

# Technical and Operational Support

The year's highlights for the Directorate as a whole were:

- the successful launches of the four Cluster satellites, in two pairs on two Soyuz launchers, from Baikonur, in July and August
- ESOC, and the Redu and Villafranca stations, successfully maintaining their ISO 9001 certification
- the start of construction of the 34 m-diameter deep-space antenna at New Norcia near Perth (W. Australia), to be ready in 2003 to support the Rosetta and Mars Express missions
- the system testing of Artemis and Envisat successfully completed in the ESTEC Test Centre
- the formulation of the new 2001 – 2003 ESA Technology Research Programme.

## Mission Operations

### ECS and Marecs

Following Eutelsat's decision to terminate ECS-5 operations, the spacecraft was moved to an orbit outside the geostationary belt and deactivated in May, having logged almost 12 years of operation. Meanwhile, ECS-4 continued to provide successful communications services to Eutelsat throughout the year, with operations conducted from the Redu (B) ground station. Marecs-B2 mission-control operations continued from Redu throughout the year.

### Ulysses

Operated by the ESA flight-control team located at Jet Propulsion Laboratory (JPL) in Pasadena (USA), Ulysses has now completed both the south and the north polar passages of the originally conceived mission. In 2000, it also completed for the second time the long journey out to Jupiter's distance and, following a southerly trajectory, arrived over the south solar pole in November, attaining a maximum heliographic latitude of 80°S. The spacecraft, in its 11th year of operation, continued to acquire excellent scientific data from all onboard experiments.

### Huygens

The Cassini/Huygens spacecraft was performing well as, in October, it commenced the fourth year of its seven-year journey to reach Saturn in 2004. In-flight checkout campaigns in February and July showed the Huygens Probe and its experiments to be in good health. Analysis and ground testing of the Huygens/Cassini radio and data link (Probe relay) was initiated to properly characterise its performance during the Probe's descent to Titan's surface, to assess the effects of the newly identified Doppler-shift problem, and to identify the resulting constraints on Cassini/Huygens trajectory planning. Having already completed two Venus and one Earth flyby manoeuvre, Cassini/Huygens passed around Jupiter on 31 December.

### XMM-Newton

After the successful launch and early-orbit phase, the XMM commissioning phase began on 4 January, and was followed by the calibration and performance-verification phase on 9 March. The routine scientific-mission phase commenced in July. The spacecraft continued to be in good health and the scientific payload generally performed as anticipated. A number of measures were taken to enhance operations efficiency, such that the success rate for scheduled observations now exceeds 95%. The mission operations are conducted from ESOC, using telemetry, telecommand and tracking data provided by ESA's Perth (Aus.) and Kourou (Fr. Guiana) ground stations. The science operations are conducted from Villafranca, near Madrid (E).

### ERS-1 and ERS-2

After a combination of onboard failures, contact with ERS-1 was lost in March. Despite an intensive search using all available ESA stations, augmented by ground-based radar imaging,



*The Cluster-II Mission Control Team*

contact with ERS-1 could not be re-established. The ERS-2 mission, on the other hand, continued to provide a mission product return of more than 95%, despite a degradation in gyroscope performance. Measures were taken to reduce gyro dependency by developing and uploading new software algorithms to the spacecraft. ERS-2 mission management and mission operations are conducted from ESOC using telemetry, telecommand and tracking data provided by ESA's Kiruna (S) and Villafranca (E) stations.

### Cluster

The four Cluster-II spacecraft were successfully launched in pairs by Soyuz-Fregat launchers in July and August. After a highly successful launch and early-orbit phase, all four were accurately inserted into the correct constellation orbit by the end of August, as planned. The payload-commissioning phase that then began was very successful and nearing completion by year's end. Mission operations are conducted from ESOC, using telemetry, telecommand and tracking data provided by two ESA antennas at Villafranca (E). Analysis of the calibration-phase science data is conducted by the Principal Investigators using their own equipment specially installed at ESOC for this purpose.

## Missions in Preparation

### Envisat

Preparation of the Envisat ground segment continued according to schedule, as did preparations for mission operations, leading to readiness for an anticipated launch in mid-2001.



