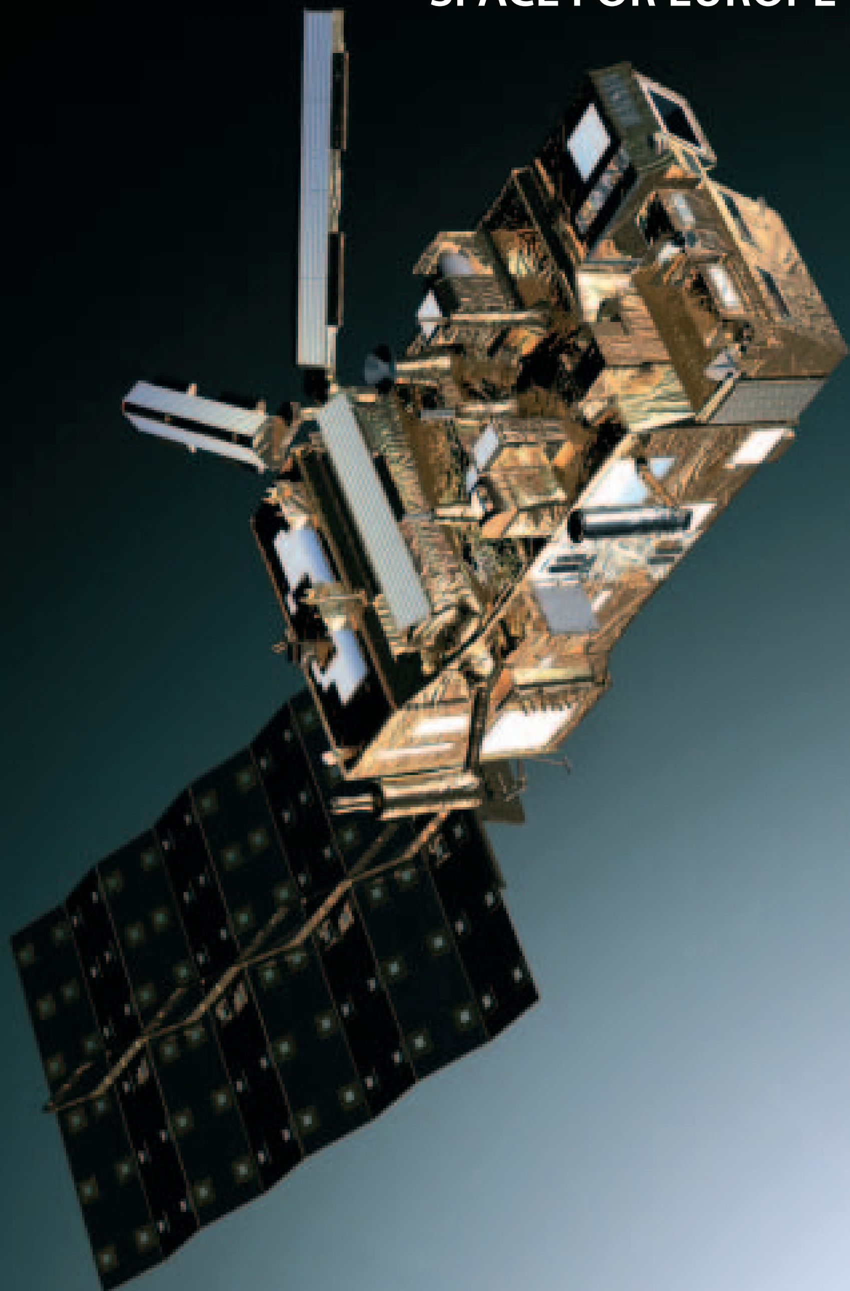
esa

number 127 - august 2006

# bulletin

SPACE FOR EUROPE



## MetOp Poised for Launch

European Space Agency
Agence spatiale européenne

## european space agency

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

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*(b) en élaborant et en mettant en oeuvre des activités et des programmes dans le domaine spatial;*
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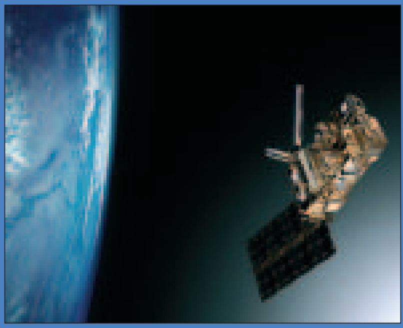
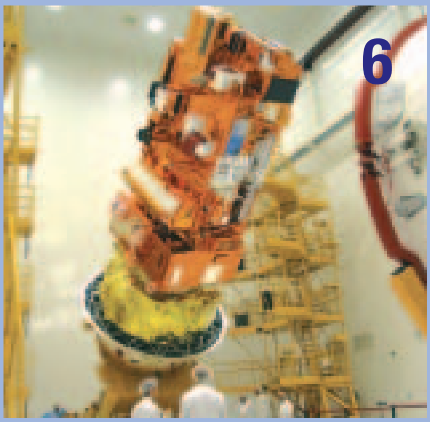


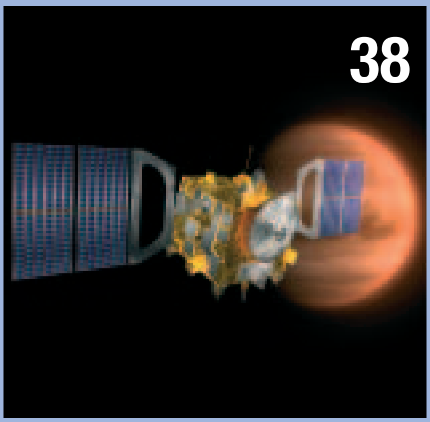
The launch of Europe's first polar-orbiting weather satellite is imminent. See pp 6–31 of this issue.

www.esa.int



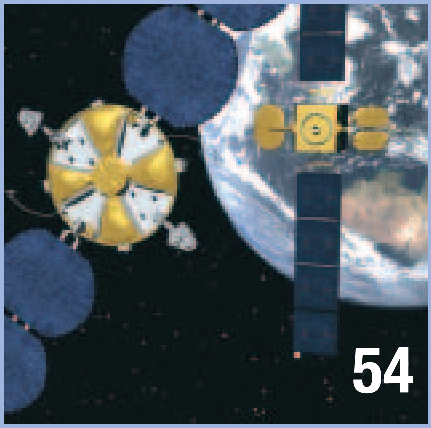

**MetOp**
Europe's First Polar-Orbiting Weather Satellite


**Columbus**
Beginning Its Voyage of Discovery

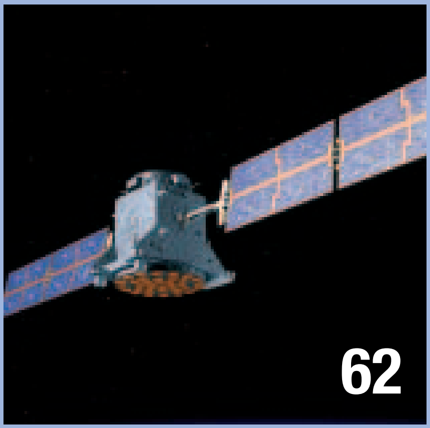



**From Earth to Venus**
Reaching our Sister Planet


**Vega on the Move**
Heading Towards Qualification




**ConeXpress**
Extending the Lives of Satellites




**The Triumph of GIOVE-A**
The First Galileo Satellite

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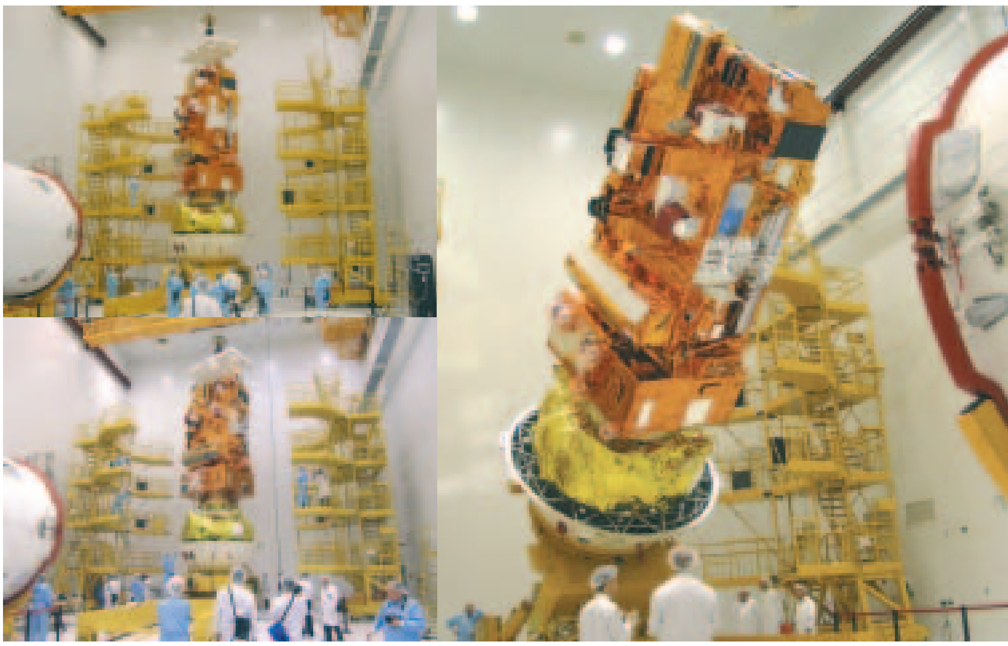
# MetOp Poised for Orbit

## Europe's First Polar-Orbiting Weather Satellite



The launch campaign for the MetOp-A satellite is the culmination of a long series of successful ESA meteorological efforts and collaboration with Eumetsat. Started in 1971, ESA's Meteosat programme launched Europe's first operational weather spacecraft, Meteosat-1, in 1977. The satellite and its successors met or exceeded all expectations and paved the way for the creation of the operational satellite organisation, Eumetsat, which opened its doors in 1986.

Meteosat has enormous advantages in terms of coverage from its fixed position over the equator in geostationary orbit. However, the 36 000 km altitude prevents detailed measurements of the atmosphere, especially for the much-needed temperature and humidity profiles. Indeed, the need for these measurements was recognised by the international community of meteorologists in the late 1960s, who initially advocated a low-orbit satellite instead of Meteosat.

The US had long understood the importance of meteorology from low polar orbit, and started its series of operational Tiros satellites in 1960, launched by NASA. This series of operational satellites is now in its fifth decade, and the US National Oceanic & Atmospheric Administration (NOAA), following its creation in 1970, has incorporated them into its Polar Environmental Satellite (POES) programme. Notably, NOAA has freely provided the data from these satellites to the international community over the last 45 years. The European meteorological community increasingly recognised this and determined that it should play its part in the provision of data from polar orbit.

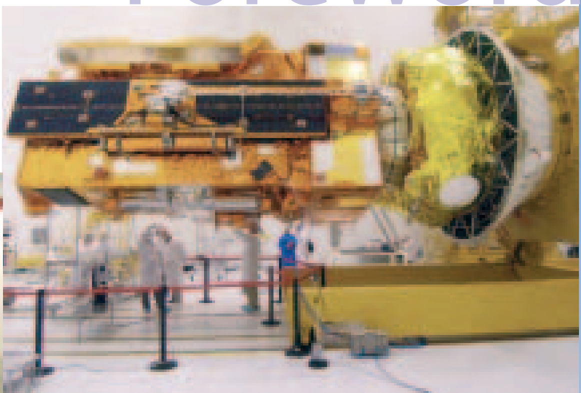
In the late 1980's, ESA began developing the Polar Orbit Environmental Mission (POEM), based on a very large platform carrying both Earth-observation instruments and an operational meteorological package corresponding to that flown on POES. POEM proved an inappropriate vehicle for an operational mission, and it was decided at the Ministerial Council in Granada in 1992 to split the payload across two satellites: the pre-operational observation instruments on Envisat, and the operational meteorological package on the dedicated MetOp.

This pivotal decision led to the preparatory programmes in ESA and Eumetsat. Largely following the model established for the Meteosat Second Generation (MSG), a cooperative programme was built so that ESA developed the MetOp satellite and Eumetsat was responsible for the overall operational system. Notably different from MSG was the provision of the instruments via a variety of partners: CNES, NOAA-NASA, ESA and Eumetsat.

The MetOp development programme (Phase-C/D) kicked off in 1998, aiming at a first launch in 2003 in a series of three. Despite a multitude of delays from development and production difficulties in the externally-provided instruments, the first spacecraft, MetOp-1, achieved flight acceptance in June 2004, albeit with a payload complement that was not fully flight-standard.

Via a complex set of rearrangements and interleaving of the three satellite integration campaigns, it proved possible

# Foreword



to mitigate these delays, and the resulting cost impacts were well within the programme margins established in ESA and Eumetsat. As a result of this juggling, the first to be launched was MetOp-2; MetOp-1 is slated for 2010, and MetOp-3 for 2015. In order to avoid the inevitable confusion, the satellites were redesignated in line with the launch order: MetOp-A, MetOp-B and MetOp-C.

MetOp will provide a real advance in the quality and range of data to meteorologists, improving the output from weather prediction models and thus forecasting. This is thanks to a notable improvement in the accuracy and resolution of vertical atmospheric sounding for temperature and humidity afforded by the IASI infrared sounder and the GRAS occultation sensor. These, together with the heritage POES instruments, will allow MetOp to play its ample part in the International Joint Polar System, where it will take over from the NOAA spacecraft in the mid-morning orbit.

In addition to its operational meteorological role, MetOp will make a valuable contribution to climate monitoring, particularly from the ASCAT sea-surface wind scatterometer, and the GOME-2 ozone and trace-gas spectrometer.

The launch of MetOp will mark the start of a new era in European satellite meteorology. It will be extended with the follow-on system for MetOp (Post-EPS) and the Meteosat Third Generation mission, already in preliminary definition.

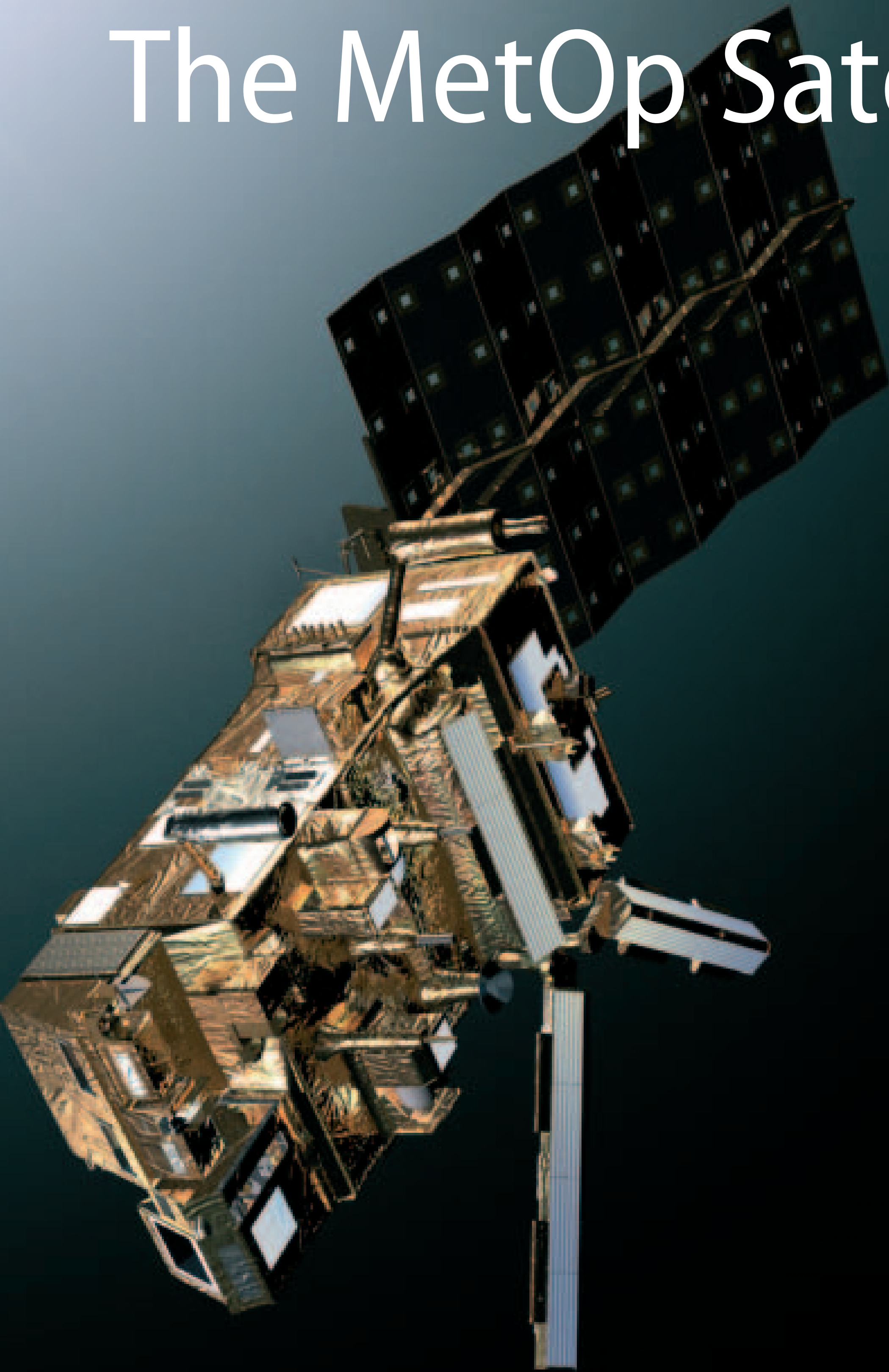
The highly successful cooperation between ESA and Eumetsat in meteorology paves the way for future cooperative endeavours, such as the Global Monitoring for Environment and Security (GMES) with the European Commission. ESA is developing the GMES space component to support European environmental and security policies. Eumetsat will take part in the system with its own satellites and is expected to be the operator for the GMES atmosphere and ocean services.

Volker Liebig
*Director of Earth Observation Programmes, ESRIN, Frascati, Italy*

Peter G. Edwards
*MetOp Project Manager, ESTEC, Noordwijk, The Netherlands*

*Launch vehicle problems halted three MetOp-A launch attempts on 17–19 July. The latest news on MetOp and its mission can be found at www.esa.int/metop*

# The MetOp Satellite



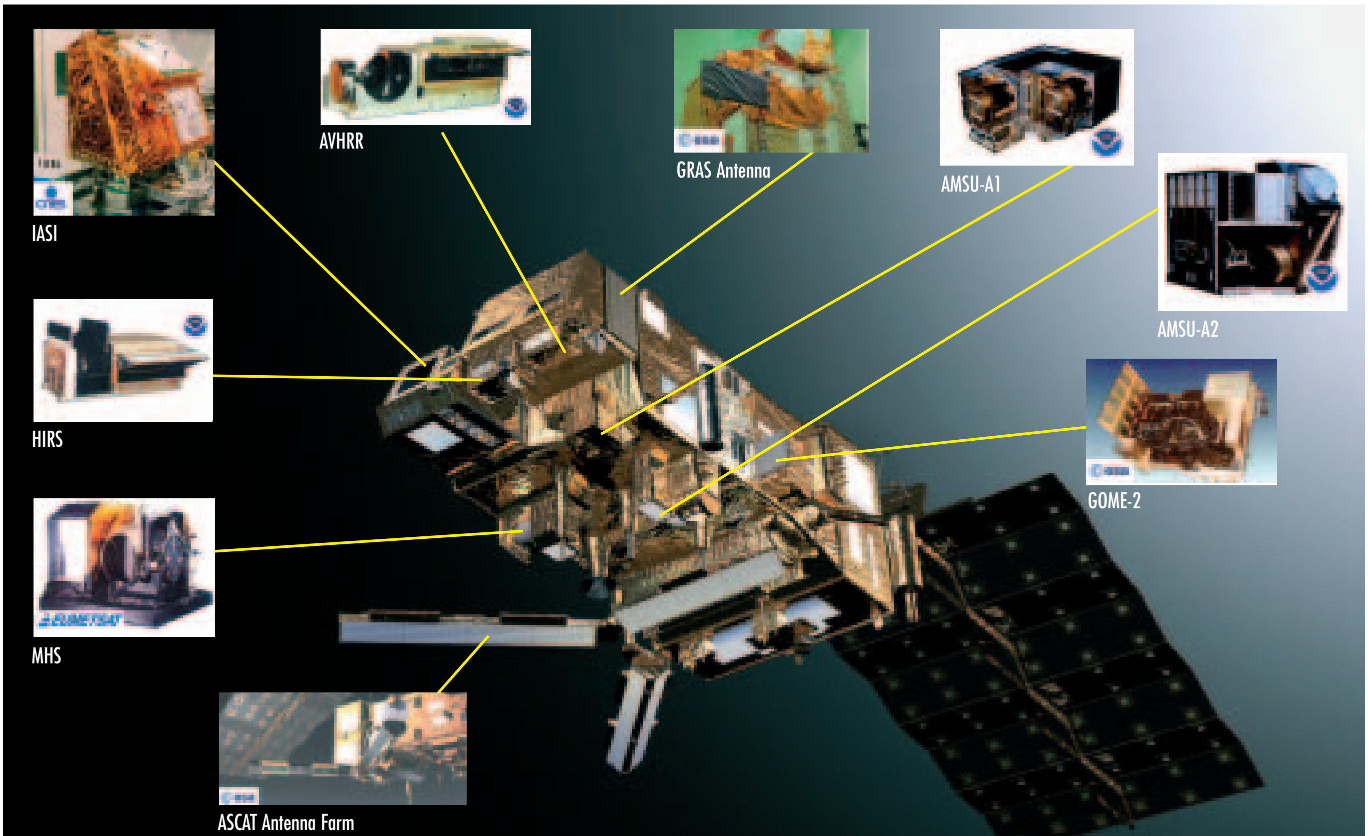
Weather Information from Polar Orbit

*Peter G. Edwards, Bruno Berruti, Paul Blythe, Joerg Callies, Stefane Carlier, Cees Fransen, Rainer Krutsch, Alain-Robert Lefebvre, Marc Loiselet & Nico Stricker*
Directorate of Earth Observation Programmes, ESTEC, Noordwijk, The Netherlands

***MetOp-A is Europe's first polar-orbiting satellite dedicated to operational meteorology. With its array of advanced instruments, it will provide data of unprecedented accuracy and resolution on temperature and humidity, wind speed and direction over the ocean, and ozone and other trace gases, making a huge contribution to global weather forecasting and climate monitoring. In addition, MetOp-A will observe land and ocean surfaces and its search-and-rescue service will help ships and aircraft in distress.***

## Introduction

MetOp-A is Europe's first satellite dedicated to operational meteorology from polar orbit. It will balance the long-standing service provided by the US since the first Tiros satellite in 1960. The US has provided the data from this evolving series free of charge to the world's meteorological community. As early as 1967, Europe looked at contributing to this effort, but selected the geostationary satellite mission as the higher priority. This led to the development of the Meteosat series, which has been remarkably successful since 1977.




## The MetOp Payload

The three satellites carry identical payloads except that HIRS and S&R are not aboard MetOp-3.

**AVHRR** Advanced Very High Resolution Radiometer: a 6-channel visible/infrared imager with a pixel size of 1 km square at nadir. Its data are used, inter alia, to identify clouds, generate cloud parameters, measure sea-surface temperature and derive vegetation conditions. AVHRR has been the primary low-orbit imager for meteorology for more than 20 years, and also flies on NOAA's satellites.

**HIRS** High-resolution Infra-Red Radiation Sounder: a 19-channel infrared sounder measures atmospheric temperature and humidity profiles, with one visible channel for cloud identification. Pixel diameter is about 10 km at nadir. HIRS is also flying on NOAA's satellites.

**AMSU-A** Advanced Microwave Sounding Unit: a 15-channel 23–90 GHz microwave sounder to produce atmospheric temperature profiles. It consists of two separate sounders (AMSU-A1 and AMSU-A2) to cover the frequency range. Microwave measurements have the significant advantage of being much less affected by the presence of clouds than infrared soundings. The AMSU-A pixel diameter is 48 km. The instrument is also flying on NOAA's satellites.

**MHS** Microwave Humidity Sounder: a 5-channel, nadir-viewing 90–190 GHz microwave sounder provides atmospheric humidity profiles. It is a technological advance on the previous-generation AMSU-B on the NOAA-K/L/M satellite series. Nadir pixel size is about 15 km. It is also carried by the NOAA-N and N′ satellites.

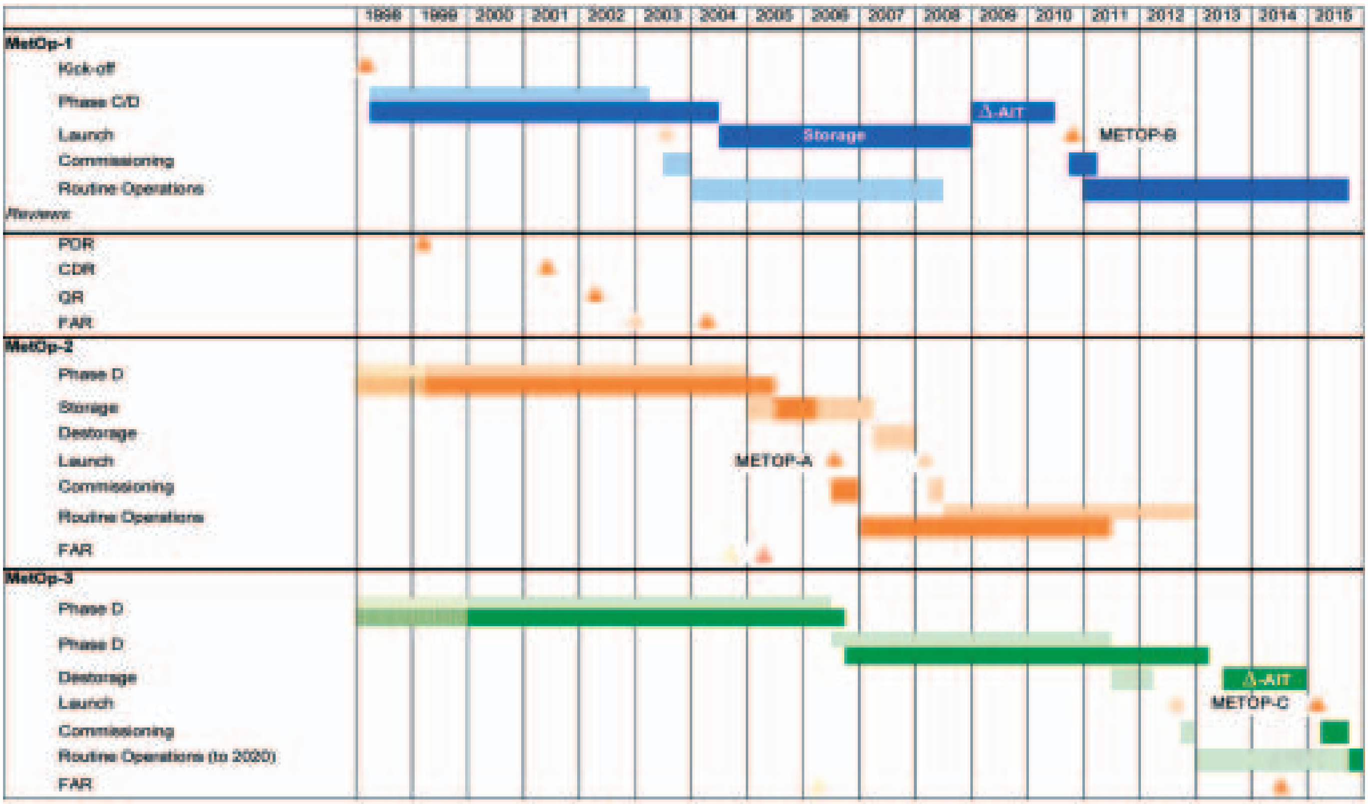
HIRS, AMSU-A and MHS together constitute the **ATOVS** Advanced TIROS Operational Vertical Sounder suite, which provide the operational sounding data from low orbit for today's numerical weather prediction models. The AVHRR imager supports this sounding mission for cloud detection. In addition to these operational sounding and imaging instruments, MetOp carries the new-generation **IASI** Infrared Atmospheric Sounding Interferometer, a nadir-viewing Michelson interferometer operating at 3.6–15.5 micron.

**GOME-2** Global Ozone Monitoring Experiment: an improved version of the GOME instrument on ERS-2. It monitors the ozone concentration and the components involved in ozone chemistry in the atmosphere. It measures the backscattered ultraviolet-visible sunlight in four bands between 240 nm and 790 nm, at a spectral resolution of 0.25–0.5 nm. It also monitors the concentrations of trace gases such as bromine oxide, nitrogen dioxide and sulphur dioxide.

**ASCAT** Advanced SCATterometer: a C-band (5.3 GHz) dual-swath (2 x 550 km) radar providing ocean wind speed and direction. It is an augmented version of the radar on ERS-1/2, with a 25 x 25 km grid resolution. In addition, high-resolution wind information can be generated over a 12.5 x 12.5 km grid. ASCAT can measure sea-ice type and boundaries. Land surface applications are an emerging area and will provide global soil moisture data for numerical weather prediction.

The **GRAS** Global navigation satellite system Receiver for Atmospheric Sounding uses signals from the GPS constellation of satellites slicing through the atmosphere to produce atmospheric temperature and humidity profiles, complementing the data from the nadir-viewing scanning sounding instruments.

Other payloads include: the **SEM** Space Environment Monitor, which measures the charged particle environment; the **A-DCS** Advanced Data Collection System, which collects data from various meteorological and other platforms; and a **S&R** Search & Rescue package for locating distress beacons.




*Comparison of the schedule planned in 1998 (lighter colours) with the achieved schedule (solid colours). CDR: Critical Design Review. FAR: Flight Acceptance Review. PDR: Preliminary Design Review. QR: Qualification Review*

In 1992 plans were formulated to extend Europe's contribution by using using satellites in polar orbit. ESA's MetOp-1 programme was approved in 1998, followed shortly after by approval of the Eumetsat Polar System (EPS). Eumetsat – the European Organisation for the Exploitation of Meteorological Satellite – is charged with operating the system once the satellites are developed and launched by ESA. The joint system is the basis for an improved being offered to the world's meteorological organisations. It also satisfies specific needs of the European and US meteorological services.

The notable improvements required from MetOp include:

- new instruments (ASCAT, IASI, GOME-2, GRAS) in addition to the existing suite on the NOAA satellites of the US National Oceanic & Atmospheric Administration (AVHRR, HIRS, AMSU-A1/A2, SEM);
- a low-rate digital direct broadcast VHF service to replace the analogue Automatic Picture Transmission system, employing data-compression to ensure high-quality images;
- continuous onboard recording of the global dataset to be dumped every orbit at a high-latitude ground station, with the ground system providing the global processed data within 2.25 hr of the measurements being made;
- high pointing accuracy and orbital stability to ensure that data can be geo-located without reference to ground-control points in imagery;
- selective encryption to meet the commercial and data-denial needs of Eumetsat and the US Government, respectively.

## Programme

The ESA MetOp-1 Programme is an optional programme of the Agency, subscribed to by 12 member states (Austria, Belgium, Denmark, Finland, France, Germany, The Netherlands, Norway, Spain, Sweden, Switzerland, United Kingdom) and covering the design and development of the first satellite as the space segment for EPS. The EPS Programme is funding the building of two recurrent satellites, the launch of all three satellites, and the design and construction of a ground segment to operate the satellites and process, archive and distribute the data collected. EPS is designed for a total operational lifetime of 14 years. The EPS Programme is also making a financial and material contribution to the ESA MetOp-1 Programme, providing 36% of the € 746 million cost (current conditions).

Accordingly, the ESA/Eumetsat Single Space Segment Team was established to manage MetOp development via a joint contract with the industrial Prime Contractor (EADS-Astrium, Toulouse, F). While this arrangement inevitably led to increased bureaucracy, and could have resulted in significant organisational frustration and friction, most potentially contentious issues in practice were addressed positively thanks to the constructive attitudes of the teams in ESA and Eumetsat.

## Challenges

MetOp carries 13 instruments provided cooperatively by Eumetsat, ESA, NOAA and CNES. They vary from the largely recurrent units (AVHRR, HIRS, AMSU-A1/A2) developed within the US Polar Orbiting Environmental Satellite (POES) Programme to wholly new instruments developed specifically for MetOp (IASI, ASCAT, GRAS). The accommodation of such a diverse payload, each with its very specific requirements and constraints, proved to be a major challenge. Coordinating and synchronising the delivery of the instruments for three satellites and an Engineering Model required significant effort and flexibility. From the start, the development schedule for two major European instruments (IASI and GOME-2) lagged significantly behind MetOp's timeline. MetOp development, which kicked off in early 1998, baselined launch-readiness of the first satellite in mid-2003. Late availability of instruments, coupled with later development problems in the ground segment, pushed the first launch to mid-2006. Then three attempts 17–19 July were scrubbed and the Soyuz launcher was returned to its factory for refurbishment.

Despite this, the financial impact caused by this major delay have been contained within reasonable bounds thanks to a complex restructuring. This allowed primary qualification of the design, including vibration, thermal vacuum and electromagnetic compatibility tests, to be achieved in mid-2004 using a payload module comprising a mixture of Engineering Model and flight-standard instruments. The MetOp-1 satellite was then placed in long-term storage and will be completed with its full flight payload for launch as MetOp-B around 2009–2010.

Meanwhile, the MetOp-2 integration and test schedule matched the availability of the first flight instruments. MetOp-2's assembly, integration and verification was completed in mid-2005 and the satellite was placed in short-term storage, awaiting call-up for the first launch in 2006 as MetOp-A. That gap was a consequence of delays accrued in the complex Eumetsat ground system.

Finally, the core modules of MetOp-3 (Service Module, Payload Module and Solar Array) have also been completed and put into long-term storage, but without the full set of instruments. The missing instruments will be delivered over the next 2-3 years and added before the call-up for launch, as MetOp-C, around 2014–2015. The satellite's own integration has also been deferred until this time.

MetOp-1 and MetOp-3 are stored as separate modules in enclosures purged with nitrogen. The Payload Modules and critical elements of the Service Modules are reactivated annually to assure longevity of important equipment.

**MetOp Main Features**

*Orbit:* Sun-synchronous, near-circular, 817 km altitude at ascending node; repeat cycle 29 days (412 orbits); local solar time 09:30 (descending node)
*Mission life:* 5 years
*Launcher:* Soyuz ST-Fregat (also compatible with Ariane-5)
*Size:* 6.2m (high) by 3.4 x 3.4 m cross-section in launch configuration; 17.6 x 6.5 x 5.2 m with solar array and antennas. deployed
*Launch mass:* 4093 kg, including 316 kg hydrazine in 4 tanks
*Attitude control:* 3-axis stabilised by reaction wheels; orbit manoeuvres by hydrazine thrusters; pointing knowledge 0.07° X-axis, 0.11° Y-axis, 0.15° Z-axis
*Data-handling:* science data acquired as CCSDS packets (the standard set by the Consultative Committee for Space Data Systems); science data formatting and multiplexing, encryption for selected instruments; instrument and housekeeping data storage in solid-state recorder (24 Gbit end-of-life)
*Communications:* omnidirectional S-band coverage (uplink 2 kbit/s, downlink 4 kbit/s); instrument global data stream downlinked via X-band (70 Mbit/s); realtime broadcasting of instrument data with HRPT at 3.5 Mbit/s via L-band for all instruments, and LRPT 72 kbit/s

*The Svalbard station in the far north of Norway provides contact with MetOp on every orbit*

## System Overview

EPS is devoted to operational meteorology and climate monitoring. It consists of the MetOp satellites, the core ground segment of satellite command, control and health monitoring, instrument data processing and dissemination, data archiving and retrieval facilities in Eumetsat's central site in Darmstadt (D), and a control and data acquisition station in Svalbard (N). Svalbard's northerly position (78ºN) inside the Arctic Circle gives it the unique advantage of being within range of MetOp on all 14 orbits each day.

***Satellite***

The satellite and its payload embody a great deal of heritage from Spot, ERS and Envisat, leading to significant cost savings in development and paving the way to efficient exploitation of the data. Further, most of the instruments are either fully recurrent units or have operational precursors. The sole exception is GRAS, and even this is the operational follow-on to an in-orbit experiment.

The satellite is modular, consisting of two largely independent modules, the Payload Module (PLM) and the Service Module (SVM), and a deployable Solar Array.

The PLM houses the instruments and their support systems. Instrument sensors and antennas are mounted on the external panels, while most of the electronics are housed internally.

The SVM is derived from the Envisat and Spot-5 service modules. It consists of a box-like structure interfacing with the launch vehicle and the PLM. Subsystems provide standard support such as attitude and orbit control, electrical power (solar array) and data management, including telemetry generation and telecommand processing.

***The Payload Module***

Accommodating a large set of instruments was a major design driver for the overall satellite and the PLM configuration, with many constraints originating from the instruments' fields of view, antenna patterns and thermal radiators. The PLM also houses all of the avionics to ensure:

– power regulation for the US instruments (they need a 28 V regulated power bus not available from the SVM);
– power distribution: each unit or instrument is powered through a switchable and protected line, provided by specific PLM units;
– command and control: a dedicated data bus, based on the European On-Board Data Handling Standard is used. The PLM computer receives commands from the SVM and interfaces with the European instruments' control units, the MHS adaptation unit and the NOAA interface unit for the US instruments;
– handling of scientific data via acquisition, formatting, encryption and transmission to ground of packetised data through the regional broadcast links: High-Rate Picture Transmission (HRPT), which contains all the science data, and the limited subset of Low-Rate Picture Transmission. Additionally, following storage in the solid state recorder, the global data-set is transmitted to ground through an X-band link.

*MetOp and its Soyuz launch vehicle*

***The Service Module***

The SVM provides all the standard service functions, including:

– attitude and orbit control, to maintain accurate Earth-pointing for the various operational modes, and to perform orbit acquisition and maintenance;
– propulsion, for orbit and dedicated manoeuvres, and propellant storage;
– power generation, through the solar array, storage, conditioning and overall distribution;
– distribution of commands from the ground and onboard, and collection of housekeeping telemetry data for transmission to ground through the S-band link;
– central software for telemetry generation, telecommand processing and various application functions, such as thermal control, onboard surveillance and automatic command sequencing.

## Changes and Problems

Large and complex satellites usually encounter changes to the requirements and technical and programmatic difficulties along the way. MetOp was no exception in its 8 years of development.

***Launcher***

The programme began on the basis of a dual launch on Ariane-5, but the lack of available co-passengers compatible with MetOp's very specific orbit meant that an alternative had to be sought. Eventually, following a competitive process run by Eumetsat, the Starsem Soyuz-ST was selected. This required no modifications to the MetOp design, as the Soyuz interfaces were fully consistent with the Ariane standard, and the launch environment (particularly mechanical) was generally equivalent to, or more benign than, Ariane-5.

*Checking the radio emissions of MetOp in the anechoic chamber in Intespace. The satellite's complex payload and many antennas made it difficult to avoid interference*

However, some additional system analyses were necessary. The compatibility of the propulsion system and MetOp's structural fatigue life with the horizontal encapsulation, launcher integration and ground transportation imposed by Soyuz had to be assessed. Analysis of the random vibration levels generated by Soyuz (not required for Ariane) was carried out, and an analysis (primarily thermal) of the extended period required for MetOp injection into the baseline orbit (some 70 minutes after lift-off, versus 20 minutes for Ariane) was necessary.

In reality, however, the major effort resulting from this shift was in the additional preparation and planning required for the launch campaign in Baikonur, ensuring the compatibility of the cosmodrome facilities with MetOp's final integration, test and encapsulation, and preparing the logistics. MetOp-A and its support equipment for the launch campaign filled three Antonov-124 heavy-lift cargo planes!

