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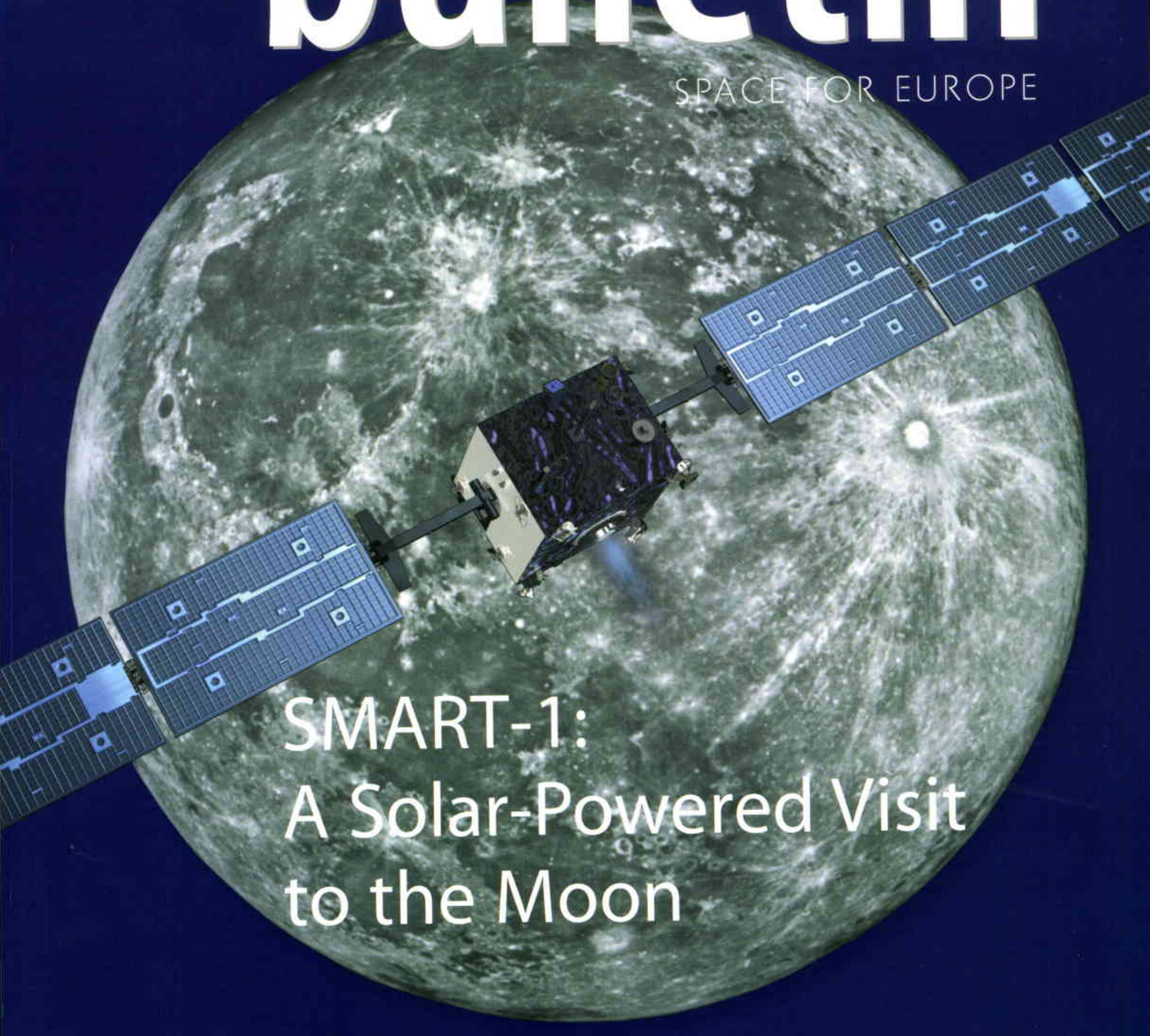
SPACE FOR EUROPE



SMART-1: A Solar-Powered Visit to the Moon

European Space Agency
Agence spatiale européenne

european space agency

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

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

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

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

The ESA HEADQUARTERS are in Paris.

The major establishments of ESA are:

THE EUROPEAN SPACE RESEARCH AND TECHNOLOGY CENTRE (ESTEC), Noordwijk, Netherlands.

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

ESRIN, Frascati, Italy.

Chairman of the Council: P. Tegnér

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agence spatiale européenne

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

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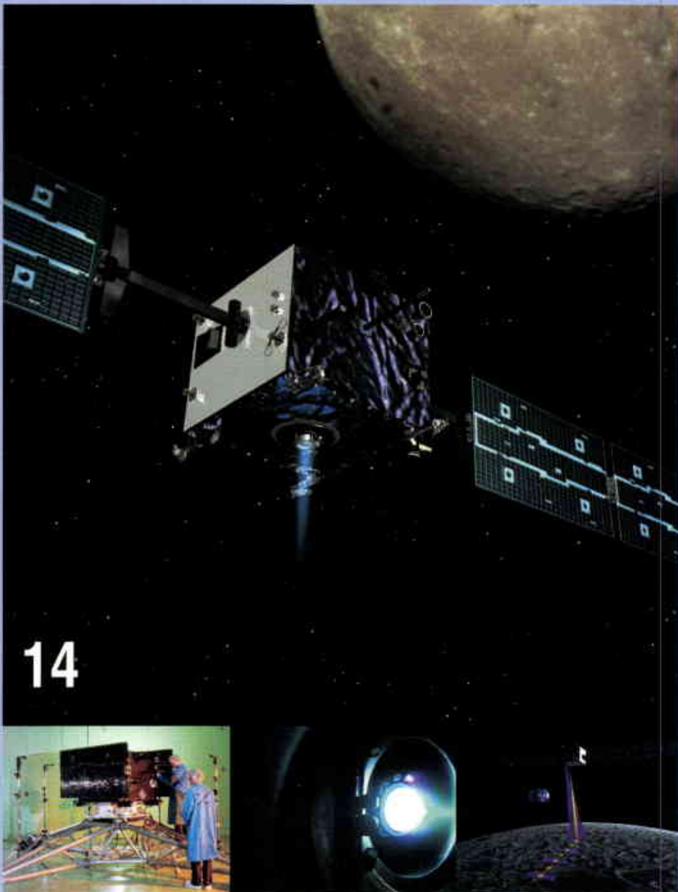

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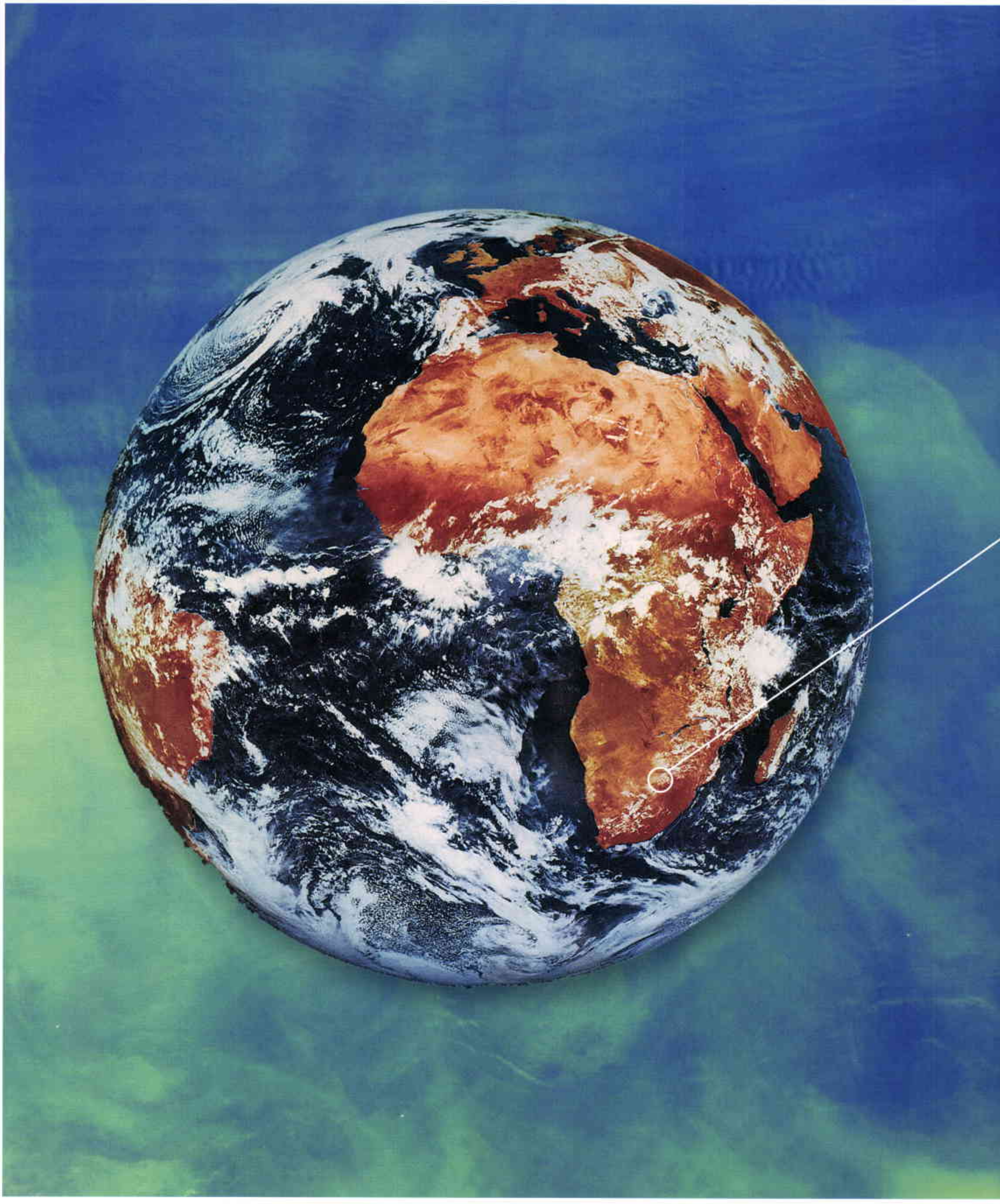


Space's Contribution Recognised at the Johannesburg World Summit

José Achache & Josef Aschbacher
Directorate of Earth Observation, ESA, Paris

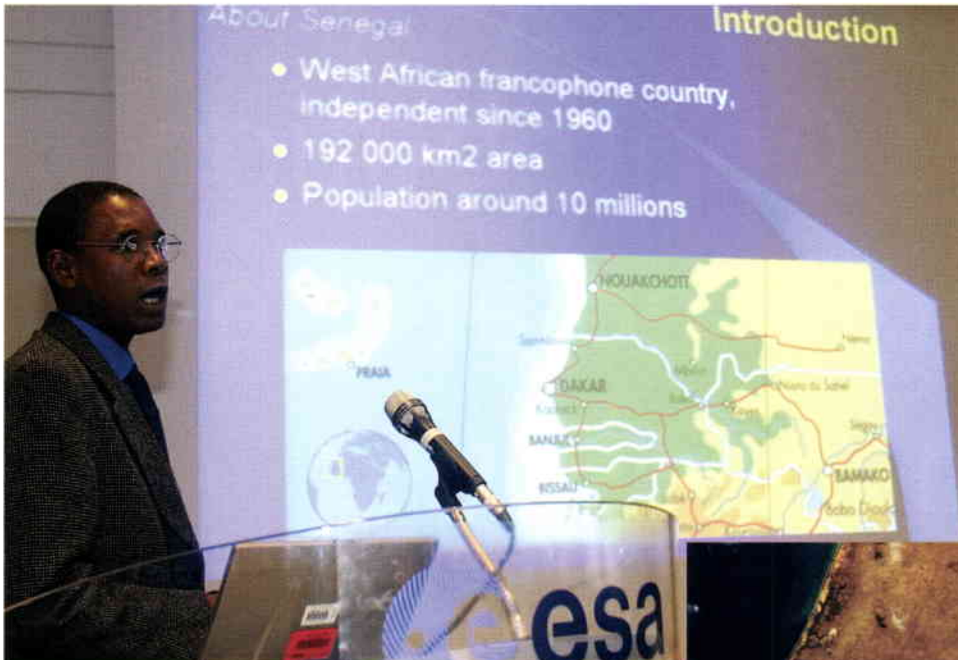
Stephen Briggs
Earth Observation Science and Applications Department, ESRIN, Frascati, Italy

The 16th CEOS Plenary held in November 2002 at ESA's ESRIN establishment in Frascati concluded a busy, but very successful year in terms of ESA's chairmanship of the Committee on Earth Observing Satellites (CEOS). One of the highlights was the launch of a Johannesburg World Summit Follow-up Programme by the international space community, which bears testimony to ESA's strong efforts at the Summit.

The Committee on Earth Observation Satellites (CEOS)

CEOS was created in 1984 under the auspices of the G7, with the goal of coordinating Earth-observation satellite missions among its Members. The 23 Members include space agencies that have active Earth-observation satellite programmes, while the 21 Associates include organisations that receive, process or use environmental data from space. ESA is a founding member of CEOS and a permanent member of the Secretariat, which is conducting most of the executive work in support of the annually rotating chairing agency.

Having chaired CEOS during 2002, ESA will be followed by NOAA in 2003, China in 2004 and BNSC in 2005.



One of the participants in the ESRIN meetings, Dr. Souleye Wade of Cheikh Anta University of Dakar, Senegal, demonstrating technology transfer from ESA to his home region

An image of Dr. Wade's home country taken by Envisat in March 2002

The Johannesburg World Summit on Sustainable Development (WSSD)

The Johannesburg World Summit on Sustainable Development acknowledged the important role that Earth-observation satellites can play in assisting sustainable development. CEOS was accredited as an intergovernmental organisation through ESA, who attended the WSSD as a formal observer and participated in the negotiations underpinning the final documents adopted by Heads of State. Several interventions were made by ESA at the Summit and during the preceding Preparatory Committee (PrepCom) meetings.

José Achache, ESA's Director of Earth Observation, addressed and presented an official statement to the WSSD Plenary, highlighting the role of space observations as part of an integrated global observing system. ESA, on behalf of CEOS, made a further intervention at the Plenary in the 'cross-cutting session' emphasizing the role of satellite Earth observation in pursuit of sustainable development. This intervention was strongly supported immediately afterwards by the US and Japanese Ambassadors to WSSD.

In addition, a number of ESA staff participated in the associated meetings, discussions and workshops, highlighting the use of satellite data. Thanks to the strong support from the ESA Communication Department, the Agency was able to provide two exhibition stands during the Summit, at Ubuntu Village, Johannesburg, one as CEOS and one as ESA.

The effort invested at WSSD has paid off. The 54-page WSSD Plan of Implementation contains 12 specific references to Earth observation, clearly demonstrating that the Summit recognised the importance of space technology for sustainable development. This outcome is a clear improvement compared to the Rio 1992 Agenda 21, where the need for global observations is barely visible.

Two important WSSD partnership initiatives concerning Earth-observation data were launched in Johannesburg: the first by IGOS (Integrated Global Observing Strategy) concerning the use of space and ground measurements for sustainable development; and the second by CEOS to encourage partnership in education and training in Earth observation. Both measures will widen the use of Earth-observation data to protect the environment, particularly in developing countries, and to ensure that this data becomes available to all.

To turn words to action, ESA organised a high-level meeting at ESRIN, inviting guest speakers from a number of UN organisations, the World Bank, the European Commission and developing countries. This meeting, which preceded

The CEOS Plenary in session at ESRIN, with José Achache, ESA's Director of Earth Observation, in the chair

the CEOS Plenary, was aimed at raising awareness and informally discussing potential follow-up activities. During the subsequent two days of the 16th CEOS Plenary, high-level representatives from space organisations around the World have adopted a CEOS WSSD Follow-up Programme.

WSSD Follow-up

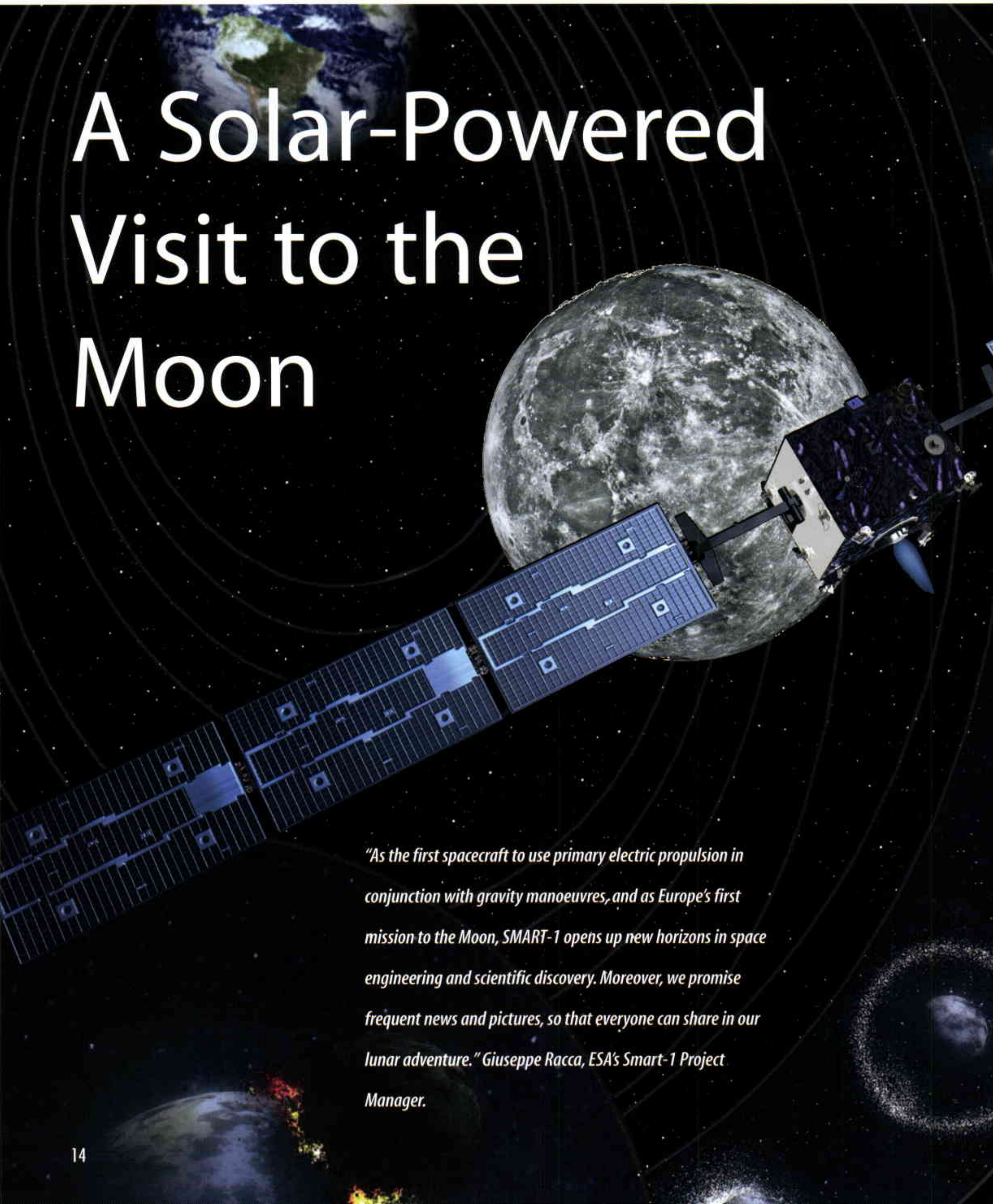
The CEOS Members and Associates agreed to launch a 'WSSD Follow-up Programme' as a visible concrete action by the international space community in support of sustainable development. Three 'Modules' were agreed for an immediate start to address some of the areas identified in the WSSD Plan of Implementation where space-based Earth observation would be essential to assist sustainable development activities. The first, led by NOAA and UNOOSA, is aimed at education, training and capacity building; the second, led by ESA and NASDA, is focused on management of water resources; the third, led by USGS and CCRS, deals with the use of Earth observation for global mapping. Space agencies have indicated their willingness to develop additional activities in these three areas. The programme allows CEOS members to provide their contributions 'as and how they see fit'.

ESA's Tiger Project

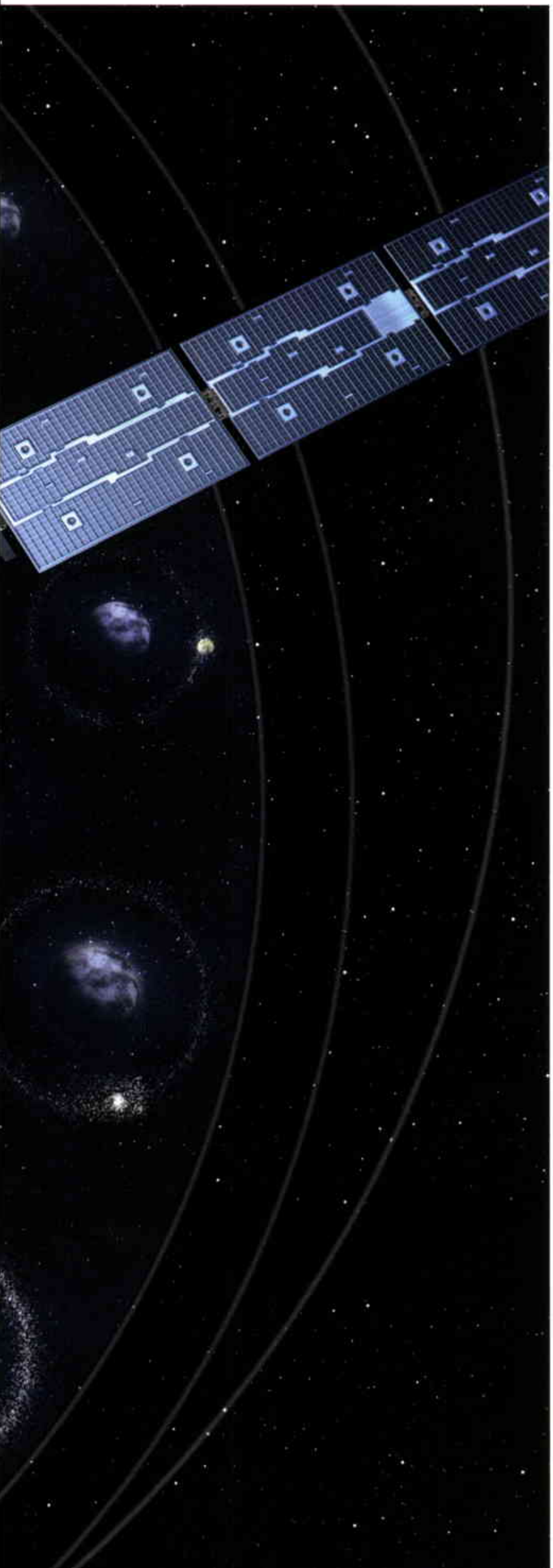
ESA's proposed contribution to the WSSD Follow-up Programme, the 'Tiger Project', aims at providing Earth-observation data from its latest Envisat satellite and other ESA missions to assist in managing water resources, primarily in Africa. The project would be driven by the needs of the local populations in developing countries, would facilitate access to relevant Earth-observation data, and would transfer the relevant technology to developing countries.

The delegates attending the 16th CEOS Plenary and associated meetings, gathered at ESRIN

A Solar-Powered Visit to the Moon



"As the first spacecraft to use primary electric propulsion in conjunction with gravity manoeuvres, and as Europe's first mission to the Moon, SMART-1 opens up new horizons in space engineering and scientific discovery. Moreover, we promise frequent news and pictures, so that everyone can share in our lunar adventure." Giuseppe Racca, ESA's Smart-1 Project Manager.



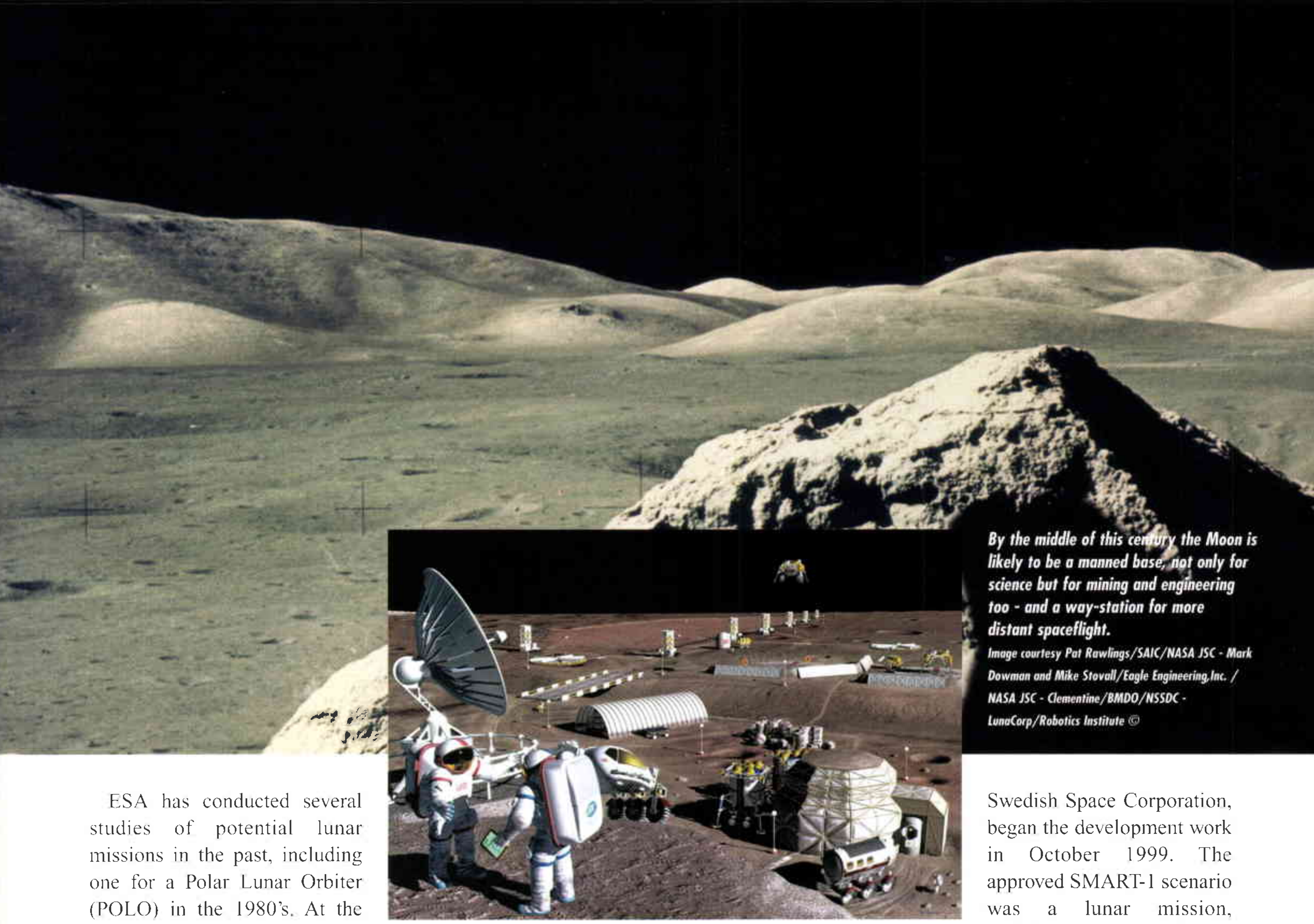
The SMART-1 Mission

Giuseppe Racca, Bernard Foing, and the SMART-1 Project Team
ESA Directorate of Scientific Programmes,
ESTEC, Noordwijk, The Netherlands

By July 2003 a hitchhiking team of engineers and scientists will be at Europe's spaceport at Kourou in French Guiana, thumbing a lift for a neat little spacecraft, ESA's SMART-1, on the next Ariane-5 launcher that has room to spare. It's not very big - just a box a metre wide with folded solar panels attached - and six strong men could lift it. It weighs less than 370 kilograms, compared with thousands of kilos for Ariane's usual customers' satellites. So it should pose no problems as an auxiliary passenger.

SMART stands for Small Missions for Advanced Research in Technology. They pave the way for the novel and ambitious science projects of the future, by testing the new technologies that will be needed. But a SMART project is also required to be cheap - about one-fifth of the cost of a major science mission for ESA - which is why SMART-1 has no launcher of its own. Its main purpose is to allow the engineers to evaluate a new way of propelling spacecraft on far-ranging space missions. Power from SMART-1's solar panels will drive an electric-propulsion system called an 'ion engine'. The demonstration task is to overcome the Earth's gravity and put the spacecraft into orbit around the Moon.

After 40 years of Soviet and American lunar exploration, knowledge of the Moon's surface is still surprisingly incomplete. Always ready to seize the chance to make new discoveries, Europe's space scientists have fitted SMART-1 with very modern and compact sensors to map lunar minerals in greater detail than ever before, using infrared rays. With X-rays too, it will make the first comprehensive inventory of key chemical elements in the lunar surface. Adding to this the many scenes coming from its advanced multi-colour camera, Bernard Foing, ESA's Project Scientist for the mission, believes that SMART-1 will *"renew our view of the Moon and prepare for future lunar and planetary exploration"*.



By the middle of this century the Moon is likely to be a manned base, not only for science but for mining and engineering too - and a way-station for more distant spaceflight.

Image courtesy Pat Rawlings/SAIC/NASA JSC - Mark Dowman and Mike Stovall/Eagle Engineering,Inc. / NASA JSC - Clementine/BMDO/NSSDC - LunaCorp/Robotics Institute ©

ESA has conducted several studies of potential lunar missions in the past, including one for a Polar Lunar Orbiter (POLO) in the 1980's. At the beginning of the 90's, wide consultation with the scientific community led to a survey of the possible scientific and social benefits that renewed lunar exploration might bring. A strategy for progressive exploration in four phases - precursor missions, landers, resource utilisation and deployment of large infrastructures, and a permanent human presence - was proposed by ESA, and agreed with other space agencies coordinated by the International Lunar Exploration Working Group (ILEWG) after the Beatenberg International Lunar Workshop in 1994. Between 1994 and 1996, ESA studied a scientific lunar mission (MORO) as a contender for a medium-cost mission. In the same time frame, technical studies were also conducted on a lunar lander (LEDA), and between 1996 and 1998 a study called 'Euromoon' addressed the possibility of making a landing near the lunar south pole. In parallel, a series of key technologies for future lunar and planetary exploration were developed. In 1995, ESA's Long-Term Space Policy Committee made strategic recommendations for Europe's future space endeavours, which included the eventual building of a permanent lunar base, and robotic precursors.

Faster, Cheaper, Smarter

The SMART series of missions have been introduced into the ESA Scientific Programme in order to prepare the technologies needed for the major future science missions, the so-called 'Cornerstone' missions. At mission approval, SMART-1 was assigned four goals:

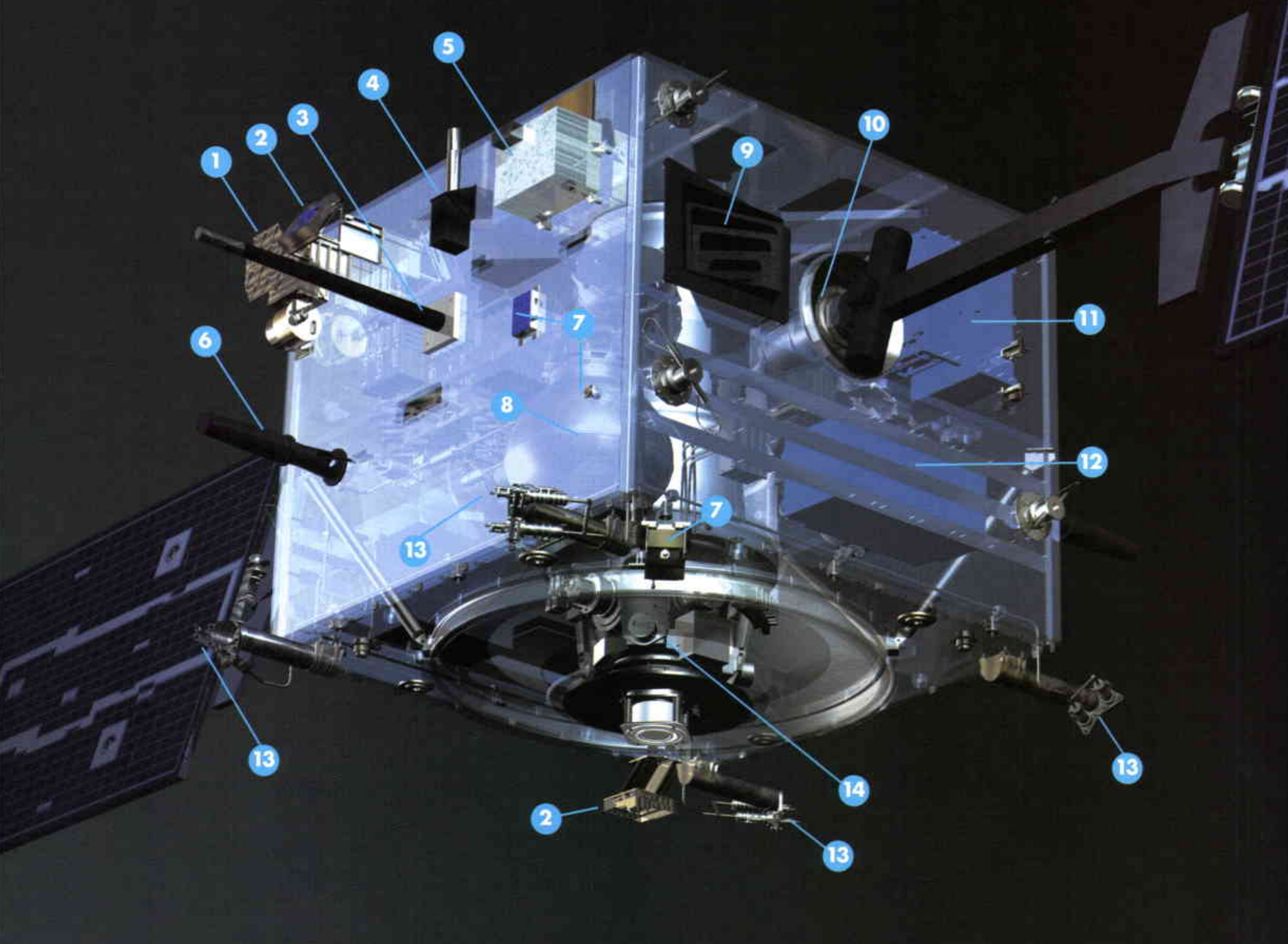
- to demonstrate the use of Solar Electric Primary Propulsion, in preparation for future deep-space missions requiring high-energy trajectories, like the Bepi-Colombo mission to Mercury and the Solar Orbiter mission
- to demonstrate a new 'faster, cheaper, smarter' approach for spacecraft procurement and management, compatible with the low overall mission budget and highly demanding mission requirements (taking higher risks was considered acceptable for this mission)
- to demonstrate new spacecraft and instrument technologies, and
- to provide an early scientific opportunity for instruments and investigations.

ESA's Science Programme Committee approved the SMART-1 mission in September 1999, and the prime contractor, Swedish Space Corporation, began the development work in October 1999. The approved SMART-1 scenario was a lunar mission, including six months of scientific operations in lunar orbit. The total budget allocated to the mission is 101.5 MEuro: 68.2 MEuro from the ESA Science Programme, 12 MEuro from the ESA Technology Research Programme, and 21.3 MEuro from a special compensation programme funded by France, the United Kingdom and Denmark.

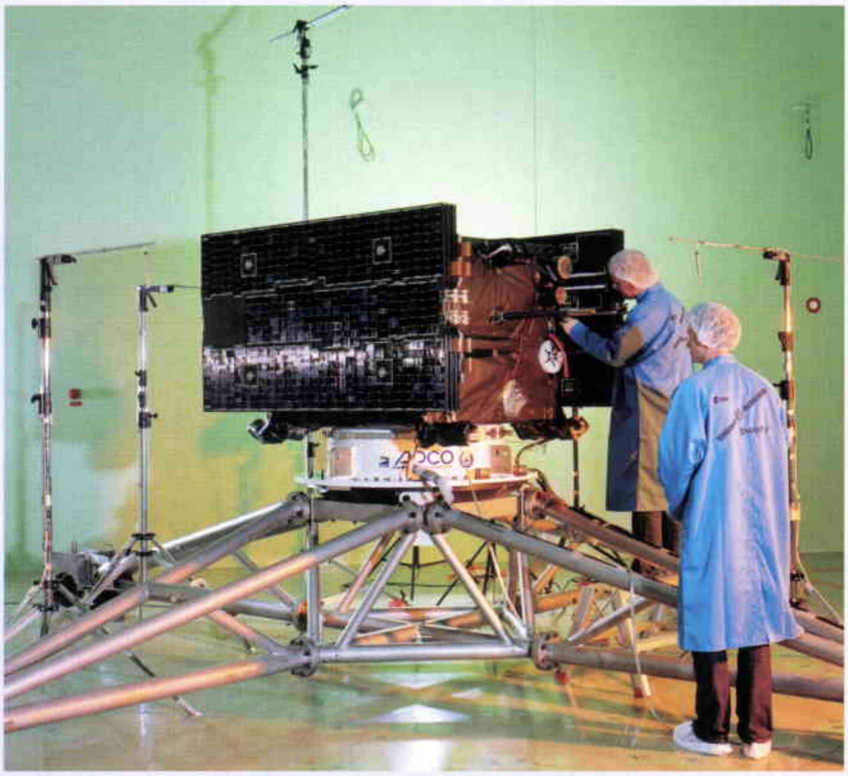
Besides its novel primary electric propulsion, SMART-1 includes innovative technologies within the spacecraft's systems and instruments. To reduce development time and increase reliability, strong emphasis has been placed on modularity, commonality and the use of commercial-off-the-shelf hardware and software components. The spacecraft platform combines the heritage from previous small satellite programmes undertaken by the Swedish Space Corporation and the latest technology developments from ESA, commercial space programmes and other branches of industry.

