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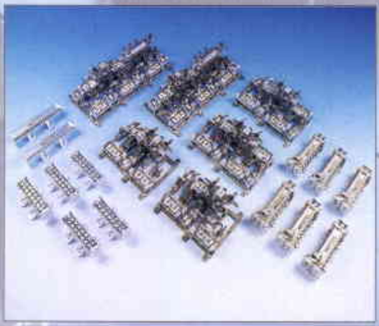

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The ESA Council at Ministerial Level

Edinburgh, 14-15 November 2001

The Director General's Proposal for ESA's Policy and Programmes

A. Rodotà

Space services are part of everyday life. TV broadcasting, weather forecasting, protection of the environment, financial services, and car-navigation all rely on globally operated satellite systems. At the same time, space is a vital tool for scientific research, serving the advancement of our understanding of the origins of life, the development of the Universe, and the complexity of the terrestrial ecosystem.

The resources offered by space also contribute significantly to meeting many of the challenges facing the Europe of today. I am thinking here of:
- safeguarding and further improving the well-being, security and prosperity of every citizen,
- protecting the environment and ensuring sustainable development, and
- preserving Europe's cultural identity, diversity and value systems,

in short, becoming 'the most competitive and dynamic knowledge-based economy in the World'.

To meet these challenges, Europe must do more than continue to exploit space effectively, drawing wherever possible on the results already achieved. It must also strive to improve the overall efficiency of the entire European space sector, which includes the efforts of scientists, industrialists, public agencies (national as well as ESA), and service companies.

Within this challenging environment, the European space community is already producing value for Europe. I am thinking in particular of:
- first-class science
- a large share in the World market for space infrastructure and services
- major contributions to public-service provision for citizens.

First-class science
Even with a continuing decline in the budget for science programmes, the European science missions have achieved significant results in the last six years:
- Soho has explored the Sun's internal structure, providing insights into the workings of the solar nuclear fusion reactor and the solar dynamo.
- Cluster is giving us a comprehensive vision of space weather.
- ISO has discovered the ubiquitous presence of water molecules in the Universe.
- XMM-Newton has greatly expanded our understanding of the composition of the enormous high-speed jets emitted by young stars.

A large share in the World market
Worldwide expenditure on space is estimated at around 70 billion Euros in 2001. The public sector still accounts for a very significant proportion of that spending, though the commercial sector is moving rapidly towards a share of about 50%.

Out of total public expenditure of about 38 billion Euros, the United States' share stands at 76%, the figure for Europe being just 14%, equally divided between ESA and the national programmes. The rest of the World spends 10% of the total.

Although in interpreting these figures account has to be taken of variations in purchasing power from one country to another, the fact is that Europe's investment is about one fifth of that of the United States. Even so, Europe has been able to secure a steady increase in its companies' share of the World commercial market – although the USA had a start of almost ten years.

In the early eighties, Europe launched no commercial payloads at all and was completely out of the market for commercial satellites, a market that had come into being some seven years before. Today, twenty years on, thanks to

substantial public investment in developing Ariane and building the first European communications satellites (ECS and Marecs), European companies have gone on to take:
- 56% of the global commercial launcher market, and
- 27% of the global commercial satellite market.

European companies have been equally successful in the telecommunications-services marketplace. They currently account for about 28% of the overall market and are increasingly globalising their business with the acquisition of large overseas international operators.

Public-service provision for citizens
There are at least three areas in which the contribution of space to the everyday life of citizens is both evident and, increasingly, vital.

The first is meteorology. Even though Eumetsat, the Agency that operates meteorological services, is currently a non-profit organisation, studies point to an indirect return on investment in excess of 8. Through the Meteosat and MetOp satellites, which ESA and Eumetsat have been jointly developing for a number of years, Europe is also contributing, together with the USA, Russia, China, India and Japan, to a global network disseminating meteorological information all around the World.

The second example is the use of Earth-observation data for disaster monitoring. The International Charter on Space and Major Disasters, initially signed by ESA and CNES, and later by ISRO, CSA and NOAA, seeks to provide a unified system for acquiring space data and delivering it to people dealing with natural or man-made disasters.

The third example is the contribution being made by space to the information-society infrastructure, providing a complementary but nonetheless important means of access to the Internet, and its enabling role for new services such as telemedicine and distance learning.

These enormously valuable results were achieved through the combined efforts, at European level, of the scientific community, industry and the space agencies.

What specific contribution has the European Space Agency made to the emergence of such first-class capabilities and the achievement of such outstanding results? I would like to focus on what I see as the three main strands of this specific ESA input:
- Programme management
- Technical management
- Internal efficiency.

Programme management
The evolution of mission cost per tonne is a good indicator of ESA's increasingly effective management of space – and in particular satellite – programmes. Mission cost per tonne has been in steady decline since the early eighties, falling by about 40%, with a roughly stable level of risk and innovation in the various programmes.

This in turn means that ESA has, over the last fifteen years, demonstrated its ability to put progressively larger payload masses into space per year, a clear pointer to the growing through-put of the entire European space sector. No such positive trend is to be found in the NASA programmes.

Technical management
It is important to underline that better performance in programme management has been obtained by ESA maintaining product quality. The following are just a few indicators demonstrating the technical quality of the Agency:
- ESA has never had any catastrophic satellite mission failures (compared with a 30% failure rate in NASA programmes).
- ESA has negotiated insurance premiums at about 50% of market rates.
- ESA satellites usually exceed their estimated and planned lifetimes (for instance, ERS-1).

Last but not least, I want to underline the recent recovery of our Artemis satellite, which, together with the earlier recovery of Soho, testifies to the excellence of our technical teams.

Internal efficiency
A lot of effort has been devoted to improving the Agency's internal efficiency. Two indicators confirm the gains in efficiency that have been made.

The first is the amount of budget managed per staff member. For programmes directly managed by ESA, the chart shows a steady yearly increase of 8.2% in recent years, compared to a 2.2% increase obtained by NASA. This has been accompanied by very tight cost control applied to ESA programmes.

The second indicator is the deviation of programme costs at completion from the costs initially estimated. Comparing the status of overruns on major ESA programmes in 1997 and in 2001 clearly demonstrates the effectiveness of the efforts devoted by managers at the Agency to proper control of all programmes, while at the same time organising industrial competition and an acceptable geographical distribution of contracts. Here again, if we compare our results with the data coming from NASA, we can be more than proud of our achievements.

I have perhaps taken too long over showing the results of the European space sector and the Agency in recent years. But I find it important, when you are about to decide on the future of the European space sector and on new investments for Europe, for you to feel convinced of the absolute necessity of these investments and of ESA's dedication to efficient, responsible use of taxpayers' money.

I would like to stress that all the reported achievements have been made possible by the continuous efforts of each and every Agency staff member and the intelligent support received from our Member States.

The Agency is now at a crossroads: it has to operate in a rapidly evolving space and industrial sector. European citizens have new requirements, and users have new demands with regard to space. Moreover, the context in which space activities are conducted is likely to be dramatically changed by the events of 11 September.

A few years ago, ESA initiated a comprehensive assessment of how it should evolve to meet the challenging demands of the future. This has already led to important results – first of all in the new relationship with the European Union. We are very proud that space has become firmly established on the European agenda and delighted that the President of the Commission will be addressing the ESA Council today.

Additional effort is now required to make space one of the pillars of tomorrow's Europe and to make ESA the Space Agency of Europe. This will translate into additional tasks for ESA. In order to maintain the quality of its work in response to these new demands, it will be necessary to slightly increase the general budget. This Council will hopefully give a clear indication in that direction, together with full support to the programmatic lines aimed at providing services to all European citizens.

I would like to come back to the events of 11 September, tragically echoed on Monday, since they have potential implications for the Agency. We have to consider whether those events put the very basis of our policies in question, or whether they simply mean that those policies have to be pursued in a number of additional directions? The Agency has already started deliberations on the matter, but it is too early to present conclusions, just a few preliminary observations.

This crisis is, indeed, a great test for Europe and does require a political response. The increasingly close links between the European Union and ESA will enable Europe to use space as a means to achieve its common foreign and security policy objectives. Technology is not an objective per se, but space technology, integrated with other technologies, will prove essential and even critical in the context of these policies. International peace and security are essential values to be preserved and space can make significant contributions to this crucial objective.

Within the complex situation emerging from the September events, it is furthermore evident that worldwide inequalities will have to be addressed in greater depth. Space systems have contributions to make in reducing inequalities: providing means of conveying education and information, supporting sustainable development, improving water and natural-resource management, enabling prevention, forecasting and management of natural and man-made hazards.

Most of the programmes proposed today for your attention address these issues. They are essential to the future of Europe. Decisions need to be taken now to ensure that Europe can use space to implement its policies in an independent manner. You,Ministers, are today called upon to take those decisions, supporting the programmes and giving the Agency the means to execute them successfully. esa

The Programmes and Budgets

The Programmes tabled for decision in Edinburgh covered the Level of Resources (Science and General Budget), Earth Observation, Telecommunications and Satellite Navigation, the International Space Station, Launchers and the start of a new European long-term initiative for the robotic and human exploration of the Solar System.

