion in non-equilibrium aerosols, provided by Prof. J.C. Legros and Dr A. Vedernikov (Univ. of Brussels, B) and Prof. F. Prodi (ISAO-CNR, Bologna, I).
- Annular flow film thickness and pressure drop measurements in microgravity, provided by Prof. K. Rezkallah (Univ. of Saskatchewan, CDN) and Dr C. Colin (Inst. of Fluid Mechanics, Toulouse, F).
- Preliminary tests for the International Microgravity Plasma Facility, provided by Prof. G. Morfill and U. Konopka (Max-Planck Institute, Garching, D).

In life-sciences, two physiology experiments studied the cardiac system and two biology experiments investigated plant gravitaxis and cell and particle motion by ultra-sound:

- An assessment of the feasibility and effectiveness of a method of performing cardiopulmonary resuscitation during microgravity, provided by S. Evetts (School of Biomedical Sciences, King's College London, UK) and Prof. T. Russomano (Univ. do Rio Grande do Sul, Porto Alegre, Brazil).
- Acute heart response to weightlessness conditions during parabolic flights, provided by Prof. A. Aubert, Dr. F. Beckers and Dr. D. Ramaekers (Univ. of Leuven, B).
- Investigation of physiological parameters of gravitaxis in Euglena gracilis, provided by Prof. D-P. Häder (Univ. of Erlangen-Nuremberg, D).
- Ultrasonic particle and cell manipulation in microgravity, provided by Dr. L.G. Briarty (Univ. of Nottingham, UK).

Two experiments were proposed by students and selected after two international competitions, one in a medical field and the other in space technology:

- Pulse transit time for the non-invasive determination of arterial wall properties, provided by P.F. Migeotte, T. Dominique and R.C. Sá (Univ. of Brussels, B).
- Globular Cooking Facility, provided by S. Podhajsky and G. Grillmayer (Univ. of Stuttgart, D).

The eleventh experiment was flown for promotional and educational purposes. Several secondary-school teachers, attached to the Euro Space Centre in Transinne, Belgium, conducted simple classroom experiments in physics and chemistry, emphasizing the role of gravity's absence during parabolic flights. These experiments were recorded and will be shown later to the general public and schools attending space classes at the Centre to promote early awareness of the characteristics and possibilities of the space and microgravity environment. Springs, yo-yos, gyroscopes, magnetic balls, pendulums, and simple foods (sweets, bananas, grapes) in microgravity will be used to explain their different behaviours in weightlessness and the difficulties that astronauts encounter in their everyday lives in orbit.

ESA's next parabolic-flight campaign is scheduled for May 2001 and will carry a mixed complement of life- and physical-sciences experiments, again including student-proposed experiments.

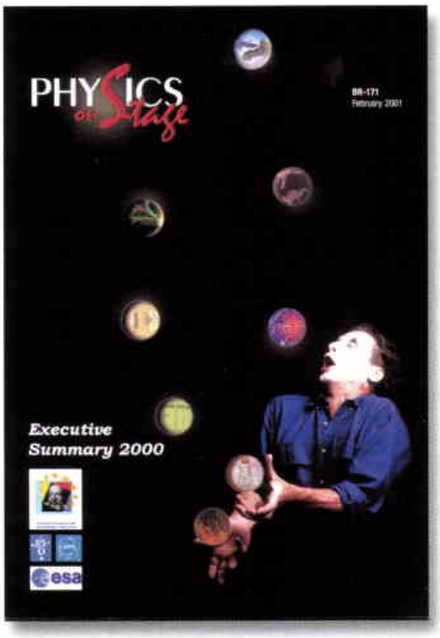
More information on ESA parabolic flights can be found at:
www.estec.esa.nl/spaceflight/parabolic

The 'Physics on Stage' Festival

A screeching noise emanates from one of the 22 stands at the fair: the Irish delegates are demonstrating with a violin bow, a metal plate and some sand, how sound waves propagate through a metal plate. New patterns form in the sand depending on where the bow is struck. A few metres away, in CERN's main auditorium, 400 physics teachers and physics popularisation experts are tossing small wooden blocks into the air to find out about which axis they rotate in a stable manner. Two young Germans – one dressed as a talk-show host, the other as a confused scientist – have captured their audience's attention with their performance. A few doors down the hall, a workshop group of some 30 delegates are sitting deep in discussion over how physics should best be taught in secondary schools to motivate the youth of today to become the scientists and engineers tomorrow.

