BR-230

# BENEFITS OF

# *Human Spaceflight*

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SPACE FOR LIFE

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# BENEFITS OF HUMAN SPACEFLIGHT

BR-230 Benefits of Human Spaceflight

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# FOREWORD

Few people can fail to be inspired by the sight of a multinational, mixed-gender crew setting forth on a mission to outer space. Many accounts have been written about the courage, determination, fortitude and, sometimes, sacrifices, required by astronauts who have dedicated their lives to the exploration of this alien environment.

Less familiar are the benefits for humanity that spring from this unique endeavour. Yet, as this brochure shows, human spaceflight has now moved beyond the era of adventure into a period of technological maturity. With the permanent human occupation of the International Space Station (ISS) has come the opportunity to study and utilise the unique conditions offered by microgravity.

In this brochure, we have selected just a few examples to illustrate the tremendous advances that have already been achieved as the result of European human spaceflight activities, together with some of the successful spin-offs and potential breakthroughs that will help to transform society in the years to come.

Alongside fundamental research in fields such as life and physical sciences, Europe's human spaceflight programme has already made notable contributions in applied science. By studying human adaptation to microgravity, important advances have been made in understanding and treating conditions related to ageing. Other innovations in materials science and automation/robotics have led to major practical benefits for industry.

At a time of European Union expansion and international tension, the human spaceflight programme also has the potential to contribute to the welfare of society as a whole by providing new opportunities for international cooperation and multicultural understanding. In the field of education, human spaceflight also has an important part to play, not only through 'out of this world' demonstrations of key scientific principles, but also through the astronauts themselves, who are able to offer positive role models for young people.

Although Europe is a relative newcomer to the field of human spaceflight, ESA and its member states have made remarkable strides in the utilisation and exploitation of near-Earth space. The importance of this endeavour was recently recognised by the European Commission, which published a White Paper advocating the development of an extended space policy that will be able to take advantage of the special benefits that space technologies can bring.

The White Paper recognised the potential for human spaceflight to support many of the European Union's policies and objectives: faster economic growth, job creation and industrial competitiveness, enlargement and cohesion, and sustainable development.

The challenge is to push forward the boundaries of our human capabilities in order to explore beyond the limits of today's knowledge and thus inspire future generations. This, in turn, will help to encourage young scientists and engineers while strengthening Europe as one of the world's leading knowledge-based societies.

As the following pages demonstrate, the first important steps towards achieving this ambitious vision have already been taken. We look forward to even greater rewards from our investment in human spaceflight in the years to come.

Jörg Feustel-Büechl
Former Director of Human Spaceflight
European Space Agency

# INTRODUCTION

## Europeans in Orbit

**For more than a quarter of a century, Europeans have been experiencing the wonders of space travel and leaving behind the gravitational bonds of planet Earth.**

Ulf Merbold aboard Spacelab

Since the pioneering flights of Vladimir Remek (Czechoslovakia), Miroslav Hermascewski (Poland) and Sigmund Jähn (Germany) in 1978, there have been a total of 45 missions involving 31 astronauts from ESA member states to the end of 2004. Of these, 26 were cooperative programmes with NASA, while 19 involved collaboration with the Soviet Union or Russia.

Europe's involvement in human spaceflight began in 1969, after the spectacular success of Apollo 11, the first manned landing on another world. Invited to participate in NASA's post-Apollo programme, European countries opted to develop the Spacelab modular laboratory, to occupy the payload bay of the US Space Shuttle. The 1983 maiden flight of Spacelab made history when Ulf Merbold became the first ESA astronaut to fly in space and the first non-American 'guest' aboard a US space vehicle.

**Key Achievements:**
- **45 missions since 1978.**
- **Participation in many groundbreaking missions.**

Spacelab eventually flew 22 times in various configurations between 1983 and 1998, enabling scientists to exploit the unique microgravity conditions, opening the way to advances in numerous areas of research. European astronauts also participated in various groundbreaking joint missions aboard the Shuttle, such as the Eureca retrievable satellite, the Hubble Space Telescope, the Tethered Satellite and the Shuttle Radar Topography Mission. Experience in long-term space operations was gained by sending 12 astronauts to Russia's Mir space station, including the 179-day Euromir-95 mission that saw Thomas Reiter become the first ESA astronaut to walk in space.

With the creation of a unified European Astronaut Corps in 1998, in parallel with the establishment of the European Astronaut Centre in Cologne, ESA is now prepared to use the state-of-the art facilities aboard the International Space Station (ISS). Already, six ESA astronauts have made short visits, conducting a variety of experiments, and further missions are planned.

Today, about 20% of ESA's budget is allocated to human spaceflight, with additional allocations to microgravity research and technology transfer. As one of the five major partners in the International Space Station programme, Europe is advantageously placed to build upon the success of Spacelab. After the launch of ESA's Columbus laboratory to the ISS, Europe can look forward to a decade of groundbreaking research,

particularly in the fields of life sciences and physical sciences.

ESA's human spaceflight programme has made its mark in many areas of scientific and technological research. Some important spin-offs have already led to the creation of new jobs and companies, while providing significant benefits for society as a whole. Further advances can be expected in the decades to come as humans venture forth to explore new worlds, supporting the EU strategic objective to make Europe the most dynamic knowledge-based society in the world.

Finally, the potential for human spaceflight to promote European integration and international cooperation must not be underestimated. As participants in joint training programmes and space missions, astronauts offer powerful role models for young people, not only inspiring them to pursue science and technology, but also demonstrating that individuals from diverse backgrounds can learn to live and work together in harmony in pursuit of a common goal.

Thomas Reiter made the first ESA spacewalk.

Europe seen from space.

# SOCIETY

## Multicultural Understanding

INTERNATIONAL COOPERATION AND CULTURAL UNDERSTANDING

**Almost every human space mission since the mid-1960s has involved two or more astronauts. Today, with the advent of large, long-term orbital facilities such as the International Space Station (ISS), crews typically contain a mixture of people with different nationalities and cultural backgrounds. By the end of 2004, astronauts from 10 nations had visited the ISS: USA, Russia, Japan, Canada, Europe (Italy, France, Belgium, Spain, The Netherlands) and South Africa.**

Astronauts from many nations working together inside Mir. Left to right: S. Avdeev (Russia), T. Reiter (Germany), K. Cameron (US), J. Halsell (US), Y. Gidzenko (Russia), C. Hatfield (Canada), W. McArthur (US), J. Ross (US).

As a unique example of global cooperation, involving 15 different participating states, the ISS programme may be viewed as an opportunity for diverse cultures to learn to live and work together in pursuit of a common goal.

**Key Achievements:**
- **Unique example of global cooperation.**
- **Role model for societies on Earth.**

The initial stages of this crew familiarisation process take place during extended sessions of training, often in foreign countries where language and customs are quite alien. The foundations of future success are established during these sessions, not only by learning new communication skills but also by increasing awareness of subtle differences in ideas and behaviour, and by moulding the various individuals into a team.

The space station itself is a small-scale model of Earth, on which representatives of different countries and different social, cultural and religious backgrounds are obliged to co-habit in an enclosed space for periods lasting typically 4-6 months. Since the high cost of space transportation means that resident crews are changed infrequently, they have to live and work together in a confined and very vulnerable micro-environment that provides them with all the necessities for their survival and well-being.

Prolonged space missions resemble life on a desert island, when interpersonal and cultural issues among a multicultural crew can damage morale and threaten the success of the overall mission objectives. In their own interest and that of the mission, the crew members have to learn to make compromises, accept their differences and even to take advantage of their diversity.

On account of the high visibility of their mission, their little community in space becomes a role model for larger communities and societies on Earth.

The International Space Station is, therefore, not only a laboratory for scientific and technological research, but also a laboratory for social interaction and a highly visible demonstrator and role model for peaceful cooperation and friendship among people.

'I HAD THE OPPORTUNITY TO EXPERIENCE HUMAN SPACEFLIGHT ON BOARD THE INTERNATIONAL SPACE STATION. APART FROM BEING AN EXTRAORDINARY ADVENTURE, SPACE IS, FOR ME, A WINDOW TOWARDS THE FUTURE – A FUTURE THAT INVOLVES COOPERATION BETWEEN PEOPLES, SCIENCE AND INDUSTRY, AND WHICH ALSO INVOLVES EUROPE, WHOSE AMBITION IN SPACE IS SO IMPORTANT.'

DR. C. HAIGNERÉ
FRENCH MINISTER FOR EUROPEAN AFFAIRS
PARIS, FRANCE

By providing a demonstration of international understanding and cooperation, crews on the ISS help to counterbalance the negative images of nationalistic hatred and conflict frequently provided by the media. Instead, the astronauts – seen by the young as adventurers and modern heroes – demonstrate to the world that it is possible to distance oneself from narrow sectional attitudes and overcome prejudice towards other cultures and peoples.

There can be few better practical demonstrations of the key principle described in the preamble of the Charter of the United Nations, which invites the people of all nations 'to practise tolerance and live together in peace with one another as good neighbours...'

Cultural heterogeneity is an issue now facing many work places. The development of cross-national and cross-cultural relationships is becoming increasingly important, not only in human spaceflight programmes, but for life on Earth.

ESA astronaut André Kuipers (right) at breakfast onboard the ISS with Alexander Kaleri (left) and Michael Foale.

## European Values

### The European Astronaut Corps and European Identity

**Individually, most of the 15 ESA Member States would be regarded as relatively insignificant contributors in the field of space exploration, but, together, their current investment in space is second only to that of the United States. This strength through unity has enabled Europe to play a key role in the challenging realm of human spaceflight.**

European Astronaut Corps.

The desire for cooperation within ESA was reflected in the formation of a single European Astronaut Corps in 1998. Although the common European identity of the 13 ESA astronauts (four from Germany, two from each of France and Italy, and five from the other Member States) is not immediately obvious because of their diverse cultural backgrounds, the formation of this group has been a great success, providing an example of how Europeans can achieve 'unity in diversity'. The astronauts have become skilled at overcoming their national differences and taking advantage of their unique cultures and experiences as they learn to work together towards a common goal.

**Key Achievements:**
- **Creation of a European Astronaut Corps.**
- **Supporting a European project.**

At a time when the European Union has been expanded, with the addition of 10 countries from Central and Eastern Europe, one of the most important social and political challenges of the coming decades is to strengthen an emerging common identity. One way of achieving this goal is to harness the energies, talents and skills available in Europe to develop a vibrant human spaceflight programme. By sharing their experience and vision with people all over Europe, astronauts not only spark public interest in European science and technology, but also become ambassadors of a unified Europe.

The current diversity of European countries will be challenged through the development of a unique and complex civil programme. The continued evolution of an ambitious, successful human spaceflight programme will reinforce political and industrial cohesion across the continent by offering a pride-driven focal point for an emerging European identity. By cooperating and working together on such a long-term endeavour, new opportunities will arise for the integration of scientists, industry and the population in general throughout an enlarged Europe.

In the long-term, human exploration of the Moon and Mars will provide a unique opportunity for peoples of many nations to learn how to live and work together in isolation as they strive to explore and develop the resources of another world. Many of these aspirations are included in the Charta of the European Astronaut

'The success of the enlargement of the European Union will greatly depend on how it is perceived by its citizens and this will influence whether its policies can be realised and its humanistic values promoted. A highly visible project that captures the imagination of many citizens, centred around human spaceflight and a unified European Astronaut Corps, will inspire the coming generation and promote a European identity. This will help to build the European knowledge-based society of tomorrow."

Mr. F. De Winne
ESA Astronaut

Corps, which has as its vision the 'shaping and sharing of human space exploration through unity in diversity'.

The Charta goes on to describe the mission of the Corps: 'We shape space by bringing our European values to the preparation, support and operation of spaceflights that advance peaceful human exploration. We share space with the people of Europe by communicating our vision, goals, experiences and the results of our missions.'

The European Astronaut Centre of the European Space Agency, in Cologne, Germany.

# KNOWLEDGE

## Research

GROUNDBREAKING SCIENTIFIC RESEARCH

**Today, an increasing number of Europeans is surviving to reach the once-rare age of 100 years old. This growing band of centenarians bears witness to the remarkable scientific and technological advances that have dramatically improved living conditions and provided the driving force behind the progress of Western civilisation.**

ESA astronaut Pedro Duque using the Microgravity Science Glovebox aboard the ISS.

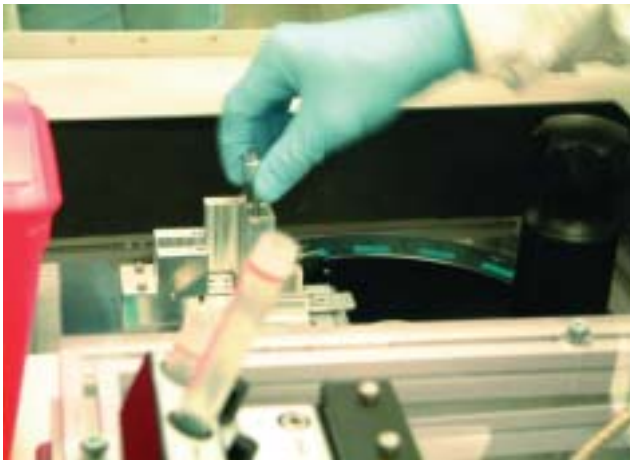
In the last few decades, space exploration has assumed a significant role in the scientific advancement of many nations. In particular, human spaceflight has enabled the emergence of new research: physical and life sciences in space. ESA has supported fundamental and applied research in these disciplines since the mid-1980s. Although flight opportunities have been rather scarce until now, the scientific community participating in such research already encompasses some 1000 scientists, and more than 100 companies are involved in related, applications-oriented research.

**Key Achievements:**
- **Emergence of new research fields.**
- **Fundamental research to benefit society.**

By exploiting the unique conditions in space, particularly microgravity, scientists have begun to examine many fundamental processes in physics, chemistry and biology that would normally be masked by Earth's gravity.

Human spaceflight is also helping to improve our lives on Earth. Experiments that have flown on the Space Shuttle and on space stations have already contributed to the development of new theories and the discovery of new phenomena. Such fundamental research offers good prospects for applications that will benefit society as a whole, notably in the areas of biotechnology, new materials, combustion, fluid physics and medical science.

Astronauts play a key role in ensuring that each orbital experiment operates properly and functions according to the criteria established by its creators. The involvement of the crew is essential, not

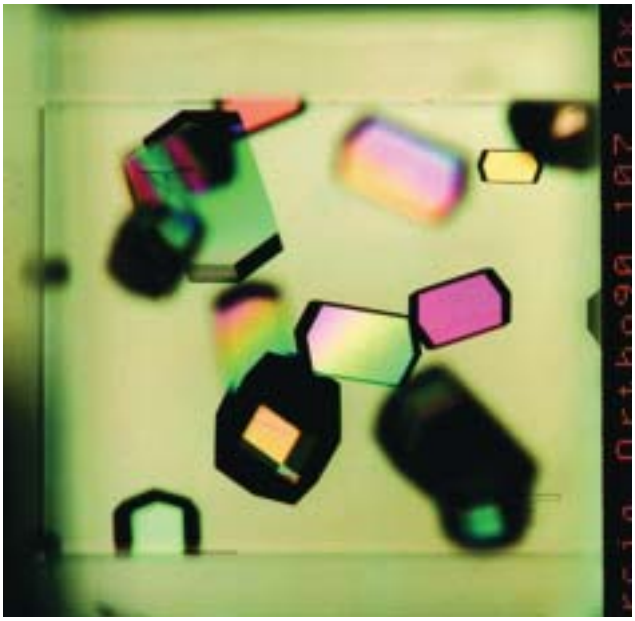


Preparing a vial for snap freezing.

only when the experiment is being set up, but also throughout its operation, when they may adjust parameters according to the phenomena observed, interact with ground investigators and exchange modules for new experiments. In the case of biomedical research, the astronauts also serve as test subjects.

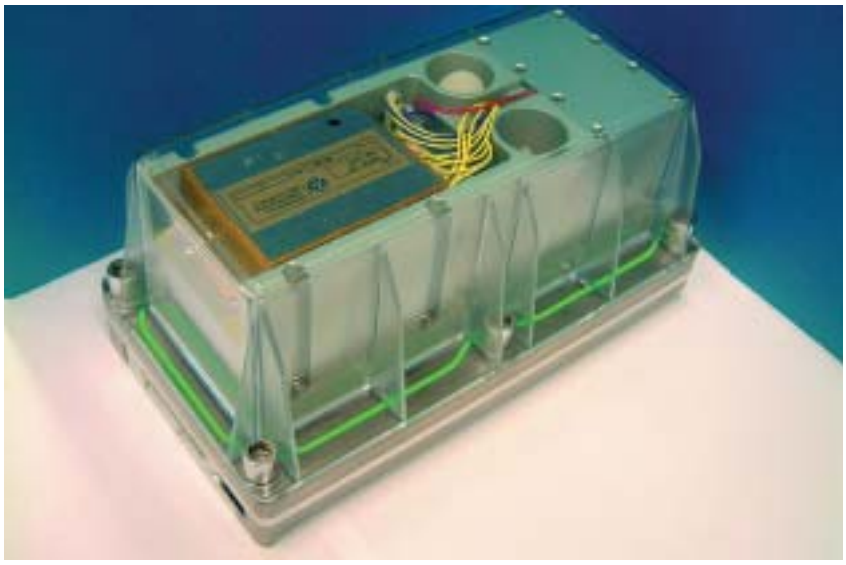
European astronauts have supported research in life and physical sciences through Spacelab missions sponsored by ESA and national agencies, long-duration flights such as Euromir, and national missions to the ISS using the Soyuz ferry craft. The quantity and quality of scientific papers based on this research increased dramatically during the 1990s, with internationally recognised results published in leading journals.