LEVEL OF RESOURCES

The Level of Resources determines the funding available for the basic activities of the General Budget and for the Science Programme.

General Budget
The General Budget covers corporate and administrative costs, technical activities such as the basic General Studies and Technological Research Programmes, plus Earthnet and Education (funding of fellowships, etc.).

The total of Member State contributions to the General Budget for the period 2002–2006 amounts to 775 MEuro.

Science Programme
The funding for the next five years should cover:

- the maintenance of scientific missions already launched (Hubble Space Telescope, Ulysses, Cluster-II, SOHO, Huygens/Cassini, XMM-Newton)
- approved scientific missions in the development phase (Integral, Rosetta, Mars Express, Smart-1, Herschel-Planck), and
- new missions under study or to be chosen and initiated within this period (i.e. the Cornerstones BepiColombo, GAIA and LISA
- with Smart-2, and the Solar Orbiter flexi-mission)

The total contribution received for the Science Programme for 2002–2006 amounts to 1869 MEuro.

EARTH OBSERVATION

Earth-Observation Envelope Programme, EOEP-2
The EOEP implements Earth Explorer Core and Opportunity missions and also funds mission exploitation, instrument redevelopment and support for market development. Earth Explorer missions such as Cryosat, the Gravity-field and steady-state Ocean Circulation Explorer (GOCE), the Soil Moisture Ocean Salinity (SMOS) mission and the initiation of full implementation of the Atmospheric Dynamics Mission (ADM-Aeolus) are major achievements of the first phase of this programme. The second phase, EOEP-2, will give the Earth Science community and industry a stable outlook whereby one new mission will be launched each year. It will also cover the preparation of Earth Watch missions.

The financial commitments received from Member States for EOEP-2 amount to 926.44 MEuro for the period 2003–2007.

Earth Watch Programme
The Earth Watch initiative will include a number of Earth-observation missions supporting public and private-sector applications such as mapping, natural-resource management, major risks and security, geology, etc. Earth Watch will also cover the requirements of the Global Monitoring for Environment and Security (GMES) initiative, currently being drawn up with the European Commission, addressing in particular global change, natural and man-made hazards, environmental stress and monitoring of treaty commitments.

The following financial commitments received from Member States for Earth Watch Slice-1 cover the period 2002–2006:

- GMES service elements: 83 MEuro.
- Thematic L/X-band SAR element based on the joint proposal from the British and German space agencies (BNSC/DLR) for Infoterra/TerraSAR: 25 MEuro.

– Consolidation of the infrared element based on the Spanish CDTI Fuegosat proposal: 9 MEuro.

TELECOMMUNICATIONS

Advanced Research in Telecommunication Systems (ARTES) Programme
Several actions/projects have been identified to further increase the competitiveness of European industry in satellite telecommunications, many of which are continuations and amplifications of ongoing activities within ESA's ARTES Programme:

ARTES 1: Preliminary Studies and Investigations
Funding for 2002–2006: 27.22 MEuro

ARTES 3: Satellite Multimedia (also covering mobility and inter–satellite links)
Funding for 2002–2006: 213.3 MEuro

ARTES 4: ESA/Industry Telecommunications Partnership (dealing with part of the technology and user-segment activities)
Funding for 2002–2006: 165.3 MEuro

ARTES 5: Advanced Systems and Telecommunications Equipment (consisting of technology, user segment and in-orbit demonstration)
Funding for 2002–2006: 53.85 MEuro

ARTES 8: Large Platform Programme
Funding for 2002–2006: 133.85 MEuro

Additional funding for the ARTES programme yet to be allocated to specific activities: 350 MEuro

Galileo Programme
Europe's global navigation system, Galileo, is a joint initiative of the European Commission and ESA and will deploy a full constellation of navigation satellites by the end of 2008, with superior technical and operational capabilities compared with the American GPS and Russian Glonass systems.

After a Definition Phase (end 1999 – end 2000) devoted to overall system design, Galileo is now entering its Development and Validation Phase (2001–2005). The in-orbit validation of the system is based on the deployment of a limited constellation of three to five satellites and a representative ground-control segment and test receivers.

ESA's contribution to the Galileo Development and Validation Phase is 527.87 MEuro. A similar contribution is expected from the European Union in December.

The full Galileo system will consist of some 30 satellites in medium Earth orbit at 24 000 km altitude, and the associated ground infrastructure. The cost of the overall Galileo project is estimated at some 3 BEuro. Financial schemes for the deployment and operational phase are currently being finalised.

HUMAN SPACEFLIGHT AND MICROGRAVITY

ISS Exploitation Programme Continuation
The objectives of the Programme are to develop European operational capabilities in the key areas required for long-term human space exploration, to build up the knowhow necessary to master the operation of a complex human outpost in space, and to support exploitation of the ISS by the European user community.

Exploitation Period 1 (2002–2006) covers activities such as partial funding of the first Ariane-5 and full procurement of the third Ariane-5 for the ATV, plus ATV procurement activities, including the first production unit. Period 1 of ISS exploitation is composed of fixed and variable cost activities.

The finances available for this programme amount to 846.69 MEuro.

Human Spaceflight Studies, Technology and Evolution Preparation (STEP)
The objectives are the improvement of existing ISS services, the reduction of operational costs and the preparation of future infrastructure capabilities. It is conceived as a framework programme structured in periods of three years, with contributions on a 'pay as you go' basis.

The first three-year period of activities (2002–2004) is funded with 12.4 MEuro.

ISS Commercialisation Utilisation Programme
This Programme is designed to lay the foundation for commercial utilisation of the ISS, to stimulate commercial utilisation to generate revenues and thus reduce the contributions payable by participants in the ISS exploitation programme, and to promote the image of the ISS in order to attract a larger community of users.

This Programme will be submitted for approval when the overall ISS situation is clarified.

ISS Additional Flight Opportunities Programme
This Programme's objectives are to maintain and develop an active and experienced

European Astronauts Corps, offering further flight opportunities. The Programme, which envisages the procurement from Russia of four Soyuz flights to and from the ISS in the period 2003–2006, will be submitted for approval in connection with the submission of the European astronaut policy in Spring next year.

ELIPS Programme
The Programme's objectives are to maximise the benefits to society of ISS utilisation, to promote European competence and competitiveness in the life and physical sciences, to pursue basic scientific research in the life and physical sciences and also industrial and commercial applications in space, and to set up a coherent framework for European activity in this area.

The financial envelope for Period 1 of the Programme (2002–2006) amounts to 166.52 MEuro at 2001 economic conditions.

LAUNCHERS

Ariane-5 Research and Technology Accompaniment (ARTA-5) Programme
The objectives of the ARTA-5 Programme are to maintain the reliability and level of qualification of the Ariane-5 launcher throughout its operational lifetime, to eliminate any design flaws and weaknesses that might appear during operational use, and to improve knowledge about the functional behaviour of the launcher in flight.

The four-year extension of the ARTA-5 Programme (2003-2006) is funded with 302.97 MEuro (2001 e.c).

Ariane-5 Infrastructure
This Programme, covering the fixed costs of the ELA-2 (Ensemble de lancement no. 2) and ELA-3 launch complex facilities, covers the period 2002–2004.

The three-year extension is funded with 131.45 MEuro (2001 e.c.).

Guiana Space Centre, CSG (Centre Spatial Guyanais)
The agreement on CSG management and funding has until now covered the upkeep and operating costs of the Centre's range facilities to ensure long-term stability of the strategic investment in Europe's assured access to space.

The new proposal covering CSG's fixed costs for the five-year period 2002–2006 has a budget of 423.2 MEuro (2001 e.c.).

Ariane-5 Plus
The objective of this Programme is to ensure that Ariane-5 evolves and remains competitive on the World market by increasing its performance and versatility, and bringing down the launch price.

The Ariane-5 Plus Programme has been broken down into three steps. The first step, decided at the Council Meeting in June 1998, covered the first year of activities. The second was decided at the Council Meeting at Ministerial Level in May 1999 and covered the initial development of the Vinci engine, initial ground segment upgrading and full development of the versatile version of the existing upper stage, together with completion of the Ariane-5 ESC-A version (first launch planned for mid-2002), raising its lift capacity to geostationary transfer orbit to 9 tonnes.

The third step will round off the Programme, and will see the completion of Vinci engine development, completion of the ground segment upgrade, and completion of the Ariane-5 ESC-B version and its first launch (planned from 2006), bringing the GTO lift capacity to 12 tonnes.

The completion of the Ariane-5 Plus Programme has a budget allocation of 699.14 MEuro (2001 e.c.).

AURORA PROGRAMME

Aimed at developing a European long-term plan for the robotic and human exploration of bodies in the Solar System, in particular those holding promise of traces of life, the Aurora Programme activities will be pursued in coordination with European and international partners. Relevant technologies and mission scenarios will be developed in the three-year preparatory period.