A masterpiece in miniaturisation, SMART-1 is 14 metres across with its solar panels extended, but everything needed for its propulsion, communications, house-keeping and instrumentation fits into a

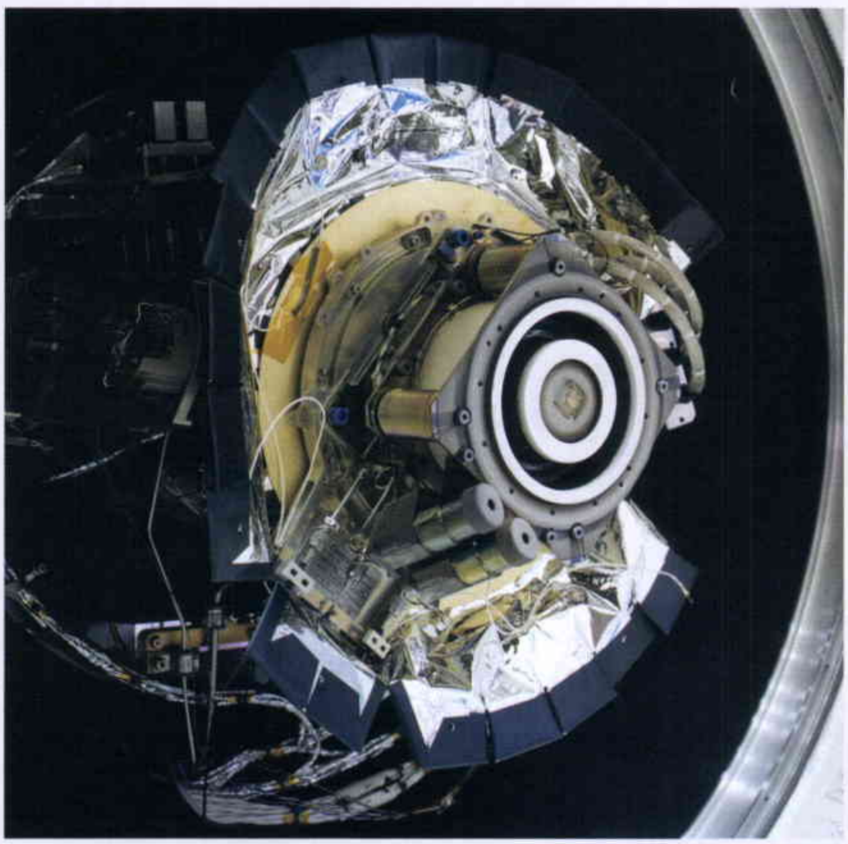
The SMART-1 spacecraft



1. SIR
2. Sun Sensors
3. SPEDE boom
4. AMIE camera
5. D-CIXS
6. Communication antenna
7. EPDP sensors
8. Fuel tank for attitude control
9. Star tracker
10. Motor to turn solar array
11. Communication transponders
12. Ion engine control electronics
13. Attitude control thrusters
14. Ion engine with orientation mechanism (to maintain thruster pointing as fuel tanks drain)



SMART-1 during the acoustic testing



SMART-1's ion engine

cube just 1 metre across. The solar panels use an advanced type of gallium-arsenide solar cell rather than the traditional silicon cells. The avionics architecture is state-of-the-art and will test new communications and navigational techniques. Of the total launch mass of 370 kilograms, 19 kilos is available for a dozen technological and scientific investigations. Like the spacecraft's other components, the scientific instruments employ state-of-the-art concepts and miniaturisation methods to save space, weight and cost.

The spacecraft has also been designed to require a minimum of ground intervention throughout its operational lifetime to further constrain costs. During its journey to the Moon, SMART-1's electric propulsion system will function autonomously for periods of up to 10 days. When orbiting the Moon, the spacecraft will be contacted for an average of just 8 hours twice per week using ground stations on an 'as available' basis.

In spite of the low budget, ESA has not compromised in the pre-launch testing of SMART-1. Notwithstanding the tight schedule, the spacecraft programme has included:

- mechanical qualification of the structural model (August 2001)
- electrical and functional testing of the flight Model (June 2002 - January 2003)
- electromagnetic compatibility, thermal-balance, thermal-vacuum and vibro-acoustic testing of the flight model (October - November 2002)
- end-to-end testing of the flight model's electrical-propulsion system (December 2002).

The Magic of Ion Engines

Operating in the near-vacuum of space, ion engines shoot out a propellant gas much faster than the jet of a chemical rocket. They therefore have a much higher specific impulse (thrust per unit of propellant used). The ions that give the engines their name are charged atoms, accelerated by an electrostatic field generated by various techniques. If the power comes from the spacecraft's solar panels, the system is known as 'solar-electric propulsion'.

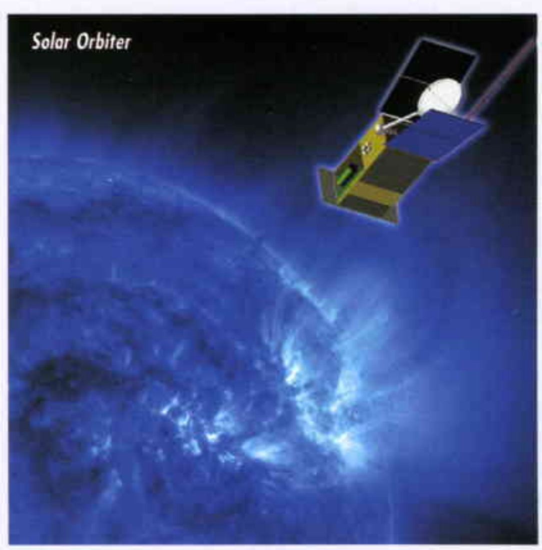
The type of ion engine chosen for SMART-1 is called a Plasma or Hall-Effect Thruster, as it makes clever use of an effect discovered by the American physicist E.H. Hall in 1879, whereby a current flowing across a magnetic field creates an electric field directed perpendicular to the current. This phenomenon is used to accelerate ions of xenon, a chemically inert gassy element with atoms about 131 times heavier than hydrogen atoms. Fed with 1350 Watts of electrical power from the spacecraft's solar panels, SMART-1's ion engine, manufactured by SNECMA of France, generates a thrust of 0.07 Newton, equivalent to the weight of a postcard!

Due to their weak thrust, ion engines work their magic in a leisurely way. As normal-sized solar panels supply only a few kilowatts of power, a solar-powered ion engine cannot compete with the enormous thrust of a chemical rocket. However, a typical chemical rocket engine burns for at most a few minutes, while an ion engine can go on pushing gently for months or even years on end – basically for as long as the Sun shines and the small supply of propellant lasts! Thus, the ion-propelled tortoise will eventually overtake the chemically-propelled hare, and continue accelerating, slashing the time for interplanetary travel. So far this is only a theory, but it is one that SMART-1 is out to prove correct!

SMART-1 will go no further than the Moon, but it will also demonstrate more subtle operations of the kind needed for long interplanetary missions, which will combine solar-electric propulsion with manoeuvres exploiting the gravitational pull of planets and moons. BepiColombo, ESA's future mission to the innermost planet Mercury, close to the Sun, will use an ion engine to speed it on its way. The Solar Orbiter, which will swoop even closer to the Sun for close-up views, will use the same type of ion drive as BepiColombo. Other planned ESA science missions are also expected to use ion engines for complex manoeuvres in the vicinity of the Earth's orbit, including LISA, a mission that will detect gravitational waves coming from the distant Universe.

SMART-1 ion engine being test fired

BepiColombo

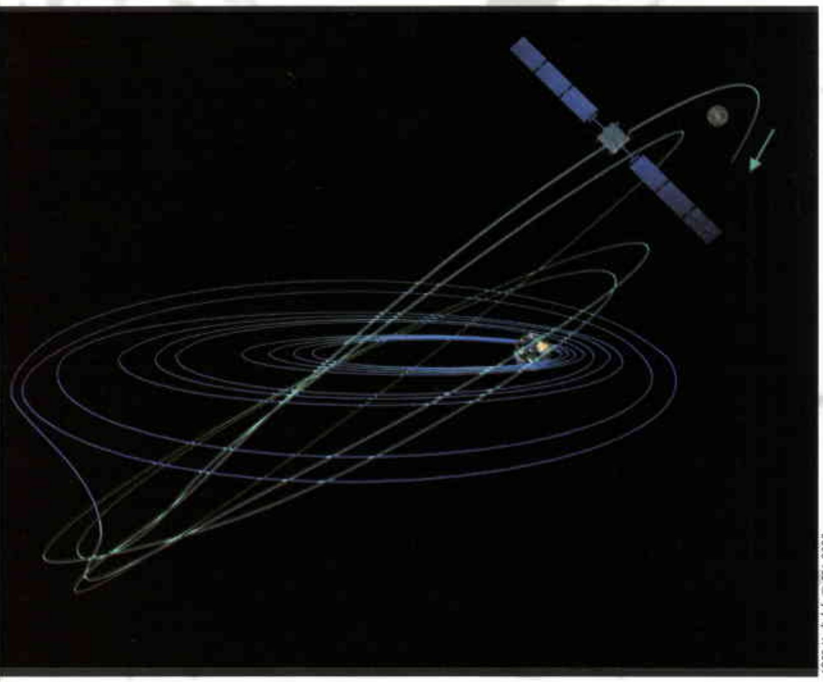


Solar Orbiter

"An ion engine can slash almost four years off the time that BepiColombo will take to get to Mercury. But we need hands-on experience with SMART-1 to be confident about using this new technology," says Gordon Whitcomb, ESA's Head of Future Science Projects.

The SMART Way to Travel: A Spiral Path to the Moon

By accelerating SMART-1 constantly at 0.2 millimetres per second per second, this incredibly gentle thrust could in theory fling the spacecraft right out of the Solar System, if sustained for long enough. In practice, however, SMART-1 will use its ion engine only intermittently over a 16-month period following its release from Ariane, to fend off the Earth's gravitational pull and put itself into orbit around the Moon.

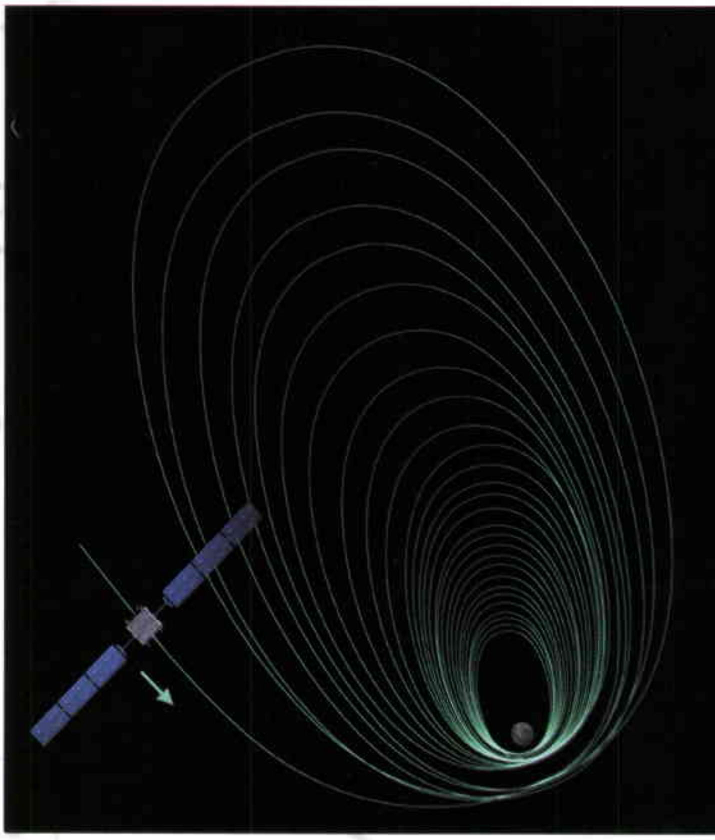


SMART-1 first orbits the Earth in ever-increasing ellipses. When it reaches the Moon, its orbit is altered by the lunar gravitational field. It uses a number of these 'gravitational assists' to position itself for going into orbit around the Moon.

The Ariane-5 launcher will put SMART into an elliptical orbit around the Earth. Controlled by the European Space Operations Centre (ESOC) in Darmstadt, Germany, on two days per week, repeated burns of the ion engine will change the ellipse into a circle and gradually expand it into a spiral. Each month the Moon revolves around its own orbit, 350 000 to 400 000 kilometres from the Earth. As SMART-1 gains distance from the Earth, its speed will slacken. When 200 000 kilometres out, the spacecraft will begin to feel significant gravitational tugs from the Moon as it passes by.

ESOC's mission controllers must then inaugurate a new era in space navigation. For the very first time, they will exploit the sustained thrust of electrical propulsion jointly with manoeuvres under gravity. This is quite a complex process and optimisation of the manoeuvres that will be needed has required extensive analysis. The tug of the Moon will at first help to widen the spiral orbit, in regular encounters called 'lunar resonances'. By the time SMART-1 passes within 60 000 kilometres of the Moon, the effect of its gravity will be much more pronounced, in encounters known as 'lunar swingbys'.

As first noted by the mathematician Joseph-Louis Lagrange in 1772, the gravitational effects of the Moon and the Earth are in balance at a point known as 'L1' (Lagrange Point No. 1), 50 000 to 60 000 kilometres out from the Moon on the earthward side. At this point, SMART-1 will reach a crucial stage in its journey, passing through an 'invisible doorway in space' involving the spacecraft's 'lunar capture'. Thereafter it will fly over the lunar north pole, aiming at a point of closest approach above the south pole, so achieving a wide polar orbit around the Moon. During the weeks that follow, SMART-1's ion engine will gradually reduce the size and duration of this orbit, to improve the view of the lunar surface.



Once SMART-1 has been captured by the Moon's gravity, it begins to work its way closer to the lunar surface.

Welcome to the Earth-Moon Double Planet

When human beings first went to sea many thousands of years ago, they monitored the phases and motions of the Moon in order to estimate the state of the tide in various harbours. More subtle shifts, up and down the sky, fascinated prehistoric experts who wanted to predict eclipses. Computing the first full Moon after the spring equinox defined Easter in the Christian calendar. Before modern lighting, convenors of meetings chose dates with predictable moonlight, to help participants on their way.

Beauty and science go hand in hand. The artist Leonardo da Vinci was perhaps the first to realize 500 years ago that the subtle glow on the dark part of a crescent Moon is due to light from the Earth. Now astronomers and space scientists measure that 'earthshine' to gauge variations in our planet's cloudiness, and the role of clouds in climate change.

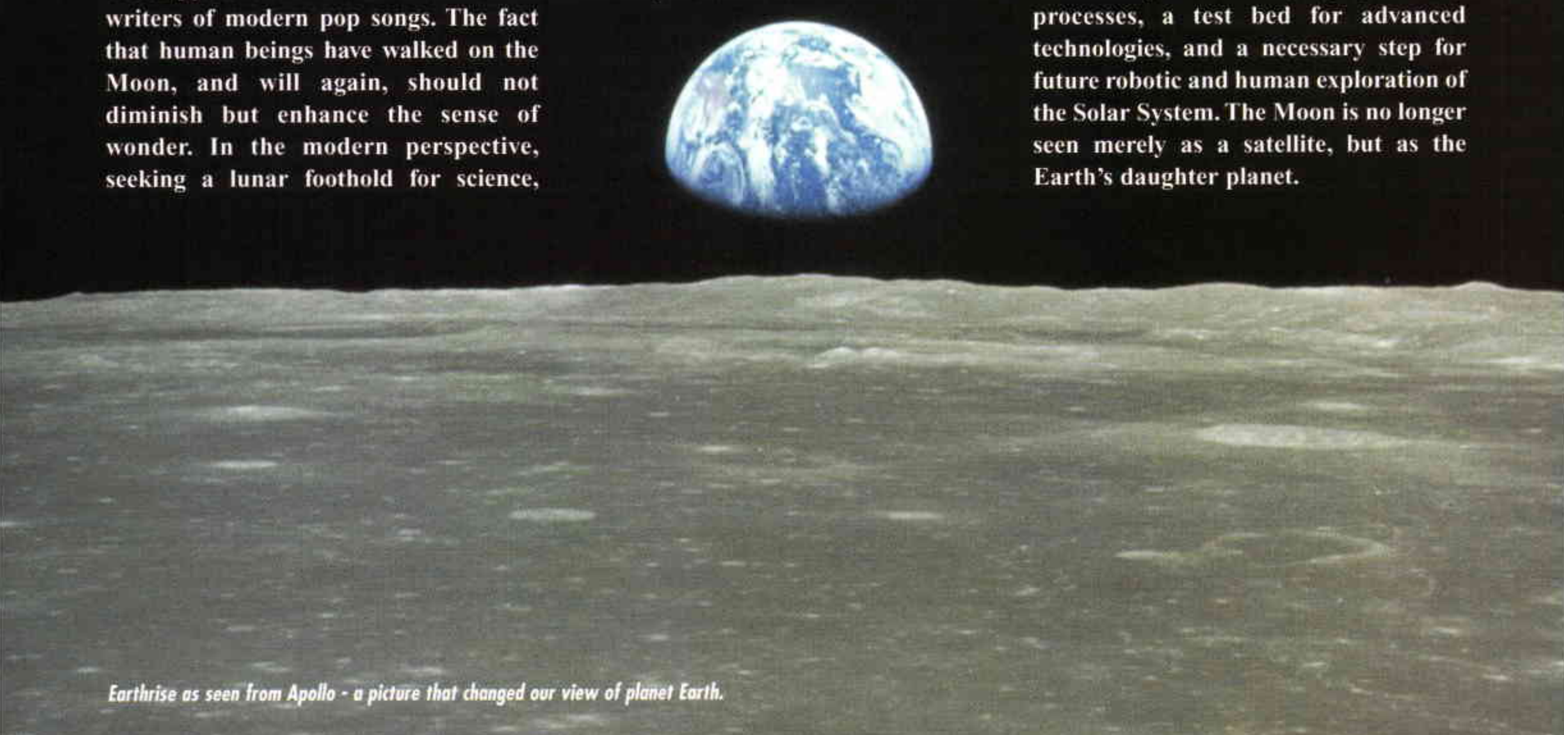
Such ancient technical interest in the Moon never conflicted with the admiration for its beauty, from pagan worshippers of Diana the Huntress to writers of modern pop songs. The fact that human beings have walked on the Moon, and will again, should not diminish but enhance the sense of wonder. In the modern perspective, seeking a lunar foothold for science, technology and exploration can help to inspire our society to innovate and go further.

The Moon is almost as large as the planet Mercury, and 27% of the diameter of the Earth. Compared with its mother planet, it is relatively far larger than any other moon in the Solar System. Our neighbour Mars has two small moons, and Venus none at all. The geology of those planets is totally different from ours. So it is not far-fetched to ask whether the Moon's existence gives the Earth qualities especially suited to life.

The Earth and the Moon have shared a common history for 4500 million years. The effect of lunar tides on the Earth's oceans and biosphere is well known. It has been proposed that the Moon has influenced Earth's early geological history. It has been shown that the Moon's tidal influence has prevented the Earth's rotational axis from varying chaotically, a factor that has stabilised the Earth's climate. Knowing the Moon more thoroughly will help scientists to understand our home in space much more fully, making us better able to safeguard its future.

What is new about the Moon? The Apollo and Luna mission samples have been put into a more global context by the Clementine and Lunar Prospector data. It has been shown that the distribution of elements detected from orbit differs from that derived from lunar samples, which were limited in their geographical coverage. The South-Pole Aitken Basin is the largest impact basin so far detected in the Solar System; it differs significantly in composition from highlands or maria and may provide a window to mantle materials.

SMART-1 is Europe's first mission to the Moon. The scientists taking part have a 21st-Century view of our companion in space, which makes our connection with it more intimate than ever. The Moon holds the key to planetary science and exploration and lunar data can teach us about the formation and evolution of rocky planets and moons. The Moon also serves as a 'laboratory' for studying planetary processes, a test bed for advanced technologies, and a necessary step for future robotic and human exploration of the Solar System. The Moon is no longer seen merely as a satellite, but as the Earth's daughter planet.



Earthrise as seen from Apollo - a picture that changed our view of planet Earth.

SMART-1 Instrument Technology, Planetary Science & Exploration

Bernard Foing, and the Science & Technology Working Team

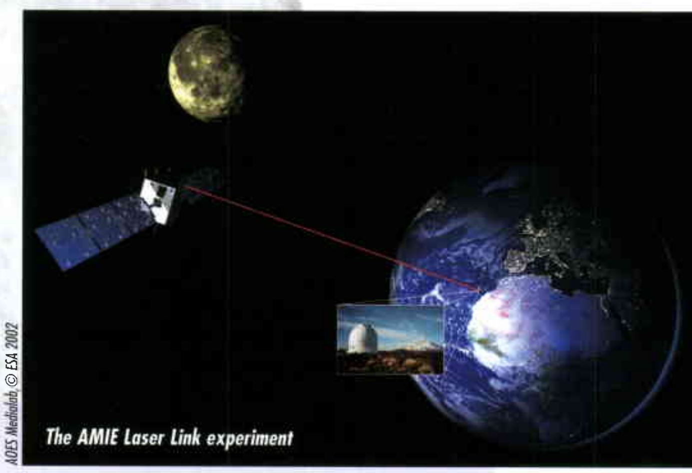
What Will All of SMART-1's Instruments Do?

Multinational teams of scientists and engineers will conduct ten different investigations coordinated by a Science and Technology Operations Centre. The instrument teams are led by Principal Investigators from Finland, Germany, Italy, Switzerland and the United Kingdom. All ESA Member States are participating by providing Co-investigators for the various experiments, which fall into two main categories:

Testing new techniques

EPDP and SPEDE: Designers of future solar-electric spacecraft want to know exactly how SMART-1's ion engine performs, what side effects it has, and whether the spacecraft interacts with natural electric and magnetic phenomena in the space around it. Possible problems include deflection of the ion engine's thrust direction, erosion of surfaces, short-circuits by sparks, interference with radio signals, and accumulation of dust. These effects will be monitored by EPDP and SPEDE.

KaTE and RSIS: Small changes in SMART-1's motion will reveal the precise thrust being delivered by the ion engine. Like police radars used to catch speeding motorists, RSIS will exploit the Doppler effect to log how the changes in speed alter the wavelength of radio pulses. It will use the very short radio waves of KaTE. The primary purpose of KaTE is to demonstrate the next generation of radio links between the Earth and far-flung spacecraft. Microwaves in the Ka band, around 9 millimetres in wavelength, can be



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The AMIE Laser Link experiment

The People Behind SMART-1

SMART-1 has been built by a six-nation European team involving fifteen industrial companies, led by the Swedish Space Corporation as prime contractor. The ESA Mission Team is based at the European Space Research and Technology Centre (ESTEC) in Noordwijk, The Netherlands. Giuseppe Racca is the Project Manager, and Bernard Foing the Project Scientist. The spacecraft will be controlled from the European Space Operations Centre in Darmstadt, Germany.

The SMART-1 Science and Technology Working Team – formed by the payload Science Principal Investigators (PIs) and the Technology Investigators (TIs) – will conduct ten different investigations coordinated by a Science and Technology Operations Centre located at ESTEC. They will be supported by their teams of Co-investigators, associated scientists and students.

Experiment	Subject	PI/TI Investigators	Participating Countries
SPEDE	Space plasma environment	Walter Schmidt, SF	SF, S, ESA, USA
EPDP	Ion engine's side effects	Giovanni Noci, I	I, ESA, SF, A
KaTE	Microwave communication	Reinhard Birkl, D	D, ESA, UK
RSIS	Radio science	Luciano Iess, I	I, USA, D, UK, F, ESA, S
Laser-Link	Laser communication	Zoran Sodnik, ESA	
OBAN	Spacecraft navigation	Finn Ankersen, ESA	
AMIE	Camera	Jean-Luc Josset, CH	CH, F, NL, I, E, ESA
SIR	Infrared analysis	Uwe Keller, D	D, UK, CH, I, IRL, ESA
D-CIXS	X-ray analysis	Manuel Grande, UK	UK, SF, S, E, I, F, ESA, USA
XSM	Solar X-ray monitoring	Juhani Huovelin, SF	SF, UK, ESA

focused into relatively narrow beams by the small dish antennas available on the spacecraft.

Laser Link: This is another communications experiment. ESA already has laser links with telecommunications satellites from an optical ground station on Tenerife in Spain's Canary Islands. Aiming the laser beam becomes much more difficult if, like SMART-1, the spacecraft is far away and moving rapidly. The hope is that the AMIE camera on SMART-1 will see Tenerife aglow with laser light.

OBAN: Future spacecraft will need to be more self-reliant in guiding themselves along pre-defined paths towards distant destinations. OBAN will evaluate a computer technique for on-board autonomous navigation. It will use the bearings of stars seen by SMART-1's star trackers, and the Earth, Moon and possibly asteroids seen by the AMIE camera.

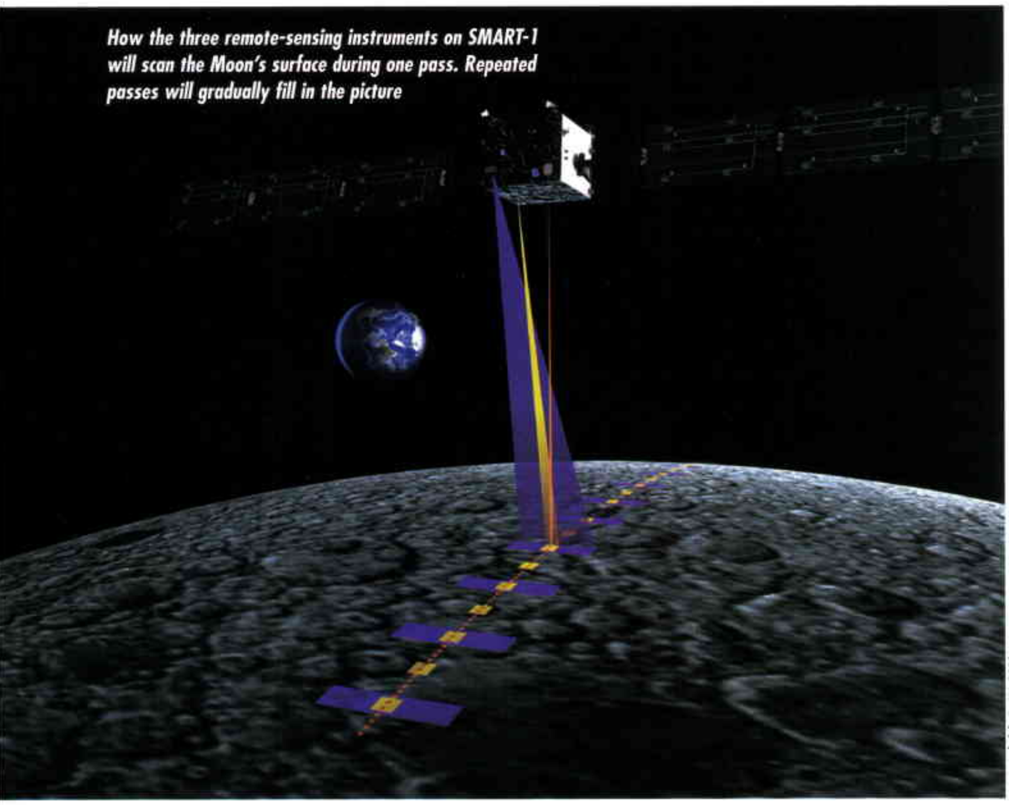
The AMIE camera

Observing the Moon, the Sun and the Sky

Different kinds of visible and invisible light coming from the lunar surface which provide clues to its chemical composition and geological history will be measured by the AMIE, SIR, and D-CIXS instruments:

AMIE: This ultra-compact electronic camera will survey the lunar terrain in visible and near-infrared light.

SIR: This infrared spectrometer will chart the Moon's minerals.



How the three remote-sensing instruments on SMART-1 will scan the Moon's surface during one pass. Repeated passes will gradually fill in the picture

AOES Medialab, © ESA 2002

D-CIXS: This X-ray telescope will use new technology for collimating and detecting X-rays to identify and map key chemical elements in the lunar surface.

XSM: The D-CIXS measurements could be confused by variations in solar X-ray emissions, which depend on how stormy the Sun is at the time. SMART-1 will therefore monitor the solar X-rays with its XSM instrument, which will also make its own independent study of solar variability.

SPEDE: Like a ship at sea, the Moon leaves a wake in the solar wind - the non-stop stream of charged particles and associated magnetic fields coming from the Sun. This electrical experiment will observe this effect at close quarters.

RSIS: With the help of the KaTE microwave system and the AMIE camera, the RSIS radio experiment will demonstrate a new means of gauging the rotations of planets and their moons. It should be able to detect the well-known 'nodding' of the Moon, which slightly tilts first its north pole and then its south pole towards the Earth.

The instruments and their techniques will first be demonstrated during a technology-commissioning phase, then during a cruise- science phase, and finally in lunar orbit. The major scientific goals are described in the following pages.

The Moon, Daughter of the Young Earth

The current consensus is that a Mars-size planet embryo impacted the proto-Earth, and that the Moon resulted from the re-accretion of material ejected during the impact, coming mostly from the impactor. The global composition of the Moon can constrain our understanding of the proto-Earth and of the physico-chemical processes that followed the impact. The compositional similarities between the Earth and the Moon are still a puzzle.

Rocky planet formation models assume accretion from planetesimals originating from different parts of the Solar System. The Moon carries a record of the bombardment history in the inner Solar System, which was erased on Earth. Also the gravity, physical and chemical signature of giant impact basins is still imprinted on the lunar surface. The physics of impact processes can be investigated on different scales, making use of remote sensing, in-situ and sample data.

As a small planetary body, the Moon is a cornerstone for comparative planetology, allowing us to study the processes of planetary differentiation, magmatic activity, volcanism, crust formation, and single-plate tectonics. The Moon appears to have melted significantly after its formation. To constrain theories about a possible magma ocean and the origin of the lunar crust, the abundance of magnesium needs to be determined, which is a key goal for future X-ray measurements.

The lunar surface is also a huge repository, which has collected comets, asteroids, and even samples ejected from the early Earth, during the era of giant bombardment or emergence of life. It has been proposed that water ice could have survived in the permanently shadowed craters at the poles. Lunar Prospector recently detected enhanced hydrogen concentrations in these areas. There is still a debate as to whether this results from enhanced solar wind hydrogen trapping, or from successive impacts of recent comets or water-rich asteroids. More data will be obtained from orbit on these polar volatiles, but we will need in-situ measurements, and possibly also deep samples, to unravel the history of water-rich impactors in the inner Solar System. The outcome of this water-ice issue has important consequences for sustained human lunar exploration in the future.

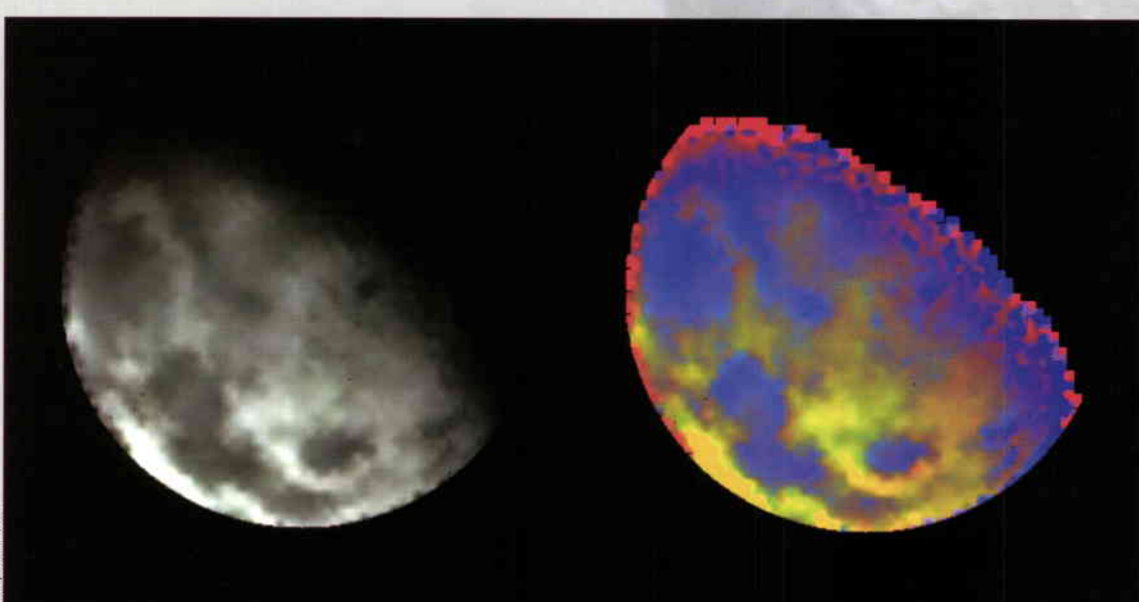
Lunar Science with SMART-1: Still Plenty Left to Do!

The Moon's pockmarked face gives us an idea of what the Earth must have looked like around 4 billion years ago, when comets and asteroids rained down on the newly formed planets of the Solar System, creating craters both large and small. The Earth's wounds have mostly 'healed', but the Moon has scarcely changed from 3.5 billion years ago, when molten lava formed the flat, dark features known as 'maria'.

From their six landings during NASA's Apollo Programme (1969-72), astronauts brought home rock samples for analysis in the world's laboratories. Three unmanned Soviet spacecraft also recovered Moon rocks. Scientists prized them as samples of the primordial minerals that went into making the Moon and the Earth, and as chroniclers of impacts. However, all of these samples were acquired in the nearside equatorial region. The far side of the Moon and the polar regions have never been sampled.

Much later, in 1994 and 1998, two small American spacecraft, Clementine and Lunar Prospector, were put into orbit around the Moon, carrying a variety of remote-sensing instruments to map the whole lunar surface. Lunar Prospector also explored the Moon's gravity and discovered magnetic regions. But many unanswered questions still perplex lunar scientists.

A key lunar feature is the South Pole Aitken Basin, which dominates the Moon's south polar region and is the largest known impact crater in our Solar System. The SMART-1 spacecraft will examine this and



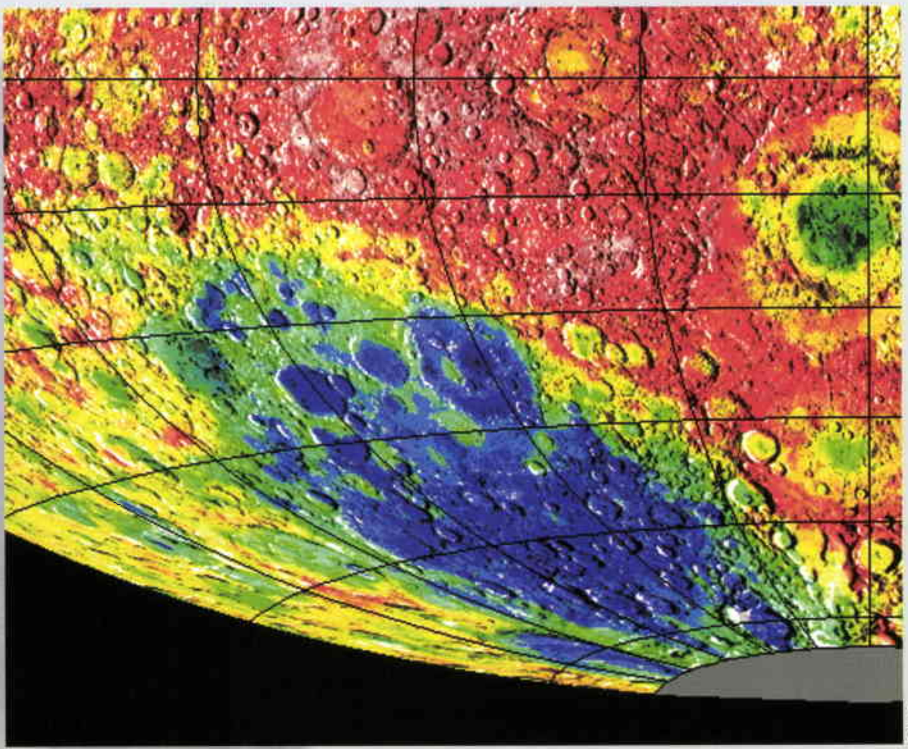
Courtesy of NASA/JPL

SIR on SMART-1 will map the minerals of the Moon. Materials that often look merely grey in visible light are more colourful in the infrared. When seen in the form of a spectrum, showing relative intensities at different infrared wavelengths, each mineral has a distinctive signature depending on which wavelengths it absorbs most strongly.

the thousands of other lunar craters that chronicle a prolonged bombardment of the double planet by comets and asteroids. Our own planet suffered even more severely from such impacts.

SMART-1's camera AMIE will enable scientists to study afresh the Moon's topography and surface texture. It measures visible light at a million points in a field of view 5 degrees wide, and filters can select yellow light, red light or very short infrared rays. By looking at selected regions from different angles, and under different lighting conditions, AMIE will provide new clues as to how the lunar surface has evolved.

With longer infrared rays, the infrared spectrometer SIR will map the surface distribution of minerals such as pyroxenes, olivines and feldspars, in 256 wavelength bands from 0.9 to 2.4 microns and thus in far more detail than Clementine with its six infrared bands. The mineralogy from SMART-1 will reveal the effects of cratering and maria formation, and the nature of subsurface layers exposed by fractures in the Moon's crust.



The South Pole - Aitken Basin, the largest known impact crater in the entire Solar System. Coloured blue in this topographic map, it is 2500 kilometres wide and up to 12 kilometres deep.

BENEFITS FROM LUNAR EXPLORATION

Learning about the Formation and Evolution of Planets
- Understanding how rocky planets form and evolve
- Chemical constraints on Earth-Moon origin
- Signatures of accretional processes in inner planets
- South Pole Aitken Basin and large impact basins
- Evolution of the Earth/Moon system
- Impacts: giant bombardments in the inner Solar System.

Studying Comparative Geophysical Processes
- Volcanism, tectonics, cratering and erosion
- Deposition of ices and volatiles
- Geophysics and geochemistry.

Using the Moon as a Collector of Extraterrestrial Samples
- Regolith sample of the solar wind's history
- Samples of icy cometary deposits over the last 10^8 years
- Samples from the early and the evolving Earth
- Samples from Venus, Mars and asteroids.

Preparing for Future Lunar and Planetary Exploration
- Survey of lunar resources (minerals, volatiles, lighting)
- High-resolution studies for landing sites/outposts
- Coordination between lunar missions
- Environment studies in support of human exploration.