Research aboard the ISS allows projects to be implemented through international partnerships at the highest level, while international peer selection guarantees scientific excellence. Microgravity research has also attracted some internationally renowned scientists, including Nobel Prize-winner Samuel Ting and the German materials physics scientists Prof. D. Raabe and Prof. K. Sammer, who won the Leibniz Prize in 2004.



Crystals grown in the Advanced Protein Crystallisation Facility (APCF) during the Spacehab/STS-95 Mission.

The full benefits for Europe will be harvested once the major research facilities in ESA's Columbus laboratory are operational on the ISS. This will further improve scientific knowledge and create new industrial applications for the benefit of society.



An Experiment Container for the European Modular Cultivation System (EMCS).

## Research

FUNDAMENTAL PHYSICS

**There is now a growing interest in using microgravity to investigate various aspects of fundamental physics. Several experiments have been designed or are under consideration.**

The Atomic Clock Ensemble in Space (ACES) is a 1 m cube weighing 225 kg.

The European plan to place the Atomic Clock Ensemble in Space (ACES) on the ISS is of considerable importance for both fundamental and applied physics. The laser-cooled atomic clock will provide ultra-precise measurements of time, attaining accuracy levels 10-100 times higher than on Earth.

Atomic clocks in space are of particular interest for use in future navigation systems such as Galileo, where the accuracy of a navigation system depends directly on the timing accuracy of its reference clocks. They will also provide a unique, universal time reference for basic science (e.g. checks of relativity theory) and other applications such as Earth observation, geodesy and telecommunications.

**Key Achievements:**
- **Ultra-precise measurements of time.**
- **Unique studies of dust and aerosol particles.**

Another important area of research aboard the International Space Station is aerosol physics. Each litre of air that we breathe is filled with millions of specks of dust. This dust plays an environmental role, too, and it is clearly essential to understand how such particles influence Earth's climate.

In space, the gravitational force between dust particles is practically zero, so they remain in suspension. The 'Interactions in Cosmic and Atmospheric Particle Systems' (ICAPS) scientific programme on the ISS will allow scientists to take advantage of microgravity by manipulating clouds of dust and aerosol particles, colliding other particles with them and studying their physical attributes. These experiments will improve our knowledge of such fundamental processes as the effect of dust on the light-scattering properties of the atmosphere, the growth of ice crystals and their influence on the formation of clouds and rain, the aggregation of dust and aerosol particles, as well as the agglomeration of interplanetary dust that leads eventually to planet formation.

Research into complex and dusty plasmas is also being conducted aboard the ISS using the ESA IMPACT Facility for Complex Plasmas and Dust/Particle Aggregation in the Columbus module. There is growing interest in the worldwide scientific community for this exciting new research field, with more than one peer-reviewed publication per day on average.

'THE ACES SCIENCE TEAM REGARDS THE ACES MISSION ON THE ISS AS A VERY IMPORTANT FIRST STEP IN THE CONTROL AND MANIPULATION OF ULTRA-COLD ATOMS IN SPACE. IN THE FUTURE, A PERMANENT, HIGH-QUALITY TIME REFERENCE IN SPACE WILL BE KEY TO MANY ADVANCED TECHNOLOGICAL AND SCIENTIFIC APPLICATIONS.'

PROF. C. SALOMON
ECOLE NORMALE SUPÉRIEURE
PARIS, FRANCE


Artist impression of the Columbus laboratory complete with external payload facilities.

Fundamental physics of space investigates how what happens in space relates to what happens on Earth. Possibilities for further fundamental physics investigations are currently being explored.

## Research

### Complex Plasmas

**Everyone is familiar with the three 'normal' states of matter: solids, liquids and gases. However, there is another form of matter, known as plasma. Although it is one of the main constituents of the Universe, plasma is not widely recognised on Earth because it is made up of invisible, charged particles. Nevertheless, it can be found in some easily identifiable examples such as a candle flame or a glowing gas inside a fluorescent tube.**

Cosmonaut Sergei Krikalev with Plasma Kristal (PK) Experiment-Nefedov. This and PK-3 plus are national DLR payloads. PK-4 is planned as a cooperative ESA/DLR development, and all PK units in the future will be open for European utilisation.

In the last 10 years, scientific interest in 'complex plasmas' has been growing worldwide as researchers have discovered new, unusual liquid and crystalline plasma states. Complex plasmas consist of ions, electrons and charged microparticles, each individually visible because they are some 50 000 times larger than a plasma ion.

This additional microparticle component is important because it enables scientists to 'see' the kinetics of plasmas for the first time. The microparticles also increase the complexity of the plasma and slow down the plasma dynamics. In this state, the plasma physics becomes optically observable with a powerful microscope, opening the way for researchers to investigate the liquid and crystalline plasma states.

**Key Achievements:**
- **New understanding of unusual plasmas with exciting prospects for future applications.**

Unfortunately, since the microparticles are relatively heavy, gravity is the dominant destructive force in these complex plasmas. Although research can be conducted on Earth by using strong electric fields to support them, this places major constraints on the experiments, constraints that do not exist in space.

Experiments aboard the International Space Station have allowed scientists to study many aspects of complex plasmas: 3-D self-organisation of matter; fluid physics at particle level; flow around an obstacle; flow through a constriction (nano-jets); interpenetrating flows; coalescence of two liquid plasma drops; charge-induced coagulation; crystal growth at particle level and interfacial melting. These experiments are increasing our knowledge of fundamental questions in physics, such as crystal growth, solid-liquid phase transitions, transition from laminar to turbulent flow, and the properties of fluid nano-surfaces.

The role of specially trained astronauts has been crucial for the success of this early stage of complex plasma

'Since the discovery of liquid and crystalline plasma states, the number of publications has grown dramatically each year, to over 400 in 2003 alone. This makes 'Complex Plasmas' one of the most dynamic research fields in physics. My research experience involving the ISS has been most rewarding, the interactions with the cosmonauts/astronauts and the agencies provided a unique experience, for which I am truly grateful. The experiments yielded so much new and unexpected science – sometimes it simply took my breath away. And there's more to come...'

Prof. G. Morfill
Director Max-Planck-Institut
für extraterrestrische Physik
Garching, Germany

research. Their continuous presence means that they are available to set up and observe the experiment, adjust the parameters, and update or exchange the equipment – steps that would be impossible with automated systems. There has also been at least one example of the 'serendipity effect', when an operational mistake by an astronaut on the Station resulted in an exciting new discovery: coagulation of microparticles into super-aggregates. One potential application of this discovery is nano-particle filtering for the cleaning of contaminated fluids.

An exciting prospect for the future is the ESA 'IMPACT' Facility for Complex Plasmas and Dust/Particle Aggregation, which will fly in ESA's Columbus laboratory. Numerous ground-based applications are expected from this research. Examples include plasma deposition for improved surface coating (e.g. self-lubricating surfaces), design of new composite materials (e.g. polymer solar cells) and bioplasma physics (e.g. sorting of bacteria for cell cultures and killing harmful bacteria).

Hubble Space Telescope image of the Eagle Nebula, showing plasma clouds in space.

## Research

Life Sciences

**Since life on Earth has evolved under the influence of gravity, new insights into the processes that support life can be obtained by studying the functional changes that take place when the effect of gravity is removed.**

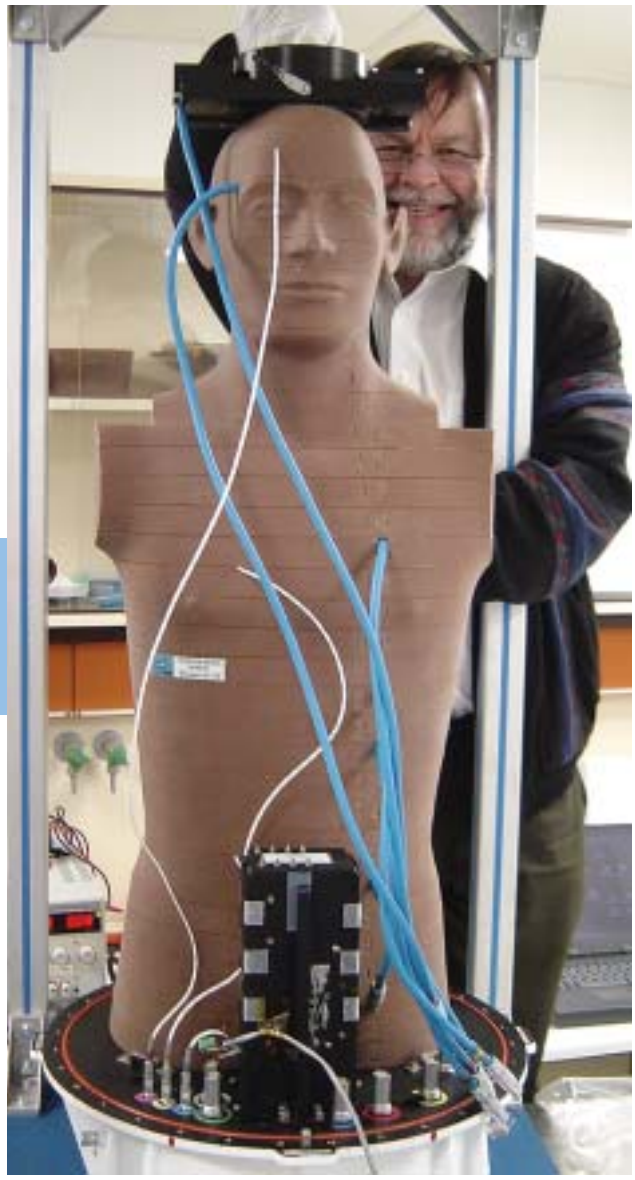
Research in space has advanced fundamental knowledge in understanding the role that gravity plays in life processes at various levels: genes, cells, organs and entire organisms. Changes in the functioning of plants, animals and humans in microgravity have been studied, as well as the underlying molecular, genetic and cellular mechanisms.

In-orbit studies have been performed on how plants perceive gravity and respond to microgravity, on the life cycle of plants and on the ways in which later generations adapt. Results have shown that plants can reproduce and survive in a weightless environment.

**Key Achievements:**
- **Understanding the key role of gravity in life processes.**
- **New research into radiation and human physiology.**

Other experiments have examined transmission of gravity-sensitive signals by genes, with studies of cell growth, motion, differentiation and proliferation. Results have shown significant alterations in gene expression, signal transduction, cell membrane functions and cell proliferation, together with changes during division of cells.

An important area of study covers major changes in human physiology caused by prolonged exposure to microgravity. Adaptations under investigation involve



Matroshka: a 'phantom' head and torso simulating the human body.

'Ten years ago I became aware of the existence of life sciences research in space as a member of a panel reviewing research proposals. Since then, I have provided inputs on several working bodies, including a long period as Chairman of the Life Sciences Working Group. As a scientist previously uninvolved in space-related research, I appreciated the efforts of the ESA Executive to be as objective as possible and to implement the suggestions of the scientists. The ground research and the simulation of weightlessness, as well as the possibility of controlled and repeatable experiments in space, represent a valuable combination of assets to be maintained and developed, since they can provide real advancements in life sciences.'

Prof. A. Colombatti,
University of Udine
Udine, Italy.

the deterioration of the cardiovascular system, lung function, shifts in body fluids, bone loss, muscle atrophy and changes in energy metabolism. The influence of gravity on the immune system, spatial orientation, posture/locomotion and human brain functions has also been studied.

One main thrust of future activities is to develop adequate countermeasures and advanced diagnostic techniques to ensure the survival and robust health of long-duration crews. Research into the effects of space radiation on the human body is clearly imperative. Although radiation levels inside the International Space Station are well documented, exposure levels during spacewalks are still uncertain. In order to obtain precise measurements, ESA and the German Aerospace Centre (DLR) developed Matroshka, a 'phantom' head and torso that simulates a spacesuited human body as closely as possible. The ISS crew placed Matroshka outside the ISS on 27 February 2004 in order to provide definitive information on the radiation doses experienced by spacewalking astronauts.

Like the famous Russian matrioshka dolls, Matroshka consists of several different layers. The simulated human element is composed of natural bone and a material that closely resembles human tissue. A lower density material simulates the lungs. These 'tissue' layers are coated with a simulated skin layer and covered by an external container that represents a spacesuit. Radiation sensors are placed within the spacesuit element and at different key organ locations such as the stomach, lungs, colon, eyes and skin.

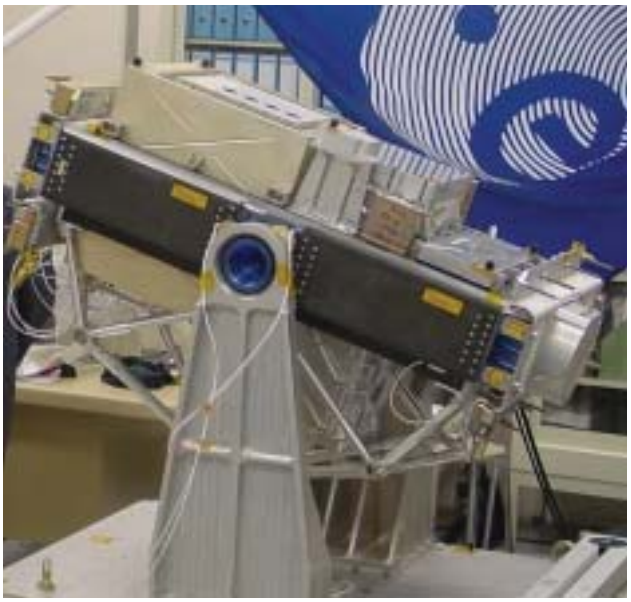
The ISS is also being used for biotechnology experiments on the growth of cells, tissues and bacteria, with potential applications in medicine, agriculture and environmental management (e.g. biological air filters and biosensors). A general-purpose exposure facility (EXPOSE) for chemical and biological samples will eventually be positioned outside Columbus. Mounted on a pointing device, it will enable experiments to be oriented towards the Sun for several hours each day.

Astronaut Michael Foale with the Matroshka package in the Zvezda Service Module of the International Space Station.

## Research

SPACE SCIENCES

**The International Space Station will accommodate external payloads, particularly those involving astronomy and solar physics, Earth observation and technology experiments. These payloads will be installed during spacewalks or by astronauts operating the ISS robotic arms.**



SOLAR: Solar Monitoring Observatory facility with three instruments.

Among the research instruments currently being developed or under study are two astronomical facilities.

The SOLAR observatory will monitor changes in the Sun's radiation output – the 'solar constant' – with unprecedented accuracy. Its three complementary instruments will cover almost the entire solar spectrum (17-3000 nm). Apart from making important contributions to our knowledge of the processes taking place inside the Sun and other stars, the observatory will provide information of great importance for understanding the interaction between the solar energy flux and Earth's atmosphere, with major implications for climate modelling.

**Topics Addressed:**
- **Observatories on the ISS.**
- **The search for antimatter and dark matter.**

The SPOrt Sky Polarisation Observatory has the main goal of measuring the polarisation of the diffuse cosmic background radiation, the faint, leftover 'glow' from the birth of the Universe during the Big Bang. By performing measurements of the sky in an unexplored microwave frequency range (20-90 GHz), the observatory should provide significant new inputs to cosmological theory.

Nobel prize winner Samuel Ting (Massachusetts Institute of Technology) is leading an international collaboration of 37 universities and laboratories – most of them from Europe – to fly a state-of-the-art particle physics detector called the Alpha-Magnetic Spectrometer (AMS) on the ISS, supported by the US Departement of Energy and NASA. The compact precursor version, AMS-1, was first tested on a brief mission on the Space Shuttle in 1998, while AMS will eventually spend 3 years on the ISS studying the properties and origin of cosmic particles and nuclei, including a search for antimatter and the mysterious dark matter that seems to pervade the Universe.

AMS-2 is the only large-scale fundamental physics experiment to be flown on the ISS. Mounted outside the Station, it will use the first superconducting magnet in space to measure the charge of cosmic antimatter, which cannot be done on Earth because matter and antimatter annihilate each other in the atmosphere.

'HUMAN CURIOSITY IS THE DRIVING FORCE BEHIND SCIENTIFIC AND TECHNOLOGICAL DEVELOPMENTS. THE TOTALLY UNEXPECTED DISCOVERIES OF COLUMBUS AND MAGELLAN OPENED A NEW ERA OF INVALUABLE ADVANCEMENTS, WHILST THE WRIGHT BROTHERS' FIRST AEROPLANE FLIGHT, 100 YEARS AGO, CHANGED THE WORLD. SIMILARLY, THE BENEFITS OF HUMAN SPACEFLIGHT WILL CHANGE HUMANKIND IN AN INCALCULABLE WAY."

PROF. S. TING
CERN
GENEVA, SWITZERLAND

During its 3-year operation, it is expected that AMS-2 will confirm the existence of anti-helium and anti-carbon in space. If these particles are not detected, it will indicate that antimatter does not exist in the distant reaches of the Universe, confounding current theories of how the Cosmos was created.