The overall financial commitment for the first three-year period is 14.1 MEuro (2001 e.c.)

ESA Press Release

15 November 2001

The Ministers responsible for space affairs in the countries that make up the European Space Agency – its Fifteen Member States and Canada – today concluded a two-day meeting in Edinburgh of the Agency's ruling Council by endorsing the next stages in a series of ongoing programmes and committing to new initiatives that will help keep Europe at the forefront of space science and technology, Earth monitoring from space, telecommunications, satellite navigation, launchers, human space flight and planetary exploration.

In particular, ESA and its Member States made significant progress in shaping a range of future-oriented programmes, with major decisions aimed at enhancing Europe's role in the space sector.

The Agency signalled its strong commitment to closer cooperation with the European Union. A first Resolution highlighting the importance of a balanced, ambitious space programme serving Europe's citizens was adopted unanimously.

The Members agreed on a Declaration embodying financial commitments for the development of Galileo, Europe's satellite-navigation system. ESA now looks forward with confidence to the European Union Transport Ministers' approval of their contribution to Galileo at their December meeting. Galileo is a major component of Europe's transport policy and will be deployed in partnership with the business sector. It will offer a wide range of independent navigation services for commercial and private users, and promises to generate new commercial services in areas such as road-vehicle navigation and air-traffic control.

Further collaboration with the European Union will focus on the Global Monitoring for Environment and Security (GMES) Programme, which will address such issues as global change, natural and man-made hazards, environmental trends and monitoring of treaty commitments. Earth observation is today an essential resource for surveillance of the environment and the management of natural resources. GMES and a number of other Earth-observation projects were approved as the first elements in a series of applications missions within the Agency's Earth Watch initiative.

The Delegations also decided to back a programme that will see the Ariane launcher, which for many years now has held more than half of the World market for commercial launches, evolve in terms of power and versatility. ESA is confident that Ariane will remain the World's number one choice for carrying commercial satellites into orbit. The European strategy for independent and affordable access to space is based on the provision of competitive European launch systems. The Ministers stressed that to make that strategy work the right balance has to be struck between the respective roles, responsibilities and financial commitments of the public and private sectors. Restructuring of the launcher sector in Europe would be another key factor.

Concerning the ongoing discussions in the United States on the future configuration of the International Space Station (ISS), the European Ministers sent a clear message to the ISS partners confirming that ESA will fulfil all of its obligations, and by the same token expects NASA to keep to the International Treaty. ESA's main focus of interest is an intensive scientific research programme calling for specific onboard resources, one being the presence of full-size crews. One of the Resolutions passed by the Ministers, concerning ISS utilisation, provides the financial resources required by ESA, but makes release of the final 60% conditional on NASA's confirmation of the original agreement.

The Science Programme is the backbone of ESA's activities – its highly successful missions have made Europe a World leader in space science. The outcome of the meeting ensures that science at ESA will remain a European flag carrier, contributing to our knowledge-based society.

Telecommunications satellites provide services that enhance many aspects of our lives, and Europe already provides more than a quarter of the World's commercial platforms. The ongoing ARTES Programme will lead to new services and offers the prospect of continuing commercial success in a rapidly evolving market.

Europe now needs to exploit the strategic potential of space systems more effectively to further its scientific, economic, social and political objectives. The Ministers acknowledged this in Edinburgh by renewing and expanding ESA's mandate to establish closer ties with the European Union.

The process of wedding the public policy objectives of the European Union and the capabilities of the European Space Agency got underway some years ago. ESA is increasingly committed to closer cooperation with the European Union to further its aim of putting space at the service of European citizens, and also to focus attention on space at the highest political level in Europe. Pursuing these goals, ESA and the EU are now engaged in the development and implementation of a truly European space policy. The foundations of that policy were laid in November last year, when the ESA and EU Councils endorsed a joint document on a European Strategy for Space.

As Europe grows, ESA is bound to grow too: the recent accession of Portugal, the interest expressed by Greece in becoming a Member State, and the intensifying cooperation with Central and Eastern European countries, all testify to the continuing vitality of the Agency and its programmes.

The cooperation extends beyond Europe, with last year's renewal by Canada of its long-standing Cooperation Agreement with ESA and an expansion in the Agency's joint work on facilities and programmes with the United States. Japan and ESA are also working together closely in Earth observation and science. The existing cooperation arrangements with Russia will be further developed in areas of benefit to Europe. Ventures involving emerging space-faring nations – notably in the Asia-Pacific region and in Latin America – are also on the ESA agenda.

Outstanding space programmes are only possible with a strong technology base, which is the key to the competitiveness of European industry in World markets. The Ministers sought therefore to underline the importance of deriving maximum benefit from technology, with measures to encourage technology transfer and spin-off.

The Ministers expressed appreciation for ESA's efforts in coordinating communication and education programmes and in encouraging young people to widen their career horizons. They urged the Agency to make European citizens more aware of the knowledge and benefits they can derive from European-led space research.

The closing Press Conference: from right to left, Minister Edelgard Bulmahn of Germany, who chaired the Edinburgh Ministerial Conference, Mr Antonio Rodotà, ESA Director General, and Mr Franco Bonacina, ESA Spokesman

Council in Session

Lord Sainsbury hands over the Chair to Mrs Edelgard Bulmahn

Welcome by the Lord Provost of Edinburgh, the Rt. Hon. Eric Milligan

The participating Ministers, together with EC President Romano Prodi


NORWAY


FINLAND


IRELAND


CANADA


PORTUGAL


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SWITZERLAND

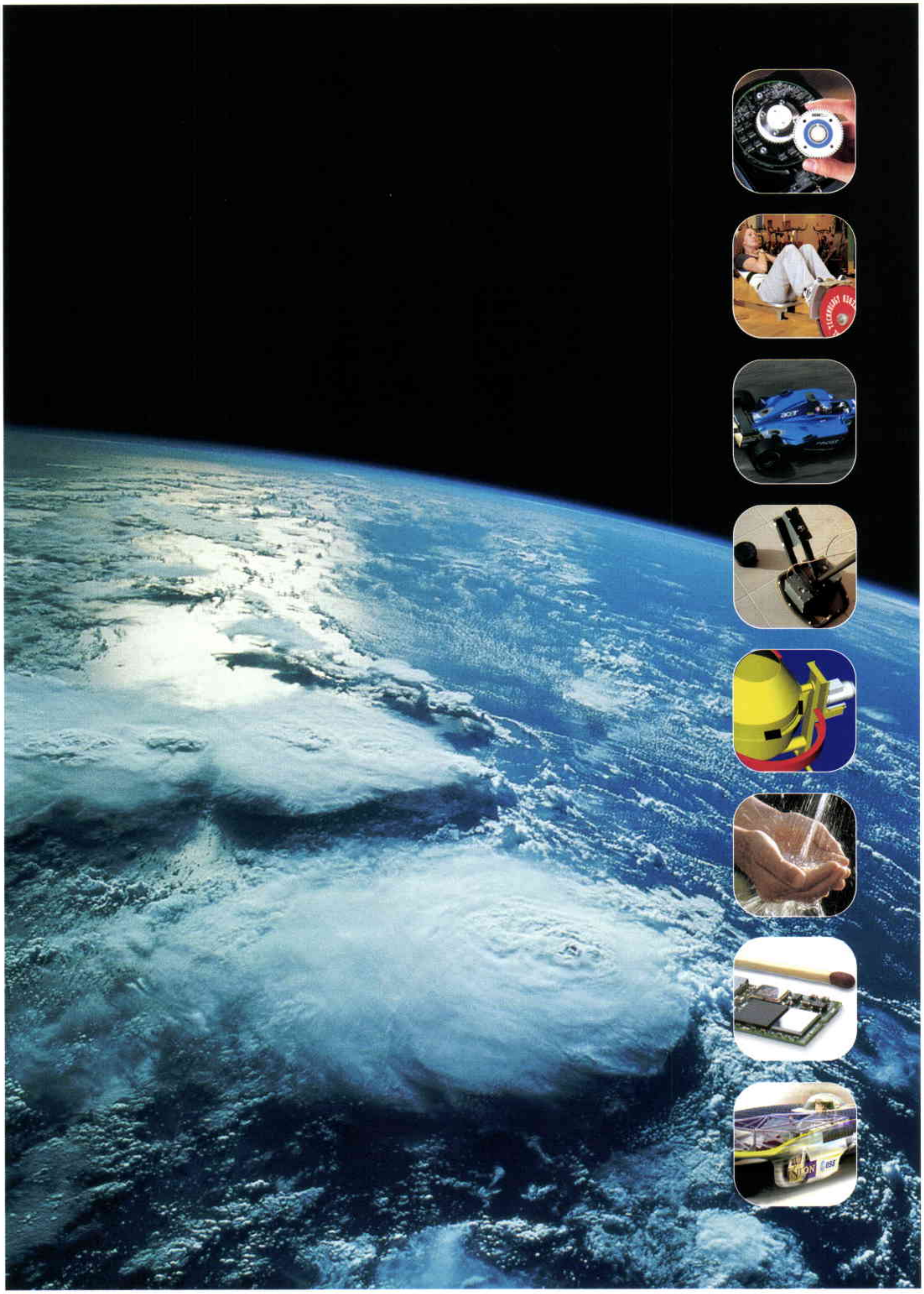

ITALY


FRANCE

OBSERVERS

Arrival of Mr Romano Prodi

The closing Press Conference



Down to Earth
– Everyday Uses for European Space Technology

P. Brisson & D. Raitt
Technology Transfer Programme, ESA Directorate of Industrial Matters and Technology Programmes, ESTEC, Noordwijk, The Netherlands

J. Rootes
JRA Technology Ltd., Marlow, United Kingdom

Introduction

Technology transfer is the process of using technology, expertise, know-how or facilities for a purpose they were not originally intended for by the developers. Technology transfer thus implies that a technology developed for one sector is then used as a spin-off in a totally different area. It often results in the commercialisation of products through licensing or the improvement of products and processes – though this usually takes a couple of years to happen.

