→ SPACE FOR LIFE
human spaceflight science newsletter
Issue 4 | September 2013


NASA

↑ NASA astronaut Mike Fossum performing an ultrasound scan on JAXA astronaut Satoshi Furukawa in 2011 for the joint Vessel Imaging/Integrated Cardiovascular protocol as part of research activities during Expeditions 28/29

In this issue:

→ ISS RESEARCH ACTIVITIES:

Overview of Science Achievements During Expedition 35

ESA research was on-going during ISS Expedition 35 which started on the night of 15-16 March 2013 with the undocking of Soyuz 32S, and concluded on the night of 13-14 May with the undocking of Soyuz 33S (signifying the start of Expedition 36). Even though Expedition 35 covered only 2 months an extensive amount of ESA research was undertaken in this time period.

Human Research Activities

Cardiovascular Research

ESAs Vessel Imaging experiment reached a successful conclusion of on-orbit activities during Expedition 35 with ISS Flight Engineer Tom Marshburn undertaking the final ultrasound scanning session of the experiment on 2 May, with support from DAMEC and CADMOS, two of the User Support and Operations Centres for ESA, via the Columbus Control Centre in Oberpfaffenhofen in Germany. The Vessel Imaging experiment evaluates the changes in central and peripheral blood vessel wall properties and cross sectional areas of long-duration ISS crewmembers during and after long-term exposure to weightlessness.

Immunology
In immunology another experiment to come to a successful conclusion with all test subjects during Expedition 35 is the Immuno experiment which has been on-going since Expedition 12. Russian ISS Flight Engineer Roman Romanenko completed his second and final session on 8 May providing blood and saliva samples in addition to filling in a Stress Test Questionnaire. The Immuno experiment is determining changes in stress and immune responses, during and after a stay on the ISS.

↑ Session of the Neurospat experiment 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

Neuroscience
In neuroscience all data for the Neurospat experiment was downlinked to ground in March via the European Physiology Modules facility in Columbus. This followed on from the final session of the experiment with ISS Commander Chris Hadfield as the fifth and final test subject in February 2013.

↑ NASA astronaut Sunita Williams undertaking the Reversible Figures experiment in Columbus on 19 July 2012

Neuroscience activities continued with the Reversible Figures experiment with ISS Commander Chris Hadfield and ISS Flight Engineer Tom Marshburn carrying out their fourth and final sessions as subjects of the experiment in the Columbus laboratory on 26 April. Neurospat and Reversible Figures are both studying different aspects of altered perception in weightlessness.

Nutrition, Sleep and Well-Being
The Energy experiment, which is discussed in detail in a separate article was also carried out during Expedition 35 with ISS Commander Chris Hadfield and ISS Flight Engineer Tom Marshburn as the third and fourth test subjects (following on from ESA astronaut André Kuipers and JAXA astronaut Akihiko Hoshide). The experiment, which consists of an 11-day on-orbit period of data acquisition, aims at determining the energy requirements of astronauts during long-term spaceflight. ESA astronaut Luca Parmitano is scheduled to be the next test subject for the experiment.

↑ ESA astronaut Luca Parmitano during sample handling activities with the a MELFI freezer unit in orbit. Parmitano is scheduled to be the next test subject for the Energy experiment

Two more test subjects concluded ESA's Space Headaches experiment during Expedition 35. Expedition 35 Commander Chris Hadfield and Expedition 35 Flight engineer Tom Marshburn (the 4th and 5th test subjects for the experiment) completed their 20th and final weekly questionnaires for the experiment on 12 May prior to their return on Soyuz 33S.

The weekly questionnaires follow on from one week of filling in daily questionnaires during the first week after launch on Soyuz 33S on 19 December 2012. Headaches can be a common astronaut complaint during space flights. This can negatively affect mental and physical capacities of astronauts/cosmonauts which can influence performance during a space mission.

The Circadian Rhythms experiment (Covered in detail in a separate article along with the completed Thermolab and EKE experiments) which is providing a better basic understanding of any alterations in circadian rhythms in humans during long-duration spaceflight is still on-going and Chris Hadfield and Tom Marshburn finished their final two 36-hour sessions in April/May prior to their return to Earth.

↑ TriTel hardware in the Columbus laboratory on the ISS

Biology Research

The new joint ESA/NASA Seedling Growth experiment comprises 3 major parts and the first of the experiment series started on 21 March with the first of four runs undertaken in the European Modular Cultivation System which is located in the Columbus Laboratory. By the end of Expedition 35 the third run of the experiment was underway. Seedling Growth builds on previous space flight experiments with Arabidopsis thaliana seeds and studies the effects of various gravity levels on the growth responses of plant seedlings (The experiment is covered in detail in a separate article).

On-orbit activities for the Seedling Growth experiment were undertaken by NASA astronaut Tom Marshburn who also replaced the rotor belts of the European Modular Cultivation System.

Radiation Research

Expedition 35 saw the successful completion of the TriTel experiment (covered in detail in the last newsletter) on 10 May with a cumulative total of 139 days of data being gathered using its active cosmic radiation detector hardware and passive detectors located inside the Columbus laboratory. ISS Expedition 35 Commander Chris Hadfield carried out the close out activities on the final day, with data downlinked and a USB of data and the passive radiation detectors packed and returned on Soyuz 33S which landed on 14 May.

The active detector hardware includes three different detector types which are able to provide a 3-dimensional mapping of radiation entering Columbus i.e determining the time-dependent level of radiation and direction with which it travels into/through Columbus.

The Dose Distribution inside the ISS 3D (DOSIS-3D) experiment has continued data acquisition using the two active detectors and a third set of passive detectors which were installed in different locations around Columbus on 3 April by ISS Flight Engineer Chris Cassidy, following transportation to the ISS on Soyuz 34S. The active detectors undertake time-dependent cosmic radiation measurements for the experiment. The passive detectors are used in order to undertake 'area dosimetry' i.e. to measure the spatial radiation gradients inside the Columbus module

The aim of the DOSIS-3D experiment is to determine the nature and distribution of the radiation field inside the ISS and follows on from the DOSIS experiment previously undertaken in the Columbus laboratory. Comparison of the dose rates for the DOSIS-3D and the DOSIS experiments has shown a difference in dose level which can be explained due to the different altitude of the Station during the measurements. The DOSIS-3D experiment will build on the data gathered from the DOSIS experiment by combing data gathered in Columbus with ISS International Partner data gathered in other modules of the ISS.