AMS-2 installed on the ISS truss (image courtesy CERN).

## Education

### Space In The Classroom

**'The tension was unbearable. The children in the classroom had learned so much about space in the last few months. Now it was time for one of the heroes in space to speak to them and answer their questions. On the computer screen, they saw the International Space Station approaching. Students and teachers held their breath.'**

This description of an amateur radio link-up between school students and an astronaut on the ISS captures the excitement and relevance of human space exploration for young people. At a time when the number of European students choosing to devote themselves to scientific and technical disciplines is falling, human spaceflight can provide a strong stimulus and motivation by engaging and inspiring young people, not only in mathematics and science, but also in social studies, languages, design and art.

**Key Achievements:**
- **Teaching and inspiring young people.**
- **Hands-on experiments in microgravity.**

By using the example of the greatest engineering project ever undertaken in peacetime, teachers can illustrate physical principles, real-life uses of mathematical concepts and the benefits of teamwork. One of the most fascinating aspects of spaceflight, but also one of the most difficult to explain, is the concept of microgravity. However, through demonstrations both on Earth and in space, the ISS programme has spawned numerous educational projects in all of the partner countries.

Although it is not possible for most people to become astronauts, ESA's annual student parabolic flight campaign offers 120 students the next best thing: the opportunity to experience repeated periods of weightlessness. Each of the 30 experiments carried out aboard the Airbus-300 during these campaigns is designed by teams of four students from ESA Member States.

A student parabolic flight.

The 2002 ESA Space Station Utilisation Contest (SUCCESS) competition asked university students from all disciplines to propose microgravity experiments, taking into account the absence of gravity effects, the

'Our job puts us in a position admired by all children and young people. Such a privileged position must be used to the fullest extent possible in a world where very few stimuli drive children towards science. We will need thousands of brilliant young people to choose to become scientists and engineers to keep Europe competitive, and thousands more if we are to improve its international standing. We astronauts are aware of our responsibilities and not only endorse but participate with enthusiasm in ESA's educational programmes."

Mr. P. Duque
ESA Astronaut


The ISS Education Kit.

vacuum of space, the altitude above Earth, and the isolated environment for the astronauts. The winning proposal may be developed and qualified for a parabolic flight or installed on ESA's Columbus laboratory.

For younger students, experiments are performed and recorded in the ISS for wide distribution to European schools. Live links between students and ISS crew members, organised through the Amateur Radio on International Space Station (ARISS) group, also help to make spaceflight more real for young people.

ESA's future commitment to education has been assured through the establishment of the ISS Education Fund, which will enable the ISS Education Programme to continue developing, producing and disseminating teaching materials for primary and secondary school students.

The most popular example of ISS teaching material is the ISS Education Kit for secondary school pupils aged 12-15 years, containing interdisciplinary exercises common to European curricula. 40 000 copies were produced in 11 languages and distributed to teachers throughout Europe in 2003.

Students participating in the Seeds in Space experiment carried out during the Dutch DELTA Soyuz Mission, 21-30 April 2004.

ARISS, as part of the 'Zeg het ISS' project, enabled students to make radio contact with André Kuipers aboard the ISS during the Dutch DELTA Soyuz Mission.

# INNOVATION

## Health

BENEFITS FOR HEALTH ON EARTH

**Ever since the first astronauts ventured into space, physicians have been aware that major changes occur in the human body as a result of prolonged exposure to microgravity.**

Bedrest studies provide important results for both astronauts and patients on Earth.

Astronauts experience physiological adaptation in four main areas:

- Atrophy and functional changes in muscle. These are similar to disuse muscle atrophy on Earth, which is caused by prolonged limb immobilisation, trauma or secondary diseases. There is also a resemblance to sarcopenia, the loss of muscle mass associated with ageing.
- Mass loss of load-bearing bones at a rate of up to 1% per month, an effect similar to or more serious than osteoporosis problems in post-menopausal women.
- Respiratory system changes in chestwall displacement, lung ventilation, blood perfusion etc.
- Sensory integration in the brain suffers under the conflict between the visual information provided by the eyes and that of the vestibular system (balance organs) during an adaptation period of several days.

Such changes have important implications for astronauts' well-being and efficiency, both in space and after their return to Earth. As a consequence, health and long-term survival in a weightless environment have been the major motivations for physiological research since the early stages of human spaceflight.

**Key Achievements:**
- **New understanding of physiological processes.**
- **Numerous medical spin-offs.**

One of the most valuable techniques, both for simulating the physiological effects of weightlessness and for gaining new insights into everyday medical conditions such as osteoporosis and diabetes, involves bedrest studies.

Since opportunities for investigating human physiology in the microgravity of space are limited, the ground-based model of prolonged, head-down tilt bedrest has been used by ESA and other agencies to study the human body's response to musculoskeletal unloading.

More than 200 bedrest studies have been performed during the last four decades. The development of countermeasures against the muscle and bone loss associated with inactivity can be tested in clinical trials and helps to improve the health of the general population.

'SPACEFLIGHT LEADS TO CHANGES IN MOTOR CONTROL WHICH BRING ABOUT A DECREASE IN MUSCLE POWER DURING SHORT, INTENSIVE EFFORTS. THIS CAN BE COUNTERACTED BY SHORT 'EXPLOSIVE' ACTIVITIES INVOLVING EXERCISES. THESE TECHNIQUES ARE NOW ALSO UTILISED TO PREVENT THE DECLINE OF MUSCLE POWER CAUSED BY OLD AGE, NEUROMUSCULAR DISEASES OR PROLONGED IMMOBILISATION.'

PROF. P.E. DI PRAMPERO
UNIVERSITY OF UDINE,
UDINE, ITALY

Such research not only results in a significant increase of knowledge and understanding of physiological processes, both on Earth and in space, but it also drives the development of new, miniaturised, automated devices for medical diagnostics and countermeasures applied in space. These innovations have already resulted in numerous spin-off instruments and therapies used by clinics and individual patients, leading to improved health care and the development of novel types of medical technology.

Future research into these changes on the International Space Station promises even more significant contributions to the improvement of health on Earth and of astronauts during long-term missions. A large number of experimental studies in the areas of cell and developmental biology, biotechnology, integrated physiology, bone and muscle physiology and neurology have been proposed, selected and prioritised for ISS utilisation.

In the long-term, this physiological research will pave the way for humans to travel beyond Earth orbit and begin the exploration of other worlds.

A volunteer taking part in a bedrest study.

## Health

### Cardiovascular System

**Major changes in the human cardiovascular system take place within the first week of a space mission, when the astronauts lose 4-8% of their body weight, mainly through water loss. Such cardiovascular deconditioning in microgravity is induced by the displacement to the head and upper torso of up to two litres of body fluid. Astronauts then complain of shrinking legs, facial swelling and a 'stuffy' feeling in the nose and ears.**

ESA astronaut André Kuipers working with the Advanced Respiratory Monitoring System (ARMS) training model.

This rapid redistribution of fluids results in significant changes to the cardiovascular system, including an increase in fluid and electrolyte excretion by the kidneys, followed by a rise in the heart rate combined with a reduction in blood volume.

**Key Achievements:**
- **Development of miniaturised,automated instruments.**
- **Countermeasures against the effects of microgravity**

Significantly, these physiological alterations are not restricted to space travellers. The deconditioning effects are remarkably similar to those observed during the normal ageing process on Earth. It follows that studies of cardiovascular changes in weightless conditions will contribute towards our understanding of human physiological processes, thus helping to solve one of the main health issues in Western countries.

Comparative gravitational physiology in space is a valuable tool for understanding the blood pressure mechanism, blood constituents and body-fluid regulation, involving heart, kidneys and the glandular system. The investigation of the reduced performance of the cardiovascular system in young, healthy astronauts allows the development and testing of countermeasures and drugs.

The use of specialised instruments in space, such as the echocardiograph, has helped to clarify the changes that take place. At the same time, various countermeasures have been introduced to prevent the fluid shift, notably the wearing of inflatable cuffs and 'vacuum' trousers that prevent blood and tissue fluids returning from the lower limbs. A more active countermeasure is the introduction of several hours of exercise per day, using various machines such as bicycle ergometers and treadmills.

Meanwhile, space simulation studies on the ground, such as prolonged periods of head-down rest on a tilted bed, have enabled physiologists to compare the responses of their test subjects with those of astronauts in orbit.

Space physiology and medicine have led to reconsideration of the role played by gravity in living

'Systemic research on human cardiovascular physiology and salt-water balance under microgravity conditions has revealed several important results that have improved our overall understanding of physiological and pathophysiological mechanisms.'

Prof. H.-C. Gunga
Charité-Medicine University of Berlin
Berlin, Germany

systems, particularly in the human cardiovascular system. By discovering that concepts derived from Earth-based studies often do not match the realities in space, scientists have been able to modify their theories and make significant progress in such fields as geriatrics and psycho-physiology – the effects of isolation, overcrowding and stress on the cardiovascular system.

Cardiovascular research in space has led already to the development of many miniaturised, automated devices and instruments for diagnostics and therapies, which are finding medical applications on Earth in fields such as post-traumatic rehabilitation, sports medicine and the treatment of stress-related disease and elderly people.

Portapres equipment ready for measuring blood pressure.

NASA astronaut Michael Anderson prepares the ARMS Bicycle Ergometer during Shuttle mission STS-107.

## Health

### Human Balance System

**During the first three days of weightlessness, about half of all astronauts have to endure a form of motion sickness that is popularly known as 'space sickness'. This unpleasant condition occurs when the brain receives conflicting signals from the eyes, the muscles, the skin and the vestibular system (balance organs).**

The electrode cap, part of a multi-electrode measurement module for studying brain functions.

3-D eye-tracking device.

Although the body's nervous system eventually learns to compensate for the loss of gravity-induced stimuli by relying solely on visual inputs, the period of sensory imbalance can seriously impede a crew member's efficiency. Furthermore, hazardous human operations such as spacewalks are avoided during the initial phase of a mission in case an astronaut experiences symptoms of motion sickness.

**Key Achievements:**
- **Advances in neuroscience research.**
- **New instruments for eye clinics.**

Numerous microgravity experiments have been undertaken in order to improve our understanding of the mechanisms involved in human balance, motion and posture. Much of the research focuses on understanding the brain's interpretation of the body's orientation in 3-D space. Other experiments planned for the International Space Station will carry out non-invasive studies of brain functions and protocols for neuroscience research, with great advances in knowledge expected. A total of 17 research projects in this field has been selected as high-priority European experiments for the ISS.

Such research has an important practical value, since millions of people on Earth suffer from balance disorders and related neuro-physiological problems.

Further benefits come from the development of new diagnosis instruments that can then be adapted for clinical use. Two examples of such spin-offs are the Video Oculograph (VOG) and the Three-Dimensional Eye Tracker, which were developed for experimentation in space and later introduced into eye clinics for high-precision strabismus (squinting) operations on swivel-eyed children. The Video Oculograph is used to measure eye orientation and movements, while the 3-D Eye Tracker provides fully digital measurement of eye movement and is used for ophthalmological and neurological examinations, as well as corrective surgery.

'The utilisation in space of precisely controlled stimuli for the visual and vestibular senses, associated with accurate recordings of posture, eye movements and brain function in humans, provides a unique opportunity to study the adaptive mechanisms of spatial orientation to gravity levels ranging from 0 to 1 g. Information from this research is being used to develop countermeasures against disorientation, gaze and balance problems that occur during spaceflight and subsequent to lesions of the vestibular system. In our laboratory, we are evaluating equipment and procedures from space investigations as potential tests of balance disorders and in clinical programmes of vestibular rehabilitation.'

Dr. G. Clement
Faculté de Medicine Rangeuil
Toulouse, France

## Health

### Osteoporosis

**Half of women over 60 years of age suffer from an age-related condition called osteoporosis, which involves substantial loss of bone mass and density. About 50% of elderly women and 15% of men suffer from fractures of the hip, wrist or spine as an indirect result of osteoporosis. The global cost of the subsequent operations and post-operation therapy amounts to tens of billions of Euro each year, and the bill is likely to climb in a world of ageing populations.**

A normal spine (left) compared with osteoporetic spine (right).

This problem is not confined to the elderly. In the weightlessness of space, even the youngest, fittest astronauts suffer greatly accelerated bone loss owing to the lack of use of their weight-bearing bones. The resulting decrease of up to 1% of bone mass per month poses a significant threat of bone fracture for astronauts during and after reentry.

**Key Achievements:**
- **New understanding of bone demineralisation.**
- **Improved diagnosis and treatment.**

Osteoporosis occurs when the body fails to produce enough new bone and/or when too much bone is reabsorbed. This is usually the result of a deficiency of blood vessels or a reduction in skeletal loading through immobilisation or weightlessness, although there are many other potential causes.

Microgravity research offers the potential to understand the mechanisms of bone demineralisation and the degree to which its effects are reversible, both in astronauts and in elderly people on Earth. Countermeasures and diagnostic instruments developed for astronauts, combined with new biological models and techniques for bone modelling, bone tissue engineering and growth will help to improve the treatment of osteoporosis for millions of people.

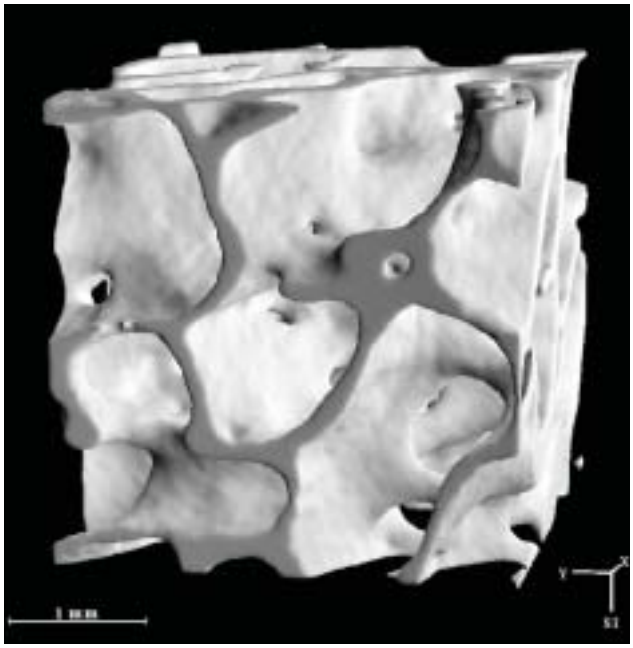
Novel diagnostic instruments and counter-measures such as physical exercise, medication and nutrition have been developed during European space life sciences programmes. One example from the Euromir-95 mission is a bone densitometer that used ultrasound techniques in order to avoid harmful ionising radiation. The pioneering instrument provided accurate information on the deterioration of bone density and structure in the heel bone and tibia. A terrestrial version of this instrument, called 'Osteospace', has since been produced by the French company Medilink/Diagnostic Medical Systems.

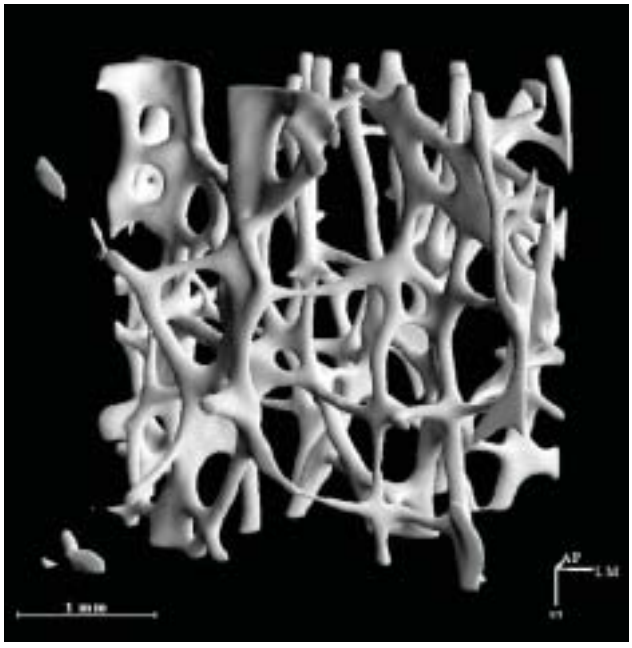
'In view of increasing commercialisation of medical research and shortage of public grants, human spaceflight medical research is making an indispensable contribution to independent, pure research. A recent medical bedrest study, examining muscle and bone atrophies, makes it possible to develop and optimise efficient non-medicinal therapy strategies for osteoporosis.'

Prof. Dr. D. Felsenberg MD, PhD
Charité-Medicine University of Berlin
Centre for Muscle and Bone Research
Berlin, Germany

In recent years, portable, lightweight Osteospace units with improved ultrasound probes have also been developed. Such advances have considerable commercial potential, since the world market for bone densitometers is very large ($600 million per year), and the ultrasound technique is gaining an increasing share of this market.

Meanwhile, further space studies of the changes that take place at cellular, tissue, molecular and hormonal level will be of great value for medical care of terrestrial osteoporosis. One key programme, involving many European and Canadian research institutes and companies, is the ERISTO (European Research in Space and Terrestrial Osteoporosis) project. It will improve our understanding and control of the mechanisms of bone remodelling and the development of new biological models and techniques (e.g. a bone micro-architecture imaging system). One of the objectives of this bone tissue engineering project is to provide high-quality artificial bone for implantation in mice. A total of 11 additional bone experiments has been selected as high-priority investigations for the ISS.