'Physics on Stage' took place at CERN in Geneva from 6 to 10 November and was a great success. It was the brainchild of three international organisations: CERN (European Organisation for Nuclear Research), ESA, and ESO (European Southern Observatory). It was a unique initiative that had a significant impact on the public understanding of physics and on the teaching of physics in Europe's schools. The European Commission supported the project as part of its 5th Framework Programme.

The five-day festival in Geneva was the climax of the year-long 'Physics on Stage'



ESA BR-171, February 2001

programme and it brought together over 400 experts on physics teaching and popularisation, including high-school physics teachers, university lecturers and researchers, curriculum developers and scientific and educational journalists. Delegates from 22 European countries presented their ideas and techniques for making physics a fascinating subject for schoolchildren and the public alike. The range of ideas was as wide as it could be – experiments with electricity, light, sound, speed, chaos theory, toys, free fall and the Big Bang – and the ways in which these ideas were presented were highly creative and original.

The festival in Geneva was the culminating event in a year of wide-ranging activities in each of the participating countries. The national programmes organised by the National Steering Committees played a crucial role in the 'Physics on Stage' programme.

Thanks to the enthusiasm and commitment of all delegates, the main objectives of 'Physics on Stage' have been successfully realised:
- A debate on physics teaching amongst educators, the media and politicians has been catalysed.
- The most effective and innovative methods for teaching physics have been identified, incorporating demonstrations, lectures, innovative teaching materials, hands-on-activities, theatre, video, web applications, etc.

A colourful highlight of the 'Physics on Stage' festival was the physics teaching fair, where all countries had the opportunity to present their methods, ideas, experiments, books, and brochures. It was buzzing with life, sound, conversation and surprises at every turn. It was so much of a real fair that there were even gingerbread hearts (stamped, of course, with $E = mc^2$!) and heart-shaped helium balloons proclaiming 'Physics is at the Heart of Everything'.

The French performance

The Physics Fair

The Dutch presentation

The Plenary presentations and special performances were all well-attended

Workshop group

Other important components of the festival were the Plenary presentations, which were of outstanding quality, and the special performances, which brought theatre and physics to the stage hand in hand, and more than once made the audience roar with laughter or go silent with astonishment.

The visit of the Directors General of ESA, ESO and CERN and the active involvement of the European Commissioner for Research, Dr. Philippe Busquin, during the Festival were an important source of motivation and inspiration for the educational community, as well as for the organising team. The European Commission and the European Science Organisations demonstrated strong political support to the 'Physics on Stage' Festival and its outcome.

Throughout the Festival, participants met in small groups to discuss various themes close to the heart of physics education. These Workshops, with titles such as 'Mapping the Crisis', 'Women in Physics' and 'Curriculum Developments', provided a forum for the delegates to suggest actions that could be taken to improve the current state of physics literacy in Europe. From a total of 74 recommendations emanating from 'Physics on Stage', the present crisis in the teaching of physics has been clearly identified:

This crisis will have a major impact on the cultural identity of Europe. A frightening trend is underway in terms of the lack of interest in physics among the general public (particularly young people) and the diminishing number of physics teachers in Europe. Together, these points indicate that, if action is not taken now, Europe will enter a dark age of knowledge.

ESA, ESO and CERN had discussions in Geneva with the educational community regarding what role the three European organisations could play in the future of physics education.

To close the Festival, there was a voting session involving all participants to establish priorities in the list of recommendations. The results of this vote represent a good statistical assessment of the will of the European physical teaching community.

It was a wonderful week: many contacts were established across European frontiers and the 'Physics on Stage' participants are eagerly looking forward to putting some of the new ideas into practice.