Lunar Testbed for Solar System Exploration
- Synergies with other planetary missions (Rosetta, Mars Express, Venus Express, BepiColombo)
- Advanced technologies (propulsion, landing, robotics, energy tele-presence, autonomy, life support).

Social Benefits
- Technology challenges and jobs for industry
- Inspiration for the general public and youth for knowledge, science, technology & innovation
- Future commercial opportunities
- Moon base as refuge for humans in case of a global nuclear or asteroid impact catastrophe.

References: International Conference on Exploration & Utilisation of the Moon, ESA SP-462
Earth-like Planets & Moons, ESA SP-514

How did the Moon and Rocky Planets Form?

The fashionable theory is that the Moon is the result of a collision soon after the birth of the Solar System 4500 million years ago. When the Earth was nearly complete, a gigantic wandering asteroid the size of Mars supposedly collided with our planet, flinging vaporized rock and debris from both bodies into space. Some of it went into orbit around the Earth, and re-accreted to form the Moon. The impact would have greatly altered the outer layers of the Earth too. So a fuller understanding of both the Earth and the Moon depends crucially on confirming, refuting or refining this theory.

If the story is right, then the Moon should contain less iron than the Earth, in proportion to lighter elements such as magnesium and aluminium. By gauging the relative amounts of chemical elements comprehensively for the very first time, SMART-1 can make a major contribution to the resolution of this momentous scientific issue. Its D-CIXS instrument will provide a 50 km resolution map of the absolute abundances of magnesium, silicon and aluminium. The magnesium mapping is key to studying the evidence for a primitive lunar source, the constraints on magma/ocean model evolution, the sources of rocks containing magnesium, iron, potassium and rare-earth elements.

Peering into the Darkest Craters to Look for Ice

The presence of water ice on the Moon was predicted more than 25 years ago. The story was revived in 1994 with the confirmation of shadowed polar areas and a tentative radar detection of ice by the Clementine spacecraft. In 1998, another NASA spacecraft, Lunar Prospector, provided indirect evidence of the presence of water ice by detecting high levels of hydrogen in shadowed craters near the Moon's south and north poles. Scientists estimated that up to six billion metric tons of water ice could be

Compared to Apollo silicon/aluminium ratio maps over 10% of lunar surface, D-CIXS will have global X-ray cover and will detemine absolute chemical element abundances.

buried in the craters, but an attempt last July to find direct evidence by 'crashing' the Lunar Prospector into a crater near the Moon's south pole produced no observable spectroscopic evidence of water.

To have survived, any water must be in the form of ice in places always hidden from the Sun, where the temperature never rises above minus 170 degC. Such dark places do exist near the Moon's poles, notably in the bottoms of small craters. SMART-1's very sensitive imager and spectrometer (SIR) will map what's inside the shadowed craters, looking for the infrared signature of water ice and perhaps of frozen carbon dioxide and carbon monoxide too. There is no direct illumination in the target areas, but rays reflected from nearby crater rims may light the ice sufficiently for SIR to see it when data from many passes are added together.

Exploration and Inspiration

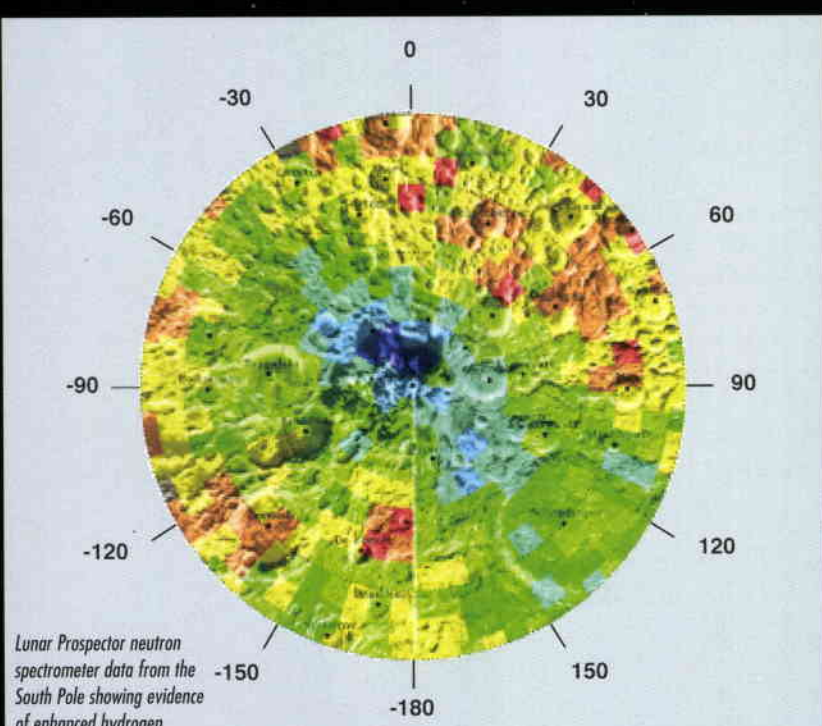
The data gathered by SMART-1 data will be released not only to the scientific community, but also to the general public and for educational projects. In particular, the AMIE micro-imager will provide a visual record of the cruise from the Earth to the Moon, and views of the Earth, Moon and sky for education and science communications. The SIR infrared spectrometer and D-CIXS X-ray spectrometer will also be used for educational and public outreach activities.

SMART-1's adventures will be used to educate the public about the fundamental scientific questions associated with the origin and evolution of the Earth-Moon system and its rocky planets, as well as providing information about advanced technologies. Publicising this smaller, faster project to visit the Moon can show the youth of today what international teamwork and dedication can achieve and will hopefully help to attract them into careers in science, technology and innovation, and can inspire the next generation to continue to pursue the development of a knowledge-based society in Europe.

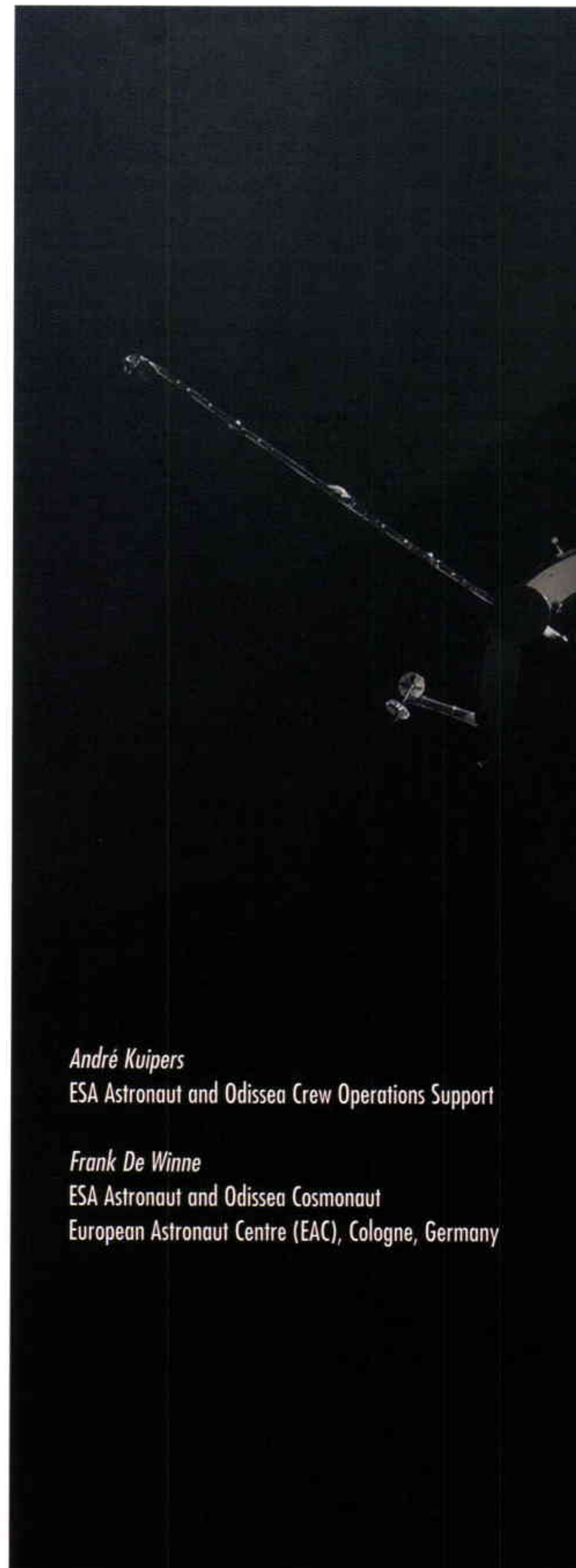
International Lunar Exploration: The Future?

The technological and the scientific results from the SMART-1 mission will be used to prepare for future lunar and planetary exploration. The Japanese Lunar-A mission, to be launched in mid-2004, will place two penetrators with seismometers on the Moon's near and far sides to analyse its internal structure and core. In 2005, we expect the launch of the Selene lunar orbiter with an impressive set of instruments for remote-sensing, gravity, plasma, and radio-science measurements. India's Somayana lunar scientific mission could be launched in 2007. In its Decadal Plan, the US National Research Council has recommended a sample-return mission to the South Pole Aitken Basin to learn about giant impact processes and to probe the lunar mantle in the context of the formation and evolution of rocky planets.

The International Lunar Exploration Working Group (ILEWG), which brings together ESA, NASA, the Japanese, Russian, Indian and several other space agencies around the world, is the main forum for the coordination of these initiatives and for preparing the next steps. There are already proposals for landers to try to measure the depth and composition of the ices in the craters or to return samples. The Moon can also serve as a test bed for the development of instruments, geophysical stations, robotic outposts, international robotic villages, in-situ resource utilisation, deployment of large infrastructures astrobiology/life-science laboratories, and permanent human outposts, as a first step towards the robotic and human exploration of our Solar System.



Lunar Prospector neutron spectrometer data from the South Pole showing evidence of enhanced hydrogen



André Kuipers
ESA Astronaut and Odissea Crew Operations Support

Frank De Winne
ESA Astronaut and Odissea Cosmonaut
European Astronaut Centre (EAC), Cologne, Germany

Introduction

Approximately every six months, a Soyuz rocket is launched to carry a new Soyuz capsule to the International Space Station (ISS), to replace the one that has been docked there since the last visit. This regular schedule is dictated by the fact that the ISS's current crew of three relies on the docked Soyuz capsule as a lifeboat should they have to leave the Station unexpectedly. Since the start of the Station's build-up, there have been four Soyuz-capsule exchanges. Each Soyuz flight brings up an additional crew of three, who stay on board for 8 days to perform scientific research.

Because there are presently only three permanent crew members on the ISS, instead of the intended seven, ESA has been forced to look for additional flight opportunities. Negotiations with the Russian Space Agency resulted in a cooperation agreement that enables ESA astronauts to fly in the Soyuz capsule as 'flight engineers' and then perform scientific experiments whilst aboard the Space Station.

Following similar initiatives by France and Italy, the Belgian Federal Department for Scientific, Technical and Cultural Affairs (OSTC) decided to fund such a Soyuz mission within this framework for October 2002. An extensive scientific programme was developed and prepared by ESA and OSTC. Belgian ESA astronaut Frank De Winne was appointed to perform these experiments and to fly to the ISS as Soyuz flight engineer. He had the additional privilege of being on the maiden flight of the latest model of the Soyuz spacecraft, known as Soyuz-TMA.

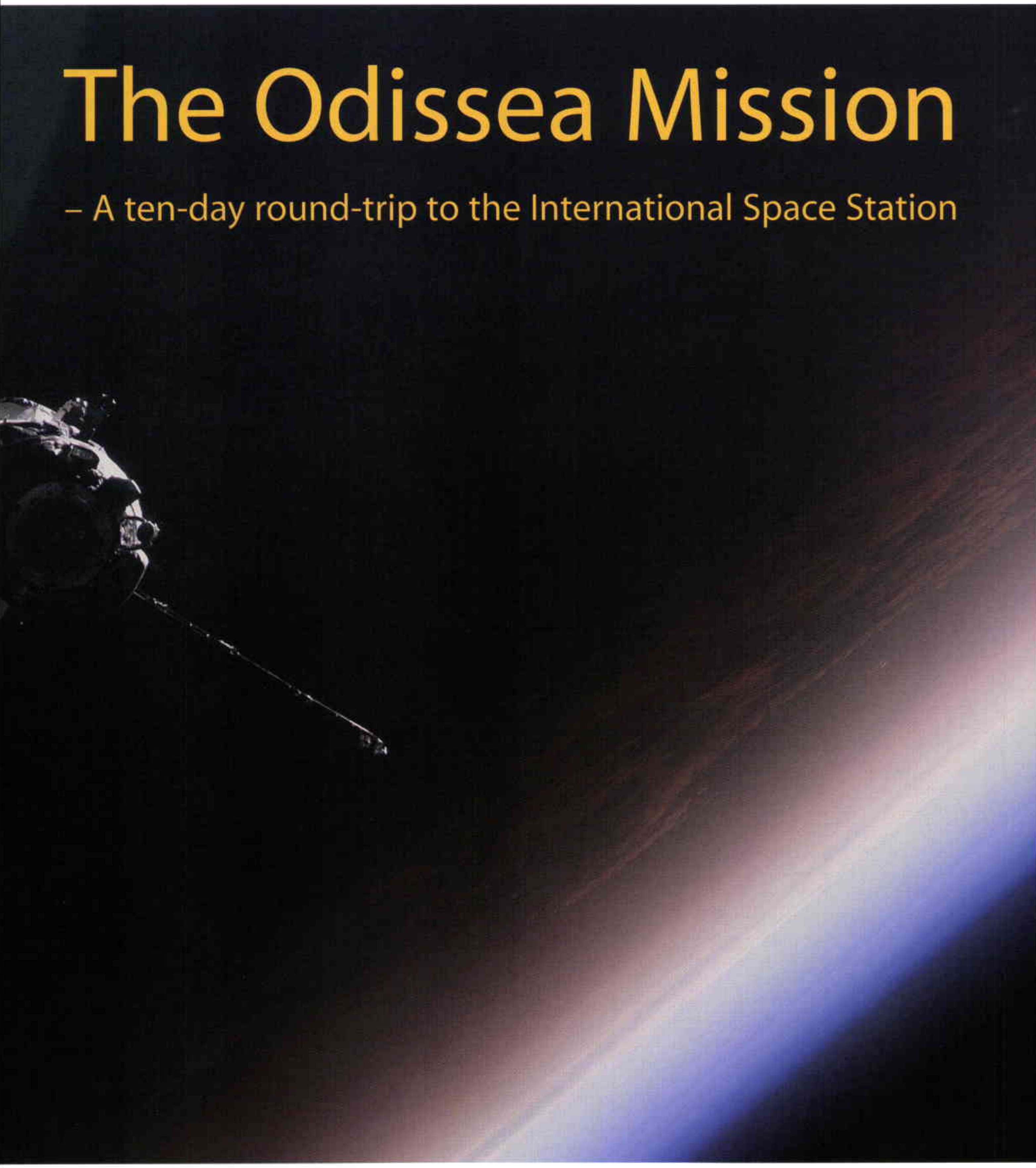
The mission also had some other firsts for an ESA astronaut, namely: the use of the ESA-developed Microgravity Science Glovebox, the fact that Frank was to work in both the US and Russian segments of the ISS, and the novelty that he was to fly in two different models of the Soyuz capsule.

After one and a half years of training and experiment preparation, the Soyuz lifted off on 30 October 2002, with commander Sergei Zaletin (the last commander of the Mir space station), with Frank as flight engineer in the left-hand seat and with flight engineer Yuri Lonchakov (reserve commander) in the right-hand seat. The two-day trip to the Station went according to plan and the eight-day programme of experiments conducted on board was a great success.

On 10 November, the visiting crew returned in the Soyuz TM-34 capsule that had carried the crew that included Italian ESA astronaut Roberto Vittori to the ISS in April 2002. It made a very special night landing in Kazakhstan. Frank subsequently 'continued' his mission through extensive baseline data collection for the demanding set of medical experiments that he had conducted in orbit.

The Odissea Mission

– A ten-day round-trip to the International Space Station



ESA astronaut Frank De Winne checks out his Sokol space suit

Getting Ready

Frank's intensive training for the mission had begun in August 2001, doing his initial training together with Roberto Vittori. Besides the many hours spent in the classroom learning about all the different aspects of the Soyuz and the ISS, there was also survival training in the Black Sea and in winter conditions, for the unlikely event that the landing would not be in the Kazakh steppes. They also did weightlessness training in an Ilyushin-76 aircraft, as well as riding in a human centrifuge to prepare them for the g-forces that they would experience during launch and landing. One of the most demanding parts of the training was mastering the Russian language!

As already mentioned, the crew for the Belgian flight had to master both the old Soyuz TM capsule in which they would be returning to Earth, as well as the brand new Soyuz TMA. The TMA (the 'A' stands for anthropometric) differs from the previous TM version in several aspects, not least of which is the greater space available for the cosmonauts, allowing taller cosmonauts to fit into the capsule, and the fact that many of the real buttons in the older version have now been replaced by virtual functions on displays.

Eight months into the training programme, the practical training in the Soyuz simulator began. The crew spent long hours, many in their space suits, training in the simulator in order to prepare them for all kinds of events and eventualities. The two ESA flight engineers were in good hands with the Russian trainers at the Yuri Gagarin Cosmonaut Training Centre, who have extensive experience in training cosmonauts, including foreign crew members. As flight engineers, Frank and Roberto would be responsible for controlling critical parts of the spacecraft, working very closely with the Soyuz commander during the in-orbit manoeuvres, docking/undocking with the ISS, and the subsequent return to Earth.

Extensive medical examinations are an important part of the mission preparations. These tests took place at regular intervals to check and safeguard the health of the cosmonauts, and hence ultimately also the success of the mission. Equally important and demanding are the sessions for fitting and checking out the Sokol space suits. One such session is a leak test in which the cosmonaut is strapped in his cramped flight position for several hours inside a vacuum chamber. As the Odissea cosmonauts would also be living and working in the US part of the ISS, training sessions at the NASA/Johnson Space Center in Houston were scheduled too.

Although the flight-engineer training involved the greatest preparation time, the scientific objective of the mission was to complete the extensive experimental programme. This meant that as launch approached the crew spent more and more time training to conduct those experiments. This training took place under ESA's control and much of it was done at ESTEC in Noordwijk (NL). The crew worked closely with the scientists responsible for the experiments in familiarising themselves with the equipment and the experimental procedures. Some of this training also took place in Houston, as four of the experiments needed to be performed using the ESA-built Microgravity Science Glovebox for extra safety.

The baseline data collection for the physiological experiments was particularly time-consuming, requiring many samples to be taken from the cosmonauts themselves. These sessions started long before the mission, not only in Russia but also in the Netherlands. The physiological testing intensified close to the launch and was at its peak for a few days after the landing, continuing less frequently for several weeks thereafter.

The Experiments

Belgium's support for the Odissea mission made it possible for a total of 23 experiments to be performed, which would otherwise have had to wait several years for an appropriate flight opportunity. The experiments flown, which were selected by ESA after scientific peer review and an accommodation study, included both Belgian and international experiments and they covered both scientific and educational topics. The OSTC coordinated the Belgian experiments.

Many of the experiments conducted were in the life-sciences domain, ranging from cell research at the DNA level to cardiological and neurological studies on the cosmonauts themselves. In the physics-related field, there were three crystallisation experiments, an experiment to study combustion reactions in a metal mixture, and a fluid-physics experiment to study diffusion in oils. Educational experiments were videotaped for schools, with which there were also amateur-radio sessions during the mission.

Most of the equipment used for the Odissea experiments was developed by the national institutes or by ESA and had been carried to the ISS a few months earlier by an unmanned Progress capsule, while some was already onboard in the NASA laboratory or had been carried up as part of the equipment pool from previous flights.

The three Odissea crew members set out for the launch pad in Baikonur

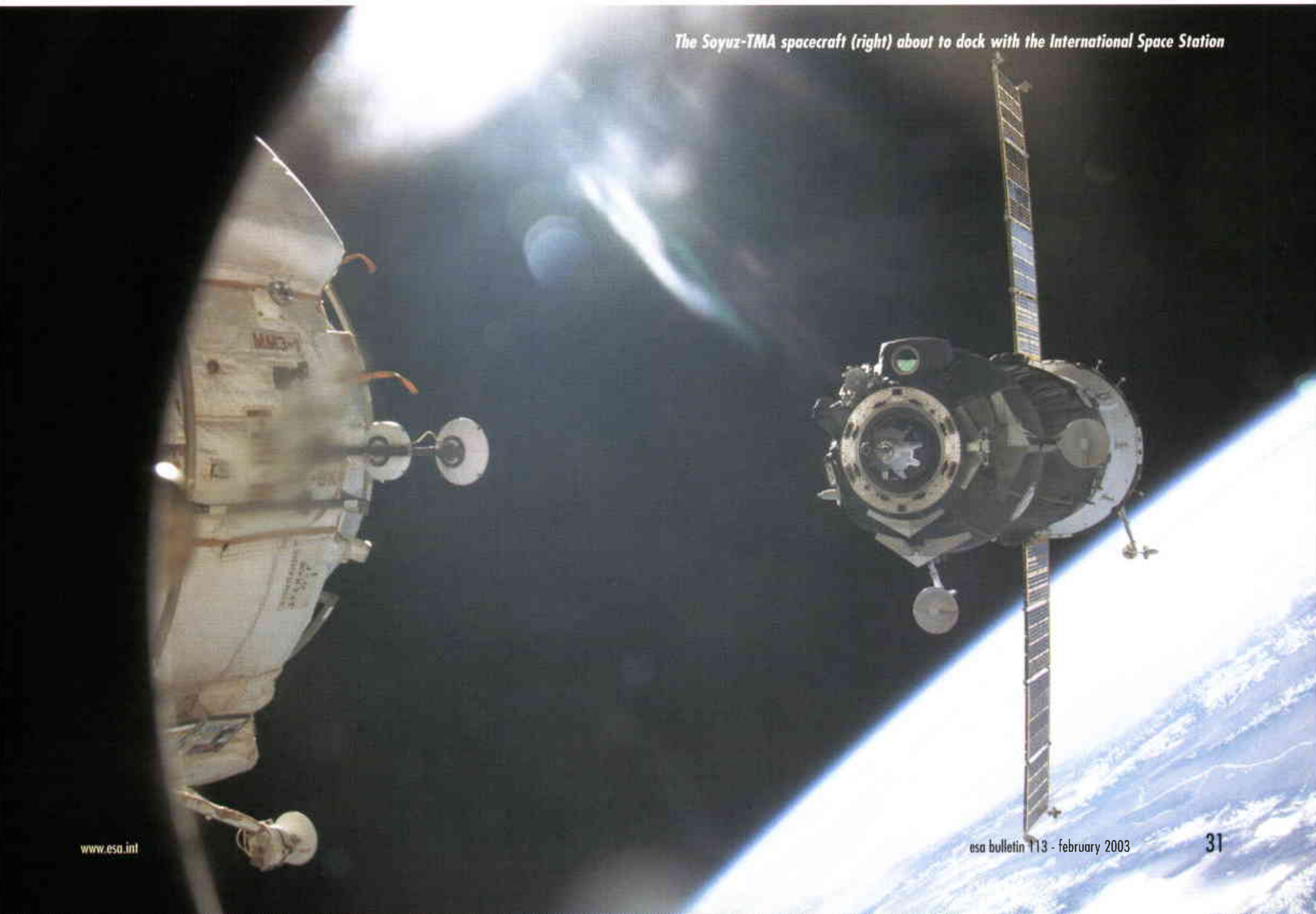
The Flight

The crew got up very early during the night of 30 October to prepare for the early-morning launch. After the traditional walk from the cosmonauts' hotel in the small town of Baikonur, the three were transported by bus to the launch complex. The Sokol spacesuits were donned four hours before the launch and their air-tightness tested once again. There was then the traditional ceremony in which the crew reported to the State Commission, surrounded by a crowd of invited guests and the media, before being transported to the launch pad. This same pre-launch ritual has been followed since Yuri Gagarin's flight in 1961.

Two and a half hours before lift-off, the three crew members entered the capsule. Thereafter, the radio-links and the air-tightness of the capsule were tested, as well as the air-tightness of the suits one last time. The final flight instructions were loaded according to plan shortly before lift-off and the automated ignition sequence was initiated.

In fact, the launch took place in dense fog, which gave the onlookers the special sensation of only feeling rather than seeing the rocket's ignition and lift-off. The ascent was according to plan and after just 8.5 minutes the Soyuz was in orbit. After all the necessary checks had been conducted, the crew could safely get out of their spacesuits, disconnect their medical monitoring wires and enjoy the relative 'comfort' of the orbital module above the landing capsule.

During the next two days, the crew conducted many tests with the new spacecraft and prepared the capsule for



The Soyuz-TMA spacecraft (right) about to dock with the International Space Station

Frank De Winne at work in the ISS with ESA's Microgravity Science Glovebox

docking with the ISS. During the periods of ground contact, they were able to talk to their families who had gathered in the Soyuz control room in the flight control centre. Despite their limited meals and lack of sleep, they were also able to enjoy their long awaited view from space of planet Earth and to experience life in microgravity.

This maiden flight of the new TMA Soyuz capsule was successfully completed with an automatic docking to the International Space Station on 1 November. After careful checks for any leaks, the hatch was opened and the permanent residents warmly welcomed the visiting trio, for whom floating through the more roomy Space Station modules seemed like luxury after their days in the Soyuz.

After a video conference with officials on the ground, followed by an hour and a half of unpacking, there was plenty of time to chat with family and friends back on Earth before starting eight days of intensive work. The following days were fully occupied in conducting all of the experiments, with the permanent station crew helping out during certain experiments. Equipment had to be started up, experiment cartridges had to be changed, electrodes attached, blood samples taken, ongoing tests filmed, malfunctioning devices repaired, pictures taken of particular locations of interest on Earth – such as the erupting Etna volcano – temperatures checked, videotapes exchanged, questionnaires filled in, etc., etc. Despite this hectic schedule, the experiments worked very successfully, with hardly any delays or problems. 22 experiments were completed, to the great satisfaction of the scientists, the ground teams and the crew.

Several public-relations events were organised during the mission, with the crew communicating sometimes in Dutch and sometimes in French with VIP's, mediators, officials, schoolchildren and students in Belgium and at ESTEC sites, as well as with television crews. In Frank De Winne's hometown, thousands of people gathered in the market square to witness these live broadcasts on giant TV screens.

The Mission Operations

The Odissea mission was controlled from the TsUP flight-control centre in Kaliningrad near Moscow. Through the close cooperation with the Russian flight controllers, the ESA crew-support team was able to be in direct contact with the visiting crew. This ESA support included medical support by a doctor from EAC, who was similarly in close contact with the Russian medical staff. The experiment investigators were gathered at the User Support Operations Centre in Brussels (B), where they could be quickly consulted by the ESA engineers at ESTEC in the event of any problems.

As the ISS crew operates on the basis of Greenwich Mean Time, the people at TsUP work into the night, while their NASA counterparts are active early in the morning. Every day, a so-called Form 24 containing the daily planning was sent to the Station, with other inputs to the crew such as new or updated procedures being conveyed by radiogram or by direct voice communication. The latter rely on a VHF channel when there is coverage by the

Russian ground stations, which occurs only a few times per day. At other times, communication relies on the US ISS segment's S-band link with Houston, including e-mail exchange, and the radio-amateur sessions.

The Return

For the Odissea crew, the 10 days of the mission passed all too quickly. The last two days were mostly spent in packing the Soyuz TM34 return capsule with the experiment results and data carriers, some small items of equipment, and personal belongings. As the allowed volume and mass, as well as the access to the various storage locations, are strictly limited, this is not a trivial task. Most of the experiment equipment is left onboard the ISS for later reuse or is stored in the Progress capsule for subsequent removal and eventual destruction on reentry into the Earth's atmosphere.

Having successfully concluded their hectic programme of experiments onboard the ISS, the visiting crew bade farewell to their colleagues and closed the hatch. Having donned their pressure suits once again and checked carefully that everything was properly sealed, they undocked their Soyuz from the Station and slowly drifted away. The descent operations towards the Earth's atmosphere went according to plan, and the deceleration for reentry was started with a burn of the Soyuz's engines. The living module and the equipment part of the Soyuz were separated from the landing capsule, which entered the dense layers of the Earth's atmosphere soon afterwards. After 10 days of weightlessness, the crew had then to withstand the deceleration forces of re-entry and the subsequent swinging movements that accompany parachute deployment.

The landing was always destined to be an historic one, since it was the first ever Soyuz night landing. For the rescue helicopter crews, the intense glow of the returning capsule provided an impressive and quite unique sight. The landing itself was a hard one due to the frozen ground and the repeated tumbling of the capsule before it finally came to rest on its side.

The Soyuz capsule on the frozen steppes of Kazakhstan, after its historic first nighttime landing

The jubilant Odissea crew safely back on terra firma: from left to right, ESA astronaut Frank De Winne, and Russian cosmonauts Sergei Zaletin and Yuri Lonchakov

Although in a rather uncomfortable position, the crew were in good health and good spirits when the support team reached them. The ESA support personnel retrieved the time-critical scientific samples and other important items from the capsule and the three crew members were taken to a tented facility for a medical check-up. There they were also able to share their experiences with colleagues, friends and officials, including the Belgian Crown Prince.

Reflecting on all that had happened during his hectic first voyage into space, Frank described his experience as 'the most intense, challenging and unbelievably fulfilling 10 days of my professional life'.

This, however, was not the end of the mission for the Odissea crew, who still had to submit to the many post-flight medical tests in the days to come, in order to assess their re-adaptation to normal gravity conditions. The scientific researchers, of course, also have lots of work ahead of them on all of the data brought back from the ISS and will only be able to draw definitive conclusions from their experiments several months from now.

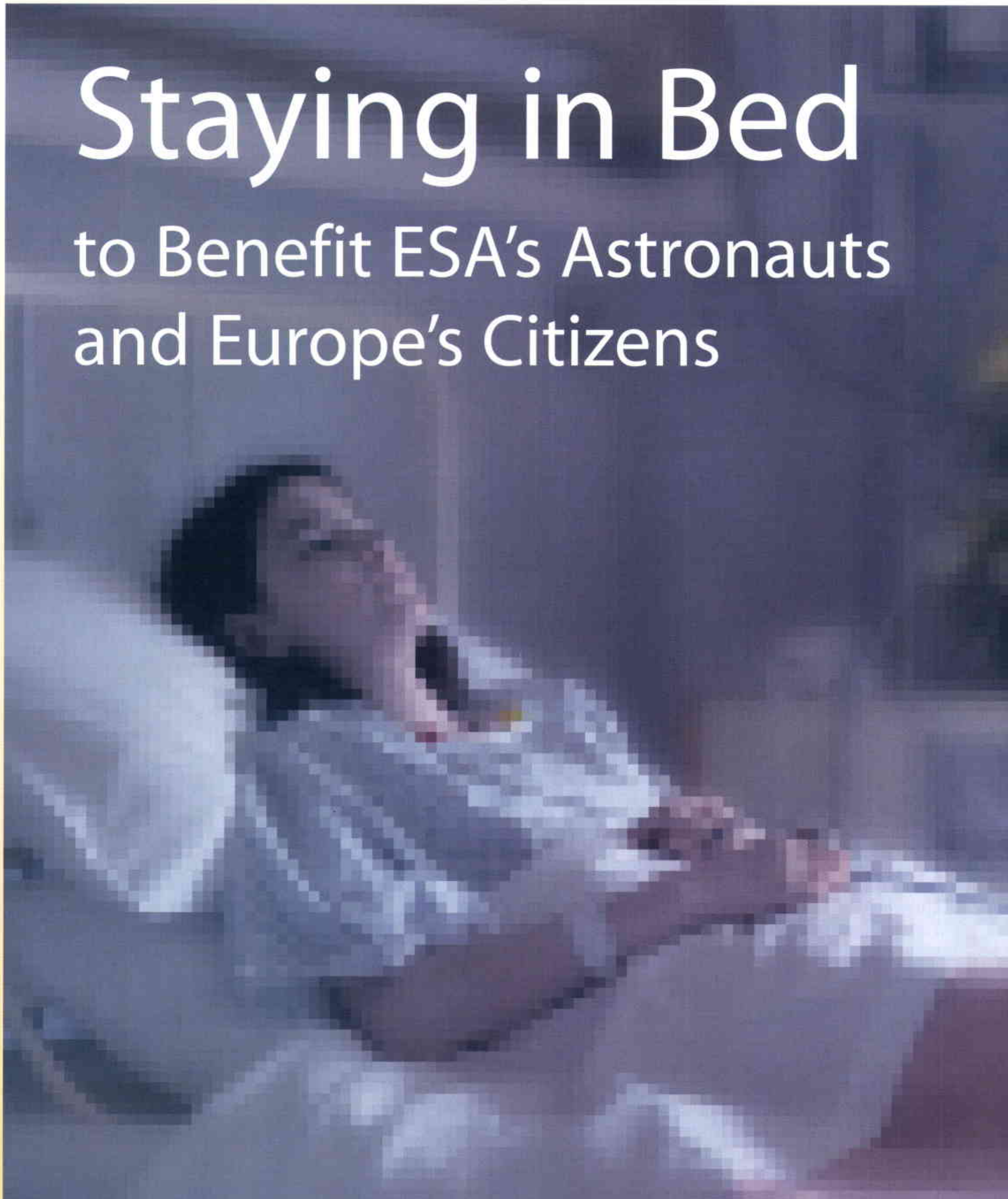
Conclusion

The Odissea mission was extremely successful, with all of the main goals – the testing of the new Soyuz vehicle in flight, the exchange of the Soyuz vehicles as rescue craft for the ISS, and the scientific/educational programme – being achieved exactly as planned.

The cooperation on the ground between all of the international partners at the different sites worked well, with the few difficult issues that did arise being resolved in a very professional way. The Odissea mission therefore stands out as a good example of how such nationally funded missions can serve the national, European and international scientific community and can help to stimulate the youth of today to choose technical and scientific careers. The experience gained during this 'extra' mission will also be very useful for the preparation of the next Soyuz flights, carrying ESA astronauts from Spain and The Netherlands.

Staying in Bed

to Benefit ESA's Astronauts and Europe's Citizens



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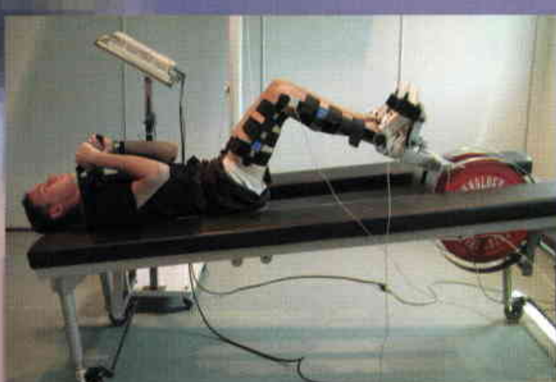


Introduction

Since Yuri Gagarin's historic first flight into space in April 1961, it has quickly become evident that the space environment influences the human body in many different ways and causes it to adapt in ways that can lead to problems when returning to Earth's gravity. Much research has been performed in the meantime and our understanding of what happens to our bodies in space improved considerably during the Mir space station and Space Shuttle/Spacelab era. However, many questions, particularly regarding how to counteract those changes that we now know take place, still need to be addressed through studies on the International Space Station (ISS) and through simulations on the ground.

As we enter an era in which crews will spend longer periods in space on the ISS and of longer term plans by almost every space-faring nation for missions to Mars, it is clear that much more knowledge is needed, and quickly. Although a few hundred men and women have already travelled into space, the operating environment severely limits the amount of systematic research that can be performed - a situation that is unlikely to change. Other avenues for addressing specific scientific questions in a controlled research environment must therefore be found.

One of these complementary alternatives is head-down-tilt bed-rest studies in which volunteers are confined to beds that are tilted –6 deg below the horizontal at the head end. Every activity, including eating, reading, showering, etc., is performed in this position for the duration of the study. This leads to changes in the human body that are very similar to those seen during spaceflight, such as bone-mass and muscle-mass loss, cardiovascular and neuro-sensory de-conditioning. The controlled bed-rest setting therefore allows meaningful research into the bodily consequences of spaceflight and possible countermeasures. It also gives the scientific community interested in space-related medical research more ready access to a clinical model.

The benefits of these studies go far beyond their space application. Patients bed-ridden because of illness or accidents suffer the same symptoms and can thus also profit from the studies. As a clear indication of this link, the clinicians and researchers involved in the bed-rest campaigns typically spend the majority of their time exploring 'terrestrial' problems.

A Medical Challenge for Europe

The long-duration bed-rest study performed over the last year was an initiative of the International Space Life Science Working Group, involving ESA, CNES and NASDA. Lasting 90 days and with 25 test subjects participating, it was certainly a very challenging endeavour. Over 1000 candidates applied, 120 of whom were medically and psychologically screened. Sixty-six scientists from more than 30 research centres in 8 ESA Member States took part, and 20 hospital laboratories and units were involved on site. About 250 people were involved in organizing the study, including 140 doctors, nurses, physiotherapists, psychologists, para-medics, nutritionists, and technicians who were present at the MEDES clinic for various periods during the two study phases.

The amount of scientific data collected is equally impressive: during the study 4350 tubes of blood samples were drawn, plus 825 during the follow-up period, 5500 urinary assessments were made, plus 500 during follow-up, and the blood pressure of each volunteer was taken 250 times. Altogether, about 1000 hours of testing were performed on each volunteer, 43 750 Magnetic Resonance Imaging (MRI) scans were made, etc.

How Our Bodies Change in Space

Some of the most significant adaptational features known to occur when space crews are exposed to microgravity for long periods are:

- Major changes in the circulatory system, such as altered blood pressure and heart-rate control and pulmonary function.
- Decreases in muscle mass and in the neuronal control of muscle activity.
- Differences in posture and locomotion control.
- Altered perception and cognition strategies of the brain.
- Bone loss, exceeding 1% per month in weight-bearing bones, in addition to potentially unrecoverable changes in bone structure.
- Changes in metabolism such as nutrition absorption and control of water and salt excretion.

The bone and muscle changes, which are the most challenging when contemplating long-term spaceflight, were the prime focus of the bed-rest study. In addition, the physiological parameters pertaining to circulation, sleep quality, fluid intake, standard blood parameters and general activity patterns were carefully monitored. Such basic parameters as body weight, blood pressure and temperature were also tracked.