↑ 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

Solar Research

During Expedition 35 three Sun visibility windows (63rd, 64th and 65th) for SOLAR, which is located on the external platform of Columbus, were undertaken for the facility to acquire scientific data when the ISS is in the correct orbital profile with relation to the Sun. The first two were completed (16-26 March, 17-29 April) while the 65th window which started on 12 May was on-going by the end of Expedition 35 (and completed on 24 May)

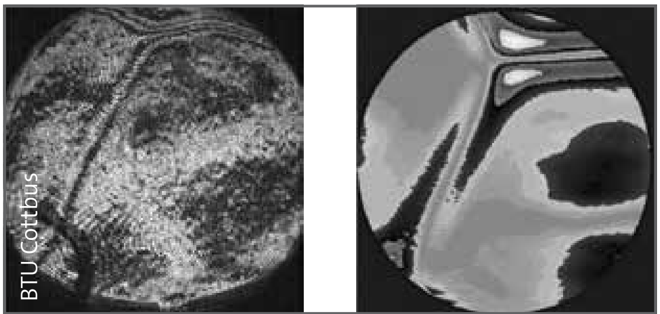
↑ The SOLAR facility (centre) pictured on the International Space Station in June 2008 during an STS-124 mission spacewalk

The SOLAR payload facility is studying the Sun's irradiation with unprecedented accuracy across most of its spectral range. This has so far produced excellent scientific data during a series of Sun observation cycles. An extension to the payload's time in orbit could see its research activities extend up to early 2017 to monitor the whole solar cycle with unprecedented accuracy.

In addition to science acquisition, the Solar facility underwent a software upgrade between 12 April and 2 May.

Fluid Science

Fluid Science saw the completion of the Geoflow-2b experiment series with a number of experiment runs in the Fluid Science Laboratory in April culminating in the final scheduled long-duration no-rotation run on 23 April. For the recent science runs data was directly transferred to ground rather than being recorded on orbit due to a Fluid Science Laboratory Video Management Unit error which is currently being resolved. As a final activity ISS Flight Engineer Chris Cassidy removed the experiment container for the Geoflow-2/2b experiments from the Fluid Science Laboratory on 13 May.



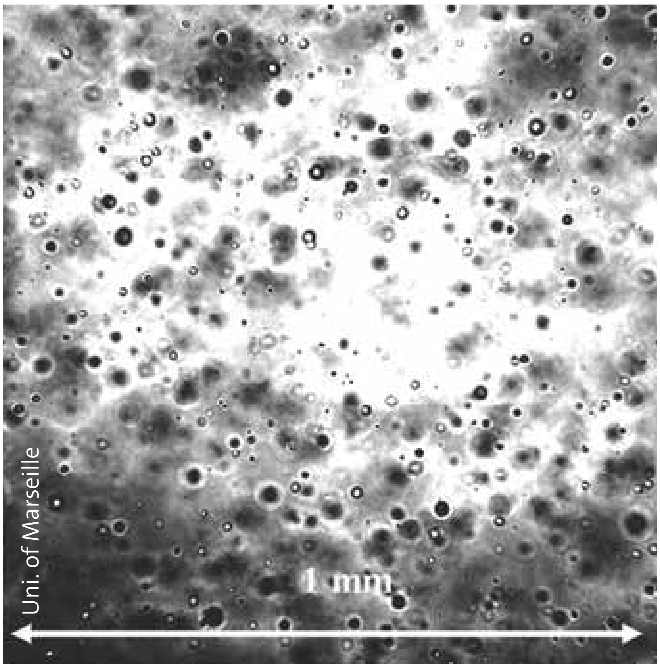
↑ A comparison of an interferometry image (top) taken from the first Geoflow experiment and an image generated from a numerical model (bottom), both with the same temperature and rotational parameters

The Geoflow-2 and -2b experiments (which follow on from the initial Geoflow experiment with new scientific objectives and a different experiment configuration) are investigating the flow of an incompressible viscous fluid held between two concentric spheres rotating about a common axis as a representation of a planet. This is of importance for astrophysical and geophysical problems such as global scale flow in the atmosphere, the oceans, and in the liquid nucleus of planets. For the Geoflow-2 and -2b experiments the incompressible fluid is nonanol which varies in viscosity with temperature (unlike silicon oil as in the first Geoflow experiment) to provide a different aspect of research with more of a simulation to Earth's geophysical conditions. Geoflow-2 and -2b already cover 18 months research on the ISS.

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

For the upcoming FASES (Fundamental and Applied Studies of Emulsion Stability) experiment high rate data downlink test activities were undertaken on 15-16 April and 15 May. One purpose of the tests was to assess if more data bandwidth (~24Mbps instead of 16Mbps) could be routed end-to-end from the Fluid Science Laboratory to ground, in support of the FASES experiment.

The FASES experiment investigates the effect of surface tension on the stability of emulsions. Thin emulsions of different compositions will be stored inside 44 individual sample cells through which the emulsions will be optically and thermally characterised. Results of the FASES experiment hold significance for oil extraction processes, and the chemical and food industries. The FASES Experiment Container was scheduled for upload on ATV-4 in June 2013 (See detailed article on ATV-4) with immediate execution in the Fluid Science Laboratory following docking.



↑ 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

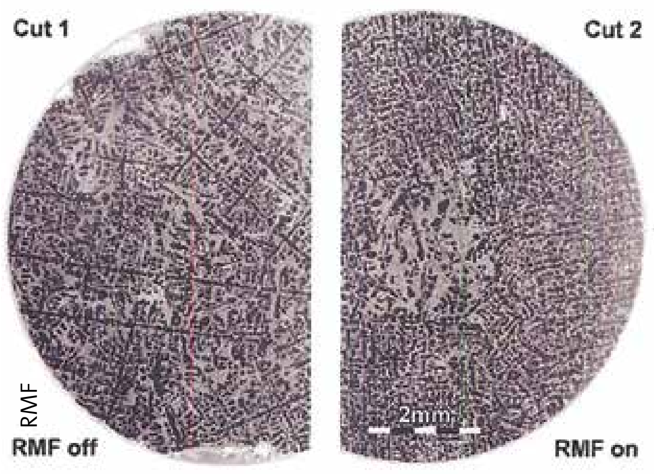
Materials Research

Within materials research no sample processing was undertaken during Expedition 35 though activities were undertaken prior to the restart of the Batch 2a (CETSOL-2, MICAST-2, SETA-2) experiments in ESA's Materials Science Laboratory in the US Laboratory. A seal inspection of the Materials Science Laboratory vacuum chamber was performed by ISS Commander Chris Hadfield on 12 April which was followed by a successful leak check of the Materials Science Laboratory on 22 April. This opened the way to restarting the Batch 2a experiments which are studying different aspects of solidification in metal alloys which will help to optimise industrial casting processes.