MetOp's mission requirements call for use of the new-generation Soyuz-ST with a Fregat upper stage. Soyuz modifications include a new fairing (similar to an Ariane-4 fairing), mechanical adaptation and strengthening of Fregat, and a new digital avionics system for a more flexible launch trajectory and sufficient stability margins to cope with the aerodynamics of the new fairing. Specifically for MetOp, the thrust is offset from the longitudinal axis for both stage-3 and Fregat to cater for the large offset of MetOp's centre of mass.

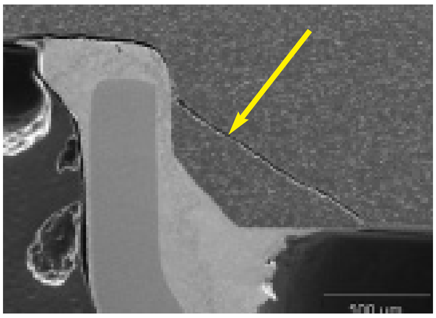
All of these launcher modifications were subjected to a rigorous qualification campaign from late 2004 to May 2006.

***Electromagnetic and RF interference***

Avoiding electromagnetic and radio-frequency (RF) interference between the instruments and avionics was one of the greatest design and verification challenges. Two main concerns were evident from early on in the programme. The first was the necessary common electrical grounding all elements despite their different design heritages. The second was the coexistence of powerful radio transmitters on one side and extremely sensitive receivers in a large frequency band (100 MHz up to 200 GHz) on the other.

The radio-compatibility campaign was particularly demanding because of the second point, with the high number of transmitters/receivers and the multi-purpose antennas. This required early testing with a full-size satellite mock-up to determine how they were coupling and, in some cases, to assist in finalising the antenna design.

MHS and GOME were modified after it was discovered that their emissions were being picked up by the Combined Receive Antenna owing to the extreme sensitivity of the Search & Rescue receiver. Later tests on MetOp-1 showed the need for additional local GOME shielding and improvement in the electrical harness shielding of the SVM Sun and Earth sensors. The testing also confirmed the need for an electro-



Brazing the cell connectors in MetOp-type batteries sometimes created cracks (arrowed)

magnetic enclosure to reduce the emissions from the interface harness between the PLM and SVM. The modifications were verified on MetOp-2, with additional 'sniff' checks made at Baikonur to confirm the shielding on the final flight configuration.

***Batteries***

Leaks in cells of MetOp-type nickel-cadmium batteries have been seen a few times on Envisat, Spot/Helios and ATV. They finally appeared on MetOp, but affected only the 'integration batteries' used on the ground. The cause was found to be cracks in the ceramic material isolating the cell connectors, from thermal/mechanical stress during brazing to the battery cover.

Investigations to isolate the problems and to develop and qualify improvements were exhaustive – taking more than 3 years. They were ultimately successful, with no further leaks occurring in the flight batteries delivered for MetOp.

***Thruster control valves***

During the MetOp-A SVM thermal tests, a leak of pressurising gas from a propellant flow-control valve was found at low temperature. A similar event occurred later on the MetOp-C SVM. It was puzzling, because these valves have a long and successful history in space, having been used on Eureca, XMM-Newton and Integral without problems. The cause was found to be a combination of thermal contraction and creepage of the valve's elastomeric seal.

As a result, all the valves on all MetOp models were leak-tested at low temperature on a special rig. On MetOp-A, valves leaking above 4ºC (the lowest qualification temperature, and the freezing point of hydrazine) were replaced with leak-tight valves.

A test representing the MetOp storage time and the mission duration was performed on two leaking valves to monitor any change over time. Although it showed that the temperature at which leaks started increased with time, it confirmed there would not be a problem under realistic conditions: with the hydrazine pressurised at 22 bar, both valves remained leak-tight even at abnormally low temperatures of around +5ºC. The operating conditions in flight are always warmer than 11ºC in safe mode and 25ºC during normal operations.

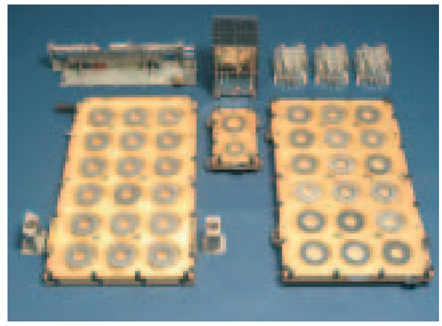
It was also demonstrated that MetOp is rather insensitive to leaks. Early detection, isolating a leaking branch and even disabling the entire thruster system are at the disposal of the operator (procedures are detailed in the flight operations manual) without major impact on the mission.

***GRAS ground processing prototype***

The GRAS ground processing prototype (GPP) was developed to validate the performance of the GRAS instrument and its level-1b algorithms. It was a demanding task becasue the error sources are numerous, depending on the instrument and external sources such as the GPS navigation satellite constellation, the atmosphere and ionosphere. A detailed error budget was compiled by the instrument supplier, and had to be confirmed using the GPP.

To demonstrate this budget, a complete simulator environment was developed to simulate the signals generated by the full GPS satellite constellation. All the errors can be added one by one, or all together and with variable magnitude.

In view of the accuracy needed for GRAS, which is much greater than for a standard GPS receiver, the verification of all the simulator modules and their interfacing was a meticulous task that took more time than expected. It included extensive testing with various datasets from the real instrument. The results of this complex test programme have been used for correcting and fine-tuning the level-1b data-processing algorithms for the instrument.



Gold-plating the GRAS antennas solved the corrosion problem

***GRAS ASIC***

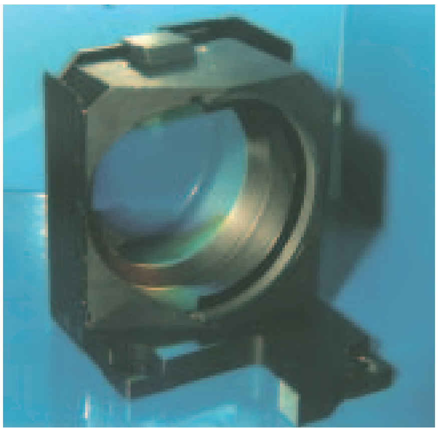
The GRAS receiver is built around an Application-Specific Integrated Circuit (ASIC) known as 'AGGA-2' which performs most of the digital processing of the GPS signals. This was developed for another space application, but was finally qualified within the MetOp programme. A significant number of problems were discovered during the process, which led to the ASIC's redesign as the AGGA-2A. The redesign and requalification took considerable time, and risked MetOp's schedule. Extra efforts in industry, coupled with workarounds for the satellite integration, avoided this.

***GRAS antenna metallisation***

The three GRAS antennas (one for navigation and two for occultation measurements) initially had carbon-fibre structures finished with a layer of aluminium. It transpired that the combination can lead to corrosion – and MetOp's antennas shed flakes of corroded aluminium. Instead, gold-plated antennas were qualified and remanufactured.

***GOME-2 improvements***

Once in orbit, GOME-2 must be

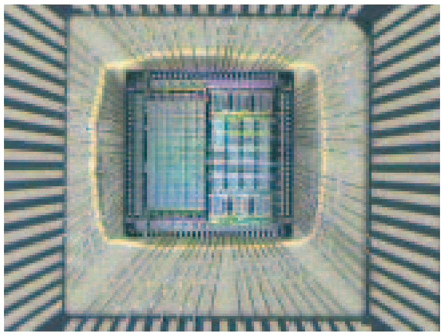


GOME's diffraction gratings had to be recoated to prevent absorption of moisture

precisely calibrated by 'observing' a set of three light sources: a hollow cathode lamp for spectral calibration, a tungsten lamp for the broadband, and the Sun via a diffuser. On GOME-1 this diffuser was an electrically-grounded aluminium surface. Even though this type of diffuser adds only very small spectral features to the incoming light (less than a fraction of 1%), it still distorts GOME's results. Instead, a 'quasi-volume diffuser', which contributes only a tenth of the aluminium's effects, was identified. Following lengthy qualification, the original aluminium diffusers were replaced by the new models in all of the GOME-2 models.

***GOME gratings***

During calibration of GOME-2, the optical efficiencies of channels 1 and 2 were found to be lower than expected. It was soon established that the efficiencies of their diffraction gratings had degraded. After deep analysis by the supplier, the cause was identified as the porosity and resultant moisture absorption of the coating, which affected, at the sub-micron level, the geometry of the gratings. A slightly modified coating process was developed to produce stable coatings.



ASCAT's switching front-end ASIC

The deficient gratings were stripped and recoated, and GOME's calibration was successfully repeated. In parallel, the long-term stability of grating samples is being carefully monitored.

***ASCAT switching front-end ASIC***

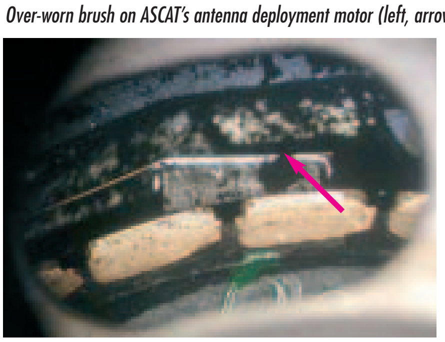
This ASIC for the ASCAT scatterometer includes both analogue and digital circuits that turned out to involve non-standard (and now obsolete) technology. Their production proved to be very time-consuming, and then, in addition to the delays caused by late delivery of the components, two major issues were found during development. First, the technology was found to be highly susceptible to electrostatic discharges, which destroyed many parts during assembly. Improvements in the ASIC's design (causing further delays) and in the soldering process did not completely remove the risk. However, sufficient numbers could be produced, and the discharge threat was not a problem once the components were assembled in the units. Dedicated life tests on all the switching front-end units confirmed their flightworthiness.

The second issue was that radiation tests showed the parts were highly susceptible to proton and heavy ions, causing a high rate of bit-flips. If this happened in flight, ASCAT would be unavailable while it was reset. The problem was solved by reprogramming the switching logic, so that the antenna switches were systematically reset at the start of each switching cycle.

***ASCAT antenna deployment motors***

Excessive wear of the motor brushes was found during life testing of the ASCAT antenna deployment motor. The motors were tested in air, vacuum and under simulated orbital conditions. Following an unsuccessful search for a better brush material, it was decided instead to replace the brushes close to flight.

Over-worn brush on ASCAT's antenna deployment motor (left, arrowed). Normal wear on a bedded-in brush (right)



## Conclusion

MetOp is one of the most complex satellites ever developed in Europe. It provides both continuity and major advances in observational data for meteorologists and Earth scientists.

Despite significant delays in the deliveries of key instruments, and many challenges along the way, the first MetOp was launched from Baikonur in July in time to meet Europe's commitment to the Initial Joint Polar System of meteorological satellites with NOAA. This is thanks in no small part to the close cooperation between ESA, Eumetsat, CNES, NOAA and NASA, founded on the excellence of the ESA industry teams led by EADS-Astrium for MetOp and Galileo-Avionica for GOME-2. esa

*Detailed information on MetOp and its mission can be found at www.esa.int/metop and in the new brochure "MetOp: Monitoring the Weather from Polar Orbit" (BR-261, available from ESA Publications)*

## FAR to Launch: A Long Journey

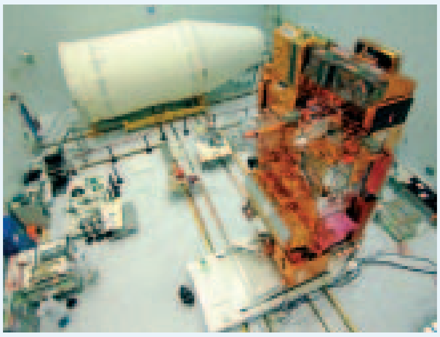
MetOp-A completed its Flight Acceptance Review (FAR) at EADS-Astrium in Toulouse in July 2005. The go-ahead to prepare for launch in early summer 2006 was then given. At the same time, remaining open items had to be taken care of, including retrofitting some instruments, swapping some avionic units and completing the investigations of anomalies.

Soyuz has seen more than 1700 launches so far, with a reliability exceeding 95%. It is the workhorse of the Russian space programme and a key element for operating the International Space Station. Starsem has used it for 16 successful commercial launches. Starsem is a European-Russian partnership created in 1996 by the key players involved in the production and operation of Soyuz (EADS Space, Arianespace, Roskosmos, TsSKB-Progress).

Baikonur is the world's largest space centre, spread over thousands of square kilometres among the barren steppes of Kazakhstan. Built in the mid-1950s as a strategic test site, it dispatched hundreds of launchers and missiles each year at its peak from around 65 pads.

Organising the MetOp launch campaign was a complex task. Three fully loaded Antonov-124 cargo flights were needed to transport all the flight and ground hardware from Toulouse to Baikonur. Its size meant that MetOp's Service Module, Payload Module and Solar Array had to be transported separately, and then reassembled and tested. A large quantity of electrical ground support equipment was transported and installed at Baikonur, occupying some 500 m$^2$ of the Payload Processing Facility and the Upper Composite Processing Facility (UCPF) in the MIK 112 building, to perform the final checks on the satellite and its instruments.

The solar array is attached to MetOp during final reassembly at Baikonur



The flight-ready MetOp awaits encapsulation in its Soyuz fairing

MetOp-A arrives at Baikonur

Permission to ship was finally granted in March 2006, at the end of the satellite preparation activities in Europe and after the Launch and Operations Readiness Review confirmed the ground segment was ready. On 10 April the first of the Antonovs was on its way to Baikonur, followed by the main flight elements on 17 April and the final cargo with the Solar Array on 20 April.

The launch campaign team, representing the main participants in developing the satellite (ESA, Eumetsat, Astrium, DutchSpace) and instruments (NASA, CNES, ITT, Northrop-Grumman, Galileo Avionica), worked in Baikonur for 3.5 months. Averaging 55 people, this is the largest team involved so far in a Starsem launch campaign.

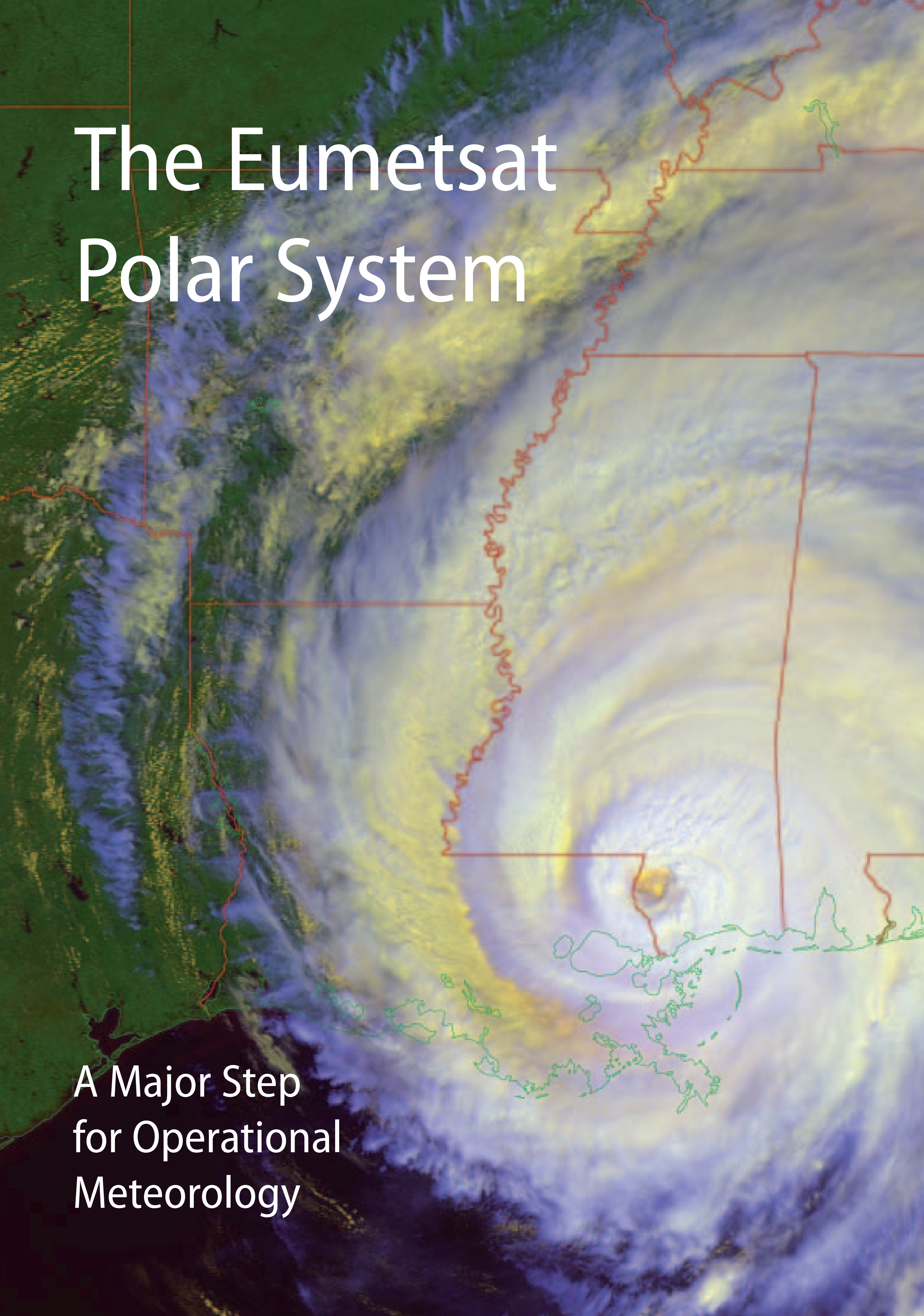
After arrival in Baikonur, 9 weeks were required for the satellite's final assembly and checkout, achieved by mid-June. During this time, unplanned last-minute replacements of two US instruments (AMSU-A1 and -A2) were made. They were urgently shipped from the US following the discovery of problems affecting the MetOp-A instruments.

The satellite was fuelled in the second half of June and finally, at the beginning of July, MetOp-A was declared ready to meet its Soyuz upper stage in the UCPF cleanroom. Reflecting the team's hard work in preparation over the previous months, MetOp, the Soyuz adapter, the Fregat upper stage and the intermediate bay were stacked flawlessly in sequence.

On 8 July the team had the last chance to wish good luck to MetOp before it was slowly slid into the large fairing during the horizontal encapsulation. Following a 6-hour train transfer, the fairing composite reached MIK40, where the upper composite was mated with its Soyuz.

A final short train ride brought the vehicle to Pad 31 on 14 July where, after the last countdown rehearsal, the launch was targeted for 22:28:10 local time (16:28:10 UT) on 17 July. But faulty software checking the inertial platform's alignment stopped the countdown 1 h 36 min before launch. On 18 July, the automated checkout routines proved unable to deal with the partially-fuelled launcher configuration, which had resulted from investigations into the previous abort. This led to an abort 3 h 10 min before launch. On 19 July, it was within 185 sec when the ground system again stopped the clock, this time due to an operator error. Unfortunately, this meant that the Soyuz exceeded the maximum time it can be kept on the ground after fuelling, so it had to be returned to the factory for refurbishment. Meanwhile, the upper composite was demated and arrived back in in MIK 112 on 22 July, where the fairing was removed. Everything is being kept ready awaiting the decision on a new launch date.

# The Eumetsat Polar System



## A Major Step for Operational Meteorology

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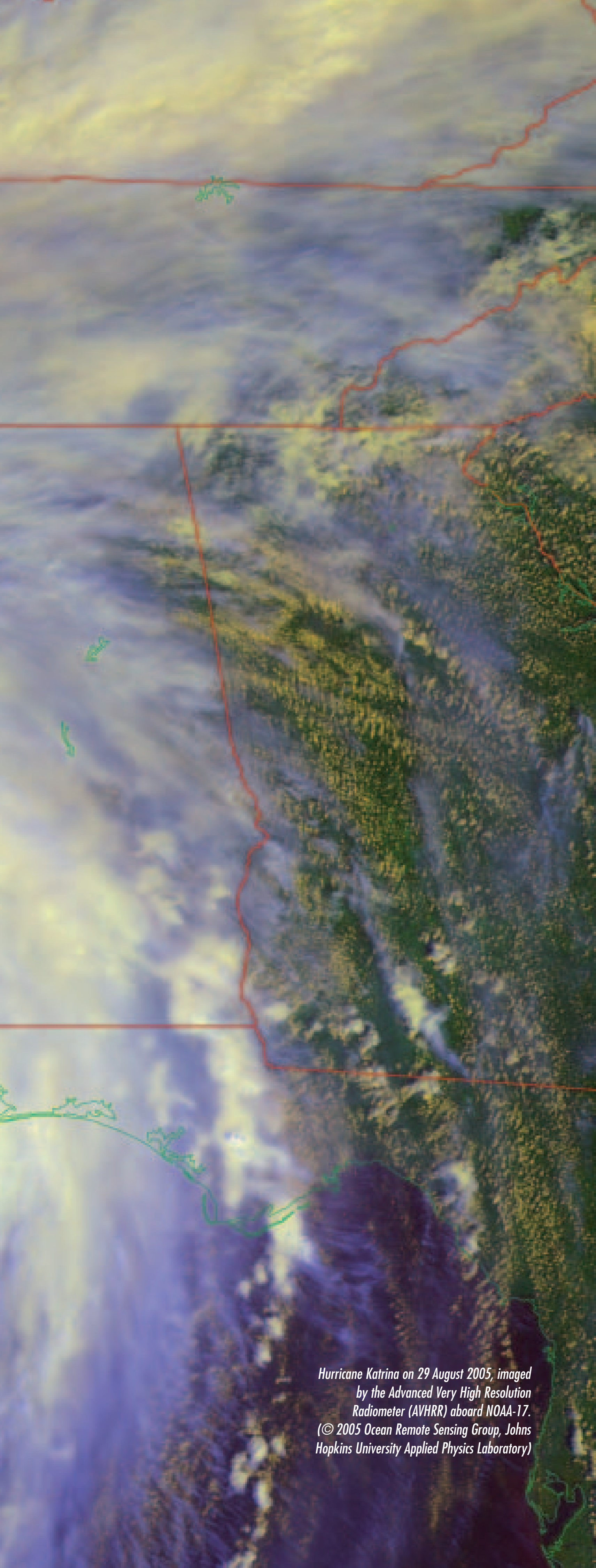


*Hurricane Katrina on 29 August 2005, imaged by the Advanced Very High Resolution Radiometer (AVHRR) aboard NOAA-17. (© 2005 Ocean Remote Sensing Group, Johns Hopkins University Applied Physics Laboratory)*

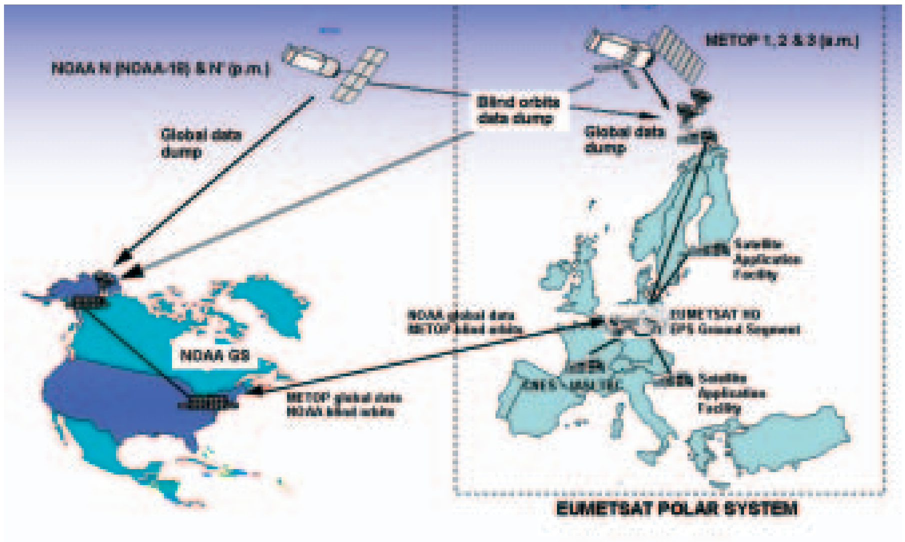
***The Eumetsat Polar System (EPS) covers the MetOp satellites and Eumetsat's ground infrastructure and services. It is the European contribution to the Initial Joint Polar System, established jointly with the US National Oceanic & Atmospheric Administration (NOAA). EPS will patrol the 'morning orbit' while NOAA continues with the 'afternoon orbit'. In addition to its prime objective of operational meteorology and climate monitoring, EPS also addresses a wide range of other environmental issues such as the atmosphere's minor constituents, cloud distribution and ocean-surface wind effects. EPS is planned for 14 years of operations, starting in 2007, following completion of in-orbit commissioning.***

## Introduction

For more than 30 years, the operational meteorological satellite data from low orbit have been provided by a series of satellites operated by the US National Oceanic & Atmospheric Administration (NOAA). At any one time, the system has two operational polar-orbiting satellites in 'morning' and 'afternoon' orbits (referring to the local time as the satellite crosses the Equator).

Many years of discussions and planning on Europe assuming the responsibility for the morning service culminated in the ESA Meteorological Operational (MetOp) and the coordinated Eumetsat Polar System (EPS) Programmes being approved in 1998 and 1999, respectively.

The ESA MetOp-1 Programme covers development of the first satellite, while the EPS Programme includes the manufacture of two further satellites (MetOp-2 and MetOp-3), the launch of all three and a new ground segment to operate these satellites and process, archive and distribute their data. EPS is designed for a total operational life of 14 years. The EPS Programme also provides a financial and material contribution to the ESA MetOp-1 Programme.




*The Initial Joint Polar System. An orbit is 'blind' when the satellite does not come within range of its usual ground stations. GS: Ground Segment.*

## EPS and International Cooperation

EPS is the European element of the Initial Joint Polar System (IJPS), established through a Cooperation Agreement between Eumetsat and NOAA to contribute to the global meteorological polar-orbiting observing system.

The objective of the IJPS is to ensure the continuity and timely availability of meteorological data through a series of polar satellites with a mid-morning equator-crossing time of 09:30 (Europe) and an afternoon equator-crossing time of 14:00 (USA).

EPS is built around a Space Segment (the MetOp satellites and their payloads) and a dedicated Ground Segment, described below. MetOp's instruments result from a number of international cooperations: AVHRR, HIRS, AMSU-A and SEM are provided by NOAA as part of IJPS; MHS is directly procured by Eumetsat; IASI is a joint development by Eumetsat and CNES; GOME-2 and GRAS are jointly funded by Eumetsat and ESA; ASCAT is provided by ESA; A-DCS is provided by CNES; the Search & Rescue package is provided by CNES and the Canadian Department of National Defence. (The instrument acronyms are explained in the companion article 'The MetOp Satellite'.)

## The EPS Missions

***Operational meteorology***

Operational meteorology covers a wide spectrum of activities for predicting how the atmosphere, and especially associated weather conditions, will evolve. These activities are supported by observations coordinated through the World Weather Watch (WWW) of the World Meteorological Organisation (WMO). Standard observations are routinely made every 3–6 hours (the 'synoptic hours') and distributed to the operational meteorological community over the Global Telecommunications System (GTS) of the WMO.

Observations provided by operational meteorological polar satellites are essential components of this observing system. Existing satellites have many well-established operational capabilities, while MetOp will add to them based on heritage from pre-operational missions or will allow promising operational evolution.

***Climate monitoring***

Earth-observation satellites have an important contribution to make in understanding our climate; operational satellites are pre-eminent in providing the necessary long-term monitoring required for detecting real climate change.

It is necessary to observe many different climate parameters and study them simultaneously in a multi-disciplinary approach. Even quite small trends in the climate, if continued over the long term, can lead to immense environmental problems and enormous expenditure to counter the adverse effects.

Many climate-monitoring requirements coincide with, or overlap, the requirements for operational meteorology. The objectives for monitoring climate change that are additional to those already established for operational meteorology are listed in the table on the facing page.

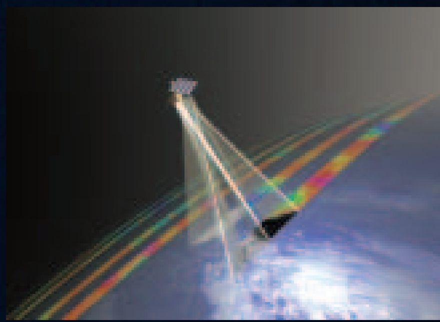
***Further mission capabilities***

Although driven by the need to return operational meteorology and climate-monitoring data, the EPS mission is also a source of data on a wide range of other environmental issues, including:

– Earth sciences;
– atmospheric minor constituents and trace gases;
– cloud distribution;
– wind forces at the ocean surface.

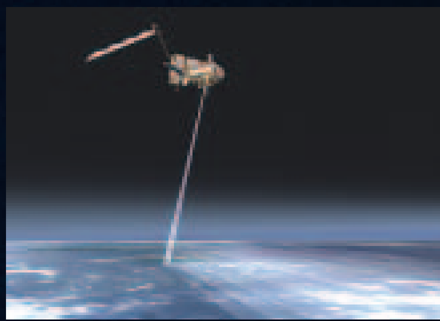
***Additional services***

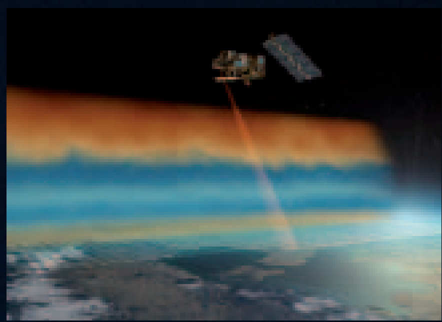
The satellite is further designed to



**EPS/MetOp Missions**

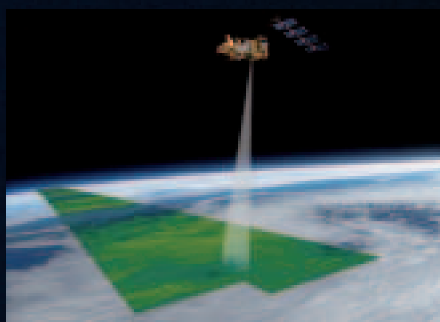
| *Mission* | *Function* |
|---|---|
| Global operational sounding | Provides information on the 3-D temperature and humidity of the atmosphere, to support Numerical Weather Prediction (NWP) |
| Global imagery | Provides cloud imagery for forecasting applications, sea-surface temperatures and global radiation budget parameters. Supports the global sounding mission by identifying cloud-free areas |
| Global ocean surface wind vectors | Provides wind speed and direction over the global ocean surface and supports NWP systems by providing these data in otherwise data-sparse regions |
| Data collection and location | Collection of observations from ocean buoys and similar *in situ* Data Collection Platforms (DCPs). Includes determination of the DCP location. Supports the WWW |
| Global data access | Delivery of global data to the meteorological services within 2.25 hours of observation; primarily supporting global-scale forecasts |
| Local data access (HRPT and LRPT) | Broadcast of data to local receiving stations while a satellite is visible, supporting regional forecasting. Two services are required: High-Resolution Picture Transmission (HRPT) and Low-Resolution Picture Transmission (LRPT) |





**Climate-Monitoring Missions**

| *Mission* | *Function* |
|---|---|
| Sea-ice monitoring over the oceans | Provides information on the coverage of ice and snow (in addition to ship routing in operational meteorology) |
| Ice and snow monitoring over land | Provides information on the coverage of land surfaces by ice and snow (in addition to operational meteorology) |
| Global precipitable water mapping | Provides information on the global distribution of water (also supports NWP) |
| Global ozone mapping | Provides information on the distribution of ozone in the upper atmosphere |



monitor its space environment, for routine analysis of the charged particles in low orbit. EPS will also become part of the international search and rescue service that is already operating via today's NOAA satellites.

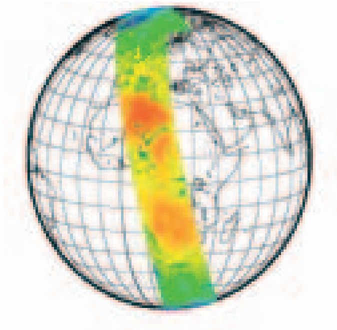
## The MetOp Satellites

MetOp and its payload ensure continuity with the current observing system and adds new capabilities inherited from pre-operational missions such as Envisat.

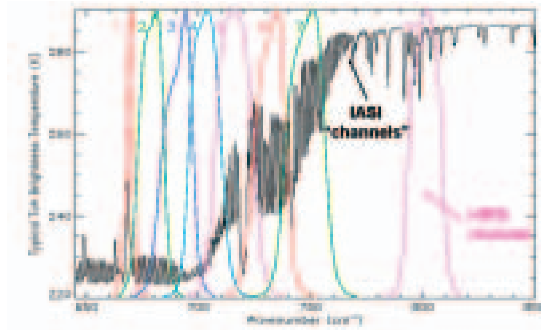
The HIRS, AMSU-A and MHS instruments constitute the Advanced TIROS Operational Vertical Sounder (ATOVS) suite. With AVHRR, they match the instruments carried by the NOAA satellites.

In addition to these currently operational sounding and imaging instruments, MetOp is carrying new-generation instruments: the Infrared Atmospheric Sounding Interferometer (IASI), the Global Ozone Monitoring Experiment (GOME-2), the Advanced SCATterometer (ASCAT) and the Global navigation satellite system Receiver for Atmospheric Sounding (GRAS).

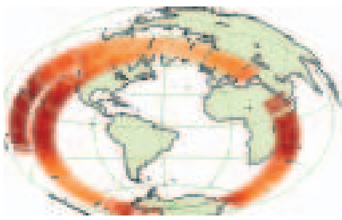
Other payload items include the Space Environment Monitor (SEM), the Advanced Data Collection System (A-DCS), and the Search & Rescue (S&R) package.



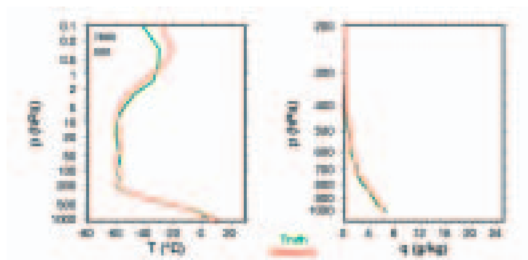
*The temperatures processed by Eumetsat from the MHS instrument on NOAA-18*




*A typical IASI 8461-channel spectrum compared with the 19 channels of the previous-generation High Resolution Infrared Radiation Sounder (HIRS)*

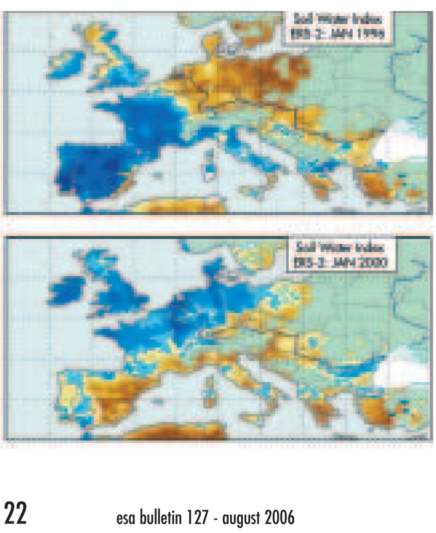


*The atmosphere's temperature extracted from simulated IASI data*



*Simulated IASI data showing how accurately temperature (T), pressure (p) and humidity (q) can be calculated. The red curves show IASI's result against the green true values*

*ASCAT will provide the data for emerging land applications such as monitoring global soil moisture. This will also contribute to Numerical Weather Prediction. The example here uses information from ESA's ERS-2 satellite; blue indicates higher moisture levels*



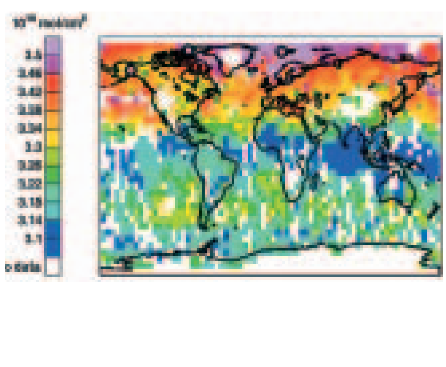
## The IASI Instrument

IASI is a major element of the EPS/MetOp mission. It represents the next generation of atmospheric sounders and should allow a significant step forward in providing temperature and humidity profiles of much higher accuracy and resolution than hitherto available.

IASI is introducing new and advanced technology. As a Michelson interferometer working in 8461 spectral channels, its main task is to measure the atmosphere's temperature, water vapour and trace gases globally.

Part of the instrument is an Integrated Imaging System, consisting of a broad-band radiometer working at 10–12 micron at high spatial resolution. The field of view covers 64 x 64 pixels and provides information in the focal plane of the sounder, allowing coregistration with AVHRR for precise knowledge of position and detailed analysis of cloud properties inside the IASI sounder pixels.

*IASI will be important for measuring key trace gases in the atmosphere, such as the methane shown here*



The IASI data will be used in synergy with the microwave sounding instruments, to which the scanning is synchronised. It is expected that IASI will considerably improve the quality of weather forecasting through the direct ingestion of its measurements into the forecast models. It will also improve climate monitoring by measuring key trace gases such as ozone, carbon dioxide, methane and nitrous oxide, all important for atmospheric chemistry.

## The EPS Ground Segment

The EPS Ground Segment includes all the ground facilities required to support the orbiting MetOp satellites and the EPS mission, including both normal and degraded mission modes. Its objectives are:

– to ensure that the satellites perform their mission nominally.
– to perform the ground operations to fulfil the global mission, acquiring and processing the global data received from the NOAA and MetOp satellites and disseminating the processed data to the Eumetsat member states. This includes product quality control, data archiving, and provision of user services.
– to perform all the ground operations to support the local data-access mission (HRTP/LRPT).
– to support NOAA for global data acquisition and telemetry, tracking and control during blind orbits of the NOAA ground segment (and on request for specific operations).
– to support the space environment monitoring and data-collection missions.

The core ground segment provides the following functions at the different sites:

– the Central Site, at Eumetsat headquarters in Darmstadt (D), includes all the functions for monitoring and controlling the satellite and the ground segment. Included are the generation of the centrally extracted products and their dissemination.
– the Polar Site, at Svalbard (latitude 78°N), hosts the Control & Data Acquisition (CDA) station that will receive the MetOp recorder dump every orbit and command the satellite. The CDA will also receive NOAA satellite data dumps when they are beyond their own stations.
– the Back-Up Control Centre (BUCC) Site, close to Madrid (E), was created in case of major problems with the central site.

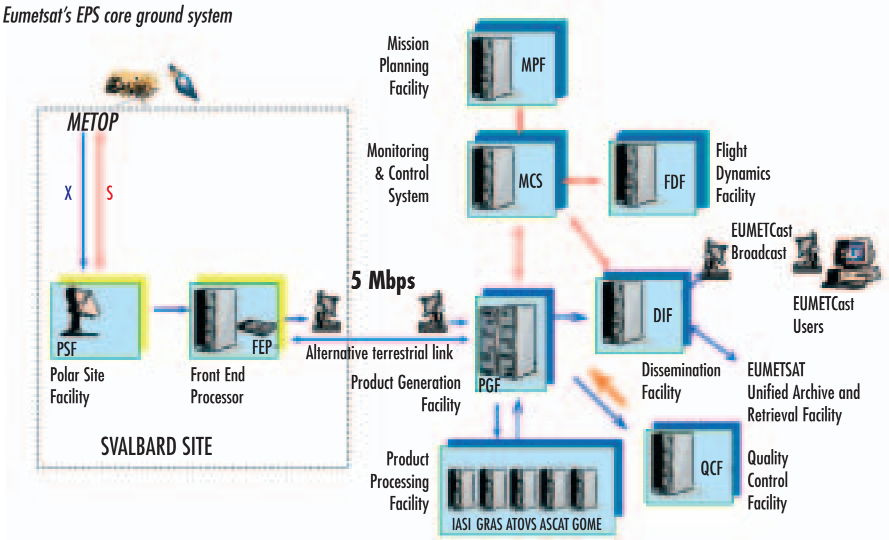
The core ground segment was developed by a European consortium led by Alcatel Alenia Space (F). The Polar Site and BUCC infrastructure services are contracted out to KSAT (N) and INTA (E), respectively.