Maintenance of muscle function and bone strength would be crucial for trips to Mars, for example, which would last some 500-550 days, with about 170 days of exposure to microgravity in the spacecraft in each direction, and the rest of the time being spent in the 0.38 g of Martian gravity.

The Study and Its First Results

The first period of the study was completed just before Christmas 2001 and Phase 2 began in March 2002. At the time of writing, the first scientific findings have been presented. The details of the bed-rest study itself were presented in ESA Bulletin No. 108, in November 2001.

Three groups of volunteers (seven, nine, and nine subjects, respectively) were selected: the first group was to undertake a specific exercise programme using the flywheel resistance device selected for flight on board the ISS, the second was to receive one-time medication against loss of bone material (explained later), whilst the third was to function as a control group, neither taking exercise nor receiving any medication.

All three groups received identical nutrition, calculated on the basis of individual pre-study bodyweights, and following general international guidelines from the World Health Organization, to ensure that no weight variations would be due to over- or under-nourishment.

The state-of-the-art clinical diagnostic tools applied in accurately monitoring the changes in muscle and bone tissue for all three groups included Magnetic Resonance Imaging (MRI), two levels of Quantified Computer Tomography (QCT and pQCT), as well as Dual X-ray Absorptiometry (DEXA), which allows the total mineral content (BMC) of the body's bone skeleton to be estimated very accurately.

The early study results are extremely illuminating in terms of the counter-measures applied, looking at the summary data only in the following areas:

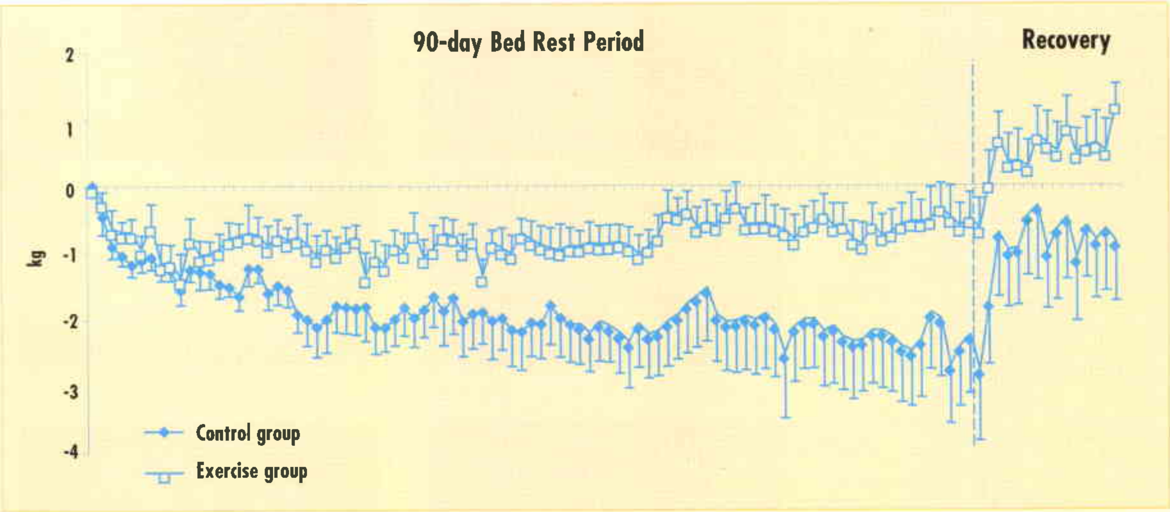
- body weight
- muscle mass and function
- bone mineral content
- gait (walking) and balance
- food absorption.

Monitoring bodyweight

The group that undertook 20 mins of intensive exercise over one hour two to three times a week maintained their bodyweight better than the other two groups. The spread within the non-exercising group becomes larger over time, which indicates a cumulative effect, or rather that these persons continue to lose weight, whereas the exercising group seems to loose the entire amount during the first 10-15 days, and thereafter remains constant.

The data also indicate another interesting trend, namely that the spread in weight data, i.e. with some losing much more than others in the same group, is much larger in the control group than in the group that exercises. Interestingly, this would seem to indicate that the regulation of bodyweight is better when the body burns energy, with energy-demanding activity maintaining the weight parameters within a much smaller tolerance.

Likewise, long-term bed rest leads to loss of body-weight in patients, which is known to be a significant problem in the elderly in particular. This alone can be life-threatening in relation to long-term sickness. Short bursts of maximum-intensity exercise may therefore be a potential countermeasure.



Changes in volunteers' bodyweights during the study, compared with the non-exercising 'control' group

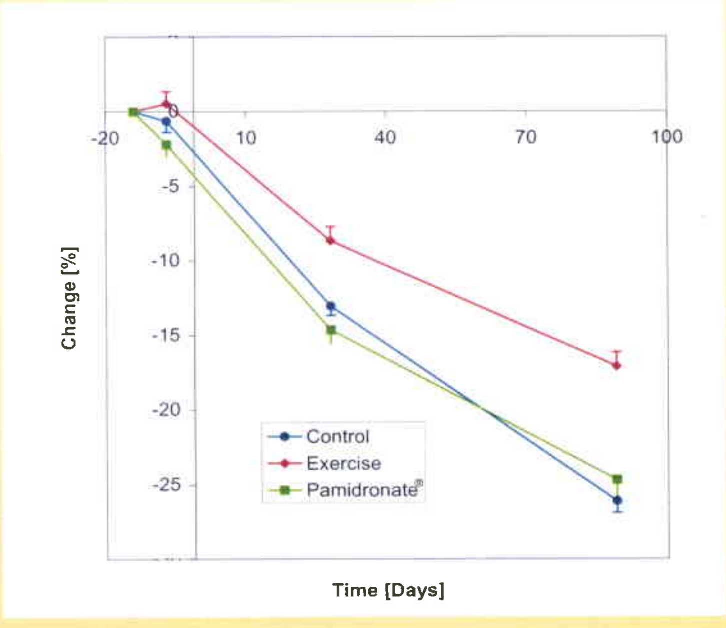
Preserving muscle mass

Due to the sophisticated methods applied in our study, one can discriminate very well between the effects on bone and muscle tissue of preventive medication and of exercise. This allows us to draw clear conclusions as to the next step in defining suitable countermeasures for the negative effects of microgravity.

The exercising group basically preserved their thigh muscle mass almost 100%, whereas the non-exercising groups showed a significant loss. The calf muscles showed a less good result with the current protocol, although exercise helps reduce the loss of calf volume by some 50% compared to the non-exercising groups. In addition, using the flywheel resistance training device increased the static force of calf muscles compared to pre-study levels. This may be because the average person does not usually train this 'locomotion' muscle using this kind of high-output exercise.

The question that still remains is the lack of maintenance of muscle volume, which is probably because the type of exercise applied provided insufficient stimulus for that muscle, which is mainly composed of 'slow fibres'. This suggests that the exercise regime applied is not sufficiently appropriate for training that muscle.

The accompanying illustration shows the relative changes in calf-muscle cross-sectional area (CSA) during 90 days of bed rest. The reduction in CSA is significantly smaller in the exercising group than in the other two groups.

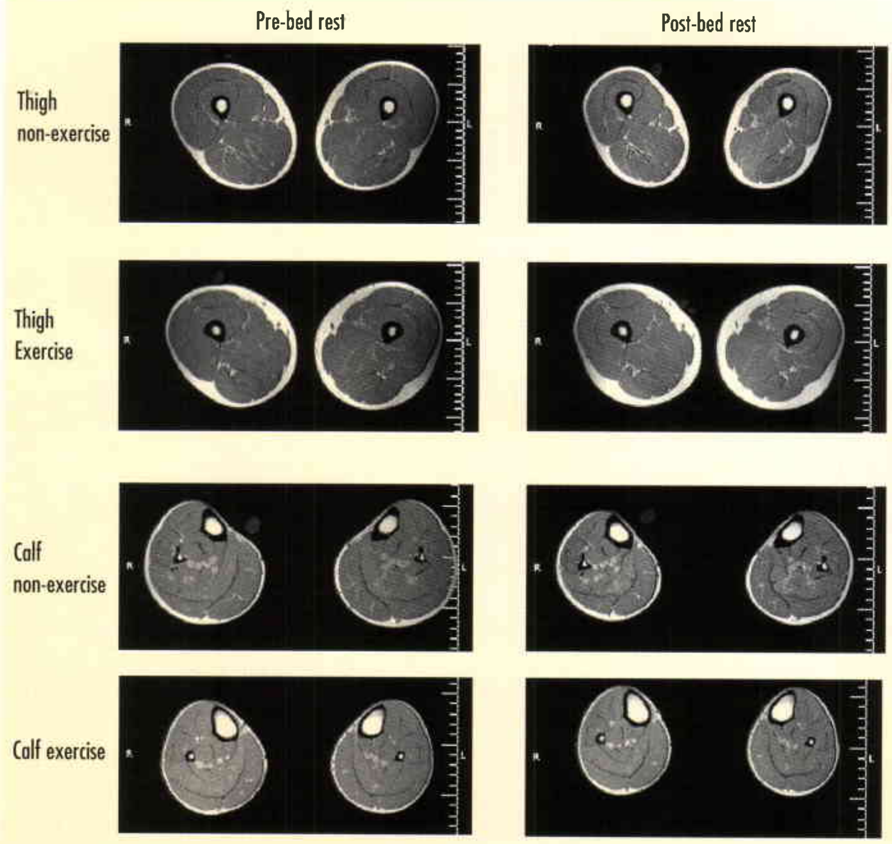


Changes in calf-muscle cross-sectional area as measured by peripheral Quantified Computer Tomography (pQCT) for the three groups

Maintaining cardiovascular function

The resistive flywheel exercise seems to provide no protection against orthostatic intolerance when returning to the vertical again after the bed rest. This intolerance, which affects 50% of astronauts post-flight, means that sufficient blood pressure cannot be maintained in the standing posture for a period of a few minutes. This is crucial for ensuring the return of sufficient blood to the heart and hence to the brain. No significant effect from this exercise regime on this problem was expected, but it had never been tested before over such a long period.

The body's circulatory reflexes rely on a complex system of sensors and effectors, the sensors being pressure sensors in the heart and lungs as well in the large arteries on both sides of the neck. When stimulated, the effectors create appropriate constrictions of the blood vessels, particularly below the level of the heart. This ensures that enough blood is returned to the right side of the heart sufficiently quickly. It is particularly important that these reflexes work correctly in the standing position after a long a time in bed, to avoid blood pooling in regions below heart level, which would lead to insufficient blood getting to the brain and hence to fainting.



Cross-sectional images of thigh and calf muscles made by Magnetic Resonance Imaging (MRI), showing the effect of flywheel resistance exercise for a typical subject

Retaining bone structure

Bone development during one's growth years is governed primarily by metabolic processes driven by nutrition and other growth factors. Thereafter one's bones adapt to the changing loading conditions. This process called 'bone resorption' removes bone tissue in one place by 'digging' microscopic cavities, which the bone formation process later refills. In this way, bone slowly adapts to the longer-term loading pattern by strengthening itself where it is most needed.

Calcium is bound into bone tissue in a complex structure, and this is what the traditional screening methods look for when assessing whether or not a person is osteoporotic. Bone mineral content peaks in the early twenties for males, and somewhat earlier for females, and then essentially remains constant for the next 15 to 20 years. Thereafter a natural, age-related slow loss of bone mineral sets in. Post-menopausal women have a much higher risk of developing osteoporosis than similarly aged men, who also tend to have osteoporosis problems much later in life, usually after the age of 65. Osteoporosis therapy is somewhat complicated, as the responses to loading (exercise) or to medication, like the estrogen hormone that plays a significant role in bone preservation, particularly in women, vary significantly from person to person.

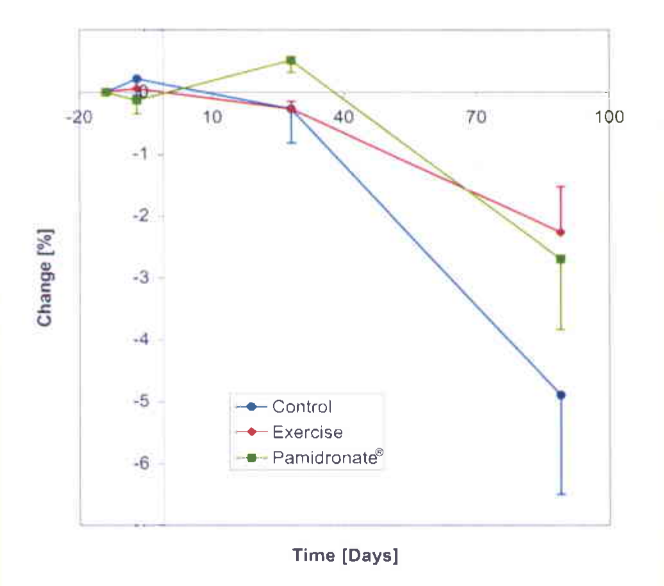
Our studies have shown that one type of medication, Pamidronate®, which belongs to the bisphosphonates family, effectively blocks the bone resorption process. In bone detectable changes take place very slowly and are therefore difficult to monitor with non-biochemical methods in the short term. It is however possible after just 24-48 hours to see biochemical changes in the metabolites in the blood as a kind of 'footprint' of the two processes that maintain bone tissue appropriate to the loading being experienced. Both processes, resorption and formation, leave these metabolites in blood and urine, in quantities that reflect in general terms how much one or other process has been active. Bone tissue 'fitness' can be expressed in terms of how well it responds to changing loading patterns, and thus maintains or even increases the bone mineral content, and not least maintains the crucial internal structural arrangement.

Our bed-rest study has shown that bone mineral content was significantly better maintained in the group that exercised compared with those who did not. The loading of the large leg muscles even with short bursts of strenuous exercise has a direct conservational effect on bone structure and composition, despite the test subjects being in a near-horizontal position for months on end. This is probably the first well-controlled confirmation for humans of earlier similar findings with animals. The clinical significance of this finding, therefore, is that physical exercise per se is a crucial health-preserving factor for patients faced with long-term stays in bed.

Space experience shows that for some reason the resorption process dominates in weightlessness, leading to a so-called 'negative calcium balance'. There is an accelerated loss of calcium bound into the bone, even when compared to osteoporosis patients. It is assumed that the total absence of gravitational pull on the body when in orbit is the main reason. Hence when people remain horizontal for a longer time on Earth, a similar, although probably less pronounced effect should be observed - gravity is not nullified, but its direction is changed by 90 degrees. The bed-rest study data confirm that assumption.

Regardless of whether or not they exercised, all three groups showed a loss of roughly 0.5% of bone mineral content from the lower leg after 30 days in bed. After 90 days, however, the non-exercising control group had lost 5% on average, whilst the exercising group had lost only around 2%. In addition, a rather large variation between individuals was observed, partly ascribed to genetic factors.

The bone-loss data from the calf bone (tibia) are supported by similar data from the thigh bone (femur), but with less loss in the femur than in the tibia. This corresponds well with the muscle data. What is also very interesting is that exercise had a more constant positive effect than medication, which is probably



Changes in bone mineral content in the lower leg during 90 days of bed rest, as assessed with pQCT. The reduction is clearly smaller both in the exercise group and in the Pamidronate-treated group compared with the control group

due to the slowly diminishing effect of the pre-injected drug over time. Another very important point is that the apparent kinetics and effects of the Pamidronate medication have now been mapped in a bed-rest situation – something that can probably be directly transferred for future bone tissue stabilisation measures for long-term space crews. The clinical applications of this finding are no less important, as such long-term studies on humans with a year-long follow up period have never been performed before.

Does Medication Help?

During the first 30 days of bed rest, the medication, administered once at the start of the study, actually increased the bone's mineral content by some 0.5-1%. This can be attributed to two apparent causes. The first is that it effectively halts the bone resorption process, and as resorption and formation normally more or less cancel each other out the net result is an increase. At the same time, we can conclude that, despite the intense resistance training, which has been primarily designed to maintain muscle mass, over the first 30 days this does not manifest itself in terms of a distinction between the exercising and non-exercising volunteers in terms of changes in BMC, but for the remainder of the study the slope of the loss-curve is significantly smaller for the exercising group than for the other two. Thus although the exercise is primarily designed to maintain muscle, it also has a marked positive effect on bone condition. This is an important new finding, both qualitatively and quantitatively, coming out of our bed-rest study.

Finally, without medication against bone resorption, the first 15 to 30 days of an unloading regime seems to be the time constant for a change in BMC of some 0.5-1% to take place. If this is confirmed, the effect of exercise that starts at the outset of the bed-rest period should be visible after that time, which appears likely from the accompanying illustration. Differences in bodyweight development between the exercising and the control groups are already visible some 10 days into the bed-rest period, whilst the BMC data show strong dissociations from day 30 onwards.

Do Genetics Play a Role?

A potentially important factor, the genetic profile, has not yet been addressed. The volunteers were not genetically tested prior to the study. Between the definition of the experimental programme and finalisation of the study, however, it was decided that this was a potentially interesting area of research if certain genes could be shown to be associated with high or low responses to exercise. Genetic screening is therefore being performed retroactively, but those results will only be available later.

Conclusion

The long-term bed-rest study that has been described here is unique and clearly a first from a duration and completeness point of view, a fact widely acknowledged by the considerable press coverage that it attracted. It will also be a first from the scientific results point of view in that we expect it to generate several tens of publications in the scientific literature. Similar cooperative long-duration bed-rest initiatives with NASA are already under discussion. ESA's planned long-duration bed-rest study with female volunteers in the coming year is the next logical and necessary step, thereby consolidating the Agency's leading position in this area of research.

Other Interesting Findings

- Normal walking after the bed-rest study required 40% more energy! This is an important indicator of the difficulties to be expected after long-term bed rest or a long space flight.
- The locomotion pattern was changed, being less coordinated and efficient than normal. Running was basically not feasible at all.
- Muscle fibres seemed to become shorter, and their angle of insertion into the tendon plate became smaller. The result was a reduced momentum.
- Exercise seemed to have an impact on how many naps the volunteers needed - maybe another positive effect of exercise in the bed-rest situation.
- Oxygen uptake, a measure of overall fitness, was reduced by around 30% in all groups after the bed-rest phase.

Acknowledgement

The authors would like to thank all of the scientists who participated in the study and who provided the data to support this article.

Feeling Free, Feeling 0-g!

- The Fifth ESA Parabolic Flight Campaign for Students

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Introduction

Following the great success of the Student Parabolic Flight Campaigns that it organised in 1994 and 1995, ESA decided to make them an annual event for students from the Agency's Member States. An initiative of ESA's Education Office, the campaigns give talented students a unique opportunity to experience weightlessness whilst performing their own scientific experiments, and hopefully encourage them to consider pursuing a career in space.

The fifth Student Parabolic Flight Campaign (SPFC) took place from Bordeaux-Mérignac Airport in southwest France in the first weeks of September 2002, with more than 120 students participating. Their thirty-two experiments had been selected in a Europe-wide competition and covered a wide variety of disciplines. The great enthusiasm shown by the students and the wide coverage that the campaign received in the media demonstrated the growing interest in space education and the promotional value of the campaign.

The Selection Procedure

The selection procedure for the 5th SPFC took place in three phases. In Phase-1, launched in October 2001, students were invited to apply individually. Phase-2, launched in January 2002, solicited applications from teams of four students (aged 18 to 27 years), who were asked to provide an outline of their experiment and the name of their academic professor endorsing it. Phase-3 was launched in February 2002, when the teams were requested to describe their experiments in detail, as well as the major parameters of the equipment to be used. They were also asked at that stage for information about the journalist which each team had to nominate to accompany them.

ESA and Novespace (the operator/ manager of the A300 Zero-G aircraft to be used) then assessed the experiment descriptions submitted by the student teams. Thirty-two experiments were selected for the campaign based on their originality, technical complexity and the degree of outreach that would be achieved by the team. They were divided over two weeks of parabolic flying, with 16 groups taking part each week.

Table 1. Geographical distribution of the SPFC 2002 experiments

Germany	9
The Netherlands	1
United Kingdom	3
Spain	3
Finland	1
Switzerland	2
Belgium	1
Sweden	1
France	5
Italy	3
Poland	1
Portugal	1
Denmark	1

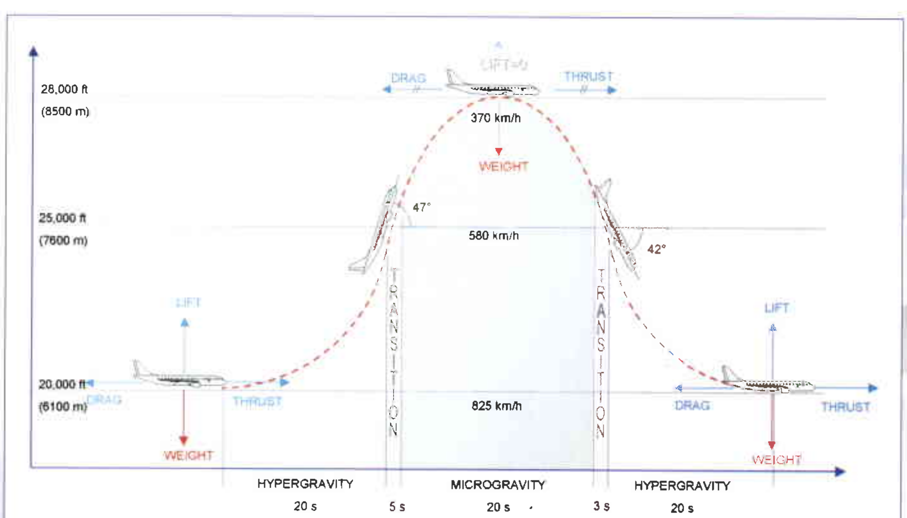
Preparing the Campaign

Since aircraft parabolic flights are officially classed as 'test flights', specific precautions must be taken to ensure that all flight operations are performed safely and that the 'passengers' are adequately prepared for the quickly repeating cycles of high and low gravity that they will experience.

Prior to the campaign, Novespace and the French Test Flight Centre (Centre d'Essais en Vol, CEV) provided support in the design of the test equipment and related safety aspects. Several months before the campaign began, experts reviewed all of the experiments to be conducted and all of the equipment to be installed aboard the aircraft, from the structural, mechanical, electrical, safety and operational points of view. Technical visits were made to the students' institutes to check on the progress/status of each experiment, to give advice where needed, and where necessary to suggest modifications or additions to each experimental set-up. A safety review was held one month before the flight campaign began to assess the overall status of each experiment.

In the week before flight, the experiments were made ready and checked out in the workshop supplied by Novespace, before being installed in the A300 aircraft. During this preparatory process, the students in the different teams had ample opportunity to exchange ideas about the various experiments that they were going to conduct.

Before the first flight, the Airbus aircraft also received a full safety check to verify that all of the equipment that had been installed complied with the appropriate safety standards. All of the students whom ESA selects to participate in its parabolic flights have to pass a special medical examination tailored for such flights. All such certifications are checked prior to the first flight of the campaign. For experiments to be conducted on human test subjects, the ESA Medical Board reviews the medical protocols to ensure that the proposed research will be conducted in accordance with the ethical rules and the safety rules applicable for space flights.



The mechanics of the parabolic-flight procedure

The Flight Weeks

Since the 32 experiments were divided over two weeks of flying with two flights each week, each experiment was flown twice, with two students working on the experiment on each flight. During a pre-flight safety briefing, the procedures for a parabolic flight, the emergency procedures, and all of the experiments to be conducted were explained by CEV personnel to all of those taking part - students, journalists and ESA staff.

During the flights, specialised CEV personnel supervised and supported the experiment operations. In addition, there was a flight surgeon on board to monitor the medical aspects of the in-flight operations and to assist any students suffering from motion sickness due to the rapid gravitational changes. In an attempt to counteract this problem, a 'familiarisation flight' has been introduced during which the students are given a short five-parabola flight whilst staying in their seats with their seatbelts loosely fastened. The most sensitive students are then recommended to fly during the second rather than the first parabolic-flight day. Whereas previously some 30% of the students would be sick, since the introduction of the familiarisation flight this number has fallen to less than 10%. Anti-motion-sickness medication is also made available to the students before their flights.

A standard flight lasted about three hours, allowing 31 parabolas to be flown. The outcome of each flight was reviewed in a formal debriefing during which the aircrew gave their assessment of the flight and the student teams reported on their experiments.

Outreach

Each student team had to provide outreach material (web page, presentation, media) concerning their experiment. In addition, approximately 20 journalists participated in the campaign, representing television, radio, newspapers and scientific magazines. Hence the students' experiments are not only often fundamentally new and exciting, but can also become front-page news!

Table 2. Affiliations of participating journalists

Kupla Media	Finland
Polish Television	Poland
BBC Tomorrow's World	UK
Terra-Lycos Networks	Spain
Welt der Wunder	Germany
Libération	France
Portugal National TV	Portugal
Le MatinE - 24 Heures	Switzerland
VRT	Belgium
The Irish Democrat/ The Independent	Ireland
Süddeutsche Zeitung	Germany
Journal l'Alsace	France
Natuur & Techniek/Ingenieur	The Netherlands
Raumfahrt Concret	Germany
Star Observer	Germany

Conclusion

The 5th ESA Student Parabolic Flight Campaign was a great success, with the participating students experiencing the thrill of weightlessness for the first time. It also gave them the chance to work and exchange ideas with their contemporaries from other European countries, resulting in the creation of a network of contacts and plans for a 'Parabolic Flight Participants Club'.

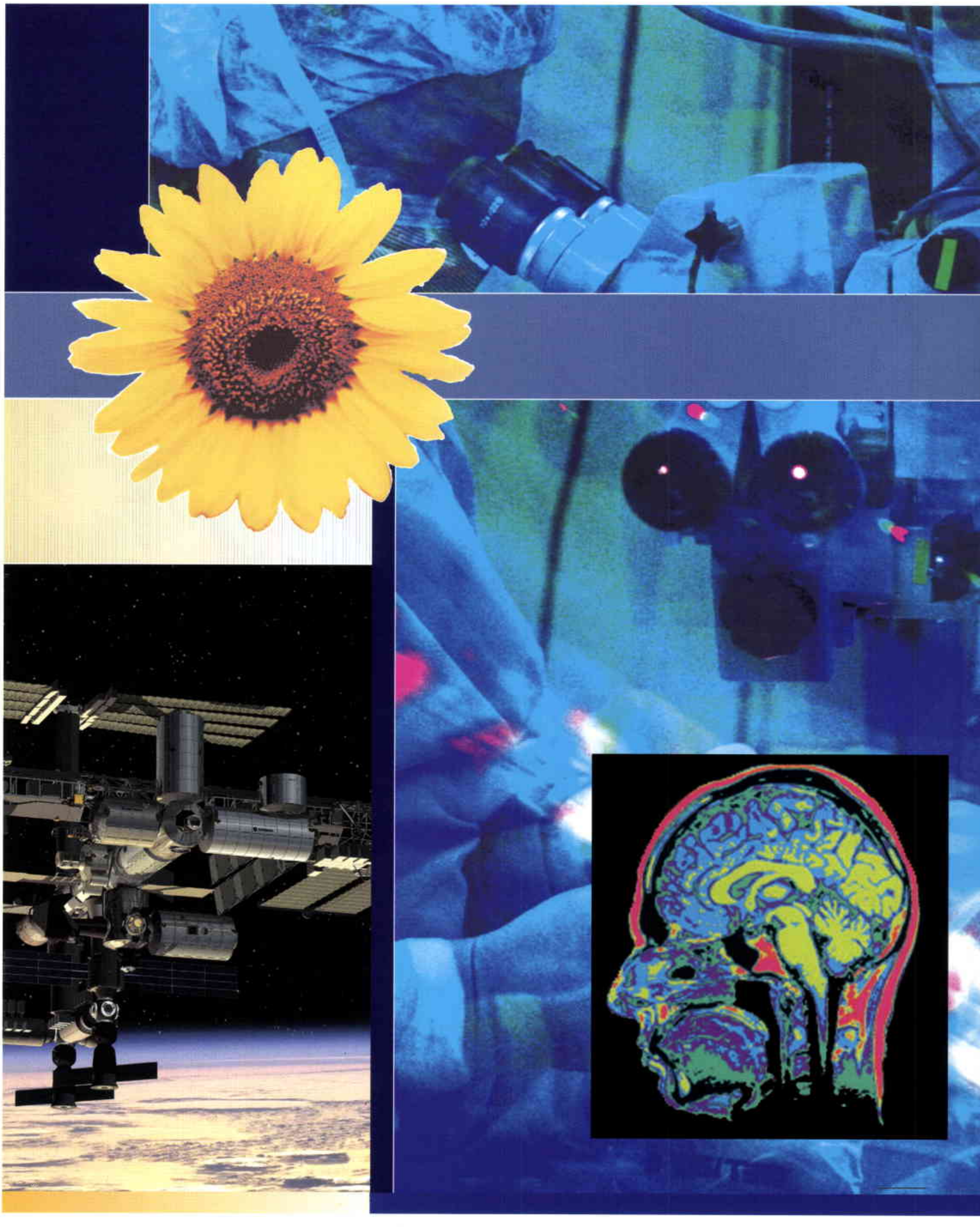
At the end of the Campaign, all of the students received a special certificate attesting to their participation. For the two best student experiments, there will be the opportunity to participate in ESA's Professional Parabolic Flight Campaign in March/April 2003. In addition, the ESA Education Office, in co-operation with the ESA's Directorate of Human Spaceflight and Microgravity (D/MSM), is offering microgravity-related student experiments a chance to fly on the Russian Foton recoverable capsule. In the future, selected student experiments will also be eligible for flight on the International Space Station.

By learning from each other's experiments and through their unique personal experience of weightlessness, the students who participated in this Campaign have become ambassadors for microgravity research and its applications, with a strong interest in space. These young people will be a part of the next generation to make use of future microgravity research opportunities and to implement many of today's far-reaching plans in space.

Further information can be found at: www.estec.esa.nl/outreach or www.esa.int/education

Acknowledgements

The author would like to thank the following people who made this 5th Student Parabolic Flight Campaign such a success: ESA staff members Vladimir Pletser, Anneke van der Geest, Anne-Marie Rémondin and Michel van Baal, the Novespace team, and all of her ESA Education Office colleagues for their support throughout the Campaign.



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From Technology Transfer To Start-up Creation

– The European Space Incubator Network

The ESA Technology Transfer Programme (TTP) has grown since its inception in 1990 into an efficient machine creating many spin-off success stories. The Programme now has a well-established team, a sound methodology, access to networks like SPACELINK, the European technology brokers' network, access to funding, a close relationship with the European Commission (DG Research) and strong political support throughout Europe. Today, more than 150 space technology transfers have been successfully achieved to such non-space sectors as medicine, textiles, automobiles, the oil & gas industry, etc. These transfers represent a turnover in excess of 150 MEuro for the donor and receiver companies, and a projected estimated turnover of about 1 BEuro by 2005.

The trend towards the creation of start-up companies from the ESA/TTP spin-off process began some four years ago. Already, about 20 such new companies have been created successfully in Europe thanks to the 'virtual' business incubation process provided by the TTP.

A famous example is provided by Anson Medical, founded by Tony Anson, a researcher at Brunel University's Institute for Bioengineering in the United Kingdom. Tony was investigating applications for a novel smart material called a Shape Memory Alloy (SMA). SMAs had been considered for use in space for various micro-actuation applications, such as the controls in bio-experiments, deployment of micro-solar arrays and antennas, etc. Tony was also investigating the use of these materials for medical and industrial markets. The UK SPACELINK representative, JRA Technology Ltd., encouraged Tony to promote his concepts through the ESA TTP and such was the interest in potential medical devices incorporating these materials that he decided to leave the University and set up a spin-off company, Anson Medical Ltd. Anson Medical was provided with support and assistance by the ESA TTP and JRA, who in the early stages identified prospective partners and licensee organisations, and helped the company to secure public R&D funding, including both EUREKA and CRAFT grants from the European Union. In 2001, Anson Medical was acquired by the UK-quoted company Lombard Medical plc for in excess of 40 MEuro. The company is continuing the development of SMA medical devices, with several nearing the completion of early medical trials.

More examples of successful spin-offs from ESA's Technology Transfer Programme are given in the accompanying panels.

There is now beginning to be a real awareness of the possibilities for exploiting space technologies and systems in the non-space sector thanks to the:

- space Technology Transfer portfolio of over 450 space technologies that are available for transfer and licensing
- applications of existing space systems in such domains as global navigation (GNSS), Earth observation, and satellite communications
- EC-ESA common strategy for space, signed in November 2000, aimed at developing more market-oriented programmes, such as the Galileo and GMES.

As a consequence, greater opportunities are being given to entrepreneurs to innovate and create their own companies dealing in space-related products and services, where 'Space for Business' can be the new maxim.

New opportunities are nice, but it is a tough challenge to progress from an initial idea to actually developing a start-up company and convincing investors to put their money into space-technology-related products and services. Space has historically been considered as 'a business for large players' and a 'niche market', with 'long times-to-market' and often with fierce terrestrial competition, the telecommunications sector being a good example. Consequently, seed capital is hard to come by.

Therefore, to progress beyond the TTP support and the virtual incubation process, ESA and the EC are supporting the creation of physical business incubation centres, within an organised network (ESINET), aimed at boosting entrepreneurship in Europe and in Canada. These 'incubators' are providing entrepreneurs, innovative start-ups, Technology Transfer spin-offs and spin-ins, and early-stage new businesses, with operational services and know-how to get space-technology-related projects off the ground and help them to develop into viable businesses.

Dynamic Material Devices (DMD) Ltd.

DMD was established by Tony Anson, shortly after he set up Anson Medical, to investigate industrial applications of SMA. Since his partial retirement from Anson Medical Ltd in 2001, he has been devoting his efforts to the expansion of DMD. Early-stage venture finance is currently being sought for the company to fund the development of various products, including one potential breakthrough product in the computer-memory field. The ESA TTP and JRA have provided support to DMD to aid its expansion and JRA has acquired a share-holding in the company. Many of the expressions of interest in the SMA technology identified during the early stages of Anson Medical's development through the ESA TTP were from industrial companies, and DMD intends capitalising on these.

REM Ltd.

Like Anson Medical and DMD, REM Ltd. was founded by a researcher working in Brunel University's Physics Department. Dr. Andrew Holmes-Siedle has worked in the area of Radiation Field-Effect Transistors (RADFETs) for a number of years, and he set up REM to commercialise various RADFET-based sensor devices that he had invented. The company has already proved reasonably successful and further expansion and development of its product range are planned. REM has received considerable support from SPACELINK over the years, including numerous introductions to potential end-users and licensees for the technology. JRA has also generated considerable media interest in this technology, with numerous articles on the technology appearing in the press. The technology also featured in a short film produced in the United Kingdom.

Radiation Systems Ltd.

Radiation Systems Ltd. was established by Dr. ?? Ramsden, a researcher in the Astronomy Group at Southampton University. He has been involved in the development of detectors and imaging systems for gamma-ray astronomy for many years, and has pioneered the development of instrument techniques for this area of high-energy astrophysics. Radiation Systems was set up to commercialise a patented high-resolution gamma-ray spectroscopic detector invented by Dr Ramsden and colleagues in his research group. The technology has significant potential for application in cancer diagnosis, particularly in the detection of breast cancer and also the resulting spread of cancer cells throughout the lymphatic system. Radiation Systems is being supported by the ESA TTP and JRA. JRA provided guidance on the protection and exploitation of its intellectual property, and also on the proposed evolution of the company. Co-funding for a market research/feasibility study has recently been made available by ESA.

Telelogic-QSS UK Ltd.

Dr. Richard Stevens founded a company to commercialise a requirements-management software tool based on concepts he had originally developed while working at ESA/ESRIN in Frascati, Italy. The company, called QSS Ltd., devised a software package called 'DOORS', which was based around the core software technology developed at ESRIN. QSS experienced considerable growth and expansion in the 1990s, with the company successfully entering the US market during this period. The growth of QSS has been such that its DOORS software package is now widely considered to be the de facto standard in requirements management. QSS was acquired by the Swedish company Telelogic in 2000 for in excess of 120 MEuro.

JRA has been a significant user and promoter of the DOORS software tool. In 2000 the two companies entered into a strategic alliance to jointly market the software package to public and private organisations operating in the aerospace sector. Several JRA personnel are fully trained DOORS implementers, and JRA has introduced the tool into the UK Ministry of Defence's validation and verification process for the EuroFighter project.

MRPB Ltd.

This company grew out of the efforts of the Microwave Radiation and Biological Processes research group of scientists and engineers who began working together in the 1990s. The aims of the Group are to explore and seek to characterise the relationship between microwave radiation and biological processes

ESINET

Launched in Brussels in July 2002, ESINET is the European network of space-related incubators able to link existing national and regional incubators in the ESA Member States, in the EU Countries, and in the EU Candidate Member States. ESINET consists so far of 25 Incubators in 14 countries, making it the first network of its kind to link space-related business and technology centres throughout Europe.

The ESINET objectives are to:

- *promote the creation of new enterprises:* ESINET will allow the exchange of best practices and experiences with other incubators, especially when the transfer of space technologies and the use of space systems are involved
- *facilitate technology transfer between the space and ground sectors:* ESINET will be used to facilitate the extraction of space technologies from ESA and other European space organisations
- *help start-up enterprises gain access to finance, advise them on Intellectual Property Rights (IPR), networking, marketing and legal matters, and provide consulting services:* ESINET will provide powerful consulting resources in order to help entrepreneurs build competitive businesses
- *establish strategic trans-national partnerships and networks:* ESINET will provide start-up transnational partnership opportunities for participating, for instance, in EU and ESA proposals
- *build gateways for international markets:* ESINET will provide start-ups with the commercial introductions/partnerships needed to expand their activities further in Europe
- *form a critical mass to achieve visibility with major venture capitalists and European institutions:* ESINET will make the space incubators and start-up companies visible at a European level to investors or associations of investors. It will also improve the dialogue between entrepreneurs, ESA and the EC.

A new and important member of ESINET is the European Space Incubator (ESI) inaugurated in December 2002 and hosted by ESA/ESTEC in Noordwijk (NL). It will be established with a seed capital fund of 25 MEuro, and will be at the disposal of all ESINET entrepreneurs.

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and, based upon an enhanced understanding of that relationship, to develop diagnostic, therapeutic and analytical techniques and devices.