Every year billions of dollars are spent on research and development activities in virtually every technological sector. Sadly, although many such activities have a wide potential of application, the results of this research are still a long way from commercialisation. However, companies, research organisations and academic institutes are now waking up to the fact that it has become increasingly necessary to exchange, transfer and license the technologies (including software) and knowledge they have developed in order to access new markets and revenue streams. On the other hand, it also becomes ever apparent that companies need to acquire new technologies, particularly the leading-edge technologies being developed within the space industry, in order to exploit their ideas and create new products.

Where space is concerned, it is worth bearing in mind that much of the technology that lies at the heart of spacecraft and their systems has its origins on the ground – the earliest space systems were based on established 'terrestrial' technologies. What space programmes have done over the past 40 years is to invest in raising these technologies to new levels of performance and capability – and this is the benefit that is 'spun off' to us here on Earth. The reason, as is made only too clear by the occasional costly failure on the launch pad, is that space exploration is a complex and risky business. It is also very difficult to get into space to fix equipment when it breaks down, and it used to be impossible before the advent of the Shuttle. From the outset then, reliability has been the primary requirement for spacecraft systems. Wherever possible, early designers sought out tried and trusted materials and components with which to make their spacecraft, and most of these were themselves spin-offs from the European and US defence and weapons industries developed after the Second World War.

What space research has done has been to develop and perfect these technologies to unprecedented levels such that the technologies can be transferred to new and often highly beneficial applications down on Earth. The range of these applications is enormous and organisations have established special programmes to facilitate technology transfer and commercialisation.

In the framework of its research and development (R&D) activities, ESA spends some 250 million Euros each year and, recognising the enormous potential of the know-how developed within its R&D activities, set up a Technology Transfer Programme over ten years ago. The Programme saves money by adapting space technologies, systems and know-how to other non-space users and applications. It maximises the return on investment in space research conducted by ESA for the benefit of its Member States and minimises the duplication of research between the space and non-space sectors. In addition, the Programme provides opportunities for researchers to collaborate with other organisations, thus allowing the possibility for two-way transfer – both through spin-off from space to non-space sectors and 'spin-in' of technologies developed in non-space sectors which might be relevant for space.

Over the past ten years, ESA's Technology Transfer Programme has achieved some remarkable results:

- more than 100 successful transfers of space technologies
- over 120 million Euros received by companies making the technologies available
- 15 new companies established as a direct result of exploiting space technologies
- nearly 2500 jobs created or saved in Europe
- a portfolio of over 450 space technologies available for transfer and licensing.

This article provides a few examples of successful transfers of space technologies that have been achieved in Europe and Canada over the past few years.

Applications for Health and Fitness

A healthy outlook

Using technology that enables astronomers to probe the distant reaches of the Universe – and with a little help from the glow worm – biomedical researchers can see deep inside a living cell. Like all modern optical instruments used by astronomers, the Hubble Space Telescope's Faint Object Camera (FOC), developed by ESA, exploits detectors called 'charge-coupled devices', or CCDs. These are silicon chips consisting of arrays of light-sensitive 'pixels', which convert impinging light into an electric charge that can then be used to generate an image. Today, CCDs are found everywhere – in digital and video cameras, for example, and in the office photocopier – but those employed in the Faint Object Camera are rather special in that they can detect single particles of light (photons).

These CCDs are controlled by special software, which ESA subsequently licensed to a British company specialising in making CCD cameras for biomedical applications. The company supported the work of medical researchers in the UK who were using some novel techniques for 'observing' the workings of living cells. Inserting a bio-luminescent protein extracted from glow worms into a living cell illuminates the cell's activity. The luminescent molecules attach themselves to calcium ions (thought to be the cell's 'messengers'), which can then be followed visually as they move around the cell. Using the CCD detector, cells can be seen responding in real time and, in an early experiment, the response of a seedling being touched by an ice cube was noted. This ability to observe the innermost workings of a cell is important in understanding and controlling disease, and is the focus of much of the current work.

The story does not stop, however, with CCDs. The technology is moving on and a new type of light detector called a superconducting tunnel junction (STJ) diode is being developed, which can also register the colour of the photons – information of great interest to astronomers and biomedical researchers alike. Researchers at the University of Wales College of Medicine are now developing a range of genetically engineered 'rainbow' proteins, programmed to change colour when they bind with a particular chemical in a living cell. This research has exciting implications for our future health. For example, a potentially cancerous cell will change from red to green, or from red to blue, and the next generation of cameras will be able to record this, providing scientists with more valuable information for the fight against the deadly disease.

How nosy can you get?

In a different application, technology that emulates our sense of smell is now being used to detect infections. The human nose is extremely sophisticated – it can detect and distinguish a huge range of odours and, as well as informing and enhancing the experience of eating, our noses also act as early-warning devices by helping to sense danger or decay. If you smell gas at home, it is usually easy enough to locate the source. This is not quite so easy to do in space, however, and this is why ESA supported the development of sensors to act as gas detectors on space stations such as Mir.

Scientists studying how smell works in humans have employed electronics to mimic the processes involved. Arrays of sensors can imitate the different types of olfactory receptors found in our noses. Processing electronics then convert the signals from the sensors into patterns and store them for future recognition. Typical 'electronic noses' employ many different types of sensors and sampling devices. The University of Manchester Institute of Science and Technology (UMIST) in the UK was contracted by ESA to produce a gas-sensing device for monitoring vital safety functions on Mir – the air quality, in particular any contamination resulting from leakages, and also signs of any fire break-outs.

In 1994 the technology was transferred from UMIST to a company called Aromascan (now Osmetech plc). Osmetech employs sensors made of conducting polymers arranged in arrays of up to 48 individual detectors. The way the polymers are arranged is unique to Osmetech and enables each element on the array to have a different conductive property. These multiple sensors can detect a range of distinctive smells and odours. Osmetech realised that there were many potential applications for the electronic-nose technology.

Figure 1. The Osmetech core sensor array

For example, when micro-organisms metabolise, they emit volatile components often possessing a characteristic smell, which the Osmetech sensor array technology can detect. The company recognised that the sensor arrays could therefore detect the presence of pathogenic bacteria, fungi and moulds such as those causing urinary tract infection (UTI), infections that result in women going into early labour, bacterial throat infections and pneumonia. These sensors can now be incorporated into automated multi-sample instruments for use in a hospital laboratory or at the doctor's surgery.

Keeping fit with a yoyo

Keeping fit in the weightless environment of space requires special kinds of exercise programmes and equipment. In space, everyone can manoeuvre objects they would not have a chance of lifting on Earth, but the downside of this is that the body does not get the exercise it needs to keep in top condition. Being in space is an extremely demanding activity, and a huge amount of attention is paid to astronauts' well-being and fitness, particularly as missions get longer and longer. Engineers and doctors are working together to design equipment and exercise programmes suited to the specific needs of space travel and weightlessness.

YoYo Technology based in Stockholm, Sweden has developed a machine designed to meet these unusual requirements. With support from the Karolinska Institute, the Swedish Space Corporation and the Swedish National Space Board, YoYo has developed equipment that uses the inertia of flywheels to provide resistance. The Fly-Wheel Resistance Exerciser differs from the normal equipment found in gyms because it provides 'two-way' resistance. The user is required to pull the cord from a flywheel and at the full stroke the flywheel begins to wind the cord back in. The user has then to resist this by pulling back on the cord. In effect, this is the same principle as that behind the familiar children's toy of the same name. The advantage of this system is that the load can be easily varied by changing the flywheel or altering its diameter. Users can also determine the amount of 'impact' in their training. Unusually, astronauts in space are encouraged to do high-impact exercise as it maximises body strength while minimising bone loss at the same time.