The EPS ground segment includes the Eumetsat multi-mission dissemination system (EUMETCast) for near-realtime delivery to users of the global data and products derived from the MetOp data for the morning orbit and NOAA data for the afternoon orbit.

## Conclusion

The EPS Programme is a major investment by Europe's meteorological and research and development communities in the global meteorological observing system. It will provide products and services of unprecedented quality to the European and international operational users, as well as to the larger community of Earth scientists.

Eumetsat's EPS core ground system




### Research Announcement of Opportunity

The instruments on the MetOp satellites provide continuity for the operational sensors that have long been flying on the NOAA satellites. Such series of long-term data are valuable sources of information for research into, for example, climate change. MetOp also carries the advanced European ASCAT, GOME-2, GRAS, IASI and MHS instruments, which not only largely fulfil the requirements for operational meteorology and climate monitoring, but also offer a unique opportunity for innovative research in all aspects of Earth sciences.

This is why ESA and Eumetsat jointly offer free access for the worldwide scientific community to the EPS data and products for the projects selected through the joint Research Announcement of Opportunity (RAO) that was opened in July 2004. Such free data access is also granted to those proposals exploiting synergy with Meteosat Second Generation and Meteosat, as well as the ERS and Envisat data and products.

The peer review selected 50 proposals, mainly from European scientists but also some from Argentina, Australia, Brazil, Canada, Kyrgyzstan and the US. More than 250 researchers are involved.

About half of the projects request ERS and Envisat data, demonstrating the synergy of MetOp with such missions. In particular, this is the case for the GOME and SCHIAMACHY instruments in atmospheric chemistry.

The first Workshop of selected Principal Investigators took place at ESRIN on 15–17 May 2006, before the first MetOp launch. More than 40 scientific projects were presented to a restricted audience by the Principal Investigators, explaining their plans in atmospheric research, land, oceanography, hydrology, climate, methods, calibration and validation. In return, the scientists were briefed on the status of MetOp and the EPS ground segment, including information on how and when to get the data.

The interest in MetOp raised among the research community was highlighted by the success of the call for innovative projects. The first results will be presented at the second Workshop about a year after MetOp's launch.

# Preparing MetOp for Work

## Launch, Early Operations and Commissioning

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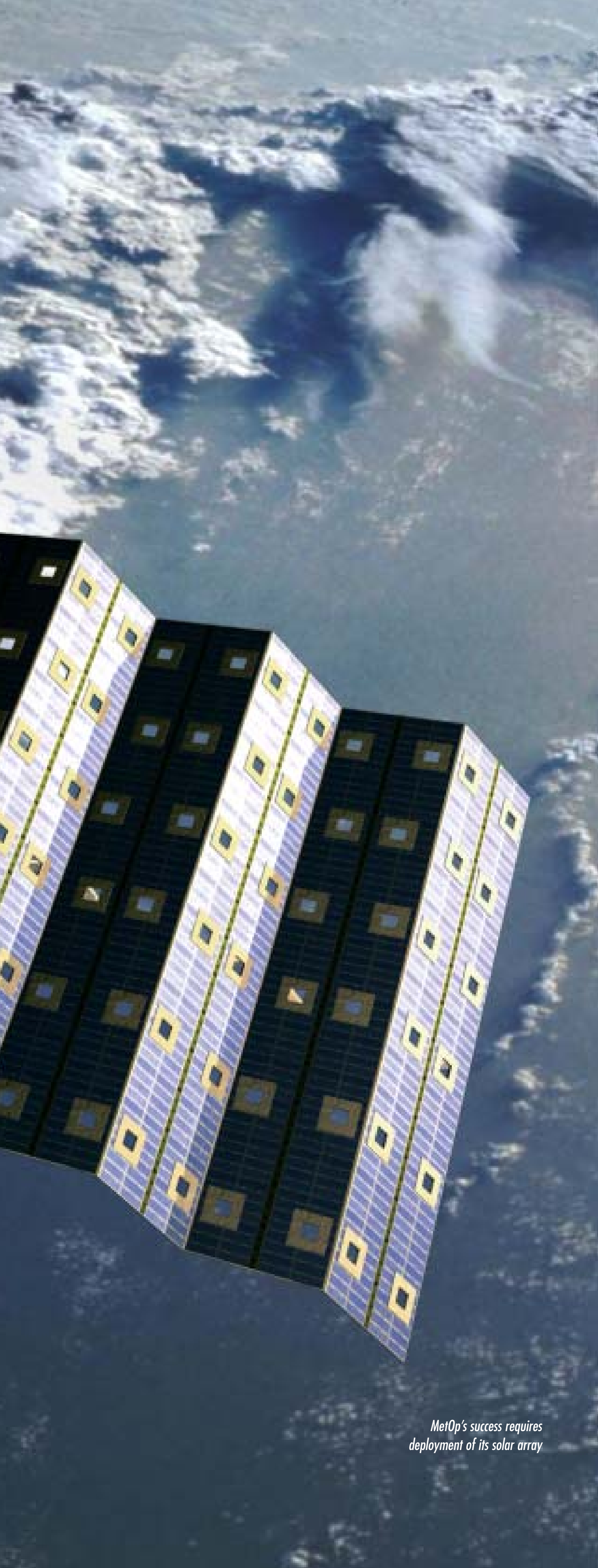
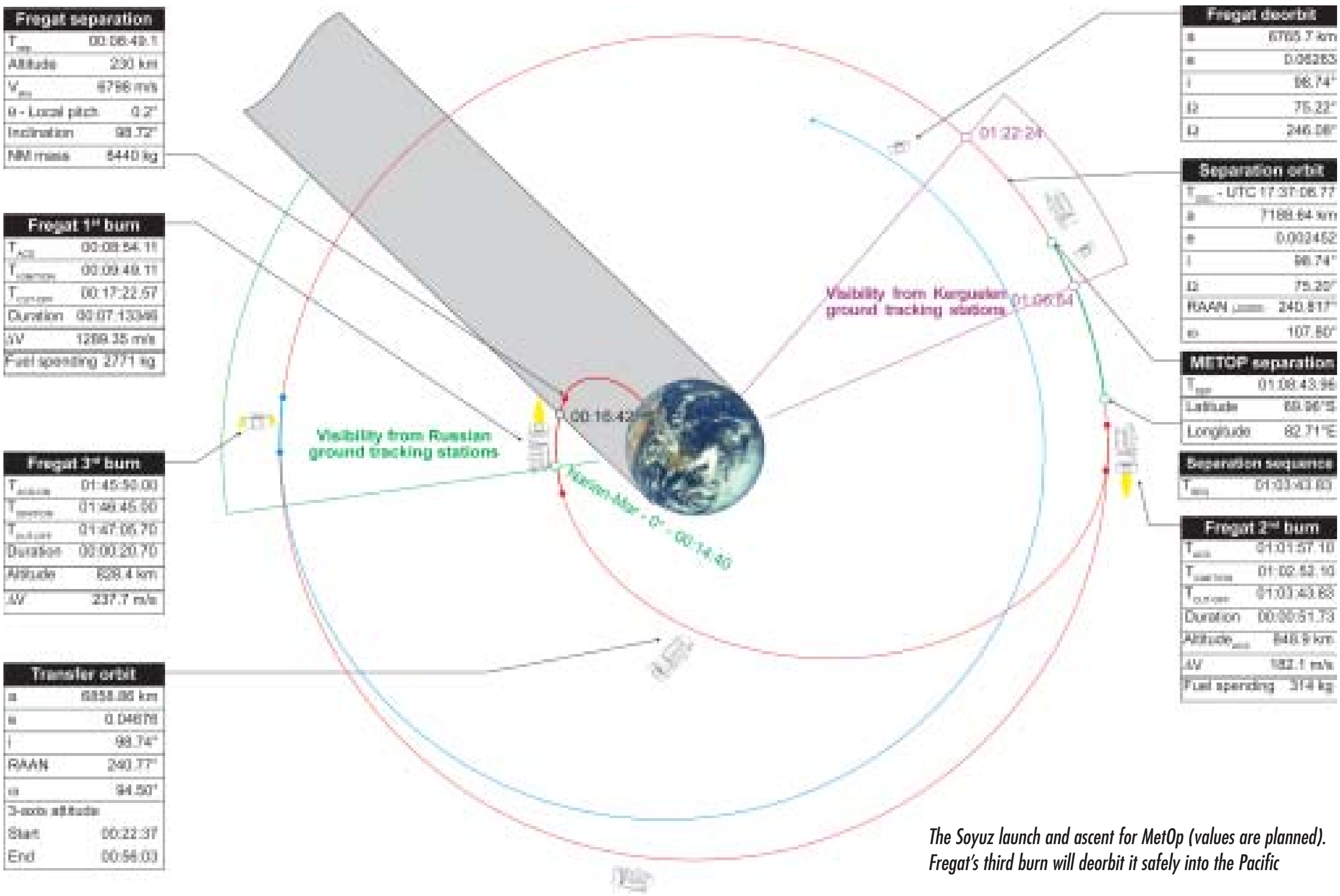


MetOp's success requires deployment of its solar array

***The launch of MetOp will signal the beginning of a hectic schedule for the operations team at ESOC. It is their job to activate and test the satellite's most critical functions before handing it over to Eumetsat team for commissioning. All satellites have to be shepherded carefully through this process but MetOp's commissioning in orbit is particularly complex because of its solar array deployment and numerous instruments.***

## Introduction

The goal of the Launch & Early Orbit Phase (LEOP) is for ground controllers to convert MetOp from its near-inert launch condition into an autonomous satellite. The critical event is successful deployment of the solar array, as MetOp's batteries alone can provide enough power only for three orbits. After the 3-day LEOP, the lengthy Satellite In-Orbit Verification (SIOV) begins, systematically switching on and checking all of MetOp's systems and instruments; this will take about 3 months. Finally, in 2007, MetOp's services can be progressively brought online for users.




*The Soyuz launch and ascent for MetOp (values are planned). Fregat's third burn will deorbit it safely into the Pacific*

## Launch & Early Orbit Phase

***From launch campaign to LEOP***

MetOp's Launch & Early Orbit Phase is handled by ESA's European Space Operations Centre (ESOC) in Darmstadt (D) under contract to Eumetsat. Responsibility for the satellite resides with prime contractor EADS-Astrium before launch and then shifts to ESOC's flight operations team just before lift-off after MetOp's hardware and software are switched into the launch configuration. Before lift-off, ESOC has access for a final check of the telemetry and telecommand interfaces, and of MetOp's onboard software to verify the programming of the attitude and orbit control system (AOCS) and the telemetry recording setup for when ground stations are out of sight. MetOp will be launched with its batteries fully charged, with the central flight software waiting for separation to trigger the automatic sequence for deploying the solar array. Deployment is programmed in for a set time (1 hour 52 minutes) after launch, allowing for visibility from the network of LEOP ground stations.

***Launch and ascent***

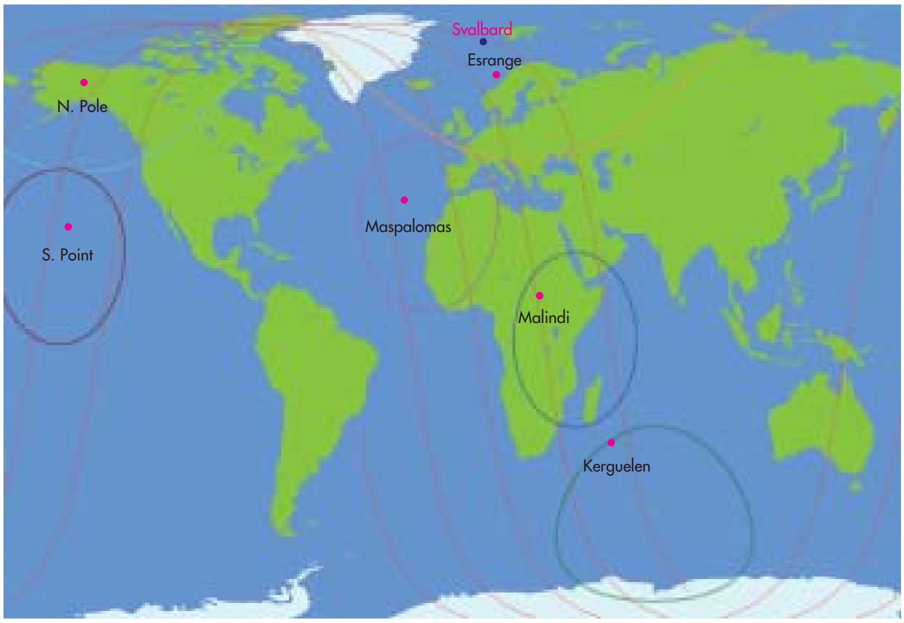
The time between lift-off and satellite separation is 68 min 59 sec, within range of the Kerguelen station. For MetOp, Fregat's first burn will be the last event that can be monitored by the Russian ground stations, before a long autonomous coast without coverage. Several measures will therefore be taken to increase the chances of seeing the Fregat/MetOp composite in the event of faulty injection or separation, maximising the odds of recovering the satellite. A wide-beam antenna has been added to the standard LEOP station at Kerguelen in order to monitor MetOp's separation. The Svalbard Control & Data Acquisition (CDA) station used by Eumetsat for routine operations and ESA's Kiruna station will also monitor part of the coast to confirm a normal ascent. The US NORAD military system will track the Fregat/MetOp ascent and provide independent orbital information.

***LEOP infrastructure and organisation***

LEOP involves a distributed network of ESOC personnel, a Eumetsat representative and an ESTEC/Astrium Project Support Team. The core LEOP mission control capabilities are built around the SCOS 2000 software kernel, using a Mission Reference Data Base from Astrium. Procedures for handling normal and recovery situations were developed by ESOC and proved during the satellite system validation tests or using the MetOp simulator. The flight dynamics team is responsible for

**LEOP Ground Stations**

| *Station* | *Location* | *Latitude/Longitude* |
|---|---|---|
| Malindi | Kenya | 2.99°S/40.19°E |
| Esrange | Kiruna | 67.9°N/21.1°E |
| N. Pole | Alaska | 64.8°N/147.5°W |
| S. Point | Hawaii | 19.0°N/155.6°W |
| Kerguelen | Kerguelen | 49.35°S/70.25°E |
| Maspalomas | Spain | 27.76°N/15.63°W |




*MetOp visibility from the LEOP ground stations*

updating MetOp's AOCS parameters during LEOP, planning and carrying out orbital manoeuvres, and routine activities such as orbit prediction.

MetOp control is performed via a network of S-band ground stations around the world. The stations are optimised to cover the solar array deployment, to monitor AOCS operation and payload deployments, and more generally to provide coverage during particularly critical activities in case of problems.

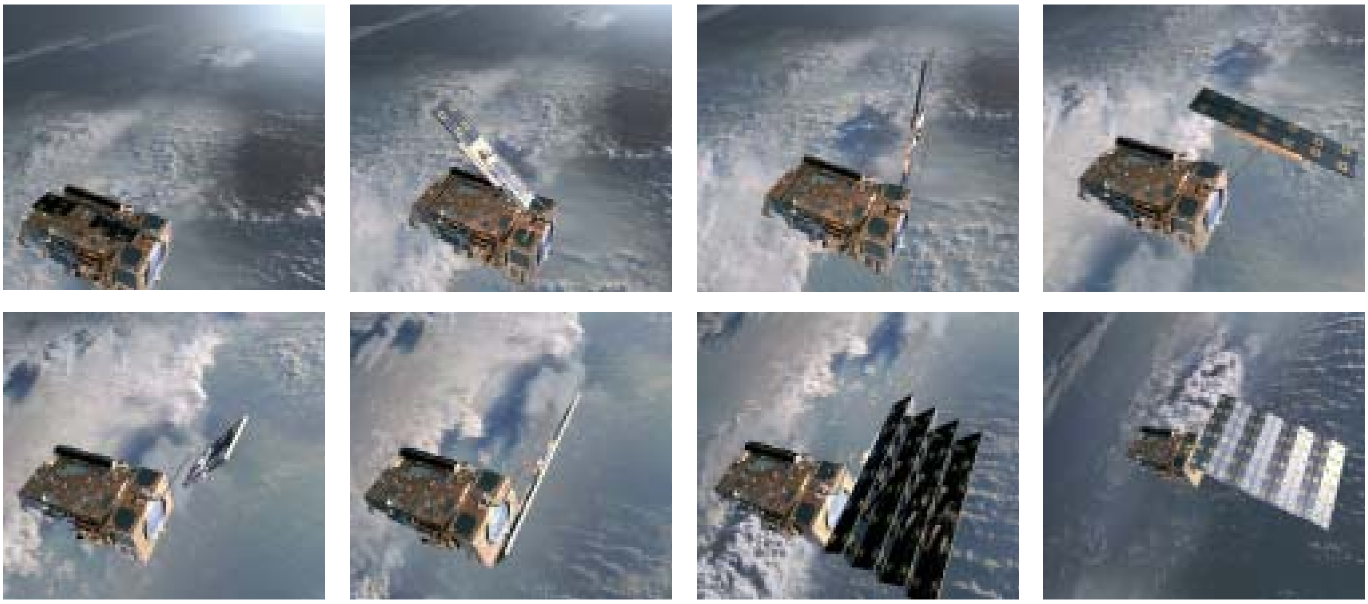
The mission control and support teams are trained to interact and optimise their responses to identify anomalies, and to formulate and agree upon recoveries quickly. They can quickly identify appropriate procedures during normal operations or well-identified failures, create new procedures to cope with unexpected anomalies, and safely command MetOp under pressure. LEOP simulations before launch are invaluable in preparing for flawless satellite operations during LEOP.

### *LEOP milestones*

The main objective of LEOP is to put MetOp into an operational and autonomous condition. This requires the following sequence of events:

| *Main LEOP Activities* | *Mission Elapsed Time* | *Ground Station Coverage* |
|---|---|---|
| ***From Launch to Operational Mode*** | | |
| Lift-off | 0:00:00 | – |
| Separation | 1:08:59 | Kerguelen |
| SA thermal knives activation | 1:09:11 | Kerguelen |
| SA primary deployment driving (root hinge) | 1:25:39 | Malindi |
| SA primary deployment driving (mid and top hinge) | | Out of coverage: telemetry recording and dump |
| SA secondary deployment driving | 1:43:01 | Esrange |
| Rate Reduction Mode | 1:51:11 | Esrange |
| **MEGS unlocking/SFM enabling** | **1:52:20** | **Esrange** |
| **Fail-safe point → Solar Array deployed** | | |
| Coarse Acquisition Mode | 1:52:20 | Esrange |
| Reaction wheels unblocking | 1:52:29 | Esrange |
| End of automatic sequence | 1:52:29 | Esrange |
| Transition to FAM1 | 1:56:00 | Alaska |
| MEGS rotation start | 2:13:03 | Alaska |
| Transition to FAM2 | 2:28:06 | Out of coverage: telemetry recording and dump |
| Enabling of onboard surveillances for autonomous failure detection, isolation and recovery | 2:49:47→6:56:19 | Kerguelen, Malindi, Esrange, Alaska, Hawaii, Maspalomas |
| Flight Dynamics presents MetOp orbit information | 8:00:00 | |
| Command transition to OPM/GEO and verify convergence | 10:23:28→14:58:50 | Alaska |
| ***Payload Module initialisation & antenna deployment*** | | |
| PMC, TCU, PCU, PDU initialisation | 14:58:50→17:05:59 | Hawaii, Alaska, Esrange |
| Verify PLM thermal stabilisation | 20:25:50 | Esrange |
| ASCAT RF antenna deployment | 25:25:09→25:33:09 | Esrange |
| ASCAT RA antenna deployment | 27:08:09→27:22:09 | Esrange, Alaska |
| GRAS (GAVA and CRA) and LRPT antennas deployments | 28:39:09→29:03:39 | Maspalomas, Esrange, Alaska |
| RTU initialisation | 33:58:34 | Alaska |
| ***Manoeuvres & handover to Eumetsat*** | | |
| In-plane or/and out-of-plane manoeuvres, depending on Fregat/MetOp separation performance | 47:33:44→ ? | All LEOP network |
| Eumetsat commandability checks | 66:04:57 | All LEOP network, plus Eumetsat CDA station |
| Latest handover to Eumetsat for SIOV | 16:28:51 | Esrange/CDA |

*LEOP chronology and coverage. CDA: Control & Data Acquisition. CRA: Combined Receive Antenna. FAM: Fine Acquisition Mode. GAVA: GRAS Anti-Velocity Antenna. GEO: Geocentric Pointing. MEGS: Mecanisme d'Entrainement du Generateur Solaire. OPM: Operational Mode. PCU: Power Conversion Unit. PDU: Power Distribution Unit. PLM: Payload Module. PMC: Payload Module Computer. RA: Right Aft. RF: Right Forward. RTU: remote terminal unit. SA: solar array. SFM: safemode. SIOV: satellite in-orbit verification. TCU: Thermal Control Unit. Payload acronyms are explained in the companion article 'The MetOp Satellite'*



The deployment sequence of MetOp's solar array

- the automatic deployment of the solar array involves the primary deployment of the root, mid and top hinges, and the secondary deployment that extends and tensions the solar panels. This complex sequence of cutting Kevlar cables by thermal knives and activating motorised hinges will be triggered by the satellite separation. This step is particularly important because MetOp relies on its internal batteries until the solar array is able to provide power; the satellite can survive for only three orbits on batteries.
- achieving the correct orientation using thrusters and its fine-tuning to the operational mode via reaction wheels and magnetotorquers.
- the deployments of the antennas for ASCAT, GRAS and LRPT (Low-Resolution Picture Transmission). Some could interfere with thruster firings in the event of an emergency situation, so they have to be completed as quickly as possible.
- orbit adjustment to account for possible separation errors.

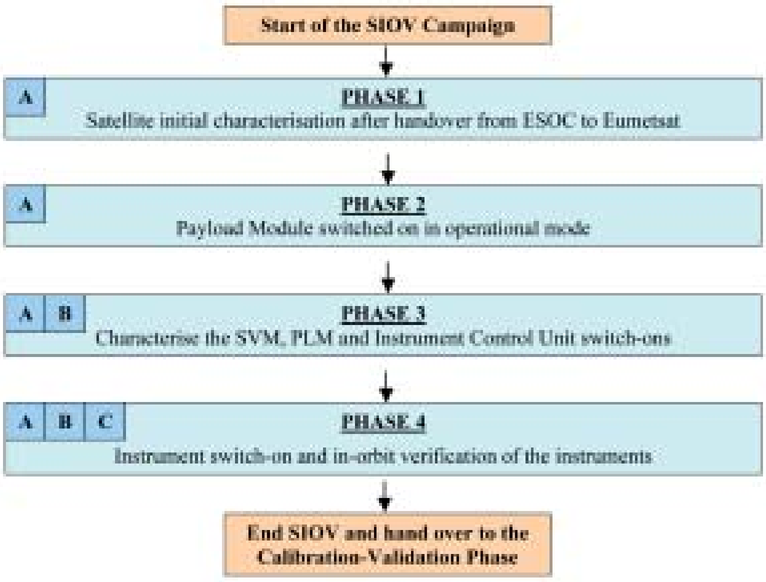
Three days are allocated for the overall LEOP, with a fourth kept in reserve.

## Handing Over MetOp to Eumetsat

For MetOp's handover from ESOC to Eumetsat, the Service Module will be fully operational. Some of the instruments will be switched on, with the computer, remote terminal units, thermal control and power systems on. Eumetsat will test several functions before taking full mission control, including:

- acquisition and decoding of mission data from ESOC in order to ensure continuity and consistency of commands.
- telemetry, telecommand and ranging by the Eumetsat station in Svalbard.
- acquisition and processing of MetOp house- keeping telemetry.
- commanding the satellite.

After checking these vital functions in less than a day, the formal start of Satellite In-Orbit Verification (SIOV) will be declared 4 days after launch.




The main phases of SIOV activities. A: analysis of housekeeping telemetry. B: analysis of science data format. C: analysis of science data content. PLM: Payload Module. SVM: Service Module.

ESOC will remain on hot standby for 2 weeks in case of emergencies severe enough to threaten the mission. If that happens, the Payload Module will be switched off and ESOC will begin the recovery process.

## Satellite In-Orbit Verification

SIOV will systematically switch on all of MetOp's functions and verify the performances of the Service Module, Payload Module and instruments. This is a complex phase that involves all the actors in MetOp and the Eumetsat Polar System; it demands strict planning and uses specialised tools for mission analysis and performance verification. The Svalbard CDA station will provide contact with MetOp for at least 10 minutes every orbit. For the instruments, the length of the in-orbit validation varies, ranging from 3 weeks for MHS to 3 months for IASI, which requires long decontamination before it can be operated.

### *SIOV objectives*

The first objective is to verify that the satellite and its instruments are operable, by commanding them and observing the telemetry.

The second objective is to verify that the scientific data can be provided according to specifications via the onboard recorder and the X-band dump, and in real-time using the High/Low-Resolution Picture Transmission (HRPT/LRPT) regional broadcast system.

The third objective is to verify that the instruments are performing as expected by checking that their engineering data match those from the ground tests. The range of SIOV tools to do this was either specially developed or adapted from ground equipment.

### *The SIOV timeline*

Design and operational constraints of the satellite and ground segment had to be respected in elaborating the SIOV timeline. These activities normally follow three main steps: initial characterisation after handover from ESOC to Eumetsat based on housekeeping telemetry received in S-band; switching the Payload Module into its operational mode, allowing the first tests of science data continuity and format; detailed verification of the in-orbit performance of the instruments using the SIOV ground tools.

### *The SIOV organisation*

In line with the respective responsibilities for developing the satellite, the definition and coordination of the SIOV is delegated by Eumetsat to the joint Single Space Segment Team. The planning and implementation of this complex task involves the various partner space agencies (Eumetsat, CNES, NOAA and ESA) and companies (EADS-Astrium France, EADS-Astrium Germany and Galileo Avionica). Spread over a number of sites, it requires very strict organisation of team functions and tasks, from management to execution levels. Decisions involving satellite commanding are by nature critical and must be based on careful data analysis and rigorous procedures, for example through Anomaly Review Boards. To support SIOV, a complex data and information delivery system was set up to ensure timely access to data for the various participants. The SIOV uses specialist engineers to monitor 'their' subsystems or instruments at Eumetsat, and performance-verification teams operating remotely for specific data analysis. The SIOV will be reviewed on a daily basis to accommodate problems and recoveries that affect the overall schedule.

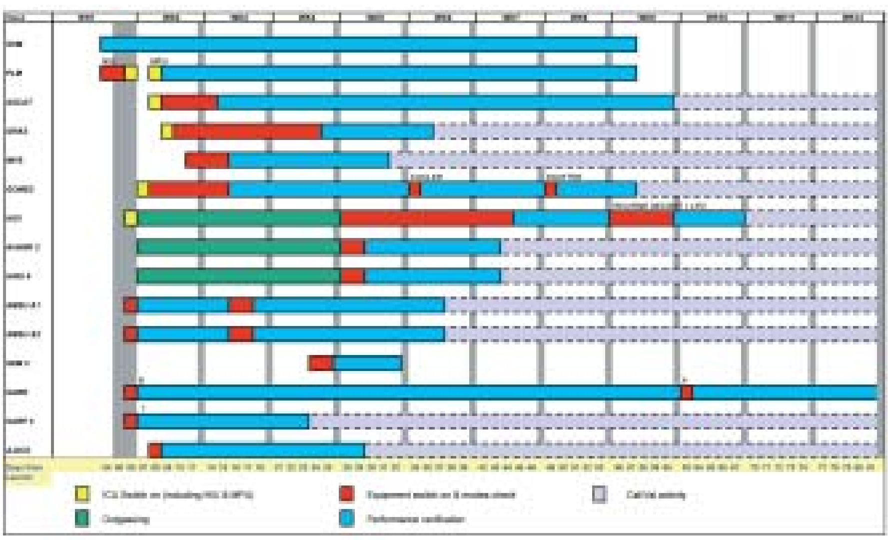
The outcome will be documented through a data package presented to Eumetsat at the SIOV system review. Lessons-learnt for the MetOp-B and MetOp-C SIOVs will be identified.

## EPS Verification and Validation Phase

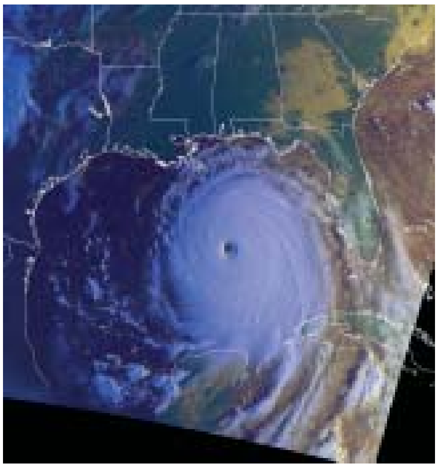
Once the MetOp satellite has been verified in orbit, the Verification and Validation of the full Eumetsat Polar System (EPS), and in particular of its services to the users and its meteorological products, can formally begin. Considering that the SIOV durations vary with each instrument, a progressive release of 'instrument chains' from SIOV into system validation is planned.

The activities at system level during this period can be grouped into two main areas:

- verification and validation of the main EPS ground system functions, data flows, links and services to the users.
- calibration and validation activities for the centrally generated EPS products.



*Chronology of SIOV activities*



*Once commissioned, MetOp will be able to return valuable images such as this: Hurricane Katrina captured by the AVHRR instrument of NOAA-15 on 28 August 2005 (NOAA)*

***EPS system and services verification and validation***

These activities start progressively, often in the background of SIOV operations. They are formally completed only once the corresponding satellite functions are formally verified, at the end of the SIOV phase. They include:

– precise characterisation of the space-to-ground links (S-band, X-band, HRPT, LRPT). This begins as soon as the transponders are switched on.
– HRPT/LRPT local broadcast service verification, starting after the HRPT/LRPT switch-on 5 days after launch, with a verified service available after about a week. This work is completely combined with the SIOV work, for efficiency.
– verification of the Level-0 (raw) data archive & retrieval service. This started when the first instrument data were acquired, about a week after launch. A verified service limited to Level-0 will therefore be available to the SIOV partners (ESA, NOAA, CNES) within a few days. When early Level-1 (uncalibrated) meteorological products are generated, the service will be extended to these products.
– the EUMETCast near-realtime data and products dissemination service will be used to transfer Level-0 data to the partner organisations during SIOV. This begins when level-0 data are available (a week after launch) and will last for the SIOV duration. Then, EUMETCast will be ramped up towards its operational configuration, adding verified Level-1 products as they become available. At the end of commissioning, the full complement of products indicated below will be available on EUMETCast.
– the readiness of the Global Telecommunication System depends on the readiness of the encoding of the EPS products and on the availability of the early products themselves. It is planned to be completed at the latest by the end of commissioning.
– NOAA cross-support services are part of the Initial Joint Polar System between NOAA and Eumetsat and cover the provision of support to NOAA blind orbits and MetOp Level-0 data exchange. These services provided by EPS to the NOAA ground segment will not be exercised initially during the SIOV phase and will be progressively established during the commissioning phase.
– Search & Rescue, Data Collection System Level-0 and Space Environment Monitor Level-0 services will be verified as part of SIOV and become available accordingly.

All EPS services to the users will be operationally validated by the end of the system commissioning at the latest, with the exception of the Level-2 (calibrated) product dissemination service.

***Products: calibration and validation***

Before launch, all EPS processing functions for Level-1 products (corresponding to geo-located, calibrated instrument data) were brought up to their target commissioning baseline, which incorporates all critical changes, bug fixes and updates to the product formats resulting from testing. This configured baseline is reflected in the product format information available on *www.eumetsat.int* and will be used for the initial processing of the data.

Thanks to the common instrument suite between MetOp and the NOAA-18 satellite launched in 2005, extensive testing could be performed using real NOAA data dumped to the Eumetsat CDA station in Svalbard or transferred by NOAA via the high-rate transatlantic link. These data were regularly processed in near-realtime within the EPS ground segment. This covered Level-1 products from the AVHRR, MHS, AMSU and HIRS instruments. All other Level-1 products from the IASI, GOME, ASCAT and GRAS instruments were tested before launch using real Metop data, synthetic data or modified data from satellites.

For each instrument chain, the logical sequence is:

– after the verification of an instrument and its release from SIOV, the correct geo-location and radiometry of the Level-1 products are verified using the tools at Eumetsat and partner-organisation premises. Then, the products are disseminated as preliminary validation products via EUMETCast.
– these Level-1 products are then validated over several weeks to several months. During this, the processing parameters are optimised. A Validation Report is produced at the end of the commissioning phase.
– validation of the Level-2 products can start only once the corresponding Level-1 products have been validated. This will begin some 6 months after launch for IASI and ATOVS. Early products will be released once verified. Specific sounding campaigns are planned.

## The Organisational Challenge

The challenge of the MetOp LEOP and commissioning lies in the very complex cooperative and/or contractual arrangements of the numerous actors across Europe and the US. Managing LEOP and SIOV requires very clear coordination to keep a large number of distributed activities focused on the objectives over a long time.

# Columbus Begins its Voyage of Discovery

*Alan Thirkettle & Bernardo Patti*
Directorate of Human Spaceflight, Microgravity & Exploration, ESTEC, Noordwijk, The Netherlands

***The Columbus laboratory was delivered to NASA's Kennedy Space Center in Florida on 30 May, to be prepared for launch in September 2007. As Europe's largest single contribution to the International Space Station, Columbus will host a wide range of important experiments for years to come.***

## Development

Columbus development began in 1996 with the signature of the ‘Phase-C/D’ contract between ESA and prime contractor EADS Space Transportation (DASA at the time). Phases-C and -D are the detailed development and manufacturing phases of a spacecraft, concluding with delivery to the launch site.

In parallel with development of the module, work also began on the scientific payload racks: Biolab, Fluid Science Laboratory (FSL), European Physiology Module (EPM) and the European Drawer Rack (EDR).

Along with the usual challenges of a conventional Phase-C/D programme, the Columbus engineers had to cope with changing multiple interfaces as the rest of the International Space Station (ISS), including its Node-2 in-orbit

*Columbus is removed from its shipping container in the Space Station Processing Facility. In the background is Japan’s Kibo module*


At a ceremony to mark the delivery of Columbus by EADS Space Transportation to ESA in Bremen on 2 May, German Chancellor Angela Merkel expressed her view that research under weightlessness has brought incredible progress to the various disciplines involved and considered the scientific possibilities provided by the Columbus laboratory as being of inestimable value

Columbus is loaded into its transport container in Bremen (ESA/S. Corvaja)

Loading the cargo plane at Bremen Airport

Columbus arrives at the Space Station Processing Facility on 31 May

Columbus is removed from its shipping container.

physical host, and the distributed multinational ground system were developed at the same time.

The Preliminary Design Review for the whole system took place at the end of 1997. Shortly after, the Exposed Payload Facility was added to the design and work began on the SOLAR telescopes and the European Technology Exposure Facility (EuTEF) external payloads. At the end of 2000, the design phase was completed and Columbus passed its Critical Design Review.

When the contract was signed in 1996, the target launch date was 2002. But delays in the Russian ISS segment, in particular the Zvezda Service Module, required the Columbus schedule to be slowed for a launch in October 2004. That period saw several modifications: an autonomous Ku-band terminal, a 100 Mbit/s Local Area Network and the Digital Video System.

In February 2003, the tragic loss of Shuttle *Columbia* and its crew meant another delay, this time of 3 years. During this period, the programme completed its qualification process, with a successful Qualification Review of the whole system completed in late 2004.

## Shipment

Following a Final Acceptance Review, consent to ship the module and its


Columbus lands on the Shuttle runway at KSC on 30 May

In the background is Japan's Kibo module

Columbus Project Manager Bernardo Patti waits for Columbus to be hoisted from its container


Alan Thirkettle, ESA's ISS Programme Manager, marks the arrival of Columbus at its launch site

internal payloads to KSC was given in early May. The 4.5 m-diameter cylindrical module was packed into its transportation container at EADS Space Transportation in Bremen (D). On 28 May, the container was loaded onto an Airbus A300-600 Beluga heavy-lift aircraft at Bremen Airport. With overnight stopovers in Iceland and Canada along the way, and short refuelling stops in Edinburgh, Greenland and Cleveland, Columbus touched down shortly after 15:00 local time on 30 May at the Shuttle Landing Facility at KSC.

Columbus was unloaded from the Beluga and transported to the Space Station Processing Facility. The Beluga flew back to Turin (I) with the empty transport container which will be used in early 2007 for the shipment of Node-3, the last major European-built element and now nearing completion at Alcatel Alenia Spazio.

## Launch Campaign

The launch campaign was initially planned to last 7 months but has now been divided into two phases. During Phase-1, from June to August 2006, Columbus will have its arrival inspection, undergo a leak test in the KSC Large Vacuum Chamber and complete a series of interface tests that are essentially 'fit checks' between the module's berthing system and NASA's Node-2 simulator.

Columbus is installed in its processing stand. Almost hidden at far right is Node-2, which Columbus will be attached to on the ISS

Around March/April 2007, about 6 months before launch, activities will resume with Phase-2's final health check of the systems, replacement of the water in the cooling loop and the hand-over to NASA for integration of the module into Shuttle *Endeavour*.