The members of the Group are the millimetric wave group at Rutherford Appleton Laboratories and Astrium plc, who have produced many devices for space applications (mainly Earth observation), and also the University of Wales College of Medicine and the Cardiff and Vale National Health Service Trust.

In 2000, the Group received 15 kEuro in support from the ESA TTP towards a programme and business planning exercise, and in September that year was successful in attracting investment from the Cardiff Partnership Fund towards the establishment of a spin-off company (MRBP Research Ltd.) in recognition of the commercial potential of the work. The bulk of the experimental work to date has been undertaken at the Rutherford Appleton Laboratory, making use of the very sophisticated on-site facilities and equipment available there. In 2001, the ESA TTP contributed 50 kEuro to support the transition of key research staff from the academic to a commercial environment.

The company is currently working to increase its Intellectual Property base and is looking for second-stage funding.

AK Rainbow Ltd.

Prof. Anthony Campbell became one of the first beneficiaries of the ESA TTP when he acquired one of the earliest photon-counting devices incorporating the novel ESTEC matrixing software (which constituted the first ESA TTP transfer success in the form of a licence granted to Photek Ltd. in the UK, facilitated by JRA Technology).

Professor Campbell has used the device to further his research into the use of bioluminescence techniques for biomedical research. More specifically, he is researching into living-cell signalling mechanisms, as well as developing a range of novel bio-luminescent assays using proteins extracted from fireflies and glow-worms.

Recently, Prof. Campbell has formed AK Rainbow Ltd. as a potential vehicle to exploit his patented discoveries. JRA Technology is advising the company on set-up and intellectual-property exploitation issues.

TEVE

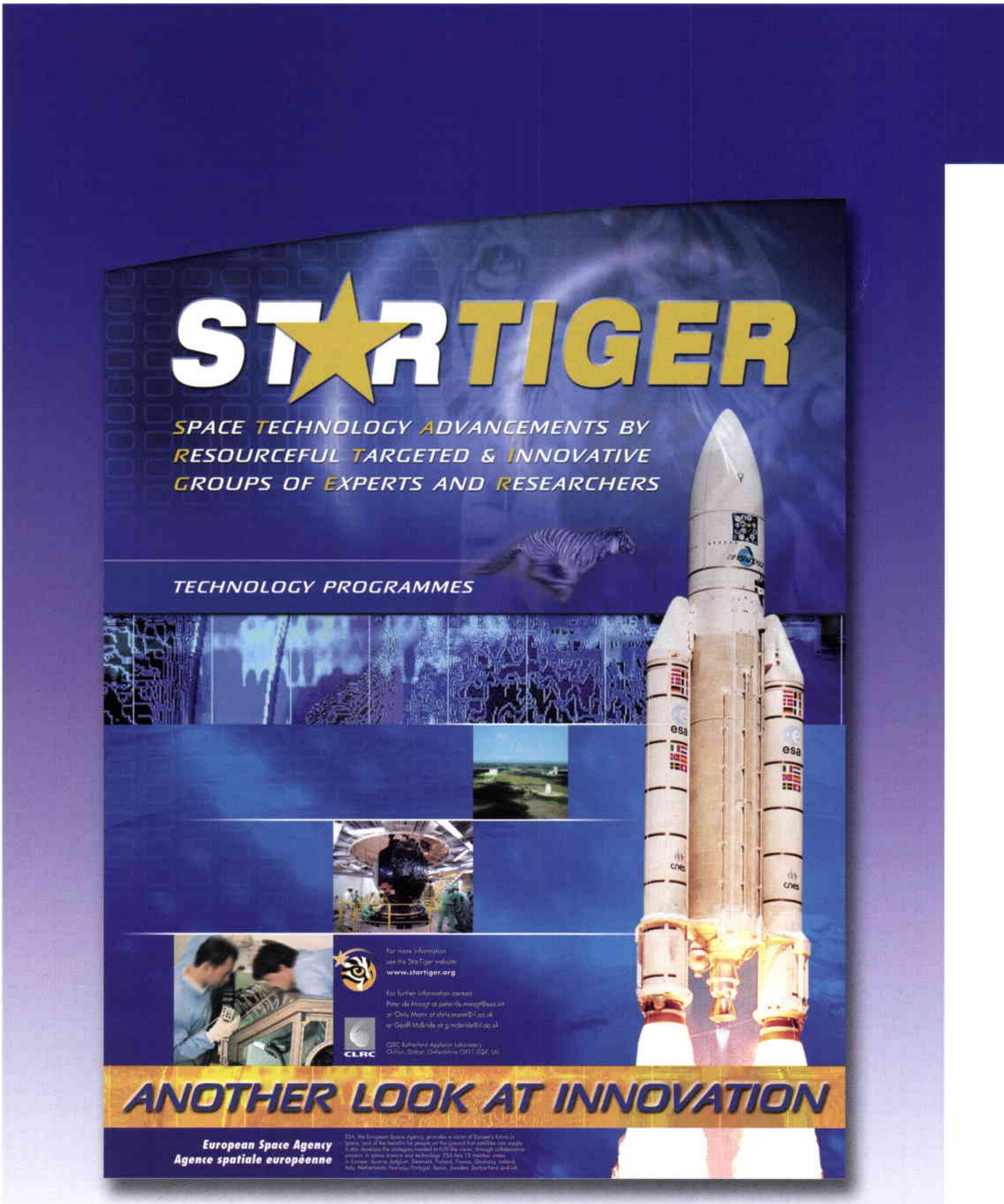
TEVE is a start-up company founded by Mr Roberto Zannini, which is active in slope consolidation. The company co-operates with major Italian companies working in the same field. He has developed and patented the prototype of a cage able to perform deep drilling on rocky walls. The company is further developing the concept within the framework of a co-operative project with Space Application Services in Belgium, and the department of Mechanical Engineering of the University of Genoa (Italy), both of which are already involved in space tele-operation and robotics applications.

Iris-Tech

Iris-Tech is a spin-off company of Iris SpA providing personalised solutions for the use of network technologies. The structure of the company and its highly qualified staff are tailored to the rapid development of the 'made-to-measure' applications demanded by today's technologically sophisticated market. Iris-Tech is specialized in the development of complex applications through the web, interfacing them with the most common databases used as management tools, and in the recovery of data to be exported on the Internet. The company is currently involved in the development and validation of vision technologies for completely automated quality management in textile companies, based on the parent company's unique experience in applying space-borne vision technologies.

Systela Sas

Systela is a start-up company founded in November 1999 by André Carrion and Eric Harle for developing and assembling an electric motor and battery kit for bicycles. This kit can be installed on almost every kind of bike in a matter of seconds. The enabling technologies have been developed within European space programmes. Systela's policy is to exploit mass-production opportunities to reduce manufacturing costs, thereby increasing the market for its products.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StarTiger

- A Fresh Look at Innovation

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Poul Nielsen
EJR – Quartz, ESRIN, Frascati, Italy

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Rutherford Appleton Laboratory (RAL), Abingdon, United Kingdom

As exciting as it was challenging, the StarTiger project had a twofold objective: to develop a new and promising technology, and to conduct leading-edge R&D in a novel and innovative manner. It has proved to be very successful on both counts, illustrating ESA's innovation policy as well as reflecting its overall policy of striving to serve European citizens.

Introduction

Bring together a small group of highly motivated researchers, grant them full access to laboratory and production facilities, remove all administrative distractions, and let them work intensively four to six months. That's what 'StarTiger' was all about! It is a new approach to conducting R&D that aims to demonstrate the feasibility of a new and promising technology within a very short time scale. In line with the recent initiative within the Agency's Basic Technology Research Programme (TRP) to facilitate innovative and breakthrough research, StarTiger has also provided a fresh look at innovation, specifically addressing the way in which space-related R&D is conducted and implemented.

The StarTiger concept - Space Technology Advancements by Resourceful, Targeted and Innovative Groups of Experts and Researchers - can be applied to all innovative technological research. The field of antennas was chosen for the pilot project and the goal was to develop a compact submillimetre-wave imager using state-of-the-art micro-electromechanical technology. Such an imager would overcome a number of barriers currently limiting progress both in space-application fields and in terrestrial systems.

The pilot project started at CCLRC Rutherford Appleton Laboratory (RAL) in June 2002 and was scheduled to last for four months. RAL was chosen as the most suitable location because of its advanced laboratories and technical support facilities. The team would be granted full access to the resources of the Central Microstructure Facility and the Millimetre-Wave Technology Group, and would be supported by the laboratories' engineers and scientists. This would ensure that emerging ideas could immediately be applied and confronted with reality.

A team of eleven scientists from seven European countries were handpicked in April 2002 for their expertise and their ability to work together, to push present state-of-the-art technology to its limit. Highly motivated, they also possessed as a team all of the know-how needed to make the project a success within the tight schedule. The project was officially inaugurated on 24 June by Lord Sainsbury, the UK Minister for Science and Innovation.

The Birth of a New R&D Concept

The concept for StarTiger was born out of research into photonic band-gap technology led by ESA's European Space Research and Technology Centre (ESTEC) in Noordwijk (NL) in the late 1990s. By the end of the decade, this had resulted in the development of one of the first photonic-bandgap antennas able to operate at sub-millimetre wavelengths. At the same time, several other researchers were working at ESTEC on similar topics and the potential synergy did not go unnoticed.

'We noted that the total result would be larger than the sum of the individual parts. This eventually led to the idea of providing a more solid framework for collaboration,' says ESA's Peter De Maagt, one of the originators of the StarTiger idea.

Elsewhere, a suitable programmatic framework for the project was falling into place. The first version of the ESA Technology Master Plan had been issued in 2000 and among the directives set was one to allocate 50% of the Technology Research Programme (TRP) budget to 'innovative/prospective technologies'. To serve this innovation policy properly, a whole new set of approaches was being proposed and implemented. Not only compliant on the technology side – because it was to demonstrate a unique and highly promising technology – the StarTiger project was also appropriate because of what it offered in terms of a potential new way of performing technology R&D. The project was therefore presented at the Space Technology Innovation Workshop held on 6-7 September 2001 in Copenhagen, Denmark. The following month ESA's Industry Policy Committee (IPC) approved the pilot project and the hunt for the best scientists and engineers to work on it began.

An advertisement was published in the 21 March 2002 issue of the science magazine 'Nature', as well as on its web site. On 2 April, an article announcing the project and the recruitment campaign was published on the ESA web portal and an extensive e-mail campaign was begun. With the tight deadline imposed by the planned project start in June, an unconventional approach to candidate selection was required: from 30 eligible applicants, 16 scientists and engineers were invited to an assessment weekend, on the 27 and 28 April, at a hotel near the planned 'home' for the StarTiger team.

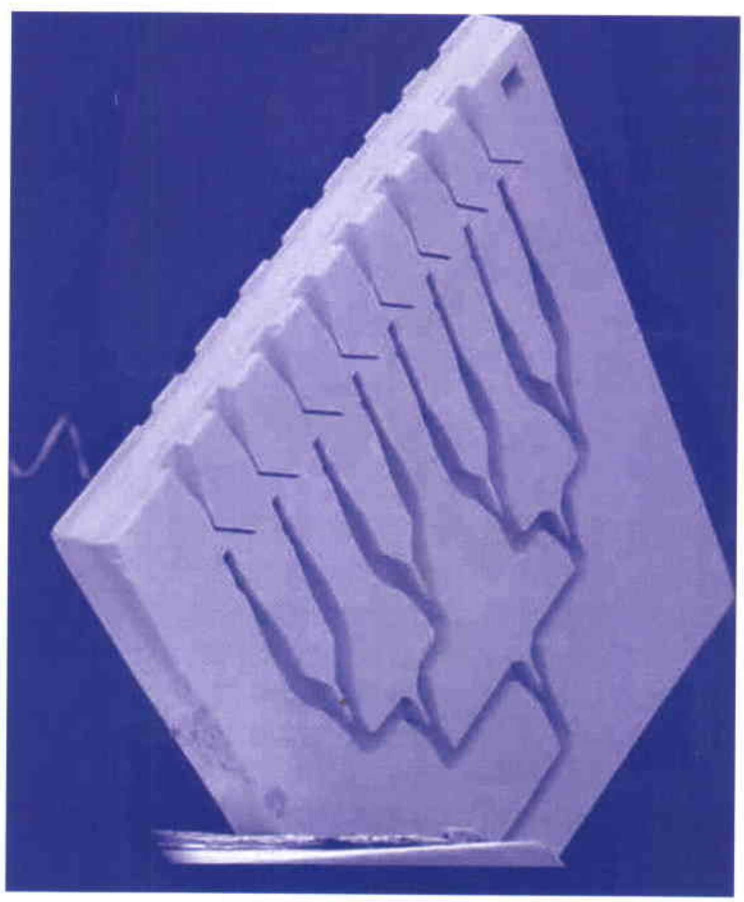
In addition to the interviews and several selection tests – including personality, mental and physical awareness, as well as technical skills testing – it was important during this weekend to familiarize everyone with the engineering tasks ahead and the special working demands of StarTiger. Everyone had to be able to concentrate 100% on the project for four months and to 'forget', as far as humanly possible, all other commitments. The multi-disciplinary research team finally selected consisted of 11 scientists and technical specialists from seven European countries – France, Germany, Ireland, Italy, Netherlands, Spain and the United Kingdom.

'As the StarTiger team attempted to combine technologies still in their infancy, it was clear that they needed to overcome some daunting tasks along the way,' says Chris Mann, RAL Team Leader. 'The members were handpicked for their expertise and their ability to work together, so we had the best chance of pushing the present state-of-the-art technology to its limit.'

The R&D 'race' began on 5 June 2002 with the goal to achieving a terahertz image of a human hand within four months.

The Imager

Although many options existed for a pilot project, the terahertz imager was chosen primarily because such a technology simply did not exist but was highly desirable. Development of the StarTiger 'colour' sub-millimetre-wave imager has integrated such innovative technological areas as planar antenna technology, planar detector technology, micro-machining technology, photonic band-gap materials and miniaturised back-end electronics.



The micro-machined dual-frequency feed-horn array

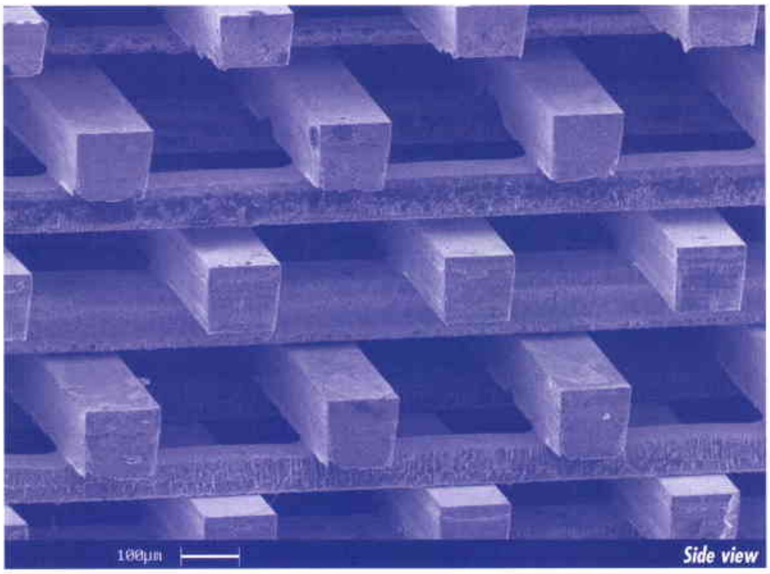
Previous attempts at making an imager for the terahertz frequency range have primarily been based on waveguide-based technology and assembled from discrete elements, making them bulky. Cost also restricts the maximum number of pixels available with this approach. Recent advances in lithography and micro-machining offered the potential for making a much larger, truly two-dimensional imaging array. Such an approach greatly simplifies manufacture and assembly and enables a much larger scientific throughput.

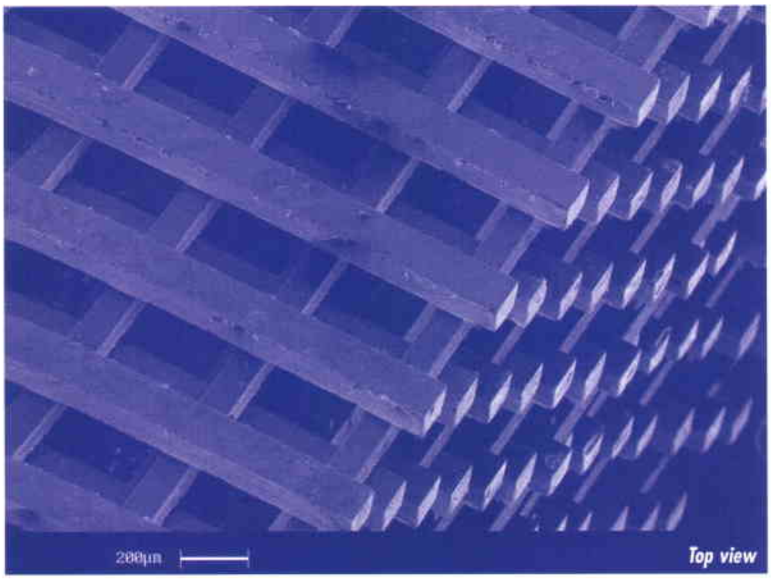
Micro-machining technology had been investigated through ESA funding. It had proved possible using Micro Electro Mechanical System (MEMS) fabrication techniques to produce micro-machined structures for the first time and at very low cost.

The photonic band-gap material is silicon-based and can be machined in very much the same way. Instead of absorbing the terahertz radiation as a semiconductor normally does, it reflects it and focuses it onto the detector elements. This is done by making short parallel grooves on both sides of a thin wafer of silicon, by a combination of lithographic processing and plasma etching. Silicon layers are then built up so that the lines form a 'wood pile' structure, with the spacing between the grooves determining the operating frequency.

Both technologies can be used together to integrate the active devices in the complete imaging front-end. The single-pixel demonstrator focuses the radiation onto oscillators, mixers, amplifiers and detectors all embedded in the silicon. A 32 x 32 pixel image is built up using moving mirrors to scan radiation from different parts of the object across the sensor.

The StarTiger terahertz image demonstrator operates at 0.25 and 0.3 THz. By responding to natural submillimetre waves at these two frequencies, it can discriminate between materials with different transmission and reflection properties, effectively creating two colours.





The silicon wafer with its micro-machined 'wood-pile' structure

Four Months in the Making

Two core matters that had to be settled before starting the activity were the question of Intellectual Property Rights (IPR) and the criteria for success. An IPR agreement was drawn up to facilitate the free exchange of ideas and technical information needed to foster an innovative and collaborative environment. The contract was also driven by the need for the fair treatment of all participants in order to ensure sound multidisciplinary teamwork.

The approach chosen was that the eleven team members would be the co-owners of any invention made during the work undertaken within the framework of StarTiger, allowing them to protect inventions by patenting or another form of IPR in accordance with applicable laws. As the host institute, RAL is entitled to a free, non-exclusive and irrevocable licence to use and copy the information resulting from the project for its own needs in the field of space research and technology and their space applications, without the right to grant sub-licences. ESA and the Member States are entitled to a free of charge, non-exclusive, irrevocable licence to use the invention for their own purposes in the field of space research and technology and their space applications and are allowed to grant sub-licences for these purposes within the territories of the Member States.

Secondly, criteria had to be defined to measure the (expected) success of the project, and to provide a clear, simple and undisputable way of assessing the outcome. If the capture of a passive terahertz image of a hand was the criterion defining technical – and consequently project – success, the team had been provided with a technical achievement scorecard range of 1-5. The conservative approach would result in the minimum success achievement of 1, whilst a fully electronically scanned system would receive a score of 5.

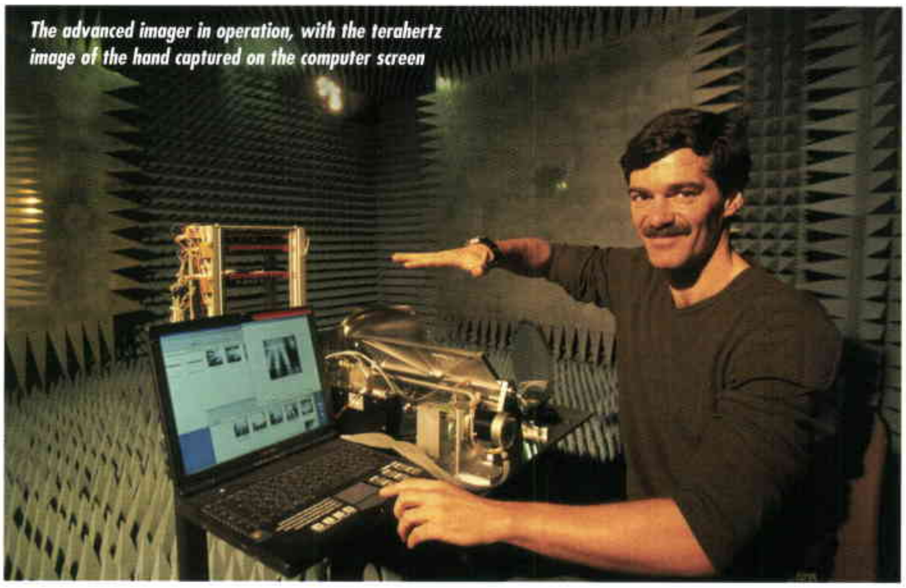
The following five items had to be progressed from a design on paper to hardware realisation:
- the micro-machined room-temperature detector
- the two-colour micro-machined wave-guide array
- the photonic band-gap mixer
- the two-dimensional array
- the electronically scanned array.

The last three items were thought to be pretty much unattainable given the time scale, but everything was now in place and StarTiger could start.

Key to the StarTiger principle was the bringing together of a team from several different backgrounds, including chemistry, material science, lithography, physics, as well as RF design. Consequently, many of them had never even heard of terahertz technology before, but it was hoped – and subsequently shown – that such a broad range of experience would provide different approaches to the problem and thus enable innovative solutions. To speed up the team-building process, they spent the first weekend surfing and cliff-climbing together, but also that weekend devised their basic strategy for the task ahead!

They decided to split their approach into two phases. Initially they would build a system relying on conventional mechanical scanning technology to enable an early demonstration and uncover any underlying problems. Whilst this system - dubbed the 'conservative approach' – was being designed and built, in parallel the team would study possible options for the final 'advanced approach'. The team also quickly identified the critical technology needed to meet the fifth level of success, namely a low-loss phase shifter. Parallel development plans were drawn up in order to succeed in this area. The team also worked in parallel on photonic band-gap electronics, bolometer arrays and novel fabrication technologies.

Among the other new technologies demonstrated was the world's first active photonic band-gap component, designed using finite-element analysis and built in just 16 days. The team also demonstrated novel room-temperature bolometers, and the key new technology needed to enable electronic scanning at sub-millimetre wavelengths, namely an electronic phase shifter. The details of some of these items have to remain confidential for the time being for patent reasons. However, the fact that five patent applications are in process is a good indicator of the degree of innovation that has taken place under the StarTiger umbrella.



The advanced imager in operation, with the terahertz image of the hand captured on the computer screen

The team worked extremely hard, achieving many successes and also overcoming many difficulties. Morale was kept high by the constant successes, but also by persevering with attempts to overcome seemingly impossible challenges. They made use of mobile telephones in more ways than one - not only were they used to communicate quickly across the site, but the latest miniature electronic components developed for the mobile industry were exploited to build some of the hardware !

The first image was captured six weeks before the end of the project using the conservative system. Not surprisingly, a great shout went up when it appeared on the computer screen. However, the greater task, namely to capture a colour terahertz image with an array of sixteen detectors, was still to be achieved in the time remaining.

After four months of intensive work, and right on schedule, the StarTiger team presented its results at ESA/ESTEC on 25 October 2002. The team had indeed successfully built an image demonstrator and had managed to capture the world's first picture at 0.25 and 0.3 terahertz of a human hand !

Alive and Kicking: The Potential Applications

The unique properties of terahertz waves can undoubtedly pave the way for numerous, as yet unforeseen space and non-space R&D applications based on their colour-imaging capability.

The use of optical-wavelength focal-plane arrays (e.g. CCDs) in imaging applications for astronomy, high-resolution still and video cameras, star trackers, etc., has become commonplace within both the defence and civilian sectors. Detection systems capable of high-resolution imaging in the millimetre and sub-millimetre wavelength region are still far less common, due to technical difficulties and perceived costs associated with the development of arrays with sufficient sensitivity. Even if much still remains to be done before a terahertz camera flies in space, the StarTiger image demonstrator has definitely broken down many of the intervening barriers.

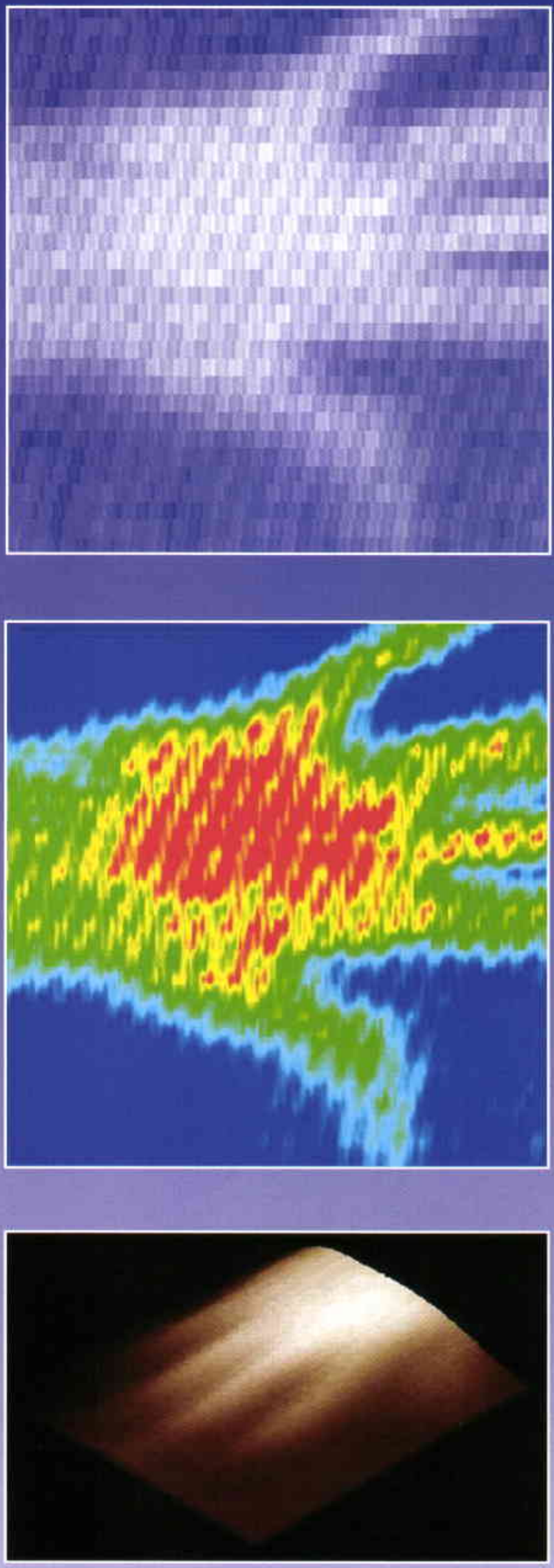
Cosmology, the science of how the Universe formed and is now evolving, has become one of the richest fields of experimental research. It has been discovered that there are very many small variations in the cosmic microwave background and that these form the fingerprints of what happened in the very early stages of the Universe. The precise shape and intensity of these temperature variations can be determined accurately by combining millimetre and sub-millimetre wave measurements.

Space astronomy observations at sub-millimetre wavelengths will also open up a virtually unexplored part of the electromagnetic spectrum that cannot be well observed from the ground. This could help answer some of the big questions as to how stars and galaxies formed in the early Universe, and how they are continuing to form.

In the area of Earth environmental monitoring too, there are several very important processes taking place in the atmosphere that deserve our attention, not least the greenhouse effect and ozone depletion. There is an ever-growing awareness of the possible detrimental effects of man's activities on climate. Sub-millimetre wave frequencies can be used to obtain important data for studies of ozone-depletion mechanisms, while millimetre-wave frequencies can focus on exchanges between the troposphere and stratosphere, providing very useful complementary information for global-change studies.

Apart its uses for space missions, a terahertz imager also has considerable potential for non-space applications. In the

Raw images of a hand



(i) The pixellation and scan lines

(ii) Introducing false-colour brings out more subtle features

(iii) Three-dimensional representation, in which the height represents intensity medical field, for example, terahertz imaging is fast being recognised as a totally new diagnostic technique. It can provide an X-ray-like image without the use of harmful radiation. Terahertz waves may also be able to investigate the uppermost layers of skin, making the early detection of skin cancers an exciting possibility. Several such non-space applications were anticipated before the start of the project, but numerous others popped up somewhat unexpectedly during the team's ongoing work.

Media-wise, StarTiger received unusually large coverage for an R&D activity. Articles were published on numerous web sites, in the specialist press, in leading scientific magazines (Science, New Scientist) and in daily newspapers (Die Zeit, Sunday Telegraph, NRC Handelsblad). This media coverage generated many requests for information about the use of terahertz waves in such non-space fields as: dental imaging, antique authentication, antipersonnel-mine detection, airport security and aircraft visibility in poor conditions. Others ideas put forward included the checking of how injuries are heeling under surgical bandages, as well as a system for the automatic detection of chemical and biological postal threats – for which the exact frequency to be used will have to be established, but the demonstrator has already shown promising results when used to see through books.

With such wide-ranging potential applications, therefore, the development of a compact terahertz imager is clearly very much in line with ESA's policy of serving Europe's citizens.

The StarTiger team together at ESTEC on 25 October 2002

The Way Ahead

The StarTiger pilot project has proved very successful, clearly validating the relevance and efficiency of the approach and achieving technical success – namely the imaging of a human hand - six weeks before the deadline. Success in terms of the five criteria established at the outset was rated as follows:

- Micro-machined room-temperature detector: 100%
- Two-colour micro-machined waveguide array: 90%
- Photonic band-gap mixer: 100%
- Two-dimensional array: technology route identified
- Electronically scanned array: key technology demonstrated.

The next step would be to develop an electronically scanned array, for which the key component – the phase shifter – has already been demonstrated. A system would need to be built around it to demonstrate that the beam can indeed be scanned electronically.

The network-building capability of StarTiger was also extremely interesting. A multi-disciplinary team of European engineers and scientists was created, the members of which have acquired substantial insight into each other's fields of expertise. As a result, the team could now confidently tackle problems in areas unrelated to terahertz imaging. Also, a network now exists whereby someone from the team either knows the answer or knows someone who does!

The media coverage generated – equivalent to more than 650 kEuros of paid advertising space – was unexpectedly high and portrayed space technology as forward-looking and dynamic. It also gave StarTiger the high profile needed to recruit good people.

From a planning point of view, with the short time-scale for development, the StarTiger approach brings the future closer to the present, which is something that should not be overlooked.

ESA is now working on continuing StarTiger through other projects. In order not to stifle the innovation dimension, they might not all follow the route traced out by the pilot project. But before deciding, all of them should be confronted with the invaluable lessons learned through this first, pioneering undertaking. The challenges to be overcome in order for StarTiger to succeed were very high and need to remain so in order to maintain excellence. To build on the unique opportunity that StarTiger has provided, it is essential to keep the pioneering spirit alive, remembering that people are at the heart of every such success, and to encourage a sense of enthusiasm.

The StarTiger story continues !

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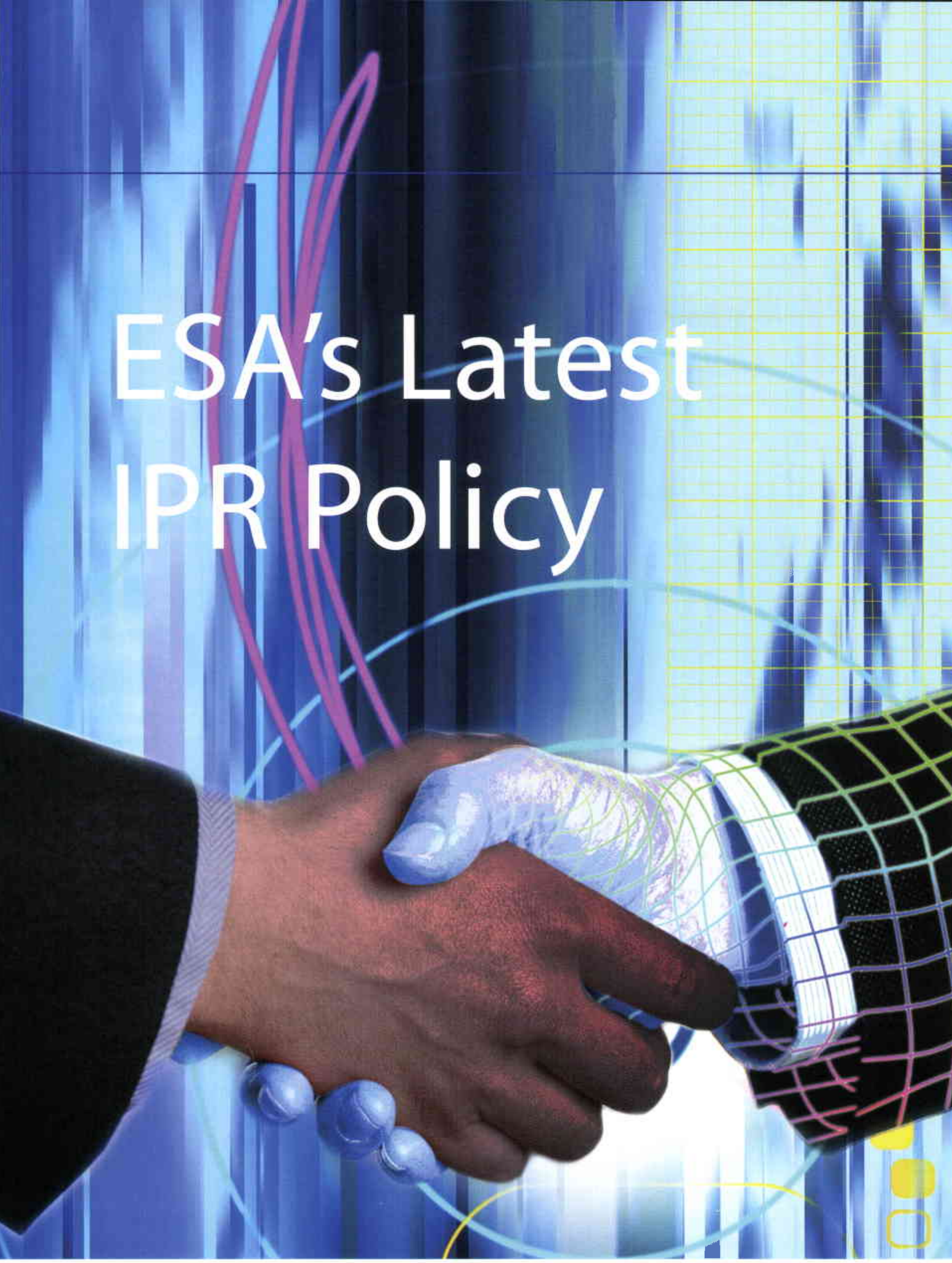


ESA's Latest IPR Policy

Anna Maria Balsano
Legal Department, ESA, Paris

ESA's former policy on Intellectual Property Rights (IPR), adopted in 1989, outlined in broad terms the general objectives of the Agency with respect to rules on information and data emanating from the work of its staff and contractors, and obtained from experiments carried out with payloads flown within the framework of the Agency's programmes. In addition, it covered issues associated with the transfer of technologies outside ESA's Member States and the protection of information.

The main emphasis was on:
- the public interest, by providing free access to ESA-funded information and data to Member States and their nationals, and
- the dissemination of scientific data.

The former rules were designed to encourage the development of industrial entities by widening the circulation of information and data. The objectives of the 1989 policy did not, however, tackle the full spectrum of intellectual property, nor

Access Rights for Fully Funded Contracts

	Information, Data and Intellectual Property resulting directly from a contract	Background Information and Data
Beneficiaries	**Access and Use**	**Access and Use**
ESA	• Free of charge for the execution of an ESA programme	• In the framework of an ESA programme, to achieve contract purpose or for reproduction rights. No dissemination without a prior agreement
Participating States	• Free of charge when participating in an ESA programme • Favourable conditions for their own public requirements	• In the framework of an ESA programme, to achieve contract purpose. No access for other purposes.
Persons and Bodies under Jurisdiction	• Free of charge when participating in an ESA programme • Market conditions for any other use	• In the framework of an ESA programme, to achieve contract purpose. No access for other purposes.
Scientific Research Institutions	• Free of charge for scientific use only	• In the framework of an ESA programme, to achieve contract purpose. No access for other purposes.

did it reflect the evolution in intellectual property rights at international level. Moreover, many of the goals of the 1989 policy were not realized, because the industrial entities were not encouraged by the free-access approach to exchange the technologies being developed.

Consequently, in May 2000 the Member States asked ESA's Executive, with the support of a group of experts nominated by the Agency's Administrative and Finance Committee (AFC), to rethink the Agency's overall policy on Information, Data and Intellectual Property.

The revision of the rules carried out in 2001 was based on the following fundamentals:
- worldwide recognition of the need to adequately protect the technology so as to enhance the competitiveness and economic and social growth of industrial entities;
- the need to accompany the allocation of public funds to R&D by proper measures to protect the results and attract additional public or private investments; and
- awareness of the increased value of space technology because space-related activities had moved from the purely scientific domain to include applications in several strategic fields.

ESA's Council adopted this new 'Resolution on the Rules concerning Information, Data and Intellectual Property' in December 2001.

Main Principles

ESA's role in the management of its Information and Data Policy, as foreseen by Article III of the Convention, is to strike the appropriate balance between the public interest and the interests of European space industry. The drivers for the new policy were therefore based on:
- the awareness that in the new environment for conducting space activities, the principles contained in the former policy
- mainly the free access to ESA-funded information and data by Member States and their nationals - were no longer appropriate;
- the wish to make ESA an attractive and reliable partner for industry without putting an additional burden on the Contractors;
- the willingness to encourage Contractors to use and exploit the technology that has been developed under ESA contract.

