esa

→ SPACE FOR LIFE

human spaceflight science newsletter

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ESA astronaut André Kuipers following landing of the PromISSe mission on 1 July 2012

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→ RESEARCH WITH A LOT OF PROMISSE

A look back on André's ISS mission

ESA once again celebrate the successful conclusion of a long-duration mission and associated experiment programme on 1 July with the landing of André Kuipers and his fellow crew members. This research programme included bringing a number of established experiments to their successful conclusion as well as starting some experiments for the very first time.

A host of experiments were undertaken by Kuipers himself as part of the PromISSe* mission, either as a subject of human research experiments or as an operator by initiating experiments in other research domains.

Additional ESA experiments within the PromISSe mission were undertaken by ISS Partner astronauts and cosmonauts or controlled/ monitored from ground by the extensive network of User Support and Operations Centres (USOCs) under the overall coordination of the Columbus Control Centre.

Human Research

Cardiopulmonary and Musculoskeletal

Human Research activities are always one of the main focal points of any human spaceflight mission. This was even more poignant for the PromISSe mission with Kuipers being a qualified medical doctor. No fewer than five major long-duration cardiopulmonary experiments were undertaken by Kuipers (and ISS Partner astronauts), two of which (CARD and Vessel Imaging) are covered in a separate article. With gravity playing such an

* (Programme for Research in Orbit Maximising the Inspiration from the Space Station for Europe)

important role in blood circulation on earth, understanding the cardiovascular adaptation that occurs in space is not only important for planning future human exploration missions it can also provide very important indications as to the mechanisms behind conditions such as hypertension and cardiovascular disease (which was estimated to cost around € 170 billion in the countries of the European Union in 2003).

NASA astronaut Don Pettit using the Portable Pulmonary Function System whilst on the CEVIS exercise device during activities for the joint Thermolab/EKE/VO2 Max experiments

ESA's Thermolab and EKE experiments have been improving our physiology knowledge since 2009. Three astronauts (Kuipers and NASA astronauts Don Pettit and Dan Burbank) undertook monthly in-orbit sessions of the experiments during the PromISSe mission. This will help to determine thermoregulatory and cardiovascular adaptations during long-duration spaceflight within Thermolab and help in the development of an improved diagnostic tool within EKE, in order to reduce the time spent on assessing endurance capacity (physical fitness) in orbit. In order to optimise the use of ISS crew time resources these experiments are carried out in conjunction with NASA's VO2 Max cardiopulmonary experiment.

ESA astronaut André Kuipers using the Portable Pulmonary Function System.

These joint experiments record a variety of pulmonary measurements during varying degrees of exercise using the ESA-developed Portable Pulmonary Function System. This key piece of ISS diagnostic apparatus is a mobile version of the ESA/NASA Pulmonary Function System. The Pulmonary Function System is itself a central focus of ESA's new Energy experiment which André Kuipers started as the very first test subject in May. The science team for the Energy experiment will determine the energy requirements of astronauts during long-term spaceflight by combining astronaut cardiopulmonary measurements with recorded activity levels and dietary intake, and analyses of markers excreted in urine. As weightlessness has a negative influence on energy balance/requirements this experiment will be extremely helpful in planning for future human exploration missions.

Food containers for the Energy Experiment

For musculoskeletal research ESA's major investigation in this area (SOLO) came to a successful conclusion of on-orbit activities in March, while the last samples were brought back to earth with Soyuz 28S end of April 2012. This is also discussed in detail in a separate article.

Neuroscience

Gravity plays a fundamental role in our perception of our environment on earth. Adaptation to, and living under weightless conditions, and thereafter re-adaptation to gravity, are challenging for astronauts. Differences in perception have already been highlighted from previous research on the ISS. In neuroscience ESA saw the successful conclusion of the Passages experiment in March 2012 (see later article). Even though Kuipers was not a subject of this experiment he was a key test subject for the Neurospat experiment which uses visual stimuli and EEG monitoring to investigate the ways in which crew members' three-dimensional perception is affected by long-duration stays in weightlessness. Kuipers who became the third ESA astronaut test subject of the experiment was fundamental in finalising Neurospat activities on orbit during the PromISSe mission, resolving a hardware problem to retrieve data and supplying additional research questionnaires for the science team which was not part of the original experiment protocol.

Session of the Neurospat experiment on the ISS in February 2012. ESA astronaut André Kuipers looks through light shield at visual stimuli displayed on attached laptop. At the same time brain activity is monitored through an EEG cap.

Kuipers successfully rounded off neuroscience research during the PromISSe mission with completion of weekly questionnaires for another new experiment, Space Headaches, which is determining the incidence and characteristics of headaches occurring within astronauts in orbit. NASA astronaut Joe Acaba is currently the second test subject for this experiment on the ISS.

Immunology

ESA's human research activities during the PromISSe mission were completed in the area of immunology with the ROALD-2 experiment (see separate article) and the Immuno experiment, which has already involved four cosmonauts completing stress test questionnaires in 2012 and supplying blood and saliva samples to be checked for hormones associated with stress response and carrying out white blood cell analysis.

Fluids Research

On-orbit activities for four fluid science experiments were completed during the PromISSe mission. The SODI-DSC experiment which was processed for two months until January 2012 successfully brought to conclusion a major experiment series using the Selectable Optical Diagnostic Instrument (SODI) installed inside the Microgravity Science Glovebox (MSG).

The DSC ('Diffusion and Soret Coefficient Measurements for Improvement of Oil Recovery') experiment is supporting research to determine diffusion coefficients in different model fluid mixtures, which are respresentative of petroleum field samples, and refine petroleum reservoir models to help lead to more efficient extraction of oil resources. On orbit, temperature gradients were applied along the DSC experiment cells with the associated fluid thermodiffusion and molecular diffusion phenomena observed inside the cells. There were some considerable challenges at the start of the experiment runs as image quality was initially insufficient for analysis and one experiment cell also became unusable as an air/gas bubble showed up in its field of view.

SODI-DSC experiment hardware located in the Microgravity Science Glovebox on the ISS

However, due to the excellent work of the science team a post-processing algorithm was quickly programmed which significantly improved image quality and possibly the expected science return of this experiment. By the end of the DSC science campaign inside the MSG, more than 70% of science runs were completed. The first DSC data disk (out of 5) was successfully returned with Soyuz 28S, while the remaining ones are currently manifested for return on the Space-X 1 vehicle (NET October 2012). Soyuz 28S also returned the scientific results of the SODI-Colloid 2 experiment (another SODI experiment which finished in November 2011). The Colloid experiment covers the study on growth and properties of advanced photonic materials within colloidal solutions which could be promising candidates for new types of optical components.

In the area of fluid science one of the principal experiments completed during the PromISSe mission was the Geoflow-2 experiment in the Fluid Science Laboratory (see also separate article) though André Kuipers carried out additional activities on the Fluid Science Laboratory hereafter to prepare it for the execution of the FASES (Fundamental and Applied Studies of Emulsion Stability) experiment in 2013. FASES will hold significance for oil extraction processes, and in the chemical and food industries. One final experiment which André Kuipers supported was the Foam Stability experiment (which serves both education and science). The experiment aimed to demonstrate the behaviour of aqueous and non-aqueous foams in weightlessness and how gravity influences their stability.

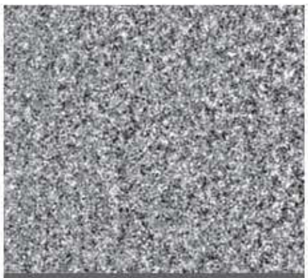
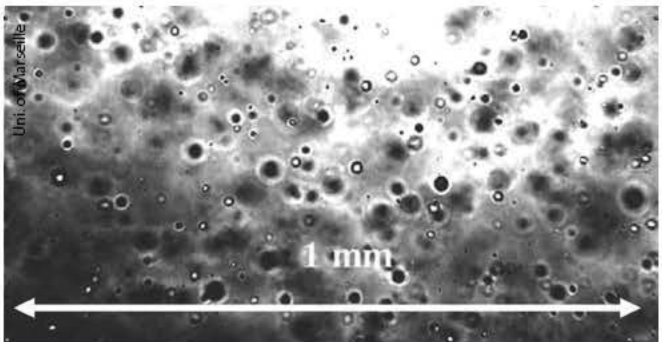


Image from the Colloid experiment showing aggregation in the colloidal solution

André Kuipers preparing the Fluid Science Laboratory in May 2012 for optical testing for the FASES experiment



Emulsion of hexane in water from ground testing of FASES experiment. The black dots, which are due to light diffusion in the drops, provide the position and the velocity of the drops

Radiation and Solar Research

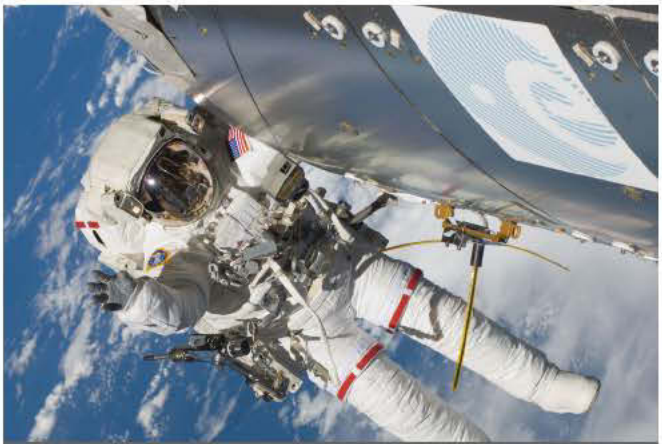
Kuipers was a key astronaut in setting up two new radiation research experiments on the ISS during the PromISSe mission: the DOSIS-3D experiment and the Shielding protocol of the ALTEA-Shield composite experiment. These experiments which are improving our knowledge of the radiation environment in low-Earth orbit are discussed in separate articles. Meanwhile throughout the PromISSe mission ESA's Solar payload facility on the external surface of the Columbus laboratory continued studying the Sun's irradiation with unprecedented accuracy including successful data acquisition during a large Solar storm in January/February 2012, the 50th data acquisition period for the facility (currently during more than four and a half years on orbit), and simultaneous measurements taken in coordination with ESA's Venus Express spacecraft.