Clovis de Matos, Helen Wilson, Barbara Warmbein

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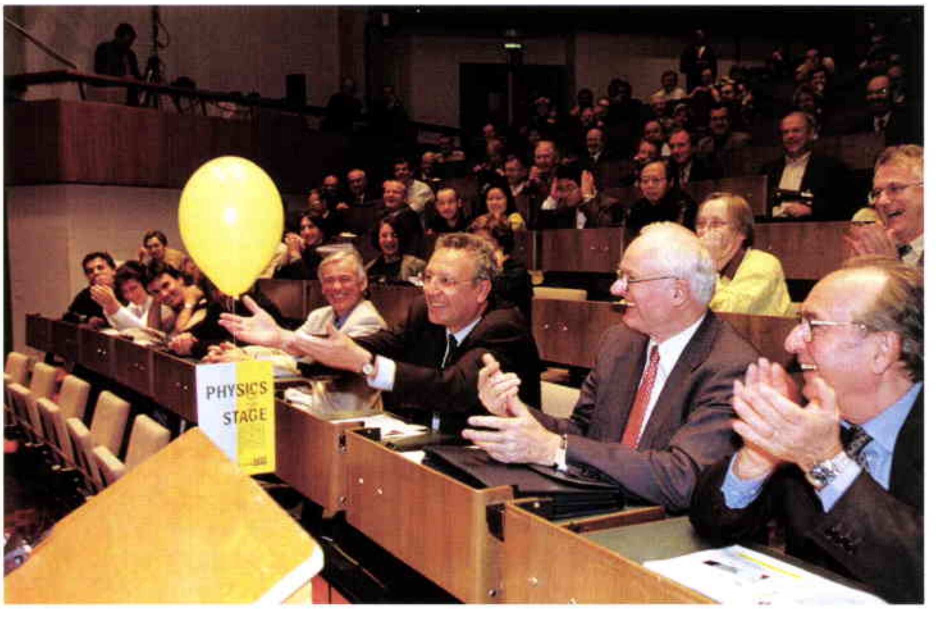
For more information about the 'Physics on Stage' project, visit the following web sites:
www.estec.esa.nl/outreach/pos
or
www.cern.ch/pos



Entering into the spirit of 'Physics on Stage': Dr. Philippe Busquin (centre)

ESA Helping to Develop the Next Generation of the World Wide Web

With the World Wide Web (WWW) being used by more and more people, its limitations in dealing with huge amounts of data are becoming ever more apparent. Its successor, 'The Grid', should comprise computing resources in which super-computers, processor farms, disks, major databases, informatics, collaborative tools and people are linked by a high-speed network.

The DataGrid initiative originated in the framework of the European Summit in Lisbon, Portugal, in March 2000, when the idea of a dedicated network for European science applications research was put forward. The objective is to develop and demonstrate an informatics architecture geographically distributed throughout Europe with high-data-rate transmission links. The project was submitted to the European Union in May for funding through its Fifth Framework Programme for Research and Technological Development. Funding of 9.8 MEuro over three years was authorised at the end of December and a contract has been awarded to CERN as project leader.

ESA, through its ESRIN establishment in Italy, is one of six partners* in the DataGrid Project and will demonstrate use of the distributed infrastructure for Earth-observation applications. The novel distributed-computing environment, specifically designed to analyse and move vast amounts of data, will be developed and deployed using emerging technologies and 'open source' code to create a new worldwide data and computational facility on a scale not previously attempted. The resources will be made available transparently to a wide community using new 'middleware' between the computer operating systems and applications that enables and facilitates collaborative working in new ways. This 'middleware' – to be developed in collaboration with some of the leading centres in Grid technology, thereby leveraging practice and experience from existing Grid activities in Europe and elsewhere – will subsequently be made available to industry, potential partners and research bodies.

The DataGrid Project will provide scientists around the world with flexible access to unprecedented levels of computing resources, and will therefore usher in a new era of e-science. It will enable next-generation scientific exploration using shared databases of up to a petabyte (equivalent to a pile of CD-ROMs standing over a kilometre high), across widely distributed scientific communities. International connectivity will be achieved through an advanced research networking infrastructure, which is the subject of another EC initiative.

Further information can be found at:

The DataGrid website:
www.cern.ch/grid
The DataGrid Earth Observation Science Application:
http://tempest.esrin.esa.it/~datagrid

* The other partners are: CERN (CH), CNRS (F), INFN (I), NIKHEF (NL) and PPARC (UK). esa

Opening Event of ESA 'Mars City Competition'

Ex-astronaut Wubbo Ockels arrived at his old primary school in Brielle, Holland, in a school milk truck with the very first 'Mars City Competition' package on Friday 2 February.

Over 2000 of these packages have been delivered to Dutch primary schools with their Melkunie school milk. The packages contain a Space Kwispel game, developed by ESA's Education & Outreach Office in collaboration with the Dutch toy company 'King International' and ESA Publications Division. Children 10 -12 years old will use the Space Kwispel in their search for information to help them design and build a Mars City from school milk cartons.

The children in Meester Eewoutschool in Brielle built an enormous, glittering and inventive Mars City from the school milk cartons that they had been collecting. The model, which they had just two hours to complete, included a meteorite gun for protection, oxygen generators, a greenhouse, a burger and pizza café, and even a soccer pitch for the future soccer team, the 'Mars Maniacs'.