## The Challenges Ahead

Columbus is scheduled for launch in September 2007. Shortly before, a number of critical activities have to be completed in addition to those mentioned above:

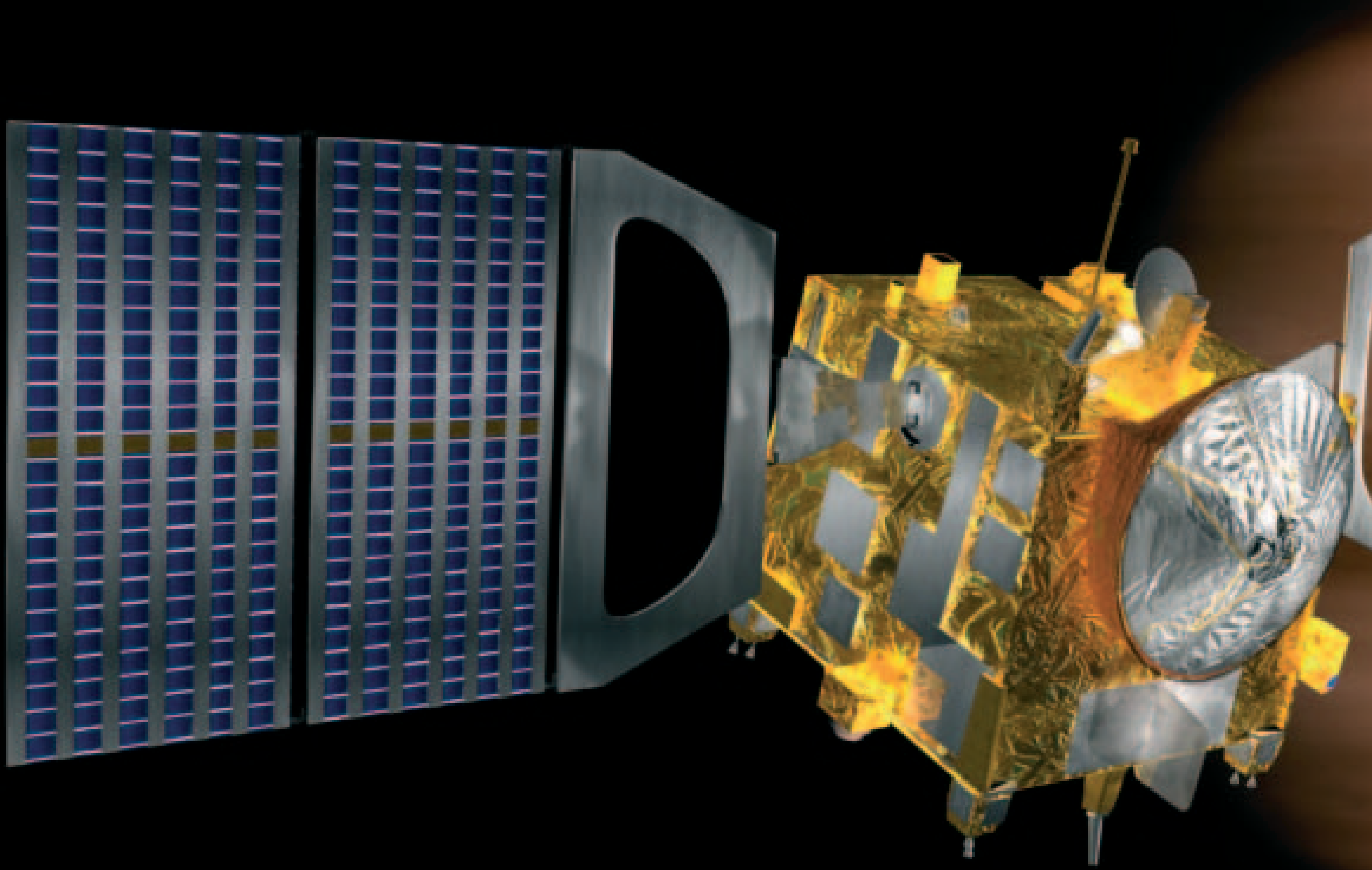
- acceptance of the SOLAR and EuTEF external payloads, together with their end-to-end test campaigns;
- validation of operational procedures for system and payloads and the completion of the end-to-end test campaign with NASA;
- simulations required for ground operator/flight controller training and certification;
- commissioning and readiness of the Columbus Control Centre (at DLR Oberpfaffenhofen in Germany) and the associated User Support Operations Centres throughout Europe;
- training astronauts and cosmonauts for the launch of Columbus (ISS flight 1E) and the subsequent on-orbit commissioning and science operations during ISS Increment-16.

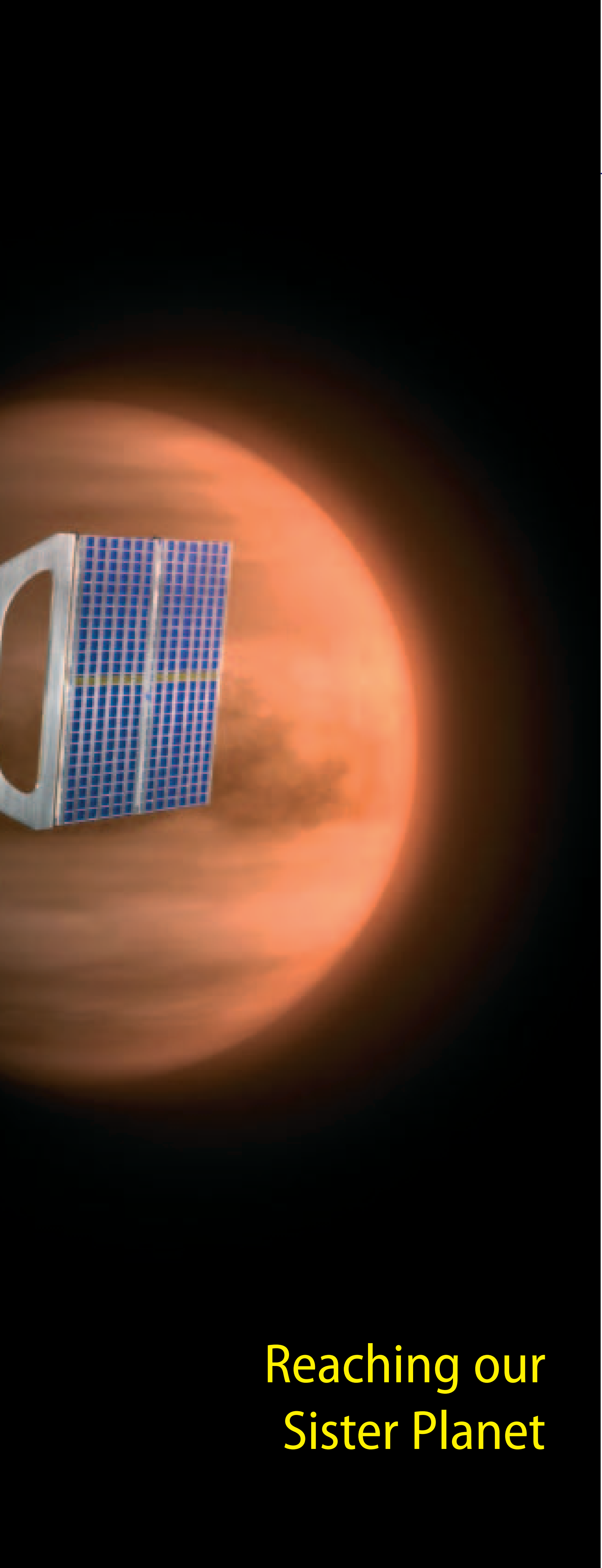
Some open issues also need to be resolved:

- selection of crewmembers on ISS flight 1E for a long-duration flight of an ESA astronaut during Columbus commissioning;
- accommodation of the experiment manifest in the payload rack facilities (Biolab, FLS, EPM and EDR);
- the potential use of Columbus spare mass capacity for carrying extra cargo to the ISS on 1E; every kilogramme of cargo is so important now that Shuttle retirement is approaching.

*Late news:* Hans Schlegl was announced on 21 July as the ESA astronaut to accompany Columbus to the ISS. See the *In Brief* section in this issue for more information.

# From Earth to Venus





# Reaching our Sister Planet

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Mission Operations Department, Directorate of Operations and Infrastructure, ESOC, Darmstadt, Germany

***In the early morning of 9 November 2005, Venus Express left Earth aboard a Soyuz launch vehicle and headed for Venus. After several months of interplanetary cruise, a perfect capture burn on 11 April 2006 placed the spacecraft in orbit around our neighbouring planet. Only 48 hours later, the first astonishing images of the south pole were received on Earth. A few weeks later, after orbital manoeuvres, Venus Express achieved its operational science orbit ready to begin several years of observations.***

## Travel Planning

Preparations for the Venus Express mission began in early 2003 at ESOC with the build-up of the Flight Control Team and the definition of the systems required to test, control and monitor the new spacecraft for its flight to and around Venus. Major reuse of the systems developed for Rosetta and Mars Express allowed the ground teams to focus on the required modifications and improvements. The preparation phase went smoothly even though the mission posed new challenges for the operations team, mainly through the thermal


The Cebreros ground station

problems created by the roasting hot environment. In parallel, ESA built a new 35 m-diameter deep-space dish antenna in Cebreros (E) to cope with the workload from the four interplanetary missions operated by ESOC: Rosetta, Mars Express, SMART-1 and Venus Express.

System validation tests were conducted during the summer of 2005, before the simulation campaign of July–October. It was only at the end of this successful campaign that the ground segment was declared 'green' for launch.

## Launch and Early Orbit Phase (LEOP)

The first launch attempt was scheduled for 26 October 2005. However, routine inspection of the assembled launch vehicle revealed tiny pieces of insulation deposited on various surfaces of the spacecraft and the Fregat upper stage. Their origin was uncertain, so the launch was postponed to study the unexpected problem. It was quickly determined that hydrazine propellant had damaged Fregat's engine insulation, which had peeled off and was dispersed by the air circulation system inside the fairing. For safety, it was decided to return the entire vehicle to the assembly building and refurbish the Fregat. After frantic repair work, all was well for launch in the early hours of 9 November. This time, everything went according to plan: the Soyuz vehicle and its upper stage operated flawlessly, delivering Venus Express into the targeted escape trajectory with near-perfect precision.

The early orbit phase went smoothly. In the first contact after launch, the signal was acquired from the craft's S-band omnidirectional antennas. The solar wings were deployed automatically following separation from the upper stage, and the reaction wheels were spun up and put into service by the control team. Over the next few ground station contacts, Venus Express was configured for commissioning. Critical activities included switching communications to X-band (for a high data rate) using the spacecraft's second high-gain antenna (HGA2) on the second day, and a small course correction of 3.43 m/s 12 hours later. In total, it took less than 53 hours to complete all these activities, ready for the Near-Earth Commissioning Phase to being immediately afterwards.

## Near-Earth Commissioning Phase (NECP)

During NECP, the spacecraft systems and payloads were checked out for the first time in space; this took from 12 November to 15 December. Venus Express was still close to Earth, so the brief travel time for the signals allowed very careful near-realtime commanding. Critical checkout operations were conducted during the 7 hours per day of ground station contact using the new antenna at Cebreros.

NECP was split in two parts. The first week was dedicated to a checkout of the spacecraft subsystems, while the remaining 4 weeks were used to test all the scientific instruments.

### *Subsystem checkout*

During the spacecraft checkout, all the units of the radio-frequency (RF) subsystem (transmitters, receivers and antennas) were tested and the HGA-2 radiation pattern was calibrated. For the thermal system, several heater configurations were tested to prove that the

Andrea Accomazzo, Spacecraft Operations Manager, in ESOC's Mission Control Room during the launch of Venus Express on 9 November 2005

The mission control team anxiously await confirmation of orbit capture, ESOC Main Control Room, 11 April 2006

heater lines and heater switches were working properly.

As part of the Attitude and Orbital Control System (AOCS) checkout, a startracker health check was performed together with calibration of the alignment. The Reaction Control System thrusters were fired to test their performance; a 'disturbance torque characterisation' assessed the forces from solar radiation on the spacecraft in various attitudes. Finally, the redundant Solar Array Drive Mechanism was tested by rotating the wings a few degrees.

For the data-handling subsystem, several memory areas of the computers were dumped to serve as a reference ground image of the onboard software. In addition, the redundant Transfer Frame Generator, responsible for the telemetry composition and modulation on the RF signal, was tested.

### *Payload checkout*

During the payload commissioning all the scientific instruments were switched on, tested and calibrated to check the interfaces with spacecraft power, data-handling, telemetry and telecommand systems, and to verify that the overall performance was satisfactory.

On 22 November, after the initial instrument health check of VMC and VIRTIS, the two cameras were pointed towards Earth and imaged the Earth-Moon system from 3.5 million km out. A minor modification to the VMC software was then installed to prepare it for the upcoming pointing and interference campaign. Following this, SPICAV was commissioned.

To accommodate requests from the science community for instrument calibrations with special spacecraft pointing, a dedicated pointing campaign was prepared by the Venus Express Science Operations Centre (VSOC) for 27 November to 3 December. It was also used to validate further the ground segment interfaces between VSOC at ESTEC in The Netherlands and the Mission Operations Centre (MOC) at ESOC in Germany. The PFS, ASPERA and VeRA instruments were then commissioned.

Once all the instruments were checked out separately, a dedicated interference test concluded the NECP on 15 December. Several instruments were operated simultaneously in various modes to look at potential interferences between them and with the spacecraft systems.

## Interplanetary Cruise Phase (ICP)

After NECP, the ICP lasted formally until 4 April 2006, a week before the Venus Orbit Insertion (VOI). ICP was initially considered as a quiet period operationally speaking, with only a few spacecraft activities to be carried out in preparation for VOI. However, it soon turned into a very busy period during which many important spacecraft and payload operations were scheduled.

### *Payload operations during cruise*

While only a 1-week payload checkout was originally planned, in mid-January 2006, payload operations in reality had to be scheduled throughout the entire cruise phase. Following the second payload pointing campaign in January, almost all of the instruments were operated several times for various reasons. While the magnetometer was kept on for most of the time, to measure interplanetary magnetic fields, ASPERA was activated periodically to prepare for the routine mission. The Radio Science

ESA Director General Jean-Jacques Dordain congratulates Flight Director Manfred Warhaut upon receiving confirmation thatVenus Express had successfully entered orbit, 11 April 2006 team performed several frequency-drift tests on the onboard Ultra Stable Oscillator to characterise the frequency stability over time. The PFS, SPICAV, VMC and VIRTIS instrument teams took the opportunity to retest, fine-tune and improve their onboard software.

***Spacecraft operations during cruise***

During the cruise phase, the experiment teams were not alone in using the time to prepare for the routine mission – the Flight Control Team had to get the spacecraft ready for Venus arrival. At the start of ICP on 16 December, the batteries were discharged to 50% for a month to save battery life for the routine mission. During the rest of the month, several navigation tests were performed using NASA's Deep Space Network (DSN) stations and, for the first time, Cebreros combined with the New Norcia station in Australia. Those tests prepared for the intense navigation and tracking campaign later during cruise.

Following the payload pointing campaign, an intense thermal characterisation campaign started on 23 January 2006 to correlate the thermal model with flight data. Venus Express was pointed so that the Sun illuminated the heat-critical faces +Y, –Y, –Z and –X at an angle of 5º each for 24 hours, followed by an equivalent cooling period. This exercise confirmed the thermal tolerances were acceptable for operations. It was noted that the reaction wheel temperatures were higher than predicted after the Sun had been shining at 5º on the –X face. It was soon found that this contributed to some 'outgassing events' that disappeared later on.

In preparation for Venus arrival, the startrackers were checked on 7 and 8 February by pointing them at the same regions of sky as they would see in the days just before VOI.

From 9 February, all activities focused on the mission's next major milestone: the first firing of the main 400 N engine. In preparation for this important event, the thermal system was configured to warm the helium tank, the data-handling system was switched to a special telemetry mode that provided more frequent subsystem data, and the RF system transmitted an S-band carrier signal throughout the engine burn to simulate the operation planned for VOI. On 17 February, the engine firing went perfectly – to the relief of the whole project team! A week later, a small adjustment was made using the 10 N thrusters, tweaking the trajectory change from by the main engine test.

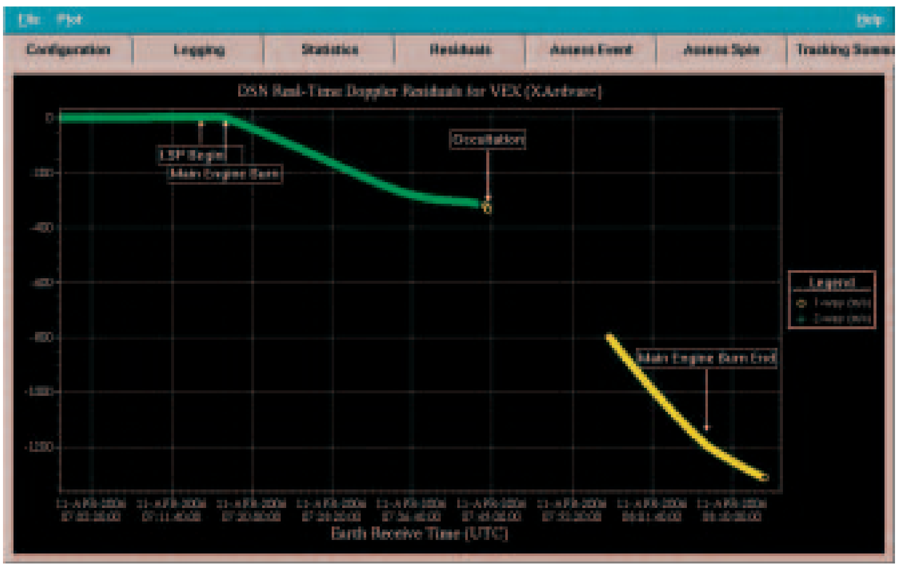
The next milestone was then a rehearsal on 6 March of the VOI operations, performed using the 70 m DSN antenna in Madrid. To train the Flight Control Team and ground station operators from ESA and DSN, and to rehearse the communications aspects of VOI, Venus Express was turned to simulate the same low-gain antenna geometry with Earth. Acquiring the S-band uplink was practised and one-way and two-way Doppler data were monitored. Even the occultation by Venus expected during VOI was simulated by temporarily switching off the onboard S-band transmitter.

From the beginning of March until VOI on 11 April, the navigation and tracking campaign was very intense. Throughout the cruise, about 50 ground station passes in addition to the normal Cebreros communication passes were scheduled with NASA stations to get Doppler and ranging measurements from an independent (non-ESA) source for orbit determination. In addition to the conventional Doppler and ranging methods, the new 'Delta Differential One-way Range' technique was used for navigation. With two ground stations simultaneously measuring the signals from Venus Express and an extragalactic source (a quasar), navigators could determine the position of the spacecraft very accurately.

## Venus Orbit Insertion

VOI lasted from one week before the capture burn to 26 days afterwards, when the last of a series of seven orbit-control manoeuvres placed Venus Express in its operational orbit. The main strategy during this phase relied on an early upload of the minimum set of commands necessary to perform the insertion burn (done 4 days before the burn). This set of commands included the slews to and from the burn attitude, the X-band transmitter switched to 'OFF' and 'ON' (as the transmitter was kept off during the burn), and related attitude control mode transitions.

In the final days before insertion, additional slots were reserved for




*The Doppler signal from Venus Express during the capture burn, displayed using Jet Propulsion Laboratory/DSN software installed at ESOC specifically for VOI*

**How Venus Express Reached Operational Orbit**

| *Date (UT)* | *400/10 N?* | *Burn Type* | *Speed Change (m/s)* | *Duration (s)* | *Venus Orbit* |
|---|---|---|---|---|---|
| 10 Nov 05 | 10 N | test | 0.500 | 50 | – |
| 11 Nov 05 | 10 N | launch correction | 3.430 | 211 | – |
| 17 Feb 06 | 400 N | main engine calibration | 2.840 | 154 | – |
| 24 Feb 06 | 10 N | main engine calibration comparison | 0.137 | 14 | – |
| 30 Mar 06 | 10 N | trajectory correction | 0.130 | 14 | – |
| 11 Apr 06 | 400 N | capture | 1251.590 | 3163 | 330 685 x 662 km, 9 d |
| 15 Apr 06 | 10 N | pericentre control #1 | 5.806 | 504 | 330 685 x 257 km, 9 d |
| 20 Apr 06 | 400 N | apocentre lowering #1 | 200.300 | 529 | 99 108 x 259, 40 h |
| 23 Apr 06 | 400 N | apocentre lowering #2 | 105.320 | 343 | 70 463 x 268 km, 26 h |
| 26 Apr 06 | 10 N | apocentre lowering #3 | 9.165 | 670 | 68 000 x 268 km, 25 h |
| 30 Apr 06 | 10 N | apocentre lowering #4 | 8.035 | 603 | 67 000 x 268 km, 24.2 h |
| 3 May 06 | 10 N | apocentre lowering #5 | 1.952 | 233 | 66 582 x 268 km, 24.02 h |
| 6 May 06 | 10 N | pericentre control #2 | 3.101 | 301 | 66 582 x 249 km, 24.0 h |

trajectory-correction manoeuvres (13, 6 and 2 days before the burn), to correct for minor targeting errors as the spacecraft approached Venus. A 'last chance' emergency manoeuvre slot was reserved at 6 hours before the burn. This upload opportunity was to be used only if a trajectory estimation anomaly was identified in the final hours before passage through pericentre (the closest approach to Venus). In that case, an emergency pericentre-raising burn could be commanded if the path was too low (which would plough the craft into Venus), or conversely a longer insertion burn if it was too high. Fortunately, only the first of these slots, 13 days before arrival, had to be used to perform a tiny correction.

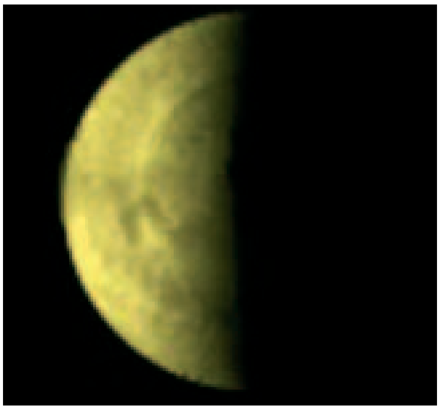
During this phase, Venus Express was gradually commanded into a special, fault-tolerant configuration in which most of the autonomous 'Failure Detection, Isolation and Recovery' functions were disabled, thus transferring some monitoring functions to the Flight Control Team. This minimised the chances of an automatic spacecraft reconfiguration being triggered close to or during the insertion burn, which would have resulted in a missed insertion and no possibility of trying again. The various measures taken to increase robustness included turning off monitoring of the power system. Most AOCS and data-management system monitoring was either disabled or allowed only at local level; only low-level reconfiguration possible. Rebooting the Processor Module was forbidden and the Mass Memory was also switched off.

This last point meant that no telemetry could be stored during the burn; in the event of problems, the Flight Control Team would have had very limited information on the possible causes. The last command was sent up to Venus Express 12 hours before the burn.

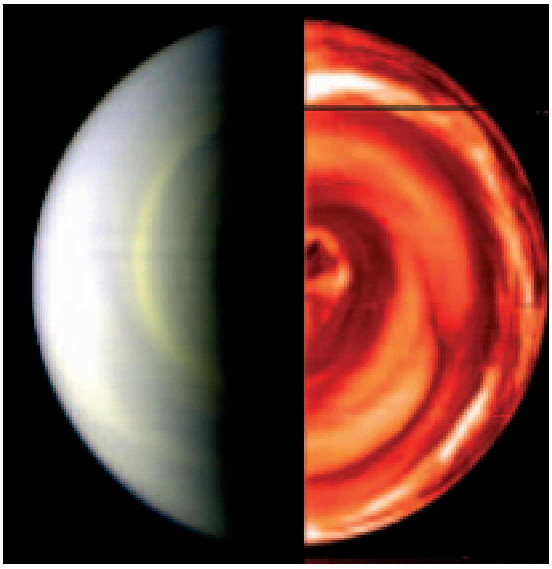
On 11 April 2006, the spacecraft ignited its main engine at 07:10 UT (at the time, the signal took about 7 minutes to reach Earth). During the burn, contact with the ground via the high-gain antenna was not possible owing to its orientation, but the front low-gain antenna was configured with the redundant transmitter to emit an S-band carrier. The 70 m DSN antenna at Madrid picked up this signal, which was relayed in real-time to ESOC to monitor the spacecraft during most of the manoeuvre.

About half an hour into the burn, the spacecraft swung behind Venus, cutting off its signal. It was reacquired on schedule at 07:55 UT, confirming that the capture trajectory was nominal (again, to the relief of controllers). The burn lasted about 50 minutes, and slowed the spacecraft by around 1250 m/s. Venus Express was now in a highly elliptical, 10-day orbit around Venus.

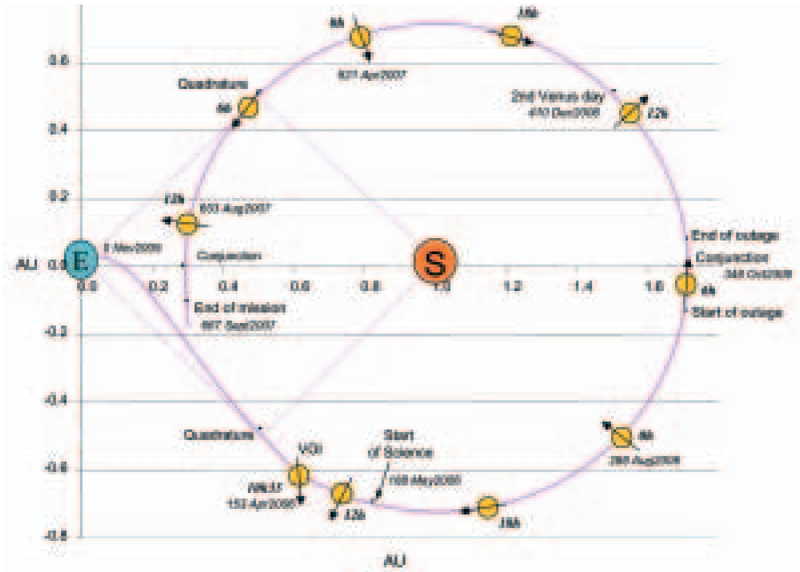
The burn was performed close to quadrature – the Sun and Earth were 90º apart as seen from the spacecraft. Given the spacecraft design, controllers wanted to avoid direct Sun illumination of the craft's cold faces in order to prevent overheating. This meant swapping high-gain antenna usage from



*VMC's first image of the planet's south pole. (ESA/MPS, Katlenburg-Lindau, Germany)*



VIRTIS first image of the south pole. (ESA/INAF-IASE, Rome, Italy/Observatoire de Paris, France




The Venus Express mission

HGA-2 to HGA-1. Awkwardly, this had to be done during the insertion phase. It was decided that the safest strategy (in order to avoid blinding the startrackers with sunlight reflected from Venus) was to remain on HGA-2 until after capture, and make the swap 24 hours later.

With the spacecraft safely orbiting Venus, the Flight Control Team went ahead with the first batch of science observations of the planet, which were produced and downloaded to the ground only 2 days after having successfully performed the capture burn.

The team then commanded a series of manoeuvres to bring the spacecraft down to a 24-hour polar orbit suitable for science operations. To do this, five manoeuvres were made at the pericentre of the transfer orbit, and two more at the apocentre. Two firings were executed with the 400 N main engine, first slowing Venus Express by 200 m/s and then by 105 m/s. The others used the 10 N thrusters, which will also be called on from now on to maintain the orbit. Finally, on 7 May, the operational orbit was reached and the commissioning of the scientific payloads could be completed on schedule.

## Outlook

Venus Express is now orbiting the planet in its routine science operations phase, to end in October 2007 after two Venusian sidereal days (486 Earth days). The spacecraft is operated by the MOC at ESOC with inputs for science activities from the VSOC at ESTEC. Daily contacts with the spacecraft are established through Cebreros. Science data collection has just started and will proceed in the coming months with additional types of observations possible only when the spacecraft is in an Earth-occultation season (July–August 2006) or a solar-conjunction phase (October–November 2006).

After the superior solar conjunction in October, when the Sun is between the spacecraft and Earth, the Earth distance will start decreasing again. This will allow higher data rates for the science downlink. Spacecraft resources have been designed so that an extension of two Venusian days is possible, to January 2009. With the current condition of Venus Express and the propellant margin, it is perfectly feasible and might stretch even further. esa

**Acronyms**

- AOCS: Attitude and Orbit Correction System
- ASPERA: Analyser of Space Plasmas and Energetic Neutral Atoms
- DSN: Deep Space Network
- HGA: High-Gain Antenna
- ICP: Interplanetary Cruise Phase
- MOC: Mission Operations Centre
- NECP: Near-Earth Commissioning Phase
- PFS: Planetary Fourier Spectrometer
- RF: Radio Frequency
- SPICAV: Spectrometer for Analysis of the Venus Atmosphere
- VeRA: Venus Radio Science Experiment
- VSOC: Venus Express Science Operations Centre
- VIRTIS: Visible Infrared Thermal Imaging Spectrometer
- VMC: Venus Monitoring Camera
- VOI: Venus Orbit Insertion
- VSOC: Venus Express Science Operations Centre

*Detailed information on Venus Express and its mission can be found in Bulletin 124 (November 2005), pages 8–32. The Venus Express website provides up-to-date information at www.esa.int/venus*

# Vega on the Move

## Heading towards Qualification

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Direction des Lanceurs, CNES, Evry, France

***Vega, the European small launcher, will expand the range of launch services offered by Arianespace from French Guiana. It is particularly suited to the smaller Earth-observation and scientific satellites from European institutions, and will reinforce Europe's strategy of guaranteeing affordable access to space. The first launch is scheduled for November 2007.***

## Introduction

Vega is an ESA optional programme financed by Belgium, France, Italy, The Netherlands, Spain, Sweden and Switzerland. It is managed by the Vega Department within the Directorate of Launchers, with an Integrated Project Team from ESA, ASI and CNES at ESRIN (Frascati, I) and the CNES Launcher Directorate (Evry, F). The two Vega programme declarations cover three projects:

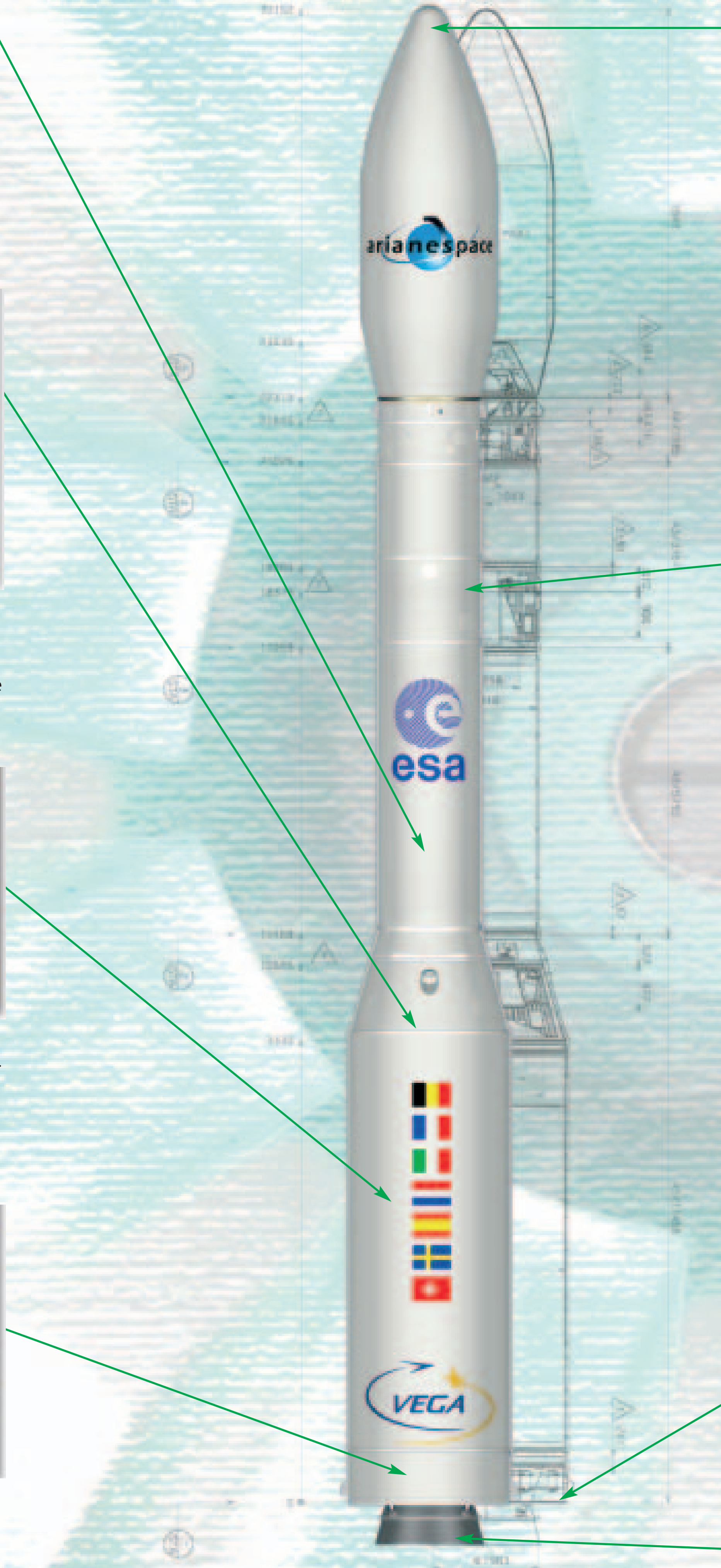
- the Launch Vehicle, with ELV SpA (Colleferro, I) as prime contractor;
- the P80 Demonstrator (the Vega first stage solid-propellant motor), with

The Z23 Zefiro stage-2 solid-propellant motor is prepared for shipment to Sardinia for the June 2006 firing test.

The Structural Model of Interstage-1/2 at Dutch Space in Leiden (NL) during integration. The interstage remains attached to stage-1 and carries six forward-facing solid-propellant retrorockets to ease separation at the end of the 107-second P80 burn. The interstage qualification tests are under way.

The P80 motor case (length 10 m, diameter 3 m) at Avio in Colleferro (I). The case is then shipped to French Guiana for propellant casting, integration of components such as the nozzle, thrust vector control and sensors. The qualification firing is scheduled for November 2006 on the site's BEAP teat stand. *(ESA/S. Corvaja)*

The completed interstage-0/1, developed by SABCA (B). The large box is the Control & Power Distribution Unit (SABCA, B), flanked by four Li-ion batteries (SAFT, F). This model will soon complete qualification mechanical tests.



*Contraves Space (CH)*
*Fairing*

*EADS CASA (E)*
*Adapter*

*Thales, Zodiac, Galileo Avionica, CRISA, SAAB, SAFT*
*AVUM Avionics*
*Avio (I)*
*AVUM (stage integration and test)*

*EADS CASA (E)*
*AVUM Structure and AVUM Skirt*

*Avio (I)*
*AVUM Propulsion System*

*Avio*
*Italy, 3rd Stage (production, integration and test)*

*SABCA (B)*
*3rd Stage Thrust Vector Control*

*Oerlikon Contraves Italia (I)*
*2/3 Interstage*

*Avio (I)*
*2nd Stage (production, integration and test)*

*SABCA (B)*
*2nd Stage Thrust Vector Control*

*Dutch Space (NL)*
*1/2 Interstage*
*Stork Product Engineering (NL)*
*Stage 1-2 igniters*

*Avio (I)*
*1st Stage (stage integration and test)*

*Europropulsion (F)*
*P80 Filament Wound Motor*

*SABCA (B)*
*Interstage Skirt*

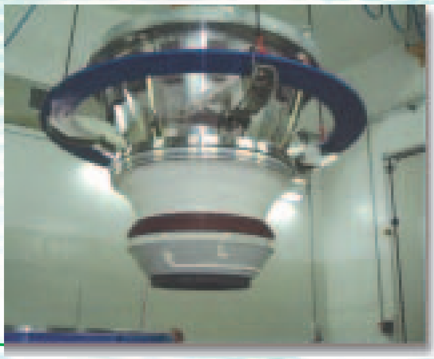
*SABCA (B)*
*1st Stage Thrust Vector Control*

*SNECMA Propulsion Solide (F)*
*Nozzle*

Final integration of the fairing qualification model at prime contractor Contraves(CH). Mechanical and separation tests will be performed on this model during the summer.

Interstage-2/3 tests at ELV. The interstage is being developed by Oerlikon Contraves Italiana (I). It has satisfied the qualification vibration level (higher than the expected flight environment), and a separation test was successful in February 2006.

The 'Maquette de Pilotage' facility at ELV (Colleferro, I) was inaugurated in April. It is now being used to characterise the P80 small control loop: moving the nozzle via the electromechanical actuator developed by SABCA (B). Later on, it will be connected to the onboard computer to simulate complete flight sequences and to check the real-time and dynamic performances under realistic conditions. The current tests include rehearsals of the sequence of nozzle movements for the P80 firing test in French Guiana in November. *(ESA/S. Corvaja)*



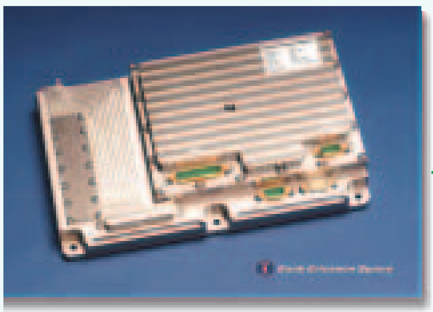
Hoisting the P80 nozzle for integration in the control-loop test facility. The nozzle was developed by SNECMA Propulsion Solide (F). The advanced technologies used for the flexible joint and exit cone were covered by the separate P80 demonstrator programme in order to optimise the recurring cost in production. The nozzle for the P80 qualification firing in November was shipped in July to French Guiana for integration with the motor.

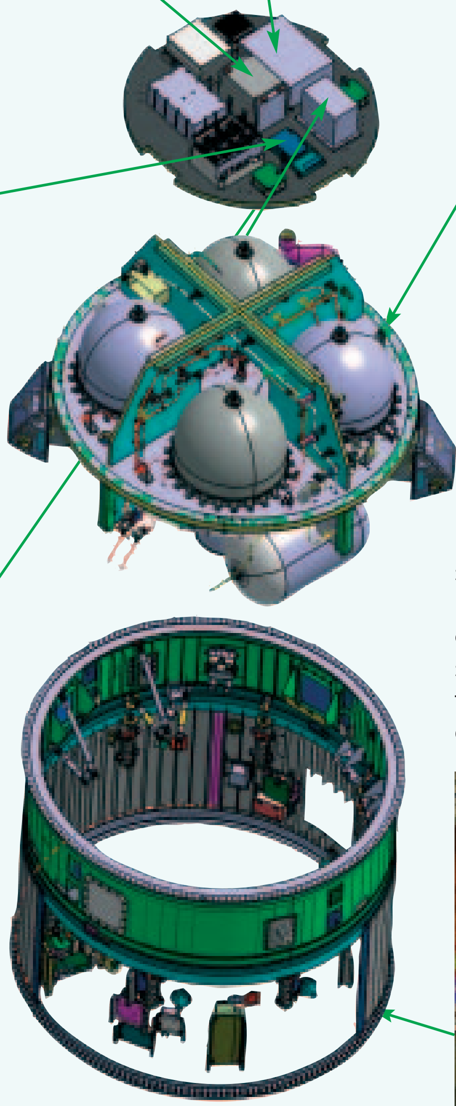
Vega's Inertial Reference Navigation System (Thales, F) is an off-the-shelf item from Ariane-5.

The Multifunctional Unit, developed by EADS-Astrium (E), distributes power to avionics units and relays pyrotechnic commands from the computer.

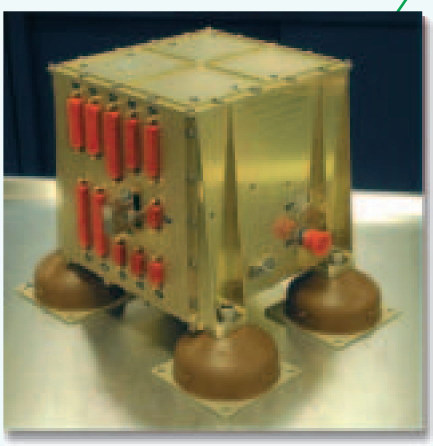
Integration of the AVUM structural models and fluid subsystem components at ELV (Colleferro) for the upper composite mechanical tests.
*(ESA/S. Corvaja)*

The On-Board Computer, developed by SES (S).

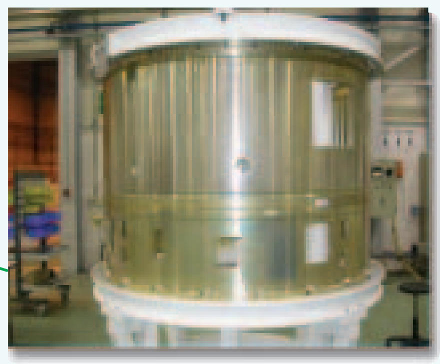




The Safety Main Unit, developed by Galileo Avionica (I). Qualification is planned for summer 2006. Part of the 'Safeguard' system, its job is to issue destruct commands to the lower stages in the event of flight problems.



Manufacture of the interstage-3/AVUM structure at EADS-CASA (E). This will be integrated with the other upper composite elements (AVUM fluids subsystem and avionics, adapter, fairing) for the overall mechanical and acoustic qualification tests at ESTEC later in 2006.



*The former ELA-1 Ariane-1 launch pad in French Guiana is being reworked for Vega*

Avio SpA (Colleferro, I) as prime and Europropulsion (Suresnes, F) as main contractor;
– the Ground Segment, with Vitrociset SpA (Rome, I) as prime contractor.