*The ESOC Main Control Room, configured with the latest SCOS-2000 mission-control system*

### Integral

Integral ground-segment activities proceeded according to schedule. Of particular significance was the successful back-to-back interface test between ESOC and JPL using the new Space Link Extension (SLE) services. On-line end-to-end system validation tests between the Control Centre and the flight-model spacecraft served to prove the ability of the new generation of ESOC mission-control systems (SCOS-2000) to support complex scientific missions.

### Proba

Proba mission operations will be conducted from the Redu (B) ground station, and the mission-operations preparations progressed well. The SCOS-2000 system will be used for both the satellite test/integration phase and the flight phase, thereby reducing overall project costs.

## SMART-1

Work on the ground segment proceeded according to plan. The Ground Segment Design Review held in November was declared a success.

## Rosetta

Procurement activities for the new ESA 35 m deep-space antenna proceeded according to plan. Construction activities at the New Norcia site, about 130 km north of Perth in Western Australia, are well under way. The Rosetta Ground Segment Design Review was successfully completed in mid-October.

## Mars Express

The ground-segment preparation activities progressed well. A number of development activities take advantage of the synergy with systems under development for the Rosetta ground segment. The Ground Segment Design Review was completed successfully at the end of October.

## Herschel/Planck

Support was provided throughout the year to the Herschel/Planck (previously First/Planck) project and to the Science Operations Centre for the definition of the space and ground segments, mission analysis and related interfaces.

## Earth Explorer Missions: CryoSat/GOCE

Work started on the definition, together with the respective project teams, of the ground-segment requirements.

## Ground Systems Engineering

### Flight Control Systems

The SCOS-2000 new-generation mission-control system attracted much interest from the European space community. The Herschel Principal Investigators decided to employ it as instrument Electrical Ground Support Equipment (EGSE), and DLR in Germany also opted for this product to equip its new Control Centre. Many licences were also granted to other users.

SCOS-2000 was also fully established operationally. A coherent programme of studies and investment was initiated to further expand its functionality, to respond to evolving market demands in terms of secure remote operation (via the Internet), data distribution and mission-constellation support. The Space Link Extension (SLE) infrastructure was successfully put in place to allow cross-operation with NASA stations conforming to the new CCSDS data-interchange standards.

The XMM Science Operation Centre system at Villafranca demonstrated ESOC's ability to quickly establish and successfully manage a large and complex software system, and at much less cost than in the past.

### Ground Station Engineering

For the Station Systems Division, the year focused on the implementation of the Agency's Deep-Space Ground Station at New Norcia (W. Australia). The main construction work was contracted out and was well underway by year's end. The antenna metalwork was shipped, occupying nearly a full freighter. Major progress was also made on important subsystems. The up- and down-converters are now compliant with the Rosetta requirements and the first production unit of the Intermediate Frequency and Modem System (IFMS) is



Construction of the antenna base in progress at ESA's new Deep-Space Ground Station in New Norcia, Western Australia. Above: Site location map

undergoing acceptance testing. The high-precision time and frequency system needed was defined and an open Call for Tender issued.

A GSTP study on 'Very-High-Speed Frame Synchronisation and Viterbi Decoding' resulted in the implementation of an 160 Msymbol/s ASIC together with the associated programmable hardware. The Viterbi decoder is an innovative design, and is believed to be the world's fastest.

## Flight Dynamics

The year's major achievement was the successful orbital insertion in July and August of the four Cluster-II spacecraft, and the operations for manoeuvring them into their initial tetrahedron constellation with inter-spacecraft distances of 600 km, plus or minus a few kilometres. The launches of the satellite pairs followed excellent collaboration with the Starsem French-Russian launch service company, involving detailed interface definition and the monitoring of two test flights of the Soyuz rocket with its new Fregat upper stage, both supported by ESOC Flight Dynamics and Mission Analysis. In the five days following each launch, a series of very critical, large orbit-change manoeuvres (five per spacecraft), together with associated larger and smaller attitude changes, had to be prepared, executed and evaluated. The objective was to bring the spacecraft, in pairs, from the launch-injection orbits with 240 km perigee, 18 000 km apogee and 65° inclination, into polar orbits close to the final ones needed for the scientific mission, with 18 000 km perigees and 119 000 km apogees. In late August, an additional series of small orbital trim manoeuvres was initiated, gradually converging towards the exact tetrahedron constellation with 600 km inter-spacecraft separations at the two positions in the orbit where they pass through the cusp of the Earth's magnetosphere. Despite the planned interruptions during the payload-commissioning phase, this was successfully completed by the end of the year.