Other classes from schools around Holland will submit photographs of their 'Mars City', along with design data, in order to enter the competition. The winning team will be treated to space-related prizes and a 'Space Day' at ESTEC to see satellites and astronauts first hand and to show off their design work to real space scientists and engineers. The competition ends on 16 March.

For more information, visit:
www.estec.esa.nl/outreach/kwispel

or contact:
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Our Galaxy – In Three Dimensions !

Measuring the distances to the stars accurately is one of the great challenges that continues to face experimental astronomy. Hipparcos was an original and highly successful scientific mission, conducted by ESA in collaboration with European space scientists between 1981 and 1997. Its goal was to create a map of the stars with unprecedented precision.

New techniques allow the projection of the sky in three-dimensions, precisely as measured by Hipparcos. On 8 February, Michael Perryman of ESA's Space Science Department showed some of the 3D results to a packed audience in the Newton Conference Auditorium at ESTEC in Noordwijk (NL). Using an elaborate projection system based on polarised-light images, the audience was able to view a number of 3D movies using polarising glasses. They could see how stars travel through the Galaxy over intervals of millions of years, observe the space distribution of some of the recently discovered extra-solar planets, and follow the passages of stars whose space motions brought them close to the Sun in the geologically recent past. Other sequences illustrated the new insight that the Hipparcos data are giving into the details of our Milky Way Galaxy, for example its age, three-dimensional structure, and its possible formation process.

The GAIA Cornerstone science mission, recently accepted by ESA for launch a decade from now, will build on the results of Hipparcos to map the three-dimensional structure of more than one billion stars extending throughout our Galaxy.

Dr. Michael Perryman

The ESTEC audience in their 3D polarising glasses

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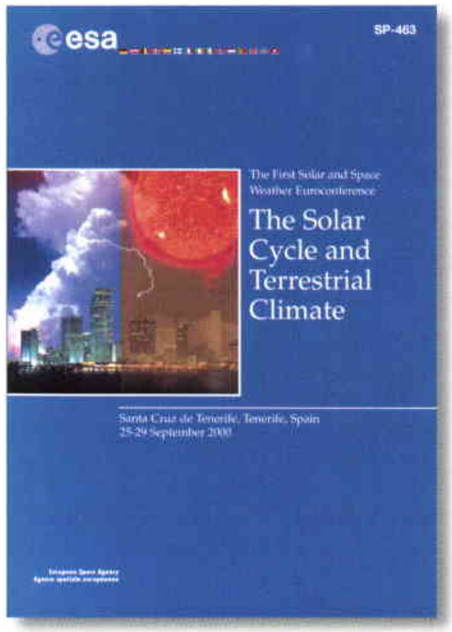

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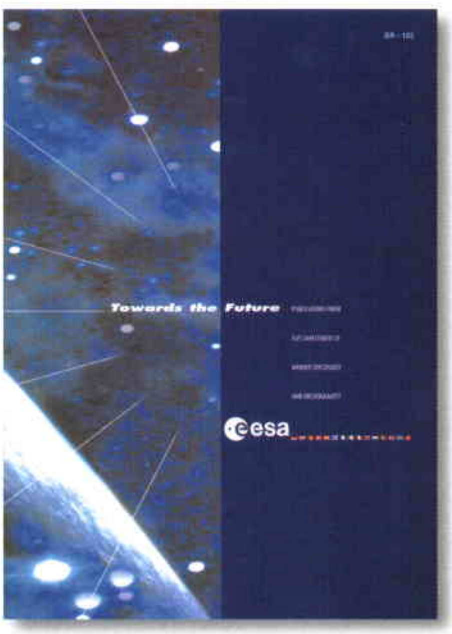