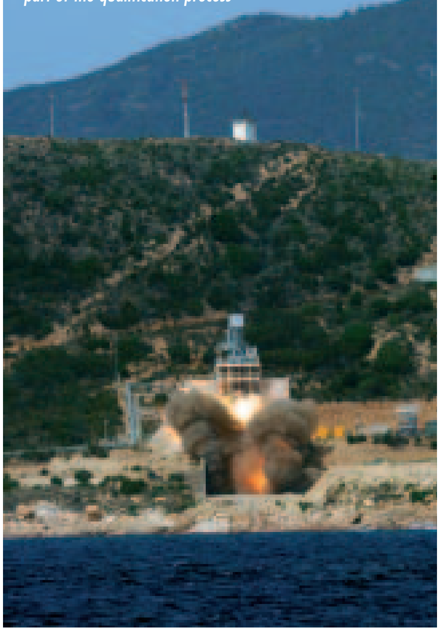
Vega has three solid-propellant stages topped by a liquid-propellant upper module. It is about 30 m high, 3.0 m in diameter and has a launch mass of 137 t (excluding payload). The three main sections are the Lower Composite (principally the three solid motors and their interstages), the Restartable Upper Module and the Payload Composite. The thrust at lift-off is about 2700 kN and reaches a maximum of 3040 kN during the P80 first-stage burn.

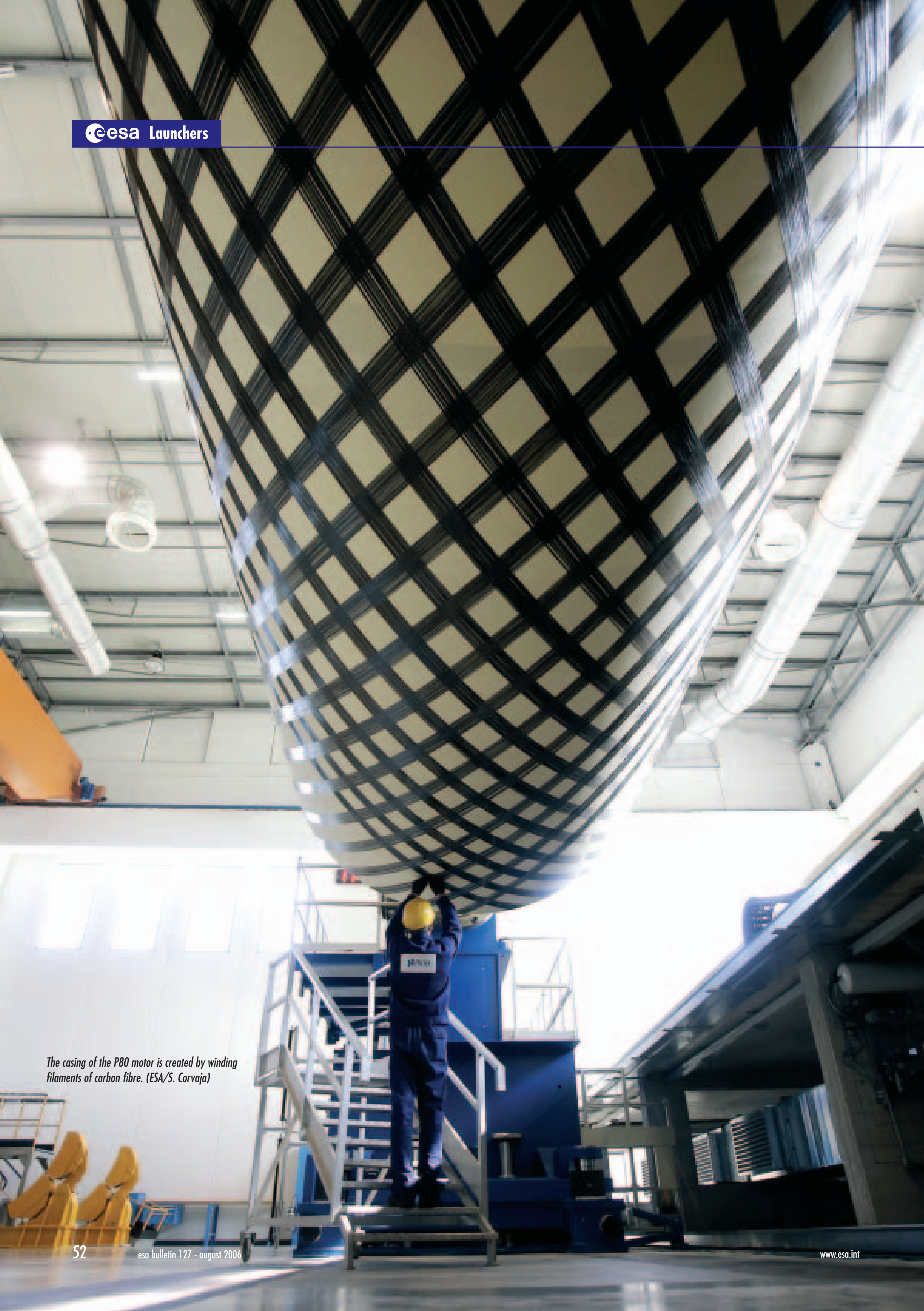
Vega is sized to deliver 300–2000 kg payloads (and eventually as multiple payloads) directly into Sun-synchronous orbits, polar circular orbits or circular orbits of different inclinations with altitudes ranging from 300 km to 1500 km. In addition, the reignition capability of the Attitude & Vernier Upper Module (AVUM) offers great flexibility for servicing a variety of elliptical orbits.

## Status

Where is the Vega programme today? Many subsystems have passed their Critical Design Reviews and some have begun the qualification process. Since last year, testing has progressively replaced the specification, design and trade-off analyses and simulation work; this trend will become even more obvious in 2006. In October 2005, a firing test of the AVUM engine was successful at contractor Yuzhnoye in Ukraine. This was followed in December by the first firing of Vega's Zefiro-9 third-stage motor, at Salto di Quirra in south-eastern Sardinia. esa

*The first Zefiro test, in Sardinia during December 2005, was followed by a Z23 stage-2 motor firing on 26 June. Further tests are planned for end-2006 and in 2007 as part of the qualification process*





The casing of the P80 motor is created by winding filaments of carbon fibre. (ESA/S. Corvaja)

This year is even more challenging for Vega, because many of the subsystems are now undergoing significant testing and beginning their qualification process. Three solid-motor firing tests are planned – two in Sardinia and one at Europe's Spaceport in French Guiana. At the same time, the Upper Composite mechanical tests and hardware-in-the-loop tests at system level have started and will be completed before the System Critical Design Review at the end of 2006. This is a major step towards the combined tests of mid-2007, integrating the launch vehicle and the ground segment components to check the interfaces and the operational concept to be used for the qualification campaign.

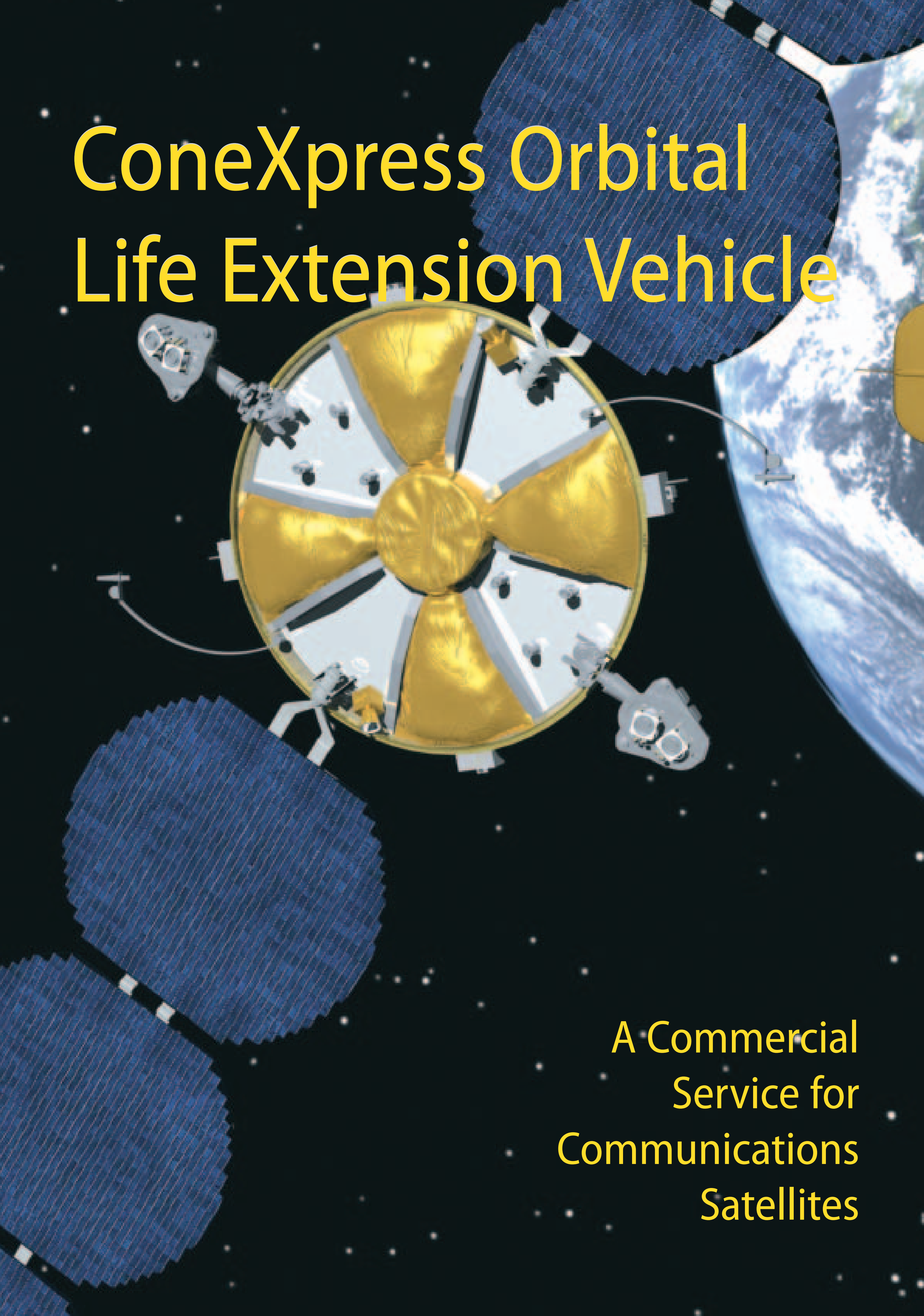
At the Spaceport, work continues on adapting the former Ariane-1 launch pad for Vega. The Mobile Gantry, where Vega's integration and preparation will be performed, will be completed in the last quarter of 2006. This then allows the installation of subsystems such as air conditioning, fluids and power to go ahead. Vega's control centre will be located in the Centre de Lancement CDL-3, the same building used for conducting Ariane-5 operations.

The qualification flight at the end of 2007 will give the green light for the exploitation phase by Arianespace. The VERTA Vega Research & Technology Accompaniment programme, approved by the Ministerial Conference in Berlin in December 2005, includes five demonstration flights, mainly of ESA missions, to demonstrate the vehicle's flexibility in various configurations and orbits.

## Acknowledgements

The authors would like to acknowledge the excellent work by industry colleagues in Vega, P80 and ground segment development and operations. They would also like to thank all their colleagues in the Integrated Project Team in Frascati and Evry, as well as those supporting the Project in Evry, Estec, ESOC and HQ.

# ConeXpress Orbital Life Extension Vehicle



## A Commercial Service for Communications Satellites



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*Gianfranco Visentin & Guillermo Ortega*
Directorate of Technical and Quality Management, ESTEC, Noordwijk, The Netherlands

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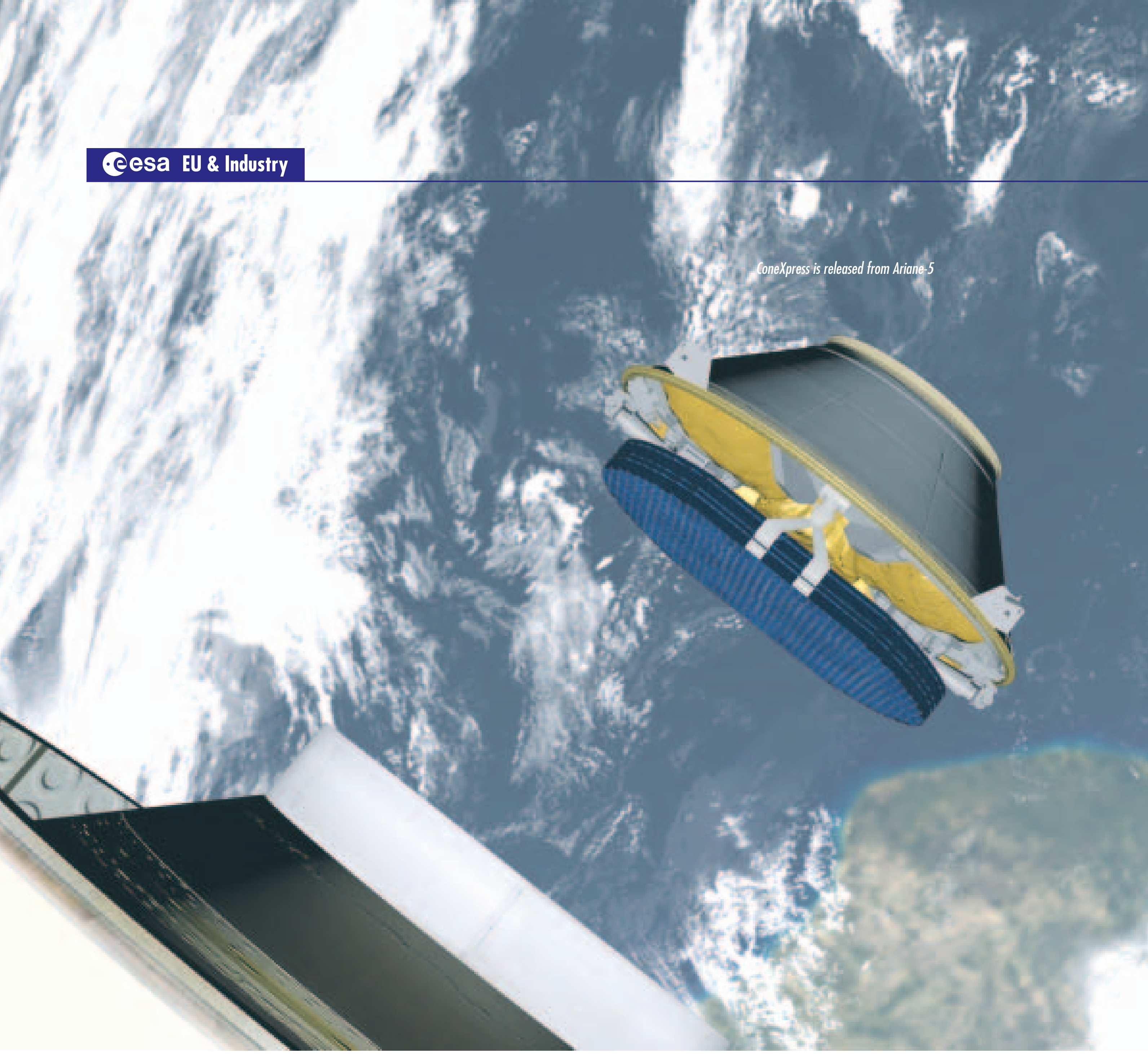
Dutch Space, Leiden, The Netherlands

***Telecommunications satellites are designed for useful lives of 10–15 years before they are 'junked' when their propellant runs out. This is a waste of huge capital investments, because all or most of the satellites' revenue-generating communications payloads is still functional. The ConeXpress Orbital Life Extension Vehicle is a novel spacecraft that will significantly prolong the operating lives of these valuable satellites. Launched aboard Ariane-5, it is designed to dock with a satellite and operate as an orbital 'tugboat', supplying the propulsion, navigation and guidance to keep its host in the proper orbital slot for many more years of revenue-earning service.***

## Introduction

The ConeXpress Orbital Life Extension Vehicle (CX-OLEV) can extend the lives of large geostationary satellites for up to 12 years beyond their original productive lives. It can also recover satellites launched into incorrect orbits, move them along the orbital arc, or manoeuvre them into to a disposal orbit. ConeXpress is a wholly European initiative and it is the only commercial on-orbit servicing project in advanced development. This on-orbit service market is being pursued by Orbital Recovery Limited (ORL) of the UK.

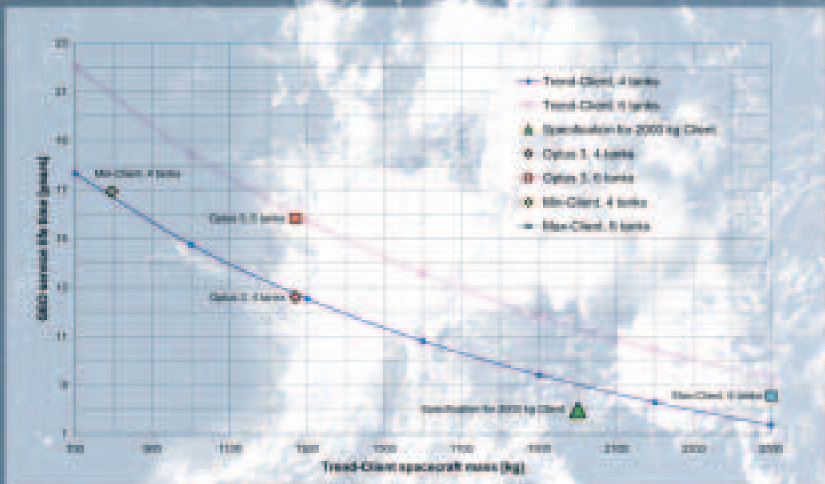


*ConeXpress is released from Ariane-5*

ConeXpress is an innovative concept tailored around Ariane-5 to enable affordable missions to high orbits such as geostationary (GEO) or even deep space using a lunar flyby. ConeXpress exploits the spare capacity of Ariane-5 under the primary satellites. It uses the standard Ariane-5 conical payload adapter as its main structure. This creates a uniquely versatile satellite with ample capacity for high-orbit missions at exceptionally low prices – about €35 million in orbit (plus the cost of building the payload). The enabling technology is electric propulsion, which has been successfully demonstrated by ESA's SMART-1 mission to the Moon. Indeed, ConeXpress has significant heritage from SMART-1, including the propulsion system, computer, databus and thruster-pointing mechanism.

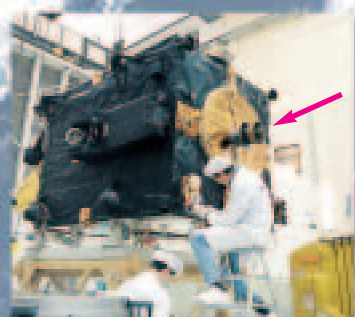
The idea of servicing and extending the lives of ailing satellites is as old as the space industry itself: NASA performed extensive studies in the 1960s and 1970s; ESA studied a Geostationary Service Vehicle in the 1990s; The German-Japanese Getex/ETS-VII docking experiment was successful in 1999; and ESA's Robotic GEO Orbit Restorer (ROGER) studies were performed in 2002–2003.

NASA and the US Air Force have conducted demonstration missions of rendezvous and docking in recent years: DART and XSS11. Further orbital servicing efforts are under way at the US Department of Defence, notably the Orbital Express project. However, all of the above efforts are restricted to research and development. The commercial servicing envisaged by ORL is unprecedented, and several years ahead of any competitors. ConeXpress is also unique in that it can dock with 'uncooperative targets' – satellites that are not designed for docking. To do this, it exploits a feature common to almost all GEO satellites: the apogee engine, using the inert nozzle as a docking port. ConeXpress captures the satellite by inserting and locking a probe in the nozzle's throat and then retracting the probe until the two craft are firmly lodged against each other.

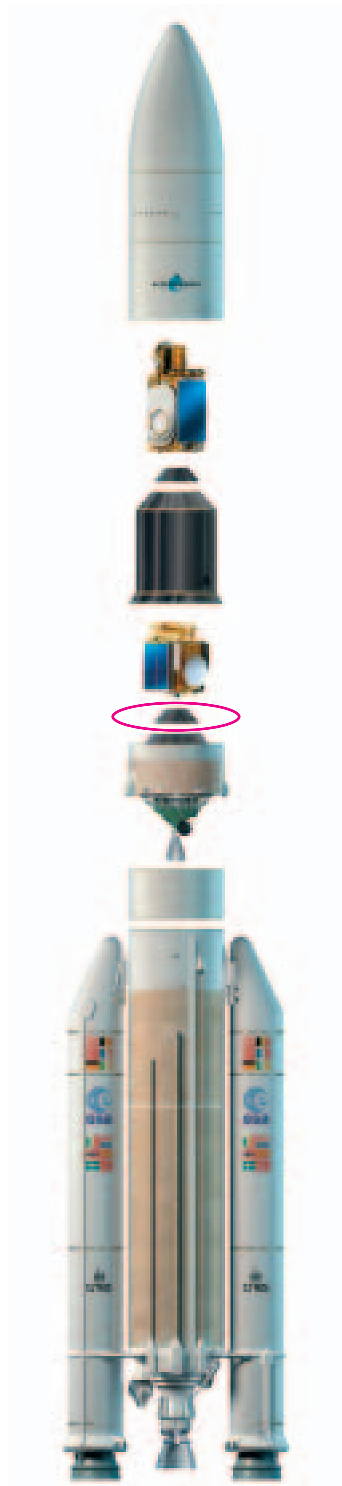


*Achievable orbital lifetime extension as a function of the client satellite's mass at the time of docking. The design specification shows that the life of a 2 tonne satellite is extended by about 8 years. The diagram assumes routine N-S and E-W stationkeeping only, without GEO relocation or major inclination manoeuvres. Optus is an Australian communications satellite that may be an early customer of the service. The '4 tanks' and '6 tanks' refer to the number of xenon propellant tanks carried by ConeXpress*

*Ariane's payload adapter outfitted as the ConeXpress free-flying spacecraft*



*ConeXpress docks with the satellite's nozzle (arrowed)*

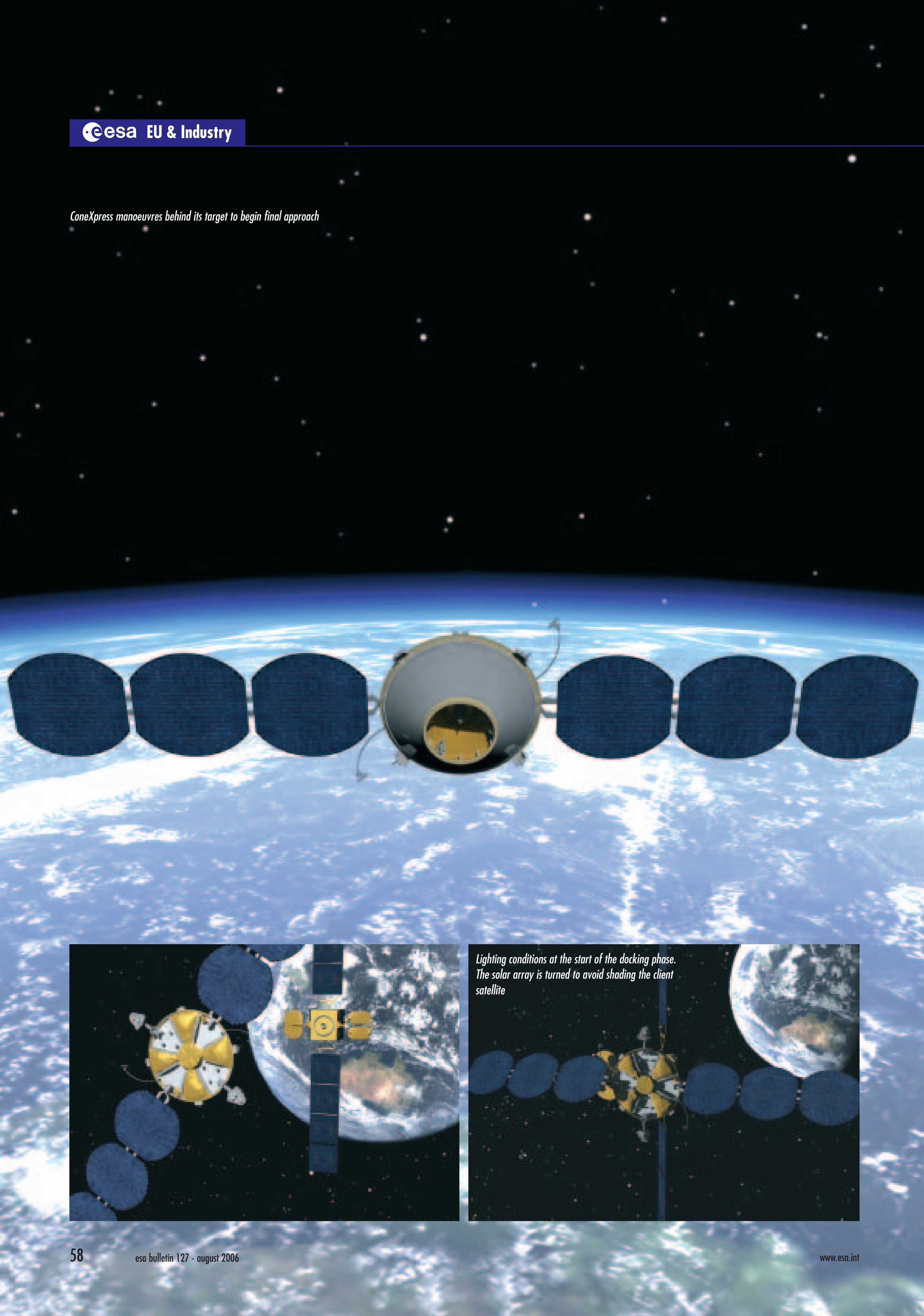


## Market Aspects

Orbital Recovery Ltd has established a preliminary business plan for CX-OLEV. It considers only commercial communications satellite clients of high value, because these are a tangible and well-defined set with much information publicly available. The addressable market for CX-OLEV is larger and includes institutional programmes for science, Earth observation and military applications. More than 60 commercial telecommunications satellites will reach their ends of life through lack of propellant before 2009, representing a value of around €13 billion. Another market potential is the less predictable early failures of propulsion and attitude-control subsystems. Statistically, one geostationary satellite suffers such a failure every 18 months. ConeXpress offers a way to rescue these satellites and extend their useful lives by several years.

Lengthening the lives of satellites running out of fuel is of interest to their owners, while rescuing satellites suffering early failures is frequently an issue for satellite insurers, making both operators and insurers potential customers. ORL projects that 10% of the initial total addressable market may be captured, and assumes an average of two missions per year. Market limitations result from the expected initial slow take-up rate.

At the end of the 1990s, there was a surge of GEO communication satellite launches and these craft will reach the



*ConeXpress manoeuvres behind its target to begin final approach*

*Lighting conditions at the start of the docking phase. The solar array is turned to avoid shading the client satellite* ends of their fuel-limited lives from 2010 onwards at a rate of about 20 a year. ConeXpress is planned to be ready to harvest this rich market. Various operators have declared their interest in using ConeXpress to develop new businesses by exploiting cheap, second-hand satellites. This could be more efficient than the current practice of using small satellites to develop the market and large satellites to exploit the mature market or to continue inclined-orbit operations. Operators are also interested in risk-mitigation in unclear market situations and in using ConeXpress as a new tool for their fleet management. Discussions with potential clients have revealed some added-value for ConeXpress users, over and above life extension, such as:

- orbital slot protection using ConeXpress in free-flying mode;
- repositioning along the GEO arc;
- restoration of orbital inclination and orbit-node position;
- creation of a second-hand satellite market by using old satellites for services to developing regions.

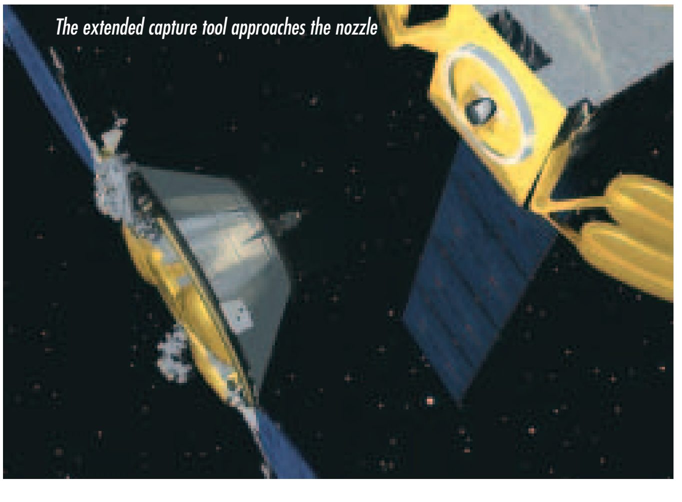
Today, there is no competitor on the market to ConeXpress, and there is none under development. It is a pioneer in commercial orbital servicing. In the future, there will be an even larger market following the introduction of satellites designed for refuelling or equipment exchange.

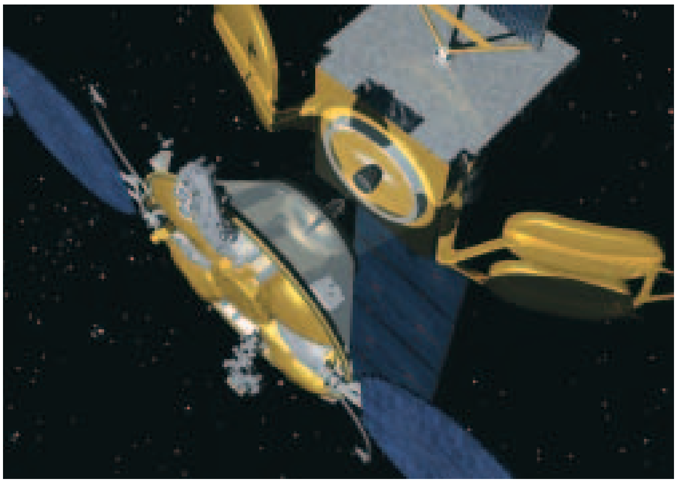
## Mission Description

ConeXpress will be launched as a standard payload adapter in the bottom position of the Ariane-5 payload stack, filling the vehicle's spare capacity after accommodation of its primary satellite payloads for launch into geostationary transfer orbit (GTO). Using the payload adapter creates a uniquely powerful auxiliary satellite with ample capacity for high-orbit missions at a very low cost. ConeXpress then uses electric propulsion to raise the orbit from GTO to GEO. Electric propulsion is compact and lightweight in comparison to traditional chemical thrusters. The transfer lasts about 6 months and is optimised for minimum duration by using continuous thrust from two parallel electric thrusters burning simultaneously. ConeXpress carries four of the same PPS-1350 80 mN thrusters as SMART-1. Swung out from 'under' the bus on orientation mechanisms, they are paired for redundancy.

Rendezvous and docking is divided into three separate phases: final transfer, rendezvous and docking. The final transfer relies on conventional ground-based ranging for independent position determinations of ConeXpress and the client satellite. During rendezvous, ConeXpress cameras relay images of the target to the ground for highly accurate relative position determination. ConeXpress attaches itself to the satellite's zenith side (the anti-Earth face), allowing the client to continue uninterrupted service. The solar arrays of ConeXpress point east-west to minimise any shadowing of the target's north-south arrays. Two docking cameras create a stereo image to assist the ground operator in steering ConeXpress. Closer in, a xenon cold-gas system orientates it. A capture tool on a deployable and retractable boom is inserted into the target's inert nozzle and locked. The boom is then retracted to pull the client onto the ConeXpress support mechanisms to create a rigid mated structure. Rendezvous and docking require typically 36 hours, timed to ensure ideal illumination conditions for safe docking. Closing in, ConeXpress moves from in front of the satellite along an elliptic trajectory to a zenith position. At this point, it rotates 90º to orientate its solar wings east-west, eclipsing the target's array by less than 2%. After docking, ConeXpress commands and telemetry are routed via a dedicated S-band station at the client's command centre.

ConeXpress is designed for up to 12 years of operations in or near geostationary orbit. The service life for a particular mission depends on the mass of the client satellite and the type of operations required. The mission concept avoids the risky aspects envisaged in more advanced future automated servicing scenarios. For example, docking is under manual control until the capture tool is in the cone, when it is automatically centred


The extended capture tool approaches the nozzle



using internal lasers. Nor are their any robotic arms or manipulators.

ConeXpress is designed for docking and undocking to allow multiple missions. Once it has transported the satellite to a graveyard orbit some 300 km above GEO, it can undock and return to GEO to work with another target. The process is repeated until ConeXpress and its last customer reach the graveyard orbit and retire there.

## ConeXpress Platform

The ConeXpress platform is being developed by Dutch Space in Leiden, The Netherlands. Ariane-5 offers 3–4 opportunities per year to make use of its otherwise-unused capacity. The ConeXpress stack comprises the payload adapter and an extension cylinder incorporating a separation mechanism and mountings for the inner structure. The inner structure accommodates equipment such as avionics and the rendezvous and docking payload. Immediately after separation from Ariane-5, ConeXpress deploys its antennas, solar wings, thruster-steering mechanisms and client-support mechanisms, in that order. It is now ready for its 6-month journey to GEO. During this transfer, and while preparing for rendezvous and docking, ConeXpress resembles a conventional geostationary communication satellite with its solar panels pointing north-south.

The mass and lifetime requirements for the coupled spacecraft define the ConeXpress propulsion system. The velocity increment and the mass range of the target rule out chemical propulsion. With current technology, the only choice is electric propulsion. The required amount of xenon gas, in turn, drives the design and mass budget. During orbit transfer, the two electric thrusters operate simultaneously, while only one is required for stationkeeping in GEO. The Hall-effect thrusters are suitable for prolonged operation, mounted on deployed steering mechanisms. The direction of the required stationkeeping velocity increment dictates the thruster orientation. Additionally, the thrust vector has to point through the combined centre of mass of the mated spacecraft for stability. North-south and east-west stationkeeping manoeuvres are combined in order to minimise perturbations on the target's antenna pointing. For north-south stationkeeping, 50 cm-long arms place the thrusters as far out of plane as possible. The thrusters are gimballed to align with the mated vehicle's centre of gravity to allow north-south thrusting through the centre of gravity in order to maintain the target spacecraft nadir pointing. Reaction wheels assist in nulling any residual thrust misalignment. The manoeuvres are limited to about an hour each day, around the orbital nodes. ConeXpress needs only a fraction of the power from the solar arrays when docked to its client. ConeXpress will not thrust during periods of eclipse, when there will be almost a kilowatt-hour of battery power to preserve ConeXpress. Eclipses will last no longer than 72 minutes, during equinox.

The platform offers a range of applications beyond these servicing missions. Under investigation are optical data-relay missions and the DuneXpress deep-space science mission for stellar dust research (Max Planck Institute Heidelberg, D), and Earth observation and meteorology missions from GEO.

## Docking Payload

Docking with GEO satellites is not a simple task because they are not designed for such operations and do not offer standard provisions for capture and docking. Even worse, although all GEO satellites have similar functions, they vary greatly, depending on their manufacturer and production family. Luckily, every potential client satellite is equipped with an Apogee Kick Motor (AKM). This boosts the satellite from its initial parking orbit into GEO, but then typically is never used again.

The concept of capturing satellites view their AKM nozzles is not new: it was explored by ESA in the Geostationary Servicing Vehicle study (*Bulletin* 78, May 1994).

### ConeXpress Characteristics

*Launch mass*: 1400 kg
*Docked mass:* ~1200 kg
*Size:* 2.6 m diameter, 1.35 m height, 14 m solar array span
*Solar cells:* 4704 GaAs RWE 3G cells
*Solar panels:* 6 panels max. 1.74 m across ($18\ m^2$); output 4.03/3.62 kW beginning/end of life (12 years)
*Batteries:* Li-ion SAFT VES 180S, 6480 kWh (50 % depth-of-discharge)
*Main engines:* 4 PPS-1350G 80 mN Snecma Hall-effect plasma thrusters (from SMART-1)
*Propellant:* 165 kg xenon, delta-V 2370 m/s, total capacity 3220 m/s
*Attitude control thrusters*: 4 clusters of 5 Xe cold-gas thrusters (same supply as main engines)
*Reaction wheels:* 4 skewed wheels
*Rendezvous:* under manual control until capture tool in cone then automatically centred using internal lasers

For ConeXpress, the Capture tool Deployment Mechanism (CDM) inserts the tool into the nozzle and locks it into place. The CDM is basically an extending boom made of three stems, enabling out/in movement of the tool. After capture, the CDM retracts the target satellite onto ConeXpress interface points to create a rigid mechanical link. The docking payload is at the heart of the spacecraft. The other main elements of the Docking Payload are:

– the Camera and Lighting Unit, to measure the satellite's position with respect to ConeXpress, and to provide visual aid to ground operators during docking;
– the mechanism to hold the satellite against ConeXpress;
– the Docking Payload Control Unit, with Camera Control Electronics.

DLR, the German space agency, is providing the Docking Payload. It has developed the capture tool and the sophisticated telepresence software for the servicing missions. Kayser-Threde is responsible for industrialising this capture technology and its integration into the docking payload. The rendezvous and docking system is controlled by the Marco telepresence system developed by DLR. Marco is currently in use in space by the ROKVISS robot on the International Space Station. This use of proven and operational software is reducing the risk for ConeXpress.

## Operation and Ground Segment

ConeXpress is controlled after launch and during the initial free-flight phase by Orbital Recovery Ltd. Docking and checkout of ConeXpress with its satellite client is a joint effort between ORL and the telecom satellite operator. Once the docking and checkout are completed, long-term control is handed over to the satellite operator or its designated contractor, with technical support provided by ORL throughout the operating lifetime.

The design of the ground segment is dictated by three factors:

– the need to provide global telemetry, tracking and command during the launch and early orbit phase;
– the need to receive low-speed (<10 kbit/s) housekeeping telemetry data and high-speed memory dump and video data (<500 kbit/s) during rendezvous and docking;
– the desire to maintain operational autonomy and cost-effectiveness during the operational phase.

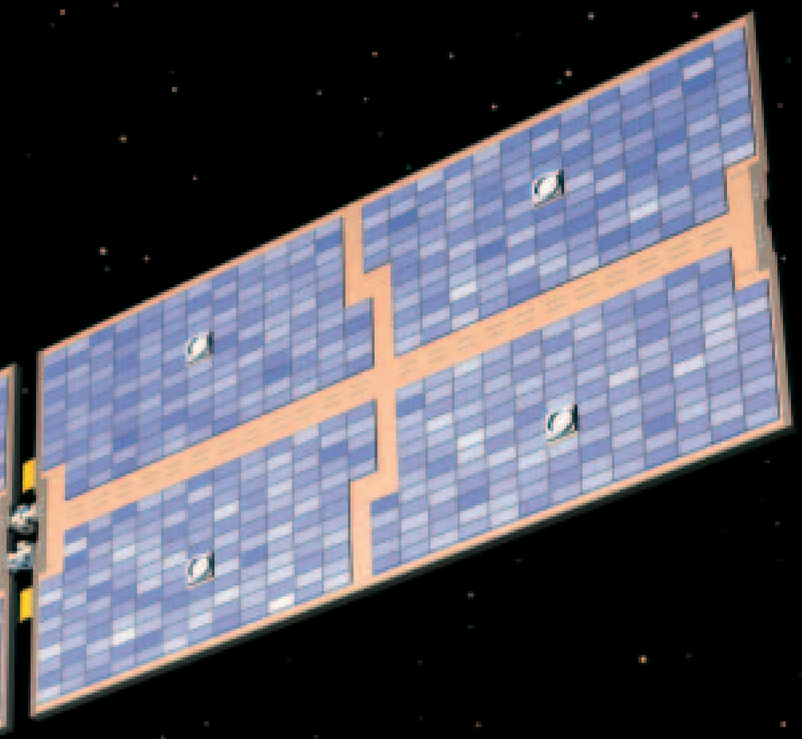
The ground segment is provided by the global PrioraNet ground station network, which may be extended by partnership with national and international networks. The stations are connected to the primary ConeXpress control centre under the authority of the Swedish Space Corporation at Esrange in Kiruna (S). The ground stations operate at S-band using 13 m-diameter antennas. A dedicated and transportable ground control facility provides command uplink, tracking and low-speed housekeeping telemetry reception at S-band using a 3.5 m dish. This facility will be located at a suitable position during orbit transfer, and collocated with the client operator's control centre during the rendezvous, docking and routine phases.