A major activity during October and November was participation in the preparation, monitoring and evaluation of the deployments of the four 43 m-long wire booms on each of the Cluster spacecraft, involving spin manoeuvres designed to contribute to the orbit constellation improvement goal, and careful assessment of spacecraft dynamic behaviour. By year's end, a total of 100 manoeuvres had been carried out, 56 of which contributed to the achievement of the constellation.

## Mission Analysis

ESA is studying a number of lunar and interplanetary missions (e.g. SMART-1, LISA, SOLO, Mercury Cornerstone) that exploit the benefits of solar electric propulsion. The latter's combination of a high specific impulse and a low acceleration level requires new methods of trajectory optimisation. The combination of low-thrust propulsion and gravity assists is the key to reducing propellant consumption and still placing sufficient payload mass into the desired target orbit.

The mission design for Mars Express was further improved, and the analysis of missions to the L2 libration point of the Earth-Sun system (for Herschel/Planck, GAIA and Darwin) continued.

## Space Debris

European cooperation on space debris was reinforced with the formation of the Pilot Network of Centres Working Group on Space Debris, of which ESA, ASI, BNSC, CNES and DLR are members. An important milestone was achieved in December with the ESA Council's unanimous approval of a 'Resolution for a European Policy on Protection of the Space Environment from Debris'. This Resolution emphasizes the global dimension of the space-debris problem, and also underlines the importance and urgency that Europe attaches to it.



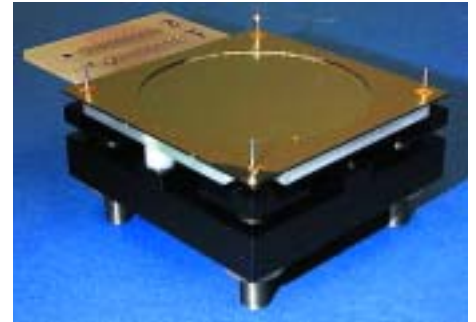
*The FGAN 34 m Tracking and Imaging Radar (TIRA) at Wachtberg-Werthhoven, in Germany, which can detect 2 cm pieces of debris at a distance of 2000 km*



## Mechanical Engineering

In the mechanical-systems area, major technology development efforts were directed towards the miniaturisation of optical and mechanical devices. Using MEMS (Micro-Electro-Mechanical System) technology, an electrostatically actuated two-axial silicon mirror was micro-machined and tested, permitting fine

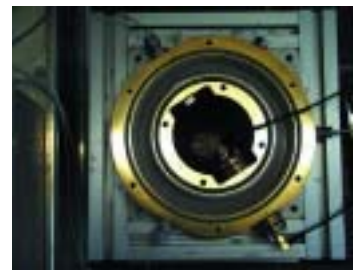
pointing of laser beams in inter-satellite links with high accuracy and large bandwidth. Similarly, a miniature onboard optical correlator was developed for the correction of push-broom camera image distortions induced by satellite attitude instabilities, particularly in small-satellite applications. Micro-Channel-Plate (MCP) technology was further advanced towards 10 micron square-pore, radially-packed plates of up to 60 mm diameter for use in X-ray focussing. An adaptive-optics wavefront correction device was prepared in the form of a polychromatic reflective system to improve the optical imaging quality of extremely lightweight space optical systems, using Shack-Hartmann wavefront sensing and an electrostatically deformable membrane mirror.