Normal bone structure (left) compared with osteoporetic bone (right).

## Health

### Muscle Atrophy

**We rely on our muscles to overcome gravity so that we can lift objects, walk and climb stairs. However, if the muscles are rarely used, they tend to suffer loss of mass and strength, with a consequent rise in fatigue levels. Failure to use muscles for a substantial period of time – possibly as a consequence of confinement to bed (bedrest), casting of a broken limb, injury or trauma owing to ageing – can result in a debilitating condition known as muscle atrophy.**

MARES: Muscle Atrophy Research and Exercise System prototype.

A similar condition occurs in space, where even the youngest, fittest astronauts suffer from muscle atrophy after lengthy periods in weightlessness. Although the effects of this are not readily apparent in space, they can result in serious weakness and fatigue, both during and after the astronauts' return to Earth. Clearly, the microgravity of space provides a unique opportunity to study the effects of long-term muscle disuse on muscle function, physical performance and health and to compare the results with those relating to studies of disused muscle atrophy on Earth.

**Key Achievement:**
- **Development of countermeasures.**

Muscle atrophy is now known to be due to multiple factors, among which muscle protein degradation and altered neuromuscular control are probably the most important. Countermeasures have been developed in order to reduce or prevent muscle atrophy of astronauts in orbit.

Tests have shown that resistance exercise programmes using high-force and low-repetition muscle actions are most effective in preventing atrophy in space and in increasing muscle mass and strength on Earth. However, further development of countermeasures depends on improved understanding of the physiological and pathological reasons for the negative effects. More advanced countermeasures developed for astronauts can then be applied as direct spin-offs for health care on Earth.

The International Space Station offers an excellent environment for testing the efficiency of various countermeasures on a large number of astronauts over a period of 10-15 years. This should enable scientists to derive the most appropriate countermeasures, such as aerobic exercise, resistance exercise, drug treatment, lower body negative pressure, electric stimulation,

'The study of muscular changes in actual and simulated microgravity is fundamental for understanding the deterioration in muscle performance caused by prolonged disuse and ageing, when a reduction in physical activity is common. 90 days of bedrest result in a 30% loss of muscle mass, which approaches the limit beyond which muscle atrophy becomes life threatening (a loss of 40% of muscle mass). Hence, if humans are ever to explore other worlds, the development of efficient countermeasures against muscle atrophy seems mandatory.'

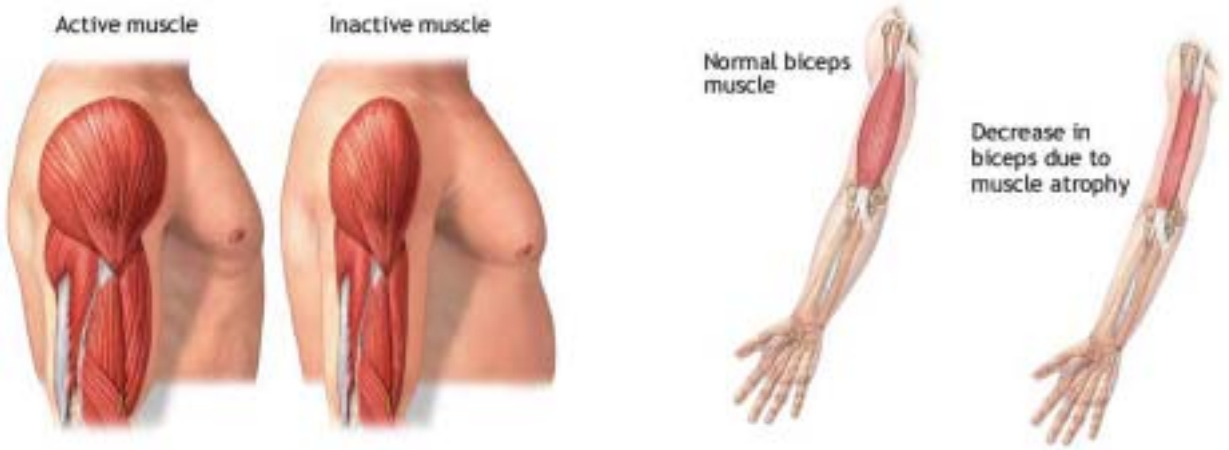
Prof. M. Narici
Manchester Metropolitan University
Manchester, UK

explosive and flywheel ergometers. Many of these may then be introduced to combat muscle atrophy on Earth.

The ESA-developed Muscle Atrophy Research and Exercise System (MARES) will also be used on the ISS to carry out research on muscle-skeletal, biomechanical, neuro-muscular and neurological physiology and to evaluate the effect of countermeasures to microgravity-induced atrophy.

ESA is now developing the Flywheel Exercise Devise (FWED), a gravity-independant mechanical device that provides resistance during coupled concentric muscle actions, through the inertia of a spinning flywheel assembly. OHB, the German company developing the FWED, intends to offer a commercial version for rehabilitation centres and for gymnastic halls to train athletes.


Demonstration of Flywheel Exercise Device.




The effects of muscle atrophy.

## Health

### Telemedicine

**For millions of people around the world, immediate access to a doctor is impossible because they live far from the nearest clinic or hospital. One way of eliminating the physical separation is telemedicine, a two-way satellite voice/video link between a patient and medical expert.**

Former ESA astronaut Michel Tognini performing a remotely controlled echography (image courtesy Université François-Rabelais).

The first large-scale practical application of telemedicine took place during the 1988 earthquake disaster in Armenia. With the terrestrial communication networks destroyed, satellite communications helped to provide emergency medical help.

At the beginning of the 1990s, ESA set up the first telemedicine testbed for human spaceflight. This was successfully used on a 10-day Spacelab mission in 1993, when echo-cardiology experiments were conducted with Anthrorack, the forerunner of today's telesurgery. After the Anthrorack echo-graphical images were transmitted to Earth for interpretation by medical specialists in the telemedicine testbed, the experts gave instructions to the astronauts in Spacelab on how to move the sensor probe.

**Key Achievements:**
- **Improving treatment in remote areas.**
- **Driver for new technology.**

Since the mid-1990s, there has been an explosion of telemedicine activities around the world, with support from the World Health Organisation (WHO), European Union (EU), the G-7 countries, NATO and armed forces of several nations, as well as many medical organisations. The commercial value of telemedicine is growing rapidly as a result of increased access to medical specialists, reduced transportation and hospitalisation costs after surgery, alongside substantial advances in home care, the establishment of electronic health records, electronic health cards, etc.

Taking advantage of its great experience in sensor technology development and in the management of international projects, ESA is supporting and marketing telemedicine services via satellite, while, in parallel, playing a role as coordinator of international telemedicine organisations with the ultimate objective of making this a routine medical procedure.

In this regard, ESA has been leading the Telemedicine Alliance, a consortium including the WHO Regional Office for Europe and the International Telecommunication Union. Sponsored by the European Commission's Information Society Technologies Directorate, the initial phase of this project was to formulate an overlying policy for the application of eHealth in Europe. The aim of the second phase is to bring the vision closer to realisation by focusing on the interoperability of healthcare services and mobility of patients.

'Since 1999, at the request of the health authorities, France and CNES have been supporting a programme in the field of tele-health that uses satellites for communication, Earth observation, global positioning etc. Two main areas were prioritised: (1) the teleconsultation approach in remote areas and (2) tele-epidemiology, which assists in the prediction of human transmissible diseases related to changes in the local environment."

Dr. A. Güell
CNES
Toulouse, France

An example of how the Agency is promoting telemedicine-related technology transfer to small- and medium-sized companies is TeLeCare, an ESA-Canada co-funded project that enables remote patient diagnosis and monitoring via satellite. A lightweight, portable health monitoring kit derived from this technology has been used during recent ascents of Everest.

Teresa is a cooperative R&D project involving ESA and the EU, in which a robot controlled by an expert in radiology remotely moves an echographic probe across the body of a patient or astronaut to obtain high-quality 3-D images of the internal organs. This system could be of tremendous value in places where there are few specialised medical services, as well as in space.

In preparation for future long-duration missions, ESA is cooperating with the Concordia Antarctic base, which is an analogue environment for some aspects of human space exploration. In order to monitor the adaptation and general health of personnel overwintering in the base, a Long-Term Medical Survey device is being developed by ESA. Health information will be fed back to crew members and reviewed by the station's doctor, but it will also be possible to transfer information to experts in Europe for advice or a second opinion.

Remotely controlled echography (courtesy Toulouse, cité de l'espace).

Concordia Base in Antarctica.

## Health

### Advanced Medical Equipment

**Few people have their health and physical well-being more closely monitored than astronauts orbiting the Earth, and huge amounts of medical data have been returned over four decades. As a result, numerous new products have already been developed for non-space medical applications, with a total market value of about €100 million per year.**

The Self Tonometer is an instrument for routine monitoring of intraocular pressure in glaucoma patients, derived from a self- operated instrument used by astronauts (ESA).

One medical problem that can benefit from space technology is glaucoma, a condition that causes poor eyesight or even blindness. Some 70 million people in the Western world suffer from glaucoma. However, a personal instrument, known as a self-tonometer, has been derived from space experiments and is now helping to combat the disease. Ocuton-S, developed by German company EPSa, will enable millions of people to monitor their own eye pressure regularly and determine when they need medication, so avoiding blindness.

**Key Achievements:**
- **Numerous spin-off products.**
- **Global markets and commercial opportunities.**

Another piece of advanced equipment derived from human spaceflight is Osteospace, an instrument that uses ultrasound to measure bone density and structure. Developed by French company Medilink/DMS and now available as a portable unit, Osteospace offers an alternative to X-rays for diagnosis of osteoporosis, one of the most debilitating conditions afflicting elderly people.

Respiratory Gas Analysers, developed under an ESA contract by Danish company Innovision, offer a non-invasive technique to determine the condition of the cardiac system and lungs. The latest commercial model, Innocor®, which is much smaller, faster and cheaper than its predecessors, is expected to have a major impact on efficient prediction of dysfunctions due to heart diseases. The importance of this capability is underlined by the fact that symptoms from heart diseases are the primary cause of serious health problems in the adult population over 40 years of age.

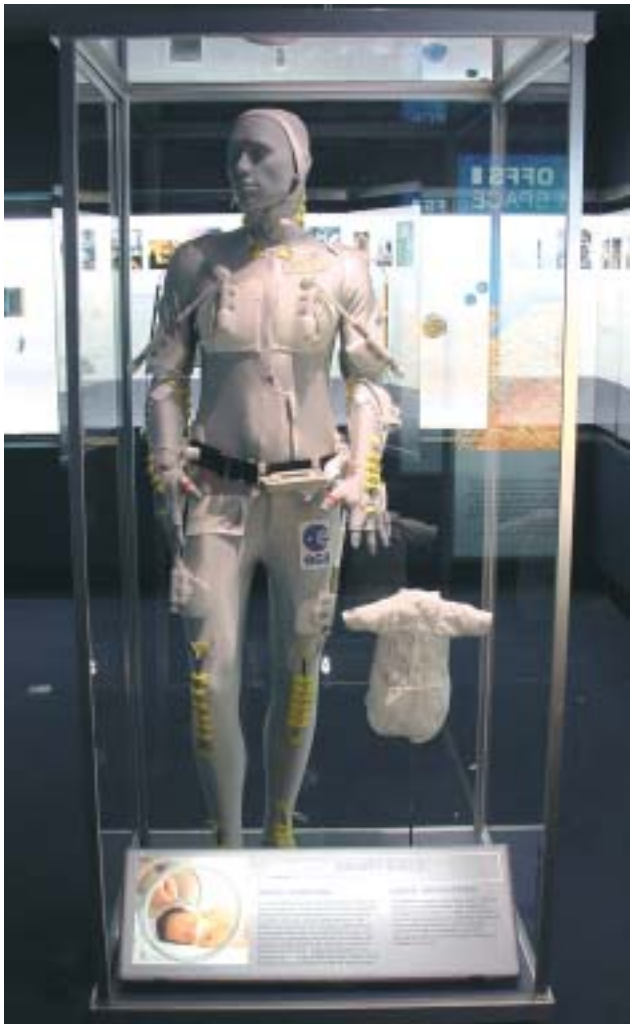
Sterilite is a safe disinfection system for hospitals and biochemical laboratories that is based upon flush cleaning with ozone gas. Developed for biological research in Spacelab's Biorack and the International Space Station, Sterilite has now been developed for commercial use by Dutch company Bradford Engineering. It is estimated that world demand for this system could be up to 100 000 units.

Mamagoose is a prototype pyjama suit for babies who may be threatened by Sudden Infant Death Syndrome,

'Innovision A/S and Damec Research ApS have been involved in the development of Respiratory Gas Analysers for use in ESA-funded Space Projects and for the commercial market since 1985. The commercial models AMIS2000®, AMIS2001® and Innocor® represent outstanding examples of spin-off from Space to the commercial market. ESA, through the development of 'Portable PFS', ensured that this spin-off, or spin-back, process continues to the overall benefit of both space and the commercial market.'

Mr. O. Gløe-Jakobsen
Managing Director
Damec Research ApS
Odense s, Denmark

Using a Respiratory Gas Analyser for non-invasive measurement of cardiac output, $VO_2$ and $VCO_2$ .



The Mamagoose prototype pyjama suit is based on a 'smart' suit developed for astronauts in the early 1990s.

popularly known as 'cot death'. Based on a 'smart' suit that was developed for astronauts in the early 1990s, it uses motion sensors to measure rib cage and abdomen movements during respiration. The sensors are linked to a miniaturised computer that sounds an alarm if these movements stop. A simplified version known as Babyguard is now under development by Verhaert (Belgium).

Another type of protective suit is being developed for children who suffer from Xeroderma Pigmentosum (XP), a rare genetic disorder that causes extreme sensitivity to ultraviolet sunlight and may eventually result in cancer. After an approach from a mother whose son was unable to venture outside during the day without special protection, specialists from ESA and industry used their expertise to create an anti-UV suit and helmet. Prototype suits that will allow XP patients to go outside in safety and comfort are now under development by Bertin Technologies (France) and D'Appolonia (Italy), and a production version may soon be available for every XP child in Europe.

The Video Oculograph and the 3-D Eye Tracker are used in eye clinics for high-precision operations, as on children with a squint. Two companies (SMI and Chronos Vision) have been founded to produce and market these instruments, which have numerous applications in areas such as medical diagnostics, ophthalmology, neurology, physical therapy, brain research and psychology. The world market in this field is now around $15 million per annum, of which SMI has a 30-40% share.

## Fluid and Materials Research

### Applications of Fluid and Materials Research

**In our daily lives, we take many things for granted. For example, that sand will sink to the bottom of a river, a candle flame will taper upwards and cold water will collect at the bottom of a bath. However, these assumptions are overturned in the microgravity environment of space, where substances can behave very differently.**

A drop formed as a result of a crystal growth experiment onboard the ISS (NASA).

The principal objective of microgravity fluid and materials research is to gain an understanding of how gravity affects such fundamental processes as the solidification and crystallisation of materials, and the behaviour of fluids. By taking advantage of opportunities to use this 'unearthly' environment, scientists are able to understand the formation, structure and properties of materials at various scales, from atomic to macroscopic.

**Key Achievements:**
- **New insights from space research.**
- **Unique studies in microgravity.**

Such insights cannot easily be gained on Earth, where gravity induces buoyancy-driven convection, sedimentation and hydrostatic pressure, thereby creating defects or irregularities in the internal structure of materials, which, in turn, alter their properties and limit their strength or performance.

The changes in fluid behaviour lie at the heart of space studies in materials science. By removing gravity-induced effects, the experimental conditions can be greatly simplified, so that their thermo-physical properties can be measured and the fundamental processes that influence fluids can be more readily explored.

Only in the microgravity of space, for example, is it possible to conduct quantitative studies of segregation, a phenomenon that influences the distribution of a solid's components as it forms from a liquid or gas. Similarly, as demonstrated by astronauts drinking blobs of floating liquid, hydrostatic pressure is suppressed in weightless, opening up the possibility of processing liquids without containers.

Fluid and materials research in space has many potential applications here on Earth. Indeed, the transfer of results from such research onboard Spacelab has already improved production in industrial materials processing, crystal growth, fluid management, combustion and biotechnology.

The new understanding of the effects of convection on metallic structure has enabled foundries industry to generate new or improved high-performance materials for vehicle bodies, turbine blades, golf clubs, artificial hips and many other products. Applications such as

power generation, air conditioning and refrigeration also benefit greatly from fluid science research in microgravity.

Future experimentation on the ISS may eventually enable the limited production of exceptionally high-quality materials and materials with unique properties that could be used as benchmark samples for industry.