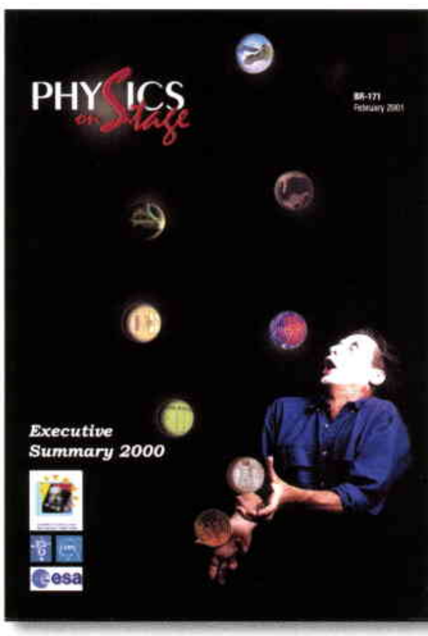

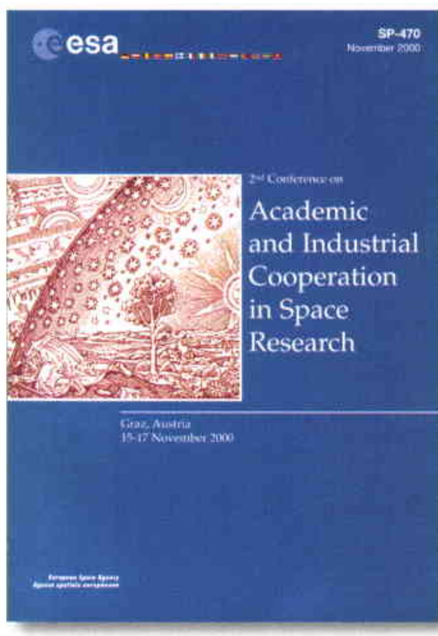

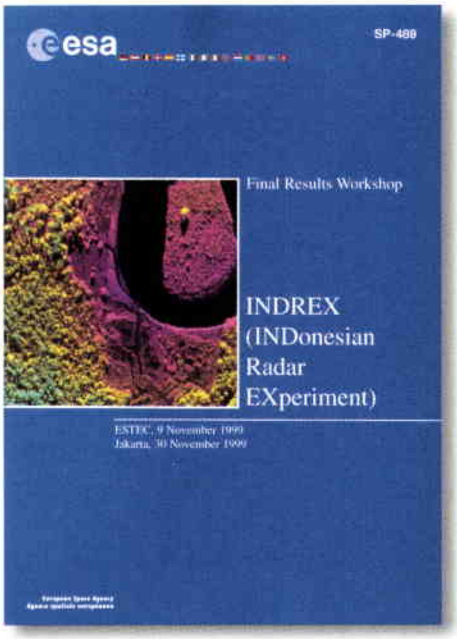

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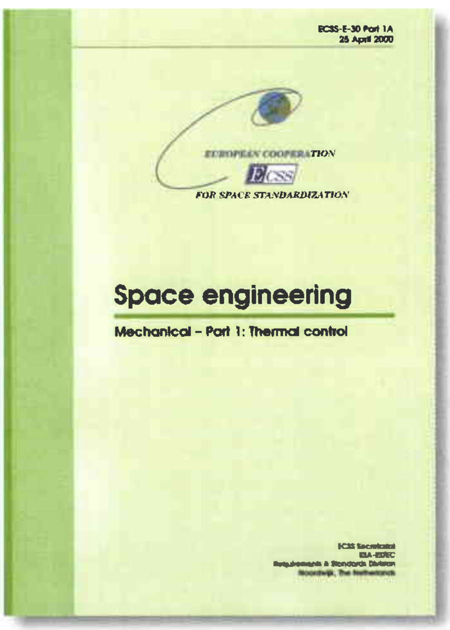