André Kuipers setting up the ALTEA Shield hardware in the Shielding configuration on 8 June 2012

Technology Demonstrations

The testing of new technologies on the ISS has proved to be very successful area of research for ESA. The Vessel Identification System (usually known as AIS) continues to monitor global maritime traffic from space and had improvements made to the system in January with a software upgrade. This upgrade has already shown significant improvements in the instrument's performance especially in the high traffic zones. First results have shown a 1.4 improvement factor for the Mediterranean region and a factor of 2.0 for the region off the coast of China.

For Kuipers, his involvement in technology research was in the area of visual imaging technologies. In addition to continued use of the Erasmus Recording Binocular 2 (ERB-2) for recording high definition 3D video images on the ISS, Kuipers tested the new NightPod nodding mechanism in the European-built Cupola Module. This new tracking device supports a Nikon 3Ds digital camera in taking high-definition pictures of the Earth, especially under low light conditions during ISS night orbital passes. This device compensates for the motion of the Space Station by tracking single points on Earth automatically. In a global outreach effort, the footage will be available for the public on the internet. The payload will also be used for education and outreach purposes in order to teach children and students about geography and demographic distribution on Earth.



The AIS antenna following installation on the outside of the Columbus laboratory

Plot of global ship positions using AIS data from the Norwegian NORAIS Receiver. NORAIS forms part of ESA's Vessel Identification System for tracking global maritime traffic

NightPod tracking device installed at a window in the European-built Cupola module

Image of the Netherlands taken using NightPod

Education and Additional Activities

ESA's research programme and education activities are often very closely linked during human spaceflight missions. In education Kuipers helped in demonstrating convection in weightlessness to students within the Convection experiment; promoted regular exercise and healthy nutrition among young people in many European countries as part of the "Mission X – Train Like An Astronaut" project; and promoted science among young people as part of the Spaceship Earth activity with events throughout Europe.

Kuipers was also involved in numerous Public Affairs activities for ESA, was a test subject for numerous ISS Partner experiments, and was a key astronaut in spacecraft integration activities following docking of Europe's ATV-3 in March and for the new SpaceX Dragon spacecraft for which he was a principal robotic arm operator for berthing and unberthing activities in May.

German Chancellor Angela Merkel talking to André Kuipers at CeBIT, the world's largest IT trade show in March 2012

ESA astronaut André Kuipers inside ATV-3 following docking

SpaceX Dragon spacecraft during berthing activities in May 2012

→ HUMAN RESEARCH

Successful conclusion of CARD and SOLO experiments

During the PromISSe mission with ESA astronaut André Kuipers, André was the subject of a variety of on-orbit human research experiments. For two of these experiments, CARD and SOLO, this also meant the successful conclusion of all on-orbit activities with the required number of test subjects being reached.

As with all human research experiments, numerous astronaut test subjects are required in order to make research data statistically significant. For this reason human research experiments tend to be long-duration, being undertaken across numerous different ISS Expeditions.

CARD Experiment

CARD is a cardiopulmonary experiment which studies how the cardiovascular system adapts to prolonged weightlessness, and in particular the underlying mechanisms of blood circulation in the peripheral parts of the human body (arm and legs) while a crewmember is in space.

On Earth increased activity in the sympathetic nervous system (associated mainly with increased physical activity) and increased cardiac output are normally associated with increased blood pressure. However, research in astronauts has found that increased activity in the sympathetic nervous system and increased cardiac output is actually associated with lowered blood pressure. The CARD experiment is examining these effects in order to provide a thorough picture of how the circulatory system changes during a prolonged stay in weightlessness.

The CARD experiment started during ISS Expedition 14 in 2006 and has now been successfully concluded with eight subjects. Completing CARD activities on orbit was not without its challenges, though these were accompanied by associated successes.

The CARD experiment requires the use of the Pulmonary Function System for analysing the breath of astronauts five times over a 24-hour period to help measure cardiac output. This is accompanied by simultaneous blood pressure measurements and subsequent urine collection and blood sampling to assess hormonal changes.

ESA astronaut Thomas Reiter preparing Pulmonary Function System for the first session of the CARD experiment in Nov. 2006

Success in the face of adversity

Activities for the CARD experiment had been temporarily on hold due to a failed module of the Pulmonary Function System though this was successfully replaced by André Kuipers in January. The CARD experiment restarted with Kuipers at the end of March though during the session a connector on a Pulmonary Function System hose (part of the Bag Filling Assembly) broke off, leading to the session being cancelled. This hose was essential for the measurements as it filled the rebreathing bag of the Pulmonary Function System with a gas mixture containing gas 'markers' that were monitored in astronauts exhaled breath to help determine cardiac output. If the connector could not be fixed in due time this could have jeopardised the availability of Kuipers as a test subject.

No spare connector of this type was available on-board, however, the ground teams at Damec Research Aps, the User Support and Operations Centre for the Pulmonary Function System, showed a great deal of innovation in quickly putting together a temporary repair in order to bring research activities to their successful conclusion. The ground teams managed to reconfigure a flow meter of the Pulmonary Function System to

ESA astronaut André Kuipers during activities to exchange the failed Photoacoustic Analyser Module of the Pulmonary Function System in January 2012

Broken connector during the CARD experiment

ISS Expedition 19 flight engineer and JAXA astronaut Koichi Wakata, preparing to use the Pulmonary Function System for a rebreathing session as part of the CARD experiment act as a Bag Filling Assembly. Once this was successfully tested on ground a video was made and uplinked to Kuipers who successfully carried out the necessary repairs on 12 April.

The rebreathing sessions continued for Kuipers on a week later, this time with all measurements being taken. Associated blood and urine samples were taken as well from Kuipers which were returned to earth for analysis on Soyuz 28S at the end of April. Even though this concluded all on-orbit experiment activities for CARD, ESA's cardiovascular research is continuing on the ISS with experiments such as the Vessel Imaging experiment which is undertaking research into properties of central and peripheral blood vessels in weightlessness, using ultrasound scans with ECG. There have already been four test subjects in 2012 including ESA astronaut André Kuipers and NASA astronauts fellow crew member Dan Burbank, Don Pettit and Joe Acaba. Data from the experiment optimises ISS resources (and scientific cooperation) by being carried out in conjunction with NASA's Integrated Cardiovascular Experiment.

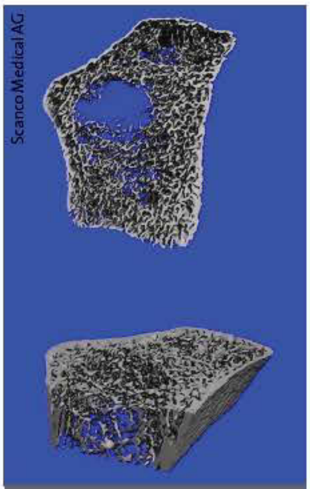
If continued research determines that long-duration spaceflight increases cardiac output and induces dilation of peripheral arteries this suggests that long-duration spaceflight is actually, in some ways healthy for the cardiovascular system. This may not only have an impact on how we prepare our astronauts and plan for future long-duration missions, it could also have an impact on the treatment and rehabilitation of patients suffering from hypertension and other cardiovascular diseases.

NASA astronaut Dan Burbank setting up Human Research Facility 1 in Columbus for ultrasound scans on André Kuipers for the joint Vessel Imaging and Integrated Cardiovascular experiments in January 2012

Musculoskeletal Research

SOLO

Turning to musculoskeletal research, another long-duration experiment which reached successful conclusion of on-orbit activities was the Sodium Loading in Microgravity (SOLO) experiment which is one of the ESA experiments targeting the effect of bone loss and related medical conditions. On earth the most prevalent of these conditions is osteoporosis, for which the treatment of fractures in Europe was estimated to cost €25 billion per year. Astronauts exhibit bone loss similar to osteoporosis, i.e. about 1% loss per month in space. The ISS is therefore a perfect test bed for carrying out this kind of research.