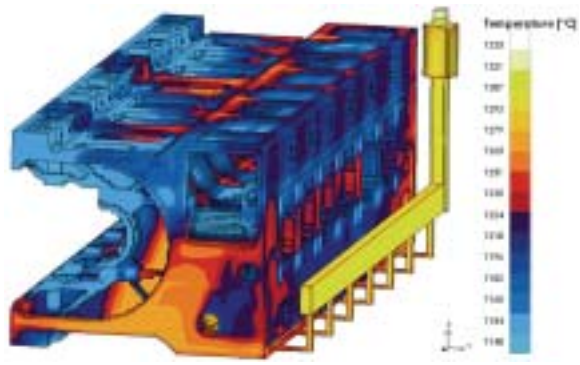
ESA has had a Microgravity Applications Promotion (MAP) programme since 1996 involving academia, research organisations and industrial R&D business units. Some 70 European industries, including metal producers, refiners and end users, oil companies, car manufacturers, energy producers and pharmaceutical companies, provide funding for these projects.

ESA astronaut Pedro Duque demonstrating the peculiar behaviour of uncontained fluids in microgravity.

## Fluid and Materials Research

### Advanced Casting Technologies

**Casting is an industrial process that involves the solidification of a molten metal alloy. Objects made from cast materials, such as steel or aluminium, are commonplace in everyday life. In Europe, more than 10 million tonnes of castings are produced per annum, generating a turnover of some €18 billion. However, the competitiveness of European companies relies upon the casting industry's ability to produce higher performance materials and to improve processing practices.**



Advanced casting of engine blocks. Measurement of improved thermophysical property data needed for the modelling of industrial processes, such as this filling simulation and control of cool-down of car engine blocks (image courtesy Magmasoft®).

New, improved materials with higher strength and stiffness are always being sought by the automotive and aircraft industries, not least because they result in weight savings and lower fuel consumption. Advanced computational methods (numerical models), which are used to predict heat transfer, melt flow and solidification, need precise data inputs on thermophysical properties (TPP), since better process control results in improved microstructure and mechanical properties. However, current TPP data for the temperature ranges of the melting points are either grossly inaccurate or non-existent.

**Topics addressed:**
- **Precise computer models of casting.**
- **Higher efficiency and material quality.**

On Earth the measurement inaccuracies are of the order 50-100%, which presents a major problem for the validity of the numerical simulation models used for the control of metal casting and the design of casting moulds. Using levitation techniques in microgravity, where the electromagnetic or electrostatic positioning forces needed for levitation are more than 1000 times smaller than on Earth, much greater precision in the determination of TPP can be achieved.

In addition, the temperature range in which levitation techniques can be applied without disturbance is much smaller on Earth than in microgravity. The small positioning energy needed in space makes it possible to enlarge the temperature range at the lower end of the scale (400-2200°C), so that it covers a wider variety of materials, especially commercial alloys such as aluminium, copper, titanium, steel and nickel superalloys.

Electromagnetic levitation in space also provides optimal spherical geometry, enables measurements on undisturbed molten samples and permits microstructure formation studies during controlled under-cooling of samples.

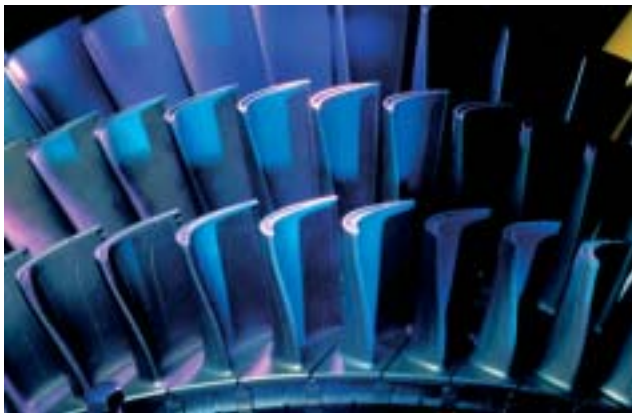
After some successful precursor experiments on model materials during sounding rocket flights and Spacelab missions, which produced TPP data up to 10 times

'High-precision measurements of the thermophysical properties of complex, multi-phase, high-temperature liquids in space are having a strong impact on the further development of European industry. This is an unexplored area of research where breakthroughs can be expected, so that nano-engineering of materials from the molten state becomes possible in the near future.'

Prof. H.J. Fecht
University of Ulm
Germany

more accurate than before, it is planned to measure the following properties for alloys on the International Space Station: melting range, density, surface tension, viscosity, heat capacity and enthalpy, thermal conductivity and diffusivity, and electrical conductivity.

The data will be used on Earth for numerical simulation models involving the casting of iron (crankshafts), steels, aluminium (pistons, engine blades), magnesium alloys, and nickel and titanium-based alloys (turbine blades, medical implants). Industries involved in ESA's Microgravity Applications Promotion projects expect improved casting control, resulting in higher production efficiency and significantly improved material quality and reliability.



Advanced casting technology data will be used on Earth for simulation models involving the casting of nickel superalloys and intermetallics, such as turbine blades.

## Fluid and Materials Research

INTERMETALLIC ALLOYS

**The ESA/EC Intermetallic Materials Processing in Relation to Earth and Space Solidification (IMPRESS) project was recently selected by the European Commission (EC) as a 'flagship' project in materials science and applications. Its scientific objective is to develop new knowledge about solidification processing, materials structures and novel, high-performance intermetallic alloys – crystalline compounds composed of two or more metallic elements.**

A Rolls Royce gas turbine engine (image courtesy Rolls Royce).

Titanium aluminides, for example, have mechanical and physical properties that make them ideal for casting of high-quality turbine blades. They are found in the last stage of gas turbines, which are used in all modern power stations and aero engines. The low-density, high-melting point and burn resistance of the titanium aluminides results in a 50% weight reduction of components, reduced fuel consumption (hence lower exhaust emissions) and higher operating temperature (equivalent to much higher efficiency).

**Key Achievements:**
- **Development of new, improved alloys.**
- **Advanced catalytic powders.**

Intermetallic alloys are equally important for advanced catalytic powders. Catalysts work by speeding up chemical reactions and have many industrial uses, as in the pharmaceutical and food industries. In the IMPRESS project, scientists will investigate catalytic powders made from nickel and cobalt aluminides. Fine, rapidly solidified particles smaller than 20 microns across will be produced, and then, after further processing, used by industry to speed up hydrogenation reactions, which are vital for producing nylon and margarine. Companies developing and using hydrogen fuel cells will also benefit greatly from this research, since catalytic powders based on nickel and cobalt are effective, relatively inexpensive materials suitable for electrodes. Considerable improvements are expected in the performance, cost-effectiveness and sales potential of these pollution-free power generation systems.

The International Space Station and other microgravity platforms will be used extensively to perform benchmark experiments on these alloys to yield important data for validating theories and computer models. The various ISS facilities to be operated by astronauts for the IMPRESS project include:

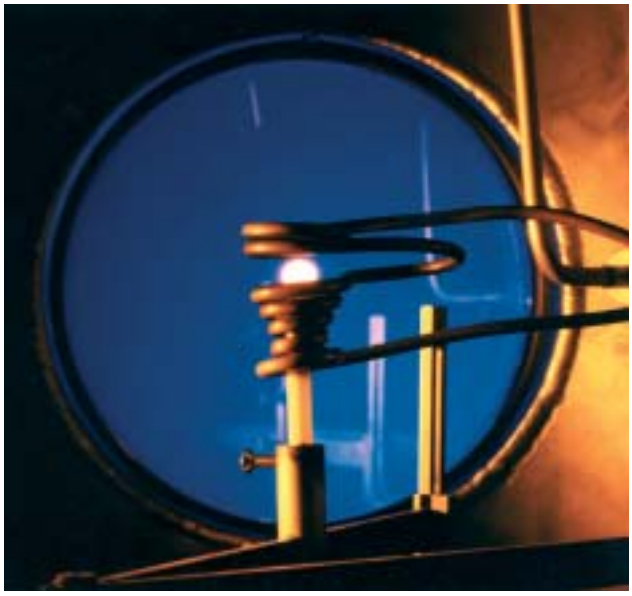
- the Materials Science Laboratory, which permits directional solidification of intermetallic alloy samples;
- the Electromagnetic Levitator, which allows

'ALL THE RESEARCHERS INVOLVED IN THE IMPRESS PROJECT ARE VERY KEEN TO SEE THE SCIENTIFIC RESULTS TRANSFERRED INTO HIGH-QUALITY TANGIBLE PRODUCTS. ONCE SUCCESSFULLY DEVELOPED, THE IMPACT OF THESE NEW GAS TURBINE BLADES AND CATALYTIC DEVICES WILL BE TREMENDOUS – NOT ONLY ECONOMICALLY, BUT ALSO ENVIRONMENTALLY.'

IMPRESS PROJECT TEAM, COMPRISING 200 WORLD-CLASS SCIENTISTS, INDUSTRIALISTS, POST-DOCTORAL RESEARCHERS AND PHD STUDENTS FROM 15 EUROPEAN COUNTRIES AND RUSSIA.

container-less melt processing and non-contact measurement of thermophysical properties;
- the IMPACT facility, which permits experiments in nano-powder formation and agglomeration.

By combining the expertise of 45 materials science research groups and companies across the enlarged European Union, IMPRESS has the potential to make Europe a world leader in the development of strategically important, new technologies such as turbines and fuel cells. It will greatly strengthen the competitiveness of European industry through the successful development of high-value products with major environmental and energy-efficiency benefits. With a steadily growing demand for gas turbines and catalytic devices, market projections suggest that global sales could reach at least €45 billion by 2011.



Levitated droplet of liquid metal (Courtesy I. Egry).

MSL-USLab Engineering Model (process chamber lid open, Low Gradient Furnace held by the furnace exchange tool) within the EADS ST laboratory rack during the ESA Crew Review conducted by ESA Astronauts R. Ewald (left) and T. Reiter (right) and NASA Astronaut S. Lindsey (centre) in December 2001.

## Fluid and Materials Research

### Crystal Growth of semiconductor Materials

**Single semiconductor crystals are the very basis of the electronic age. Modern computers would not be possible without the integrated circuits made of semiconductor wafers of single crystals. Electronic components made from such crystals play a very important role in communication, power and alarm systems, as well as automatic control in various transportation systems.**

Such single crystals are grown either from a molten liquid, solution or vapour. Unfortunately, they often contain defects and dislocations in the regular layer of atoms, as well as inclusions and impurities. This is a problem, because appliances such as mobile phones are continuously being designed to be smaller and lighter, and require fewer defects in order to increase their technical performance.

**Key Achievements:**
- **New understanding of crystal growth.**
- **Potential applications for high-energy detectors.**

On Earth, gravity-induced heat and mass flow influences the growth process and crystal quality as well as the concentration and distribution of defects. Although some progress has been made towards increasing structural perfection, studies of the influence of different kinds of convection under microgravity have also helped in the development of improved crystal growth methods.

In particular, experiments in orbit have enabled scientists to separate and quantify the normal, gravity-induced convection in fluids from surface-tension-induced flows (Marangoni convection). It has also been possible to stabilise large, liquid floating zones in order to grow large single crystals of silicon.


Gallium antimonide crystals grown in microgravity (left) and on Earth (right).

Microgravity experiments to grow much larger crystals from melt than can be produced on Earth have resulted in single crystals of gallium arsenide up to 20 mm in diameter, two and a half times the size of those grown on the ground. However, it proved difficult to apply these results to industrial production of the materials.

Today, the main reason for performing crystal growth experiments in space is to understand the basic transport mechanisms that determine the final properties of the crystals grown. The microgravity environment

'Semiconductor industries have gained much long-term benefit from space experiments to understand the complex growth phenomena during industrial processes on Earth. It has enabled an increase in development of new technologies on the ground, for example, the use of magnetic fields to decrease unwanted convectional flows in crystal melt.'

Prof. K.-W. Benz
Albert Ludwigs University of Freiburg
Freiburg, Germany

provides the ultimate conditions for controlling the transport phenomena in crystallisation processes that are characterised by diffusion-controlled heat and mass transfer. Crystal growth in microgravity makes it possible to prepare samples showing the intrinsic properties of the semiconductor materials. Such benchmark or reference samples are invaluable for assessing the required investment in the development of new materials and devices.

An example of this is the growth of single crystals of cadmium telluride and related compounds in space, the basic materials used in highly sensitive X-ray and gamma-ray detectors. These compounds have potential applications for the identification of flaws in materials and for medical purposes, such as low-dosage X-ray irradiation of patients. Until now, they have not been of practical use because the quality of the crystals is insufficient to allow economic applications.

However, the crystals grown from vapour, solution or melt in microgravity have shown noticeable improvement in homogeneity and defect density.

Further research planned for the International Space Station will quantify the influence of growth conditions on homogeneity and defect density during the crystallisation process of single, inorganic crystals.

Single semiconductor crystals are an essential part of many new technologies.

## Fluid and Materials Research

IMPROVEMENT OF CRUDE OIL RECOVERY METHODS

**Crude oil is one of the most important resources on Earth, partly because of our dependence on refined petroleum for power generation and transportation, and also because of the wide variety of products made from petrochemicals. Fluctuations in the price and availability of oil can greatly affect the global economy and have considerable impact on our daily lives.**

Since crude oil is a non-renewable resource, companies are continuously seeking ways to recover as much oil as possible from existing sources and to exploit new reservoirs more efficiently. However, the near-surface reservoirs are almost depleted and nowadays it is necessary to drill to depths of 7 km to find new deposits.

**Key Achievements:**
- **Improved accuracy of thermodynamic models.**
- **More efficient oil recovery.**

Once a new reservoir is found, the next step is to determine its size and the composition of the crude oil. This normally requires a large number of exploratory wells, which are very expensive (up to €100 million each) to drill, especially if the exploration is taking place offshore.

In an attempt to reduce the number of wells that must be drilled, petrochemical companies are trying to use thermodynamic models. These require geophysical and geological data, but, most importantly, they require precise data of isothermal diffusion coefficients and thermo-diffusion (Soret) coefficients of a few samples of crude oil from the reservoir. This knowledge is important because it provides key insights into the size of the discovery and the distribution of the crude oil constituents within it.

North Sea oil rig.

The thermodynamics of crude oil at depths below 4 km is very complex, because the multi-component hydrocarbon mixtures are deposited there under pressures of up to 500 bar, with pressure gradients of 25-100 bar for every 100 m and temperatures that may exceed 100°C. These conditions are super-critical, but there is a lack of diffusion coefficient measurements for such multi-component organic mixtures. Since the accuracy of laboratory measurements on Earth is

'THE PROJECTS FOR THE MEASUREMENT OF DIFFUSION COEFFICIENTS ONBOARD THE ISS ARE RUNNING UNDER THE UMBRELLA OF AN ESA MICROGRAVITY APPLICATION PROMOTION (MAP) PROGRAMME, AND THEY ARE PERFORMED BY A EUROPEAN-WIDE TEAM. IT IS VERY EXCITING TO EXPERIENCE THE COOPERATION BETWEEN LARGE INDUSTRIAL AND ACADEMIC GROUPS WHO ARE ABLE TO DEVELOP A MUTUAL APPRECIATION OF EACH OTHERS' CONTRIBUTIONS.'

PROF. J.C. LEGROS
UNIVERSITÉ LIBRE DE BRUXELLES
BRUXELLES, BELGIUM

affected by gravity-induced buoyancy and convection, it is not possible to conduct the diffusion coefficient measurements that distinguish more than two components of the crude oil.

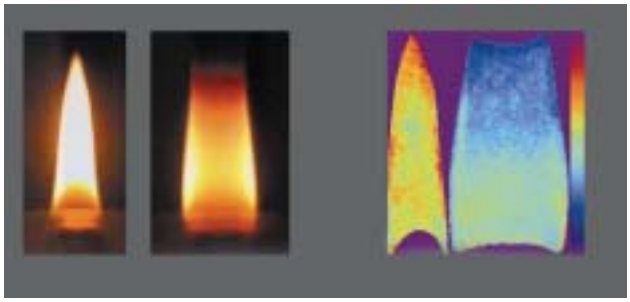
These obstacles have been overcome during space missions, when major improvements in measurement accuracy have been obtained. Oil companies are, therefore, actively involved in the preparation and implementation of experiments on the International Space Station for the measurement of diffusion coefficients. The results should eventually play a major role in improving oil recovery techniques and making them more cost-effective.

Fluctuations in the price and availability of oil can greatly affect the global economy and have considerable impact on our daily lives.

## Fluid and Materials Research

COMBUSTION

**Combustion, the process of transforming chemical energy into thermal energy (heat), is a vital part of our daily lives for both domestic and industrial use. Gas-driven turbines produce electricity, gas fires heat buildings, and gas combustion powers cars, aircraft, ships and spacecraft.**



Flame structure (left pair) and temperature (right pair) on Earth (left) and in weightlessness (right).

The reliance on fossil fuels for combustion means that most of humanity currently depends on finite, non-renewable resources for heating and energy. Another important consideration is the production of pollutants as exhaust by-products. Some of these, such as carbon monoxide and soot, are harmful to humans. Others, including carbon dioxide and oxides of sulphur and nitrogen, are involved in complex chemical reactions in the atmosphere that influence global climate.

With global consumption of fossil fuels expected to rise in coming decades, it is imperative that industry does its utmost to increase combustion efficiency and reduce pollution. However, numerical software models designed to solve these problems are of limited usefulness, since experimental data obtained on the ground are influenced by both diffusion and convection-driven effects, making optimal solutions difficult.