To achieve these objectives - and without deviating from the principle that ownership of the results should be vested with the Contractor - the new policy has identified the different types of Agency intervention in the development of new technologies and has introduced a significant modulation of rights of access to Information and Data and Use of Intellectual Property for results developed under an ESA contract.

With respect to the previous policy, which in most cases provided for free access to Information, Data and Use of Intellectual Property developed by Contractors, the proposed new policy foresees the following:

(i) For contracts fully funded by ESA, the Contractor should grant access to Information and Data and use of Intellectual Property developed under an ESA contract to:
- ESA, Participating States and their nationals under free-access conditions

Access Rights for Partially Funded Contracts

Beneficiaries	Information, Data and Intellectual Property resulting directly from a contract — Access and Use	Background Information and Data — Access and Use
ESA	• Free of charge for Agency's own requirements	Only for a given project with written agreement and non-dissemination obligation
Participating States	• Under conditions reflecting the contractor's financial participation when participating in an ESA programme • Market conditions for any other use	Favourable conditions for a given ESA project in which it is participating
Persons and Bodies under Jurisdiction	• Under conditions reflecting the contractor's financial participation when participating in an ESA programme • Market conditions for any other use	Favourable conditions for a given ESA project in which it is participating

for the Agency's own requirements (i.e. for ESA's own programmes);
- Participating States under favorable conditions for their own public requirements;
- any other third party under market conditions.

(ii) For contracts partially funded by ESA, the Contractor should grant access to Information and Data and use of Intellectual Property developed under an ESA contract to:
- ESA under free-access conditions for the Agency's own requirements;
- Participating States under conditions reflecting the Contractor's financial participation;
- any other third party under market conditions.

As far as ESA's staff are concerned, the main principles of the former policy relating to ownership, access and use remain unchanged. However, since the scope of the new policy is wider in terms of the form of IPR legal protection (targeting protection not only by patents but also by trademarks, industrial design copyright, etc.), the work of ESA's own staff also benefits from this enlargement in scope.

Finally, the main principles concerning ownership, access and use of results relating to payloads flown within the Agency's programmes remain unchanged. Nevertheless, since the rules apply to programmes that differ in nature and scope, in the kind of data produced, and in the kind of users of the said data, the new policy distinguishes three main situations:
- when a payload is financed and flown within the framework of an Agency programme or activity, it is for the Agency to define the access policy in accordance with the Council's principles;
- when a payload is financed by a provider and benefits from an Agency flight opportunity, it is again for the Agency to define the access policy in accordance with the Council's principles;
- in cases other than the two described above, the ownership, access and use of the data should be assessed having regard to the Agency's and other Parties' technical, scientific and economic interests in the flight of the payload.

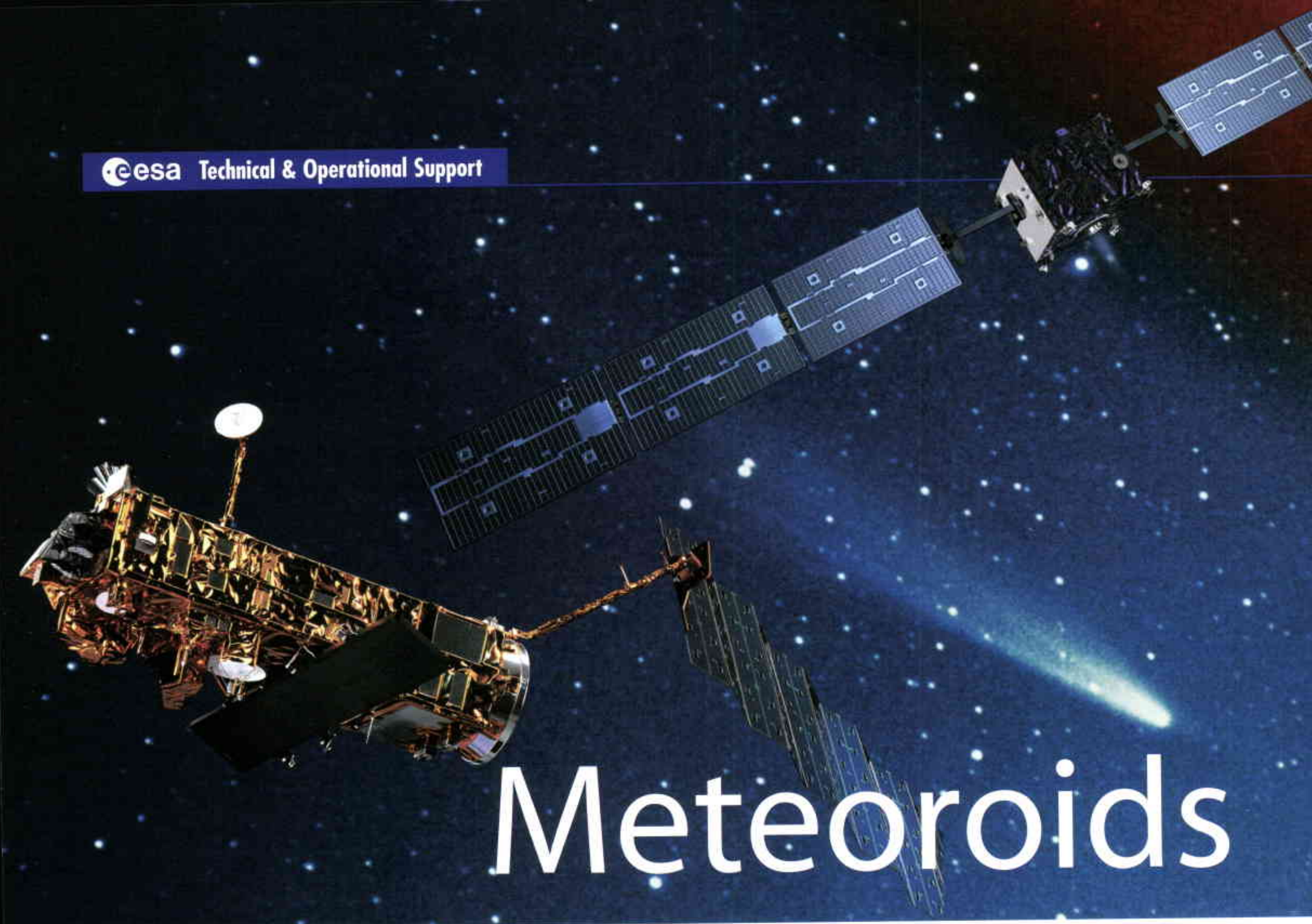
As with the former version, two distinct Chapters of the new policy are dedicated to: (a) the transfer of results outside the territories of Member States by Contractors or by ESA; (b) the protection of the information held by the Agency. The main principles applicable to the above remain unchanged.

Main Characteristics

The adoption of the new policy didn't entail amending Article III of the ESA Convention. It did, however, lead to a necessary identification of the conditions of access, use and disclosure of the R&D results with respect to the financial participation and interests of ESA, its Member States, and third parties.

As we have seen, the main changes with respect to the former policy concern Contractor-developed Intellectual Property and are designed to encourage Contractors to protect their research and technology results by Intellectual Property titles and to develop an active licensing policy in order to promote effective exploitation.

The Council Resolution requested that the Director General submit for its approval the amended provisions of the legal instruments necessary to implement these Rules. The new policy's main changes with respect to Contractor-developed Intellectual Property also require modification of the General Clauses and Conditions of ESA Contracts. This exercise is currently being carried out.



Meteoroids

– A Potential Hazard for Interplanetary and Earth-Orbiting Spacecraft

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Introduction

Meteoroids, the millimetre-sized particles that cause the spectacular streaks of light that regularly zip across the night sky, can seriously damage interplanetary as well as Earth-orbiting spacecraft. Therefore, as ESA builds up its fleet of research and applications spacecraft in orbit, it is prudent to assess the risk posed to these space missions by a potential meteoroid strike.

Interplanetary missions like Rosetta and Mars Express will encounter a meteoroid environment that is quite different from the one that we know from near-Earth space. However, observations of meteors, astronomical measurements, and detectors on earlier interplanetary spacecraft have given us much of the data needed to predict the risk of colliding with a meteoroid. The ESA Meteoroid Model contains these measurements as a database, and links these data points with a physical model of the distribution of meteoroids in the Solar System. Quantifying the risk in this manner takes us half of the way to avoiding it!

Meteoroids – Travellers in Interplanetary Space

Interplanetary space is pervaded by meteoroids more than a tenth of a millimetre across, with an average of one such particle in every 500 cubic kilometres of space at the Earth's distance from the Sun (which averages 149 597 900 km and is defined as 1 Astronomical Unit or AU).

Sporadic (non-streaming) meteoroids constitute the bulk of the particulate matter in interplanetary space. They are spread over vast regions, stretching from the close vicinity of the Sun to the Kuiper Belt and beyond. Meteoroids are being continually shed from the asteroids and comets of our Solar System as these collide with each other and as the Sun evaporates their volatile components. The most dramatic large-scale producers of meteoroids are the active comets like Halley and Hale-Bopp. Their visible dust tails consist mostly of micron- (one thousandth of a millimetre) sized grains that leave the Solar System quickly on hyperbolic trajectories. Most of the mass lost by comets and asteroids, however, goes into grains with sizes of between one tenth of a millimetre and one millimetre, which are not as visible. On the other hand, these grains are here to stay, and they orbit the Sun with enormous speeds - around 30 km/s in the case of a circular near-Earth orbit.

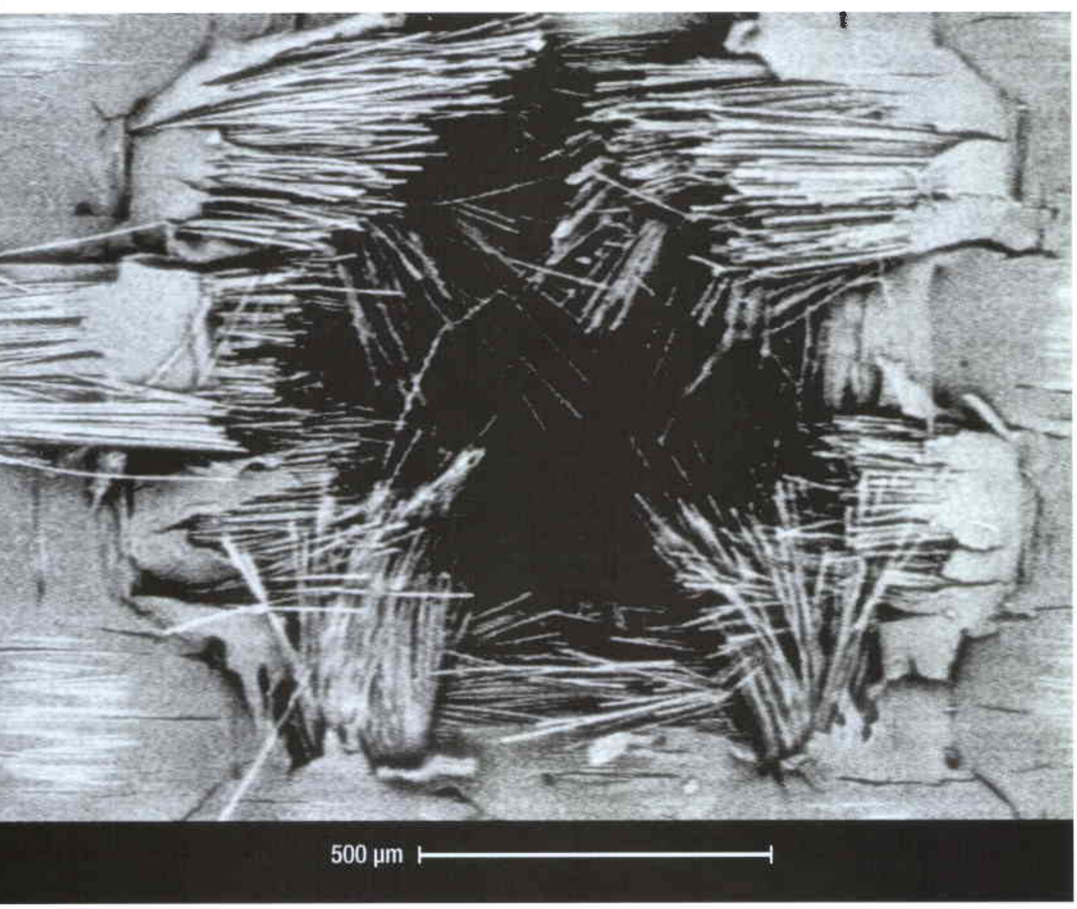
Our knowledge of the makeup of meteoroids has come mainly from the collection by high-flying aircraft of grains that have entered the Earth's atmosphere. They have a mainly stony composition, with the dominant minerals being the olivines and pyroxenes already known on Earth, but they also contain organic components. They therefore exhibit a wide range of material densities, with the average being 1 gram/cm^3. At typical encounter speeds above 30 000 km/h, a meteoroid of any density can cause considerable local damage.

Any object in space, be it a sophisticated weather satellite or an astronaut taking part in an EVA (Extra-Vehicular Activity), is exposed to the risk of a meteoroid impact. We therefore have to protect ourselves and our equipment from that risk by using shielding. But how much shielding is needed and how many meteoroids can we expect to hit our spacecraft? To answer these questions, a detailed study was performed at the Max-Planck Institute for Nuclear Physics in Heidelberg. The result is an updated version of the ESA Meteoroid Model, which provides us with reliable information on the meteoroid environment based on the latest available data and physical modelling.

The Meteoroid Hazard

How do we know that meteoroids damage spacecraft? One excellent source of proof is ESA's European Retrievable Carrier (Eureca), which was brought back to Earth by the Space Shuttle (flight STS-97) in 1993 after 10 months in low Earth orbit. From Eureca we know that meteoroid impacts cause structural damage as well as surface degradation. Serious structural damage occurs when relatively large meteoroids break essential parts of the spacecraft structure, for example struts and springs. Smaller meteoroids typically cause surface degradation by cratering the exposed surface and thus changing its optical and thermal properties.

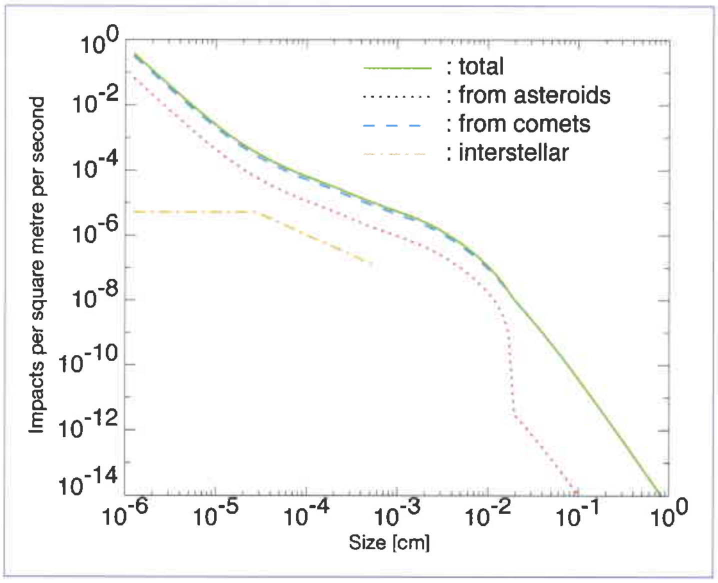
The accompanying photograph shows a piece of the betacloth blanket from Eureca that has been penetrated by a meteoroid. Betacloth is a composite material made of Teflon and fibreglass, which is normally used as a protection against meteoroid impacts. The projectile that penetrated it in this case was sufficiently fragmented by the impact that it could not penetrate much further into the spacecraft's structure. However, this example also shows that the integrity of protective layers will be degraded over time as more and more of the material is destroyed. Some recent minor damage to the X-ray detector of ESA's XMM telescope has also been linked to a possible meteoroid impact.



Hole in a betacloth blanket (Teflon-coated, woven fibreglass) from the European Retrievable Carrier (Eureca). The impact zone is highly irregular due to the structure of the material and there are signs of melting at the ends of the glass fibres

These examples demonstrate that understanding the meteoroid environment is not only important when designing spacecraft, but also for planning the operations of their scientific payloads. Optically active surfaces like the mirrors or lenses of cameras are extremely sensitive to surface degradation. They are also difficult to protect from meteoroid impacts because they need a free field of view for observation.

In addition to the direct effects of a meteoroid impact, there are also more subtle, indirect consequences. The highly energetic impact event creates a small cloud of charged particles, which can disturb electrical systems onboard the spacecraft. The failure of ESA's Olympus spacecraft on 11 August 1993 was attributed to such a disturbance. The failure of solar cells of the Hubble Space Telescope has also been linked to a discharge avalanche, which could have been started by a meteoroid impact.



Meteoroid environment of the Earth as a function of meteoroid diameter. The size distributions of meteoroids from three sources are shown: asteroids, comets, and the interstellar medium

Predicting the Risk

The ESA Meteoroid Model is a statistical model of meteoroids originating from comets and asteroids that is based on the physics of their release and distribution. It is constrained by data from ground-based observations as well as spacecraft data. It can be used to predict the rate at which meteoroids between one micrometre and a few centimetres in size can be expected to hit spacecraft travelling in the region of space between 0.1 and 10 AU from the Sun.

Since the number of such meteoroids is so enormous – there are of the order of 10^{25} particles larger than 1 micron between the orbits of Venus and Mars – a statistical description of their distribution in space and velocity can be used. However, this statistical description is only as good as the data that constrains it, most of which is from Earth-bound observations. Observations of meteors in the night sky are important because the meteoroids involved in their formation are a few millimetres in size, the same size range that can be dangerous for spacecraft. Fainter meteors, which are caused by meteoroids less than a millimetre across, can be detected by radars. In addition to the meteor observations themselves, an important source of data are astronomical observations of the heat radiated by the meteoroids in space.

As the data obtained from Earth-bound measurements do not provide the full picture of the meteoroid population, data from detectors onboard interplanetary spacecraft like Ulysses have also to be used to constrain the model predictions. However, all of the available data still covers only a relatively short period of time and a small fraction of interplanetary space. To predict the risk for future missions, therefore, we need an underpinning physical model of the distribution in our Solar System of meteoroids produced by two mechanisms: close encounters with massive planets, and so-called Poynting-Robertson drag. Close encounters with giant planets affect mainly large meteoroids, Jupiter's strong gravity field being particularly efficient in dramatically changing their orbits. Poynting-Robertson drag is a much more subtle physical phenomenon, caused by the asymmetric re-emission of sunlight by the meteoroids. Over tens of thousands of years, it makes the meteoroids spiral in towards the Sun. This means that here on Earth we can expect meteoroids originating from the asteroid belt between Mars and Jupiter, as well as from comets that circle the Sun outside the Earth's orbit.

Equipped both with the data on meteoroids in interplanetary space and the physical model of their distribution mechanisms, the ESA Meteoroid Model is well-suited to predicting the risk to any spacecraft mission venturing into the Solar System between 0.1 and 10 AU.

The Risk to ESA Missions

Whilst any space mission is at risk from meteoroids, missions on long transfer trajectories are especially vulnerable. ESA's Mars Express and Rosetta scientific missions are good examples in this respect. Both will be flying close to the ecliptic plane of the planets from the Earth outwards. While Mars Express will be exposed to meteoroids spiralling in from the asteroid belt as well as cometary grains, Rosetta will be exposed mostly to grains from comets or even more remote and exotic sources like the Kuiper Belt and the Interstellar Medium. Earth-orbiting spacecraft, on the other hand, are mainly exposed to cometary meteoroids, as can be seen in the accompanying figure.

The ESA Meteoroid Model allows us to assess the risk for Mars Express and Rosetta. Because these missions will be crossing interplanetary space, the meteoroid environment will change as they progress. The accompanying diagrams show the rate (impacts per square metre per second) of impacts on the spacecraft along the transfer trajectory of two sizes of meteoroids: relatively large ones of 1 mm diameter and much smaller ones of 1 micron. In both cases, the impacts of small meteoroids are more than one million times more frequent than those of large meteoroids.

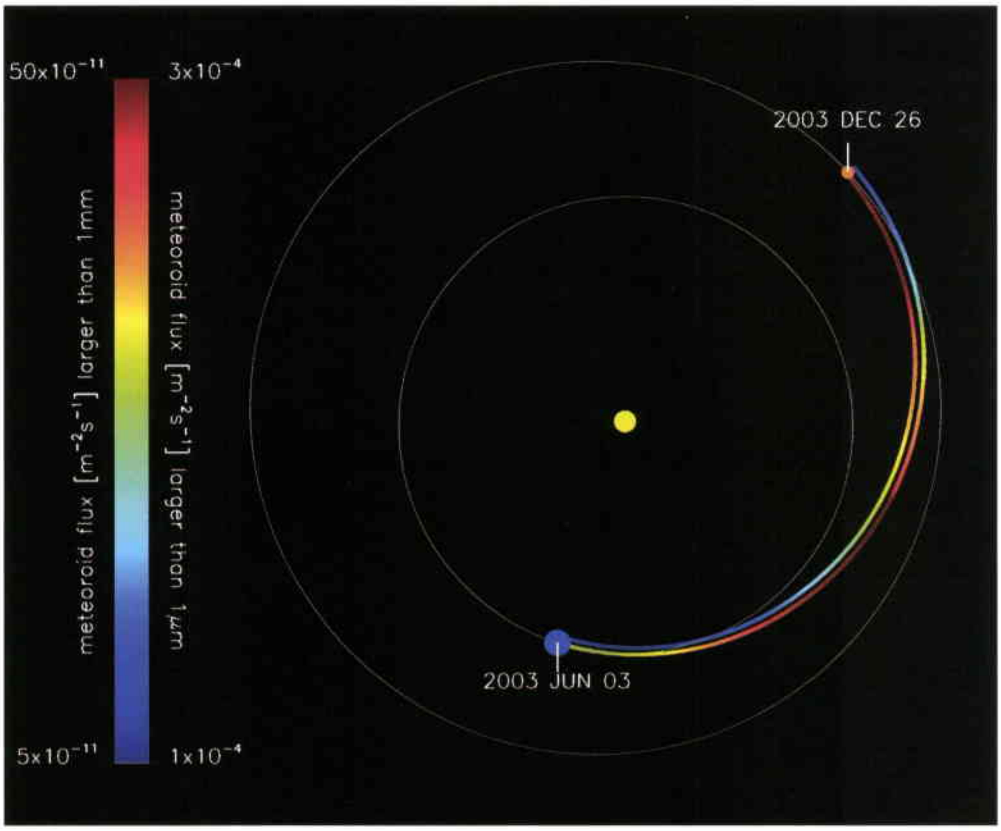
In the case of Mars Express it can be seen that, while the flux of small meteoroids decreases as the spacecraft journies further away from the Sun, the flux of large meteoroids increases. This can be explained by the large concentration of small meteoroids close to the Sun. This concentration also creates what is called the 'false sunset' or zodiacal light, which is the light reflected off small meteoroids close to the Sun that can sometimes be seen after sunset with the naked eye. These small meteoroids mainly affect the solar panels which, with their 11 m^2 surface area, will suffer 100 micron-sized-meteoroid impacts every day. This high number of impacts does not put the spacecraft at risk, however, due to the small size of the impacting particles. It is the 1 mm sized particles that can seriously damage the spacecraft, but they are so much rarer that there is only a 3% chance of such a particle hitting the 3 m^2 body of the spacecraft. There is, however, about a 10% chance that a mm-sized meteoroid will penetrate its solar panels. The flux of mm-sized particles will actually increase as the spacecraft approaches Mars, because the dynamics of large meteoroids cause them to stay close to their parent bodies - in this case the asteroids of the Main Belt, which lies just beyond the orbit of Mars.

Conclusion

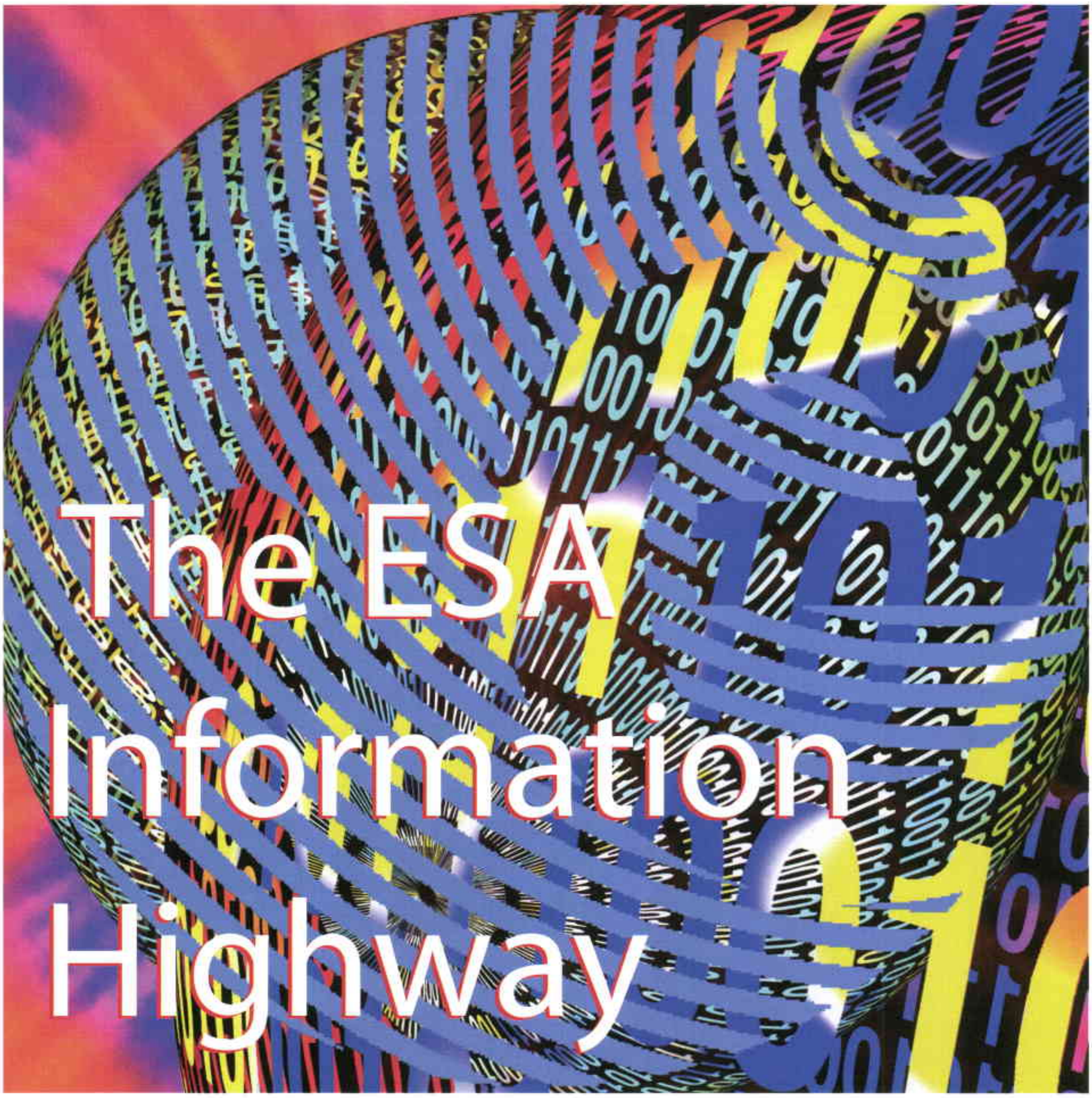
We know from hardware brought back earlier from space that the risk faced by spacecraft from meteoroids is real. The heavily pitted surfaces of Eureca and the shattered solar cells of the Hubble Space Telescope bear witnesses to the harsh meteoroid environment in Earth orbit. From measurements in interplanetary space, we know that there too one has to expect meteoroid impacts, but luckily the most prolific meteoroids are very small and the bigger ones much less abundant. Nevertheless, when designing a mission it is important to consider the meteoroid environment in which the spacecraft will actually fly and special care needs to be taken for missions that will cross the asteroid belt, where the number of millimetre-sized meteoroids is expected to be much higher.

Both Mars Express and Rosetta have just a few percent probability of being damaged by a millimetre-sized meteoroid. Future ESA missions will fly into very different meteoroid environments. The mission BepiColombo mission to Mercury, for example, can expect to encounter a very large number of small meteoroids, as these are concentrated close to the Sun. Other scientific missions like LISA and Darwin will spend a long time in interplanetary space and must therefore also be carefully analysed for meteoroid impact risk.

If we design our spacecraft properly using the environmental models available at ESA, we can fly safely in interplanetary space. Then we can enjoy the more pleasant consequences of meteoroids in the form of zodiacal light or the light shows that they bring to our skies when the Earth passes through the orbital path of a comet.



Meteoroid flux (impacts per square metre per second) on the Mars Express spacecraft from its launch on 23 June to Mars orbit insertion on 26 December 2003. The inner colour-code shows the flux of 1 mm meteoroids (left side of the colour-scale), and the outer one that of 1 micron meteoroids (right side of the colour-scale).



The ESA Information Highway

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Introduction

The evolution of ESA's corporate wide-area communications network, known as ESACOM, is driven today by two seemingly competing factors: the need to keep the IT/communications costs within reasonable bounds, and the ever-increasing user demand for network bandwidth and performance, as new network computing paradigms emerge to support the Agency's business processes. The challenge faced by ESA's Information Systems Department is therefore to respond to both of these requirements by providing a new network infrastructure that ensures minimal cost per unit of traffic exchanged, whilst still delivering the quality and performance levels required by the customers, and by integrating the different communications services to derive maximum benefit from their inherent synergies.

The fact that by nature ESA is a distributed organization with a presence in many of its 15 Member States, but with a working environment in which its business activities are not constrained by the physical locations of its resources (staff, knowledge bases, support facilities, partners), imposes the adoption of a networked enterprise organisational model, based on a powerful, flexible, state-of-the-art communications infrastructure: the ESACOM Information Highway. The new ESA corporate wide-area network therefore supports all of the Agency's corporate communications services for voice, video, and data via a single converged infrastructure.

The ESACOM Information Highway's Core Services

- **Intranet:** Interconnections between the four main ESA establishments (ESA HQ, ESTEC, ESOC and ESRIN) and sites where ESA has a permanent presence, such as the European Astronaut Centre (EAC in Cologne), the ESA ground stations (Redu and Vilspa), and several other sites where ESA has permanent offices (Brussels, Toulouse, Washington, Moscow, Star City, Kourou, Astrium-Bremen, and ATV-Les Mureaux)
- **Extranet:** project-specific network communities, i.e. the Earth Observation and Envisat PDS networks, interconnecting facilities at partner sites
- **Voice over IP:** services for international voice telephony for the main ESA establishments and Vilspa
- **Video over IP:** services for ESA-to-ESA studio-based videoconferencing for the main ESA establishments
- **Internet:** access to the Internet for all ESA staff and contractors located at the main ESA establishments
- **Remote Access:** to ESA corporate services for ESA home and travelling users worldwide.

The Road to the ESACOM Highway

The history of the earlier provision of data wide-area connectivity to ESA via an all-inclusive outsourcing contract in place since the mid-1990s, based on X.25, Decnet, and TCP-IP protocols, was well documented in ESA Bulletin No. 95 in August 1998. Early in 1998, the Information Systems Department had begun looking into the further evolution of ESACOM, as the contract with the existing service provider was entering its final phase and an open tender action was due in 2000 according to ESA's contractual rules. As a result, a nine-month study was

The current topology of the ESACOM Information Highway

conducted in 1999 to establish the basis for the future strategy for ESACOM. This study was performed by a consortium led by Vitrociset, with the participation of Cineca and Ernst & Young.

The main outcomes of that study were:
- the selection, as the preferred approach for the future of the ESACOM, of the IP (Internet Protocol) VPN (Virtual Private Network) model
- the definition of the strategic objective of integrating all of the different services, data, voice and video, on a single, IP-based wide-area network
- the proof that such an objective was technically viable, by demonstrating the envisaged technologies in a prototype environment
- the business forecast that the services' integration would also bring an economic benefit, as supported by the answers to a questionnaire that was sent to all of the major international service providers at the time.

In February 2000, an open Invitation to Tender (ITT) was issued based on a Statement of Work containing ESA's identified requirements and preferred strategic options along the lines described above. This Statement of Work foresaw a first phase with the implementation of the data services (the ESACOM Intranet, Extranet and Internet services, plus a Remote Access Service), followed by a second phase involving the integration of the voice and video communications services.

The ITT resulted in the submission to ESA of six proposals from the major telecommunications operators in Europe. After a thorough technical and financial evaluation, the contract was awarded to Equant in August 2000. The implementation and migration project (Phase-1) started in September 2000, with the objective of migrating the data connectivity of all 30 existing ESACOM sites by March 2001. The project team included representatives from ESA, Equant, Vitrociset/Terma and Serco.

In September 2001, when the new Equant-provided data service had been operating successfully for several months, the next phase of the project (Phase-2) was launched, covering the integration of voice and video services. For this phase, the industrial team was expanded to include the switching-exchange (PABX) provider, Alcatel. After careful pilot testing, the voice service went live for the main ESA sites in April 2002, while the video service is presently in the final validation phase prior to releasing the service.

Making a Strategic Choice

One of the project's key objectives was to establish a converged network to respond to the ever-increasing demand for communications capabilities and services arising from both corporate and project-specific requirements, whilst at the same time complying with the strict budgetary guidelines. The integration of all corporate telecommunications services within a single infrastructure and the consolidation of project-specific services in the same corporate service was identified as the way to achieve that, but its economic viability had to be demonstrated.

A business-case analysis was therefore conducted in two steps:
- Firstly, at the time of the ESACOM Information Highway study, the market offerings and pricings for advanced integrated services were investigated, and estimates of future cost trends for the various integration options were developed, showing the economic and technological viability of the integration approach.
- Then, through the competitive ITT and the subsequent awarding of the contract, the convergence strategy could also be defined in financial terms.

The cost objectives were identified in terms of:
- Minimisation of the unit cost for the wide-area-network capacity for data services, i.e. the guaranteed bandwidth of the connectivity, by: aligning ESACOM costs as much as possible with prevailing

Lessons Learnt

The ESACOM Information Highway implementation project was a complex undertaking involving many players and constraints. After its successful conclusion, it is possible to draw some important lessons:
- The selection of a strategic direction and the careful preparation of the ITT are essential to determine all the subsequent planning and execution phases. The IP VPN model and the services integration based on all-IP technology proved a winning choice, nowadays being implemented in the majority of new network projects. Such a strategy was not so recognised at the time it was embarked upon, and not all bidders were capable of offering it.
- The investment in the study phase and the build-up of in-house knowledge on the new technology through the study and prototyping certainly paid off and allowed the ESA staff and contractors to establish a peer-to-peer relationship with the very specialised personnel of the network provider.
- ESA's role is becoming more and more that of a service aggregator, as determined by the outsourcing policy. In this project, the most critical task was that of coordinating and focusing the various contractual parties towards the main ESA objectives of a smooth implementation of the new services within the schedule constraints. This can only be achieved when the various participants have clear responsibilities and roles, and can count on the full cooperation of their peers.
- An essential element for success was the cooperative spirit that could be established at the human level, which brought the engineers from different companies and locations together into a single team. Their motivation and commitment were fired mainly by the challenging and professionally rewarding task of implementing a new technology in a complex and demanding environment like ESA.

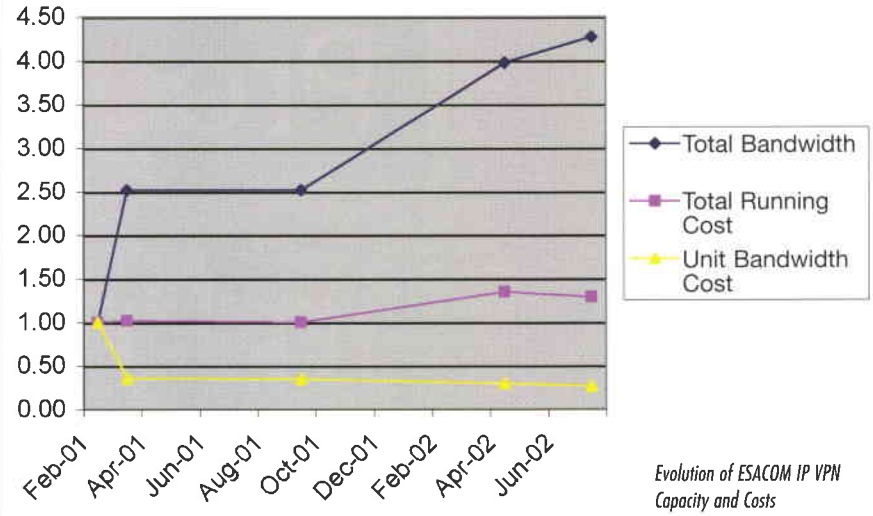
market trends, but still within a stable contractual framework according to ESA rules; and exploiting the benefits of consolidation of multiple services, thereby taking advantage of economies of scale, sharing of resources, and greater negotiating power with the service providers.
- Minimisation of the unit and overall costs for voice telephony and video-conferencing on-demand services, in order to provide an economically more attractive service than was available from the existing provider.

Reaping the Benefits

As the accompanying graph confirms, the objectives that were set for the new ESACOM Information Highway are clearly being achieved. At the outset in March 2001 when only the data service was implemented, the total running costs of the new IP VPN service were almost at the same level as for the previous service contract, but the capacity was 2.5 times higher, resulting in a dramatic 60% drop in the cost per unit of bandwidth. Also, the new network was sized from the start to accommodate future traffic requirements.

The next important milestone was achieved in April 2002, with the operational introduction of the Voice over IP service. The addition of this service, together with the capacity increase to accommodate Video over IP and other services, raised the overall capacity to four times the pre-2001 level, bringing a further reduction in unit cost.

In addition, the new contract foresees a price-revision clause that requires the service provider to propose a price reduction on an annual basis in line with market trends, with the possibility also for ESA to request an independent benchmarking exercise. This ensures that ESA will benefit from any competitive pricing reductions, whilst at the same time maintaining a stable relationship with its existing service provider, which is essential to ensure a reliable operational service and to satisfy the Agency's own specific requirements. In fact, after the initial successful experience, an extension beyond the initial contract duration has already been negotiated. This has implied a further reduction in costs since July 2002, which has been converted into additional bandwidth.