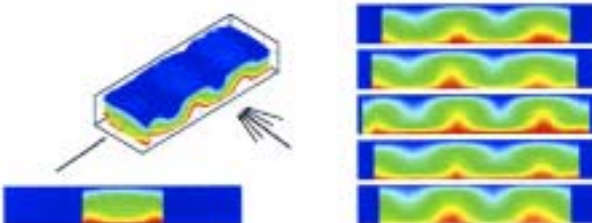
*Miniature onboard optical correlator, for the correction of push-broom camera image distortions*

*Gold-coated, electrostatically deformable membrane mirror for the polychromatic adaptive-optics system*

A number of instrument-technology developments intended for use in the first series of microgravity research facilities on the International Space Station (ISS) were completed, and new activities initiated for extending the operational capabilities of these facilities. A typical example is tomographic interferometry, which improves the performance of the Fluid-Science Laboratory (FSL) by determining the three-dimensional density and temperature distributions in fluid-science experiments from interferograms taken from various viewing directions. An increasing number of these technology-development activities are also yielding interesting commercial applications, such as microwave heating for the production of Zeolites, which are



*Autoclave for the microwave heating of Zeolite solutions in microgravity.*



important for detergent manufacturers and as catalysts in refineries. The application of microwave heating and online analysis of the Zeolite crystallisation process have been demonstrated with the help of ultrasound, and the performance of this process in microgravity will provide

*Three-dimensional reconstruction using tomographic interferometry of density/temperature distributions in Fluid-Science Laboratory (FSL) experiments*

fundamental insight into crystal formation. Similarly, a miniaturised dynamic light-scattering technique was developed for the in-orbit monitoring and ground reference control of small-particle growth processes in solution, particularly for proteins and other biological crystals.

In the area of robotics and automation, ESTEC's laboratory facilities were used intensively to support the European Robotic Arm (ERA) project with expert assessments and prototyping of innovative solutions to address critical issues encountered during testing. All four Microgravity Facilities for Columbus (MFC) projects were supported in terms of payload



control and experiment automation. Many technology developments were completed and produced impressive engineering prototypes, e.g. the first complete end-to-end control system for payload-tending robot systems on the ISS, a highly compact and fully automated mobile robot system that can assemble a drill string to collect Martian soil samples from a depth of 2 m, tiny wheeled rovers with masses of less than 0.1 kg that could operate in swarms on the surface of Mars, and a novel concept for a flying robot (autogyro-type rotary-wing aircraft) for Mars exploration. Indeed, robotic

*A micro-robot capable of assembling a drill-string to collect Martian soil samples to a depth of 2 m*



*Ceramic-matrix-composite body-flap bearing assembly for the X-38 vehicle*

devices are increasingly being considered for planetary exploration (atmospheric, surface, underground), including the new Mercury-exploration (BepiColombo) scenario for which a number of robotic technology developments have been initiated. The latest robotics developments and applications were reviewed at the very successful ESA Workshop on Advanced Space Technologies for Robotics and Automation, ASTRA 2000, hosted at ESTEC in December.

In the Mechanical Systems Laboratory, qualification and life tests were conducted in support of projects and industry for the piezo-motor of the MIDAS instrument (Rosetta spacecraft), the Columbus Condensing Heat Exchanger, and the Ka-band wave-guide isolator of the Hot Bird satellite.

The continuous increases in spacecraft system complexity, mass requirements, pointing stability and overall size are imposing high performance requirements on satellite structures. In response to these demands, the development of new structural materials, analysis tools, and verification methods was initiated. The development and qualification of highly thermo-mechanically loaded, ceramic-matrix-composite elements, e.g. leading-edge and body-flap bearing assemblies, was successfully performed for the X-38 programme. A final in-flight demonstration will be provided on the X-38 V-201 vehicle, whose flight is scheduled by mid-2002.

### Thermal-Control and Life-Support Technology

In developing the heat-transfer technology required for forthcoming high-powered European spacecraft, significant effort was devoted to the development of the COM2PLEX technology flight experiment consisting of three experimental two-phase loops, which are scheduled to fly on the Shuttle towards the end of 2001. In the field of cryogenic cooling, developments were completed of a 0.3 K sorption



*The 0.3 K sorption cooler*

cooler and a CNES/ESA co-sponsored 0.1 K dilution refrigerator, both of which are planned for use on the Herschel and Planck missions. At the other end of the temperature scale, development of a new high-emissivity coating, intended for use at high temperatures with the flexible external insulation blankets that protect the leeward side of the X-38 re-entry vehicle, was completed. The thermal-analysis model exchange ISO standard STEP-TAS, developed by ESA, gained wide acceptance. STEP-TAS converters for ESARAD and THERMICA were finalised in Europe and, in good co-operation with NASA, the most important US thermal-tool vendors successfully implemented prototype STEP-TAS converters. In 2001 this will lead to much more efficient thermal-model exchange, which is especially relevant for programmes like the ISS and the Mars missions.