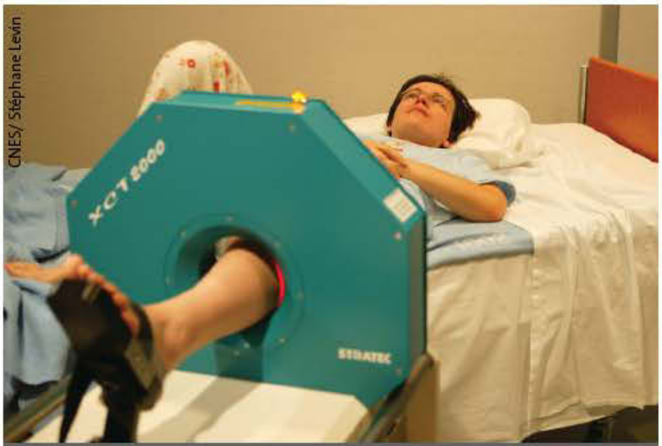
3D pQCT image of osteoporotic bone

ESA astronaut André Kuipers and NASA astronaut Dan Burbank undertook the final sessions of this experiment in January/February 2012 with their associated blood and urine samples returned to earth in April (along with samples for Ron Garan). These samples are being analysed for relevant biochemical markers to indicate the effects on bone metabolism.

ESA astronaut André Kuipers undertaking Body Mass Measurement for the SOLO experiment on 1 February 2012

SOLO has been studying the mechanisms of fluid and salt retention in space and related human physiology effects since October 2008, gathering data from different ISS Expedition crew members. The link with bone loss may not be obvious to the layman, but it is suspected that weightlessness may lead to an activation of sodium-retaining hormones causing higher than normal levels of sodium in the body. In addition sodium has a pH-lowering effect, which also could have a negative impact on bone metabolism. Average and high sodium intake in weightlessness causes sodium levels in the body that exacerbate the rise in bone resorption, i.e. the body reabsorbing bone tissue.

A special diet was followed during the two 6-day sessions for the SOLO experiment, one a lower-salt diet, the other a higher-level salt diet



Computed tomography (pQCT) measurement during second campaign of the WISE bed rest study in Toulouse, France. (Image: CNES/ Stéphane Levin)

On-orbit activities for SOLO consisted of astronaut subjects undertaking two different 6-day diet sessions, one with a lower salt diet and the other with a higher level salt diet, with the same daily calorie intake and fairly high fluid consumption. During each session the astronauts logged what they had eaten, and had body mass measured in addition to providing blood and urine samples for analysis. With the samples now returned we can look forward to the results that are generated by all the data gathered which could help to drive future research in this area.

ESA's research into bone mass reduction with SOLO is further supported by the Early Detection of Osteoporosis in Space (EDOS) experiment, which is testing the efficiency of three-dimensional peripheral quantitative computed tomography (3DpQCT) as a technique for detection of bone structure in order to provide a detailed evaluation of the kinetics of bone loss recovery after flight.

ESA's wide ranging research in this area is helping to uncover the mechanisms behind conditions exhibiting bone mass loss and helping to develop innovative tools to detect, monitor and combat the effects of osteoporosis.

This will not only help maintain the well-being of astronauts in space on longer-duration missions in the future, it will also help to alleviate the burden that conditions such as osteoporosis have to society.

Even if the data deriving from ESA's research should help in the future in simply delaying the onset of such conditions as osteoporosis this should cause a significant saving to society.

→ INSIGHTS INTO:

Immune response in the ROALD-2 experiment

ESA has a rich history in immunology research on the ISS which has provided a host of data on behaviour of elements of the immune system under spaceflight conditions. These experiments build on previous research started in the 1980's using ESA facilities on the Space Shuttle such as Biorack, which have shown that T-cell (immune system) activation is inhibited in weightlessness.

A whole series of these experiments, which have investigated different elements of immune system suppression, have taken place in ESA's Kubik incubators on the ISS, with different biological samples being processed at body temperature. Some of these were kept under weightless conditions while a selection of samples were processed on Kubik's centrifuge insert to provide 1g control samples.

The latest ISS experiment to come to successful conclusion on orbit was the ROALD-2 (Role Of Apoptosis in Lymphocyte

ESA astronaut Andre Kuipers working with the ROALD-2 experiment in the KUBIK-3 incubator in Columbus on 24 December 2011

Depression 2) experiment whose samples were returned from orbit on Soyuz 28S which landed on 27 April. The experiment containers are now undergoing analysis by the science team. The ROALD-2 experiment expands on the initial ROALD experiment from 2008 In determining the role of a certain lipid (Anandamide) in the regulation of immune processes in human lymphocytes and in the cell cycle under weightless conditions. Anandamide is the main representative of a family of polyunsaturated fatty acid amides and esters, called endocannabinoids. It is a signal for the cells to make a choice between life and death and it might be a contributor responsible for the immune system deficit observed in orbit. This could help in the development of additional countermeasures to the effects of weightlessness on the human body in the future.

A view inside the Kubik incubator during experiment procedures in October 2007

ROALD-2 was one of the first experiments to be undertaken by André Kuipers after arriving in orbit following launch in December 2011. The experiment used a Kubik incubator set up in front of the European Drawer Rack.

The ROALD-2 experiment was started after André Kuipers and Dan Burbank installed the eight experiment containers (and a dummy experiment container) inside the KUBIK-3 incubator on 24 December. After a few hours of processing Kuipers removed four of the 0g and centrifuged experiment containers from the incubator and placed them in the European-built MELFI-1 freezer at -95 deg C. He repeated this process for two more experiment containers after 24 hours, and for the final two containers after 48 hours, concluding processing with the KUBIK-3 incubator.

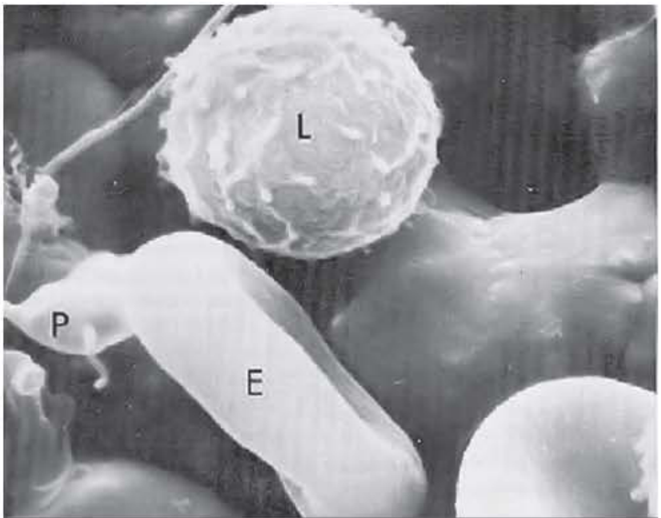
Lymphocyte samples in ROALD (Role of Apoptosis in Lymphocyte Depression) Experiment containers before being sent to the International Space Station

Expedition 30 Flight Engineer and ESA astronaut André Kuipers prepares to insert processed ROALD-2 experiment containers into a European-built MELFI freezer on the ISS in December 2011

All of ESA's immunology experiments are improving our understanding of the mechanisms by which spaceflight and low gravity conditions alters immune cell function. Several factors can adversely influence how the immune system functions in space, either directly by exposure to weightlessness and high energy radiation or indirectly due to other physiological (and psychological) changes induced by spaceflight.

In general this research provides some unique insights into how some immune cells work, which improves our general understanding of human's crucial immune system. This can help us determine appropriate countermeasures to any adverse effects, whether by pharmaceutical treatment, environmental manipulation (such as the use of artificial gravity) and protection from cosmic radiation by using shielding materials. Not only is this vitally important for our astronauts in orbit, especially when considering the increased risks on future exploration missions outside the protection of low-Earth orbit, but also to people on Earth. More sophisticated preventive methods lie in the remote future, such as the manipulation of gene sequences that trigger gravity-dependent immune cell dysfunction as well as those that protect from radiation.

This research is backed up with ground-based studies, which have illustrated that stress responses and specific immune changes in this type of environment are similar to the regulation of the immune system during spaceflight (making ground-based studies a good analogue for certain aspects of space research).



Constituents of blood. L is a lymphocyte, a white blood cell which plays an important part in the body's immune system. E is an erythrocyte or red blood cell and P is a blood platelet

Ground-based studies support on-orbit research. One of the research protocols of this study was looking into immune response and resistance to infection during bed rest.

→ NEUROSCIENCE

The conclusion of the Passages experiment

Neuroscience is one of the fascinating areas in which ESA has been making intriguing discoveries with a variety of research projects on the ISS combined with various ground-based experiments. The Passages experiment was one of the key experiments that had been on-going on the ISS since January 2010 and reached its successful conclusion of on-orbit activities in March 2012 with ISS Expedition 30 Commander Dan Burbank the final test subject.

On Earth our perception of our external world is central to how we function within it. Simple tasks such as hand-eye coordination or perception of direction and angle as we move are activities that we take for granted even though there are complex neurological processes at work for these to 'work' properly. Our perception relies on a host of sensory inputs mainly from our eyes and receptors in our inner ears and gravity plays a major influence in this process on Earth. Removing gravity

NASA astronaut Dan Burbank performing the final session of the Passages experiment in the Columbus laboratory on the ISS on 15 March 2012

therefore creates a challenge for astronauts who can experience some disorientation when first in orbit. However the central nervous system soon adapts to this free-floating environment, with astronauts relying heavily on their visual perception to maintain spatial orientation. Even so astronauts can continue to experience disorientation which can be particularly critical during for example spacewalks.