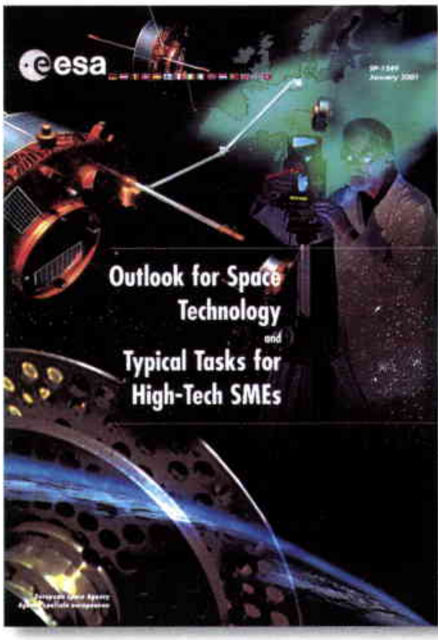

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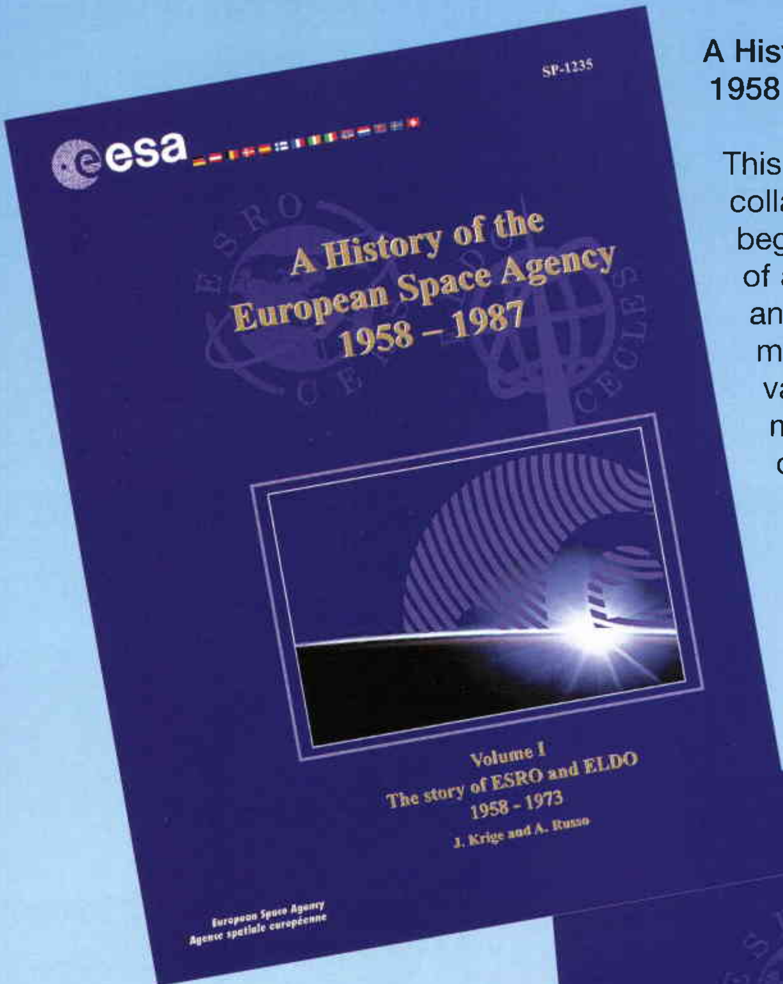

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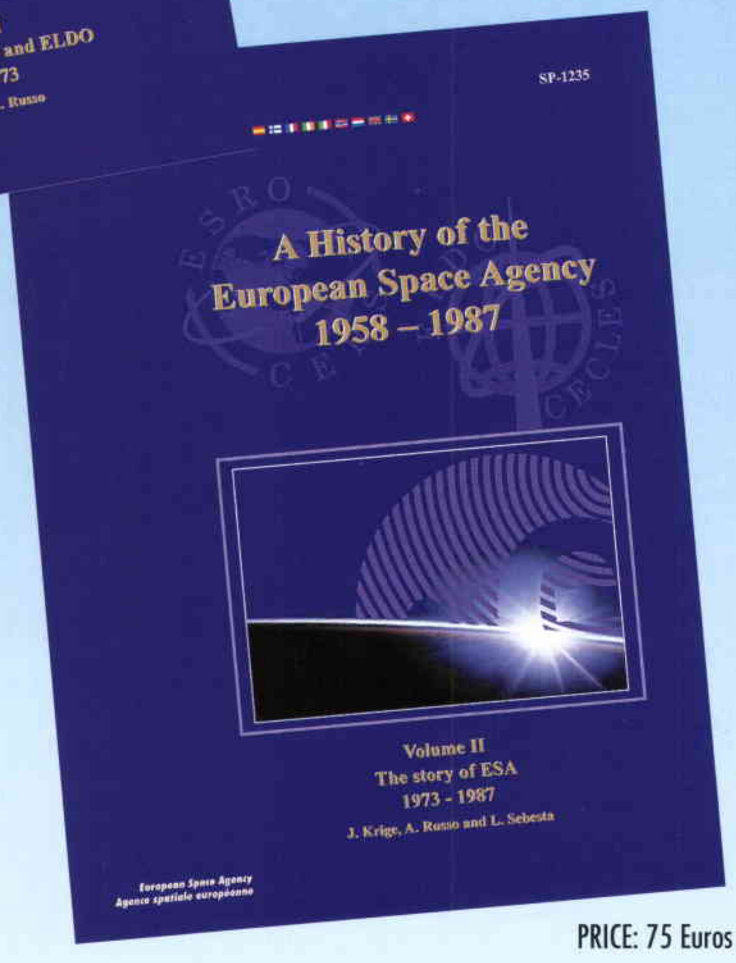

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