*Artist's impression of the Inflatable Re-entry and Descent Technology (IRDT) demonstrator*

The year saw an important increase in the profile of Europe's life-support efforts. In the context of ISS, development and testing of the 3–5 man air-revitalisation system demonstrator was completed, as discussions with NASA on the incorporation of this technology into forthcoming ISS upgrades continued. The 'blind testing' of contaminated air samples provided by Wyle Laboratories Inc. on behalf of NASA was completed, and the ESA-sponsored development was rated clearly the best by NASA. Efforts are continuing to translate this result into an opportunity for the inclusion of European trace-gas monitoring equipment on the ISS. Looking beyond ISS, in the context of long-duration missions requiring bio-regenerative concepts, the MELISSA project attracted ever-greater interest worldwide, and particularly at NASA. In an attempt to co-ordinate the worldwide development of advanced life-support systems, an International Advanced Life-Support Working Group was established, co-chaired by NASA and ESA and consisting of representatives from NASA, ESA, NASDA and CSA, with the ESA MELISSA group providing both the co-chairman and secretary.

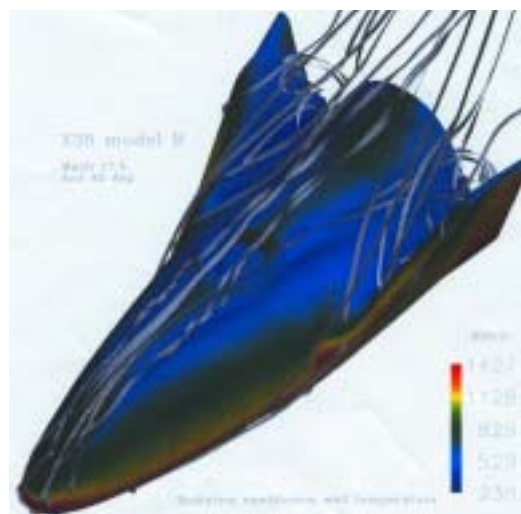
## Propulsion and Aerothermodynamics

In the aerothermodynamics domain, an Inflatable Re-entry and Descent Technology (IRDT) demonstrator was successfully flown in Russia. This test mission was supported both by ESA and by the European Commission through its ISTC Programme. Computational Fluid Dynamics (CFD) simulations contributed to the design of the X-38 aerodynamics and aerothermodynamics databases, the study of nozzle flow separation and external flow coupling in Ariane's Vulcain-2 engine, post-flight evaluation of the Atmospheric Re-entry Demonstrator (ARD), and the assessment of plume-impingement heating on the Meteosat Second Generation (MSG) heat shield.

In the domain of chemical propulsion, work continued on the development of high-performance rocket engines for spacecraft attitude and orbit control using state-of-the-art propellants. The development of advanced combustion chambers made of high-temperature-resistant materials using VPS (Vacuum Plasma Spray) technology was also pursued. The development of market-oriented propulsion-system components, such as propellant flow-control valves and propellant-tank diaphragm material, was also in progress. There were advances in the development of micro-propulsion cold-gas thrusters and feed systems using micro-machining technology, as well as in the industrialisation of advanced composite solid-launcher propellants. Tests are in progress to characterise the exhaust plumes of European thrusters, and a propulsion system and component database was developed and released on the Internet.

In the area of electric propulsion, there were significant advances in the development of the primary source of propulsion for ESA's SMART-1 mission, based on a European Hall-effect thruster. A new, medium-power Hall-effect thruster developed under ESA contract for application on new-generation European geostationary platforms was also manufactured and will be qualification tested during 2001. Field-emission thrusters currently under development are candidates for several future ESA missions and will be used on the CNES Microscope (launch 2005) scientific satellite, for which ESA is charged with procurement of the electric-propulsion subsystem.

The survey study 'Propulsion 2000' was initiated during the year to assess space-propulsion trends for the next 20 years and to identify promising R&D technologies in this area.



*Extract from the X-38 aerothermodynamics database*



*Engineering model of the ROS-2000 Hall-effect thruster (courtesy of Astrium)*

## Electrical Engineering

Satellite on-board avionics and the related disciplines saw significant advances, with very active progress in the software, data-handling, electromagnetics and power domains.