Altered orientation and perception in weightlessness takes on extreme significance for activities such as spacewalks.

Previous ESA research has shown a difference in perception in space. For example, using virtual reality software for passing through a tunnel, a greater error in angular perception was shown to exist on Earth when undertaking a nose down turn in the tunnel compared to a nose up turn. Intriguingly this difference does not exist in for astronauts in space. On the other side research has shown that objects are perceived 'elongated' in space. Astronaut subjects for example have been shown to write words shorter and wider in orbit than on earth.

CNES

Image of virtual reality tunnel as displayed in previous Neurocog experiment on the ISS.

The Passages experiment has been studying the neurological effects of long-duration spaceflight by testing the effect that long-term exposure to weightlessness has on the so-called 'eye-height strategy' for example for estimating visual distance and perceived eye height used to determine physical dimensions such as in determining the "passibility" of a doorway.

The experiment tests how astronauts interpret visual information in weightlessness using virtual reality stimuli such as traversing through a virtual door. This is displayed on a laptop screen with a visual light screen attached through which the astronauts observe the screen-displayed stimuli. The laptop is attached to the front of the European Physiology Modules facility in Columbus during the experiment sessions.

Visual light shield attached to multipurpose laptop through which virtual reality/visual stimuli displayed for specific neuroscience experiments on the ISS. This has included the Passages, Neurospat and older Neurocog experiments

The astronauts undertook two sessions of the experiment on orbit, one towards the start of their mission and one session a few months later towards the end of their mission for comparative purposes. The increase to a six-member ISS crew has allowed the experiment to complete on-orbit activities very quickly with ten subjects in just two years. This included seven NASA astronauts (including the last subject Dan Burbank), two JAXA astronauts (including the very first subject Soichi Noguchi in 2010) and ESA astronaut Paolo Nespoli in 2011.

In terms of basic research, the prolonged weightlessness on the ISS offers a unique opportunity to study various aspects of spatial orientation, which are intrinsically linked to gravity. It is the only location where the gravitational field can be removed for extended periods, and it provides the ability to manipulate spatial orientation and follow its adaptation during the early and late phases of flight and after returning to Earth-bound gravity conditions.

Results of this neurological experiment will improve our knowledge of neurological processes and provide an insight into the efficiency of performing certain tasks in space, which in turn can improve training techniques for astronauts.

Passages forms part of a widespread group of ESA neuroscience experiments undertaken on the ISS and on ground. Another experiment in a similar vein, Neurospat, was the first neuroscience experiment to utilise the full capabilities of the European Physiology Modules, and now requires only one more test subject. Ground-based pre- and post-flight experiments have included Otolith, ZAG and Spin though the first two experiments have now gathered enough test subject data and are also complete.


GCTC - Moscow

The VVIS rotational chair in Star City near Moscow. Final check before centrifugation of cosmonaut Yuri Malenchenko as part of the Spin experiment

→ FLUIDS RESEARCH

Understanding fluid flows in a spherical system to provide an insight of our planet

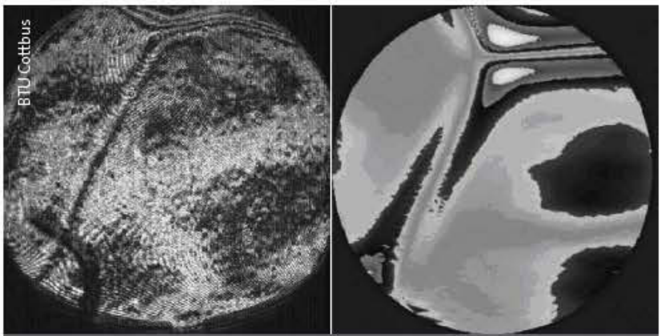
The Fluid Science Laboratory in ESA's Columbus laboratory has been the home to an important series of experiments (Geoflow) since 2008, with the second extended run of experiments (Geoflow-2) concluding almost 14 months of on-orbit activities in May 2012. With some very important results coming from the first Geoflow experiment, which is helping to provide an insight into geophysical processes occurring inside planets, what can we expect to come from the extensive amount of data generated from Geoflow-2, and where can we expand on this for the future?

How to simulate a planet

The inside of our planet moves like a highly viscous fluid, though it is not possible to physically look inside the Earth to see the precise geophysical processes at work. We therefore rely on numerical models to estimate this extremely complex situation. The Geoflow experiment has been gathering extensive amounts of benchmark data on the ISS through the use of experiment hardware which acts as a simple representation of a planet in order to validate and update models of spherical fluid systems.

The experiment container consists of an inner and outer sphere rotating about a common axis with an incompressible fluid situated between the spheres to represent the fluid-like motion inside a planet. Due to the disturbing influence of gravity on Earth this experiment has to be undertaken in the weightless environment of the ISS, where a central electrical field is generated within the Geoflow experiment container to simulate a gravitational force acting towards its centre of mass.

The parameters varied in the experiment are the rotational speed of the experiment container core (to simulate planetary rotation) ranging from no rotation up to 2 rotations/sec, and a temperature difference from outside to inside (as would be present in a planet such as Earth). This varied from no temperature difference up to 10 deg C difference (with a colder temperature at the outside sphere).



A comparison of an interferometry image (left) taken from the first Geoflow experiment and an image generated from a numerical model (right), both with the same temperature and rotational parameters

Extensive experiment runs were undertaken for Geoflow 2 at all different combinations of rotational speed and temperature difference to create different fluid flow profiles. For certain temperature differences from outside to inside the higher and lower temperatures were also varied (i.e. increasing the outside and inside temperatures by the same amount to keep the temperature difference between the two spheres the same) to monitor how this would affect the fluid system. Visual imagery of the fluid motion is carried out using interferometry.

NASA astronaut Greg Chamitoff installing the Geoflow experiment container into the Fluid Science Laboratory in August 2008

All these different combinations will allow the science team to assess in great detail how the different parameters affect the whole system and observe areas of stability/instability in the fluid. There were times when the equipment itself didn't quite perform as planned though the robust nature of the experiment hardware allowed for repetition of any data points that were missed.

Added Complexity with Different Fluids

In the first Geoflow experiment, which ran from August 2008 to January 2009, the fluid used was silicone oil, the viscosity of which does not change with temperature. In Geoflow-2 the complexity of the system was increased by using nonanol as the incompressible fluid, the viscosity of which does change with temperature. This provides a different aspect of research with more of a simulation to Earth's geophysical conditions.

Graphic image generated from a Geoflow numerical model for spherical convective regimes. This octahedral pattern is generated in conditions of no rotation and a medium temperature gradient profile

What did we get from Geoflow-I?

Even though the first Geoflow experiment did not complete all of its scheduled runs before its return to earth, some very interesting results were generated during on-orbit activities. One interesting result to come from the on-orbit data was the confirmation of the octahedral convective flow formation generated by a numerical model under conditions of no rotation and an intermediate temperature gradient from outside to inside. The dark spots in the image below are the hot spots i.e. fluid flow towards the surface, and the lighter areas represent the internal flow away from the surface.

What can we expect from Geoflow-2?

With Geoflow-2 having taken place for around 14 months this exceeded the Geoflow-I duration by almost a year and provided an extensive increase in the amount of data gathered which bodes well for future analysis and publications, and improvement of existing models, especially since all planned experiment runs with different parameters for Geoflow-2 were undertaken during the on-orbit activities.

Future for Geoflow

Even though Geoflow-2 has come to successful conclusion with respect to on-orbit activities a follow-up experiment could take place on the ISS in the near future using the same experiment hardware. This could involve the gathering of additional data using a different range of parameters, with the possibility of observing certain non-rotation runs for a longer period.

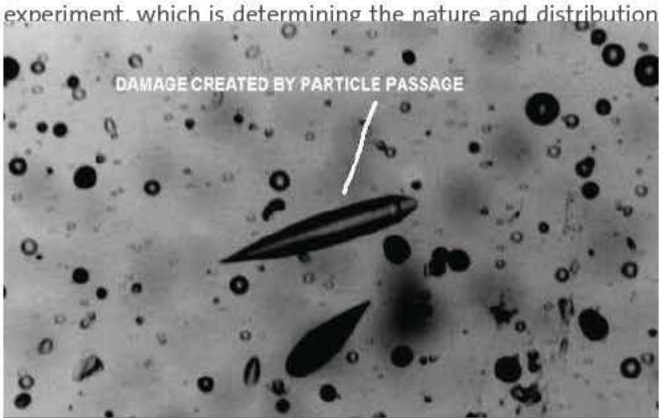
Of course if we looked further into the future there are obviously other ways in which the experiment could be built upon for example for modelling surface motion in the atmosphere rather than inside planets. This possible outlook is something that will depend on the positive scientific results and their impact that are expected to be generated from the latest Geoflow experiment.