Technology Research

Much of the technology research undertaken during Expedition 35 is also covered in separate articles on the Vessel ID System which continues to successfully test the means of monitoring maritime traffic from space and the Cruise Experiment (though CRUISE was at the end of Expedition 34). In addition ESA's NightPod Tracking Device was successfully upgraded on 7 May by ISS Expedition 35 Commander Chris Hadfield. A post-upgrade check-out activity was undertaken hereafter, which consisted of photographing different ground sites during ISS night passes. The NightPod 'tracking device' supports a Nikon D3s camera in taking high-definition pictures of the Earth, especially at night. In a global outreach effort, the footage will be available for the public on the internet. The payload will also be used for education purposes in order to teach children and students about geography and demographic distribution on Earth.

NB. Detailed articles for the Vessel Imaging, Immuno, Neurospat, Reversible Figures, and FASES experiments are scheduled to appear in subsequent newsletters.



↑ Metallographic sections of a processed MICAST sample. Left: under diffusive conditions. Right: under forced convection induced by rotating magnetic field

➜ EUROPEAN LOGISTICS SUPPORT FOR ISS RESEARCH

ESA's Fourth Automated Transfer Vehicle Arrives at the ISS

The logistics supply of research equipment, samples and crew supplies to the ISS is vital to maintain and optimise the research activities on the Station. ESA's Automated Transfer Vehicle (ATV) is currently the largest ISS resupply spacecraft in service and the arrival of ATV-4 at the ISS in June has once again brought an extensive amount of vital supplies into orbit.

ATV-4 called "Albert Einstein" was launched on 5 June at 23:52 CEST (18:52 local time) by an Ariane 5 from Europe's Spaceport in Kourou, French Guiana. Following a 10-day journey Europe's ISS logistics spacecraft docked with the aft port of the Russian Zvezda Service Module on 15 June. Europe's ISS logistics spacecraft delivered 100 kg of oxygen and air; 570 kg of water; 2580 kg of propellants for reboosting the Station's orbit and undertaking debris avoidance manoeuvres and 860 kg more to refill the tanks of the Zvezda Service Module; and 2.48 tonnes of dry cargo to the ISS.

Amongst the so-called dry cargo delivered in the pressurised section of the ATV (which is accessed by the crew) were various key items for continuing a number of ESA research activities on the ISS. In the Fluid Sciences one of the principal items delivered on ATV-4 was the experiment container for the FASES (Fundamental and Applied Studies of Emulsion Stability) experiment which investigates the effect of surface tension on the stability of emulsions. Thin emulsions of different compositions will be stored inside 44 individual sample cells through which the emulsions will be optically and thermally characterised. Results of the FASES experiment hold significance for oil extraction processes, and the chemical and food industries. At the time of compilation the experiment container had already been inserted into the Fluid Science Laboratory by ESA astronaut Luca Parmitano and research activities had started.

↑ ESA's fourth Automated Transfer Vehicle (ATV-4) called Albert Einstein during docking procedures with the ISS

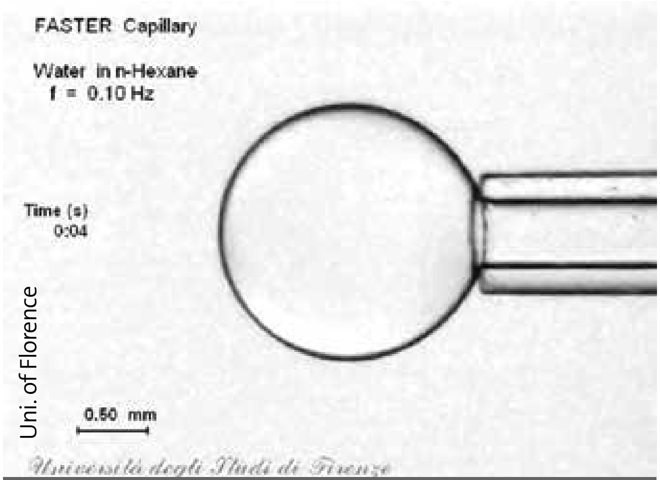
↑ ESA astronaut Luca Parmitano inside ATV-4 after docking

In addition a new Electronics Board was uploaded on ATV-4 to be installed in the European Drawer Rack to replace a similar board with unstable behaviour. This will be followed up by the processing of the FASTER (Facility for Adsorption and Surface Tension) experiment in the European Drawer Rack which will study the links between emulsion stability and characteristics of droplet interfaces. This research has applications in industrial domains and is linked to investigations such as foam stability/drainage/rheology.

In other areas of Physical Sciences, two more Sample Cartridge Assemblies were transported to the ISS for the Batch 2a experiments (CETSOL-2, MICAST-2, SETA-2) which are undertaken inside ESA's Materials Science Laboratory in the US Laboratory. The Batch 2a experiments are studying different aspects of solidification in metal alloys which will help to optimise industrial casting processes.

↑ ESA astronaut Luca Parmitano during FASES experiment installation in the Fluid Science Laboratory in the European Columbus Laboratory on the ISS

Within the Human Research, consumables and food items have been uploaded on ATV-4 for ESA astronaut Luca Parmitano (Expedition 36/37) and NASA astronaut Michael Hopkins (Expedition 37/38) for the Energy experiment studying astronaut energy requirements in orbit (and discussed in a separate article). An ESA Mini-ECCO thermal container was also uploaded to return the final samples for the Immuno experiment which is determining changes in stress and immune responses, during and after a stay on the ISS. The samples are currently scheduled for return on Soyuz 34S in September 2013.