Evolution of ESACOM IP VPN Capacity and Costs

In addition to these purely financial advantages, the new converged network has brought several less obvious, but equally important benefits, including:
- the possibility of dynamically sharing network resources between different applications, whilst still ensuring priority and guaranteed service for the most critical ones; one example is the exploitation of unused voice/video-class service capacity on the Intranet links at night for database replication traffic
- a single interface to the network provider, which eases management tasks and provides the opportunity to build a stable and mutually beneficial relationship
- the possibility to implement new applications in the areas of multimedia communication, unified messaging and mobile computing, foreseen by ESA for the near future.

Conclusion

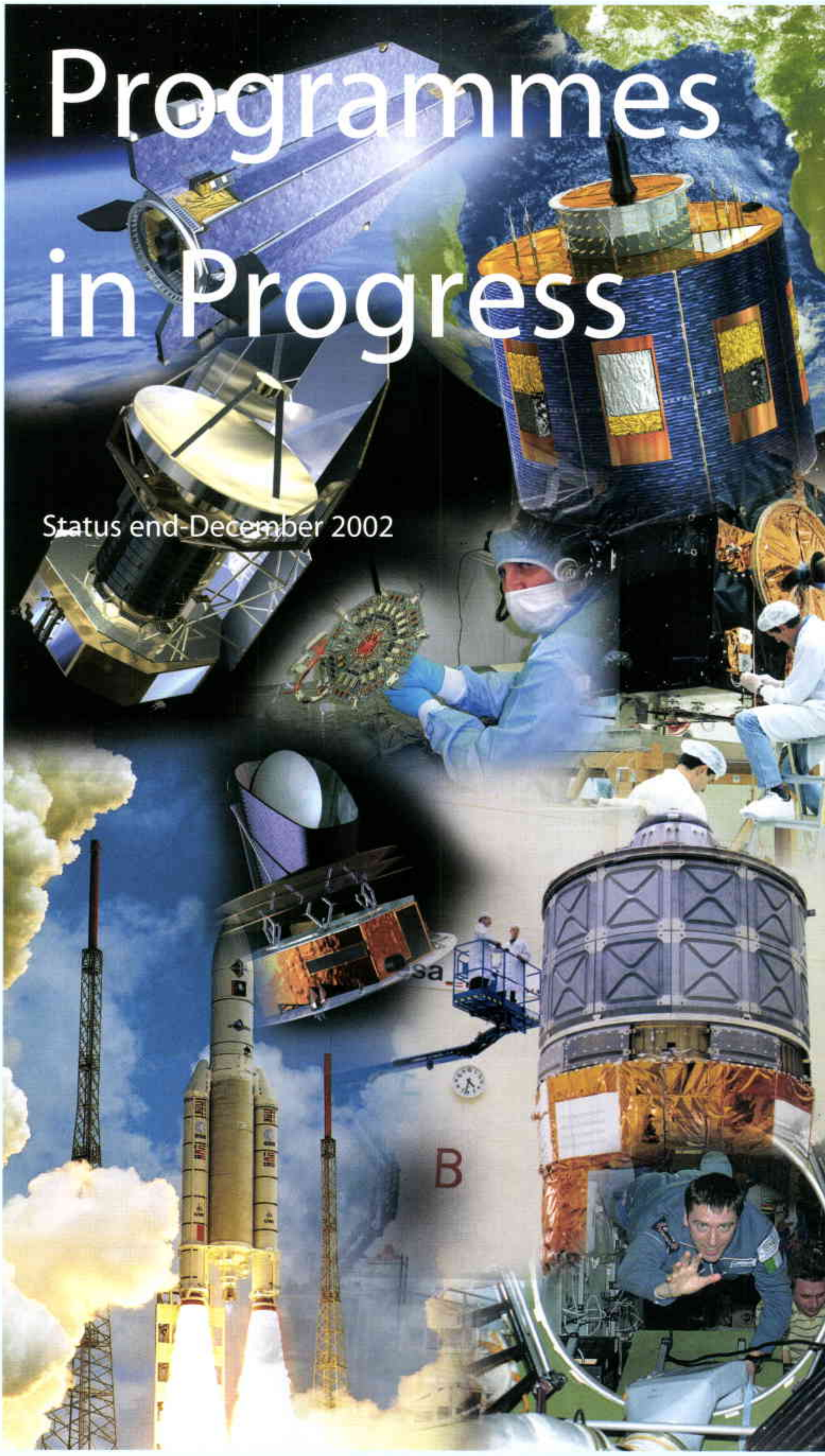
The ESACOM information Highway has now been operational for almost two years. The regularly monitored service levels are compliant with the agreed yardsticks, and the cost trends are sustainable. Experience is therefore confirming that the IP VPN solution selected is the correct one for ESA's present and upcoming connectivity requirements, combining the simplicity of the Internet model with the guaranteed quality and security that our customers require. The mid-term perspective for ESACOM foresees the addition of Internet-based VPN for particular classes of service that can tolerate a lesser, or at least less predictable, service level in exchange for significant cost savings. The longer-term perspective, if confirmed by the market trends and supporting technological evolution, will be the later merging of the IP VPN and Internet backbones into a single class of service-enabled infrastructure.

Acknowledgements

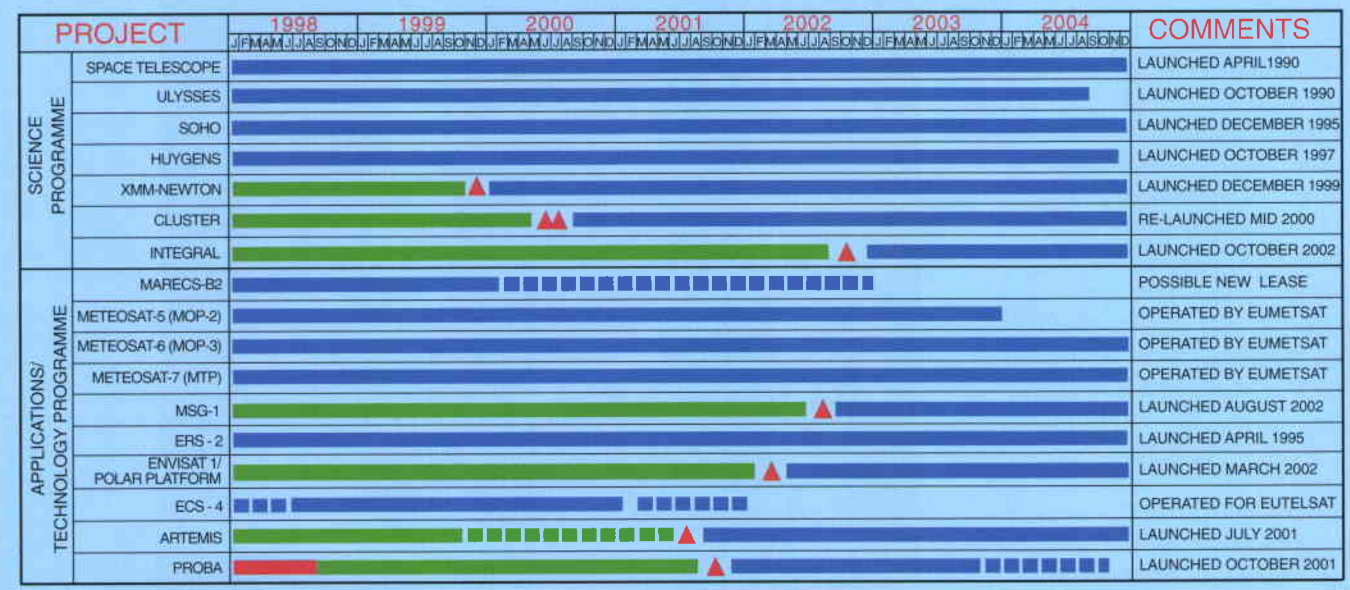
The success of this complex project has been due to the productive teamwork of the various participating entities, coordinated by ESA. The authors are indebted to the members of the Equant project team, to the Vitrociset/Terma engineering teams, to the Serco IT operations team, to the ESA 'customers' of the Site Management Service Department who supported the evolution and migration of the voice and video services, and to Alcatel, the PABX contractor. Special thanks go to Michael Tabbert who, as Head of the Infrastructure Services Division at the time, made it all possible.

Programmes in Progress

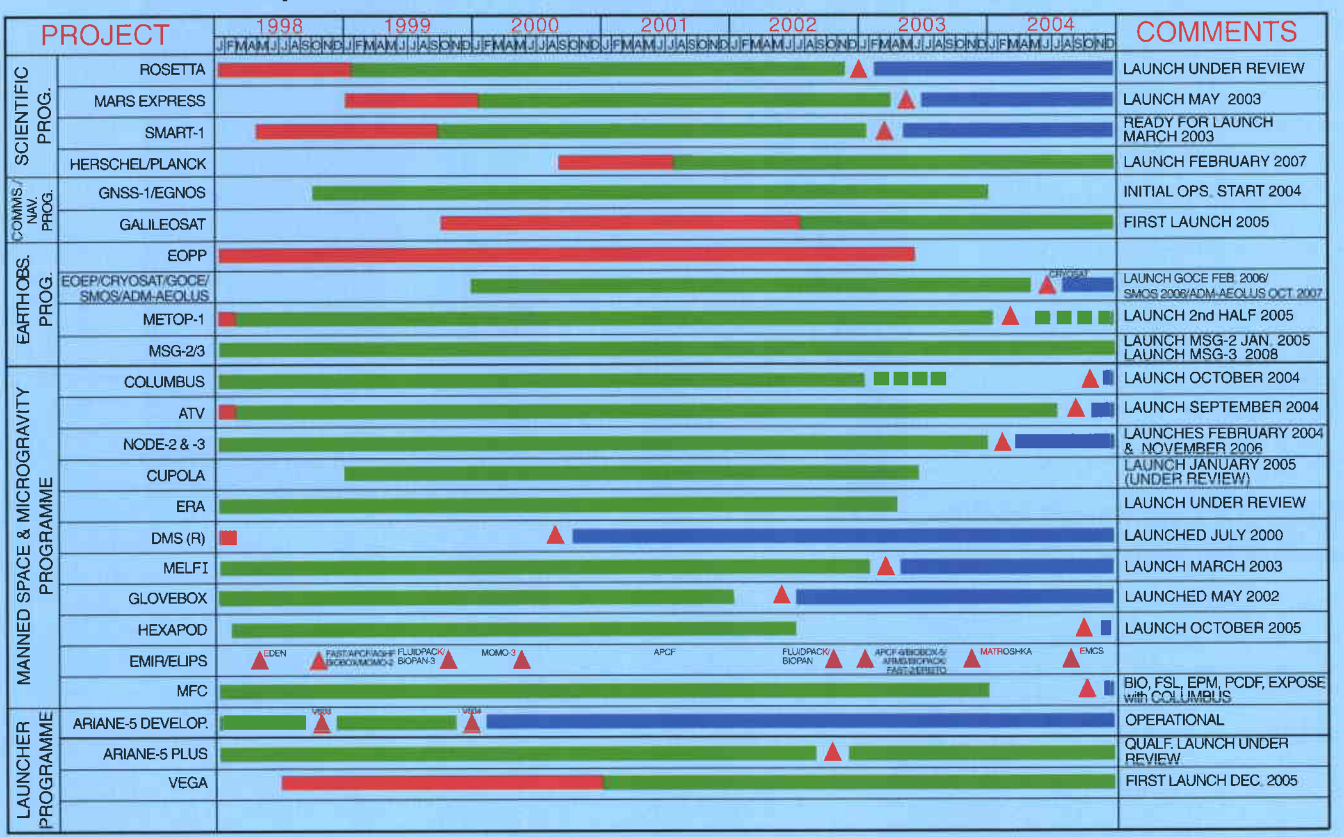
Status end-December 2002



In Orbit



Under Development



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

OPERATIONS — ADDITIONAL LIFE POSSIBLE — RETRIEVAL — STORAGE

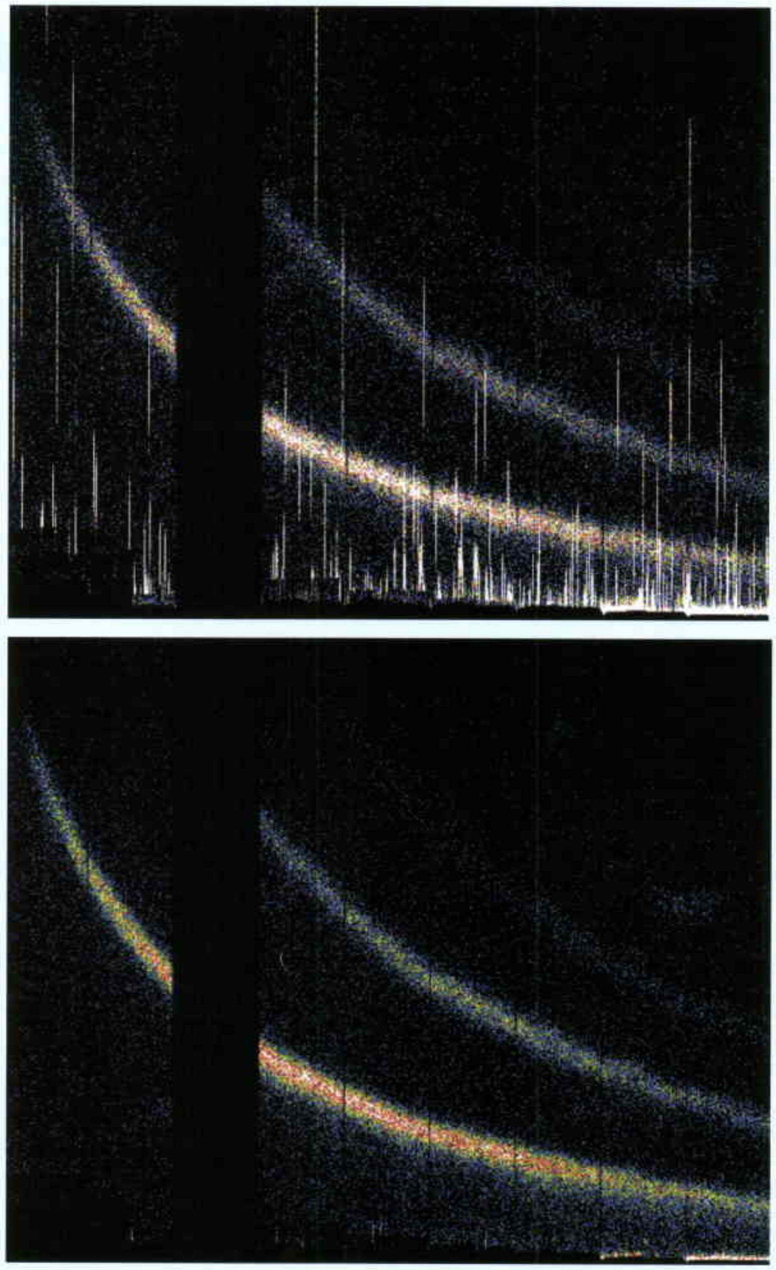
ISO

The ISO Data Centre's Active Archive Phase activities (planned to last until end-2006) continue to run smoothly. A new version (5.3) of the Archive was released in December, with enhanced capabilities for the Survey Products viewer, which is now also used by the XMM-Newton Science Archive. The ISO Data Archive now has more than 1350 users. It is always busy, with between 50 and 100 downloads being made per month, accessing typically 5% of the product content and with 20 to 30% of the usage coming from the USA.

Work on documentation continues well, with the recent delivery of the Proceedings of the Conference 'Exploiting the ISO Data Archive - Infrared Astronomy in the Internet Age' held at Siguenza (E) in June to ESA Publications Division for printing and distribution (as ESA SP-511). The legacy versions of the remaining ISO Handbook volumes (ISOCAM and ISO) are being finalised. ISO continues to have a significant presence in the refereed literature also, with some 150 papers covering almost all areas of astronomy having appeared in 2002 alone. More than 900 refereed papers based on ISO data have already been published.

Activities will now focus on implementing selected projects leading to 'Expert Reduced Data' for ingestion into the ISO Data Archive. The first sets of systematically reduced data have already been captured, including a spectral atlas of over 300 stars.

Operating at -80°C



Operating at -110°C

The improved spectral response of XMM-Newton's Reflection Grating Spectrometer (RGS-1) by operating at -110°C

XMM-Newton

Operations continue to run smoothly. Almost no time has been lost recently due to enhanced solar activity or the non-availability of ground stations due to their use to support launches. Following successful investigations into operating the onboard X-ray detectors at around –115°C instead of the previous –80°C, the operational temperatures of most of them have now been lowered. This step ameliorates some of the effects of radiation damage caused by spending over 2.5 years in space. This is nicely illustrated by the results displayed at:
http://xmm.vilspa.esa.es/external/xmm_news/items/cooling02/index.shtml

Preparations for the upcoming orbit-maintenance manoeuvre and the next eclipse season, in February/March 2003, have been finalised.

Data processing and shipment is once again nominal following the interruption related to the instrument cooling exercise mentioned above. More than 2300 observation sequences have been executed and the data for 2100 of these has been shipped. Version 1.5 of the XMM-Newton Science Archive (XSA) was successfully released as planned, in mid-November, for use by the wide astronomical community.

In March 2003, a new Call for Observing Proposals will be issued for the next 16 months of observing time, which are open to all astronomers worldwide.

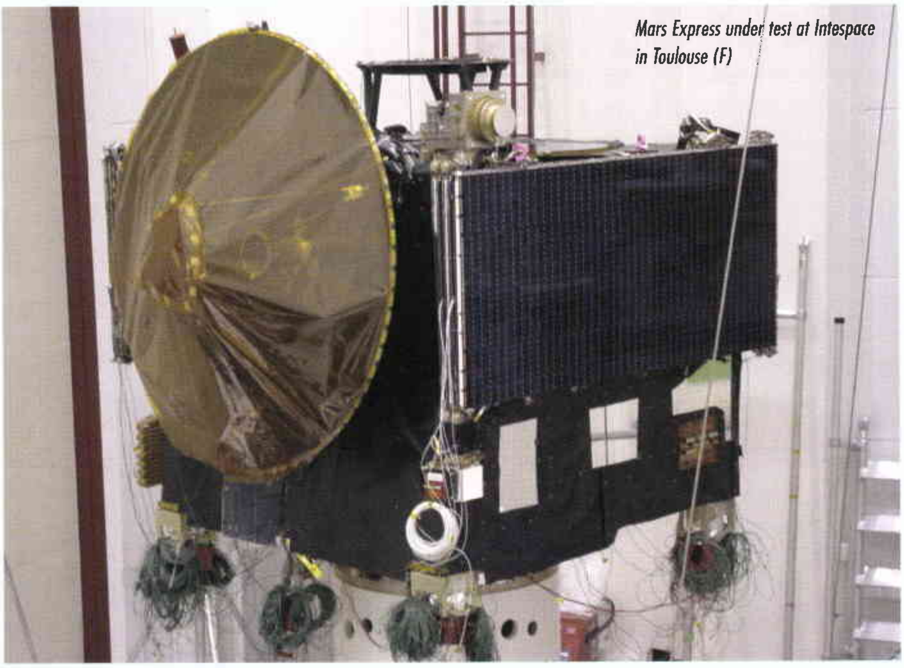
By the end of December, some 225 papers based on XMM-Newton data had been published in the refereed literature.

Integral

The Mission Commissioning Results Review in December concluded that the spacecraft payload and ground segment have been successfully commissioned and that in-orbit performance complies with mission specifications. The smooth in-orbit commissioning has resulted in an expected satellite lifetime of more than 5 years. The fine-tuning and calibration of the scientific instruments is expected to be completed by end-March 2003.

Rosetta

The Rosetta spacecraft and ground segment were ready for the opening of the launch window on 13 January. However, as a result of the launch postponement, decided upon jointly by Arianespace and ESA, the spacecraft is now being defuelled and put into a non-hazardous state. Alternative mission scenarios are being studied by all parties, with the aim of briefing the Science Programme Committee (SPC) on the various options at the end of February, with a view to a final decision being taken at the May 2003 SPC.



Mars Express under test at Intespace in Toulouse (F)

Mars Express

The spacecraft is currently in a special chamber at Intespace in Toulouse (F) to verify its insensitivity to electromagnetic radiation. This is the last in a long campaign of tests to demonstrate the spacecraft's ability to survive the launch and space environments. All results indicate that the spacecraft meets the design requirements.

A highly successful press event was held in collaboration with Ferrari in early September, when a small container holding some 'Ferrari-red paint' was mounted on the spacecraft in the presence of a very large group of media representatives.

Preparations for the launch campaign are in full swing, in close co-operation with Starsem, the Russian launch-service provider. The telecommunications facilities are being installed to allow the spacecraft to be operated remotely from ESOC in Darmstadt (D) for training purposes. The Project team has also inspected the Baikonur facilities and concluded that the launch campaign can start in late February 2003 as planned.

The ground-segment preparation has progressed according to plan, with ESOC being assigned time slots for remote spacecraft operation to test some of its in-flight procedures.

The SMART-1 electric-propulsion thruster firing in the ESTEC test chamber. The plume is visible due to the excited xenon (Xe+) ions: the central part shows a greenish light (high-energy emission), while the ions close to the cathode, on the right, emit a reddish glow (lower energy). The white annular core is where the plasma (Xe+ and e-) is generated, maintained and accelerated

SMART-1

During the last months, the fully integrated flight-model spacecraft has been undergoing system functional and performance testing at ESTEC in Noordwijk (NL), followed by the environmental test campaign (EMC, thermal-vacuum and vibro-acoustic), all of which have been completed successfully. The on-board software has also been subjected to extensive verification testing. In December, an end-to-end electric-propulsion test was successfully performed in ESTEC's HBF-3 chamber, commanding the engine to fire at different power levels, as will be needed during SMART-1's flight. The engine performed flawlessly.

The Flight Acceptance Review (FAR) began in December and will be concluded with a Review Board meeting in mid-February. Parallel acceptance reviews are being held for the electric-propulsion subsystem, procured directly by the Agency from SNECMA (F) and integrated by the Swedish Space Corporation (S), and for the payload instruments, also procured by the Agency and delivered as customer-furnished equipment. These reviews will report to the Mission Acceptance Review to be held after the FAR.

Ground segment
Preparation of the Mission Control facilities at ESOC (D) and the Science and Technology Operation Co-ordination facility at ESTEC (NL) is going according to plan. The simulation campaign has started at ESOC, with ESTEC and industry participation. The procedures now being finalised will be tested as part of the second System Validation Test (SVT-2) in February 2003.

Launcher
The spacecraft will be ready for launch at the end of March 2003 and all of the launch interfaces have already been defined. The Project is currently awaiting a launch commitment from Arianespace in order to finalise everything for a specific launch opportunity.

Herschel/Planck/ Eddington

During the autumn of 2002, the procurement activities leading up to the selection of all of the industrial consortium's subcontractors have continued apace. As a result, a number of new contractors have been brought into the industrial consortium in the last three months for important project items, including the Herschel and Planck solar arrays, the Herschel instrument optical bench assembly, the Cryostat control unit and internal and external multi-layer insulation and software, as well as a number of units for the attitude control and management systems of both spacecraft. Consequently, the Herschel/Planck procurement activities are nearing completion.

Herschel

The spacecraft design and development activities made further progress with the holding of the Herschel/Planck Spacecraft Preliminary Design Review (PDR) in the last quarter of the year. The overall system design is now complete and the development phase has been defined in detail. Several unit and subsystem preliminary design reviews have confirmed that the lower-level design is stable and progressing nominally. Detailed design work will now lead to the completion of spacecraft-hardware manufacture by the end of 2003.

Development of the spacecraft telescopes continues to run smoothly. Production of the flight-model segments for the giant Herschel 3.5 m silicon-carbide telescope is proceeding according to plan at Astrium SAS (12 'pie-type' segments are needed for the complete primary mirror). Formal acceptance of the manufactured elements took place at the end of December. Development of the Planck reflectors at Astrium GmbH is progressing well, with the full secondary reflector scheduled for completion in April.

Further progress was made with the detailed definition of the accommodation for the two spacecraft on an Ariane-5 E/CA launcher during a meeting with Arianespace in late December.

Mission Operations Centre development activities at ESOC are going according to plan, with the buildup of the Herschel/Planck MOC team who will be commanding the satellite from the ground.

The technical development of the scientific instruments is generally proceeding as planned, but financial problems are still affecting progress.

Work has also continued on the Eddington mission, which is to be integrated into the existing ESA Herschel/Planck project structure and will make use of the recurring Herschel spacecraft bus for which the Agency holds a contractual option. The establishment of a consistent Herschel/Planck/Eddington concept has progressed both technically and financially. As the next step for Eddington, ESA will contract parallel system-definition studies to industry starting in spring 2003, eventually moving into a mission-implementation phase in 2004.

Planck

Venus Express


Venus Express

After conditional approval of the mission by ESA's Science Programme Committee (SPC) in July 2002, the Project and Astrium SAS initiated all of the contractual activities needed to ensure the spacecraft's readiness for launch in November 2005, whilst still respecting the SPC-imposed constraints. The latter were removed in November when the SPC gave the green light for the full Venus Express implementation. Thanks to starting work in July, the Project was able to conduct the first major project review – the System Requirements Review – by the end of 2002, and preparations for the Preliminary Design Review began immediately thereafter.

The Science Working Team held its first formal meeting in December.

Artemis

Hurrah! Artemis has reached geostationary orbit. What many people thought impossible during the first days after the launcher malfunction during the satellite's launch has nevertheless become a reality. After perhaps the longest transfer orbit of any communications satellite, Artemis finally arrived at its nominal operating position on 31 January 2003. Its ion engine had been propelling the satellite at a rate of 15 km/day for the last several months, something for which such an engine had never previously been used. It was also a first in terms of the flexibility of the spacecraft's attitude control system. Thanks to the cleverness of its designers, operators and outstanding hardware elements, it was possible to successfully perform previously unspecified manoeuvres that had not been ground-tested and qualified in the classical sense.

With Artemis safely on station, a detailed payload performance test programme is now being conducted, to allow formal operations to start in March. There is further good news in that Artemis still has the potential to operate for its nominal 10-year lifetime.

EGNOS

The EGNOS ground-segment elements are now the final stages of qualification, all having been delivered and integrated into the system AIV platform at Langen in Germany. System-level integration and verification activities are now proceeding at full speed, having already validated all key software interfaces, towards System Factory Qualification in June 2003.

All of the 40 sites planned to host the EGNOS elements have been characterised by means of specific measurement campaigns, and all hosting entities have begun to upgrade their infrastructures to meet the EGNOS requirements. Deployment of the first EGNOS elements at their final sites was started at the end of 2002, which should enable first EGNOS test Signal in Space to be transmitted by the second quarter of 2003. Activities will continue in parallel to achieve full system deployment during 2003.

ESA's partners in the EGNOS Programme (European Air Traffic Service Operators) have set up a consortium that is intended to become the future EGNOS operating entity. All partners are working towards the Operational Readiness Review planned for April 2004 and the subsequent Initial Operations Phase of the EGNOS System.


The EGNOS integration area

In parallel, the EGNOS Test Bed (ESTB) continues its transmissions, with excellent service availability, via dual broadcasts from both the Inmarsat AOR-E and IOR satellites. Successful system demonstrations have been performed in Cairo, Nice and Bordeaux, and more are planned in Dakar. The ESTB signals are also being used for a number of other GNSS-application promotional activities.

Meteosat Second Generation (MSG)

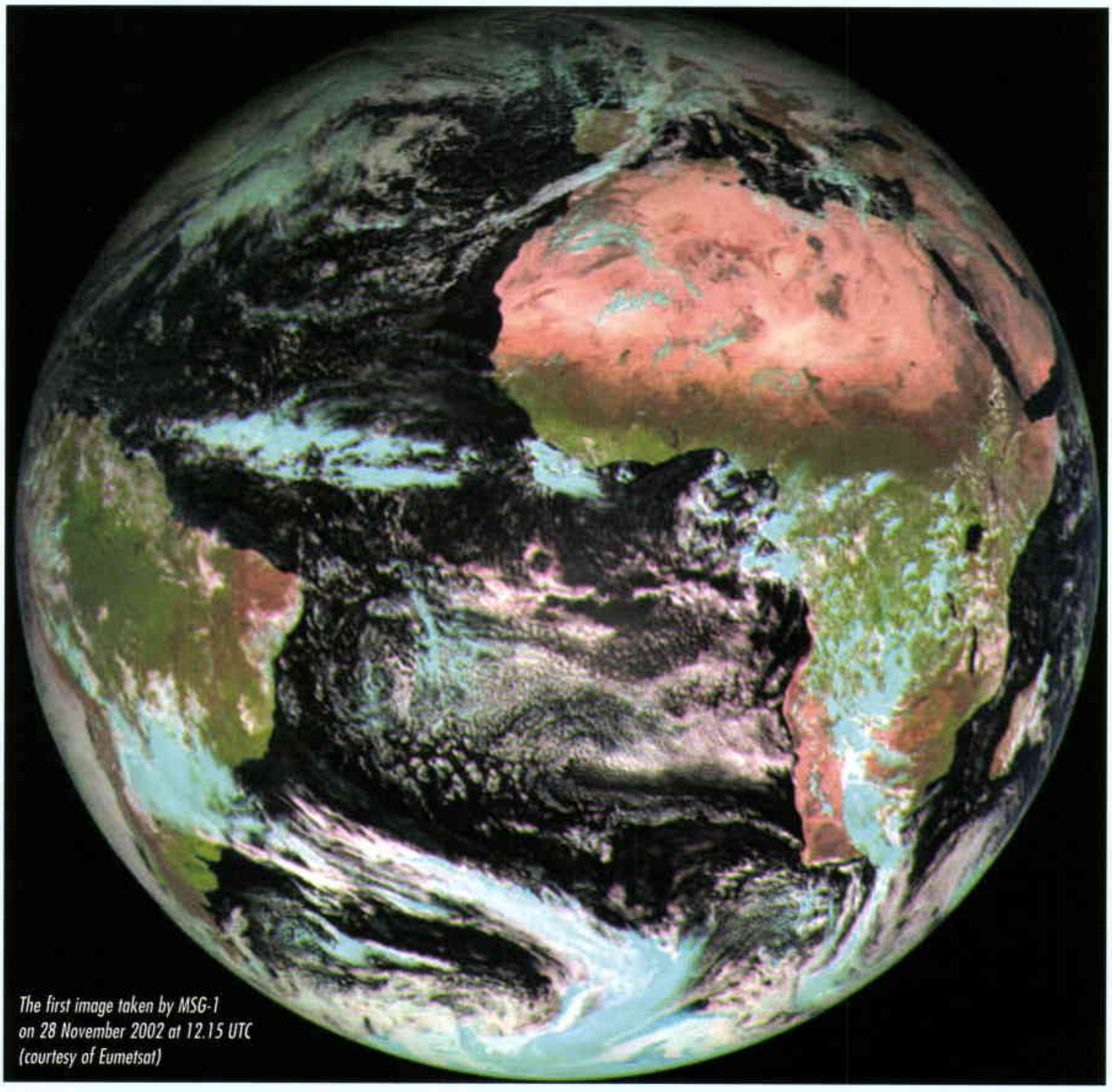
Following the handover of MSG-1 spacecraft operations to Eumetsat at the end of September, the satellite commissioning had to be put on hold on 25 October as a result of a solid-state power amplifier switch-off anomaly onboard the spacecraft. This anomaly, which is still under investigation, does not endanger the mission. The raw data gathered by the spacecraft can still be downlinked without any problem. However, an alternative solution may have to be found for the planned relay of processed data to users via the spacecraft. Investigation is on-going and looks promising.

Meanwhile, the commissioning activities have restarted and are planned to continue until mid-March. Apart from this anomaly, the MSG-1 spacecraft shows an outstanding performance, which was confirmed by its impressive first image taken on 28 November.

The MSG-2 system-integration activities have now been completed and the satellite prepared for environmental testing at Alcatel in Cannes (F). The thermal-vacuum testing was completed by the end of December. The satellite should go into storage at the end of May 2003 to await its launch, which is now foreseen for January 2005. Once MSG-2 has been put into storage, the integration team at Alcatel will resume its work on MSG-3.

MetOp

Major technical progress has been made with the very successful thermal-balance/thermal-vacuum testing of the MetOp-1 protoflight



The first image taken by MSG-1 on 28 November 2002 at 12.15 UTC (courtesy of Eumetsat) modules, with two tests being conducted in parallel: on the Payload Module in the Large Space Simulator (LSS) at ESTEC in Noordwijk (NL), and on the Service Module in the Intespace facility in Toulouse (F). Detailed correlation work is now underway to ensure that the thermal design is fully valid, which should be confirmed by the MetOp Qualification Review, planned for mid-2003.

Production of the first IASI flight-model instrument (equipped with functional, but not flight-quality detectors) is proceeding on schedule, and preparations for its integration and testing are well advanced. The impacts of the retrofitting of the sensor module for the first MetOp and for MetOp-3 have still to be worked out. A solution for the radiation sensitivity of the ASCAT switching unit has been identified and is being implemented.

The GOME-2 instrument continues to make good progress. In particular, a late modification to incorporate a quasi-volume diffuser - which replaces the existing alumina diffuser and is used to provide a reference solar spectrum - has been successfully qualified and is now being retrofitted to the instruments. This modification will result in a significant improvement in GOME-2's ability to measure atmospheric trace gases.

The GRAS engineering model has been used without problems throughout the MetOp-1 Payload Module testing. The first flight model is nearing the end of its acceptance review process. Solutions to the antenna metallisation problem are still being identified.

With the qualification phase of the project now nearing completion, greater emphasis is being placed on launch and operations preparation. Here much progress has been made with Eumetsat in defining in detail the organisation of the launch, early-orbit, switch-on and commissioning phases.

ADM-Aeolus

The design of the instrument receivers, based on the pre-development model, has been refined. Instrument interfaces both internally and to the platform have been defined. The Instrument Requirements Specification is close to agreement. Instrument operations have been reviewed and a requirements specification for the instrument control unit produced.

The platform's electrical design is sufficiently complete to specify equipment items. The operational requirements on the satellite have been defined and reviewed. The Model Based Development and Verification Environment, which will be used to verify software and procedures, has been analysed in some detail.

The prime contractor is Astrium Stevenage (UK) and the core consortium includes Astrium Toulouse (F) which is responsible for the instrument, and Astrium Friedrichshafen (D) which is responsible for the platform's electrical subsystems. Subcontractors to supply subsystems and equipment for the satellite will be selected through almost fifty competitive ESA-supervised Invitations to Tender (ITTs). The first ITT (for the transmitter lasers) has been opened to limited competition between Astrium and Galileo. A further eight ITTs are under review at ESA and will be released shortly.

Plans for one ground and two airborne campaigns with a specific instrument have been discussed with DLR Oberpfaffenhofen (D). These campaigns will be conducted as a cooperative activity with significant funding from DLR.

Mission assumptions have been agreed with ESOC (D) as a basis for planning the Flight Operations segment. Agreement has also been reached with ESRIN (I) on the organisation of the Payload Data Segment, and the technical work will begin shortly.

CryoSat

The main development (Phase-C/D) activities are progressing well and some of the flight-model elements, such as the high-pressure tank for the attitude-control system and the antennas for the telecommunications subsystem, are ready to be shipped to Astrium GmbH, the satellite Prime Contractor.

On the payload side, tests on critical elements of the SIRAL altimeter are progressing well at Alcatel Toulouse (F). Thales (F) has already manufactured the main electronic boards of the DORIS instrument for restitution of the CryoSat orbit.

Definition of the interfaces between the satellite and the Eurockot launcher is now well advanced and details are being discussed with Krunichev.

Development of the ground segment is going according to plan and definition of the algorithms for the level-2 processing is well under way. Agreement has been reached on the plan for the CryoSat validation campaigns, with preliminary activities foreseen for 2003 in the framework of the Cryovex campaign.

GOCE

Space-segment development has entered a stage (Phase-C/D) characterised by detailed consolidation of the satellite's design, based on equipment-level Preliminary Design Reviews (PDRs). These PDRs have already been successfully concluded for many equipment and payload units, and steady progress is being made in all remaining areas.

The build-up of the GOCE industrial consortium is very close to completion. The last Tender Evaluation Board (TEB), in November 2002, dealt with the selection of the Independent Software Validation contractor. Subcontractors have recently been engaged for the harness, magnetic torquer, thermal-control hardware and RF suitcase.

Significant effort has been made to kick-off schedule-critical activities related to the micro-Newton propulsion system. Negotiations concerning the solar generator have progressed with the TEB-recommended supplier and urgent work has been initiated due to its impact on the overall schedule. The thermal-cycling testing of representative photovoltaic coupons has continued, and preliminary results are available from the two potential European photovoltaic-assembly suppliers.

Some delay has occurred in preparing for the mechanical testing of an accelerometer sensor head equipped with the chosen stop material/coating, intended to demonstrate that the current accelerometer design will withstand the launch vibrations. The test should now take place in February 2003. Breadboarding of key gradiometer front-end electronics functions has also recently started, allowing the testing of vital performance-related design characteristics.

Activities on the ground-segment side have focused on completion of the Ground Segment Requirements Review (GSRR). The completeness, consistency and feasibility of the ground-segment concept and architecture have been reviewed, together with the requirements for the Flight Operations Segment (FOS) and the Payload Data Segment (PDS). The Review Board concluded that the ground segment is sufficiently well defined to kick-off the related development activity. Consequently, emphasis in the project activities has shifted towards finalisation of the documentation relevant to the Invitation to Tender (ITT) addressing the development of the GOCE PDS (data processing up to Level-1b). In addition, a study is in preparation for the Calibration and Monitoring Facility (CMF), which will incorporate critical scientific-product quality monitoring and related system health-check functions during nominal operations as well as the payload calibration phases.

SMOS

The payload design phase (Phase-B) was successfully kicked-off at the end of October, with a seamless transition from the extended study phase (Phase-A). A first round of progress meetings with subcontractors has taken place, allowing a number of critical internal interface issues to be addressed.

Preparations are proceeding to formalise ESA-CNES cooperation in the SMOS programme, as well as for the 'system support' to be provided by CNES and Alcatel.

The ground-segment Phase-A study with GMV, Indra and INSA was kicked-off in October and is producing the first output.

The MIRAS Demonstrator Pilot Projects 1 and 2 are nearing completion. The full three-segment arm deployment test in particular was very impressive and highly successful.