→ DOSIS-3D

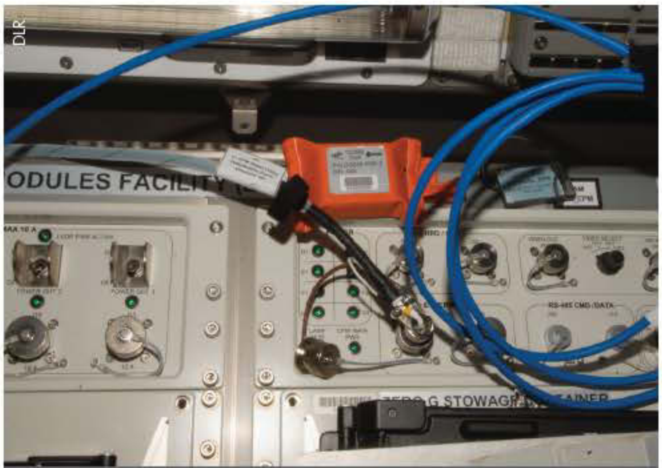
Understanding Earth's cosmic radiation environment

Radiation research for ESA has taken another big step forward in the past few months with the start of two major long-duration research activities. One of these experiments (DOSIS-3D) is increasing our knowledge of the radiation environment surrounding our planet, which not only has implications for our astronauts in orbit, it also forms part of a broad spectrum of ESA research helping to understand the effect that the space environment has on the climatology of our planet.

European involvement in radiation monitoring on the ISS has been on-going since the DosMap experiment in 2001 and has built on decades of previous radiation research in orbit. DosMap was under the lead of Dr. Günther Reitz of DLR and the expertise of Dr. Reitz and his team has since expanded with data gathered from numerous ISS experiments. The latest of these is the ESA-sponsored 'Dose Distribution inside the ISS 3D' (DOSIS-3D) experiment, which is determining the nature and distribution of the radiation field inside Columbus and the ISS.



Dark streak (centre) left by high-energy particles on CR39 plastic film as part of DOSMAP Nuclear Track Detector Packages



An orange-packaged detector located on the front of ESA's European Physiology Modules Facility in the Columbus Laboratory as part of the DOSIS experiment

ESA astronaut André Kuipers setting up the Tissue Equivalent Proportional Counter in the Zvezda Service Module of the ISS in March 2012. Data from this NASA radiation detector will form part of the DOSIS 3D experiment

DOSIS-3D

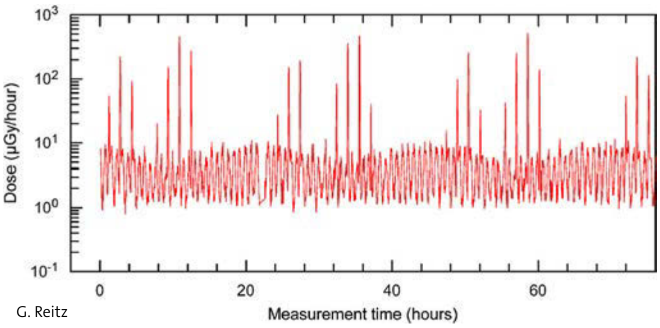
DOSIS-3D was started in May 2012 with ESA astronaut André Kuipers installing passive radiation dosimeters around the Columbus laboratory and two active DOSTEL radiation detectors inside Columbus' European Physiology Modules facility.
The passive detectors will be replaced after six months and analysed on ground to help determine the radiation field across Columbus. The two active detectors support this data by taking time-dependent radiation measurements, with good data having already been received by the science team.

DOSIS-3D builds on the data gathered from the DOSIS experiment in Columbus from July 2009 – July 2011, combing

data gathered in Columbus with data from a whole host of different passive and active detectors from NASA, JAXA and Roscosmos placed all around the ISS.
The radiation environment surrounding Earth is an extremely complex environment to assess with many different elements including UV, X-rays, and high energy particles: electrons, neutrons, protons and heavy ions (cosmic rays). The levels of these different types of radiation can vary for a number of reasons. The 11-year solar cycle causes variations, for example with increased solar flare activity. Events such as galactic supernovas can have a similar influence in increasing high-energy radiation levels. Considering the orbit of the ISS there is the additional daily effect of increased radiation when the Station passes through the South Atlantic Anomaly where Earth's magnetic field is weaker and the ISS encounters increased radiation doses for a short period of time. There are even variations in the radiation field through the ISS due to different shielding qualities in different modules.

With the complexity of the space radiation environment it is clear to see why the process of monitoring and analysing it is an on-going one involving generation of extensive amounts of data from different experiments and collaboration with International Partners. In December 2011 ESA also completed another long-duration radiation survey in the US laboratory as part of the ALTEA-Shield experiment (see next article). With respect to DOSIS-3D the experiment is scheduled to continue until at least 2013, with the passive dosimeter sets scheduled to be swapped at least once during this time.

A more precise determination of the (variations in) the radiation field in Low-Earth orbit is of great importance on many levels. On a basic level it is obviously of vital importance in monitoring and securing the safety of our astronauts currently in orbit and in the future. The data can also be used to determine the shielding qualities of different areas of the ISS and be used to improve



Data from DOSMAP experiment in 2001 which used a Dostel detector as also used in DOSIS 3D. Sets of 3-4 higher peaks due to passing through the South Atlantic Anomaly. The variation in the lower dose rate is due to a variation in ISS latitude

our understanding of how the radiation environment has an influence on the upper atmosphere and hence can influence climatology, thus helping to improve current climate models.

ESA's broad spectrum of research work touching on Earth's climatology is also supported by data coming from additional research payloads such as the Solar facility, which has been studying the Sun's irradiation with unprecedented accuracy across most of its spectral range since 2008, and will include projects in the future such as the Atmospheric Space Interactions Monitoring Instrument (ASIM), which will study giant electrical discharges (lightning) in the high-altitude atmosphere above thunderstorms. Additional Earth Observation projects based from the ISS are currently in the planning process.

In the future the data gathered within DOSIS-3D will be expanded with ESA's TriTel experiment which will detect radiation that enters the Columbus laboratory from all directions and will be recorded with time resolution so that the dynamic fluctuations of the incoming radiation and full directionality can be assessed.

→ ALTEA-SHIELD EXPERIMENT

Improving cosmic radiation shielding

The second major part of the ALTEA-Shield experiment series was started by André Kuipers in June. This part of the experiment is testing two different shielding materials (polyethylene and Kevlar) that were delivered to the ISS on ATV-3 in March. The materials have been through successful particle-accelerator testing on ground, though the question is now how will they perform during tests on orbit and what could this imply for future exploration missions and Earth-based technologies?

The area of radiation shielding is vitally important and becoming more so both in orbit and on Earth. Improved radiation shielding will be necessary for future human exploration missions which will take our astronauts outside of the protection of Earth's magnetic field in low-earth orbit. Improved shielding also holds applications on Earth in such areas as high-end technology.

ESA astronaut André Kuipers configuring hardware for the ALTEA-Shield experiment in the Columbus laboratory on 8 June 2012.

The Shielding part of the ALTEA (Anomalous Long Term Effects in Astronauts)-Shield experiment started when André Kuipers installed the hardware into EXPRESS Rack 3 in the Columbus laboratory in June. The hardware consisted of three silicon radiation detectors, two covered with polyethylene tiles of two different thickness, and a third detector with no tiles attached to act as a reference. After 40 days of data acquisition the polyethylene tiles will be swapped out for the Kevlar tiles for another 40-day session. The Kevlar tiles are also of two different thicknesses so that they have an equivalent g/cm2 measurement as the polyethylene tiles for comparison purposes.

Polyethylene radiation shielding material.

Polyethylene (the most common form of plastic) is a well-known shielding material as it is extremely lightweight and contains a lot of hydrogen (hydrogen atoms are good at absorbing and dispersing radiation). Kevlar is of great interest for spacecraft radiation shielding as it also has a known ability to protect human space infrastructures from meteoroids and debris (and most commonly used within such products as bullet-proof vests). Accelerator-based tests have clearly demonstrated that Kevlar is an excellent shield for heavy ions, close to polyethylene.

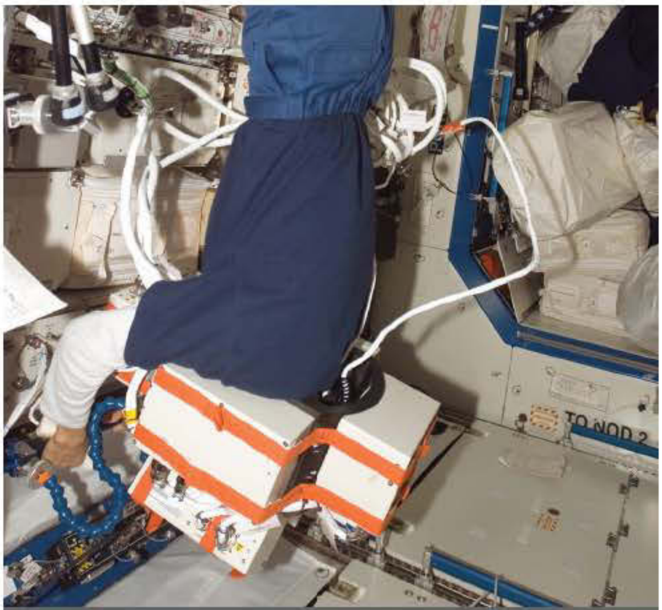
Even though ground-based tests were carried out in particle accelerators on different materials, this cannot provide the complete spectrum of radiation as present in low-earth orbit which is why such an experiment also needs to be carried out on the ISS. Once the test sessions with the polyethylene and Kevlar tiles are complete an analysis can be made of how Kevlar compares to polyethylene for its shielding qualities.