## Status

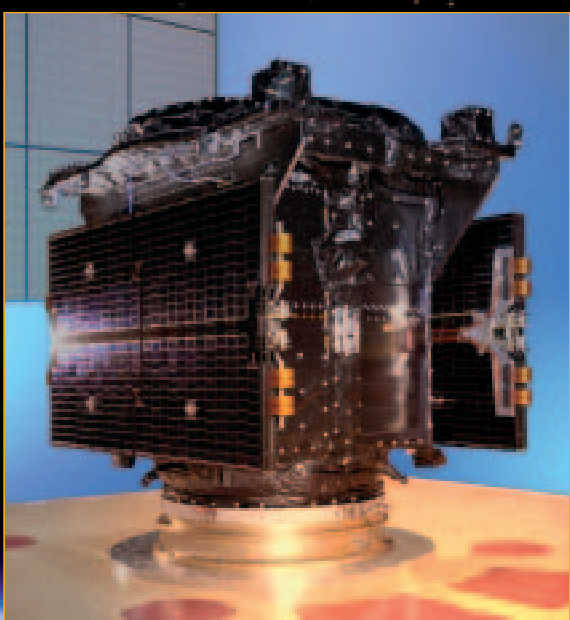
The Phase-A/B studies for ConeXpress and its OLEV application were conducted under the industrial lead of Dutch Space within ESA's ARTES (Advanced Research in Telecommunications Systems) programme. Other major contractors include Sener, GMV, Casa, Snecma, Contraves and MDA. The System Preliminary Design Review was completed in February 2006. ORL is now preparing for full development (Phase-C/D), which they want to begin this year under an ESA ARTES Public/Private Partnership framework (ARTES 4), provided they can meet the conditions imposed by ESA, in particular the consolidated business case and financing scheme. The Phase-C/D cost is about €150 million, with ESA responsible for €75 million. A customer would pay about the same as the cost of the rocket to launch a replacement satellite; the saving comes from not having to build and commission a new satellite.

The goal is for an initial servicing mission in 2010. If successful, the market for 'used' satellites would then be open for business.

# The Triumph of GIOVE-A



# The First Galileo Satellite



*Javier Benedicto, Giuliano Gatti & Antonio Garutti*
Galileo Project, Directorate of European Union and Industrial Programmes, ESTEC, Noordwijk, The Netherlands

*John Paffet, Andy Bradford, C. Jackson & E. Rooney*
GIOVE-A Project, Surrey Space Technologies Ltd., Guildford, UK

***Shortly before the end of 2005, the first Galileo experimental satellite was successfully launched. Two weeks later, GIOVE-A transmitted its first navigation signals from orbit, achieving a major milestone in the Galileo satellite navigation programme.***

## Introduction

Following the approval of Galileo in 1999 as a joint programme of the European Union and ESA, a demonstration element was added – the Galileo System Test Bed (GSTB) – to allow early experimentation with the navigation signals and services before committing to the final satellite design. GIOVE-A (Galileo In-Orbit Validation Element, formerly known as GSTB-V2/A) is the first of these two experimental satellites. The satellite's design and successes are described in this article. GIOVE-B is scheduled for launch in November or December 2006; an article is planned in the November *Bulletin* issue to cover that mission.

## The GIOVE-A Mission

GIOVE-A's main objectives are to secure the frequencies allocated to the

Galileo programme, characterise the orbit's radiation environment, evaluate critical payload technologies and enable early signal experimentation. It has succeeded magnificently in all of these goals. Creating and flying the satellite have provided valuable lessons in manufacturing, assembly, integration, testing, mission analysis, launch, early operations and in-orbit testing. All of this priceless information is being used in developing the operational Galileo satellites.

Satisfying the frequency regulations was particularly demanding because the International Telecommunication Union required a satellite transmitting at the Galileo frequencies to be in orbit by June 2006.

No previous European satellite had flown in Galileo's planned orbit at around 24 000 km altitude, so it is important to map this difficult radiation environment using detectors on both GIOVE satellites. The results are being used to improve the existing models and to show how much shielding the operational Galileo satellites must carry to guarantee flawless performance over their 12-year lives.

GIOVE-A is also providing flight experience for equipment that has never flown in space before – particularly the rubidium atomic clocks and the navigation signal generators. Their good performance is the bedrock of the service quality from the operational constellation.

The behaviour of the realistic navigation signals from GIOVE-A is being measured comprehensively and is helping to develop early versions of receivers for testing. A broad range of experiments is being carried out thanks to the flexibility of the signal generators, which can be significantly modified in-orbit by uploading software patches.

## Major Events and Mission Phasing

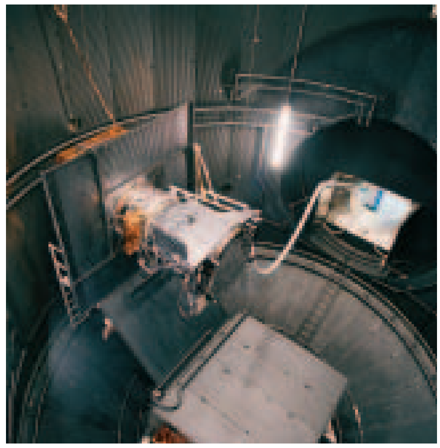
Following the GIOVE-A contract kick-off on 11 July 2003 with Surrey Satellite Technology Ltd. (SSTL), a Qualification Status review over the first month assessed which existing hardware could be reused and which units had to be freshly designed or at least modified.

*Signature of the GIOVE-A contract on 11 July 2003 by Claudio Mastracci (left, former Director of EUI) and Martin Sweeting of SSTL*

The overall mission was then reviewed at the Delta Preliminary Design Review 4 months after kick-off, when the emphasis was on the new or modified units and on approving their flight production.

As part of the satellite development philosophy, a structural model was built by SSTL and tested at ESTEC in mid-2004 to verify the new structure; previous SSTL satellites were about half the size of GIOVE-A.

The results of the structural testing, the final design and the readiness for the final satellite integration and testing passed the Critical Design Review in March 2005. The Flight Model was completed in July 2005, when the satellite was transported to ESTEC for environmental testing.



*GIOVE-A in the Large Space Simulator at ESTEC for thermal and vacuum testing*

The results of the campaign were scrutinised at the Flight Readiness Review a month before launch, to authorise shipment to the Baikonur Cosmodrome and the start of the launch campaign. The satellite's review process was completed at the Qualification Readiness Review, passed in early December 2005. The Launcher Readiness Review took place 3 days before the perfect launch of 28 December 2005.

Following commissioning, the first Galileo signal was transmitted by GIOVE-A on 12 January 2006. Payload commissioning was completed by the end of February 2006. The In-Orbit Test Review was organised in March 2006, followed by the Frequency Filings Review in April 2006; both were successful.

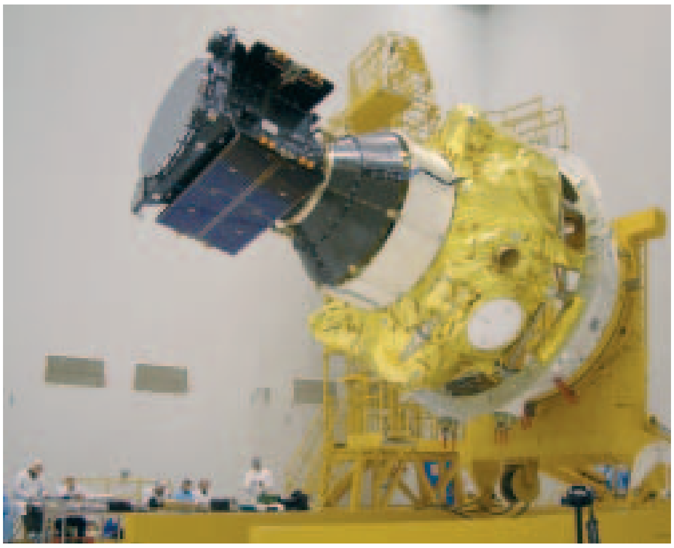
Operation Reviews are being conducted every 3 months during the 27-month life of the satellite.

### GIOVE-A Characteristics

*Orbit:* 23 260 km circular, 56°
*Launch mass:* 602 kg
*Lifetime:* 27 months
*Power supply:* 700 W beginning-of-life, 600 W end-of-life
*Stowed envelope:* 1.3 x 1.8 x 1.65 m
*Propulsion:* 2 sets of 5x50 mN thrusters, fed from 25 kg of liquid butane in each of 2 tanks
*Power system:* 50 V regulated bus for high-power load, 28±6 V unregulated bus for payload/platform
*Solar array:* 2 wings of 2 panels each (0.98 x 1.74 m) Si cells, SEPTA 31E drive, 60 Ah Li-ion battery
*Payload:* rubidium atomic clock reference, dual-signal simultaneous transmission, CEDEX and MERLIN radiation sensors, one GPS receiver

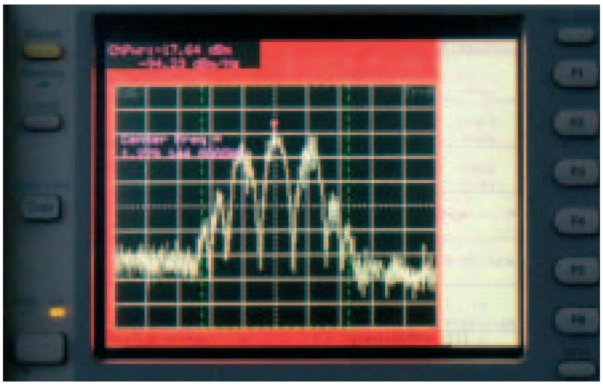
## The Satellite

All the 21 SSTL satellites after UoSAT-2 in 1984 were based on their predecessors; each mission took an evolutionary step. The 23rd satellite, GIOVE-A, is an enlarged version of the

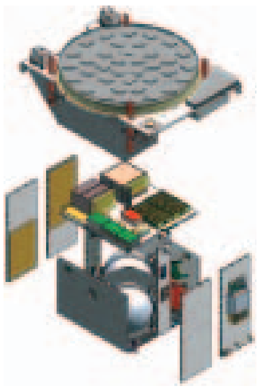


GIOVE-A is mated with its Fregat upper stage at Baikonur

The Soyuz launcher is poised for departure, 28 December 2005



A momentous achievement: the first Galileo navigation signal is received



The GIOVE-A basic structure

microsatellite platform used for the ALSAT-1, BILSAT, NigeriaSAT-1 and UK-Disaster Monitoring Constellation missions. GIOVE-A also makes extensive use of subsystems developed for the Gemini small geostationary communications satellite.

The platform is, wherever possible, dually redundant, or allows for gradual degradation, and minimises the number of single-point failures. The communications system, based on an existing design, provides 9.6 kbit/s telecommand and telemetry and payload telemetry at S-band via SSTL's station in Guildford (UK). The inherited onboard computer is cold-redundant, and provides 32 Mbytes of RAM disk. A dual-redundant Controller Area Network (CAN) bus runs around all the subsystems, providing communication and data-handling functions.

The mission lifetime and this new orbit's radiation environment dictated the strategy for selecting and shielding component. Units that have flown before are shielded such that they suffer the same total radiation dose as they did during their low-orbit missions. This means that the experience built up with them over multiple missions is still valid, providing confidence in their robustness. For modified or new units, radiation-tolerant devices were selected that can handle at least 50 krads, and preferably 100krads.

The deployed silicon-cell panels were sized to provide more than 600 W by the end of the mission, allowing the output to degrade gracefully.

***The structure***

The basic structure is an aluminium box. The main antenna is on the +Z face, facing Earth. Deployable Sun-tracking solar wings are mounted via drive mechanisms in the middle of the +Y and –Y faces, with the rotation axis in the Y-axis. The +Y and –Y faces are primary radiators; the +X face is a secondary radiator. At launch, the –Z side was attached to the Soyuz-Fregat and the solar wings covered the +Y and –Y radiators. The outer walls form a square load-bearing thrust tube supporting two equipment-carrying panels (the Earth face and the internal avionics panel).

The structure is mainly machined aluminium and aluminium sandwich panels, bolted together in preference to bonding in order to simplify the design and handling. The structure is configured into three bays: propulsion, avionics and payload.

***Propulsion features***

The propulsion system is based around butane and had already flown on several

SSTL missions. It meets the delta-V requirements and offers significantly lower cost and risk than using hydrazine.

Two redundant controller modules drive the propulsion system, each responsible for half of the 10 thrusters and four tank-isolation valves. In the event of either controller failing, the other can feed five thrusters from either tank and complete the mission. The tanks, from PSI of the US, were derived from an hydrazine tank by removing the elastomeric diaphragm. Existing 50 mN thrusters with heaters are used.

***Power system***

The power system uses the 'GMP-D' design developed for SSTL's Gemini geostationary platform. It provides a dual-voltage (27 V & 50 V) bus and its modular design makes it scalable from about 400 W to 2 kW.

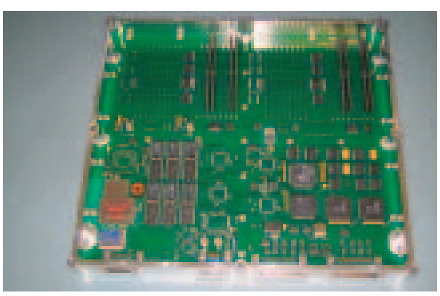
The Power Control and Distribution System is fully autonomous and fault-tolerant. The 50 V is regulated from the solar arrays during sunlit operation and from redundant regulators on the 60 Ah lithium-ion battery during eclipses. The solar array drive mechanism allows the wings to track the Sun while the antenna remains fixed on its Earth target.

***Avionics***

The data-handling system architecture is divided into three sections: the redundant CAN bus; two cold-redundant OBC386 computers; attitude safety module.

The CAN bus has been used by SSTL in several previous missions. Typical modules in the bus system could be the power system or the propulsion controller. Telemetry and telecommand nodes can autonomously switch between primary and secondary busses if a lockup condition is detected. All SSTL satellites have 'back-door connections' between the receivers and the power system, allowing a ground station to turn units on or off directly without going via the CAN bus.

*The OBC386 onboard computer had already proved itself on earlier missions*



The CAN bus links each OBC386 to sensor data (Sun sensors, gyro, Earth-horizon sensors), formatted and generated by the attitude and orbit-control module, and routes the actuator (magnetorquer, wheel, propulsion) commands. Again, most of these sensors and actuators were based on SSTL flight-proven units or standard space-qualified units.

As with all SSTL satellites, GIOVE-A was launched inert and activated by separation from the launcher. The onboard software was then loaded by the ground station.

The non-redundant attitude safety module provides GIOVE's highest level of control. After launch, it managed the de-tumble and Sun-acquisition. During the operational phase, it acts as a watchdog over the primary units, switching to secondaries in the case of failure. It also contains simple attitude-control algorithms using Sun-sensors, gyros and thrusters to maintain Sun-pointing in the case of OBC386 failure.

## The Payload

The GIOVE-A payload comprises three main sections: navigation, radiation monitoring and experimental. The navigation section contains all the elements generating the navigation signals in the E5a, E5b, E6, E2, L1 & E1 Galileo frequency bands. The elements include the Rubidium Atomic Frequency Standard (Temex Neuchatel Time, CH), the Clock Monitoring and Control Unit (Alcatel Espacio, E), the Frequency Generation and Upconverter Unit (Norspace, N), the Navigation Signal Generation Unit (Laben, I) and the Navigation Antenna (Alenia Spazio, I).

*The navigation antenna (Alenia Spazio)*

The Environmental Monitoring Section includes two monitors – CEDEX (SSTL) and Merlin (Qinetiq, UK) – to characterise the orbit's radiation and charging environment.

The Experimental Section includes SSTL's GPS receiver and a laser reflector. The receiver is a 24-channel GPS receiver developed by SSTL assisted by British National Space Centre and ESA ARTES-4 funding.

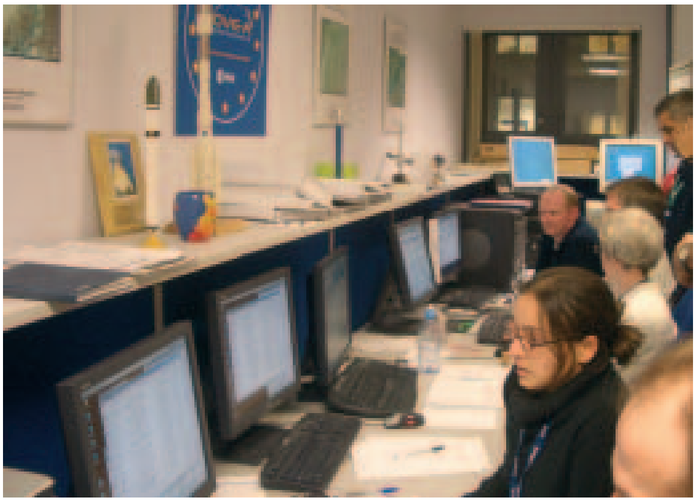
## The Ground Segment

Mission control uses an existing network of ground stations connected via the Internet to the Surrey Operations Control Centre:

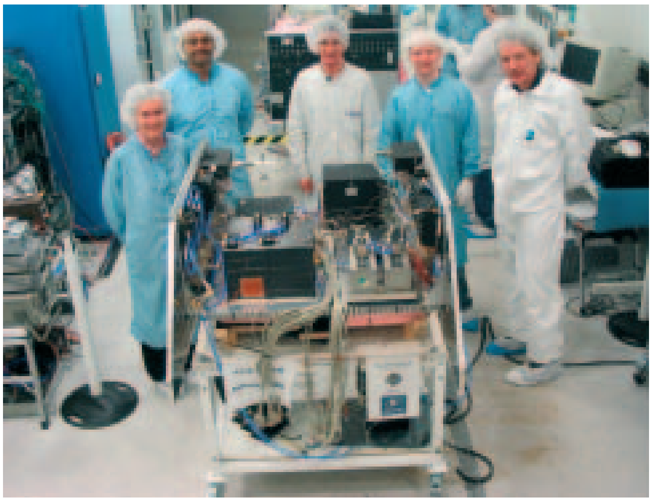
– Mission Operations Control Centre at SSTL;
– Guildford ground station for early-orbit and nominal operations;
– Malaysian ground station for early-orbit operations;
– Rutherford & Appleton Laboratory (RAL, Oxford, UK) ground station for early-orbit and nominal operations (backup);
– Bangalore (India) ground station;
– Chilbolton (UK) in-orbit testing station.

ESA's Redu (B) station was used as a complementary/backup in-orbit testing station. It will become the main station for commissioning GIOVE-B at the end of 2006.

All routine mission operations are automated, allowing SSTL personnel to staff the control centre during normal



The SSTL control centre in Guildford



Payload bay integration

working hours only. While it is not uncommon to find the centre unmanned, the satellite is automatically monitored and staff are contacted via email or paging systems in case of alert. Automatic data processing allows staff to spend their working time operating the satellite.

## Integration and Testing

The integration of the satellite began in February 2005 and was completed in a record time by the following June. GIOVE-A was then delivered to ESTEC's Test Centre for a wide range of tests: thermal-vacuum and thermal balance, vibration, mass properties and balancing, acoustic, solar array deployment, electromagnetic compatibility, clamp-band integration and release, and system end-to-end. Ground system validation tests were run through a network connection to the Guildford mission operations control centre.

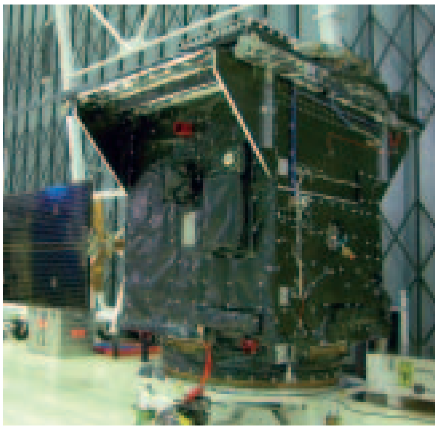
The final test campaign was completed by the end of November 2005 with the delivery of the satellite to the Baikonur Cosmodrome.

The launch campaign activities were simplified by the fact that the satellite was launched while inactive.

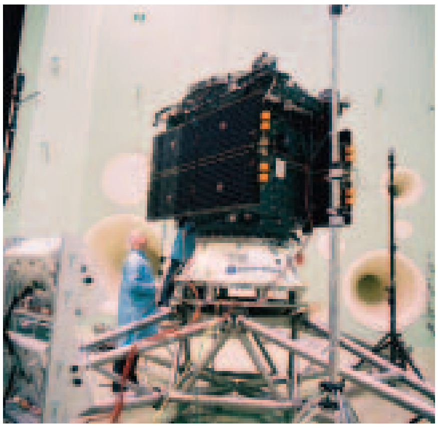
## Launch and early operations

The 4-week launch campaign culminated in the successful ascent of the Soyuz-Fregat at 05:19 UT 28 December 2005. The Soyuz trajectory and burns were normal, leading to ejection of the satellite into its final orbit 222 minutes after lift-off.

Solar array deployment tests at ESTEC



Preparing GIOVE-A for acoustic tests at ESTEC



Two minutes after separation the 'TX1' command to turn on the first transmitter was sent from the control centre via the RAL station; the satellite responded immediately. A few seconds later, the control centre began receiving satellite telemetry and could see that GIOVE-A was healthy.

The attitude control system was activated and in a very short time the satellite was stable, with one of the stowed wings facing the Sun and so providing power. Immediately, ground controllers began uploading the software into the computer. Once initialised, the computer could begin to take full control of the satellite.

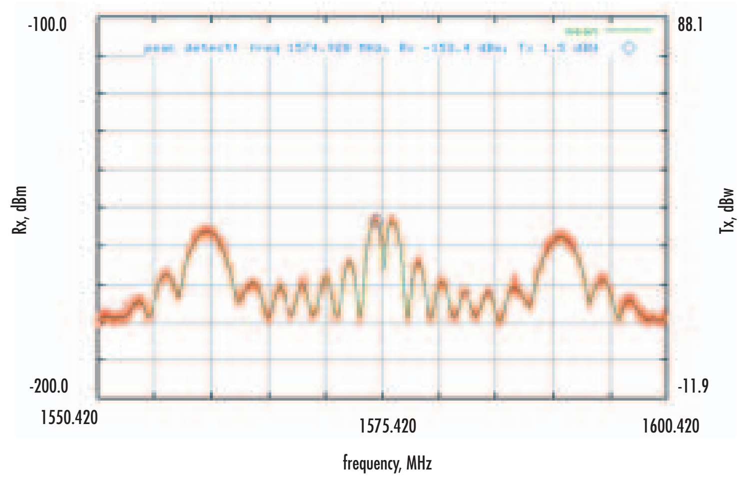
At 11:15 UT, deployment of the first solar wing began with the uploading of the command file. Wing 1 deployment was confirmed at 11:39 UT by a signal from the latch showing that it was locked. The satellite turned for the wing to generate power and to be checked out. After rotating 90º, the second wing was released and confirmed as latched in position at 12:14 UT.

The satellite then acquired its final orientation towards the Sun, and the launch and early operations phase was declared as successfully completed.

## Commissioning and Early Experiments

Platform commissioning involved 13 sessions to assess the performances of all the equipment, including redundant

*Encapsulation in the Soyuz fairing*




*The first navigation signal transmitted at L1 (1575.42 MHz)*

units, and of the various software configurations and attitude-control modes. GIOVE-A was then commanded into its nominal mode: Earth-pointing maintained by its reaction wheels.

CEDEX and Merlin were turned on a day after launch and useful data have been returned continuously ever since.

The navigation payload went through a number of checkouts following platform commissioning. It was turned on for the first time at 17:30 UT on 12 January 2005. The first L1 and E5 signals were clearly received at Chibolton and Redu, and by other observers around the world. All the experiments at Chilbolton and Redu used receivers built in record time by Septentrio (B).

Since then, different signal modes and modulations have been broadcast and carefully measured at Chilbolton to show they satisfy the frequency filings documentation. The conditions were eventually met and the International Telecommunication Union (ITU) was informed at beginning of March 2006 that the frequencies for Galileo had been put into use.

The first laser-ranging test was successful at the beginning of April 2006, providing results well within expectation. This is being used to determine the orbit with cm-accuracy, which helps the removal of orbit errors and calibration of the clocks. The laser station is in China, in collaboration with the National Remote Sensing Center in China (NRSCC).

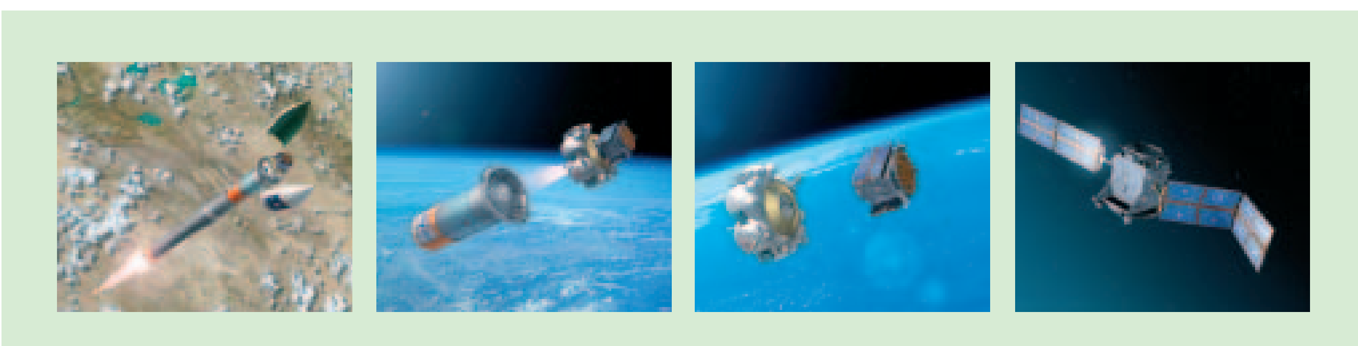
In June 2006 the first clock characterisation campaign was successfully carried out by Galileo Industries, who are building GIOVE-B and the first four operational satellites. The measurements showed that the rubidium clock is performing as expected.

Work still to be done includes full characterisation of signals in the different frequency bands and long-term characterisations of the clock and the radiation environment. Other experiments include the fine characterisation of the navigation payload performance in-orbit, which has never been done before by Europe. The overall mission duration is estimated to be 2 years. Completing the full experimental programme requires launch of GIOVE-B.

## Conclusions

The GIOVE-A mission has already achieved its first, major objective: bringing the Galileo frequencies into use as required by the ITU. This major milestone for the Galileo Programme has been realised in a record time of

*GIOVE-A launch and deployment sequence*



30 months from kick-off, by taking advantage of the flexibility of SSTL and the pre-development of several payload units by the Agency.

Working with SSTL has been a challenging and enlightening experience for ESA as the Agency has been confronted with a significantly different working approach. This small, fully integrated space company has allowed a fast-paced development programme, supported by an enthusiastic, dedicated and professional team. The GIOVE-A experience is certainly a source of lessons for future experimental ESA missions.

*The GIOVE-A ESA and SSTL teams*

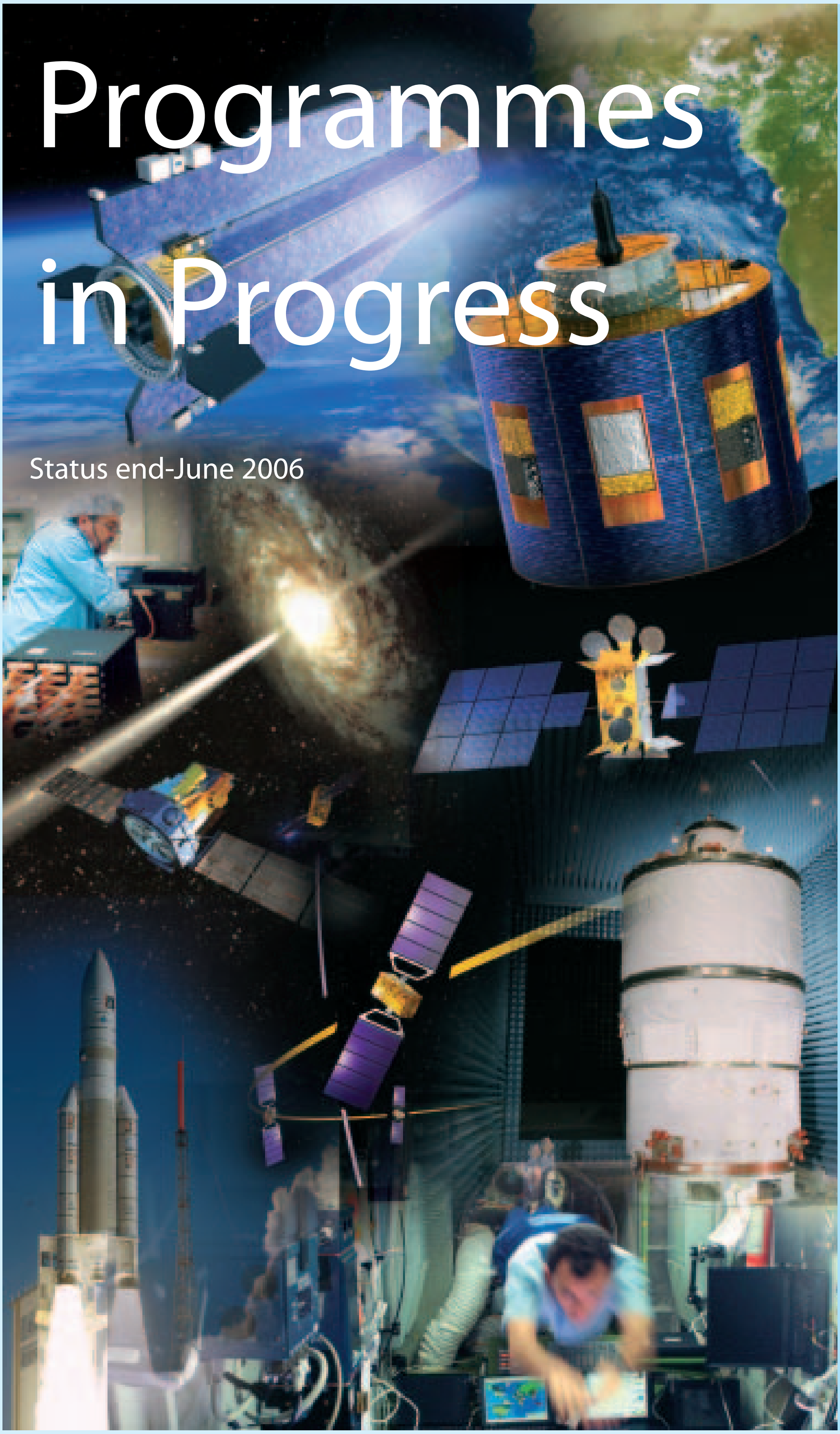
## Acknowledgements

The GIOVE-A mission is a success based on the commitment, motivation and capabilities of the SSTL team, supported by the ESA team. In addition, the fundamental contributions of the following parties should also be acknowledged: SSTL subcontractors (Dutch Space, Comdev Europe, Galileo Avionica, Thales GmbH, RAL, Qinetiq); unit suppliers (Temex Neuchatel Time, Alcatel Espacio, Norspace, Laben, Alenia Spazio); Galileo test receiver (Septentrio); launch (Starsem).

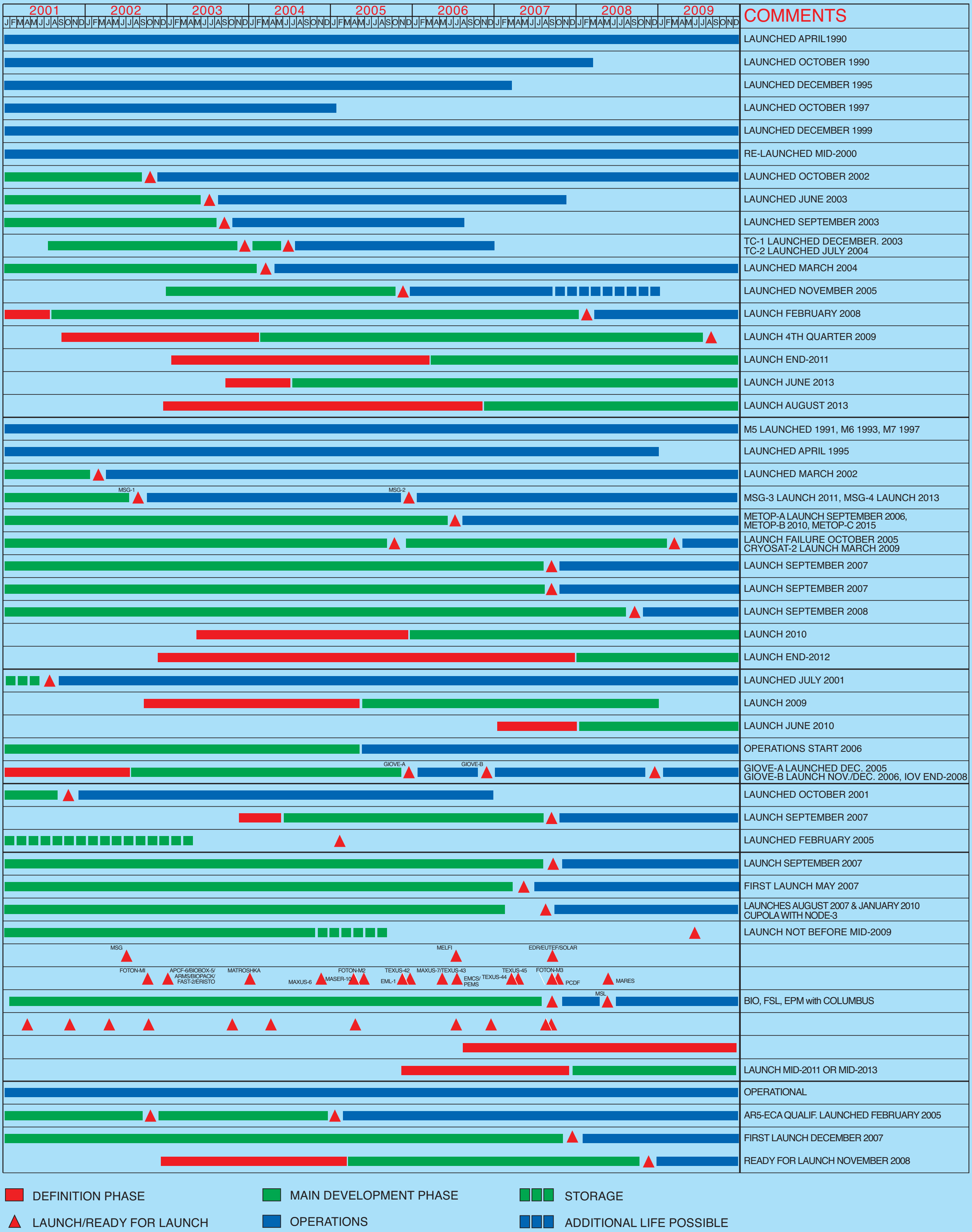
*Detailed information on Galileo and GIOVE can be found at www.esa.int/galileo. 'The First Galileo Satellites' brochure can be ordered at a cost of €10 from ESA Publications using the form at the back of this issue and quoting BR-251; a French edition is also available.*

# Programmes in Progress

Status end-June 2006



| Programme | PROJECT |
|---|---|
| SCIENTIFIC PROGRAMME | SPACE TELESCOPE |
| | ULYSSES |
| | SOHO |
| | HUYGENS |
| | XMM-NEWTON |
| | CLUSTER |
| | INTEGRAL |
| | MARS EXPRESS |
| | SMART-1 |
| | DOUBLE STAR |
| | ROSETTA |
| | VENUS EXPRESS |
| | HERSCHEL/PLANCK |
| | LISA PATHFINDER |
| | GAIA |
| | JWST |
| | BEPICOLOMBO |
| EARTH OBSERVATION PROGRAMME | METEOSAT-5/6/7 |
| | ERS-2 |
| | ENVISAT |
| | MSG |
| | METOP |
| | CRYOSAT |
| | GOCE |
| | SMOS |
| | ADM-AEOLUS |
| | SWARM |
| | EARTHCARE |
| COMMS./NAV. PROGRAMME | ARTEMIS |
| | ALPHABUS |
| | SMALL GEO SAT. |
| | GNSS-1/EGNOS |
| | GALILEOSAT |
| TECHNOL. PROG. | PROBA-1 |
| | PROBA-2 |
| | SLOSHSAT |
| HUMAN SPACEFLIGHT, MICROGRAVITY & EXPLORATION PROGRAMME | COLUMBUS |
| | ATV |
| | NODE-2 & -3 & CUPOLA |
| | ERA |
| | ISS SUPPORT & UTIL. |
| | EMIR/ELIPS |
| | MFC |
| | ASTRONAUT FLT. |
| | AURORA CORE |
| | EXOMARS |
| LAUNCHER PROG. | ARIANE-5 DEVELOP. |
| | ARIANE-5 PLUS |
| | VEGA |
| | SOYUZ AT CSG |


2001
2002
2003
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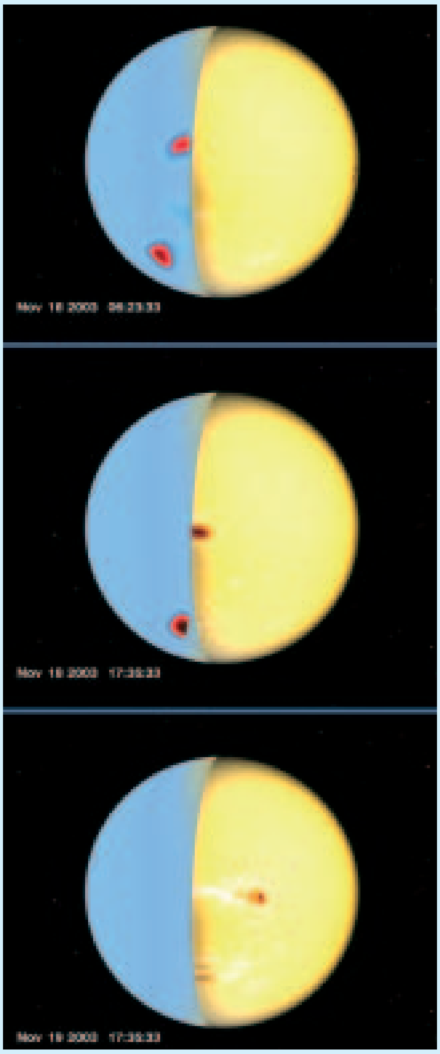
2006
2007
2008
2009
COMMENTS
LAUNCHED APRIL1990
LAUNCHED OCTOBER 1990
LAUNCHED DECEMBER 1995
LAUNCHED OCTOBER 1997
LAUNCHED DECEMBER 1999
RE-LAUNCHED MID-2000
LAUNCHED OCTOBER 2002
LAUNCHED JUNE 2003
LAUNCHED SEPTEMBER 2003
TC-1 LAUNCHED DECEMBER. 2003
TC-2 LAUNCHED JULY 2004
LAUNCHED MARCH 2004
LAUNCHED NOVEMBER 2005
LAUNCH FEBRUARY 2008
LAUNCH 4TH QUARTER 2009
LAUNCH END-2011
LAUNCH JUNE 2013
LAUNCH AUGUST 2013
M5 LAUNCHED 1991, M6 1993, M7 1997
LAUNCHED APRIL 1995
LAUNCHED MARCH 2002
MSG-3 LAUNCH 2011, MSG-4 LAUNCH 2013
METOP-A LAUNCH SEPTEMBER 2006,
METOP-B 2010, METOP-C 2015
LAUNCH FAILURE OCTOBER 2005
CRYOSAT-2 LAUNCH MARCH 2009
LAUNCH SEPTEMBER 2007
LAUNCH SEPTEMBER 2007
LAUNCH SEPTEMBER 2008
LAUNCH 2010
LAUNCH END-2012
LAUNCHED JULY 2001
LAUNCH 2009
LAUNCH JUNE 2010
OPERATIONS START 2006
GIOVE-A LAUNCHED DEC. 2005
GIOVE-B LAUNCH NOV./DEC. 2006, IOV END-2008
LAUNCHED OCTOBER 2001
LAUNCH SEPTEMBER 2007
LAUNCHED FEBRUARY 2005
LAUNCH SEPTEMBER 2007
FIRST LAUNCH MAY 2007
LAUNCHES AUGUST 2007 & JANUARY 2010
CUPOLA WITH NODE-3
LAUNCH NOT BEFORE MID-2009
BIO, FSL, EPM with COLUMBUS
LAUNCH MID-2011 OR MID-2013
OPERATIONAL
AR5-ECA QUALIF. LAUNCHED FEBRUARY 2005
FIRST LAUNCH DECEMBER 2007
READY FOR LAUNCH NOVEMBER 2008
DEFINITION PHASE
MAIN DEVELOPMENT PHASE
STORAGE
LAUNCH/READY FOR LAUNCH
OPERATIONS
ADDITIONAL LIFE POSSIBLE

# SOHO

On 7–12 May 2006, the community held a memorable meeting to celebrate 10 years of successful scientific operations of SOHO (*SOHO-17: 10 Years of SOHO and Beyond*, Giardini Naxos, Italy). Nearly 300 participants presented and discussed over 250 scientific papers, which will be published by the ESA Publications Division as SP-617.