↑ Drop of water in hexane at the end of a capillary tube during ground testing of the FASTER experiment. The shape of the drop is linked to the surface tension, which is used to calculate the interfacial visco-elasticity

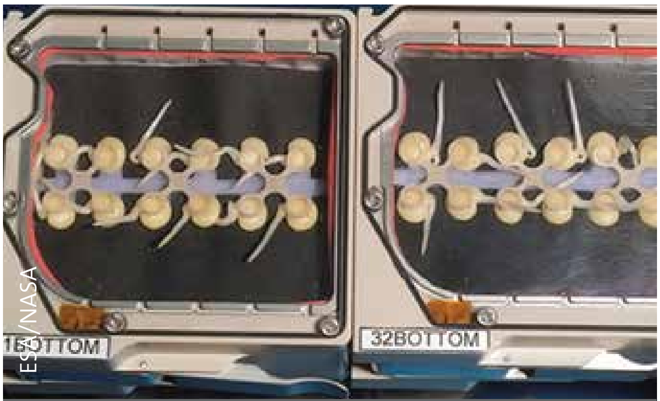
↑ Food items for the Energy experiment packed prior to launch

↑ ESA astronaut Andre Kuipers supporting ground-conducted health check activities on ESA's Biolab facility in the ISS Columbus laboratory on 18 May 2012

With ESA's biology research activities successfully continuing on the ISS with the recent completion of all runs of the joint ESA/NASA Seedling Growth experiment in the European Modular Cultivation System (EMCS) in Columbus (discussed in detail in a separate article), biology research will be expanded with commissioning activities for the Biolab facility in Columbus. Important replacement hardware for Biolab has been transported to the ISS on ATV-4. This included a new microscope, thermal control system equipment and two Life Support Modules (+ biological filters). Once these are installed in Biolab a commissioning run should take place soon after. This will pre-empt use of Biolab's thermal storage capabilities and BioGlovebox for sample processing activities for the Gravi-2 experiment which will be processed in the EMCS towards the end of 2013 and the Triplelux-B experiment, which will be processed in the Biolab facility in 2014. Gravi-2 will continue the research undertaken within the GRAVI-1 experiment in determining the threshold of perception of gravity by lentil roots, while Triplelux-B will compare the cellular mechanisms of vertebrate and invertebrate cells which cause impairment of immune function in weightlessness.

Finally, items were also uploaded for ESA astronaut Luca Parmitano to undertake education activities which make use of human spaceflight and the ISS as a means to capture the attention and the interest of students, to attract them to study, in particular, scientific and technical disciplines.

The ATV spacecraft will spend four months attached to the Station after which the vehicle filled with excess equipment and garbage will undock from the ISS and re-enter the Earth's atmosphere to burn up over the Pacific Ocean. In addition to delivering necessary supplies ATV-4 will provide extra storage space and habitable volume for the crew.



↑ Cultivation chambers from the Gravi-1 experiment in the US laboratory, which carried out research to determine the gravity perception threshold in lentil seedlings

➔ THERMAL REGULATION AND FITNESS:

The Thermolab, EKE and Circadian Rhythms Experiments

↑ NASA astronaut Sunita Williams using the Portable Pulmonary Function System whilst on the CEVIS cycle exercise device during a session of the joint Thermolab/ EKE/VO2 Max experiments in August 2012

Two of ESA's long-duration human research experiments (EKE and Thermolab) studying the impact of spaceflight on the cardiovascular system came to successful conclusions in orbit in October 2012 with a follow-up experiment to Thermolab (Circadian Rhythms) starting in July 2012. We take a look at what we have learnt so far from this research and where it is headed.

The environment of space provides a challenging environment for our astronauts on many levels, impacting on many of the body's different systems. The cardiovascular system for example undergoes deconditioning of blood pressure control mechanisms. With the cardiovascular system playing a fundamental role in maintaining fitness levels and the capacity to undertake physical work as well as playing a vital role in maintaining the thermal regulation of the body, it is important to monitor any physiological changes occurring on orbit. Maintaining the fitness and performance of our astronauts is not only a necessity to secure the well-being of our astronauts in orbit, it also secures the optimum success of each mission.

Deepening our understanding of the changes occurring in orbit not only improves our fundamental knowledge of the processes at work in the body (in space and on Earth), it also provides the basis for the development of additional countermeasures and methods to reduce any negative effects that occur through the implementation of exercise protocols, pharmaceutical or nutritional supplements, or use of new technologies as well as optimising current techniques and methods used on orbit. These methods could further be adapted, or used directly in applications on Earth.

Sharing Data to Optimise Resources

Thermolab and EKE are different experiments but very closely linked as they both share data with NASA's VO2 Max experiment and both take diagnostic measurements using the Portable Pulmonary Function System, one of ESA's most successful and utilised human research facilities on the ISS.

Sharing data with research teams and projects from other ISS Partners is a very beneficial way to maximise the use of ISS resources, saving on ISS crew time and the cost of uploading research hardware. For the EKE experiment this actually saves on both as there are only dedicated pre- and post-flight measurements taken using the ground-based Portable Pulmonary Function System (combined with on-orbit data from the VO2 Max experiment).

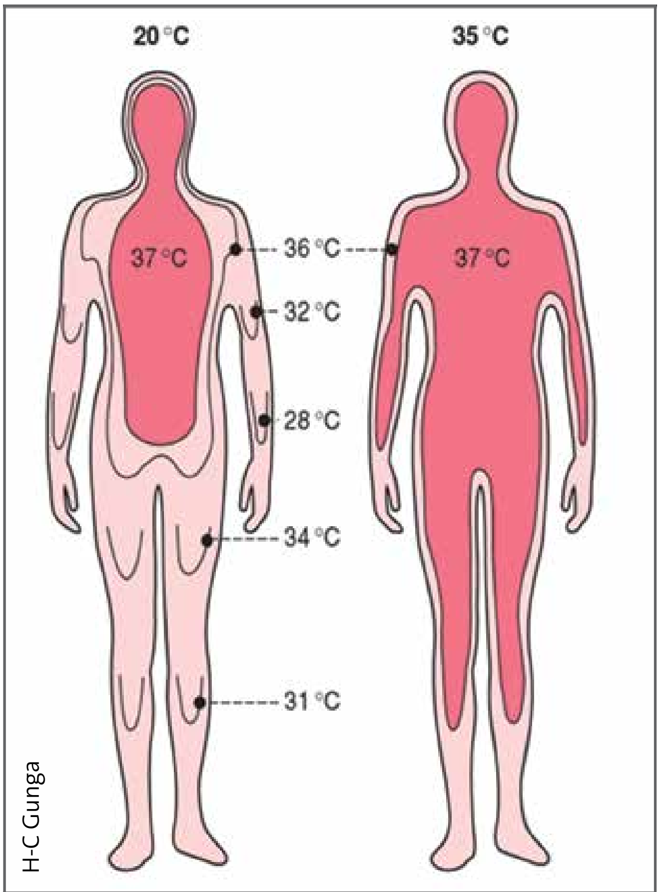
Assessing Astronaut Fitness: EKE Experiment

EKE ('*Assessment of Endurance Capacity by Gas Exchange and Heart Rate Kinetics During Physical Training*') is aiming to develop a new method to reduce time spent evaluating astronaut fitness (endurance capacity) on orbit using heart rate and oxygen uptake measurements in response to changes in exercise intensity. This is why it shares data with the VO2 Max assessment which itself uses a standard measure (called VO2 Max or maximal oxygen consumption) for evaluating aerobic capacity on ground. This provides a good indication of fitness and the capability of astronauts to undertake physical work.