These tests will provide important information which could feed into shielding strategies for future spacecraft and missions, not only human exploration missions, but also for future satellite design and extending the life of satellites in orbit by reducing the effect caused by solar and galactic radiation, which can damage satellite electronics. For satellites in orbit for example, it is estimated that a so-called Carrington-class solar flare could cost multiple tens of billions of dollars due to potential damage to the satellites currently in orbit. With life on Earth becoming increasingly dependent on satellite communications and data, this becomes even more significant when considering examples such as landing an aircraft safely.

Artist's impression of a human exploration mission to Mars where increased radiation levels call for more effective shielding methods than in low Earth orbit

On Earth as well cosmic rays which get through Earth's atmosphere can cause errors in integrated circuits such as data corruption in memory devices and incorrect CPU performance. New shielding materials could find their way into shielding applications for such electronic circuitry which is becoming more susceptible as it reduces in size. This can affect many industries from the automobile industry to aerospace to navigation. This is an area that industry has already taken an interest in.

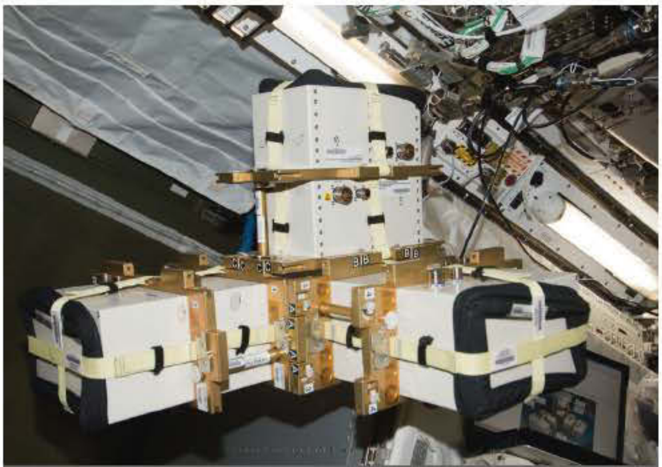
If we take a look further into the future, the development of new lighter multifunctional materials for spacecraft is an area currently being looked into by ESA (and other agencies), i.e. materials that possess good radiation shielding qualities and are also good structural materials. The focus of this is currently materials based on the lighter elements (for example hydrogen, boron, lithium, carbon) which are good at absorbing radiation as they do not fragment into smaller secondary particles like conventional spacecraft materials when struck by high-energy cosmic particles.



NASA astronaut and Expedition 14/15 Flight Engineer Sunita Williams wearing the detector helmet while conducting the ALTEA experiment for NASA in March 2007

Development of these new materials will not only improve radiation shielding, their lighter weight will also help reduce spacecraft mass. This will have the advantageous effect of reducing upload costs related to the spacecraft itself and allow for greater upload mass of necessary logistics supplies for exploration missions making the missions themselves more feasible. As examples of this for space-related missions, the MAXUS 8 sounding rocket in 2010 had a set of four new fins designed by the Swedish Space Corporation. The fins were made of carbon fibre and had 50% less mass than the older style fins. The casing of the SOURCE-2 module which flew on the Maser 12 sounding rocket was also implemented with a carbon fibre outer structure which reduced outer structure mass by almost 40%.

Even though the second part of ALTEA-Shield has recently started a lot of interesting data is still to be gathered within the experiment series. This includes the third part of the experiment which will be studying the effect of radiation on the Central Nervous System. The first part of the ALTEA-Shield experiment has however been completed, undertaking a 3-dimensional survey of the radiation environment in the US laboratory.



On-orbit hardware configured for the Survey part of ESA's ALTEA-Shield experiment

→ MSG ANNIVERSARY

10 years of on-orbit operations

June was an auspicious month for the Microgravity Science Glovebox (MSG) as it celebrated its 10th successful year in orbit. The MSG was ESA's first major research rack facility to be launched to the ISS on board STS-111 and has been supporting a wide range of physical science and other research for the past decade.

The glovebox performed its first operations activity on 1 July, 2002 and since then around 30 investigations have taken place inside the MSG covering more than 12,000 hours of operations, making it undoubtedly one of the busiest pieces of research hardware with the record number of experiments on the Station.

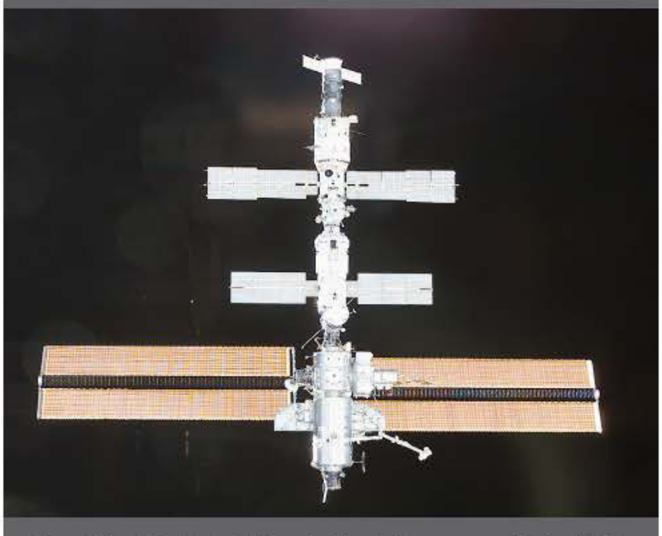
The MSG was developed by ESA within the Early Utilisation barter agreement with NASA and was mainly built by Bradford Engineering in the Netherlands under an ESA prime contract with Astrium in Bremen. In providing the MSG to NASA along with additional equipment such as the MELFI freezer units, ESA secured important utilisation rights on the ISS prior to the launch of the Columbus Laboratory in 2008.

The development of the Microgravity Science Glovebox built on a series of successes with gloveboxes built by Bradford which flew previously on the Shuttle and Mir, though the MSG is more than twice as large as these predecessors and supports larger, more sophisticated investigations. Without the glovebox, many types of hands-on investigations would be impossible or severely restricted on the Station.

The Station looked very different at the arrival of the MSG to now. The ISS consisted of only four habitation modules, plus the US and Russian airlocks and only one of the principal solar-array bearing truss sections was supplying power to the Station.

CNES astronaut Philippe Perrin with the ESA-developed Microgravity Science Glovebox on 9 June 2002 shortly after its installation as part of the STS-111 mission. Perrin joined ESA's European Astronaut Corps later the same year

NASA astronaut and Expedition Five flight engineer Peggy Whitson, works near the MSG in the ISS US laboratory at the beginning of July 2002 on the day she installed the first experiment inside



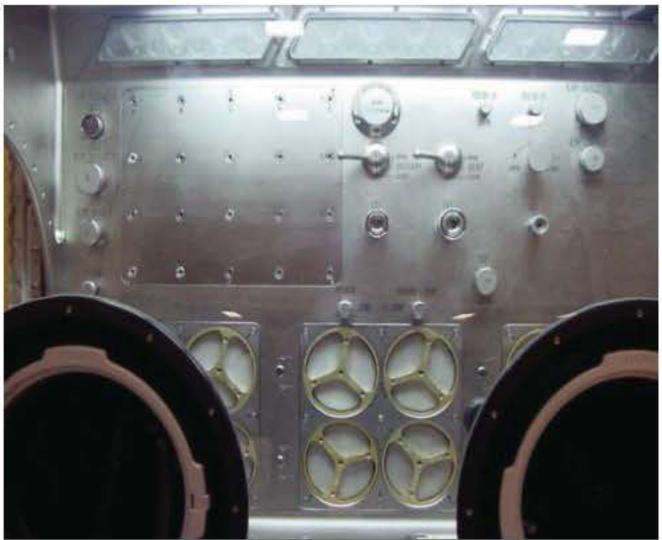
View of the ISS prior to STS-111 docking in June 2002 with the MSG as part of the cargo

However, as the Station grew so did the extent of research being undertaken in the MSG. With the arrival of Columbus in 2008 the Glovebox was relocated to Europe's laboratory. On conclusion of ESA's SODI-Colloid experiment in October 2010 the MSG was relocated back to the US laboratory. Although it was originally slated to come home in 2012, the MSG rack will get some on-orbit upgrades and now looks to 2020 and beyond to support further science on the station.