Three-segment arm deployment testing of the MIRAS Demonstrator for SMOS

International Space Station

Research and applications programmes
An update of the Assembly Sequence (Rev. F) has been signed by all Partners, including the Columbus launch for 7 October 2004 and the ATV launch for 27 September 2004. The Columbus launch will include five payload racks and two external payloads, of which one rack and one external payload will need to be confirmed by NASA as a function of Shuttle mass availability.

Assembly flights 9A and 11A carried the first starboard and port truss segments to the Station, both of which were successfully installed.

At the Heads of Agency meeting in Tokyo on 6 December, all Partners unanimously endorsed Option Path Four, as recommended by the Multilateral Programme Planning Team

(MPPT). This Path is based on improving utilisation productivity from 2003 to 2006/7, permanently increasing utilisation capacity using the existing rescue capability (Soyuz) from 2006/7 to 2010, and continuing beyond 2010 to increase utilisation capacity using existing and new crew-rescue capabilities (Orbital Space Plane).

Space infrastructure development
Acceptance testing of the Columbus Laboratory's flight model and formal qualification testing of its electrical test model are progressing well. The first part of the major hardware and software compatibility qualification test has been finalised.

Node-2 flight-unit integration is on schedule. All four avionics racks have been integrated and the electrical tests completed. Integration of the cables and actuators of the common berthing mechanisms has also been finalised.

The System Requirements Review for the Cryogenic Freezer (CRYOS) was completed in December.

Machining of the Cupola's flight unit dome and welding of the dome/ring was completed and the dome has been delivered. Acceptance testing of the shutter mechanism and flight-unit harness has been completed, as well as all Structural Test Article (STA) activities. The Cupola's launch is now planned for January 2008.

Discussions have been held with Arianespace and CNES regarding the launcher configuration for ATV flights. Currently under assessment is a proposal to use the last two available EPS (Storable Propellant Stage) upper stages for the first two ATV flights, and the future cryogenic stage, known as ESC-B, for the remaining flights.

NASA has formally cancelled the X-38 project, and detailed consultations relating to the termination of the project will start in the near future.

Operations and related ground segments
The ATV Control Centre (ATV-CC) Preliminary Design Review (PDR) has been successfully completed. The ATV-CC Phase-C/D proposal has been technically negotiated, but further negotiation on price is required. The Columbus Control Centre (COL-CC) system PDR was concluded at the beginning of December. The Tender Evaluation Board for the Phase-C/D proposal concluded that a contract could be placed provided that all open actions from the PDR have been successfully closed out.

The ground segment set up for the 'Odissea' mission successfully supported the flight and, based on the experience gained, activities are underway to set up the required infrastructure with NASA and the Russian TsUP for the 2003 Taxi Flight involving ESA Astronaut Pedro Duque.

Utilisation planning, payload development and preparatory missions
Eight Microgravity Application Promotion (MAP) continuation proposals have been recommended for continuation and three for re-submission.

The Microgravity Science Glovebox (MSG), which is installed in the Destiny Laboratory on the ISS, experienced a loss of power during an experiment on 20 November. The problem has been isolated; troubleshooting is continuing and the engineers are assessing the options for resolving the problem in-orbit.

During the 'Odissea' mission, there were eight days of intense activities during which the scientific and educational programmes, composed of 23 experiments, were performed.

The –80°C Freezer (MELFI FU 1) completed all of the acceptance tests at Kennedy Space Center (KSC), and has been integrated into the Multi-Purpose Logistics Module (MPLM) ready for launch in March 2003 on the ULF1 flight.

Hexapod flight-unit integration is progressing and delivery to NASA is now foreseen for April 2003.

The SOLAR Instrument Intermediate Design Review process has been completed.

The EXPOSE on EuTEF Critical Design Review (CDR) was kicked-off in December and completion is envisaged in February 2003.

The Payload System Requirements for the Atomic Clock Ensemble in Space (ACES) Review (SRR) was concluded in December, but the contract for its further development (Phase-C/D) has been put on-hold due to uncertainties surrounding the Pharao atomic clock.

The Critical Design Review (CDR) for Matroshka is in progress and should soon be completed.

The Data Management System for the Russian Service Module (DMS-R) is fully operational in orbit.

The European Robotic Arm (ERA) qualification programme is still ongoing, with the Flight Unit Qualification/Acceptance Review set for March/April 2003.

Several ATV follow-on production scenarios have been established between ESA and industry, and have been assessed from the technical, production-schedule and risk points of view. The industrial proposal will be submitted in Spring 2003.

The Russian Soyuz launcher carrying the unmanned Foton-M1 research satellite exploded some 30 seconds after lift-off. The flight carried 44 ESA-supported experiments.

All six ESA microgravity payloads were ready for flight in Spacehab on the ill-fated STS-107 Space Shuttle mission.

The preliminary acceptance of the Science Reference Model for Biolab has taken place. The flight-model subsystem procurement/manufacture has been completed and delivery is in progress. The flight-model integration is also progressing, along with training-model development.

The Fluid Science Laboratory (FSL) subsystem flight-model assembly, integration and testing is approaching completion and flight-model integration is in progress. The Canadian Space Agency has delivered the first Microgravity Vibration Isolation System (MVIS) hardware for integration. Training-model development has been initiated.

The engineering model of the Material Science Laboratory (MSL in US Lab) has been completed and preparations are in hand for testing the NASA Quench Module Insert (QMI); engineering-model delivery to NASA is expected early in 2003. Flight-model subsystems have been completed and flight-model assembly initiated. The Seebeck Diagnostic flight model has been delivered to ESA.

The European Physiology Module (EPM) flight-model manufacturing is almost complete and flight-model integration and training-model procurement have been initiated. NASA's Human Research Facility (HRF-2), including the EPM contribution, the Pulmonary Function System (PFS), has been integrated into the MPLM and is scheduled for launch on ULF-1 in March 2003.

A successful Crew Review of the Multi-electrode Electro-Encephalogram Mapping Module (MEEMM) has been completed.

ISS education

A pilot version of the ISS Education Kit for teachers of 12-15 year olds has been distributed to schools and other educational establishments. The final version will be produced in all of the ESA Member State languages.

In November, the ISS Education Programme (and ISS Education Kit) was presented to the 'European Council of International Schools' (ECIS) in Berlin.

Fifty students were selected to participate in the final of the SUCCESS contest (student experiments for ISS), which was held in the Erasmus User Centre at ESTEC. The winner of the contest will be announced in Spring 2003.

ESA astronaut Frank De Winne working with the Microgravity Science Glovebox aboard the ISS

In December, the ISS Education Programme for the European Astronauts Soyuz Missions was finalised. This programme has defined likely activities or student experiments for the different age groups.

Specific educational activities for the ISS Education Programme on the Spanish-sponsored Soyuz Taxi Flight have also been finalised. Students have developed twelve experiments based on Newton's Laws of Motion.

Commercial activities

The policy for commercial manned spaceflight missions with professional astronauts has been prepared for official release. The first such project has been assessed using the new internal evaluation procedure.

The joint ESA/Industry Cooperation Agreement Steering Board has approved the Strategic Marketing Plan 2003-6 and the detailed Marketing Plan 2003.

A number of Pathfinder Project proposals have been received and are being evaluated. The Rapid Eye project has been committed to a bridging phase and preparations for Phase-B activities are underway as the overall financing is secured.

Astronaut activities

The 'Odissea' Soyuz Taxi Flight, with ESA astronaut Frank De Winne as Flight Engineer, was launched from Baikonour in October. The very successful mission was completed on 10 November when the crew landed safely in Kazakhstan. EAC staff at TsUP, ESTEC and the European Astronaut Centre (EAC) provided mission support during launch and landing, and the Medical Operations Consoles at EAC were used for real-time mission support.

On 8 October, ESA astronaut Pedro Duque began training in Russia for the Spanish-sponsored Soyuz Taxi Flight, scheduled for April 2003.

The welcoming of the French astronaut Philippe Perrin into the European Astronaut Corps on 17 December completed the process of integrating national astronauts.

Vega Small Launcher / P80

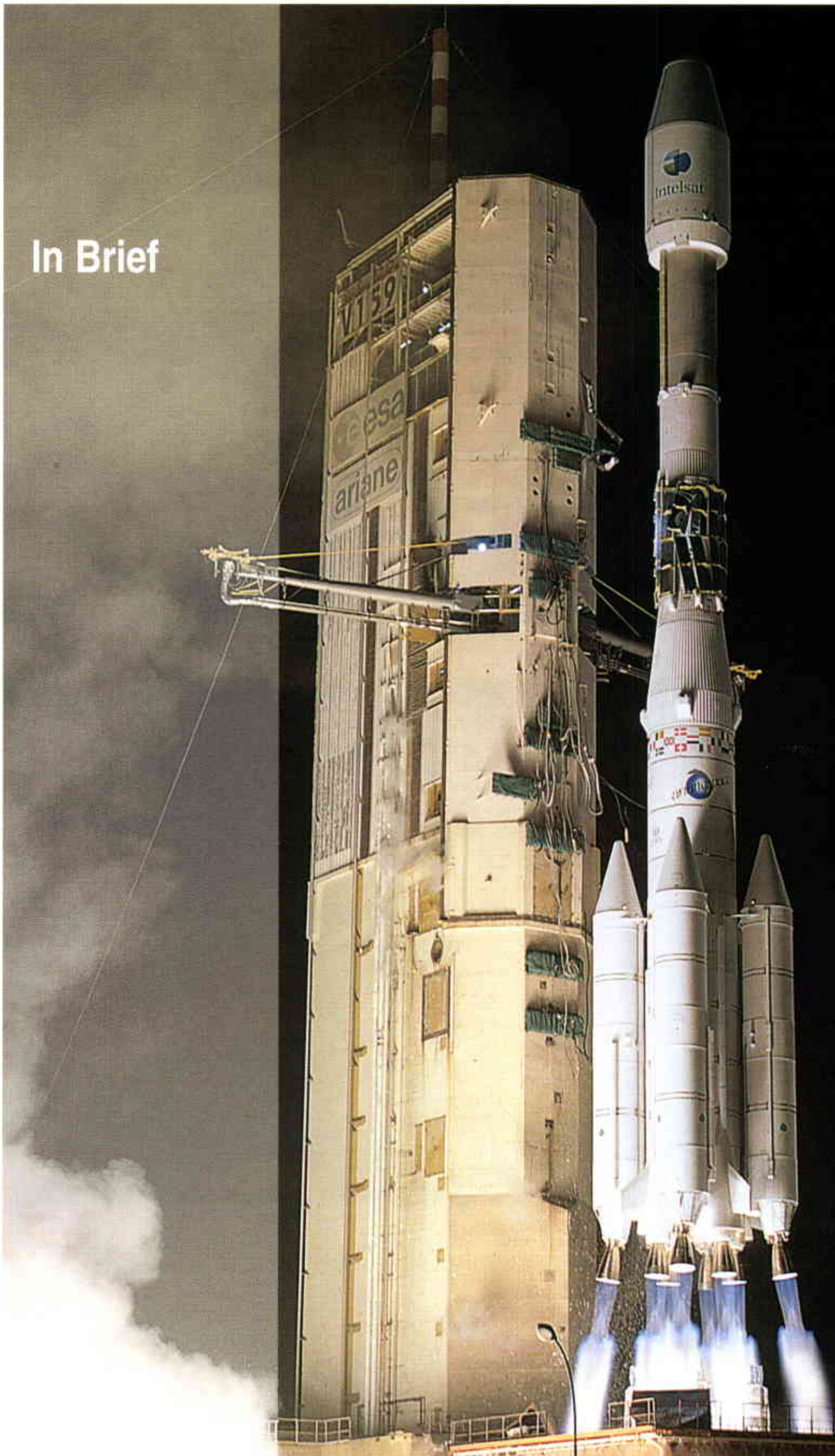
In the third quarter of 2002, the Vega contract negotiations progressed with the revision and finalisation of the technical, programmatic, and contractual baselines. The interfaces between the launch vehicle, P80 stage and ground segment have been further refined. A number of subsystem design reviews have also taken place and an Avum Working Group has jointly reassessed and defined the modifications needed to comply with the re-entry strategy agreed with Launch Safety Authority.

Other activities related, for example, to safety and reliability, controllability, guidance, navigation and control-law definition, have been progressing according to plan. A Vega Exploitation Group, including the Integrated Project Team (IPT) and Arianespace, has started holding regular meetings to exploit synergies with Ariane-5, to define overall cost-reduction options, and to follow the volatile evolution in the launch market.

On the ground-segment side, the scope and working procedures for the Engineering Support Contract have been defined in detail between IPT and CNES-SDS (Sous-Direction Sol), and a revised proposal is expected in mid-February. Work has also started on the definition of the industrial contracts to be issued in the spring for the main areas of development at the Vega Launch Base: namely, civil engineering, metal structures, fluid systems and the control bench. A baseline for the CSG buildings to be used by Vega has also been agreed.

The P80 stage development contract is close to signature and the activities are progressing as planned under the leadership of the P80 Integrated Team based in Evry (F).

In Brief



Well done, Ariane-4

For the very last time after 15 successful years Europe's Ariane-4 placed a communications satellite into orbit on 15 February 2003. The Ariane-4 launcher has a record to be proud of: it has made a total of 113 successful launches and placed 182 satellites into orbit.

The last ever Ariane-4 launcher was an Ariane-44L, the most powerful version of its family. Ariane 44L carried four large liquid strap-on boosters to augment the launcher's thrust at liftoff and during the initial ascent. For this Flight 159, each booster was adorned with a green clover leaf bearing the inscription 'good luck with the last flight'.

On board historic Flight 159 was an Intelsat 907 satellite. During its lifetime the Ariane-4 launcher has put a total of 23 Intelsat satellites into orbit. Now that Ariane-4 has been 'honourably retired from service' its place will be taken by generic Ariane-5 launchers.

esa

New DG for ESA: Jean-Jacques Dordain

Jean-Jacques Dordain will be the next Director General of ESA for a period of four years. He will succeed Mr Antonio Rodotà, whose term of office ends on 30 June this year.

Dordain, born in France in 1946, obtained an engineering degree from the Ecole Centrale in 1968. Before joining ESA in 1986, he held several positions at the Office National d'Etudes et de Recherches Aérospatiales (ONERA) as researcher in the field of propulsion and launch vehicles, coordinator of space activities and as Director of Fundamental Physics. In 1977 he was selected by CNES to be among the first French astronaut candidates.

He joined ESA in May 1986 to be Head of the newly created Space Station and Platforms Promotion and Utilisation Department. He then became Head of the Microgravity and Columbus Utilisation Department, managing about 80 staff and overseeing numerous industrial activities. In 1993 he was appointed Associate Director for Strategy, Planning and International Policy. In May 1999 he was appointed Director of the newly created Directorate of Strategy and Technical Assessment. On 15 February 2001 he took up the post of Director of Launchers.

"I feel very honoured to have been appointed Director General of ESA and welcome this challenging opportunity. I have been working for the European Space Agency in various positions over the years. The current period offers good opportunities for ESA to be even more instrumental in building the future of European citizens and the success of Europe" said Dordain.

Jean-Jacques Dordain is a member of the International Academy of Astronautics and the Académie des Technologies. He has also held professorships at the Ecole Polytechnique and the Ecole Nationale Supérieure des Techniques Avancées.

esa

ESA's new Director General

Arianespace Flight 157 – Inquiry Board submits findings

After a dramatic failure of the new Ariane-5 ECA in the night of 11 to 12 December 2002, an Inquiry Board has established the most probable cause for the failure, examined possible consequences for the baseline Ariane-5 launcher version, and recommended actions to correct the problems that occurred during the Ariane-5 ECA flight 157.

A complete analysis of all measurements recorded during Flight 157 was carried out, along with a review of documentation concerning production, quality and technical records for the Ariane-5 ECA, as well as for all Ariane-5 flights to date. Also reviewed by the Board was the work of production and development teams in Europe. The Board's findings confirm that all preparatory and countdown operations for Flight 157 went normally, as did the flight sequence until the separation of the solid boosters.

There was a leak in the of the Vulcain 2 nozzles' cooling circuits during this first flight phase, followed by a critical overheating of the nozzle. This resulted in a major imbalance in the thrust of the Vulcain 2 engine due to the nozzle's deterioration, leading to a loss of control over the launcher's trajectory.

In conclusion, the most probable cause of the failure of Flight 157 was the simultaneous occurrence of two factors: the degraded thermal condition of the nozzle due to fissures in the cooling tubes and non-exhaustive definition of the loads to which the Vulcain 2 engine is subjected during flight

The designs of the nozzles on the Ariane 5 Baseline's Vulcain 1 engine and the Vulcain 2 engine for Ariane-5 ECA differ in the shape of the cooling tubes, which form the structure of the nozzle and the technology of the nozzle's stiffeners. After reviewing operating data from the Vulcain 1 engine's 12 successful flights, the Inquiry Board did not identify any weaknesses concerning the functioning and resistance of its nozzle. The Inquiry Board nevertheless requested an exhaustive examination of the behaviour of the Vulcain 1 engine nozzle, including precise modelling to demonstrate the component's correct behaviour during the flight.

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It works! First results from Integral

On 25 November 2002, Integral observed a powerful explosion, known as a gamma-ray burst (GRB). For about 20 seconds, a shower of gamma rays bathed the spacecraft and was captured by the gamma-ray imager (IBIS) and the spectrometer (SPI) on-board Integral. This is the first time ever that a gamma-ray burst has been captured using such a powerful gamma-ray camera. Scientists expect about one GRB every month to appear in the direction that the spacecraft happens to be looking. Most GRBs are believed to be the death of an extremely massive star in the distant Universe. According to a second theory, however, GRBs may come from the collision of two neutron stars, which are extremely dense objects. This particular GRB, designated GRB021125, is thought to have been located about 5 thousand million light years away. When they occur, GRBs shine as brightly as hundreds of galaxies each containing millions upon millions of stars.

Integral, launched in October last year from Baikonur in Kazakhstan, is fully operational. Its 'first-light' images – the name astronomers give to initial observations – were presented in Paris in December.

As a first test, Integral observed the Cygnus region of the sky, looking particularly at that enigmatic object, Cygnus X-1. Since the 1960s, we have known this object to be a constant generator of high-energy radiation. Most scientists believe that Cygnus X-1 is the site of a black hole, containing around five times the mass of our Sun and devouring a nearby star. Observing Cygnus X-1, which is relatively close by in our own Galaxy – 'only' 10 000 light years from us – is a very important step towards understanding black holes. This will also help us to understand the monstrous black hole – three million times the mass of our Sun – at the centre of our Galaxy.

During the initial investigations, scientists had a pleasant surprise when Integral captured its first gamma-ray burst. These extraordinary celestial explosions are unpredictable, occurring from random directions about twice a day. Their precise origin is contentious: they could be the result of massive stars collapsing in the distant Universe, or may alternatively be the result of a collision between two neutron stars. Integral promises to provide vital clues for solving this particular celestial mystery.

To study these peculiarities, Integral carries two powerful gamma-ray instruments. It has a camera, or imager, called IBIS and a spectrometer, SPI.

Spectrometers are used to measure the energy of the gamma rays received. Gamma-ray sources are often extremely variable and can fluctuate within minutes or seconds. It is therefore crucial to record data simultaneously in different wavelengths. To achieve this, Integral also carries an X-ray and an optical monitor (JEM-X and OMC). All four instruments will observe the same objects, at the same time. In this way they can capture fleeting events completely. Integral sends the data from all the instruments to the Integral Science Data Centre (ISDC) near Geneva, Switzerland, where they are processed for eventual release to the scientific community.

"We have been optimising the instruments' performance to produce the best overall science," says Arvind Parmar, Integral Project Manager at ESA. "These images and spectra prove that Integral can certainly do the job it was designed to do, and more, which is to unlock some of the secrets of the high-energy Universe".

Integral's primary mission will last for two years, but it is carrying enough fuel to continue for five years, all being well.

Workshop on Trajectory Design and Optimisation

One of the most challenging aspects of designing a mission is the definition of the trajectory. Not only do you need a good knowledge of celestial mechanics (where the stars and planets are at any time, and how they are moving relative to one another), but you also need to perform some very complex analysis. This requires specialised mathematical software tools, plus some means of optimising the results, to ensure not just that you reach your target destination, but also that you take the best route. There are a variety of software tools available nowadays, some commercially produced and some custom designed (e.g. by NASA).

In October 2002, the ESA Advanced Concepts Team organised a Workshop on Trajectory Design and Optimisation. A number of specialists were invited to take part, some to present the state of the art in trajectory design, and others to speak about optimisation techniques that are used in other fields but not yet in space. The contributors came from Russia and the USA as well as Europe.

During discussions at the Workshop, it became clear that different specialists have their own opinions and preferences as to the optimal tools and solutions.

One interesting aspect of the workshop was seeing how different countries had evolved different methodologies: for example, computing resources in Russia were rather limited in the past, and this meant they traditionally leaned towards an approach that was less demanding in terms of processing power. However, this limit no longer applies; in fact, the computational power available in modern computers worldwide is so great, and still increasing so fast, that much more complex analyses can be performed now than was possible in the past.

As well as informing the attendees, the Workshop highlighted some potential areas of research and development that may be interesting for ESA in future.

The ESA Advanced Concepts Team (ACT)

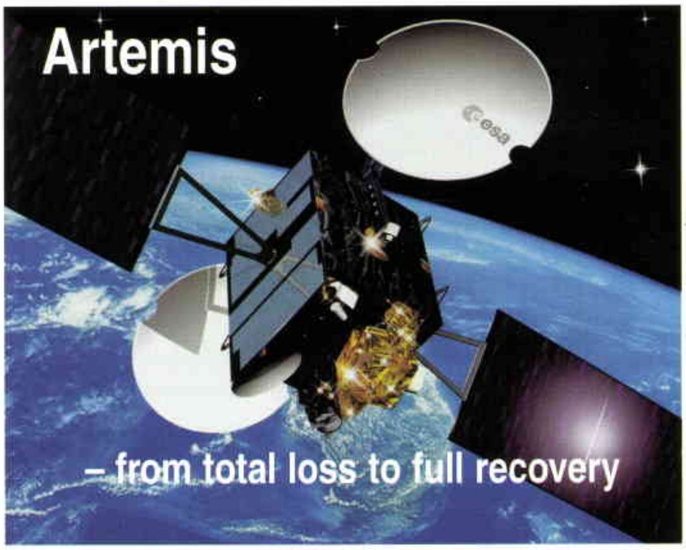
The Advanced Concepts Team is a group of scientific, technical and engineering Research Fellows (ESA's post-doc programme) working at the European Space Research and Technology Centre (ESTEC), in Noordwijk, Netherlands.

Based on strong links with academic research centres, ACT members carry out research work on leading edge concepts and emerging technologies for which both space systems engineering competence and specific theoretical knowledge are required.

The ACT is intended to provide quick and sound in-house expertise in various advanced research topics, to bridge the gap with universities all over Europe, and to develop innovative methods and approaches to problems of space exploration. In this respect, critical open-mindedness, scientific curiosity and interdisciplinary teamwork are the essential pillars of the ACT philosophy.

Current research topics comprise:
- Advanced Mission Analysis
- Advanced Space Power and Energy
- Biomimicry on Space Systems
- Near Earth Objects – Analysis of Threat
- Planetary Protection

To ensure it is always at the forefront of current thinking, the ACT occasionally organises workshops and conferences.



In the late afternoon of Friday 31 January, a final trim manoeuvre nudged Artemis into its assigned position in geostationary orbit, completing a remarkable satellite recovery operation which has lasted 18 months.

Due to a malfunction in its upper stage, Ariane-5 had left the telecommunications satellite in a lower than intended elliptical orbit. A team of ESA and industry specialists responded vigorously with a series of innovative control procedures to rescue the spacecraft. Daring manoeuvres were executed and these proved not only very successful but also highly efficient. Using almost all of the available chemical propellant, Artemis managed to reach a circular orbit at an altitude of 31 000 km only a few days after launch.

Since then, the rescue efforts have continued unabated using the four ion engines mounted on the satellite redundantly in pairs. These novel engines, instead of conventional chemical combustion engines, use ionised Xenon gas. They were originally designed only to control the satellite's inclination by generating thrust perpendicular to the orbital plane. The rescue operation, however, required thrust to be generated in the orbital plane to push the satellite to final geostationary orbit. This could be realised by rotating the satellite in the orbital plane by 90 degrees with respect to its nominal orientation.

Taking optimum advantage of the spacecraft flight configuration, new strategies were developed not just to raise altitude but also to counter the natural increase in orbital inclination. To implement those new strategies, new onboard control modes, a new station network and new flight control procedures had to be put in place. The new concept for steering the ion propulsion engines included entirely new control modes never before used on a telecommunication spacecraft, as well as new telecommand and telemetry and other data-handling interface functions. In all, about 20% of the original spacecraft control software had to be modified. Thanks to the reprogrammable onboard control concept, these modifications could be loaded by uplinking to the satellite software 'patches' amounting in total to 15 000 words, the largest reprogramming of flight software ever done on a telecommunications satellite.


The Artemis recovery team

By the end of December 2001 work on the new software had been completed, and it was subsequently validated using the spacecraft simulator as testbed. Artemis – through dogged operation of its ion engines with their modest thrust of only 15 milli-Newton – climbed at an average of 15 km per day.

After the new attitude control mode was commissioned in February 2002, and the ion engines started to expand the orbit with an almost imperceptible thrust, the workload was gruelling and almost every week brought new problems to be solved. Although generally minor, these anomalies needed investigation and sometimes resulted in an interruption in effective thrusting, slowing progress.

With these difficulties behind them, the operators turned their attention to planning for the process of station acquisition in the geostationary orbit and initial operations on station.

At altitudes only a few hundred kilometres below the geostationary ring, it takes several weeks for the satellite to drift once around the Earth. It is therefore important to avoid overshoot by tuning the drift rate to arrive at the designated station longitude (21.5 deg. East) just as the geostationary altitude is reached.

These orbital adjustments were made using small chemical propellant thrusters, activated for the first time since launch. The first thrust was performed successfully in December and two more in January, slowing the drift rate to a few degrees per day as the satellite made its last pass over Europe to arrive at its working position in geostationary orbit.

When the last manoeuvre was performed on 31 January it was an emotional moment. From the attitude control mode which had sustained the ion thrusting for so long, the satellite was turned to point to Earth for normal operations. Ground controllers were able to stand down the network of ground stations around the world that had helped in commanding the satellite.

Now on station, Artemis will function as originally planned.

The satellite can be made available to serve its first users: SPOT-4, Envisat, EGNOS and Eutelsat/Telespazio. A preparatory test will also be made with NASDA's Earth observation mission ADEOS-II. Other users planning to use Artemis in the future include ESA's Automated Transfer Vehicle and Columbus elements of the International Space Station.

Not only has Artemis clocked up a number of unique first-time applications during its recovery – first optical inter-orbit satellite link; first major reprogramming of a telecommunications satellite; first orbital transfer to geostationary orbit using ion propulsion; longest ever operational drift orbit – but it will also provide the promotional opportunity and stimulus for future European data relay services. Hence there is a promising future for this incredible mission!

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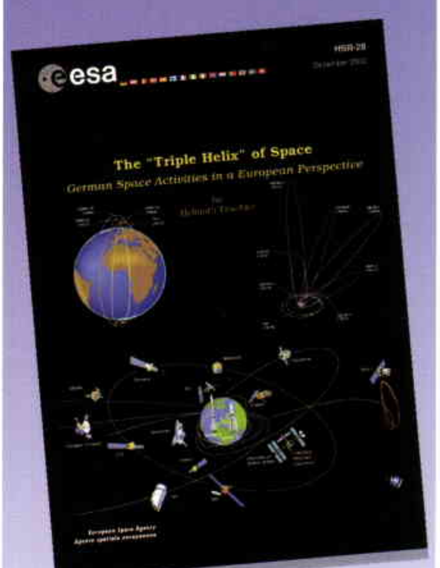

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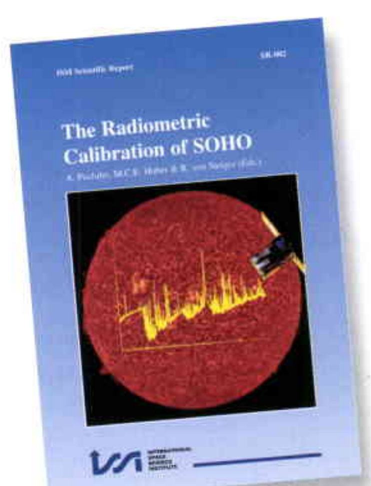

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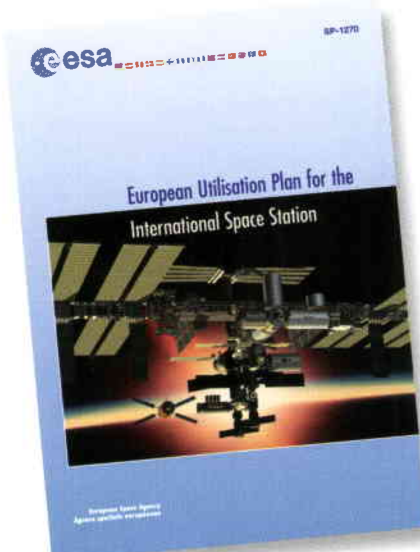

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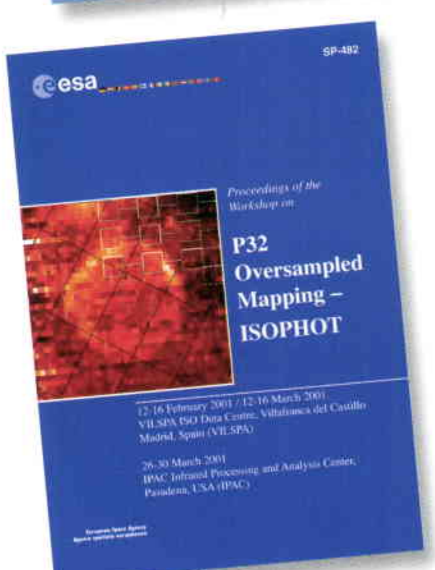

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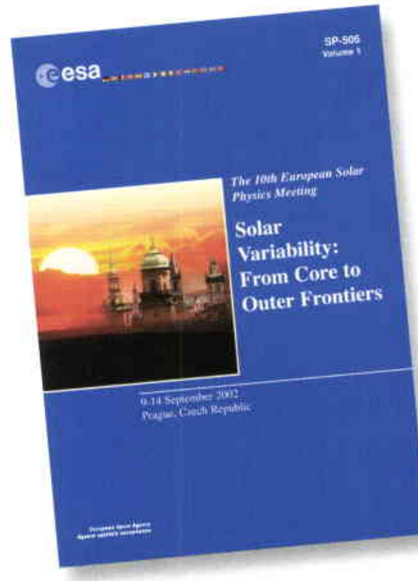

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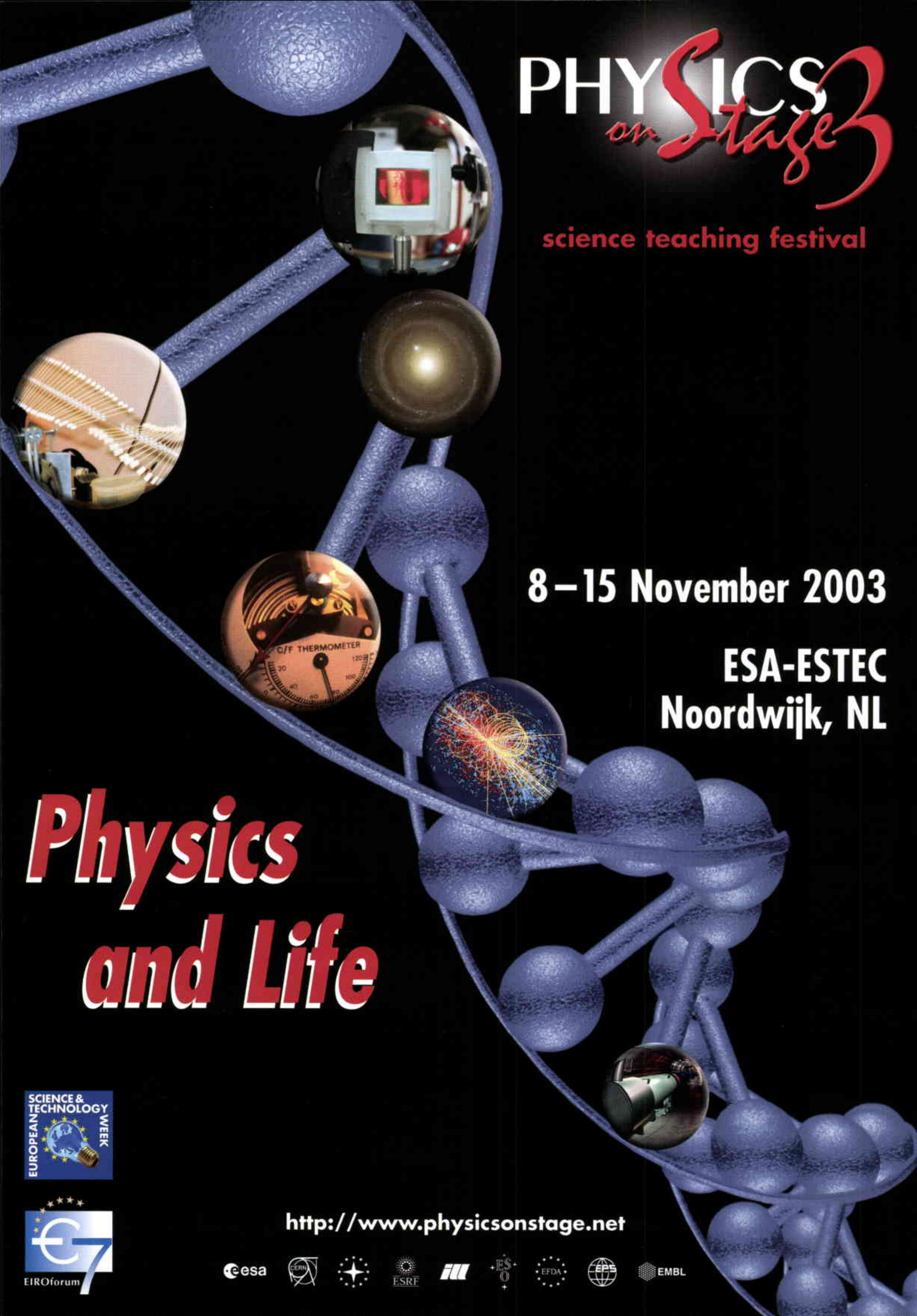
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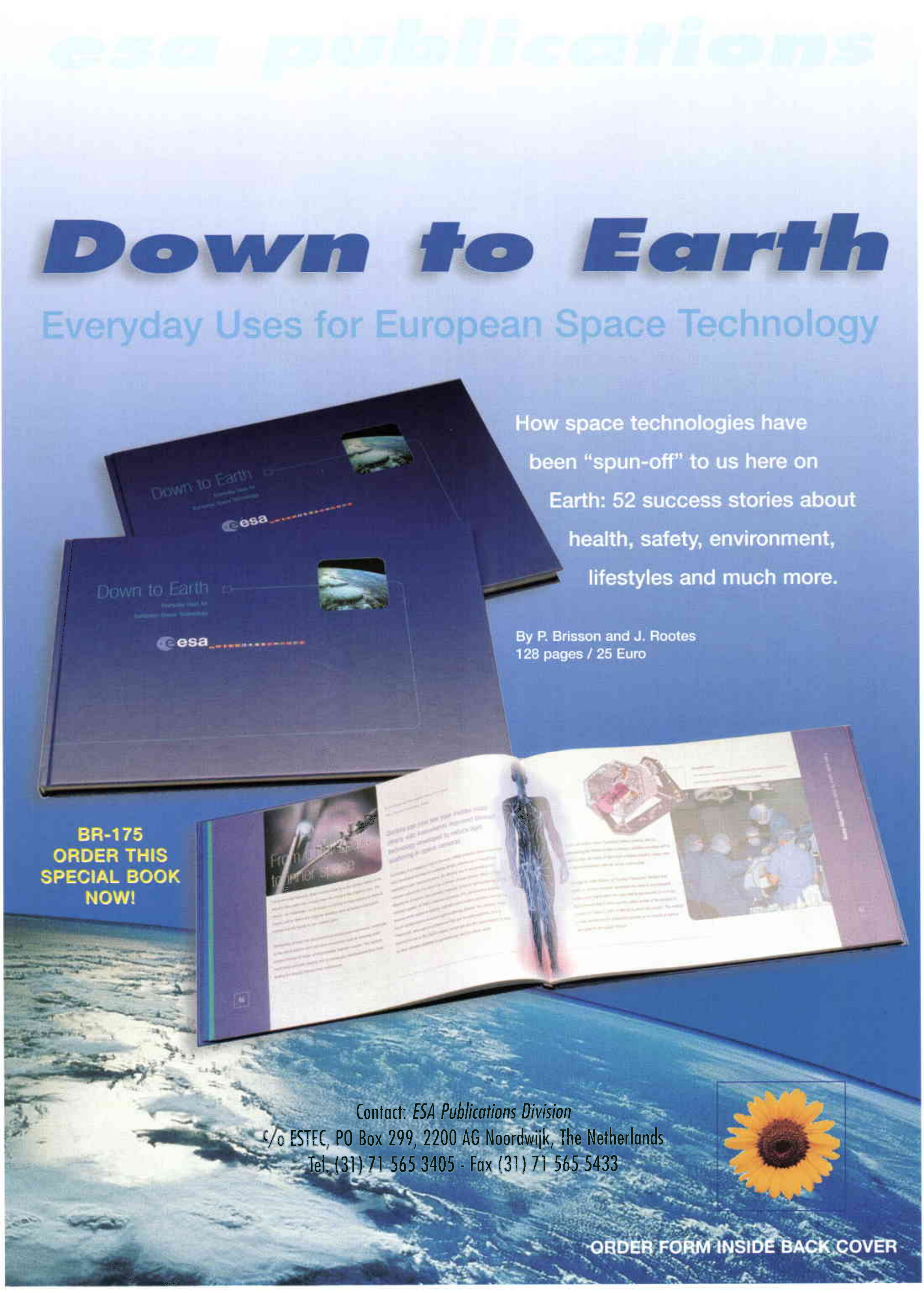
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