The VO2 Max assessment consists of astronauts performing five-minute continuous exercise sessions at 25%, 50% and 75% aerobic capacity (as measured pre-flight) followed by a steady increase to maximum exercise capacity. This is followed by a cool down period again of 5 minutes at 25% aerobic capacity. Oxygen uptake, cardiac output, and additional measurements are taken during the exercise (on the CEVIS cycle ergometer in the US laboratory) with the Portable Pulmonary Function System together with ECG (Electrocardiography) measurements.

Undertaking these assessments on a regular basis is quite time consuming, so if EKE is successful in reducing the time spent on fitness evaluation on orbit, this will allow for more time to be spent on other activities such as scientific research. In the future the EKE testing might be integrated into daily training procedures (countermeasures). Another goal of the experiment is the development of a physiological model to explore the transport delay of the deoxygenated blood from the exercising muscle tissue to the lungs. This approach allows to differentiate between the responses of heart, lungs, and exercising muscles for a more specific training prescription.

EKE started just before Thermolab with NASA astronaut and Expedition 20/21 crew member Nicole Stott as the first test subject in 2009.

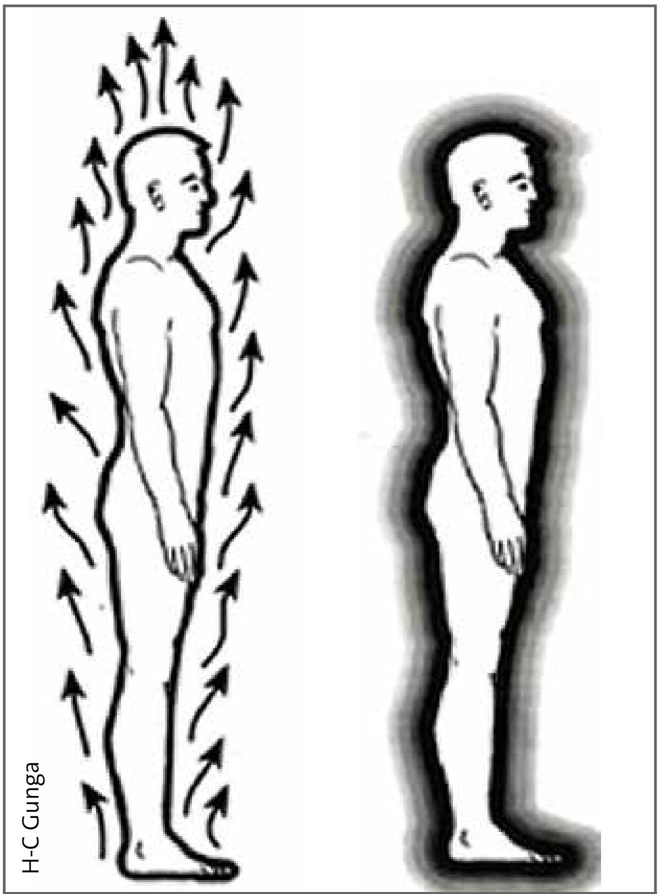


↑ Distribution of tissue temperatures from body core to body shell under ambient room (20 °C, left) and hot environmental conditions (35 °C, right)

Thermal Regulation and Circadian Rhythms

Thermal regulation in the body, which is also heavily influenced by the cardiovascular system is a complex activity and vital for our well-being. Our vital organs from the brain to the kidneys are kept at a constant temperature of 37° C whether it is the middle of a freezing winter or on a hot sunny beach. To help maintain this stability the body shivers when it is cold to generate more heat and sweats when it is hot to help remove excess heat, with the natural convection on Earth helping remove the heat from our bodies. Any disturbance to that stasis can cause symptoms such as physical and mental fatigue or in its extreme have fatal effects on how the body functions with conditions such as heat stroke and hypothermia.

In weightlessness the adaptation of the cardiovascular system, the lack of convection in space and the shifting of fluids to the upper half of the body could have a negative influence on thermal regulation. The Thermolab experiment has been looking at changes in thermal regulation and cardiovascular adaptations in weightlessness, investigating how the body heats up during, and cools down after, exercise. Additional measurements were taken during the VO2 Max experiment sessions with each astronaut subject wearing additional temperature sensors on the forehead and chest to measure the skin temperature and the heat flow in the skin, which are used to calculate core body temperature using sophisticated algorithms. The measurements in space are then compared with those measured on the ground on



↑ Convection on Earth and in space. On Earth (left) natural convection helps in the removal of excess heat from the surface of the body. In space there is no convection due to the lack of the effect of gravity. If stationary this should cause a build-up of heat around the body

the same crewmember before and after the mission. With sessions undertaken monthly this provides a good indication on how the thermoregulatory system adapts during and after spaceflight.

NASA astronaut and Expedition 21/22 crew member Jeff Williams started as the first subject of the joint Thermolab/EKE/VO2 Max experiments in October 2009. This was shortly after ESA astronaut Frank De Winne commissioned the Portable Pulmonary Function System and used it for the first time as a subject of the VO2 Max experiment, and also shortly after Nicole Stott started as the first subject of the EKE experiment. Jeff Williams concluded the monthly experiment sessions in March 2010 before returning to Earth. He was followed up by 10 additional test subjects for the joint experiments between 2010 and 2012, nine from NASA and ESA astronaut André Kuipers. Sunita Williams was the final test subject for the joint experiments with the very final on-orbit session carried out in October 2012.