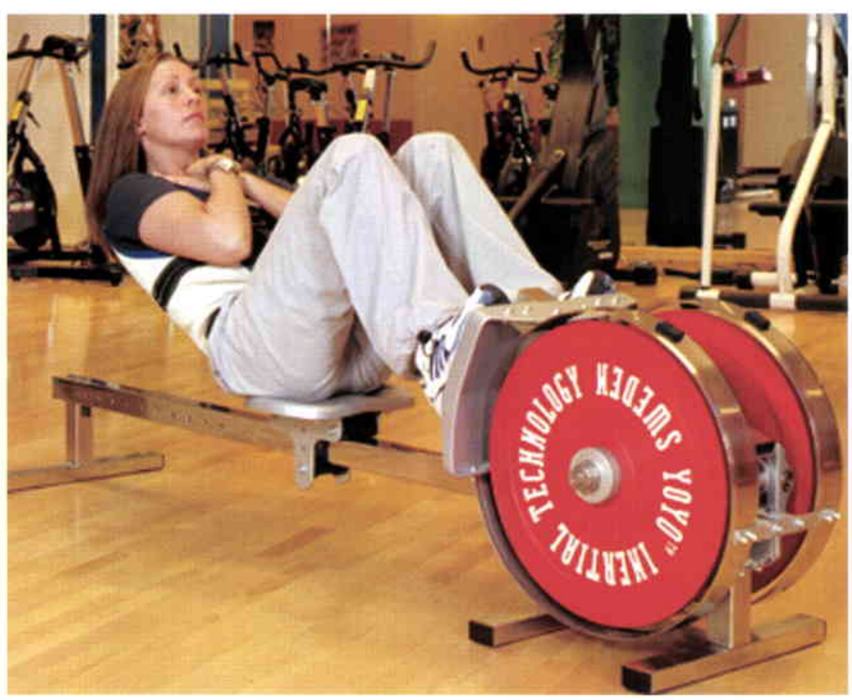
Having successfully designed equipment to meet the needs of the space industry, YoYo Technology is now turning its attention to terrestrial applications such as sports training and medical rehabilitation. The equipment is used by the Swedish Olympic athletics team, and also employed in orthopaedics to aid the recovery of stroke patients. It is proving particularly useful in re-establishing nerve connections in damaged muscles. A variant of the equipment is also being developed for use in home gyms, a market worth many millions of Euros worldwide.

Materials for Vehicle Security

Fabricating a defence against thieves

Vehicle manufacturers are continually looking for ways to improve reliability and safety. Technology originally designed for space applications can contribute to such developments. Belgian Spacelink partners (Spacelink is the ESA Technology Transfer Programme's network of technology brokers) introduced a French textile manufacturer to a consortium who needed to tackle road- and rail-transport theft across Europe. Theft from lorries and haulage containers is a growing problem, with those vehicles whose sides are

Figure 2. One of YoYo Technology's flywheel-based exercisers



made of fabric being particularly vulnerable to attack. Cargo containers spend a lot of time unattended in loading or storage depots and their tarpaulin covers, while light and convenient to use, offer little protection against the knives of vandals and thieves. By 1996, so serious had this problem become that three companies, a French manufacturer of haulage containers, a Belgian plastics and composites company and a large Belgian rail/road haulier, joined forces with CRIF – a Belgian collective industrial research centre – as the main focus of research to develop a new protection system for containers. The work was supported under the European Commission's CRAFT scheme.

The initial studies pointed towards the development of a better material for fabric screens, which would retain the advantages of lightness, flexibility and ease of cleaning, while offering great strength and resistance to attack. But where to find such a material? As part of its ESA-sponsored work, the Spacelink network surveys non-space companies throughout Europe to determine what kind of technology they might need. It was through this mechanism that the Belgian Spacelink partner Creaction circulated the requirement for a vandal-resistant textile and got a response from a French company Société Ariégeoise de Bonneterie which, following the success of its flame-proof textiles used on the Ariane rockets, had modified its knitting technique to create a flexible fabric from steel wire that was extremely difficult to cut and well-suited to the application.

By December 2000, research was completed and large-scale testing had begun. Parcouri, a consortium of eight European companies that includes a Dutch multinational producer of vehicle covers and a French SME specialising in coach building and kit fixing systems, is now developing a vandal-resistant alternative to the standard tarpaulins currently in use. Within an existing global market of 120 000 units a year, current predictions for the new material show a healthy potential market opening of 7000 units annually.

Hot brakes and airbags

Two French companies are also showing how vehicle safety is being improved with space technologies. Composite materials composed of a carbon matrix reinforced with long carbon fibres can withstand high temperatures, and are very resistant to wear. These materials were originally developed for use in the extreme conditions found in the nozzles of rocket motors. The developers realised that brakes made from such composites were more reliable, reduced vibration, and caused less pollution than traditional braking systems fitted on planes and road vehicles. Messier-Bugatti, based in France, produced a novel carbon braking system for use on aircraft such as the Airbus and now supplies one third of the world market for carbon composite brakes for commercial planes with more than 100 seats (over 230 planes were equipped in 2000 alone). Similar systems have also been employed on Formula-1 racing cars, heavy goods vehicles and passenger trains.

Another important safety feature – the airbag – has contributed a great deal to safe car travel in recent years, saving many lives and helping to prevent serious injury in collisions. Today, the device is considered to be one of the most important safety features since the seat belt was first introduced in the 1960s. When an impact above a certain force is sensed, the airbag inflates: an igniter activates compressed-gas capsules and these fill the bag with an inert gas. The whole inflation

Figure 3. A Formula-1 racing car with carbon brakes

process occurs within a split-second and the bag is completely deployed in less than one second -- fast enough to save the driver. As most new cars use such safety devices, the market for the pyrotechnic charges is large. The French company SNPE Propulsion is using its knowledge in the field of solid propulsion for space launchers to design and develop the pyrotechnic charges used in airbag gas generators and seat-belt tighteners. SNPE Propulsion estimates that its products are used in one out of every four safety devices fitted into new cars each year.

Improvements for Seeing and Feeling

A cracking solution

Ginger, an ESA technology effort, set out to develop a ground-penetrating radar in support of a proposed programme to explore the Moon. Now, the same technology is showing great promise in two new life-saving roles – in preventing mining accidents and in detecting landmines. As computer processing power increases and becomes cheaper, ever more complex signal processing can be applied to radar signals and, by careful choice of frequencies, it is now possible to use portable radars to penetrate the ground and produce images of hidden structures and objects. In tunnels deep underground, liners and supports are often used to maintain their integrity. In some areas where the rock is hard, fine cracks can lead to tunnel collapse and a phenomenon known as 'rockburst'. Until now, all that miners could rely on was experience and intuition to tell them what is hidden beneath a rock surface, so a means of assessing the rock conditions and the integrity of underground supports would be of great benefit.

Based on the work of Ginger, RST Radar Systemtechnik of Switzerland and MIRARCO of Canada have developed CRIS, a dedicated ground-penetrating radar prototype, to detect cracks in the walls and roof of mine drifts. The radar can look through metal mesh and spray-on linings. It can identify cracks from a few millimetres to a depth of more than one metre. A hand-held CRIS prototype has been field-tested and has successfully met all design targets. Future work will concentrate on perfecting the device for use in the harsh underground environment.

Finding land mines

Ground-penetrating radars hold out great hope in another area. Anti-personnel land mines have become virtually undetectable and they carry a high toll in terms of injuries and lives each year. Now, four industrial partners, Vallon, RST, Spacebel and Bats, and four research organisations, DLR, RMA, ONERA and ISL, have joined with the Universities of Karlsruhe, Bochum and Milan to create 'HOPE', a hand-held multi-sensor land-mine detector. It consists of a metal detector, a radiometer and a ground-penetration radar. The aim is to reduce the number of false alarms when detecting mines, to speed up the process and to improve safety for operators. The 5 million Euro development is being partially funded by the Schweizer Nationalfond, the ESA Technology Transfer Programme, and the European Union, with a further 50% from industry.