**Key Achievements:**
- **Improved understanding of combustion processes.**
- **More efficient combustion on Earth.**

Unfortunately, combustion processes on Earth are dominated by strong buoyancy forces and convection effects – a large temperature rise during combustion leads to dramatic local density changes in and around the flames. However, since there are no buoyancy effects in microgravity conditions, the measurements made in orbit allow access to mathematical modelling. Furthermore, the large temperature and concentration gradients found during combustion on Earth lead to vigorous convection-driven flows, which are often turbulent and result in unstable burning. The microgravity environment enables the study of stable flames, which significantly helps us to understand the fundamental physical and chemical processes involved in combustion. This, in turn, leads to an improvement of the mathematical models, which leads to an optimisation of combustion processes on Earth.

Combustion studies in various microgravity environments (using drop towers, sounding rockets and orbital research facilities) cover both fundamental research and applied research. The involved research community accepts that data from experiments under microgravity conditions resulted in marked improvement of the simulation models used in industrial combustion process designs. Past microgravity combustion experiments and modelling have led to a new understanding of basic combustion phenomena. The role of the different heat- and mass-transfer parameters in convection, diffusion and radiation is now much better understood.

'THE UNDERSTANDING OF PARTICLE FORMATION IN FLAMES IS A CRUCIAL PREREQUISITE, BOTH FOR THE REDUCTION OF SOOT EMISSION FROM TECHNICAL COMBUSTORS AND FOR THE SYNTHESIS OF ADVANCED NANOPARTICLES. EXPERIMENTS UNDER MICROGRAVITY HELP US TO PROVIDE RELEVANT DATA, SINCE THEY OFFER A UNIQUE WAY TO CONTROL BOUNDARY CONDITIONS OF COMBUSTION PROCESSES.'

PROF. S. WILL
UNIVERSITY OF BREMEN
BREMEN, GERMANY

Future experiments planned for the International Space Station will involve quantitative measurements of droplet and spray evaporation, auto-ignition conditions and soot formation in flames. In line with the political guidelines for the protection of Earth's environment, the principal research objective is to improve combustion efficiency and to reduce pollution by power plants and engines.

ESA astronaut Pedro Duque works with the Microgravity Science Glovebox (MSG) in the Destiny laboratory aboard the International Space Station.

## Fluid and Materials Research

ProCam: A Mobile Photogrammetric Measurement System

**During the preparation of ESA's fluid science research for human spaceflight missions flown in the 1990s (the D2, IML-2 and LMS Spacelab missions), there was a growing demand to measure the motion and shape of transparent liquid bodies.**

The AICON ProCam3 (image courtesy AICON).

Scientists planned a number of experiments that would deal with aspects of fluid dynamics such as convective flow patterns, the behaviour of drops in transparent fluids, and the shape and stability of floating zones. However, it became clear that non-invasive optical diagnostic tools would be required in order to obtain three-dimensional measurements of position and velocity. Two-dimensional measurements were often considered to be insufficient, while 3-D scanning methods were, in most cases, too slow and noisy because of their mechanical drive mechanism.

**Key Achievements:**
- **Innovative portable measurement system.**
- **Numerous industrial applications.**

Between 1993 and 1996, a German company called AICON was contracted by ESA to develop a 3-D method, based on a Photogrammetric Measurement Head, that could be applied to experiment cells. The method was required to obtain coordinate measurements with accuracies of ±0.1 mm within a one litre volume of liquid. In the event, the Photogrammetric Measurement Set Up developed by AICON was able to perform positional measurements throughout a fluid with an accuracy of ±15 micron (smaller than the width of a human hair), about seven times better than required.

In the meantime, a special version of the measurement head – developed by ETH of Zurich – was successfully flown on a sounding rocket to perform 3-D particle tracking. Today, different close-range photogrammetric methods are sufficiently mature for use on the International Space Station.

AICON has used its experience from this space-related work and previous studies to develop an industrial 3-D measurement system, now marketed under the name ProCam3. This commercial, mobile 3-D probe is connected to a laptop, which directly displays the coordinates. The product has important advantages over those from competitors with regard to handling, mobility, set-up time and portability. In order to avoid interference with the illumination of manufacturing premises, the most recent version of the ProCam system uses infrared flashlight.

Rapid growth in demand is expected from many industries that require accurate, portable measurement systems. Already, the automotive (VW, Daimler Chrysler, BMW), aerospace (Airbus) and shipbuilding industries have introduced ProCam for monitoring production, quality control, inspection of incoming parts

'With the support of ESA during the development of our 3-D measurement system, we were able to increase our technical expertise dramatically, resulting in a shorter time to market the resulting product.'

Dr. C.-T. Schneider
President
AICON 3D System GmbH
Braunschweig, Germany

from subcontractors and measurements of crash test vehicles.

The most recent application is in the field of vibration testing, where ProCam can be combined with newly developed 'intelligent acceleration sensors' that have built-in memory to store information about the sensor and its position. The combination of these two independent developments has led to shorter installation times and higher reliability for vibration and shock tests. Currently, ESA's Test Centre at ESTEC in The Netherlands has started to implement such a system.

By early 2004, 15 ProCam systems had been installed in Europe and the USA. The short-term sales target is 30 installations per year at a unit price of €60 000 to €80 000, rising to 50 in the longer term.

ProCam3 excels at measuring hard-to-reach points, is user-friendly and is rugged enough for the most demanding environments (image courtesy AICON).


Close-up of the AICON ProCam3 (image courtesy AICON).

## Environment

### Life Support and Waste Recycling

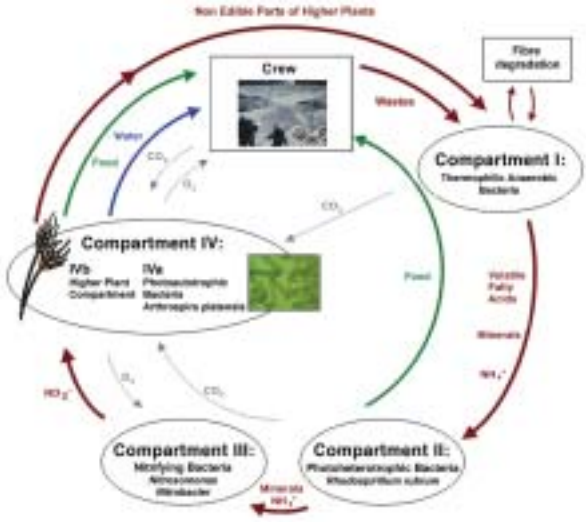
**Today, environmental issues such as air quality in cities, global carbon dioxide emissions and climatic change are rarely out of the news. Not only is there a growing awareness of the interdependency between the environment, economic growth and social well-being, but there is also a thriving debate about the threats that such problems pose for the future of humankind.**

Human spaceflight has an important role to play in this debate by demonstrating the limits of terrestrial life and showing how these limits may be expanded. Technologies developed to sustain life in the hostile conditions of space will drive research and lead to new technologies in fields such as in-situ resource utilisation, alternative (clean) energy sources, closed-loop ecosystems, waste management and water conversion.

**Key Achievements:**
- **Efficient recovery of waste.**
- **Environmental benefits on Earth.**

An example of a new space technology that has important ramifications for the terrestrial environment is MELISSA (Micro-Ecological Life Support System Alternative), a European project to develop a regenerative life-support system for future long-term missions. Since a 6-person crew would consume around 33 tonnes of food, water and oxygen, and produce substantial amounts of waste during a 3-year trip to Mars, development of such a system is clearly imperative.

To achieve that goal, a consortium under the management of ESA is developing a closed-loop system to recover food, water and oxygen from waste and carbon dioxide, using light as the main energy source.




MELISSA eco-system diagram. Compartment I biodegrades crew wastes into basically volatile fatty acids, ammonium and minerals. The $CO_2$ produced is supplied to Compartment IV (photosynthetic compartment). The volatile fatty acids and ammonia produced during the anaerobic fermentation process are fed to Compartment II, where organic carbon is transformed into inorganic carbon source. Compartment III serves mainly to convert ammonia from Compartment II into nitrate, which is the most suitable nitrogen source for Compartment IVb. Compartment IV is responsible for removing $CO_2$, generating fresh food, recovering water and regenerating oxygen for the crew. This compartment is divided into a photoautotrophic bacteria compartment (IVa), Arthrospira platensis, and a Higher Plant compartment (IVb).

MELISSA consists of four compartments containing various kinds of bacteria and plants. The crew's waste is fed into the first compartment and it is gradually broken down by the bacteria into nitrates and gases such as carbon dioxide. In the fourth compartment, where photosynthesis takes place, algae and plants remove carbon dioxide while generating oxygen, water and food for the crew compartment.

The integration and testing of the system is being performed in the MELISSA Pilot Plant at the Universitat Autònoma de Barcelona, an ESA external laboratory in

'MELISSA research aims to obtain a higher level of mastery of the environment by developing a micro-ecological system capable of recycling waste water and solid wastes, regenerating the air and producing some food. This research is a new challenge for mankind, providing the logistics that will enable humans to travel beyond the Earth and live on other worlds.

Mr. J. Brunet
President Director General,
Sherpa Engineering,
Nanterre, France

Concordia Base in Antarctica will use MELISSA technology for recycling.

Spain. So far, the feasibility of each MELISSA compartment has been demonstrated and a recycling level of more than 70% has been shown by simulation. The next steps are to quantify the effects of the microgravity environment on biological processes and to adapt the system for use in space. An experiment called MESSAGE (Microbial Experiment in Space Station About Gene Expression) has already flown to the International Space Station on the Belgian 'Odissea' and the Spanish 'Cervantes' Soyuz missions in November 2002 and October 2003.

The global engineering approach of such a small, efficient closed-loop system has potential in a number of key fields: food production, water recycling, waste recycling, oxygen production, carbon dioxide removal and microbial detection. A number of industrial spin-offs have already resulted and a company is being created to exploit the Intellectual Property Rights generated.

Studies of MELISSA's nitrifying compartment have led to the development of an innovative water filter by French company Veolia. This technology is now being used to treat more than a billion litres of waste water each day in more than 100 towns all over Europe.

Another spin-off is a new biomass sensor that has been developed with the company Frexeinet, to improve control over the production of sparkling wine. The market is estimated at 1000 units a year.

A rather different application is a treatment unit designed to biodegrade human wastes, based on the MELISSA I and III compartments. This technology is being incorporated in the waste water treatment system at Concordia research base in Antarctica.

## Environment

### Air revitalisation

**Mankind has been living on Earth for millions of years without having to worry much about fresh air. Earth's vast ecosystem with its well-balanced chemical interaction between animals, plants and the physical environment has ensured that we always have plenty of oxygen to breathe.**


The ARES principle: recovery of oxygen from carbon dioxide in a 3-step process. 1: carbon dioxide ($CO_2$) exhaled by the crew is removed from the cabin air. 2: carbon dioxide and hydrogen react over a catalyst to form methane ($CH_4$) and water ($H_2O$). 3: water is sent to the electrolyser, where it is split into oxygen and hydrogen.

However, this gift of Nature cannot always be taken for granted. Over the last century, humans have begun to live in confined spaces, such as submarines, aircraft and spacecraft, where fresh air does not come free.

In the case of human spaceflight, it typically costs more than €20 000 to deliver one kilogramme of air into orbit. Since an astronaut consumes about 0.8 kg of oxygen each day and generates 1 kg of carbon dioxide, it is clearly essential to develop some kind of air revitalisation system.

**Key Achievements:**
- **Development of a closed-loop system.**
- **Clean air in confined spaces.**

The ideal solution for a crewed spacecraft would be a closed-loop life support system that mimics Earth's ecosystem, but this is not possible with today's technology. The Environmental Control and Life Support System currently used on the International Space Station is 'open', with a continuous loss of oxygen and hydrogen. By closing the loop (converting the exhaled carbon dioxide into oxygen), the volume of air transported from Earth to the Station would be reduced by 1000 litres per year, which translates into a €30 million saving on operational costs.

European research into closed-loop air revitalisation began in 1985, using funding from ESA and national agencies. Today, this has evolved into the closed-loop Air Revitalisation System (ARES). Under the coordination of ESA, EADS-Space Transportation, Bradford Engineering, Verhaert, Iberespacio, HTS and other companies are developing a prototype that will pave the way for a future demonstration in space.

The key purpose of ARES is the recycling of carbon dioxide and recovery of part of the oxygen used by the astronauts. The exhaled carbon dioxide gas is removed from the air, then chemically processed to produce

'The benefits of a closed air revitalisation system that recovers the oxygen from carbon dioxide are evident for minimising the mass that has to be lifted into space to support long-term human missions. This technology (or parts of it) could also be beneficial for applications on Earth. For example, carbon dioxide extraction and storage is currently being discussed for power plants; sensors and control algorithms are needed for air conditioning in (closed) offices, automobiles, express trains, etc.; and high-efficiency water electrolysis is required for the production of hydrogen – a very promising future energy source. The interactions and the synergetic potentials between terrestrial and space applications are numerous and, certainly, both can greatly benefit each other.

Prof. S. Fasoulas
Dresden University of Technology
Dresden, Germany

methane and water. The water is then split into hydrogen and oxygen; the oxygen is added to the cabin air while the hydrogen is returned to the carbon dioxide processing stage.

The ARES technology has already been demonstrated as an integrated system on the ground, and a joint study with NASA has shown that it has a much higher capability, smaller volume and lower power consumption than existing systems on the ISS. A flight-standard ARES breadboard will be completed by the end of 2004 and elements of the electrolyser will be ready for testing in microgravity during a 2-week Foton mission.

Although ARES is primarily intended to reduce operational costs for long space missions and bases on other worlds, the innovative system also has applications on Earth, where there is a growing demand for more efficient recycling technologies. For example, carbon dioxide concentration is already being used aboard submarines, and there is clear potential for cutting the fuel consumption of commercial aircraft by reducing the need for an external air supply in the passenger cabins.


The ARES Demonstrator Unit.

## Environment

### Cabin Air Monitoring

**In the confined, enclosed environment of a spacecraft, the air must be monitored continuously in order to safeguard the crew's health. A rapid response by the astronauts to the release of harmful gaseous contaminants, accidental off-gassing of materials or malfunctions of the air revitalisation system is essential. Atmospheric monitoring becomes even more essential with mission duration, particularly if 'grab samples' taken periodically from the cabin air cannot easily be sent to Earth for analysis.**

The two Shuttle mid-deck lockers that house ANITA.

ESA is addressing this requirement by contracting Kayser-Threde GmbH (Germany) and SINTEF (Norway) to develop the ANITA (Analysing Interferometer for Ambient Air) technology demonstrator for trace gas monitoring.

**Key Achievements:**
- **Automated monitoring of trace gases.**
- **Health benefits for long-term crews.**

Baselined for a 10-day trial aboard the International Space Station in 2005, ANITA can be housed in two standard Shuttle mid-deck locker inserts mounted in, for example, an Express rack, and controlled by a Personal Computer (PC). The infrared spectrometer is calibrated to monitor 32 contaminants simultaneously at parts per million (ppm) to parts per billion (ppb) levels in the cabin atmosphere. These include background gases – water vapour, carbon monoxide and carbon dioxide and methane – as well as 28 organic or inorganic trace contaminants, including formaldehyde, perfluoropropane, ammonia, and three siloxanes. The instrument's fast time resolution allows the trend in air quality to be analysed instantaneously.

In automatic mode, ANITA monitors the local air by filling its gas cell, scanning the sample and storing the data on its PC's hard disk. The gas cell is then flushed into the cabin and refilled for the next measurement, each cycle taking less than 5 minutes. In semi-automatic mode, the crew collects samples by filling gasbags at the place of interest using a syringe. The gasbag is connected to ANITA's inlet for analysis. During measurement, the physical and chemical properties of the samples remain unchanged.

The ANITA flight experiment is an essential step in demonstrating the maturity of European trace gas

'An innovative gas analysis method was selected for the ISS which is well known from laboratory and environmental monitoring. Experiences with cabin air monitoring enable improvements of this method for new applications in the field of air quality control and reduction of health risks. It offers the potential of non-intrusive air measurements.'

Prof. K. Schäfer
Forschungszentrum Karlsruhe GmbH
Garmisch-Partenkirchen, Germany

monitoring. The current need for air quality monitoring aboard the ISS offers the opportunity to take that step. The wealth of experience gained during the ANITA mission will be fed into the future development of the first operational flight unit, ANITA II, the system that is designed for permanent monitoring on the ISS.

The technology also has terrestrial applications, providing improved multi-component gas measurements for various purposes, such as workplace monitoring (including aerocraft, submarines and buildings), environmental monitoring and control of industrial processes.

## Environment

SpaceHouse

**Today, more than at any other time in history, a multitude of new technologies, materials and production processes are being introduced in the construction industry. Not only do they enable architects to introduce innovative and adventurous ideas, but they can also be used to address environmental and social issues. Among these new technologies and materials are those that have been developed for and by the space industry.**

SpaceHouse.

Space technologies have the potential to play an increasing role in creating sustainable, self-contained and autonomous structures that can help to improve living conditions in inner cities, remote rural areas and places hit by natural disasters.

**Key Achievements:**
- **Utilisation of human spaceflight technologies.**
- **Environmentally attractive construction.**

Technologies transferred from Europe's space programmes, including human spaceflight, are now being adapted for buildings to provide power, durability and strength, while reducing energy consumption and conserving and recycling resources.