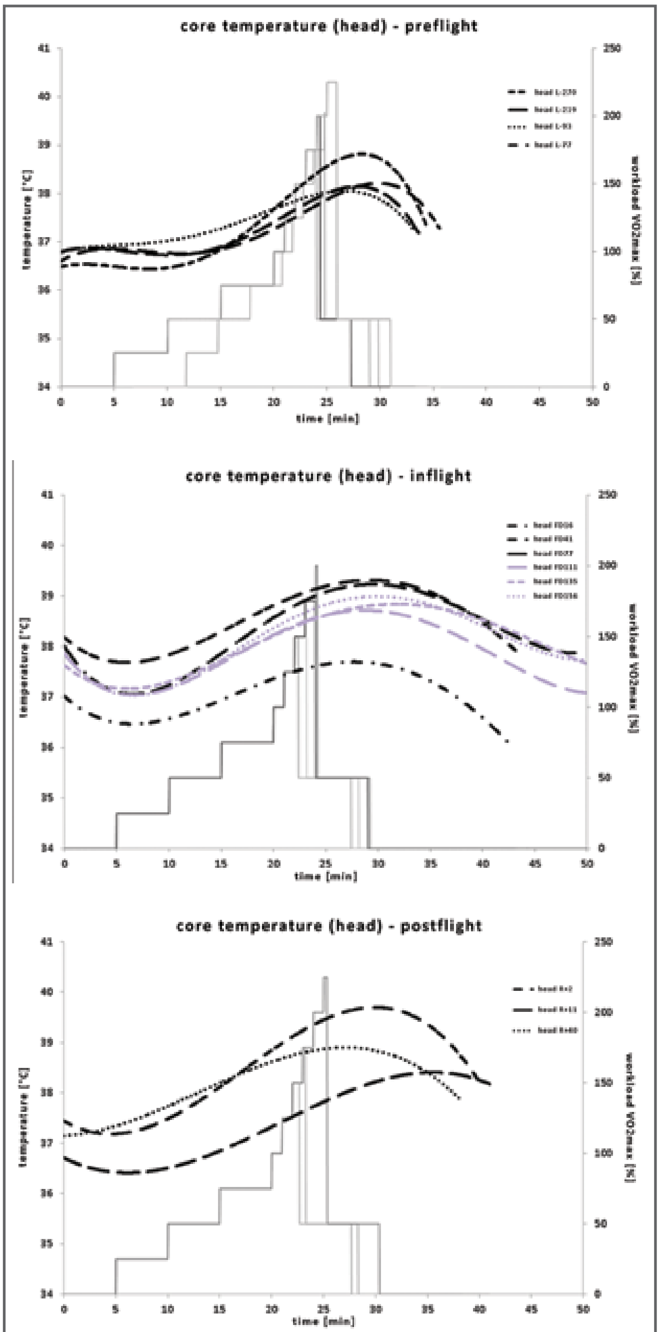
In addition the (Thermolab) experiment was testing a new type of sensor to record the core body temperature in orbit that could have novel applications on in space and on Earth. This new sensor was developed for DLR by Charité (Berlin) and Draegerwerk (Lübeck), since standard ground measurement in clinics and surgeries use an internal body probe for taking measurements which is not practical on orbit. Before it went into

↑ ESA astronaut and ISS Expedition 21 Commander Frank De Winne (background) and NASA astronaut and Expedition 21 flight engineer Jeff Williams setting up the Portable Pulmonary Function System for the first run of the joint Thermolab/EKE/ VO2 Max experiments on 14 Oct. 2009

↑ ESA astronaut André Kuipers using the Portable Pulmonary Function System during activities for the joint Thermolab/EKE/ VO2 Max experiments. Clear view of core body temperature sensor on his forehead orbit, Thermolab was thoroughly tested and optimised during a Berlin bed rest study, a study with firefighters in the SINTEF research centre in Norway, climate chamber experiments, and three parabolic flights of the German Aerospace Center (DLR).

Results and Future

It has been seen that the core body temperature rises faster during exercise on the ISS than on Earth, probably caused by fluid shifts and modified heat flow away from the body. The graphs below highlight this adaptation in the core body temperature.



H-C Gunga

↑ Three graphs showing the variation in core body temperature (measured at the forehead) before, during, after a graded exercise protocol before flight, in-flight and post-flight

Adaptation can be seen in the first six weeks on the ISS with an increase in core body temperature by around 1-1.5 deg C though this settles down to an increase of around 0.5 - 1 deg C above pre-flight core body temperature as the mission extends. With the core temperature rising faster on the ISS it is also noticeable that the body temperature takes longer to cool back down to core temperature after exercise.

The measurement of the core body temperature together with cardiovascular measurements taken during the VO2 Max protocol can be used to evaluate the subject's state of fatigue, which is obviously very important during a space mission for optimising mission success.

This makes this non-invasive double sensor a very useful diagnostic tool for recognising early warning signs of fatigue during, for example, spacewalks in orbit. On Earth firefighters (to recognize exhaustion and overheating early) or jet pilots, miners, steel workers, soldiers in combat, divers, mountaineers, polar explorers and marine fishermen working in extreme conditions could all benefit from the new measurement technology. It could also be used for monitoring during critical hospital operations such as heart surgery or for monitoring babies in incubators.

Following on from Thermolab, the same science team from Charité, Berlin are also undertaking additional research on the ISS. The dedicated thermal sensor equipment used within the Thermolab experiment has proved a valuable asset and is now the central focus of the Circadian Rhythms experiment which started in July 2012 using the sensors in the same configuration as for Thermolab.

↑ NASA astronaut and Expedition 34 flight engineer Tom Marshburn, undertaking normal daily activities on the ISS whilst wearing Thermolab sensors as part of a 36-hour session of the Circadian Rhythms Experiment

The main objective of the Circadian Rhythms experiment is to get a better basic understanding of any alterations in circadian rhythms in humans during long-duration spaceflight. This will provide insights into the adaptation of the human autonomic nervous system in space over time, and will help to improve physical exercise, rest and work shifts, as well as fostering adequate workplace illumination in the sense of occupational healthcare in future space missions. This is undertaken by measuring the change of the core body temperature which also experiences a circadian cycle. The same set up was tested during the 17-month Mars 500 isolation study, which concluded in November 2011.

The Thermolab sensors are worn on the forehead and chest for a 36-hour period running from a pre-sleep period across the following day and night and concluding the morning after.

↑ Russian crew member wearing Thermolab sensors during the MARS 500 study in Moscow

The very first session of Circadian Rhythms on the ISS started on in July 2012 with ISS Flight Engineer Akihiko Hoshide as the first test subject. Hoshide carried out further monthly sessions from August, concluding in November 2012. Hoshide has been followed up by NASA astronaut Tom Marshburn and CSA astronaut Chris Hadfield who started as test subjects at the end of December 2012 after arrival at the ISS and completed monthly sessions hereafter until their return to earth in May 2013. ESA astronaut Luca Parmitano also started as a test subject of the experiment in June 2013.