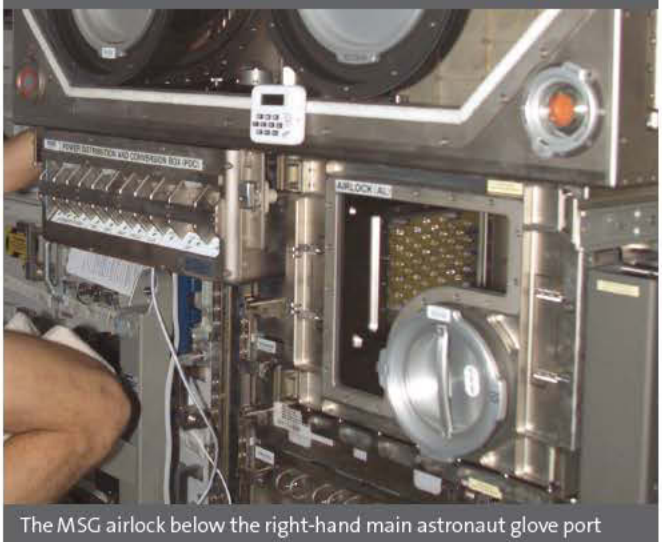
Capabilities

The MSG provides the capabilities for undertaking weightless research covering material science, fluid science, combustion science, biotechnology, crystal growth research and other investigations attempting to gain an understanding of the role of gravity in basic physical, chemical and biological interactions.

The Glovebox is a fully sealed and controlled, clean room equivalent environment with a 255 litre working area within which astronauts can manipulate items inside using versatile flexible gloves. There is also an integrated airlock that allows items to be passed in and out of the working area, power,



Utilities panel (power, data etc) at the back of the MSG Working Volume above circular air filters to create clean room environment.



The MSG airlock below the right-hand main astronaut glove port data, vacuum, venting and gaseous nitrogen connections and a coldplate for heat rejection from experiment hardware. After hardware set up in the Working Volume experiments can be either controlled on orbit, from ground or a mixture of the two.

While the glovebox has predominantly supported physical science payloads, improvements will be made to allow research with biological/life science payloads. The upgrade will see the scientific laboratory fitted with new biological filters, new gloves, an ultraviolet decontamination system, and a new video system which will feature high-definition cameras and monitors. This should be ready for flight in the Autumn of 2013.

Investigations

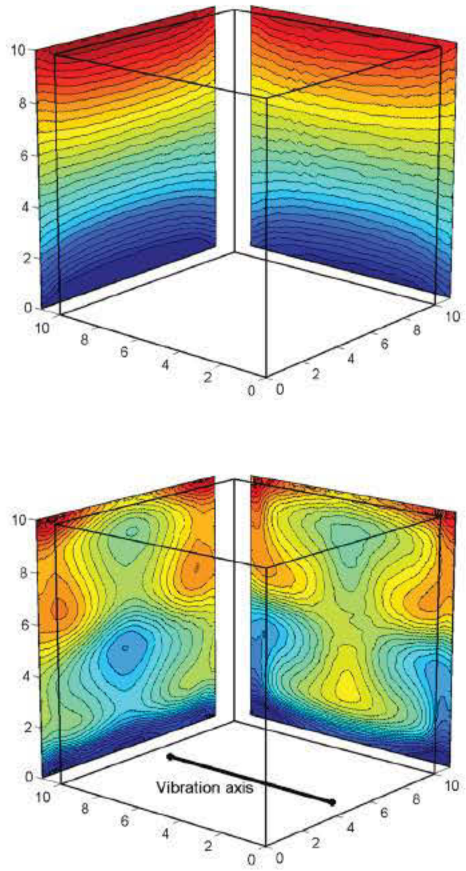
From an ESA perspective one of the most important and most recent series of experiments to be undertaken in the MSG used the Selectable Optical Diagnostics Instrument (SODI). There were three different SODI fluids physics experiments that were undertaken between October 2009 and January 2012.

ESA astronaut Frank De Winne during activites in September 2009 for the installation of the SODI-IVIDIL experiment hardware

Improvements in Data Analysis

The first experiment to utilise SODI was the 'Influence of Vibrations on Diffusion in Liquids' (IVIDIL) experiment from October 2009 to January 2010 which was an ESA project in collaboration with the Canadian Space Agency. The effect that vibration has on inhomogeneous fluid mixtures is masked on earth by gravity, so the ISS is the perfect environment to study this phenomenon. Extensive experiment runs were undertaken for more than three months on orbit with the frequency/amplitude of vibration being varied across the experiment cells as well as the temperature gradients.

The experimental results surpassed expectations with data received allowing the observation of flow patterns generated exclusively by controlled vibrations, for the first time. The experiment has been able to trace the variation of concentration of about 0.03% from the initial composition and making it possible to demonstrate vibrational effects and



Comparison between the convection flow without vibration (top) and with strong vibration (bottom) from the SODI-IVIDIL experiment

quantify their impact on the measurement of thermodiffusion coefficients. (Thermodiffusion is the diffusion occurring in a mixture due to the presence of a temperature gradient). In addition with the unavoidable presence of g-jitter present on orbital platforms coming from such influences as equipment, crew movement etc. this research confirmed the negligible influence 'g-jitters' has on measurements, which will be helpful for data analysis across all research areas.

Improvements in Optics

The next SODI experiment to take place was the Colloid experiment which generated extensive data for analysis in September 2010 and continued under the Colloid 2 experiment a year later. The Colloid experiment is studying the growth of colloidal structures from solution in an aggregation process that can be easily controlled experimentally. While the focus is on the still not fully understood physical mechanisms that govern this process, the experiment may have interesting applications in photonics, with emphasis on nano-structured, periodic dielectric materials, known as photonic crystals, which possess appealing properties and make them promising candidates for new types of optical components. Even though the analysis is still on-going, the set of images and data already studied prove extremely promising as temperature controlled aggregation has already been evidenced for the first time.

JAXA astronaut and Expedition 29 flight engineer Satoshi Furukawa during activities inside the MSG Working Volume during installation of SODI Colloid-2 experiment on 17 Oct. 2011

Once the complete data set is analysed we should be able to determine size and structure (packing) of the aggregates formed in the colloidal solutions. From this we will be able to correlate the structure of the aggregates with the strength of the aggregating forces and elucidate the mechanisms behind the aggregation process. Whatever the exact outcome, the results are expected to have an impact outside the community of colloid science. It will have an impact on crystal growth from solutions in general, and on self-organization in complex fluids.

Improvements in Oil Recovery

ESA has undertaken numerous thermodiffusion experiments in the past decade, which are feeding into fluid model systems on earth. This research was expanded with the third SODI experiment: 'Diffusion and Soret Coefficient Measurements' (DSC) experiment which finished processing in the Microgravity Science Glovebox in January 2012.

DSC is accurately determining diffusion coefficients for ternary systems that are representative of the three main families of crude oils. The basic research principle is the exposure of different representative liquid mixtures to a temperature gradient in weightlessness where gravity-driven convection is avoided. On the ISS, when a stable liquid composition profile is reached, measurements of the variations in density caused by thermodiffusion are performed by interferometry. This way, the experiment can be repeated several times and meaningful statistics are obtained. Once the thermodiffusion coefficients are determined for different samples, the scientific community will be better able to model the distribution of components within reservoirs underground.

Efficient oil recovery is currently a major challenge. At about 4000 meters below ground level, the hydrocarbon fluids are highly sensitive to applied forces, not only gravity, but also temperature and pressure gradients. The prediction of hydrocarbon composition is an important factor that contributes to reservoirs exploitation strategies. Since the cost of resources increases with depth, the oil companies are interested in reliable thermodynamic models that allow the characterisation of an entire reservoir using a reduced number of exploratory wells.

Crystallisation Research

Already a few months after the launch of the MSG to the ISS ESA started using the Glovebox as an important strategic tool in fulfilling European research requirements in advance of the launch of the Columbus laboratory. Of the first four ESA experiments to take place in the MSG during the Belgian-sponsored Odissea taxi flight mission in November 2002, two of them focussed on crystallisation processes in weightlessness (Nanoslab and PROMISS-1). The PROMISS series of experiments which were undertaken during different missions between 2002 and 2006 were studying protein growth processes in weightlessness in order to measure the parameters of the growing protein crystals, and the composition changes of liquid around the growing protein crystals. After Odissea Nanoslab continued during the Spanish-sponsored Cervantes taxi flight mission

ESA astronaut Pedro Duque works on the PROMISS experiment in the MSG during the Cervantes mission in 2003

Close up of the Nanoslab hardware in the MSG in 2003 and was studying the formation of zeolites, which are crystalline microporous aluminosilicates, which hold important applications especially in the petrochemical industry. Zeolites have interesting catalytic and molecular sieving properties with various applications as catalysts, sensors and absorbent materials, particularly in the oil industry. Though it is possible to find them in nature, the real advantage is in the potential for synthesising zeolites in the laboratory and furthermore being able to control the manner of synthesis in order to develop zeolites on an industrial scale with chosen characteristics for use in specific applications. From the experiments on the Odissea and Cervantes missions researchers discovered a formerly unknown step in the formation process of zeolites, which was not visible on Earth.

The wealth of data produced has helped in the definition of future research which will allow for observation of the early steps of crystalline formation in orbit rather than analysis post-flight. This is a likely candidate to be carried out again using an upgraded version of the Protein Crystallisation Diagnostics Facility. Results of this kind of research can lead to tailoring zeolites to different applications.

Plasma Research

In 2004 one of the ESA-sponsored experiments during the Dutch-sponsored DELTA taxi flight mission with ESA astronaut André Kuipers, which addressed plasma physics was the ARGES experiment. The ARGES experiment investigated High-Intensity Discharge (HID) lamps (which utilise plasma technology) in weightlessness, as this removed gravity as a disturbing factor.