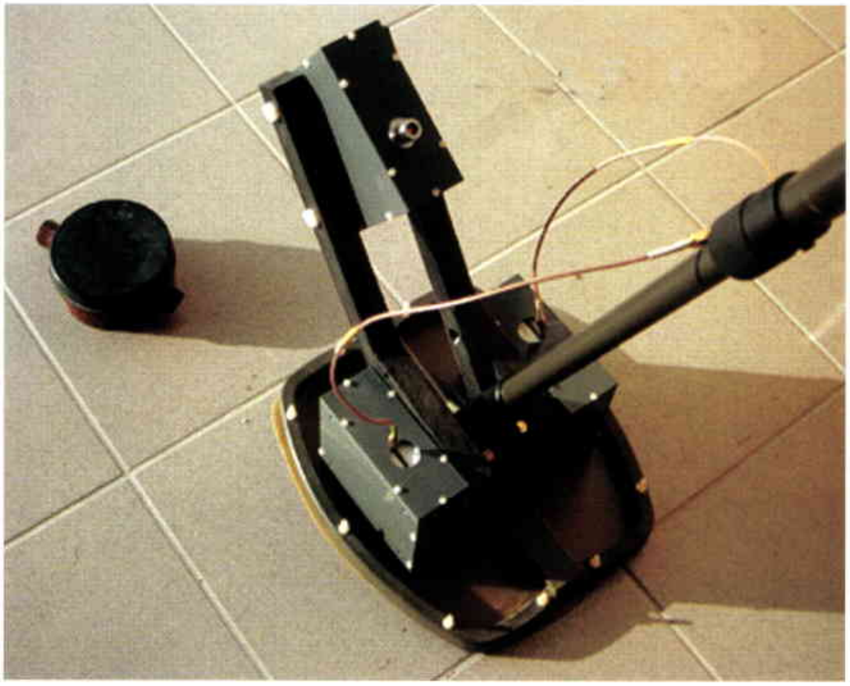


Figure 4. The Hope detector, and an anti-personnel mine

So far, the results are very promising. The three-sensor device detects foreign bodies, including plastic mines, by collecting radar data from the ground in horizontal slices; advanced off-line techniques can then be employed to generate a 3D image of the body to ascertain whether the object is a mine or some harmless piece of metal or rock. A prototype system in Bosnia has successfully detected small land mines to a depth of 40 cm.

A human touch

However, seeing is only one sense – feeling is another. To help in the construction and maintenance of the International Space Station, the Canadian Space Agency has been coordinating the development of the 'Special Purpose Dexterous Manipulator' (SPDM). This is a two-handed robot which is essentially an extension of the astronauts' own limbs. Until recently, these augmented limbs lacked one critical feature – a sense of touch! Without a sense of touch, machines can accidentally knock into other objects, which in space can have drastic consequences. Although automated vision systems have been under intensive development for several years, tactile sensing technologies are still rare and relatively primitive.

Recognising this challenge, Canadian company Canpolar East developed KINOTEX – a novel sensor that imitates human touch and can be applied like a skin or sleeve to cover entire robotic limbs. Described as a 'deformable integrating cavity', the sensor consists of a sheet or block of polymer foam with an opto-electronic transducer embedded in it. When the foam is deformed, its optical properties are altered, generating a signal in the transducer. Normally arranged in arrays, these sensors can detect and interpret contacts at many points over the surface of the machine. Because they use light to detect change, KINOTEX sensors can be very small and are immune to interference from such sources as electromagnetic radiation. They are also very responsive, sensing minute amounts of pressure and reacting extremely quickly to change.

Canpolar East is aware that KINOTEX could have many commercial uses and is adapting the technology in partnership with a number of other organisations. One of the first companies to market an application is Tactex Controls. Their KINOTEX touch pad measures the pressure and position of fingers placed on its surface, so a musician can 'play' it like an instrument. The touch pad can also be used to control mixers and other sound processors, and in 2001 it won an award for 'Most Innovative Product' from a leading music-industry publication. Tactex is also developing touch pads for the computer-games market. Many other industries are also implementing KINOTEX products. For example, car companies have acquired the rights to develop pressure-sensitive car seats that help increase safety. The KINOTEX sensors are also being considered for incorporation into energy-absorbing bumpers to determine the severity of crashes and detect collisions with pedestrians.

Getting Rid of Bad Vibes

Disturbing cables

Anti-vibration technology developed from space platforms is finding wide application in the building construction and instrumentation markets. In space, problems with very small vibrations are particularly acute and since satellite instruments usually focus their attention on small objects at very great distances, any local disturbances become greatly accentuated. These same instruments must often rely on motors and moving parts that excite the very vibrations that impede their performance.

Sensors are used to detect unwanted vibrations and, through a control loop, electromechanical actuators are used to cancel them out. The active damping of a truss structure using piezoelectric actuators was successfully demonstrated as early as 1989 and attracted ESA's interest. This early success led to several collaborations with European aerospace companies and research laboratories. A first in-orbit active-damping experiment was flown in 1995. A leader in the field, the Université Libre de Bruxelles, created a spin-off company in 1999 called Micromega Dynamics which specialises in active vibration control.

Micromega is also investigating active-damping technology to control long cable supports like those used in Space Station construction and suspension bridges. Cable-stayed bridges already span 750 metres and in future may exceed 1000 metres. These structures are very flexible and, as a result, they are sensitive to wind and traffic-induced vibration. To improve their structural damping, Micromega places an actuator at the end of each cable. The actuator, obeying signals from an associated sensor system, exerts a force that counteracts and cancels incoming vibrations. Cable structures are increasingly seen in large construction projects, including guyed towers and the roofs of large buildings, and their integrity is widely taken for granted. Active-vibration damping, based on space technology, offers a safe route to sustaining even larger and lighter structures with the same degree of confidence.

Stirred but not shaken

Another technology developed to protect satellites and space structures from vibrations during launch is making life a little quieter on building sites. The reason why concrete mixers are so noisy is because mechanical shocks occurring in the mixers due to the rough contact between the gears and the driving crown cause the tank to vibrate and act like a bell. Edil Lame, an Italian concrete-mixer manufacturer, has been investigating various possible technical solutions to reduce the noise. Unfortunately, these solutions have not proved to be reliable, mainly because of the poor conditions in which the systems have to operate (dust, water, weight of the mixed materials, etc).

D'Appolonia, the Italian representative of the Spacelink Group, found the answer in space technology. The French company Artec Aerospace had developed the SPADD (Smart

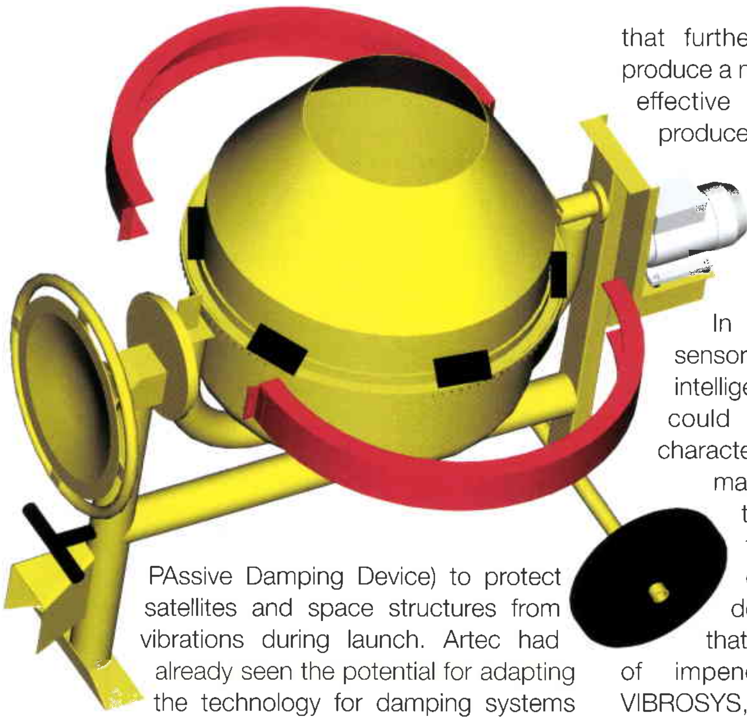


Figure 5. CAD image of a SPADD-equipped concrete mixer

PAssive Damping Device) to protect satellites and space structures from vibrations during launch. Artec had already seen the potential for adapting the technology for damping systems needed in a range of other applications, including electronic circuit boards and tennis racquets. D'Appolonia made the introduction and, based on the successful results of a feasibility study supported by the ESA Technology Transfer Programme, a contract has now been signed between Artec and Edil Lame for the manufacture and marketing of the first batch of 1000 SPADD devices. Edil Lame expects to introduce the SPADD device into between 3000 and 5000 concrete mixers per year.

Good vibrations

In yet another exploitation, tiny sensors from space are helping to warn of potentially catastrophic equipment failure caused by vibration. The German company Ops Automation recognised the need for a vibration detector that was robust and inexpensive and could be applied to a wide range of industrial machinery. At the Hannover Fair in 1998 the company noticed the tiny sensors exhibited by another German company called Mirow. These had been developed for the aerospace industry and were based on piezofoil technology – transparent plastic films that develop an electrical charge when a mechanical stress is applied. The effect depends on direction, so piezofilm sensors are excellent at detecting pressure fluctuations, vibrations or force changes.

The sensors were extremely sensitive and reacted quickly. They had been employed by Mirow and the Technical University of Berlin to sense, for example, pressure changes that indicate what is happening to spacecraft as they pass through the Earth's atmosphere. Ops Automation realised that piezofoil sensors had potential as industrial vibration detectors, but that further development was needed to produce a marketable product – a strong, cost-effective device that could be mass-produced. The work was carried out by Ops Automation with support from ESA and the project culminated in 2000 with the patent application on the design.