ESA has used many of these technologies to develop the concept of a self-sufficient SpaceHouse that could make it possible for astronauts to stay for a longer period on other planets. However, despite its name, SpaceHouse is intended for use as a self-sufficient form of accommodation suitable for any environment here on Earth, as well as on other worlds.

The SpaceHouse can be anything from 12 m to 40 m across, and have up to five floors. Based upon carbon fibre and epoxy resin composites, the unique construction is specially designed to protect against small meteorite showers. Other innovative design features associated with human spaceflight incorporated in the revolutionary structure include:

- vacuum-supported insulation to protect against heat and cold;
- air cleaning and conditioning;
- recycling of waste water;
- 'intelligent' house management.

These innovations, together with its flexible, modular design, mean that the SpaceHouse offers maximum

'It is exciting to discover that the many different technologies and manufacturing processes developed for use in the extreme environment of space have a huge potential of bringing benefits to terrestrial building in terms of energy reduction, environmental care and above all, the quality of life. I am convinced that when space technologies become properly integrated into the construction cycle, it will provide real advantages for our daily life and the environment we live in.'

Mr. P. C. van Staalduinen
TNO Building and Construction Research
Delft, The Netherlands

comfort and the most efficient use of available air, water and energy resources. As a result, it has many potential applications, apart from private housing. Other possibilities include temporary shelters in areas struck by natural disasters; business premises complete with removable walls for flexible utilisation of rooms; restaurants and leisure facilities; and research facilities in remote places such as Antarctica.

In a polluted, overcrowded world, SpaceHouse offers an environmentally-friendly alternative to traditional building designs and construction techniques, whether in run-down city centres or the shanty towns of the Third World.

## Technology

New Technologies

**The human presence in space is a key factor in enabling new technologies to be tested in microgravity, leading to advanced solutions that provide benefits for power generation, transportation, safety and standard of living.**

EuTEF among the Columbus External Payload Facilities.

Through the establishment of bases on other worlds, future human space exploration will drive technological research and development in many fields, ranging from life support in hostile environments and confined space, to large-scale construction equipment and in-situ resource utilisation.

Taking advantage of onboard resources and human presence, the International Space Station will become an advanced testbed for technology development and, eventually, the starting point for human exploration beyond Earth orbit.

**Key Achievements:**
- **Innovative technology and engineering research.**
- **Support for European Industry.**

Numerous potential technology users for the ISS have already been identified, both in support of ESA programmes and from industry. In response to ESA's Early Utilisation Announcement of Opportunity, 18 proposals came from the technology area and were selected for flight.

Technology experiments conducted on the Station will not only be of value for companies involved in development of space systems, but also be applicable to uses on Earth. One example is the application of new technologies for spacecraft thermal coatings to production of more durable paints.

Engineering research and technology development activities aboard the ISS can contribute to many different technical fields:

- Electrical power, including testing of advanced photovoltaic power generation systems and energy storage devices (including batteries, flywheels and solid-state thermal storage).
- Thermal control. The ISS will be used to test advanced thermal components such as two-phase loops, capillary evaporators, small centrifugal pumps, rotatable thermal joints, controllable radiators and high-performance heat pipes.
- Life support. Technologies to be tested include atmosphere revitalisation, water purification and recovery, and closed-loop ecosystems.
- Radiation. By exposing microprocessors, integrated circuits and other electronic components to space radiation, it will be possible to compare their

'Amongst the initiatives that have been pursued in the field of space exploration over the last few years, the International Space Station is unique because it combines human ability to work in microgravity with technology research and innovation.'

Dr. Ing. R. Aceti
Director, Carlo Gavazzi Space
Milan, Italy

behaviour with results from ground-based testing and then develop improved, radiation-resistant versions.

- Communications. The ISS will serve as a testbed for technologies of importance to future satellite communication systems, including high data-rate communications, signal processing, high-temperature superconductors, optical communications and deployable antenna structures.

Some of the first ISS technology experiments will take place outside ESA's Columbus Laboratory on the European Technology Exposure Facility (EuTEF). This programmable, automated system will house up to nine technology experiments: TRIBOLAB; PLEGPAY; MEDET; DEBIE-2; FIPEX; EXPOSE; DOSTEL; EVC; EuTEMP. These experiments are related to tribology (the study of friction, wear and lubrication related to the design of bearings and interactive surfaces), electrostatic charging/discharging phenomena, materials exposure and degradation, space debris and measurement of atomic oxygen flux. EuTEF will also carry the EXPOSE facility for exposure of chemical, organic and biological specimens to the space environment.

## Technology

AUTOMATION AND ROBOTICS

**A few decades ago, many tasks in manufacturing and distribution were almost totally reliant on human intervention. Today, the introduction of automation and single-purpose robots has taken much of the hard manual work and repetition from these areas of the economy.**

Based on the design of a star tracker, the ATV Videometer is the first automatic optical operational system ever used for spacecraft navigation.

In the harsh, unforgiving environment of space, it makes sense to use Automation and Robotics (A&R) wherever possible, either to support astronauts or to replace them altogether.

A&R technologies take many forms, ranging from robotic manipulators through automated sensing systems to advanced human-machine interfaces such as virtual presence and telepresence. They also have many applications, including spacecraft navigation, rendezvous and docking, material processing and handling, and environmental monitoring.

**Key Achievements:**
- **Development of computer and robotic capabilities.**
- **Internet technologies for commerce and education.**

ESA has already made significant progress in spacecraft automation with the introduction of the DMS-R Data Management System. Based on two fault-tolerant computers, DMS-R provides guidance, navigation and control for the entire ISS, as well as command and control for the Russian-built modules. These computers will be reused in ESA's Columbus laboratory and the Automated Transfer Vehicle (ATV) that will perform automated rendezvous and docking with the Station. ESA and Russia have also developed the European Robotic Arm (ERA) to support assembly and maintenance of the ISS. About 11.3 m long and weighing some 630 kg, ERA has seven joints, of which six can operate at any one time. Functionally symmetrical, ERA has an 'end-effector' at each extremity that works either as a hand or as a base from which the arm can operate. Each end-effector includes a special fixture that can grapple and carry payloads of up to 8 tonnes at a maximum speed of 20 cm/s and with a positioning accuracy of 3 mm. Through this fixture, the arm can supply power and exchange data and video signals. Equipped with a foot restraint, ERA will also be available for use by astronauts during spacewalks.

Such manipulator systems may also have an important role to play in future activities to assemble or service satellites in orbit. Indeed, it is possible to envisage a complete range of multipurpose robotic systems that would assist astronauts during prolonged voyages to

THE A&R WE ARE DEVELOPING FOR SPACE APPLICATIONS AND THE EXPERIMENTS THAT ARE CARRIED OUT IN SPACE USING THESE TECHNOLOGIES WILL ALSO HELP US IN THE NEAR FUTURE TO PROVIDE SOLUTIONS TO SEVERAL PROBLEMS ON EARTH (SUCH AS OSTEOPOROSIS) AND TO SUSTAIN ELDERLY PEOPLE IN PERFORMANCE OF HEAVY DAILY TASKS.'

MS. B. MIDOLLINI
AUTOMATION AND ROBOTICS PRODUCT MANAGER
GALILEO AVIONICA
MILAN, ITALY

other worlds. These could include free-flying robots that could operate both inside and outside a space station, and mobile robots to explore and sample planetary surfaces.

Another promising field is the use of 3-D computer visualisation and simulation techniques. Software developed at ESA's ESTEC establishment in The Netherlands to support astronaut training has been commercially developed by a French spin-off company called Silicon Worlds. As well as modelling the complete ISS, Silicon Worlds is now developing 3-D internet technologies aimed at e-commerce and e-learning applications.


The European Robotic Arm (ERA).

## Space-Based Services

### Repair and Servicing

**Modern spacecraft represent the remarkable technological advances made in recent decades. The requirement for them to operate continuously for a decade or more, combined with the inability to modify or repair them in orbit, means that it is in the interests of both the manufacturer and the user to ensure that unmanned spacecraft such as telecommunication and weather satellites continue to function for as long as possible. Unfortunately, the need for in-built redundancy also results in most space systems tending to be much larger, more complex and more expensive than would otherwise be the case.**

One of the most significant exceptions has been the Hubble Space Telescope (HST), which was specifically designed for in-orbit servicing. Since its launch in 1990, NASA and ESA astronauts have successfully completed four missions to upgrade and replace the HST's instruments and hardware, so ensuring that the orbiting observatory continues to provide scientific breakthroughs of fundamental importance to our understanding of the Universe. Without such human intervention, the groundbreaking telescope would have ceased to operate long ago.

**Key Achievements:**
- **Refurbishment of satellites.**
- **In-orbit assembly of large space structures.**

The successes of past Shuttle missions to service the HST and retrieve disabled satellites show the potential of establishing the International Space Station as a semi-permanent 'garage' and assembly workshop in low Earth orbit. The ISS itself is an example of the way in which astronauts, assisted by robotic cranes, can assemble a huge, modular structure in space.

At present, most space enterprises are limited by the requirement to launch entire satellites and space vehicles in one piece through Earth's atmosphere. The laws of aerodynamics and the mechanical loads generated by existing rocket propulsion place severe limitations and constraints on the size, shape and structure of systems that can operate in space. These constraints could be overcome by using the crew on board the ISS for assembly of large, complex structures that could not be launched in their operational configuration. The availability of human operators on the ISS would open up the possibility of transferring final assembly from Earth to space, and of performing regular maintenance and repair tasks which would exceed the capability of current robotic systems.

The ability to assemble space structures of a size and shape that would normally preclude their launch from the ground would also enable manufacturers to make satellites and platforms less complex (and hence cheaper). This, in turn, would reduce their launch mass and lower the cost of launches, with a knock-on effect that should make services such as telecommunications and Earth observation cheaper and more accessible to larger parts of society.

In the long term, the ISS could become a multipurpose test, demonstration and validation base, from which man-tended platforms for specific purposes could evolve, such as final assembly on orbit; inspection, maintenance, repair and retrofit, and assembly of larger vehicles for interplanetary travel.

'Servicing Hubble by Shuttle crews in orbit has not only allowed us to keep the observatory functional and highly productive for a large fraction of its time in space, but it has also given us opportunities to keep it up to date with state-of-the-art instrumentation. In addition, the intense character of these periodic visits has given a very special human dimension to one of the most successful joint ESA/NASA science programmes to date.'

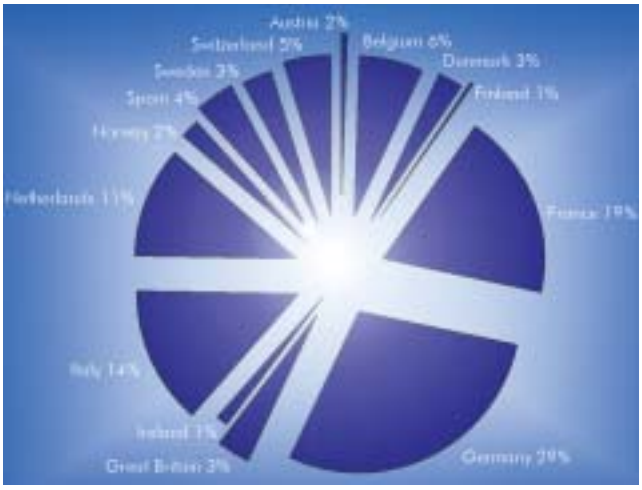
Dr. C. Nicollier
ESA astronaut

Astronaut Claude Nicollier during the STS-103 Hubble Space Telescope servicing mission.

## New Business

INDUSTRY AND INNOVATION

**Economic considerations have not usually been considered as a driver for investment in human spaceflight. Nevertheless, international programmes associated with human spaceflight have contributed to economic development by providing technical and managerial challenges to industry that require the development of new organisational and management processes.**




About 430 European organisations are today actively involved in the implementation of Human Spaceflight Programmes.

Some 430 European organisations are today actively involved in the implementation of human spaceflight programmes, including several of the largest aerospace companies in the world as well as numerous small- and medium-sized enterprises (SMEs). These firms provide direct employment for many thousands of engineers and scientists, thus boosting local and national economies.

**Key Achievements:**
- **Rapid growth of commercial spin-offs.**
- **Catalyst for creation of new enterprises.**

At the same time, human spaceflight encourages the development of close interactions between companies, European universities and other scientific research establishments. Indeed, it provides a platform for integrating different science disciplines (life sciences, physical sciences, space sciences), leading to innovation through integration (e.g. integrated physiology) and the development of new products. All of this makes human spaceflight a major contributor to the European Union's drive to create a knowledge-based society that can lead the world.

Some of the advanced technologies resulting from this research find their way into non-space applications, and many spin-offs from space life sciences have been developed for medical applications on Earth. Human spaceflight acts as a major catalyst for the creation of start-up companies in the field of medical instrumentation, since it calls for small, lightweight designs that are easy to operate and adapted for use in extreme environments. Further challenges involving long-term missions to the Moon and Mars will ensure that human spaceflight continues to be a driver for innovation of medical technologies and equipment.

The concrete benefits from this investment and their impact on the economy may not be immediate, often taking years to mature into marketable products or services. However, the commercial market value of spin-offs derived from human spaceflight facility and instrument developments is growing rapidly, exceeding €100 million in 2002.

'INNOVATION IS, WITHOUT ANY DOUBT, ONE OF THE MAIN DRIVERS OF ECONOMIC GROWTH. WHAT OTHER DOMAINS CAN RIVAL HUMAN SPACEFLIGHT, WHERE EVERYTHING HAS TO BE INVENTED, IN TERMS OF BRINGING NEW TECHNOLOGIES, DISCOVERIES AND INVENTIONS?'

MR. A. GAUBERT
SECRETARY GENERAL
EUROSPACE
PARIS, FRANCE

By stimulating cutting-edge technology, European human spaceflight-related research has led to the creation of more than 40 small- and medium-sized companies and several thousand new jobs.

The new, high tech SMEs agree that what they learn from their space projects in terms of scientific principles, methods and technical and managerial expertise is particularly important as a basis for their future, non-space developments. In addition, they acquire experience in terms of new processing and control techniques, while learning about the design, development and qualification of novel equipment with high reliability and reproducibility.

## New Business

SPACE TOURISM AND EDUTAINMENT

**Global tourism has experienced a dramatic expansion in recent decades, and today it is one of the most important economic activities in the world, generating revenues of about $3500 billion each year. As people continue to seek new adventures and experiences, space tourism has the potential to become a significant spin-off from government-sponsored human spaceflight.**


Space tourist Mark Shuttleworth (left) and ESA astronaut Roberto Vittori (right), in the Unity node of the ISS, April 2002.

Long regarded as a science fiction dream, space tourism has already become a reality for several wealthy entrepreneurs, who have been prepared to pay $20 million for a ticket to the International Space Station.

Although it is likely to be some time before substantial numbers of people can follow in their footsteps, market analyses and polls performed in the USA, Japan and Germany indicate that a large proportion of people under the age of 40 would be prepared to spend large sums to enjoy vacations in space. According to these polls, there are more than a million people – some 4% of all tourists in the Western world – willing to spend some $50 000 for a short orbital space trip, and $5000 to $10 000 for a 30-minute suborbital flight to an altitude of 100-200 km. On this basis, future revenues from global space tourism might eventually be more than double the present civil annual space budget of $30 billion.

**Key Achievements:**
- **Potential for tourism beyond Earth.**
- **New educational and leisure activities.**

To make space tourism affordable for these potential customers, the current ticket price must be reduced to less than 1% of its present level. Such drastic cost reductions will only be possible after the introduction of a new generation of reliable, reusable rockets and spacecraft that offer a rapid launch rate and cheap, efficient ground operations resembling those applied to large aircraft.

Payments from private passengers are already contributing in a modest way to the overall cost of manned spaceflight missions. In future, the financing of private flights will help to attract private industry towards the development and utilisation of human spaceflight.

'IT WAS MY GREATEST PRIVILEGE TO REALISE A PERSONAL DREAM OF SCIENCE AND DISCOVERY BY FLYING TO SPACE IN APRIL 2002. A SIGNIFICANT PART OF THE EXPERIENCE WAS THE OPPORTUNITY TO WORK WITH THE ESA ASTRONAUTS AND THE SPACE COMMUNITY. WE QUICKLY LEARNED THAT WE SHARED A LOVE OF SPACE, SCIENCE AND EXPLORATION, AND IT WAS A GREAT HONOUR TO WORK CLOSELY WITH THE TEAMS THAT PUT MEN AND WOMEN IN SPACE AND RETURN THEM SAFELY, MISSION AFTER MISSION. I ALSO ENJOYED WORKING WITH MY RUSSIAN HOSTS, WHO SHOWED WHAT CAN BE ACHIEVED UNDER DIFFICULT CIRCUMSTANCES IF ONE BUILDS ON PAST PRACTICAL EXPERIENCE. THE FLIGHT ITSELF WAS A JOY, AN ALMOST MAGICAL EXPERIENCE, BUT MOST REWARDING OF ALL WAS THE SENSE OF WONDER THE FLIGHT INSPIRED IN CHILDREN OF ALL BACKGROUNDS IN SOUTH AFRICA. IT HAS BEEN A SOURCE OF CONSTANT PLEASURE TO ME TO SEE HOW STUDENTS HAVE USED IT AS A MOTIVATION FOR THEM TO BE BOLD AND TO SET OUT TO ACHIEVE THEIR GOALS IN LIFE.'