The Circadian Rhythms science team have already confirmed that the data looks good for analysis.

The Double Sensor technology seems to be a valid, non-invasive alternative for monitoring circadian rhythm profiles and might be used for various research areas such as chronobiological/sleep research as well as peri- and post-operative core temperature monitoring both on Earth and in Space.

As is the case with many similar experiments, the operations of the Thermolab, EKE, and Circadian Rhythms experiments (as well as the VO2 Max experiment) were/are monitored from DAMEC Research Apps (now Danish Aerospace Company) in Denmark, one of ESA's User Support and Operations Centres. Their involvement in this area covers almost every level, undertaking the baseline data collection, monitoring/controlling the activities on orbit, and even the development of the Portable Pulmonary Function System (for ESA), the Pulmonary Function System (for ESA/NASA) and the CEVIS Cycle Ergometer (for NASA).

→ IMPROVED TECHNOLOGIES FOR THE ISS AND FUTURE EXPLORATION:

Enhancing astronaut performance with the CRUISE Experiment

Human exploration missions beyond Low Earth Orbit (LEO) will require new on-board information systems to support increased autonomy for the crew. Current flight operations on Columbus could also benefit from improvements of on-board crew operations support software. The CRUISE (Crew User Interface System Enhancements) technology demonstrator which took place during Expedition 34 is a first step towards the deployment of such tools on Columbus, whilst at the same time preparing integrated solutions for future exploration missions.

The objective of CRUISE is to improve overall crew performance, be it for payload or system activities. During an on-board activity, it is mandatory for the astronaut to follow a crew procedure. An activity could for example be to set up a science experiment, or perform maintenance on some infrastructure on board the ISS. Today many good features of ground-based interactive user manuals are not supported by the on-board laptop procedure viewer. The CRUISE investigation aims to improve the design of future procedure viewers, thus, for example, shortening task-to-completion time and increasing time for pure utilisation activities. The experiment is jointly funded be ESA's Directorates of Technical and Quality Management and Human Spaceflight and Operations.

Current crew information systems require astronauts to float constantly between the task at hand and the procedure viewer laptop to manually click through each step of the task with a keyboard and pointer, thus prolonging the duration of the activity. One part of the CRUISE demonstrator (the 'Voice-Activated Procedure Viewer') is testing a simple headset (Fig. 1) and commercial voice recognition software to implement a voice-controlled way of navigating the procedures so hands-busy activities are better supported. This was complemented with a simple yes/no dialogue to help the user to resolve recognition ambiguity issues, if any.

ESA

↑ Fig. 1: Demonstration of headset used within the 'Voice-Activated Procedure Viewer' part of the CRUISE experiment

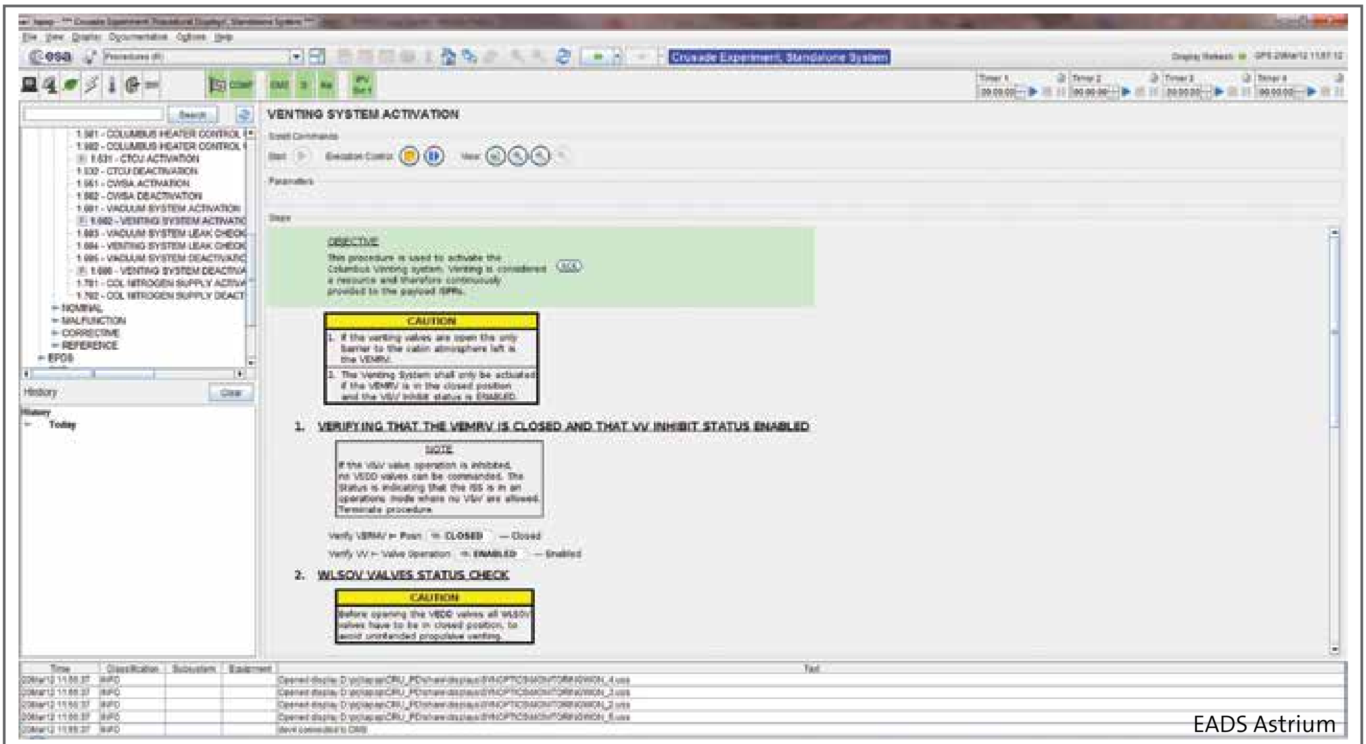
The second part of the demonstrator ('Procedural Displays') dealt with reducing time spent going between procedure viewer laptops and so called synoptic displays used to monitor and control systems or experiments. Synoptic displays allow an astronaut to read real-time data, and send commands to the equipment from their laptops, much like operators in nuclear power stations. For astronauts, constantly switching between two displays to read the correct instruction and then implement the correct action is time-consuming, results in a heavy cognitive workload, and increases the risk to make mistakes. This second part of CRUISE allowed astronauts to work with software that merged the real-time data and command actions with procedural steps within one display, with the procedural steps appearing when required (Fig. 2). This type of operational content promises to help astronauts to act as a supervisor instead of a low-level operator, thereby decreasing the duration of the task, and chance of human-machine error.