### Power Subsystems

The evolution and improvement in performance of space solar cells continued at a rapid pace: GaAs dual-junction solar cells with peak efficiencies above 24% became available, with pilot production taking place. The ESA proposal to continue with the development of triple-junction solar cells is currently being consolidated with Delegations and industry.

Silicon solar cells are still widely used in ESA and commercial satellite programmes. For this technology, the most remarkable event was the production of the LILT-silicon solar cells for Rosetta, which are a world first. They can power satellites as far as away from the Sun as Jupiter with a conversion efficiency of more than 25%.

In the energy-storage domain, 2000 saw the first real space application of lithium-ion technology. The lithium-ion battery for the CNES Stentor spacecraft was qualified, including the cell-voltage-balancing electronics specific to this technology, which were developed under ESA contract. Accelerated Stentor battery-module lifetime tests, carried out for CNES in the European Space Battery Technology Centre at ESTEC, reached the equivalent of 16 years in orbit. Because of the large mass and volume savings that this technology offers, lithium-ion



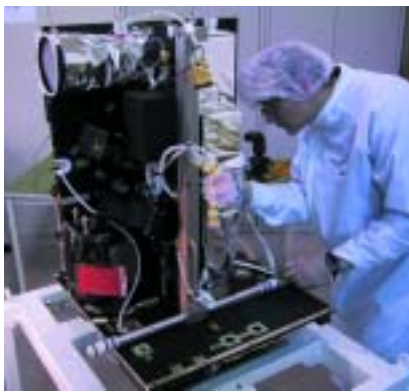
Single-axis and three-axis packages containing fibre-optic gyroscopes of the 0.01°/h drift class

batteries will be used on ESA's Rosetta, Mars Express, SMART-1 and Proba spacecraft. Ongoing life tests in support of low-Earth-orbit applications indicate that the technology is also capable of supporting long-duration telecommunications-constellation applications.

In power systems design, the main emphasis over the year was on supporting activities associated with upgrading for high-power application-satellite programmes requiring 20 kW or more. These activities, primarily supported by TRP and GSTP funding, initiated work that will result in 100 V DC power buses being available for exploitation by European satellite prime contractors.

### Data Handling and Attitude Control

One of the major technology developments in 2000 was the progress in fibre-optic gyroscopes. Based on interference between two beams counter-rotating in a fibre coil, these are electro-optical devices, with no moving parts, that can be produced with a wide range of performances. They are intended to replace mechanical gyros for future missions, at lower cost and with higher reliability. Further development in 2001 will see the delivery of a fibre-optic gyro for testing in space.



Proba satellite flight-model integration at Verhaert (B)

In the area of on-board computers, development of the single-chip 20 MIPS Sparc was completed by Atmel (F) and it is scheduled for use both on the SMART-1 mission and on the Ariane-5 launcher. This development follows on from the earlier three-chip Sparc processor (ERC-32) used in the DMS-R computer (Astrium), now in orbit on the Russian Service Module of the ISS. Also, the first in-house prototype of the next-generation processor, the 100 MIPS Leon, was implemented and proof-of-concept tested.

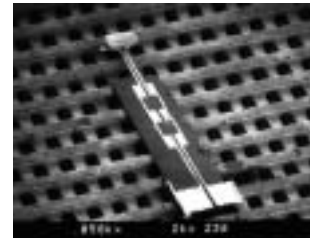
### Proba

The Proba technology micro-satellite progressed well during the year with delivery of all equipment, and system-level integration by the prime contractor. Launch is foreseen for mid-2001.

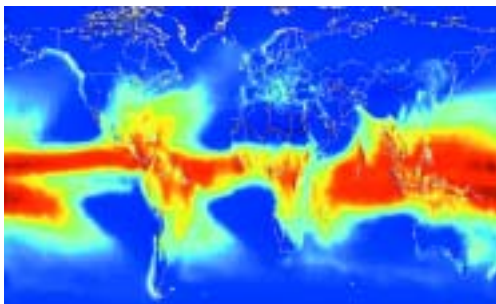
Antenna on a 'photonic band gap' substrate

### Electromagnetics

Periodic electromagnetic materials are a fast-advancing sector in electromagnetics. Since their discovery in the late 1980s, interest in photonic crystals has grown rapidly. Potential applications include highly efficient microwave devices, embedded antennas, and optical lasers. This technology is being actively developed within the Electromagnetics Division with a view to improving antenna and receiver performances for high-frequency applications in both radiometry and astronomy.