MR. M. SHUTTLEWORTH
COSMONAUT, SOUTH AFRICA

It can be expected that space tourism will be initiated by suborbital flights in the second decade of this century, followed by extended stays on board single-stage orbital spacecraft in low Earth orbit. Tourist packages could later be extended to include an orbit around the Moon and a stay in a space hotel offering artificial gravity.

Several concepts for space hotels have already been studied in various countries. The European space company Astrium (now EADS) presented its concept of the Space Hotel Berlin at space tourism conferences held in Bremen during 1999 and 2000. Their pioneering design applies existing technologies developed for the ISS, such as cylindrical habitat modules (with large windows) derived from ESA's Columbus Laboratory.

For those who cannot afford to experience at first hand the wonders of space, there will be opportunities to participate in educational and leisure activities related to human spaceflight. A number of companies are currently investigating the commercial prospects of using the Moon for such activities. These include provision of live digital video from the Moon, which would enable the public to explore the Moon remotely alongside the astronauts and to drive a purpose-built lunar rover via telepresence portals at participating science centres or theme parks.

# FUTURE OUTLOOK

## Into the Future

**Now more than 40 years old, human spaceflight has matured from the pioneering days when only test pilots with 'The Right Stuff' could venture into the Cosmos. Today, the exploitation and utilisation of space have begun, with the construction and permanent occupation of the International Space Station.**

Over the next decade, the ISS will continue to dominate the human spaceflight programme of ESA, as groundbreaking research is conducted onboard Columbus and other laboratories. Many significant scientific and technological breakthroughs may be expected, alongside a growth in commercial applications that will provide new, highly skilled jobs while benefiting society as a whole here on Earth.

**Opportunities:**
- **Human exploration of other worlds.**
- **New, highly skilled jobs.**
- **Creation of knowledge-based society.**

In the longer term, the expertise and knowledge developed through the ISS programme will also be exploited to enable human travel beyond low Earth orbit, providing a further boost to science and technological innovation. Building on Europe's historical heritage of global exploration, ESA is already studying ways to send humans to the Moon, then, eventually, on to Mars, with the ultimate aim of constructing a permanent international base for scientific research.

The primary objective of ESA's Aurora programme is to define and develop many of the new technologies and capabilities that will be required before people can take the giant leap of venturing to the Red Planet. Through this strongly proactive approach, Europe will be well-placed to participate in a global endeavour to extend human exploration beyond low Earth orbit, as outlined by US President George W. Bush in January 2004.

Artist's impression of Mars exploration.

Experience gained by establishing a permanent base on the Moon will provide opportunities for more sustainable living in limited, hostile environments on Earth. For example, the development and the operation of a lunar outpost will encourage technological innovations focused on reduced water and energy consumption, as well as in-situ resource utilisation.

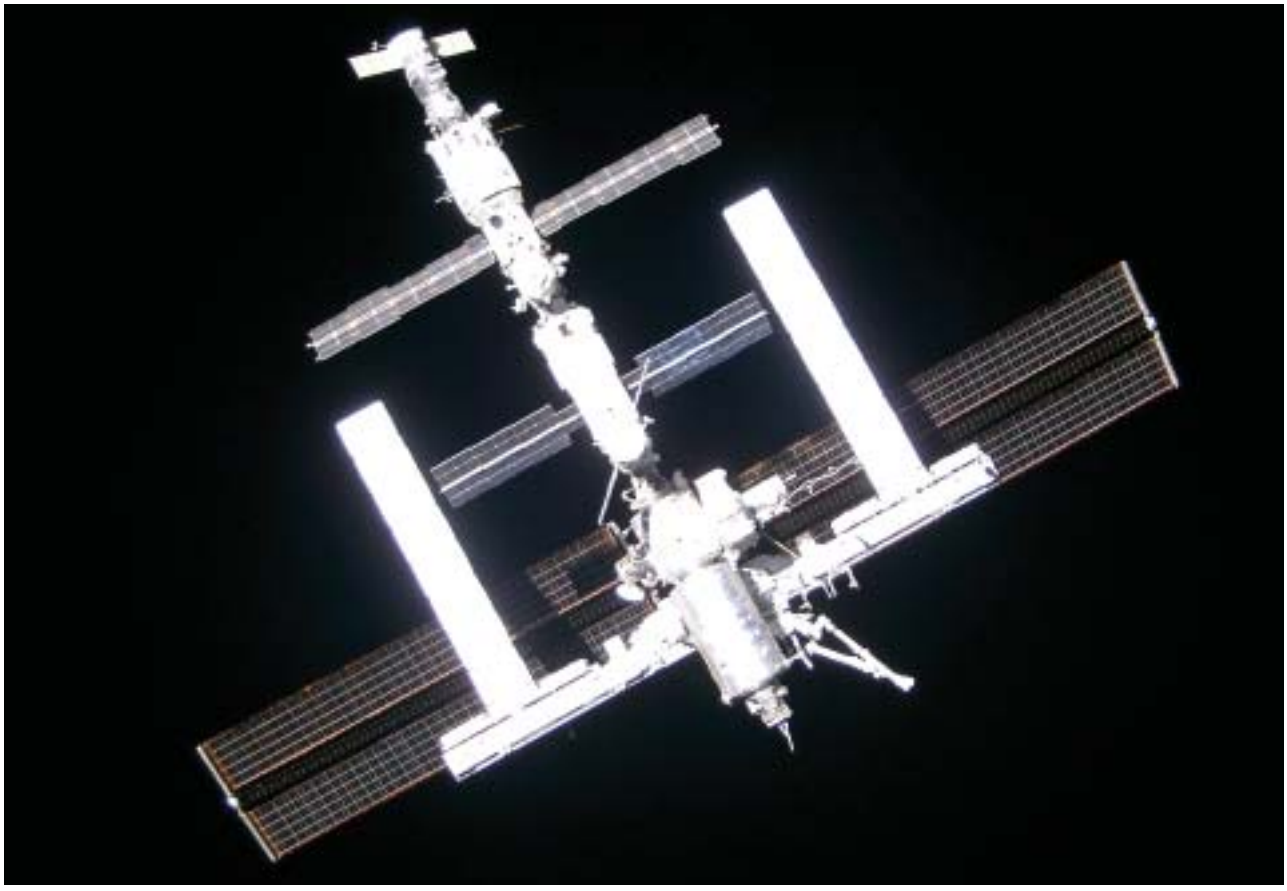
A full inventory of lunar resources will be required, so that its economic potential can be properly assessed. The most valuable of these resources may be Helium-3, which could eventually be mined and sent to Earth for use in fusion reactors, providing a clean, efficient means of meeting global energy needs in the second

half of the 21st century. The apparent discovery of ice in permanently shaded craters near the lunar poles may provide a valuable source of water (e.g. for growing food, drinking and hygiene), as well as oxygen and rocket fuel.

Exploration will help scientists to understand the formation of our Earth-Moon system, and the Solar System in general. One major objective will be the search for traces of life on other worlds, its origin, evolution and possible causes for its extinction. Advanced planetary protection procedures to prevent contamination will help to secure mankind's ultimate survivability.

Just as the Apollo programme galvanised US science and technology for several decades, so future human spaceflight programmes will help to inspire and enthuse the next generation of scientists and engineers. Direct and indirect employment in the form of well-paid, highly skilled jobs will play an important role in meeting the European Council's strategic goal – to transform Europe into the most competitive and dynamic knowledge-based society in the world, identified by sustainable economic growth in tandem with greater social cohesion.

Future human spaceflight programmes will also offer major challenges to industry, not only through research and development but also through the introduction of new organisational and management processes related to complex, international programmes. At the same time, investments in human spaceflight research and development will result in numerous spin-offs and technology transfers for applications on Earth.



Over the next decade, the ISS will continue to dominate the human spaceflight programme of ESA, as groundbreaking research is conducted onboard Columbus and other ISS laboratories.

## Further Reading

Brisson P. & Rootes J., *Down to Earth: Everyday Uses for European Space Technology*, ESA BR-175, 2001.

Clement G., *Fundamentals of Space Medicine*, Kluwer Academic Publishers, Dordrecht, 2003. (http://www.wkap.nl/prod/b/1-4020-1598-4)

Seibert G. et al, *A World Without Gravity*, ESA SP-1251, 2001.

*A Case for Humans in Space, The European Astronauts*, ESA BR-173, 2001.

ESA Technology Transfer Brochures:
- BR-184 *Racing with the Sun*
- BR-184(I) *Mining, Oil, and Gas*
- BR-184(II) *Water Management*
- BR-184(III) *Land Use & Monitoring*
- BR-184(IV) *Cars & Trucks*
- BR-184(V) *Vibrations*
- BR-184(VI) *Fitness, Leisure and Lifestyle*
- BR-184(VII) *Medicine*
- BR-184(VIII) *Safety and Security*
- BR-184(IX) *Medicine II*

*European Utilisation Plan for the International Space Station*, ESA SP-1270, 2003.

'25 Years of European Human Spaceflight', ESA *Bulletin* 116, November 2003.

*International Space Station Education Kit*, ESA BR-194, 2002.

*On Station*, The Newsletter of the Directorate of Human Spaceflight.

*The International Space Station European Users Guide*, UIC-ESA-UM-0001, 2001.

*Towards the Future*, ESA BR-162, 2000.

## Selected Web Sites

ESA Advanced Life Support
*http://www.estec.esa.nl/ecls/*

ESA Aurora Programme
*http://www.esa.int/export/SPECIALS/Aurora/index.html*

ESA Education
*http://www.esa.int/export/esaED/index.html*

ESA Human Spaceflight and Microgravity
*http://www.esa.int/spaceflight*

ESA Human Spaceflight and Microgravity – Utilisation
*http://www.spaceflight.esa.int/users/index.cfm*

ESA Technology Transfer Programme
*http://www.esa.int/technology*

ESA Human Spaceflight: Research
*http://www.esa.int/export/esaHS/research.html*

ESA Human Spaceflight: The Future
*http://www.esa.int/export/esaHS/future.html*

Telemedicine Alliance
*http://www.esa.int/export/SPECIALS/Telemedicine_Alliance/index.html*

## Acknowledgements

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# Major Achievements in Human Spaceflight

## (European achievements in blue)

12 Apr 1961 Vostok-1: Yuri Gagarin (USSR) becomes first human to orbit the Earth.

20 February 1962 Mercury Atlas-6: John Glenn becomes first American into orbit.

16-19 Jun 1963 Vostok-6: Valentina Tereshkova (USSR) becomes first woman in space.

18 Mar 1965 Voskhod-2: Alexei Leonov (USSR) becomes first human to walk in space.

20 Jul 1969 Apollo-11: US astronauts Neil Armstrong and Buzz Aldrin become the first humans to land on the Moon.

19 Apr 1971 Salyut-1: launch of the world's first space station (USSR).

2-10 Mar 1978 Soyuz-28/Salyut-6: Czech Vladimir Remek becomes the first European to fly in space.

26 Aug - 3 Sep 1978 Soyuz-31: German cosmonaut Sigmund Jähn visits the Salyut-6 space station.

12 Apr 1981 STS-1: maiden launch of the US Space Shuttle.

24 Jun - 2 Jul 1982 Soyuz-T6/Salyut-7: French astronaut Jean-Loup Chrétien becomes the first western European to visit a space station.

28 Nov - 8 Dec 1983 STS-9 (Spacelab-1): first Spacelab mission. ESA Astrronaut Ulf Merbold (D) is the first non-US astronaut to fly on a Shuttle. 71 experiments.

17-24 Jun 1985 STS-51G: Patrick Baudry becomes the first French citizen to fly on a Shuttle.

30 Oct - 6 Nov 1985 STS-61A (Spacelab-D1): German-sponsored mission with 76 experiments. Crew included ESA astronaut Wubbo Ockels (NL), German astronauts Reinhard Furrer and Ernst Messerschmid.

26 Nov - 21 Dec 1988 Soyuz-TM7: 25-day mission to Mir by French astronaut Jean-Loup Chrétien. Included first European EVA.

18-26 May 1991 Soyuz-TM12: first European female astronaut Helen Sharman takes part in a privately-funded mission to Mir space station.

2-10 Oct 1991 Soyuz-TM13: Austrian Franz Viehböck visits the Mir space station.

22-30 Jan 1992 STS-42 (Spacelab IML-1): international mission including ESA astronaut Ulf Merbold. 20 ESA experiments.

17-25 Mar 1992 Soyuz-TM14 (Mir-92): Klaus-Dietrich Flade flies on German-sponsored mission to Mir.

24 Mar - 2 Apr 1992 STS-45 (ATLAS-1): Belgian astronaut Dirk Frimout represents ESA on a scientific mission to study the Sun and Earth's atmosphere.

27 Jul - 10 Aug 1992 Soyuz-TM15: French Antares mission with astronaut Michel Tognini.

31 Jul - 8 Aug 1992 STS-46: mission to deploy the first Tethered Satellite and ESA's Eureca satellite with ESA astronaut Claude Nicollier and Italian Franco Malerba.

26 Apr - 6 May 1993 STS-55 (Spacelab-D2): second German-sponsored mission with ESA participation. Crew includes German astronauts Ulrich Walter and Hans Schlegel.

1-22 Jul 1993 Soyuz-TM17: French Altair mission with astronaut Jean-Pierre Haigneré.

2-13 Dec 1993 STS-61: ESA astronaut Claude Nicollier (CH) flies on the first Hubble Space Telescope (HST) servicing mission.

3 Oct - 4 Nov 1994 Soyuz-TM20: Euromir-94, 30-day flight by ESA astronaut Ulf Merbold. 29 experiments on the Mir space station.

3-14 Nov 1994 STS-66 (ATLAS-3): ESA astronaut Jean-François Clervoy (F) takes part in a scientific mission to study the Sun and Earth's atmosphere.

3 Sep 1995 - 29 Feb 1996 Soyuz-TM22: 179-day Euromir-95 mission with ESA astronaut Thomas Reiter included 41 experiments and the first EVA by an ESA astronaut.

22 Feb - 9 Mar 1996 STS-75 (USMP-3): ESA astronauts Umberto Guidoni, Maurizio Cheli and Claude Nicollier take part in a reflight of Italy's Tethered Satellite.

20 Jun - 7 Jul 1996 STS-78 (Spacelab LMS-1): French astronaut Jean-Jacques Favier takes part in mission to conduct experiments in life science and materials science.

17 Aug - 2 Sep 1996 Soyuz-TM24: French Cassiopée mission with astronaut Claudie Haigneré.

10 Feb - 2 Mar 1997 Soyuz-TM25: German Mir-97 mission with astronaut Reinhold Ewald.

15-24 May 1997 STS-84: ESA astronaut Jean-François Clervoy flies on the sixth Shuttle to Mir.

25 Sep - 6 Oct 1997 STS-86: French astronaut Jean-Loup Chrétien flies on the seventh Shuttle to Mir.

29 Jan - 19 Feb 1998 Soyuz-TM27: French Pégase mission to Mir by astronaut Léopold Eyharts.

17 Apr - 3 May 1998 STS-90 (Neurolab): 22nd and final mission for ESA's Spacelab.

29 Oct - 7 Nov 1998 STS-95: ESA astronaut Pedro Duque (E) participates in a scientific Spacehab mission.

20 Feb - 28 August 1999 Soyuz-TM29: 188-day Perseus mission to Mir by ESA astronaut Jean-Pierre Haigneré, the longest flight by a non-Russian.

22-27 Jul 1999 STS-93: French astronaut Michel Tognini flies on mission to launch the Chandra X-ray observatory.

19-27 Dec 1999 STS-103: third HST servicing mission includes EVAs by ESA astronaut Claude Nicollier, and control of robotic arm by ESA astronaut Jean-François Clervoy.

11-22 Feb 2000 STS-99: ESA astronaut Gerhard Thiele (D) flies on the Shuttle Radar Topography Mission.

19 Apr - 1 May 2000 STS-100: first supply mission with Italian- built Raffaello Multi-Purpose Logistics Module (MPLM). Umberto Guidoni becomes first ESA astronaut to visit ISS.

12 Jul 2000 Zvezda: launch of ISS Zvezda module with Data Management System (DMS-R) provided by ESA.

21-31 Oct 2001 Soyuz-TM33: 12 experiments on French- sponsored Andromède mission to ISS with ESA astronaut Claudie Haigneré (F).

25 Apr - 5 May 2002 Soyuz-TM34: 4 experiments conducted by ESA astronaut Roberto Vittori (I) on Italian-sponsored Marco Polo mission to ISS.

5-19 Jun 2002 STS-111: French astronaut Philippe Perrin helps install ESA's Microgravity Science Glovebox in ISS Destiny laboratory.

30 Oct - 10 Nov 2002 Soyuz-TMA1: 23 experiments on Belgian- sponsored Odissea mission to ISS with ESA astronaut Frank De Winne (B).

18-28 October 2003 Soyuz-TMA3: 24 experiments conducted by ESA astronaut Pedro Duque (E) during Spanish-sponsored Cervantes mission to ISS.

19-29 Apr 2004 Soyuz-TMA4: 19 experiments on Dutch- sponsored Delta mission to ISS with ESA astronaut André Kuipers (NL).