High-Intensity Discharge lamps for the ARGES experiment, one of the experiments for the DELTA Mission in 2004

Internal view of HEAT experiment container

HID lamps are very energy efficient and increasing in popularity. The experiment was undertaken in order to understand imperfections that existed in the technology in a similar way to the instabilities from the PK series of experiments. These imperfections cause uneven light emission and instabilities that could cause cracks in the burner wall leading to non-functionality. Instable plasma channels and de mixing of gasses were therefore determined as part of the experiment through spectroscopy.

The experiment in which electronics company Philips, and Eindhoven Technical University were participating, has yielded very promising results. Very useful data was obtained from the experiment and this helped feed into the development of more efficient and smaller-sized HID lamps, for use in space and on Earth. The first results from the experiment actually concluded that one of the main problems/influences causing flickering in the lamps was gravity itself.

Technology: More efficient cooling in space

Heat in space is a major problem. A space station has to be well insulated against the wide variety of temperatures in space, but at the same time contains all sorts of electronic equipment inside which needs to disperse excess heat. Otherwise, overheating, the failure of important components or, even worse, on-board short circuits and fires could occur. Heat is dispersed on the ISS through a series of heat pipes that transfer excess heat to cooling panels where the heat is dispersed into open space.

The Heat experiment, which took place in the Microgravity Science Glovebox during the DELTA mission with ESA astronaut André Kuipers in 2004, tested a grooved heat pipe design. The aim was to characterise its performance under weightless conditions, determine that it was more effective at heat dispersal when compared to the sleek design of pipe as well as validating mathematical models. The ultimate goal was the improvement of heat pipe design, not only for future application in spaceflight and space research but also for improved cooling systems here on Earth.

The grooved heat pipe design is a more effective design for preventing the build-up of steam on the inner surface of heat pipes which can create an insulating gas layer and thus reduce the effectiveness of pipes to disperse heat.

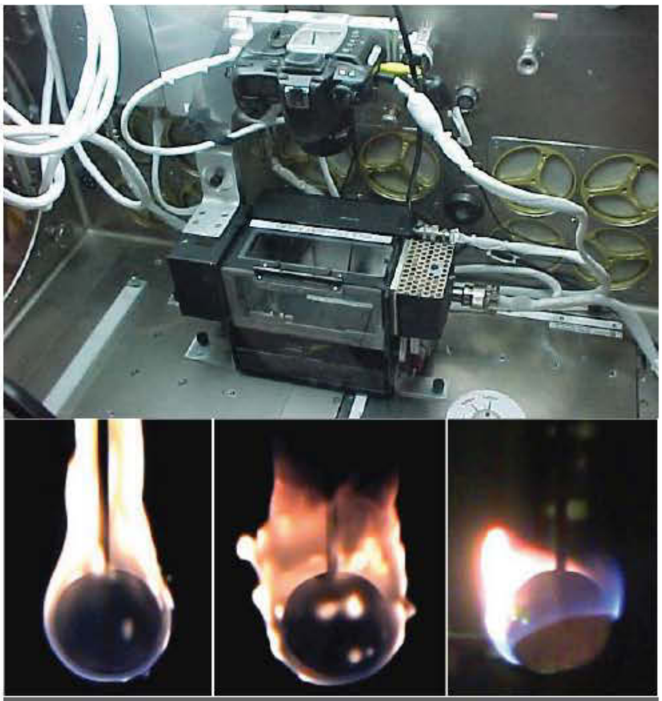
International Partner Research

Materials

With the MSG development coming from a barter agreement with NASA, it is no surprise that NASA have also undertaken many different research projects in the Glovebox over the past ten years. NASA started utilisation of the Glovebox with two materials experiment in 2002. Following on from these experiments the Coarsening in Solid Liquid Mixtures-2 (CSLM-2) experiment which started in 2003 was studying the rate at which particles of tin suspended in a liquid comprised of molten tin/lead alloy increase in size; a process called coarsening. This is studying the mechanisms and rates of coarsening that govern similar processes that occur in materials made on Earth, such as turbine blades, dental amalgam fillings, aluminum alloys, etc. Investigations such as CSLM-2 may lead to the development of improved manufacturing processes for commercially important materials. The experiment ran over multiple Expeditions with the next evolution of the experiment CSLM-3 being prepared for launch on SpaceX-2 cargo vessel.

Combustion

Combustion research is a growing topic in ISS research. NASA has undertaken four combustion projects in the MSG since 2007, three of which utilise the Smoke Point In Co-flow Experiment (SPICE) hardware installed inside the Glovebox. The latest of this set of experiments is the Burning and Suppression of Solids which started in March 2012 and examines the burning and extinction characteristics of a wide variety of fuel samples in weightlessness. This will guide strategies for extinguishing accidental fires in weightlessness and contribute to the combustion computational models used in the design of fire detection and suppression systems in microgravity and on Earth.



Top: SPICE experiment hardware also used for the BASS experiment. Bottom: Drop tower tests. Test burning of a 2 cm diameter PMMA sphere in 30 cm/s airflow. Left - 1 g; Middle - 0 g (1 s after drop); right - 0 g (4 s after application of nitrogen extinguishing agent).

Fluids Research

In addition to ESA's SODI series of experiments, NASA has undertaken numerous fluids research experiments in the MSG. One of these experiments, InSPACE (Investigating the Structure of Paramagnetic Aggregates from Colloidal Emulsions), is one of the longest investigations to take place on the ISS having started in 2002 and is still ongoing within the third incarnation of the experiment InSPACE 3. This series of investigations is studying the complex properties of a class of smart materials called magnetorheological fluids which have very small (micron-sized) magnetic particles suspended in them. These controllable fluids can quickly transition into a nearly solid-like state when exposed to a magnetic field and return to their original liquid state when the magnetic field is removed. These complex fluids are important for brake systems and robotics.

Another experiment which was a joint project between NASA and DLR was the Capillary Channel Flow experiment which was taking place in the MSG when it reached 10,000 hours of operations in September 2011. The goal of this investigation is to

The Microgravity Science Glovebox team at the Marshall Spaceflight Center monitors the glovebox experiments performed on the International Space Station.

enable the design of spacecraft tanks that can supply gas-free propellant to spacecraft thrusters, directly through capillary vanes, greatly cutting cost and weight, while improving reliability.

Biology

Even though the MSG has been used principally for physical science experiments the flexibility of the facility allows it to be utilised in other areas. The Japanese Aerospace Exploration Agency (JAXA) undertook the joint Cell Wall / Resist Wall experiment during Expeditions 16/17 using both the MSG and European Modular Cultivation System. This experiment which investigated the mechanism of gravity resistance in plants (Arabidopsis thaliana) is of high interest for the European scientists involved in ESA's Multigen plant experiment (and in fact used Multigen experiment equipment). Following processing in the European Modular Cultivation System, samples were removed from the EMCS and placed inside the Microgravity Sciences Glovebox (MSG), to prepare the plant material for harvesting. These were then placed in one of the MELFI freezers on orbit.

Top: NASA astronaut Garrett Reisman during an MSG training session at the Johnson Space Center with JAXA's Cell Wall/Resist Wall experiment. (Image: NASA). Bottom: On orbit image inside the European Modular Cultivation System showing growth of Arabidopsis thaliana for the Cell Wall/Resist Wall experiment.

Future MSG Experiments

From an ESA perspective, a number of very important experiments for processing in the MSG are still in the pipeline for launch to the Station in the next few years covering different areas of the physical sciences. The Transparent Alloys materials experiment (scheduled for launch around 2014/2015) will complement research undertaken in the Materials Science Laboratory (and CNES provided DECLIC facility) in undertaking directional solidification experiments of transparent materials (polymers) using the Bridgman technique. Transparent Alloys is a multi-user experiment facility that will be located in the MSG and aims to support the in-situ study of solidification processes and phenomena using transparent alloys with optical diagnostics.

In fluids research the DCMIX-2 experiment, which is linked to the former SODI-DSC experiment, will support research to determine diffusion coefficients in different petroleum field samples and refine petroleum reservoir models to help lead to more efficient extraction of oil resources. This experiment is due for launch in Spring 2013 on ATV-4.

Finally the Miller-Urey experiment, which is due for launch in 2014, will simulate in special vials the same conditions as present on the early days of the planets, to figure out how organic compounds were formed from inorganic gases, when sufficient energy is available. It is based on the concept of the experiment conducted by Prof. Stanley Miller and Prof. Harold Urey in 1953 at the University of Chicago.

ESA astronaut and ISS Expedition 21 Commander Frank De Winne, working with the Materials Science Laboratory in October 2009

Metallographic sections of the MICAST 4 sample processed in the Materials Science Laboratory and prepared at positions 135 mm (Cut 1) and 190 mm (Cut 2) Left: Diffusive conditions yielded periodic rectangular patterns of dendritic structures (dark regions) equally distributed across the sample. Right: Forced convection induced by magnetic stirring carried residual melt with eutectic composition (bright regions) from the mushy zone towards the centre of the sample. (RMF: rotating magnetic field)

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