In the area of propagation prediction, accurate electronic maps of radio-climatic parameters such as rainfall rate were developed in collaboration with the European Commission's COST Action 255 initiative. Such maps, which were also made available to the International Telecommunications Union's radio body (ITU-R), allow refined systems designs for commercial multi-media satellite services.



Global map showing rainfall rates exceeded for 0.01% of the year (COST Action 255)

In the electromagnetic-compatibility domain, the Discharge Detector Experiment (DDE) was designed and developed within the framework of the Technology Demonstration Programme. To locate and characterise the natural discharges occurring in orbit due to the space environment, it carries a GPS acquisition system and two sensor boxes with different shielding properties, containing a mylar sample glued to a metallic substrate. The sensor boxes are equipped with both current and E-field probes to detect any discharges, while the electronic box acts as a transient recorder. The DDE was launched on the Russian Express-3A satellite and has been operating successfully since April.

### On-Board Software

Like other hi-tech domains, software is becoming increasingly critical when designing complex space missions, with technical, cost and schedule difficulties commonplace. Since



software controls a wide range of essential spacecraft system-level functions, mastering the software development for large space systems is a major priority for both ESA and space industry. Several initiatives to improve the development and quality of on-board software are being investigated.

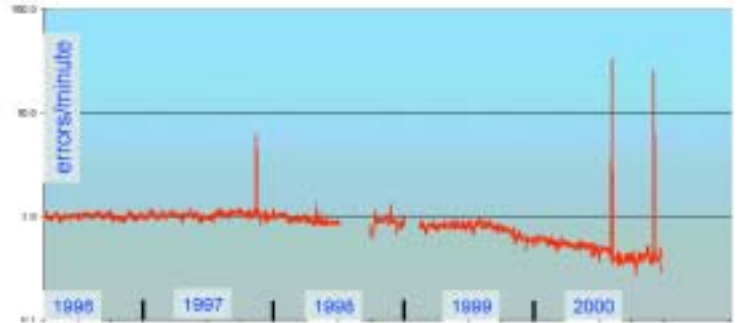
*The Discharge Detector Experiment (DDE), flown on Russia's Express-3A satellite*

### The Space Environment and Its Effects: Space Weather

For many years, ESA has been actively working to ensure the success of its missions in the hazardous environment of space resulting from complex solar and magnetospheric processes. These phenomena increasingly give rise to effects in other sectors. The accompanying illustration shows the dramatic

*Large jumps in detected error rate (Single-Event Upsets) in SOHO's onboard mass memory due to a solar flare (courtesy SOHO Project Team)*

effects of the solar flare that occurred in July on SOHO's LASCO instrument images. As a result of the growing concerns, in 2000 ESA initiated a major analysis of a possible European Space Weather Programme, addressing the needs of a wide range of potential users. A user group was set up and industrial studies initiated.



## Product Assurance

### EEE Components

The cooperative space-component initiative, involving manufacturers, user industries, national agencies and ESA, continued apace in 2000. A key achievement was the writing and negotiation of a European Space Components Coordination (ESCC) Charter, as the top-level agreement to be entered into by the ESCC founding participants. The Charter's text was approved by the ESA Council in November.



Another notable achievement was the successful release of the European Space Components Information Exchange System (ESCIES) in June. The system provides an information portal for accessing component data via the web, at [www.escies.org](http://www.escies.org). The fully searchable database includes the ESA/SCC system, the European Preferred Parts List, radiation data, and component-analysis reports.

Throughout the year, the Components Laboratory provided essential support to the Agency's component evaluation and qualification activities. Substantial efforts were again devoted to the analysis of reported field failures in ESA Projects, including investigations of radiation-hard microprocessor malfunctions and planar-diode assembly (shunt and blocking diodes) failures on solar panels. In all cases, the causes could be expediently determined and corrective actions initiated.