In parallel with the design of the sensor, the company also developed an intelligent signal-processing unit, which could analyse the frequencies of the characteristic vibrations that occur in a machine. If any defects occur, such as the machine's bearings breaking up, the noise changes. It is the combination of the vibration detector and the noise-analysis unit that gives operators advance warning of impending machine failure. Called VIBROSYS, the system is now being used in a variety of applications, such as monitoring the huge numbers of pumps employed in the petro-chemical industry, and in many other machines used by various processing companies. Based on its successes, Ops Automation, now a public company, has created 20 new jobs and is expected to have a turnover of some 20 million Euros by 2005.

Water Purification and Management

Purification by simulation

We take it for granted that the water flowing into our homes is clean and safe to drink. However, to maintain its quality, water-engineers are continually looking for better ways to remove impurities, and advanced software developed for space engineering is helping to keep harmful bacteria out of our water supplies.

One serious biological contaminant is the common parasite Cryptosporidium. It is found in water drawn from farmland where sheep and cattle graze and it causes serious illness in humans. Since the bacterium cannot be safely eradicated by chemical means, water companies have to rely on a multi-layer filtering system known as rapid gravity filtration – usually the final physical removal process in water treatment. The efficient management of the whole process, especially the filter beds through which the water passes, is therefore of paramount importance to the water industry.

In order to optimise the operation of their water treatment plants and so reduce the risk of Cryptosporidium contamination, the UK water utility Yorkshire Water decided to model the filtration process on a computer. They asked

Figure 6. Clean water, one of life's essentials!

the advanced control-software company Cogsys to develop a suitable simulation programme that would explore the ideal working conditions in different environmental scenarios. To develop the program, the company used an in-house computer tool ESL (European Simulation Language), which is well-suited to modelling highly complex systems. ESL is a robust simulation software package which was developed for ESA and has proved itself in many engineering applications over 20 years or more. Now, the same advanced software system that was originally used for space simulation is being used to help ensure that our drinking water is kept free from unwanted bugs!

Filtering out impurities

Also in the quest for purer water, a recycling system developed to supply astronauts with drinking water has helped a leading bottler of spring water to clarify a cloudy problem. Water is one of the heaviest consumable items on manned spacecraft, and on long-duration missions the crew will consume many litres. To help reduce the amount of water that needs to be launched from the ground, ESA engineers have developed an innovative automated filtration system to recycle waste water into drinking water. The waste water may include the condensation that forms on the inside surfaces of the spacecraft, effluent from washing clothes and dishes, and also water discharged from experiments and the life-support equipment.

One of the challenges of recycling waste water from a variety of sources is that it is difficult to anticipate what impurities will be present. It may contain, for instance, volatile organic compounds and pathogenic microbes, both of which are notoriously difficult to remove. The system developed by ESA has proved to be highly effective at removing all types of contamination. The system uses a series of membranes, which filter out the various impurities from the waste water as it is pumped through them. Although currently configured to meet only the astronauts' needs, the same concept can be used to treat several hundred litres of waste water per hour.

Such has been the success of this system that it attracted the interest of a major European bottler of spring water. The company concerned was looking for a filtration technology to help it overcome problems at several of the wells it was using as a water source. Water extracted from some natural springs can be discoloured as a result of high concentrations of minerals. This is a particular problem for water obtained from springs fed by hydrothermal wells. Trials carried out with the technology showed that the ESA filtration system was highly efficient at removing these minerals and other impurities. The same filtration technology is now being considered for recycling waste water on ocean cruise liners.

Space works to water works

When we turn on the kitchen tap we don't stop to think about how the clean water reaches our homes. Extracting, treating and distributing water across whole nations is a complex business. A single water utility company may have responsibility for literally dozens of reservoirs, pumping stations and treatment plants, all of which are required to operate as an integrated network in order to meet the public's demands for constant fresh water. With the privatisation and amalgamation of water utilities across Europe, individual companies have been forced to cut costs and devise new and ever-more labour-efficient ways of both monitoring and controlling their water-distribution networks. One of the problems they have had to address has been the wide geographical spread of the individual facilities.

The needs of water companies and utilities actually correspond quite closely to those of satellite operators who, ever since the start of space exploration, have needed to devise systems to enable them to remotely monitor and control spacecraft many miles from Earth. Now, these water companies are also tapping into satellite-tracking technology to operate their facilities remotely.

Science Systems is a UK company that first developed satellite-tracking systems in the early 1980s. Via telemetry links, data may be downloaded, system status monitored and routine commands enacted, allowing the day-to-day operation of the satellite to proceed largely free from the need for human intervention. Science System's desire to diversify into new markets, coupled with the privatisation of the water industry in the UK – and the consequent release of investment funds – led to the development of complementary computer-based systems which could be used by water companies. Supervisory Control and Data Acquisition (SCADA) systems, as they came to be known, have now been successfully adopted by several water companies, including Welsh Water, Thames Water and Lyonnaise des Eaux. Like the spacecraft orbiting the Earth, many water-company sites now operate highly effectively unmanned. Their status and serviceability are constantly monitored, and their routine operations controlled remotely from a central operations centre serving several sites.

Applications to Mobile Devices

Checking the waves

Mobile phones are just the latest contributors to the sea of electromagnetic radiation in which we are all immersed. The nature of the cellular system means that many base stations are needed to provide coverage of the areas served, and their effectiveness is strongly affected by local conditions. The need to offer users a good service must be offset against the need to limit stray radiation and protect the public against possible effects from prolonged exposure. From a practical point of view, effective management of this electromagnetic pollution requires tools to optimise the radio-frequency levels generated by base-station transmitters, and software designed to test the electromagnetic compatibility of satellite systems has been further developed to optimise cellular-phone networks.

For many years an Italian company, Space Engineering SpA, has been developing techniques to analyse and model electromagnetic fields from spacecraft antennas and their effects on nearby equipment. These checks on antenna performance and electromagnetic compatibility, which are vital to avoid malfunctions in sensitive onboard electronic systems, have formed part of several space projects. On Earth, propagation of the very-short-wavelength signals used for telecommunications can be badly affected by the presence of buildings, trees or even rainfall. In 1993, the company successfully turned its satellite expertise to modelling the complicated conditions experienced by mobile receivers in urban locations, and in 1998 Space Engineering spun-off TeS (Teleinformatica e Sistemi srl.) as a separate company. The aim of the new company was to exploit the know-how derived from the space work in the rapidly expanding commercial communications market.

The resulting system, Quickplan, has been developed to fulfil the needs of both radio system developers and environmental agencies. The system can calculate and display radio-frequency field levels across a highly complex urban environment, indicating both the optimum location of transmitters and the resulting electromagnetic pollution. Quickplan draws upon multiple maps and a powerful graphical interface to create a 3D image of the territory, with colour coding that clearly identifies regions where radio-frequency power levels are above or below the desired thresholds. This successful transfer of space-based expertise has provided a powerful aid for planners of radio systems to reduce their environmental impact and improve the servicing of our seemingly insatiable demand for new services.

Un-wired for sound........and text and pictures

The need for wireless equipment in manned spacecraft is further helping to drive the development of truly mobile technology on Earth. The mobile phone has revolutionised personal communications and wireless, handheld devices can combine many different features, including a connection to the Internet and text messaging. Now the frontiers of wireless technology are expanding even further with a new wireless communications standard called 'Bluetooth', which has been developed by a consortium of leading electronics companies, which includes 3Com, Ericsson, IBM, Intel, Lucent, Microsoft, Motorola, Nokia and Toshiba. Bluetooth is a tiny microchip which incorporates a radio transceiver that is built into a variety of digital devices such as mobile phones, personal digital assistants, printers, fax machines, personal computers, laptops, digital cameras, stereos and headsets, allowing them to be connected together without wires or cables. In the next few years Bluetooth will be built into hundreds of millions of electronic devices worldwide.

ESA quickly recognised the unique value of Bluetooth for space exploration, where wireless connections between spacecraft equipment and astronauts are the ideal solution. ESA sponsored Parthus Technologies, an Irish company, to develop a wireless technology based on Bluetooth that could easily be embedded into a variety of spacecraft equipment. Parthus is a world leader in the design and development of the integrated circuits and software that underpin mobile devices. The result was BlueStream, a chip design that can be used as a basis for a wide range of wireless applications – not just for spacecraft operations but

also for computing and global positioning systems. Parthus' approach of integrating BlueStream with other complementary technologies also helps to overcome one of the main challenges of wireless technology, namely power consumption. Today, Parthus' BlueStream chip design is the most widely licensed Bluetooth technology in the wireless industry, with four of the top ten wireless semiconductor companies integrating it into their products. Furthermore, BlueStream accounts for some 35% of Parthus' revenues.