The Michelson Doppler Imager (MDI) team has made significant improvements to their holographic farside imaging technique. The original method allowed only the central regions of the Sun's farside to be seen, about a quarter of its total area. With the new method, one can see the entire farside, including the poles.

Scientists of SAIC, San Diego, have presented large-scale computer simulations of the solar corona, based on magnetic field data from SOHO. They used MDI measurements of the Sun's surface magnetic field to calculate the structure of the entire solar corona. Among other quantities, the new model allows prediction of the emission of the solar corona in extreme-UV light that can be compared with observations by SOHO's Extreme-UV Imaging Telescope. The solar eclipse on 29 March offered a special opportunity to compare the theoretical predictions with polarised white-light images of the corona. The computer model passed this important test by correctly predicting the corona's large-scale structure.



*Two active regions crossing the solar east limb in November 2003. The yellow side has white-light images showing sunspots. The blue side shows predicted sunpots on the farside. Since the white light observations are images made 'straight on', they are stretched into blurry lines when projected to show the view over the limb. This is simply because there is no camera above the east limb (yet)*

# Ulysses

Ulysses, well into its 16th year of operations, continues its climb to high southern solar latitudes as it heads for the third pass over the Sun's south pole. The spacecraft and scientific instruments continue to operate well. As onboard temperatures continue to rise, albeit slowly, the risk of freezing the hydrazine fuel is no longer the overriding operational constraint. Diminishing power levels, an inevitable consequence of the longevity of the mission, are once again the limiting factor for payload operations. Nevertheless, windows of opportunity have been identified for some of the instruments that are not part of the core payload. For example, the gamma-ray burst instrument that has been switched off for the previous 18 months will be returned to operation in mid-July 2006, and is planned to remain on until the end of the year. Data-recovery levels have generally been high, although NASA Deep Space Network outages in May caused uncharacteristically low weekly averages (well below 90%) for 3 weeks running.

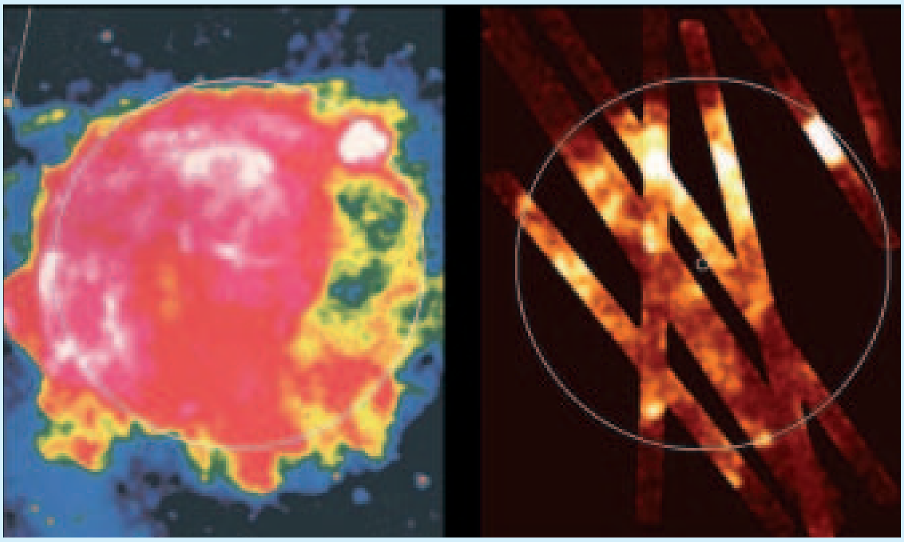
While the main focus of the mission is clearly the Sun and its environment, the Jovian system continues to play an important role in many of the Ulysses investigations. A recent study of interplanetary dust streams that are believed to come from Io has revealed a periodic behaviour, with peaks at 13 days and 26 days. This is not thought to originate at the source, but is rather due to the interaction of the dust particles with solar wind streams that corotate with the Sun. This in turn indicates that the interaction is electromagnetic in nature and that the dust grains act as charged particles.

On 1 September 2006, Ulysses will be at a radial distance of 3.4 AU from the Sun, and heliographic latitude 60º south of the solar equator.

# ISO

The ISO Data Archive Version 10 was released on 29 June. It allows queries based on object type; 143 object types are defined, hierarchically organised, based on the SIMBAD system. A total of 6117 objects are associated with 29 254 ISO observations.

ISO continues to have a significant presence in the refereed literature, with over 1350 papers published. Recent highlights include the result of the first far-IR high-resolution spectral line survey in the Orion region, obtained with the LWS in Fabry-Perot mode. The spectrum is dominated by the molecular species $H_2O$, OH and CO, along with [OI] and [CII] lines from PDR or shocked gas and [OIII], [NIII] lines from the foreground M42 HII region. Several isotopic species and $NH_3$ are also detected. HDO and $H_3O^+$ are tentatively detected for the first time in the far-IR range towards Orion-KL.



*XMM-Newton maps very large sky features during the slews between targets. Among these is the 20 000 year-old Vela supernova remnant (right), occupying a sky area 150 times that of the full Moon. The slew survey results are compared here with an image previously taken by the Rosat mission (left). (ESA/Rosat)*

## Cassini-Huygens

The latest version of the Huygens descent movies made by the DISR team was released in May (*http://saturn.esa.int*). These movies give a good account of the work done so far by all the teams to understand and interpret the probe performance during the descent and the returned science data. Science results related to the Huygens misison are now regularly submitted for publication in refereed journals.

## XMM-Newton

XMM-Newton operations continue smoothly, with the spacecraft, instruments and ground segment all performing nominally. Observations of the AO-5 A and B priority targets are expected to be completed by the end of February 2007. A total of 1138 papers based on XMM-Newton data has appeared in the refereed literature. Of these, 132 are from 2006.

The XMM-Newton Users Group expressed their satisfaction with the recent calibration improvements, especially for the low-energy response of the RGS cameras and the consequent improvement in the instrument cross-calibration. The group recommends the development of a slow-slew observing mode and the study of legacy-type observing programmes.

For the past 4 years, while XMM-Newton has been manoeuvring between targets, it has kept its cameras operating and quietly used this extra time to scan the sky. The results of this slew survey, covering some 15% of the sky, have now been made available. The catalogue includes more than 2700 bright sources and a further 2000 of lower significance. Regular updates of the catalogue are planned as more of the sky is covered.

## Cluster

The four satellites and instruments are operating nominally. The short eclipse season recently finished and a few anomalies have been observed owing to the ageing of the batteries. This has proved, however, that the satellites can survive a short eclipse with minimum power in the batteries and it provides experience for the next long eclipses, in September 2006.

The Cluster constellation is a regular 10 000 km large-scale tetrahedron in the centre of the magnetotail. This configuration will be changed to a multi-scale configuration in November 2006.

JSOC and ESOC operations are continuing nominally. The data return from mid-November 2005 to early June 2006 was on average 99.1%. The Perth station has been used nominally since 1 January 2006, with the Maspalomas station. The Cluster Active Archive (CAA) was opened as planned on 1 February 2006. A total of 227 users were registered at the end of June 2006 and more than 22 Gbytes of high resolution data were downloaded. The CAA also delivers all raw data to the Cluster PIs and Co-Is and the average download rate is above 4.5 Gbytes per day.

Fundamental 3-D properties of magnetic turbulence observed in the shocked solar wind were published in February 2006 in *Physical Review Letters*. These properties are of prime importance for model magnetic turbulence in the shocked solar wind, which plays a key role in the dynamical coupling between the solar wind and the magnetosphere. These results were obtained by combining the magnetic measurements on all four satellites using the k-filtering method. The consequences of magnetic turbulence are also relevant to astrophysical and laboratory plasmas.

## Integral

Integral operations continue smoothly, with the satellite, instruments and ground segment all performing nominally. The 4th Announcement for Observing proposals (AO-4) closed on 24 April 2006. 142 proposals were received, compared to 108 for AO-3. This increase may be due to the introduction of 'key programme' observations; 43 proposals were received requesting data rights to sources within the AO-4 key programme observation of the galactic centre region. Integral scientific results have been reported in 190 refereed and 341 non-refereed publications.

Thanks to clever design and sophisticated analysis by European astronomers, Integral can now make images of the most powerful gamma-ray bursts even if the satellite itself is pointing somewhere completely different. This technique was applied by R. Marcinkowski and collaborators, who analysed data from the two separate detectors (ISGRI and PICsIT) that make up the IBIS imager to image the bright gamma-ray burst GRB 030406 that occurred far outside the IBIS field of view, some 37º off the pointing axis.

## Mars Express

The final commissioning of the MARSIS instrument – primarily the commissioning and calibration of the monopole antenna – has been completed. A great deal of work has gone into preparing for the upcoming, power-difficult, eclipse/aphelion and conjunction season of 24 August to 5 November. A dedicated review of the operations for the most difficult part of this period was held at ESOC on 8 June. The minor problems experienced in operating the ASPERA scanner and the PFS instrument have been resolved.

With both the distance of Mars Express to the Sun (which determines the available power) and the Earth-Mars distance (which determines the telemetry rate) increasing, the resources available for science operations are seriously affected. Science operations are proceeding well, although the additional work involved in preparing for the eclipse/aphelion and conjunction season places a heavy burden on the flight control team.

With another spacecraft (Mars Recconnaissance Orbiter) added to the flotilla around Mars, NASA's Deep Space Network (DSN) is frequently required to monitor its aerobraking process, so there is less DSN availability for Mars Express.

All instruments continue to deliver excellent science. The estimated cumulative number of Mars Express publications in the refereed literature is about 145, 35 of which are from 2006. The MARSIS radar has made significant discoveries during the last night-time season; they will be published shortly.

A Mars Express topical workshop on 'The Meaning of Methane on Mars' is planned to take place in early 2007 at the Royal Astronomical Society in London.

## Double Star

The two satellites and their instruments are operating normally. The Chinese have reported on the lifetime of TC-2 (nominal end in July 2006), proving it to be extendable to end-2006, which would take operations of both to the end of the year. PIs and Chinese engineers are looking at the thermal evolution of both and a proposal for a further extension to October 2007 will be discussed with the scientists during the summer.

The European Payload Operation System (EPOS) coordinates the operations for the seven European instruments aboard TC-1 and TC-2 and is running smoothly. Data are acquired using the VILSPA 2 ground station and the Chinese stations in Shanghai and Beijing. Quicklook with the most recent data (a few days old) from all instruments are publicly available at the Double Star Data Centres in Graz, Austria and Beijing, China.

A study on surface waves in the magnetotail was published in the special issue of *Annales Geophysicae* on Double Star on 8 November 2005. It involved five satellites: TC-1 and the four Clusters. Cluster demonstrated that they were surface waves and fully characterised them, while Double Star, 30 000 km away, showed that this was a large-scale phenomena taking place over a large region of the magnetotail.

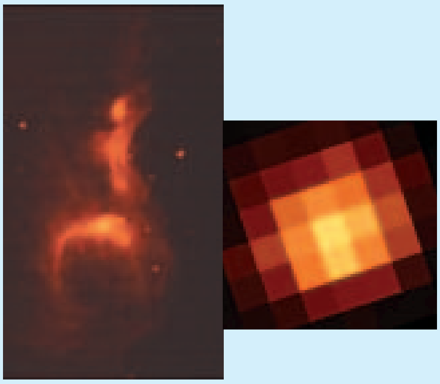
## Akari (Astro-F)

Akari, the new Japanese infrared sky surveyor mission with ESA participation, saw 'first light' on 13 April 2006 (UT) and delivered its first images of the cosmos. The images were taken towards the end of the successful orbital checkout of the satellite.

Akari's two instruments were pointed towards the reflection nebula IC4954, a region some 6000 light years away and extending more than 10 light years across. Reflection nebulae are clouds of dust illuminated by the light of nearby stars. In these infrared images of IC4954, a region of intense star formation active for several million years, it is possible to pick out recently born stars. They are embedded in gas and dust and cannot be seen in visible light. It is also possible to see the gas clouds from which these stars were created. These first images demonstrate the vastly increased scientific capability of Akari over its predecessor, IRAS, flown 20 years ago.

Akari's lifetime will be shorter than expected owing to initial problems with the Sun sensors and the consequent need to find and test alternative solutions. The observing strategy is currently being refined to maximise the scientific return of the mission. ESA's contributions are working well – regular and efficient ground station coverage from Kiruna and pointing reconstruction software, developed at ESAC, which is already in routine use.

*The reflection nebula IC4954 as seen by Akari at 9 μm (left) and by IRAS at 12 μm (right, smaller scale)*

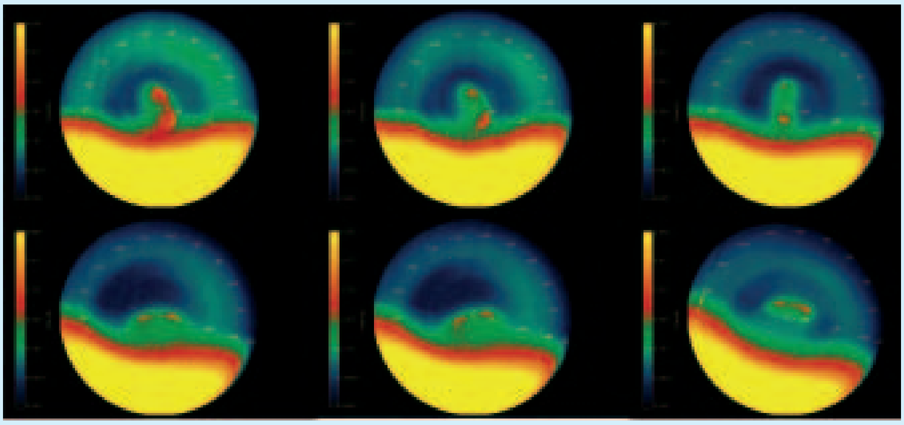


# Venus Express

The period of April to the end of June 2006 was crucial for the Venus Express spacecraft to enter orbit and manoeuvre into its final operation orbit. This was achieved in the first week of May and instrument commissioning immediately started. As part of these commissioning activities, the Venus Express Science Operations Centre was exercised in performing its planning role as an intermediary between the European scientific institutes and the Mission Operations Centre in Darmstadt (D), where the final command load is controlled. The activities were performed on schedule and routine operations began on 4 June using a pre-planned observation process that has allowed the operations to proceed smoothly.

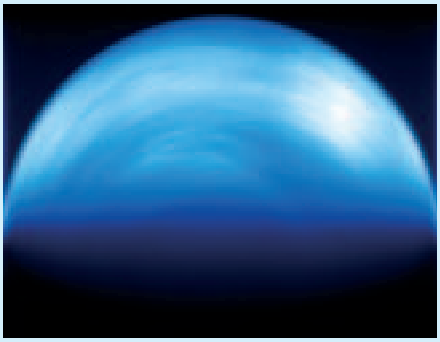
Significant science results have already been reported by the scientific community and images from some of the instruments have been publicly released to reveal features of the south pole of Venus seen for the first time.

The six different infrared images (top of page) were taken by the VIRTIS UV/visible/near-IR spectrometer 12–19 April during the first orbit around the planet. Around the south pole it is possible to see a peculiar double-eye vortex structure, never clearly seen by any other mission to Venus. The sequence shows the rotation and variation of the double vortex over time. The images also show a collar of cold air around the vortex structure (dark blue), possibly due to the recycling of cold air downwards.



*The south pole of Venus as never seen before*

*VIRTIS image of Venus in the ultraviolet*



# Herschel/Planck

The activities on both Flight Model spacecraft continue at a good pace. The refurbishment of the Herschel Cryostat in Astrium, Friedrichshafen (D), in order to implement the improvements identified in the earlier test campaigns, is making good progress. The cryostat had to be opened to the level of the main HeII tank and the activities to close it in the summer are running. In order to allow verification of the cryostat internal straylight suppression system, qualification units of the SPIRE and HIFI instruments have been mounted to the cryostat optical bench. The activities on the Herschel Service Model, now mainly integration and functional acceptance testing of the spacecraft avionics systems, continue at Alcatel Alenia in Torino (I).

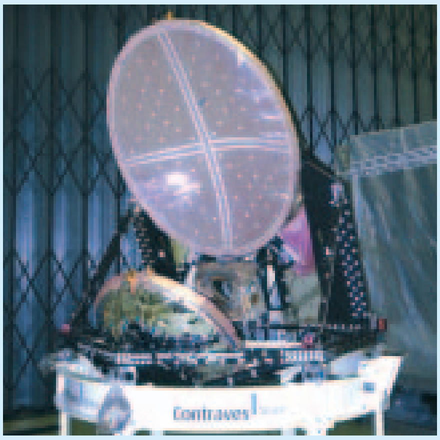
The Planck Flight Model spacecraft has been partially de-integrated at Alcatel in Cannes (F) for the upcoming Planck instrument integration activities. The Planck Service Module has been completed with the final mounting of the tanks of the reaction control system followed by end-to-end testing. On Herschel, the integration and test activities on the Service Module are concentrating on the avionics subsystem.

The Planck telescope has been fully assembled, aligned and prepared for the final telescope cryogenic-optical test, when the telescope alignment will be verified by videogrammetry measurements. The testing on the qualification model of the Planck telescope at the instrument operational frequencies up to 300 GHz has been completed for the first polarisation direction. The second test campaign addressing the other polarisation direction will be carried out in the autumn.

The Herschel telescope testing at cryogenic temperatures has been fully completed and the test data are under final review and evaluation for a delivery by end of the year.

All Herschel and Planck instruments are in the final stages of their acceptance testing and instrument flight model calibration. The Planck instruments are close to the completion of their activities and will be delivered for integration in the summer. The Herschel instrument-level testing and calibration will extend up to the end of the year.

*The Planck Flight Model telescope equipped with videogrammetry targets and protective covers on its support stand*



## LISA Pathfinder

The SMART-2/LISA Pathfinder Implementation Phase Contract is progressing well, with all activities proceeding according to schedule. The main activity in the reporting period was the design finalisation after the Mission Preliminary Design Review and the nearly completed procurement of the various subsystems and equipment.

With the exception of the thermal hardware, to be procured in early 2007, all the Invitations to Tender for the procurement of the spacecraft equipment and subsystems have been issued, proposals received, evaluated by the Prime Contractor and ESA, according to the best-practice rules, and contracts negotiated and kicked-off.

The procurement of the micropropulsion subsystem was more complicated than expected owing to the immaturity of the potential technologies. Consequently, a new Request for Quotation was issued to industry requesting the implementation of a technology phase in which parallel development of both European technologies (slit and needle field-emission electric propulsion, FEEP) will be followed by a development and qualification for flight of one of the two systems. This contract has been awarded and the activities have started.

A thorough assessment of the capability of the spacecraft to meet the mission performance (in terms of residual acceleration noise) is being carried out. This is a multidisciplinary and complex analysis involving thermal distortion, optical metrology, electrostatic sensing and actuation, and drag-free control.

The work on the LISA Technology Package (LTP) carried out by a consortium formed by ESA and the participating member states (D, I, UK, E, CH, F, NL) is progressing. All the system and subsystem Preliminary Design Reviews have been completed and the first subsystem (the Inertial Sensor Front End Electronics) is already undergoing the Critical Design Review. The criticality of several LTP technologies, such as the caging mechanism, electrostatic suspension sensing and actuation, and inertial sensor enclosure vacuum maintenance, is not yet resolved and there is still concern that these might affect the programme schedule. The activities leading to a timely delivery of the LTP therefore remain very challenging and require the full commitment of all parties involved.

The work on the NASA Disturbance Reduction System (DRS), now consisting of only the colloidal micropropulsion subsystem and the computer, with the drag-free software, is progressing nominally. Also for the DRS, the technological risks of the colloidal thrusters are not yet completely ruled out.

The launch is expected to take place at the end of 2009.

## Microscope

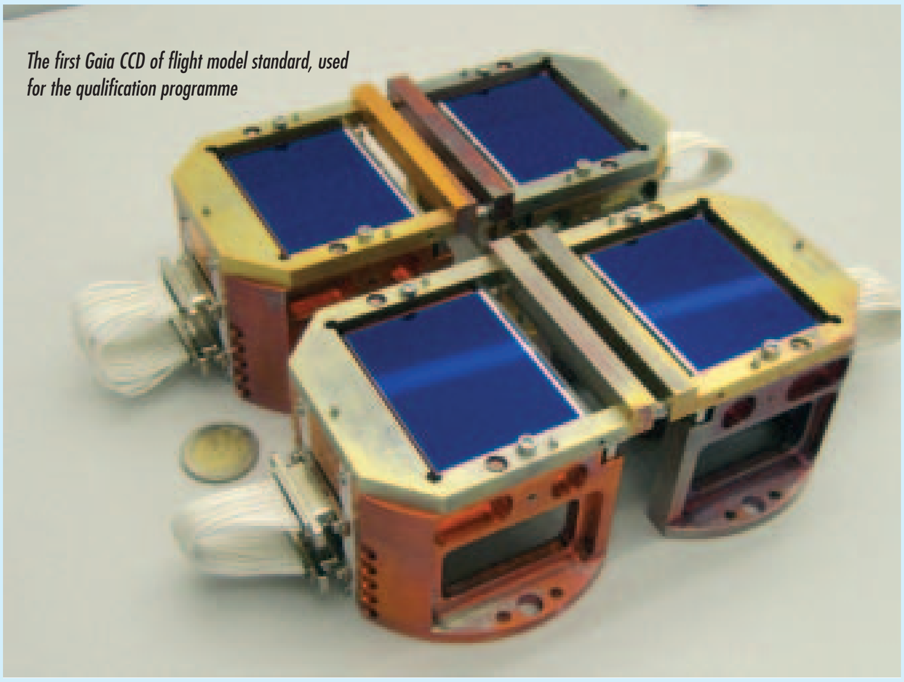
CNES has completed the preliminary study to assess the feasibility of accommodating the backup thruster systems to the baseline slit FEEP, in synergy with LISA Pathfinder. The technologies under consideration are the needle FEEP, being developed in the parallel Phase-1 of LISA Pathfinder, and the proportional cold-gas thruster under development for Gaia. The result is that accommodation is possible for both solutions, although some relaxation of requirements is required.

In June 2006 CNES presented the results of the study to their Board, which will decide if a more detailed study phase is required for one or both of the backup technologies.

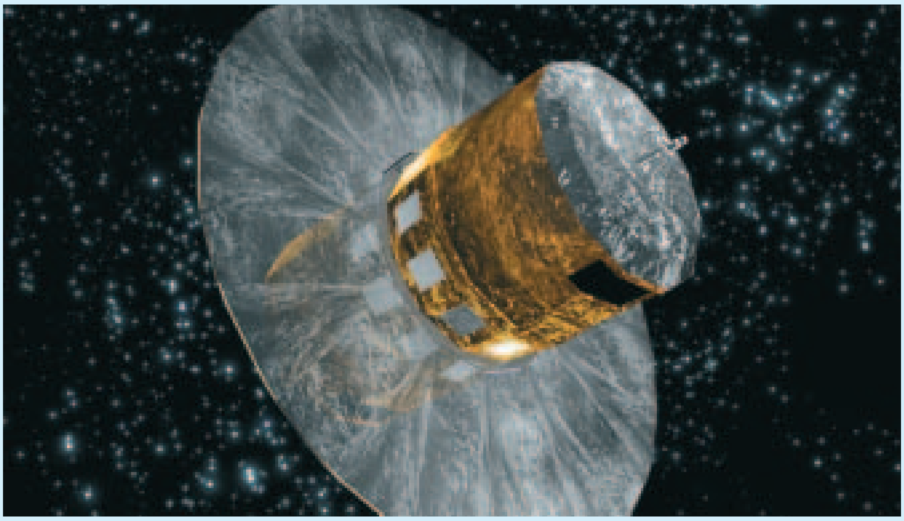
## Gaia

Gaia is proceeding at a fast pace. Two major activities are running in parallel. On the engineering side, the first major ESA review, the System Requirements Review, was successfully completed with a Board meeting on 7 July. At the same time, major attention is being paid to the competitive subsystem procurement. Together with the Prime Contractor, the project team is involved in the selection of 78 subcontractors according to ESA's best-practice process. At the time of writing, the first three contracts have been awarded.

A major change has been made to the mission scenario by significantly shortening



*The first Gaia CCD of flight model standard, used for the qualification programme*



*The Gaia spacecraft with fully deployed sunshield*

the transfer time from launch to the L2 point. The change was made possible by the rather comfortable mass situation, which allows a greater propellant load. In this new scenario, the science mission can start in early January 2012, about 4 months earlier than previously planned.

A close interface between the Gaia Science Team and Astrium is now in place to ensure an efficient process for the optimisation of the payload design and related operations.

## JWST

ESA hosted the JWST Quarterly meeting 25–27 April 2006, with more than 200 participants representing the various parties involved in the JWST partnership.

NASA has reached Technology Readiness Level 6 for six of the ten critical technologies: the sunshield membrane; the primary mirror segment assembly; and the near-IR and mid-IR focal plane assemblies. The last two elements are part of the NIRSpec and MIRI instruments.

The ESA-NASA Joint Project Implementation Plan has been agreed and signed off by the ESA and NASA Project Managers.

The build-up of the NIRSpec industrial consortium is almost complete and the last Invitations to Tender are being released by the prime contractor. Several subsystem Preliminary Design Reviews have been completed. Some have been split in two parts because of the late availability of breadboard test results and the need for the prime contractor to freeze interface definitions to progress on the optical bench design.

The NASA-provided Detector Subsystem passed its Preliminary Design Review.

The MIRI Critical Design Review (CDR) campaign has concluded. The start of the instrument-level CDR has been delayed to December 2006, allowing sufficient time to clarify the issues and concerns raised at the lower level CDRs.

The schedule of the Jet Propulsion Laboratory's Detector Subsystem underwent a thorough review because of the forecasted late delivery. Measures to reconciliate the delivery date and the MIRI instrument need date were identified and implemented. Parts and subassemblies for the instrument Verification Model are being manufactured and tested. The anticipated delay in the Instrument Verification Model is being recovered by simplification of the model build standard. This will ensure timely feedback to the Flight Model programme.

The ESA and NASA JWST project team visited the Centre Spatial Guyanese launch site during the period. As JWST is a high-performing observatory, cleanliness control was the major issue for discussion.

## BepiColombo

BepiColombo is an interdisciplinary mission to Mercury, selected as the 5th cornerstone in the Cosmic Vision programme. Owing to the high scientific potential of the planet and its environment, the mission will open a new frontier in the study of the Solar System. BepiColombo is a collaboration between ESA and the Japan Aerospace Exploration Agency (JAXA). It consists of two scientific orbiters, the Mercury Planetary Orbiter (MPO) and the Mercury Magnetospheric Orbiter (MMO), to study the origin and evolution of the planet, Mercury's interior dynamics and the origin of the magnetic field. The launch configuration is a stack of the two spacecraft and the chemical and electrical propulsion modules.

The consolidated BepiColombo mission scenario foresees a Soyuz-Fregat launch in August 2013 and arrival at Mercury in August 2019 for a nominal 1-year scientific mission. The 6-year cruise is achieved by a combination of six flybys (Moon, Earth, 2 Venus, 2 Mercury) and electric propulsion. The spacecraft design employs lightweight technologies and materials compatible with the aggressive thermal environment at Mercury.

ESA is responsible for the overall project, including the mission design, the MPO, the electrical and chemical propulsion modules, the launch, the cruise operations up to delivery of the two spacecraft in their respective Mercury orbits, and the MPO mission and science operations. JAXA is responsible for the procurement of the MMO and for its mission and science operations at Mercury. The mission definition has been completed and the scientific payloads of both spacecrafts have been selected.

Proposals from Industry were received on 17 May 2006 in response to the Invitation to Tender for the Implementation Phase of BepiColombo. The Tender Evaluation Board has completed its evaluation and the recommendation for selection of the Prime Contractor will be made to the Industrial

Policy Committee for approval in November 2006.

Final approval for implementation of the BepiColombo mission will be requested from the Science Programme Committee in November 2006.

## LISA

The Mission Formulation Mid-term Review was completed in April and the baseline configuration is now available. The industrial contractor has been requested to perform two additional trade-offs with an architecture using a single test-mass per satellite and in-field guiding. The first trade will include impact on redundancy, impact of the required modifications (e.g. optical readout) on the architecture, loss of heritage from LISA Pathfinder due to all required modifications, and impact on mission risk. The second trade-off will analyse the impact of in-field-guiding on the overall architecture considering one or two proof masses, including the optical and mechanical design, implementation of full redundancy in the architecture, budget estimates, identification of critical items and assessment of the performances of the modified baseline. Results will be available at the end of September.

The internal LISA status review was completed on 13 June with the Board meeting. It was an independent assessment of the maturity of the project based on the results of the Mission Formulation industrial activity performed by Astrium.

The cooperation with NASA proceeds well despite NASA's financial difficulty. The two teams are working as a single virtual team with good exchange of information and joint project decisions.

The 6th LISA Symposium took take place at the NASA Goddard Space Flight Center 19–23 June and was attended by 250 people. One of the hot topics was data analysis, highlighting the need to have a coordinated plan and to extend the project agreement made in 2004 with NASA to this area.

## GOCE

Two Accelerometer Sensor Heads (ASH) Flight Models (FMs) have been integrated and tested, both at the single-ASH level and at pair level. This first stiffness-free pair is due for delivery in July and constitutes the first arm of the gradiometer instrument. A third ASH FM has been integrated and environmentally tested. It was stiffness-free prior to environmental testing. Unfortunately, after vibration and thermal testing, it is suffering from an intermittent anomalous behaviour that is being investigated. The fourth and fifth ASH FMs are undergoing testing; integration and testing of the sixth unit is scheduled from August to September. The gradiometer Front-End Electronics FM1 and FM2 have been refurbished, while FM3 was tested under microgravity conditions at the Zarm drop tower in Bremen. In addition, the Thermal Control Electronic Unit Proto-Flight Model (PFM) and the Gradiometer Accelerometer Interface Electronic Unit PFM have also been completed and delivered. The schedule foresees delivery of the fully integrated and tested gradiometer electronics to the satellite prime contractor by September.

The Platform PFM integration has been completed, with the exception of the solar array and ion propulsion assembly. All solar array panels have been completed and are available for integration. Testing of the Ion Propulsion Control Unit FM revealed an anomaly that was traced to electronic circuitry in the power supply. The problem was solved, allowing completion of the unit's acceptance testing and delivery to the Platform contractor.

The activities dedicated to the closed-loop functional testing of the Drag-Free Attitude Control System on the Engineering Model Test Bench have continued. In parallel, the functional testing of the Platform PFM has started.

The manufacturing of the two Satellite-to-Satellite Tracking Instrument FMs has been completed. After verification of their standalone performance, FM1 and FM2 have meanwhile also been mechanically and electrically integrated on the Platform PFM.

On the Ground Segment side, the Flight Operations Segment and the Payload Data Segment developments continue according to plan. The PDS Version 2 Acceptance Review was completed in ESRIN in June, while the Factory Acceptance Test of the Version 1 of the Calibration and Monitoring Facility & Reference Planning Facility is planned for the beginning of July. Activities have also continued nominally at the European GOCE Gravity Consortium, responsible for the development of the High-Level Processing Facility. A pre-Acceptance Review of Version 2 of the HPF is planned in Munich by mid-July.

## CryoSat-2

The launch of CryoSat on 8 October 2005 resulted in loss of the satellite following a failure in the launch vehicle at the planned time of stage-2 engine shutdown. An explosion at about 40 km altitude showered finely fragmented debris within the planned stage-2 drop zone some 120 km from the North Pole.

A major effort has since been undertaken by all parties. The scientific community has confirmed the pressing need for the mission – it is needed more now than when first proposed. The Executive has worked with industry and the delegations to put together the technical, programmatic and financial means to build and launch a replacement satellite. The Earth Observation Programme Board approved resumption of the mission at its meeting on 24 February 2006 and the industrial activities started at the beginning of March. The launch of CryoSat-2 is planned for March 2009. This approval within 6 months of the failure is a major achievement for all the parties involved.

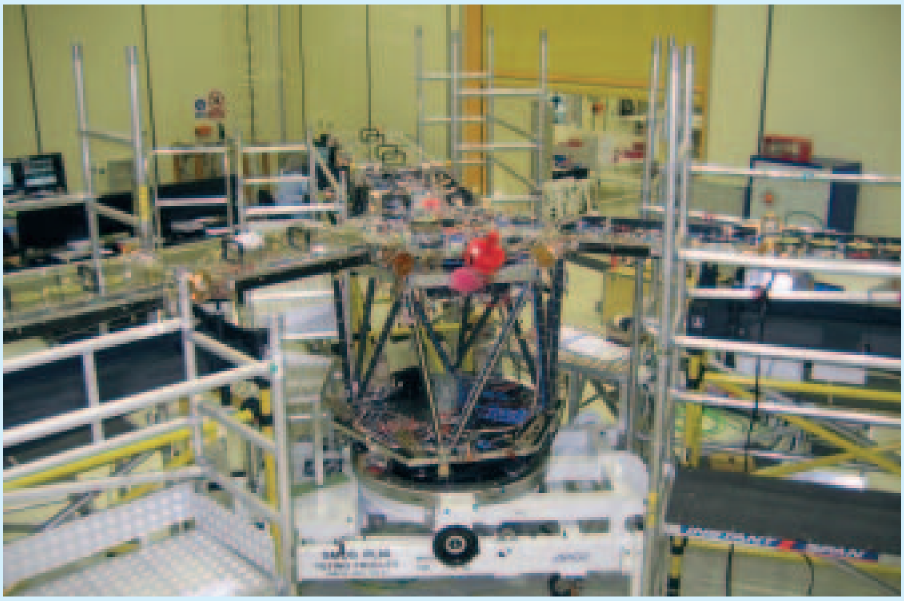
Advanced activities, to procure electronic parts with long delivery times, had already been initiated shortly after the launch failure in order to safeguard the schedule. With the full start-up of the industrial activities, the industrial prime contractor (Astrium GmbH) has been busy consolidating the design, since some items have become obsolete and new-generation replacements have to be integrated into the satellite. The work is proceeding rapidly and the first pieces of flight equipment will be delivered in mid-2007.

In the meantime, the ground segment, and in particular the science data processing facility at Kiruna, has been put into hibernation. During 2007 the facility will be updated to run on contemporary hardware, as the hardware procured during the original CryoSat development will have become obsolescent by March 2009.

Prior to the failed CryoSat launch, an extensive scientific measurement campaign in the Arctic had been planned. This campaign, CryoVEx 2006, required coordinated measurements from an aircraft equipped with both radar and laser sensors, a helicopter with an electromagnetic sensor and multiple *in situ* measurements by groups of scientists on the ice. After the launch failure, the postponement of this campaign was discussed with the groups concerned. It became clear that much valuable information could be obtained and so, during April and May 2006, the campaign went ahead as planned. Quick-look results indicate that many of the open questions that needed to be resolved in order to exploit the data from CryoSat fully will be answered by the data collected. A few issues remain, which require more measurements, but first results show that CryoVEx 2006 has been a great success.

## SMOS

Delivery of subsystem units for the payload protoflight model continues. All LICEF receivers have been delivered, and are being used to populate the arm segments of the structural model to undergo the 'on farm' antenna pattern characterisation at the antenna measurement facility of the Technical University of Denmark. All three arm measurements have been completed; still to be measured is the central hub structure with one adjacent segment of each arm. Once all the antenna characterisation activities are completed, the LICEF receivers will be transferred to the Flight Model arm segments that are under integration with electrical, radio-frequency and optical harness, thermal control hardware, and other subsystems such as the noise sources of the calibration subsystem.



*SMOS Proto-Flight Model integration at EADS CASA*

Platform integration of the recurrent Proteus platform has progressed significantly at the Alcatel Alenia Space, Cannes (F) facilities. It is interrupted owing to the resumption of the Calypso launch campaign.

Rockot launcher interfaces have been reviewed in the Preliminary Mission Analysis Meeting involving ESA, CNES, Alcatel, Eurockot and Khrunichev.

For the overall SMOS ground segment, the Preliminary Design Review has been completed. While the elements of the flight operations ground segment, both on the CNES and the ESA side, were found to be in an adequate development state, the payload data ground segment, including the data processors for level-1 and -2 data products, were judged to be rather schedule-critical. Backup solutions were suggested by the Board for investigation and eventual implementation by the project.

The building refurbishment and preparations for the X-band receive antenna are progressing nominally for installing the ESA-part of the ground segment at ESAC (E).

## ADM-Aeolus

The Flight Model propulsion system has been proof-tested at EADS-Astrium Stevenage (UK). The FM harness is being installed. The wavefront error has been measured on the FM primary mirror attached to its support structure; it is slightly better than expected. The delicate tripod that holds the telescope secondary mirror has been vibration tested.

A complete chain of the instrument's receive electronics has been successfully tested, from instrument control electronics to the detectors themselves. A series of thermo-mechanical issues has delayed the start of vacuum testing of the laser Qualification Model; these appear now to have been solved, and the test will start in September.

Launch of the satellite remains scheduled for September 2008.

# Swarm

Phase-B of the satellite activities with EADS Astrium GmbH is progressing, with consolidation at the system level of the Phase-A trade-off, satellite conceptual design and system performances. The System Requirements Review has started, with the objective of consolidating the top-level specifications and the satellite design.

Procurement of the satellite units and instruments is well advanced. Subcontractors have already issued offers for critical elements: startracker, GPS receiver, S-band transponder, vector field magnetometer, core electrical ground support equipment (EGSE). Other offers are in preparation by industry for the onboard computer, onboard software, EGSE elements, power conditioning & distribution unit, and the accelerometer instrument.