*The European Space Components Laboratory at ESTEC in Noordwijk (NL)*

The ability of electronic components to survive the harsh radiation environment of space is a major concern when selecting and qualifying components for spacecraft applications. Small margins between radiation-hardness requirements and actual component performance, frequent technology or design changes, and normal process variations necessitate extensive checks. This careful approach has been highly successful in the early detection and avoidance of system-design weaknesses, particularly as regards Single-Event Transient Effects in linear semiconductors.

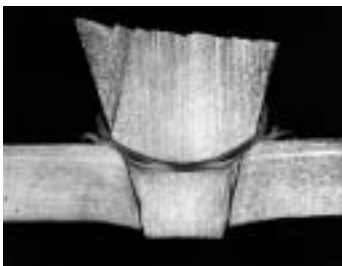


A new radiation test database was set up and made available via the Internet in mid-2000 (at <http://escies.org/public/radiation/database.html>). By year's end, more than 250 very recent test reports covering Total Ionising

Dose and Single-Event Effects in more than 220 different component types had been included, along with other pertinent information on radiation effects, test facilities and other relevant references.



*Flight model of the Hubble Space Telescope's solar array no. 3 in the Large Space Simulator (LSS) at ESTEC in Noordwijk (NL) in October*



*Example of friction-stud welding, in which a rotating 'plug' has filled and welded into a hole in a steel plate*

## Materials and Processes

ESA projects are supported in this domain at the design stage when materials engineers review and approve all of the organic and metallic materials proposed by industry for the manufacture of spacecraft subsystems, and in the production phase by monitoring the industrial processes, in an attempt to ensure that the fabrication steps – related to welding of structures, electronic assembly, surface finishing and the like – maintain the highest possible quality. Routine materials tests are performed by industry, but the ESTEC Materials Laboratories were responsible for more than 1000 analyses of organic materials and 100 metallurgical evaluations during the year. The organic work mainly concerned out-gassing tests on new or marginal space materials, the identification of contaminants on what should have been ultra-clean surfaces, and off-gassing tests on systems intended to be incorporated into the manned Columbus space laboratory.

Support to the Hubble Space Telescope solar array no. 3 concerned cleanliness monitoring and, together with Envisat, evaluation of the effect of atomic oxygen on their solar cells – a major concern

in low Earth orbits. European industry continues to select new, smaller component packages for electronic units. Referred to as 'surface-mount devices', they have been seen to require very precise assembly techniques in order to be suitable for space projects. These devices rely on miniature solder joints, which serve as both electrical and mechanical interconnections for such packages to their circuit boards. Premature joint failure can easily occur due to thermal fatigue when the package, substrate circuit and coatings have incompatible expansion coefficients. Verification programmes, involving extensive thermal cycling and vibration testing, approved 30 companies during the year for undertaking surface-mount assembly work.

Research areas included the development of new alloys that could have major applications for future space vehicles: gamma-titanium-aluminide (for hot structures and wings) and a copper-silver-chromium powder-metallurgy product intended for rocket-motor combustion chambers and novel, high-strength, high-conductivity electrical applications. Process developments included 'friction stud welding', a method that involves rotating a thin rod against a structural unit. The heat generated causes plastic flow and interfacial alloying. Such metallurgical joints have exceedingly high strengths and could be used in space during the construction of a space station, as well as in maintenance and repair operations.

## European Cooperation for Space Standardization (ECSS)

The aim of ECSS is the development of a single coherent set of space standards for use by the entire European space community. ECSS is developing through a voluntary partnership between ESA, national space agencies and industry. In 2000, significant progress was achieved with the release of 14 new standards, bringing the total now published to 57. Among the new issues are a new 'Risk Management Standard' (ECSS-M-00-03) and a six-part 'Mechanical Engineering Standard' (ECSS-E-30):

- The Risk Management standard defines, in four basic steps, the principles and requirements for integrated risk management on a space project.
- The Mechanical Engineering standard defines the high-level rules and the overall principles to be applied to all mechanical-engineering activities performed for the establishment of requirements for, and the definition, development, production, operation, and eventual disposition of, mechanical space products.

The application of ECSS standards in ESA space projects has improved significantly. Whereas in the past mainly the product-assurance standards were applied, now engineering and especially management standards are also called up in ESA's Invitations to Tender (ITTs).