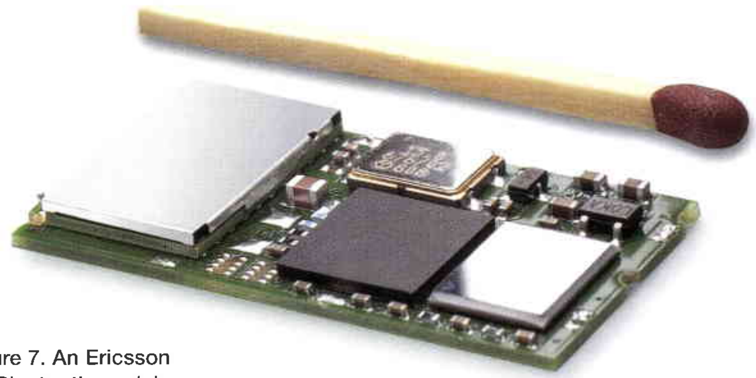


Figure 7. An Ericsson Bluetooth module

NUNA, powered by space technologies

The World Solar Challenge is the biggest race in the world for vehicles powered purely by solar energy. The race, held every two years, crosses the Australian continent north to south (Darwin to Adelaide) – a distance of over 3000 km. The first World Solar Challenge was held in 1987 in order to show the world the potential of solar power. The best solar cars perform extremely impressively, being capable of speeds in excess of 150 kph and travelling the 3000 km for a total sum of just over 6 Euros – about 50 times more efficient than an average family car!

Figure 8. The solar car designed by the Alpha Centauri team

Since the cars rely only on solar power, designers have to take into account factors such as weight, aerodynamics, robustness and safety. In addition, since solar cells do not function well at the high temperatures found in the desert, a system has to be developed to cool the cells (as well as the driver!). In order for the car not to be too heavy, the bodywork must contain a lot of plastics and composites – but the very low weight also requires a system to prevent the car being blown off the road by extreme gusts of wind.

The competition participants vary from multinational companies to high schools and universities. This November, a team from The Netherlands, consisting of students from the Delft University of Technology and the University of Amsterdam, entered the race and won in a new world record time! ESA expertise in spacecraft technology (particularly batteries and fuel cells) was provided to the team. In addition, one of the unique features of NUNA, the Dutch entry, was that their vehicle was partially powered by solar cells provided by ESA, which were actually flown on the Hubble Space Telescope. The Dutch team also used new cells designed by the people who produced the cells for Hubble, and they are among some of the best performing and most efficient solar arrays ever designed (see 'In Brief' for a full race account).

Prime Movers

Creepy crawlies

The fact that laboratory experiments on the International Space Station (ISS) have benefited from ESA research will come as no surprise. But would you have thought that the same applies for crawlers used in oil pipelines? As a Space Shuttle flight typically lasts less than two weeks, facilities designed for conducting experiments onboard are generally used only for short periods. By contrast, on the ISS the experiments are likely to be used for many years and consequently their design has to be fundamentally different. ESA has led the development of new design concepts to improve safety and reduce the time required for the astronauts to carry out equipment maintenance and calibration.

One of the companies helping ESA was Norwegian-based Prototech. By studying the design of ESA's original Spacelab facility for the Shuttle, the company was able to significantly improve the reliability, accessibility and performance of experiment modules for the ISS. For example, the pressure tubing used for the Spacelab experiments has been replaced by a novel compact manifold system. Other operations such as the exchange of filters, calibration procedures and leak testing have also been improved.

Prototech's activities were not confined to space applications, however. The company also designs and manufactures equipment for the inspection of offshore pipelines. The repercussions of failures may be as critical in these operations as they are in space, so Prototech exploited its technology originally developed in collaboration with ESA to improve the reliability of tools for pipe inspection. One example is the redesign of a crawler (called a 'Pipecat') used to pull ultrasonic inspection tools through oil pipelines. The crawler uses two sets of pads – one is pressed to the tube wall while the other set moves forward. Using the same design techniques as for space systems, the number of failure points was significantly reduced, and the redesigned system was made more compact and reliable. This has resulted in significant savings for the oil companies in terms of equipment-maintenance and retrieval costs.

Gearing up for lower speeds

In a less-specialised environment, many everyday appliances rely upon small electric motors to operate them – video recorders, car window winders and seat adjusters, tape drives and CD players all have them. Often the required shaft speed of the motor is quite low but, to provide significant power, small machines work best at high speeds. To reduce the speed of rotation and so gain an increase in output torque, or twisting power, a gearbox is needed just as in a car. If the difference between the speed of the motor and its load is great, conventional gears may need several stages of speed reduction. This leads to power loss, noise and expense. Unfortunately, large increases in output torque also cause large forces on the teeth of conventional gears, so larger teeth and better materials are needed.

Drawing upon the apparent gearing effects of nutation, an Italian space company Stam srl has created a new form of gearbox that overcomes these disadvantages. The device called SPACEGEAR was developed for use in satellites and uses an arrangement in which one bevel gear 'nutates' with another instead of rotating. The gear ratio is determined by the difference in the number of teeth of the fixed and moving gears and not, as with conventional gears, on the ratio of their circumferences. By applying the principle of nutation twice, very high reduction ratios of up to 3000 can be achieved. The design, which combines two pairs of gears, makes any ratio possible with the same simple configuration. Because the design ensures that at least two teeth are in contact at any one time, loadings are reduced and materials of lower strength may be used.

The SPACEGEAR is particularly suited to electrically-driven automotive components where high reduction ratios are required but space is at a premium. Using nutator technology, smaller, faster electric motors can provide the same level of mechanical power as their conventional counterparts. At present, such mechanisms and their electric motors typically cost from 200 Euros for a small car to 2000 Euros for a luxury car. The European automotive industry produces about 15 million cars per year, offering a potential market of 4.5 billion Euros. Stam is exploring materials for mass manufacture – both metal and plastic – and is developing a computer program for designing nutating-gear systems.

Conclusion

The first 40 years of space spin-offs have given us smaller, faster computers, exotic materials and a host of advanced technologies to enhance our everyday lives. Spin-offs from the next 40 years are likely to reflect the increase in importance of prolonged, manned space missions and miniaturised satellite systems. As may be expected, the type of spin-off we get from space tends to reflect the types of space missions being mounted. In the past, ESA has concentrated on Earth observation, communications and space science missions, leaving manned spaceflight largely to the USA and Russia, and the high level of spin-off of imaging and communication technologies and analytical software from European programmes tends to reflect this. In the future, ESA's involvement in the International Space Station (ISS), the planned Mars missions, the increased emphasis on small satellite clusters and robotic exploration, together with the inexorable drive towards the goals of 'smaller, cheaper, more efficient' space systems, should lead to new and ever more exciting technology-transfer opportunities. esa

A New Generation of Space X-Ray Imagers that Could Help Fight Cancer

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A new generation of X-ray imagers for future space-science missions is being developed by ESA in cooperation with European industry. These devices were initially intended for X-ray astronomy and remote planetary sensing, but have now been found to have immediate applications in clinical radiology. In particular, the devices are ideally suited for the imaging of low-density, low-contrast media such as breast tissue, making them invaluable in the diagnosis and clinical support in the fight against cancer.

X-ray imaging is an essential tool for a wide range of disciplines, from astrophysics to material science. Whilst the majority of applications rely on film, phosphor storage screens or other analogue integrating formats, the future development of this field lies in the exploitation of spatially resolved spectroscopy. Commercially available systems generally utilise secondary detection media, such as phosphor plates or scintillator conversion layers.

However, these methods have a number of shortcomings related to resolution and light collection efficiency, and consequently they do not offer much improvement in imaging performance, in terms of 'detective quantum efficiency' (a figure of merit describing a system's ability to resolve imaging detail in weak signals) over more traditional film-screen systems. Additionally, such systems do not make use of 'colour' information and therefore do not lend themselves easily to advanced techniques employing differential absorbtiometry.

While astrophysics has pioneered the utilisation of semiconductor detectors based on silicon at soft X-ray energies (below 10 keV or longward of 1 Angstrom), the hard X-ray band (10 to 200 keV) has proved particularly difficult to develop and has remained relatively unexplored. This band is important because it bridges the transition between thermal and non-thermal emission processes predicted to occur throughout the galaxy. By coincidence, this band is also of crucial importance in medicine and encompasses all the main energies used in clinical radiology. However, while astrophysics can, at least for now, use data from lower X-ray energies to interpolate the underlying high-energy physics, medical applications are not so lucky, since the human body is essentially opaque below 10 keV. In fact, all clinical investigations are carried out in the hard X-ray region, for example at 20 keV for mammography, 60 keV for thoracic radiography, and 140 keV for nuclear medicine (Table 1).

Table 1 shows the key X-ray energies used in space sciences and medicine. Even though the two disciplines are literally worlds apart, they clearly share a lot of common characteristics and an X-ray imager designed for space

Table 1. The various space and clinical applications of X-ray imaging

Space-science radiology	X-ray energy (keV)	Clinical radiology	X-ray energy (keV)
Earth observing (Auroral)	1–20	Mammography	17–20
Planetary	0.2–7	Dental	60–70
X-ray astronomy	0.1–10	Thoracic	50–70
Hard X-ray astronomy	10–200	Nuclear medicine	30–300