Phase-B of the Electrical Field Instrument is underway. Breadboarding of the critical elements has begun. The accommodation and interface definition of the instrument is in progress with the satellite prime contractor. The definition of the level-1b algorithms and instrument performance simulator is under way.

The Absolute Scalar Magnetometer Phase-B is progressing with LETI, Grenoble (F) under the leadership of CNES. The breadboard activities to demonstrate performances in the scalar and vector modes are under way.

The Preliminary Design Review presentation is planned for mid-December.

# MetOp

The reporting period was dedicated to the launch campaign of the Metop-2 satellite (to be redesignated as Metop-A in orbit), which began on 11 April.

At the time of writing (14 July), the satellite preparations are completed, the satellite encapsulated and Soyuz launch vehicle integrated awaiting roll-out to the pad for a scheduled launch on 17 July. *[Editor's note: three attempts on 17–19 July were aborted owing to launch vehicle problems; launch was then postponed for several months.]*

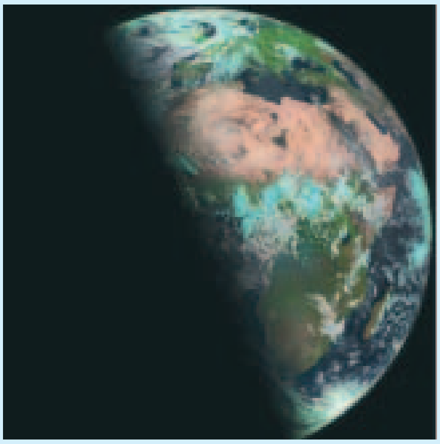
Several anomalies occurred during the first launch campaign that required significant effort and flexibility from the launch teams to resolve. In particular, a generic bearing problem with the AMSU-A instruments required both instruments to be removed and replaced at the Cosmodrome. While the task itself is well established, the logistics for the emergency shipment of the spare instruments to Baikonur and the return of the suspect instrument to the US required extensive coordination and cooperation by all parties concerned to navigate the Russian and Kazahk customs formalities. In addition, some anomalies in the satellite avionics also required extensive investigation. In one case, modification of the Central Flight Software was required.

In parallel with the satellite activities, final preparations, including formal rehearsals and simulations for both the Launch & Early Orbit Phase (LEOP), Satellite In-Orbit Verification (SIOV) and routine operations phases were completed, and both operating entities were ready for the satellite in orbit. During this period, the final Satellite System Validation Test was performed for the routine phase and LEOP, commanding MetOp from Darmstadt via the satellite link to the Cosmodrome.

# MSG

***MSG-1***
Meteosat-8's condition is nominal and the instrument's performance remains excellent.

***MSG-2***
The commissioning phase was completed at the end of June by a review at Eumetsat. It was concluded that satellite and instrument performances are well within specifications. MSG-2 is ready to start the operational phase, at which point it will be renamed Meteosat-9. It will remain, until further notice, the hot standby for Meteosat-8.



*The summer solstice for the northern hemisphere as seen by MSG on 21 June 2006 at 06:00 UTC. At this time of the year, the hemisphere is at its maximum tilt towards the Sun, producing the longest daylight period (Eumetsat)*

***MSG-3***
It is planned to put MSG-3 into long-term storage by the end of the year, awaiting launch in early 2011.

***MSG-4***
The IST1 Integrated System Test confirmed the completion of the integration activities. The environmental test programme has started. The acoustic test confirmed the MSG-4 acceptance levels to be within specification for the Ariane-5 launcher. It is planned to start the thermal-vacuum testing after the summer break.

# Human Spaceflight, Microgravity & Exploration

**Highlights**
Space Shuttle *Discovery* (STS-121) was launched to the International Space Station (ISS) on 4 July carrying ESA astronaut Thomas Reiter, who became the third member of the Expedition crew and is carrying out the Astrolab Long Duration Mission. The Shuttle also delivered the European Modular Cultivation System (EMCS), the –80ºC Freezer (MELFI) and the Percutaneous Electrical Muscle Stimulator (PEMS).

*Thomas Reiter working with NASA astronaut Stephanie Wilson in the Destiny module of the ISS*

Ground processing for the next mission (STS-115) is proceeding on schedule for a late August 2006 launch. The Assembly Sequence for completion of the ISS is being finalised, with Node-2 and Columbus currently foreseen for launch in the autumn of 2007.

The Columbus laboratory, complete with its suite of payload rack facilities, arrived at NASA's Kennedy Space Center (KSC) on 30 May 2006.

**Space Infrastructure Development**
On 2 May a ceremony, attended by the German Chancellor Angela Merkel, was held at EADS-ST, Bremen (D) to celebrate the completion of Columbus development, prior to its delivery to KSC later in the month. A final end-to-end system validation test involving the User Support and Operations Centres (USOCs) was performed and the Final Acceptance Review (FAR1) was completed with the final ESA/NASA Board meeting on 16 May. The Columbus laboratory and its four active multi-user payloads racks (Biolab, Fluid Science Laboratory, European Physiology Modules, and European Drawer Rack) were then transported to KSC.

A successful series of ATV functional test dry runs was carried out in preparation of the formal qualification tests that have now started. Major advances in completing the *Jules Verne* hardware were made, following which the system acoustic vibration tests were completed in the Large European Acoustic Facility at ESTEC.

Arianespace has informed ESA about an opportunity for an in-flight demonstration of the Ariane-5/ATV mission profile in November 2006. Such a demonstration would improve confidence in a dual-boost mission for ATV, and hence would considerably mitigate the risk to the project and the European ISS programme.

The European Robotic Arm (ERA) Mission Preparation and Training Equipment (MPTE) was shipped to Russia in February, and activities have been completed in preparation for the shipment of the flight unit. However, with the recent prospect of significant delays in the launch of the Russian Multipurpose Laboratory Module, which is the ERA launch carrier, the Flight Model will be temporarily stored in The Netherlands. ERA was showcased during a media day held in April.

Activities in the Nodes programme are proceeding very well. The Node-3 electrical and functional tests and NASA Audio & Video Tests have been completed. The delivery date of Node-3 is planned for spring 2007, but discussions are under way with NASA to transfer to Europe all of the remaining integration activities, which were planned to be performed in KSC. Thereafter, Node-3 would be stored at the prime contractor's facility in Turin (I) before shipment some months before launch in early 2010.

**ISS Operations and Ground Segments**
The activities for the Astrolab mission were replanned for the Shuttle launch in July. The Increment-12 payload activities were concluded. The activities planned for the Soyuz-12S visiting time and the start of Increment-13, which included the upload and operation of the two Kubik biological facilities and the performance of the Biology-1 experiments, were carried out nominally. Some components continue during Increment-13.

The passive Matroshka (human phantom) radiation dosimeters have been installed in the Russian ISS segment and Phase-IIA of the experiment is under way. Preparation for Phase-IIB with Roskosmos is in progress.

The Qualification and Acceptance Review for the Columbus Control Centre (COL-CC) has been conducted. A final end-to-end system validation test involving the USOCs has been performed and FAR1 was completed.

Two pre-Operations Qualification exercises were performed successfully as part of the ATV Control Centre (ATV-CC) operations preparation activities. The ATV simulator VR2.1 has been delivered to ATV-CC; a new version of the monitoring and control system has been accepted and an end-to-end test of the voice system with international partners was successful. The initial review of the ATV-CC Security Payload Local Area Network and Architecture Design Document has been carried out.

**Utilisation Planning, Payload Developments and Preparatory Missions**
An ISS utilisation symposium was held in Toledo (E), with about 60 papers and

*Shuttle* Discovery *approaches the ISS 6 July. The European-built* Leonardo *logistics module is prominent in the cargo bay*

participation from NASA, JAXA, CSA and Russia.

Following the European Commission's selection of ESA's 'SURE' proposal to use the ISS as a research infrastructure, 32 mainly scientific proposals were received. A peer evaluation is in progress.

The Maxus-7 sounding rocket, carrying a complement of five ESA-funded experiment modules, was successfully launched on 2 May 2006 from Esrange. On 11 May, Texus-43 was also successfully launched carrying three ESA-funded experiment modules. However, the ignition device of the combustion experiment failed. The hardware development for two further Texus missions and one Maser mission is underway.

The list of experiments for the 44th and 45th ESA Parabolic Flight campaigns, both planned for October 2006, is under final preparation. All payload and experiment developments (including pre-flight refurbishment activities) for the Foton-M3 mission have been initiated and continue nominally; launch is planned for September 2007.

All Final Acceptance Reviews (FAR-2) for the Columbus payload rack facilities (Biolab, Fluid Science Laboratory, European Physiology Modules, and European Drawer Rack, including the Protein Crystallisation Diagnostics Facility) were successfully closed prior to their shipment to KSC with Columbus. The Engineering Model rack deliveries to the USOCs are in progress.

The final verification activities for the External Payloads (SOLAR and EuTEF) Phase-C/D are under way. SOLAR experienced a hardware design problem and was returned to the developer, where the problem has been isolated. It will be delivered early in 2007, well in time for the launch with Columbus. FAR-2 preparation for EuTEF has started.

Definition of the ground segment for the Atomic Clock Ensemble in Space (ACES) has started. The ACES Mission-Preliminary Design Review (M-PDR) is scheduled for September 2006.

The Portable Glove Box, needed for biology experiments in autumn 2006, passed its Acceptance Tests and Safety Review, and was launched to the ISS aboard Progress-22P on 24 June. A biology experiment mission with six experiments in two Kubik incubators was successful during the visiting stage of Soyuz in April. The Increment-13 research programme focusing on human physiology, radiation and plasma physics is being performed by cosmonaut Pavel Vinogradov and progressing very well. All experiment and operations preparations for the Astrolab mission of Thomas Reiter were concluded.

**ISS Education**

An international meeting with NASA was held in April to coordinate education activities for ISS and Exploration, and in particular during ISS missions of ESA astronauts.

The second year of the Delta Research School Programme was kicked-off with the Dutch Minister of Education, the US General Consul, ESA astronaut André Kuipers and the Director of ESA External Relations.

The first cycle of ESA lectures for EuMAS (European Master in Aeronautics and Space) was completed.

The education programme for the Astrolab mission was defined. Testing and development of the two student experiments, CASPER (University of Dublin) and UTBI (University of Valencia), are on schedule for launch on Soyuz-13S.

**Commercial Activities**

ESA participated in the ILA2006 International Air Show, in Berlin, 16–21 May 2006, together with DLR and the German Space Industries Association, BDLI. Human Spaceflight and Exploration were two key areas promoted during the event.Industry Space Days 2006 (ISD2006) took place at ESTEC, 29–31 May. Several ISS Business Club members were present at the event. Preparation for ESA participation in the Farnborough International Airshow (UK) is under way.

**Astronaut Activities**

Thomas Reiter and his backup Léopold Eyharts completed their training for the Astrolab mission, finishing training at EAC in May. The final Shuttle launch training was performed at KSC. All planning and administrative preparations to support Astrolab/ULF 1.1 were finalised. EAC also supported the STS-121 Shuttle flight activities as well as the Astrolab activities.

ATV part-1 training for the International Partner pool astronaut class was conducted

2–5 May at EAC; Columbus User Level training for the same class was held 8–12 May.

ESA astronaut Paolo Nespoli has been assigned to the crew of the Space Shuttle flight STS-120 which, in August 2007, will launch Node-2, a connecting module built in Europe for NASA as part of the Columbus launch barter, to the ISS.

**Exploration**

The ExoMars Phase-B1 contract is being extended in scope and duration to implement the decisions taken at the Ministerial Council in December 2005. Procurement actions are progressing in preparation for the System Requirements Review, to be held at the end of the year, and the generation of the data necessary for the down-selection of the mission options required by the Ministers. At system-level, the selection of the contractor for the planetary protection tasks is being finalised. For the ExoMars payload, attention is focusing on the Pasteur instruments and the Geophysics and Environment Package.

A work plan for the Core Programme component of the Exploration Programme is being developed following the overall logic for consolidation of an integrated European strategy for human spaceflight, microgravity and exploration.

A common understanding between ESA and Roskosmos has been achieved regarding the mission, system concept and programmatic aspects of an advanced crew transportation system, on the basis of which an updated programme proposal, which is the evolution of the proposal on the Clipper Preparatory Programme that was submitted to the Ministerial Council in December 2005 in Berlin, was discussed in May.

# Vega

The firing test of the Zefiro-23 DM1 was successful on 26 June in Sardinia. Initial analysis shows that the pressure profile was within the predicted corridor, there were no pressure oscillations during ignition or the steady-state phases, and the thrust vector control system operated satisfactorily.

Other Vega activities included:

– the preparation of the System Critical Design Review (SCDR), with the delivery of a first set of updated documents;
– the completion of the working group on the separation of stages-1/2;
– the start of the Hardware In the Loop 1 test campaign in the laboratory;
– the kick-off meeting for the Upper Composite Mechanical test campaign (vibration and acoustics) preparation;
– the Test Review Board for level 1 analyses of the interstage-2/3 vibration and separation tests.

On the subsystems side, integration of the AVUM Stage Structural and Thermal Model has started, the interstage stiffness and strength tests have been completed, as well as the fairing static qualification tests, the Thrust Vector Control CDR has started and the development activities for the new payload adapter have begun.

P80 activities are still focused on the motor that will undergo the firing test in French Guiana at the end of November. The first composite structure (the insulated motor case) has been manufactured, proof loaded for pressure and compression/ tension and submitted to X-ray non-destructive inspection. It is now on its way to Kourou. The ‘maquette de pilotage’ test facility is ready (in Colleferro) and tests with actuators have been performed.

The Ground Segment System Design Review began on 23 May and will end in July.

# Soyuz at CSG

Earthworks at the Soyuz Launch Site continue to advance at a rapid pace. Excavation of the flame chute has proceeded as planned; infrastructure contractors started using explosives in early April to penetrate the layer of granite revealed by the 5 m excavation.

The Review Board for the Preliminary Design Review related to the interfaces between the ELS (Ensemble de Lancement Soyuz) and the BLA (Base de Lancement Ariane) took place as planned. As a result, a number of studies are to be conducted. The Board authorised the project to launch the related tender process.

The CDRi for Mechanical and Air-Conditioning aspects were conducted during May in Toulouse. No major issues were observed; the Review Boards will meet in the coming weeks.

The Review Board of the PDRi for the mobile gantry also took place in May; a major conclusion was that an *ad hoc* meeting should check the adequacy of the European part of the gantry.

# FLPP

The Period 1, phase 1 final presentation of system and experimental vehicle activities has been performed. The contract with NGL Prime Spa for FLPP1 activities including system, experimental vehicles, propulsion and materials and structures has been negotiated and is close to signature.

The FLPP2 Implementation Plan has been approved and first procurement actions have been started. The Request for Quotation for the first set of Upper Stage Engine Demonstrator activities has been issued; the proposal has been evaluated and negotiations started.

Discussions are under way with national agencies on the coordination of activities related to the IXV reentry demonstrator. Activities related to the project are progressing nominally.

# In Brief

## SMART-1 Aims at Fruitful End

After 16 months of orbiting the Moon, SMART-1 is being prepared to meet a dramatic end as it completes its scientific exploration. On 19 June, SMART-1's controllers began a 13-day series of manoeuvres to position the spacecraft to improve the science data being returned as the mission heads towards lunar impact at about 06:00 UT on 3 September.

If left alone, SMART-1 would have crashed around 17 August, but the extension provides new opportunities for low-altitude observations and optimises science returns during and after the spacecraft's controlled impact.

"*The shift in date, time and location for Moon intersection is also optimised to favour scientific observations from Earth,*" said Gerhard Schwehm, ESA's SMART-1 Mission Manager. "*Projections indicated that the spacecraft, if left as is, would impact the Moon on the far side, away from ground contact and visibility. The new location is on the Moon's near-side, at mid-southern latitudes.*"

The use of the electric propulsion system was ruled out because the xenon propellant tanks are empty. The mission control team instead developed an imaginative approach. "*The manoeuvre strategy consists of a series of reaction-wheel off-loadings combined with about 3 hours of intermittent thrust centred at apolune [orbital point furthest from the Moon] during the next 74 orbits,*" said Octavio Camino, Spacecraft Operations Manager at ESOC. "*After these manoeuvres, science activities will resume until the impact, with short interruptions for two trim manoeuvres to adjust the impact time, one around the end of July and one at the beginning of September.*" esa

## Nespoli & Schlegel Assignments

Two ESA astronauts were assigned recently to two critical Space Shuttle missions to the International Space Station. Italian Paolo Nespoli will make his astronaut debut on the Shuttle STS-120 mission in August 2007 that will attach Node-2, an Italian-built connecting module, to the Station. The Nodes control and distribute resources between Station elements. German Hans Schlegel will fly on STS-122 in September/October 2007 to add Europe's cornerstone Station element, the Columbus laboratory, to Node-2. His key role includes the installation, fitting-out and initial commissioning of Columbus. This will be Schlegel's second spaceflight; he first flew on the Spacelab-D2 Shuttle mission in 1993. esa


Schlegel Nespoli

## HYLAS Contract

ESA and Avanti Screenmedia Group PLC have signed a contract to develop the most innovative elements of the HYLAS Highly Flexible Satellite. HYLAS will be a hybrid Ka/Ku-band satellite providing broadband Internet access and broadcasting high-definition television. ESA's contribution is €34 million to the estimated project cost of €120 million. Launch is planned for late 2008 to a geostationary slot at 33.5°W.

For Giuseppe Viriglio, Director of ESA's European Union and Industry Programmes, "*HYLAS will play an important role in demonstrating the advanced technological capabilities of European space companies which are truly competitive on a global scale. It also makes significant progress in solving the social problem of poor broadband coverage in many parts of Europe and serves as a template for future large-scale projects.*"

The traffic-handling capacity of the Broadband HYLAS payload ranges from 150 000 to 300 000 simultaneous users. With high-gain Ka-band spot beams, it is possible to provide up to eight simultaneously active spots, a capacity equivalent to more than 40 conventional 33 MHz transponders. In addition, power and spectrum resources can be allocated to each spot according to the traffic demands. Two flexible Ku-band transponders will distribute and broadcast a range of high-definition programmes for Avanti Screenmedia customers over most of Europe. esa

## New Earth Explorer Candidates

ESA announced in May the shortlist of new Earth Explorer mission proposals within its Living Planet Programme. The selection procedure will eventually lead to the launch of the fourth Earth Explorer Core mission for launch 2010–2015.

The six missions cover a range of environmental issues, with the aim of furthering our understanding of the Earth system and changing climate:

- BIOMASS, to measure forest biomass globally;
- TRAQ (TRopospheric composition and Air Quality), to monitor air quality and long-range transport of air pollutants;
- PREMIER (PRocess Exploration through Measurements of Infrared and mm-wave Emitted Radiation), to understand processes that link trace gases, radiation, chemistry and climate in the atmosphere;
- FLEX (FLuorescence EXplorer), to observe global photosynthesis via fluorescence;
- A-SCOPE (Advanced Space Carbon and Climate Observation of Planet Earth), to improve our understanding of the global carbon cycle and regional carbon dioxide fluxes;
- CoReH2O (Cold Regions Hydrology High-resolution Observatory), to make detailed observations of key snow, ice and water cycle characteristics.

Their selection follows the release of the Call for Earth Explorer Core mission ideas in March 2005. ESA received 24 responses, which covered a broad range of Earth science disciplines, and in particular responded well to the priorities set by the Agency's Earth Science Advisory Committee (ESAC). These priorities focused on the global carbon and water cycles, atmospheric chemistry and climate, as well as the human element as a cross-cutting issue.

The proposals were peer-reviewed by scientific teams, and appraised technically and programmatically. Based on these reviews, ESAC evaluated the proposals and recommended the list of six mission ideas in order of priority. Following these recommendations, ESA's Programme Board for Earth Observation on 18–19 May approved the proposal of the Director of Earth Observation Programmes to initiate assessment studies.

Earth Explorer Core missions are ESA-led research missions and the budget limit for the current set is €300 million. The first were selected in 1999: GOCE and ADM-Aeolus, to be launched in 2007 and 2008, respectively. EarthCARE was selected in 2004 and will be launched in 2012.

The six new candidates will significantly extend the scientific disciplines covered by ESA's Living Planet Programme. When the assessment studies have been completed, several will be selected for feasibility studies, and the mission finally selected will be launched during the first half of the next decade. esa

*'Jules Verne', the first Automated Transfer Vehicle (ATV), has passed its acoustic test ordeal at ESTEC. The unmanned ferry will deliver supplies to the International Space Station beginning in 2007 but first it was critical to ensure that it can withstand the vibrations caused by the extreme noise generated during launch. Various test runs were conducted over several days at the end of June in the Large European Acoustic Facility while dozens of sensors measured ATV's response*

## ESA Navigation Facility

ESA's new Navigation Facility has rapidly become a world-class provider of highly accurate navigation information, significantly enhancing data from cornerstone satellite navigation systems.

In full operation since February 2006, the Navigation Facility, located at ESOC, is producing a growing series of processed data products that provide some of the world's most accurate orbit and clock calculations for global navigation satellite systems. These consist of the US Global Positioning Satellite (GPS) system, Russia's GLONASS and, soon, Europe's own Galileo system. The facility is directly connected to a network of 44

GPS signal receivers worldwide, and can receive data from several hundred others. These receivers monitor signals from the GPS satellites and relay them to a handful of highly specialised processing centres. These in turn process the raw data into sets of valuable atmospheric and geoscience information.

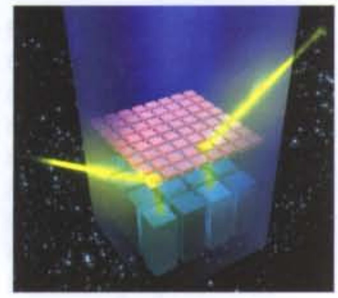
The Navigation Facility's cornerstone geoscience service consists of calculating and predicting GPS satellite orbits in near-realtime every 3 hours. Based on these orbit solutions, highly accurate timing corrections are computed every 15 minutes for all active GPS satellites and ground receivers. The most precise orbit solutions, including those from ESOC, are of the order of 3 cm, with a corresponding clock accuracy of 0.1 nanosecond.

These enhanced data are then used to boost the accuracy of the original location data sent by the satellites, improving climate monitoring and the tracking of large-scale, long-term changes in the Earth.

The facility is also developing new services for Galileo. These include providing data-validation, helping to define the fundamental geographic reference frame and setting up a network of Galileo signal receivers on behalf of Galileo Industries, the consortium of industrial partners building the system.

The Navigation Facility is also monitoring and validating data handled by the EGNOS (European Geostationary Navigation Overlay Service) system. EGNOS is a predecessor service for Galileo, and provides augmented and enhanced data from both GPS and (later) GLONASS satellites. This boost makes their data suitable for safety-critical applications such as flying aircraft and navigating ships through narrow channels. esa

## Integral Sees Round Corners!



Thanks to a clever design and a sophisticated analysis by European astronomers, ESA's Integral gamma-ray observatory can now image the most powerful gamma-ray bursts even if the satellite itself is pointing somewhere completely different.

Every day or so, a powerful gamma-ray burst (GRB) occurs somewhere in the Universe. Most last 0.1–100 seconds, so if your telescope is not pointing in exactly the right place at the right time, you will miss it – unless that telescope is Integral. The satellite can now take images round corners if the gamma-ray blast is strong enough.

When GRB 030406 exploded unexpectedly in early April, Integral was observing elsewhere, some 74 Moon-diameters away. Nevertheless, Dr Radoslaw Marcinkowski, of Poland's Space Research Center in Warsaw, and colleagues reconstructed an image of the event using the radiation that passed through the *side* of Integral's imaging telescope.

The key is that the IBIS telescope uses two detector layers, one on top of the other. Most gamma-ray telescopes contain just a single detector layer. In IBIS, the higher energy gamma-rays trigger the first detector layer, losing some energy in the process, but they are not completely absorbed. This is known as Compton scattering. The deflected gamma rays then

## International Polar Year 2007–2008

Thousands of scientists from 60 countries will be conducting research during the International Polar Year 2007-2008, armed with satellite measurements offering complete coverage of the polar regions, which play a vital role in the Earth's climate and ecosystems.

Having access to near-continuous satellite data of these regions over long periods of time is important for scientists to identify and analyse long-term climatic trends and changes. ESA will provide current and historical data, dating back 15 years, from its ERS-1, ERS-2 and Envisat satellites, as well as data from several non-ESA satellites.

Dr David Carlson, Director of the International Programme Office for the Polar Year, predicts many uses for the satellite data. "*Many researchers use satellite data as part of their daily activities. During IPY, those researchers will push to extract more and more information from the satellites, particularly to understand recent and current distributions of snow and ice. We will use every form of satellite data – passive visual, active microwave, and even sensitive gravity measurements – to understand changes in the global ice sheets.*"

Satellites have contributed to a greater understanding of polar regions, helped to identify the strong links with Earth's ocean and atmospheric processes, and made startling observations. For example, within days of its launch in 2002, Envisat captured the disintegration of the Larsen-B ice shelf in Antarctica, surprising scientists because of the rapid rate at which the shelf broke apart. esa

*Envisat's radar shows the C-16 iceberg and the Drygalski Ice Tongue collision of 30 March 2006* pass through to the layer below where they can be captured and absorbed because they have given up some energy in the first layer.

"*In this way, we are able to capture and analyse the higher energy gamma rays,*" says Dr Marcinkowski. He realised that gamma-rays from the most powerful bursts would pass through the lead shielding on the side of the telescope, then through the first detector layer before coming to rest in the second layer. The scatter locations in the two layers and the energy deposits can then be used to calculate the direction of the GRB.

Dr Marcinkowski had heard of Integral registering a solar flare in this way even though the satellite was not pointing at the Sun. He thought that if it worked with solar flares, it must work with the most powerful GRBs. On 6 April, his hunch was proved correct: Integral provided an accurate location for GRB 030406 even though it was not looking in that direction.

Until now, the science teams have been forced to rely on luck that Integral was pointing at the right place at the right time because GRBs are unpredictable. At present, they image about one a month. The Compton scattering technique could increase the number of Integral catches by half.

The team now hopes to automate the analysis routine that recognises the signals and pinpoints them. This would mean that the software could run automatically at the Integral Science Data Centre in Geneva, Switzerland and automatically alert astronomers to its gamma-ray catches as they occur.

**The Ariane-5 ECA launch of 27 May set a record for the vehicle: the Satmex-6 and Thaicom-5 telecommunications satellites totalled about 8300 kg delivered into geostationary transfer orbit. (*ESA/CNES/Arianespace/CSG*)**

# ESA Astronaut Joins ISS Crew

ESA's Thomas Reiter in July became the first non-US, non-Russian astronaut to join an International Space Station (ISS) Expedition crew on orbit. His 'Astrolab' mission is planned to last to December.

On 4 July, Space Shuttle *Discovery* lifted off from NASA's Kennedy Space Center in Florida, at 18:38 UT and successfully entered low Earth orbit. On this STS-121 mission, the first Shuttle flight in almost a year, *Discovery* carried a crew of seven, including German astronaut Reiter.

**The Mission**

Reiter joined the current permanent crew as Flight Engineer, reporting to Russian Commander Pavel Vinogradov, who flew to the ISS with NASA Flight Engineer Jeffrey Williams on Soyuz-TMA8 in March. This is the first time since May 2003 there has been a permanent crew of three. The crew size had to be reduced as long as the Shuttle was unavailable to fly logistics and servicing missions. This boost will enable the astronauts to devote more of their time to science experiments, in addition to overall Station maintenance.

The Astrolab mission is being conducted under an agreement between ESA and Roskosmos. As Flight Engineer, Reiter is in charge of vital tasks in Station guidance and control, environmental control and life support systems, power control and communications, crew health and safety and extra-vehicular activities. He will become the first ESA astronaut to perform a spacewalk from the ISS. Here again he is a veteran, having performed two EVAs during the EuroMir-95 mission 10 years ago. On that mission, he spent 179 days aboard the Russian Mir station.

While his fellow Shuttle travellers returned to Earth on 17 July, Reiter will be staying aboard the ISS for about 5 months. In September, Vinogradov and Williams will return to Earth and be replaced by NASA Commander Michael Lopez-Alegria and Russian flight engineer Mikhail Tyurin.

**In Space**

About an hour after docking with the ISS at 14:52 UT on 6 July, *Discovery's* hatches were opened and the STS-121 crew entered the Station to be greeted by the Expedition-13 pair. An early job was installing Reiter's tailor-made seat-liner into Soyuz-TMA8, making him officially a member of the Expedition-13 crew.

*Suiting up on launch day, 4 July*

*The Expedition-13 crew (from left): Reiter, Vinogradov and Williams*

On 7 July, the two crews worked together to attach the European-built Multi-Purpose Logistics Module (MPLM) *Leonardo* to the Unity node. Reiter and Shuttle Commander Steve Lindsey performed leak checks on *Leonardo* before entering to begin unloading cargo. *Leonardo* carried over 2 tonnes of cargo, the majority being food, clothing and crew consumables, as well as spare parts and experiment equipment.

The cargo included three European experiment facilities: the Minus Eighty-degree Laboratory Freezer (MELFI), the Percutaneous Electrical Muscle Stimulator (PEMS) and the European Modular Cultivation System (EMCS). MELFI's advanced freezers provide long-term storage of biological samples and experiment results at –80ºC before they are sent to Earth. EMCS will be used to grow plants in space, and PEMS was developed for human physiology experiments. This equipment will be commissioned during Astrolab, along with ESA's Pulmonary Function System, already onboard.

Once unloading was completed, unwanted equipment and a small amount of rubbish were moved into *Leonardo*. The Shuttle departed with *Leonardo* on 15 July and landed safely on 17 July.

All Station facilities need to be regularly maintained to ensure they can still be safely used in orbit. On 11 July, Reiter was busy replacing a window and seals on the European-built Microgravity Science Glovebox (MSG), installed in the Destiny laboratory module. The new window arrived with Reiter. The glovebox was the first European rack facility to be delivered to the Station, in 2002. Its sealed and controlled environment, isolated from the rest of the ISS, allows the astronauts to perform a wide variety of materials, combustion,

*Above left: in the Station's Zvezda module. Top right: working in the Quest airlock with Shuttle Commander Lindsey. Right: Reiter during the EVA of 3 August*

fluids and biotechnology experiments.

**Astrolab Continues**

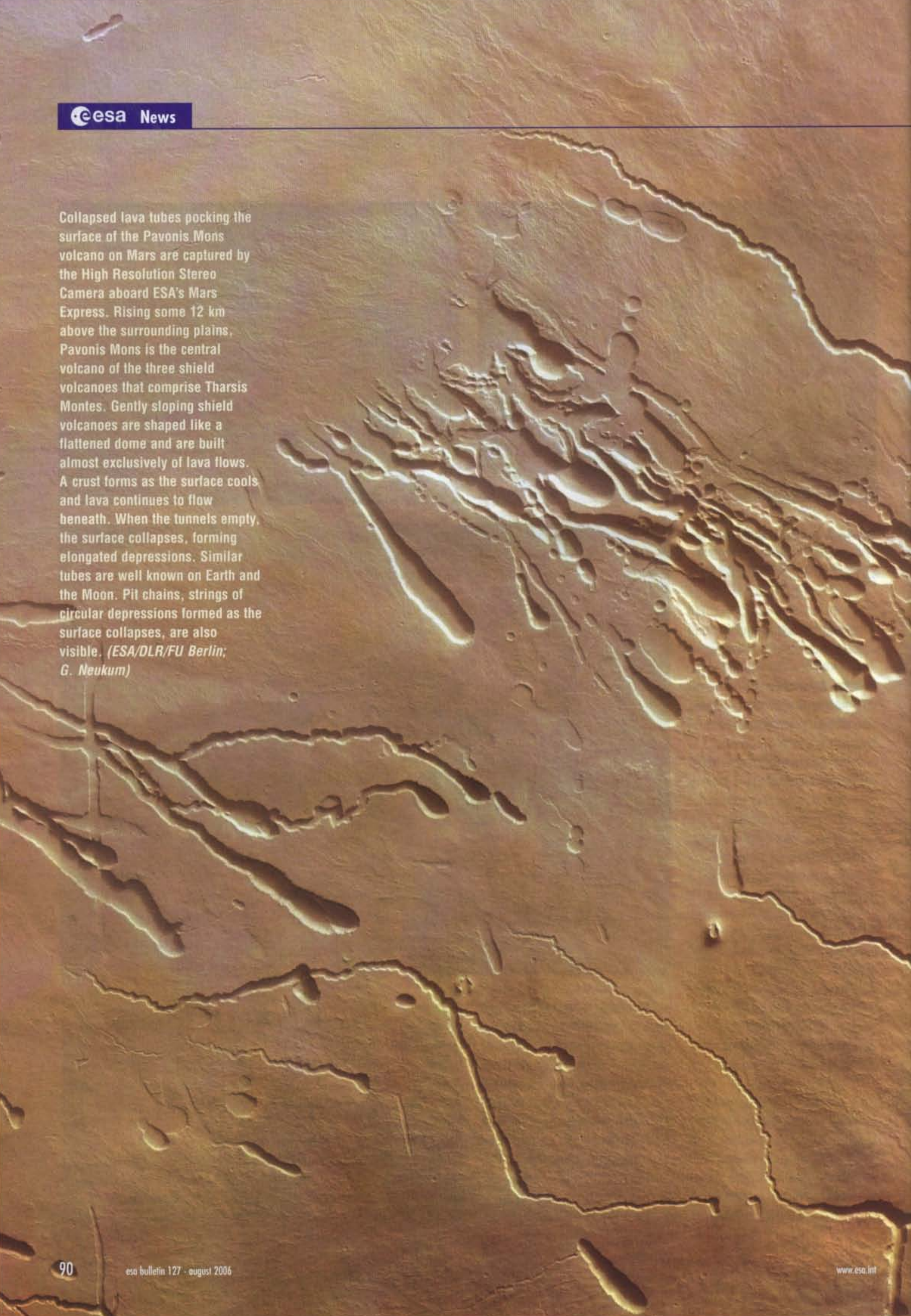
It is the first time that a European scientific programme has been created for a long-duration mission. Reiter has a series of science and technology experiments, including human physiology (cardiovascular system, bone mass, eye motion, immune system, respiratory system), astronaut psychology, microbiology, complex plasma physics and radiation dosimetry. Technology demonstrations include a 3-D video camera and industrial and educational experiments for universities and schools. Reiter and his crewmates will also taste high-quality food designed to improve the lot of astronauts cut off from Earth.

On 3 August, Reiter became the first ESA astronaut to perform a spacewalk from the ISS.

A further 17 Shuttle flights are scheduled to deliver additional elements to the ISS, including new modules, truss sections and solar arrays, through to 2010. One of the most important European assets arrived in Florida at the end of May: the Columbus laboratory, a unique science facility designed to accommodate state-of-the-art research equipment for more than a decade of experimentation. The Station's continued assembly will also be made possible by the logistics flights of ESA's Automated Transfer Vehicle, the unmanned cargo ship to be launched by Ariane beginning next year.

Astrolab is the first long-duration mission to draw on the support of a European control centre, as a rehearsal for ESA's expanded presence with the arrival of Columbus. The Columbus Control Centre, Oberpfaffenhofen (D), is also home to the European Payload Operations Centre, which is coordinating European experiment and payload operations aboard the Station while monitoring Reiter's activities.

Further information on the Astrolab mission and its experiments can be found at *www.esa.int/astrolab*



Collapsed lava tubes pocking the surface of the Pavonis Mons volcano on Mars are captured by the High Resolution Stereo Camera aboard ESA's Mars Express. Rising some 12 km above the surrounding plains, Pavonis Mons is the central volcano of the three shield volcanoes that comprise Tharsis Montes. Gently sloping shield volcanoes are shaped like a flattened dome and are built almost exclusively of lava flows. A crust forms as the surface cools and lava continues to flow beneath. When the tunnels empty, the surface collapses, forming elongated depressions. Similar tubes are well known on Earth and the Moon. Pit chains, strings of circular depressions formed as the surface collapses, are also visible. *(ESA/DLR/FU Berlin; G. Neukum)*


10 km

The 'jewel of the Kalahari': Botswana's Okavango Delta is highlighted in the lower left corner of this Envisat MERIS image, acquired on 2 July 2006. The world's largest inland delta is a labyrinth of lagoons, swamps, channels and islands and a home to a vast array of wildlife. The Okavango River flows inland and irrigates 15 000 square kilometres of the Kalahari Desert. Such wetlands are the most biologically diverse ecosystems on Earth, more productive even than tropical rainforests. GlobWetland, an ESA-led initiative, has been using satellite imagery to provide detailed wide-area views of individual wetlands to aid national and local conservation efforts. With wetlands often made up of difficult and inaccessible terrain, satellites can provide information on local topography, the types of vegetation, land cover and use and the dynamics of the local water cycle.

Japan's ALOS satellite captured this image over Cardiff, the capital city of Wales, on 15 June 2006 with its Advanced Visible and Near-Infrared Radiometer instrument, designed to chart land cover and vegetation at a resolution of 10 m. ESA is supporting ALOS as a 'Third Party Mission', meaning the Agency is using its ground systems and expertise to acquire, process and distribute data from the satellite to users. Data from Kiruna (S) are transferred electronically to ESRIN and processed in a shared approach between ESRIN and the Neustrelitz Station (D), operated by the German Space Agency. Detailed information on these and other Earth images can be found at *http//:earth.esa.int*

# Publications

**The documents listed here have been issued since the last publications announcement in the ESA Bulletin. Requests for copies should be made in accordance with the Table and Order Form inside the back cover**

## ESA Newsletters

**Connect – ESA Telecommunication Newsletter No. 02/06**
N. Menning, R. van Lieshout & B. Battrick (Eds.)
No Charge




**ECSL 32 – Bulletin of the European Centre for Space Law**
D. Danesy (Ed.)
*ESA ECSL No. 32, May 2006 // 16 pp*
No Charge

**ECSL 33 – Special Edition – Report on the 2006 ECSL Practitioners' Forum / Bulletin of the European Centre for Space Law**
D. Danesy (Ed.)
*ESA ECSL No. 33, May 2006 // 4 pp*
No Charge

## ESA Brochures

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L. Hennessy & D/REF Team
B. Battrick (Ed.)
*ESA BR-259 // 15 pp*
No Charge



**The European Space Sector in a Global Context – ESA's Annual Analysis 2005 (July 2006)**
Director General's Office for Policy
(Ed. B. Battrick)
*ESA BR-260 // 72 pp*
Price: 10 Euro

**MetOp – Monitoring the Weather from Polar Orbit (June 2006)**
C. Fransen (Eds. H. Rider & B. Battrick)
*ESA BR-261 // 17 pp*
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## ESA Special Publications

**Proceedings of ESA/CNES ICSO 2006 – Sixth International Conference on Space Optics, 27–30 June 2006, ESTEC, Noordwijk, The Netherlands (June 2006)**
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*ESA SP-621 // CD-ROM*
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**Proceedings of the First Conference on Atmospheric Science, 8–12 May 2006, Frascati, Italy (July 2006)**
H. Lacoste (Ed.)
*ESA SP-628 // CD-ROM*
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**Proceedings of DASIA 2006 – Data Systems in Aerospace, 22-25 May 2006, Berlin, Germany (July 2006)**
L. Ouwehand (Ed.)
*ESA SP-630 // CD-ROM*
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**Proceedings of the Microwave Technology and Techniques Workshop – Enabling Future Space Systems, 15–16 May 2006, ESTEC, Noordwijk, The Netherlands (May 2006)**
L. Conroy (Ed.)
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A. Wilson (Ed.)
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## ESA Contractor Reports

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Price: 25 Euro

**High Performance Dual Polarization Ku Band Feed Design – Executive Summary (June 2005)**
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EADS
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**ISTOS – Integrated Space Technologies Operational Systems for Combined Space Technology (TEL/EO/NAV) – Final Report (July 2004)**
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