The CRUISE experiment at the end of increment 34 allowed two astronauts to carry out set tasks and asked them to compare this new way of working with the old way, while also collecting quantitative data about task duration, and error occurrences.

Research Aspects

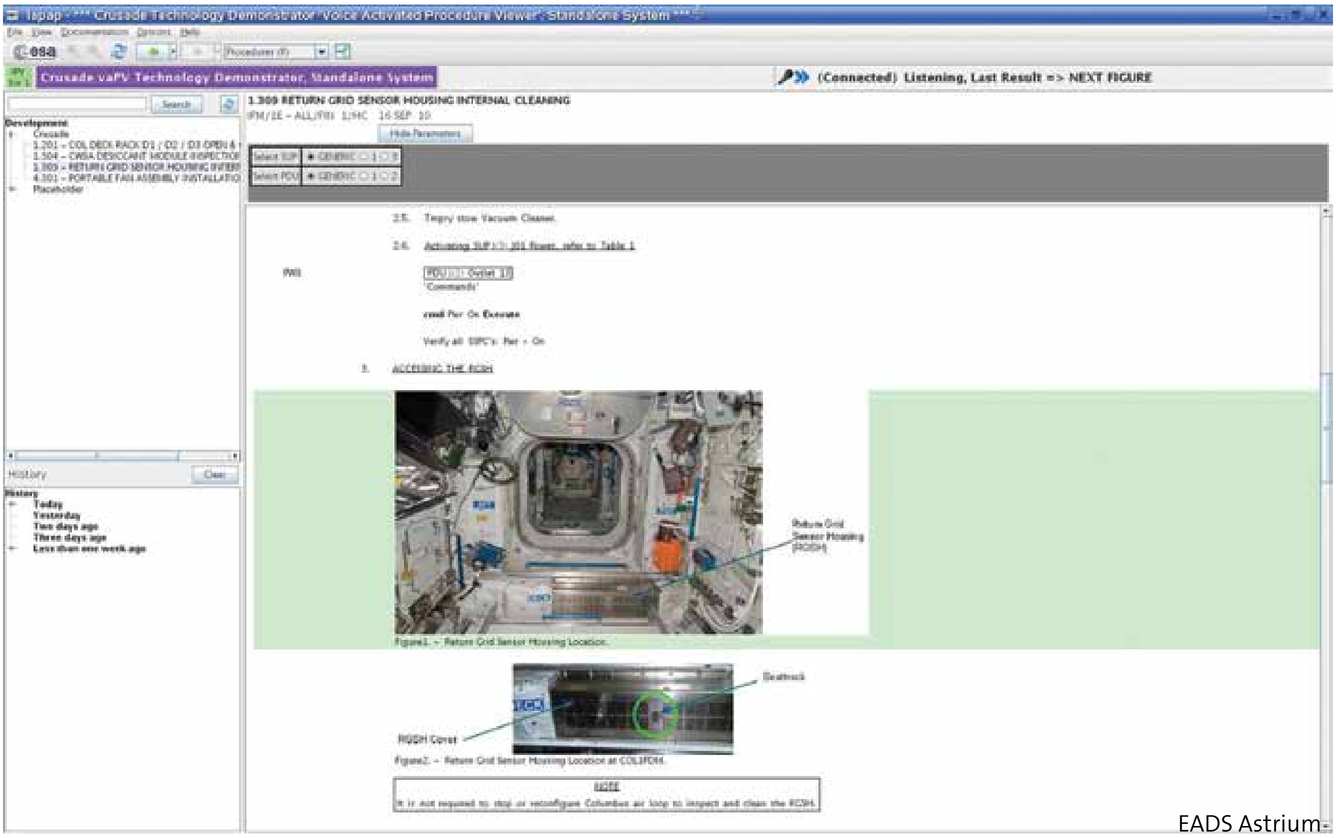
The ISS is a perfect environment for validating the CRUISE on-ground research developments in a high fidelity context-of-use environment (confined space, hostile environment, workload and weightlessness), with end-users having a profile very similar to future human explorers, as well as evaluating ISS operations for the proposed technologies and operational concepts.

The analysis approach to the demonstration is based on qualitative (e.g. user experience/satisfaction) and quantitative (e.g. reduction of human-system error incidents, reduction of



EADS Astrium

↑ Fig. 2: Partial view of screen from Procedural Displays part of CRUISE experiment



↑ Fig. 3: Partial view of screen from Voice-Activated Procedure Viewer part of CRUISE experiment

task-to-completion time) elements, including best practice human factor engineering questionnaires filled in by the participating crew members. Relevant voice-activated data (recognition rate, logged data, duplicated navigation command etc.) is also analysed. Comparison with findings from ground based evaluations will be included in the analysis. Accurate, complete and efficient usage of the system will be an indicator of the CRUISE demonstrator success.

The test configuration is based on currently operational software (Columbus system laptop software Lapap) and validated operations procedures. As such direct benefits for ISS flight crew operations are envisaged when the findings of the CRUISE technology demonstrator are incorporated in the next generation crew information systems on board the ISS.

Development and mission integration

ESA and the development team considered various on-board scenarios that would provide a good and realistic setting for the CRUISE experiment. For the ‘Procedural Displays’ part of the experiment a simulation of command and control activities for the Columbus Environmental Control and Life Support System (ECLSS) was selected. This choice offered a high level of operational realism whilst ensuring that no on-board systems could be impacted during the experiment execution. For the ‘Voice-Activated Procedure Viewer’ part of the experiment a real sub-system preventive maintenance task was selected: cleaning the Columbus laboratory ventilation system (with a vacuum cleaner), a very complex hands-on task (Fig. 3 and 4).

↑ Fig. 4: NASA astronaut and ISS Expedition 34 Commander during the Voice-Activated Procedure Viewer part of CRUISE experiment, removing a grid of the Columbus laboratory ventilation system

The software for both experiments was integrated into custom versions of Lapap, the standard crew interface for Columbus nominal system command, monitoring and control operations. The software was executed on a standard ISS T61p crew laptop, which was not connected to the onboard LAN. Operational crew procedures were developed as per the standard Columbus operations processes.

Experiment execution

The initial part of the experiment execution consisted of installing the software on a dedicated T61p laptop. The first session of the experiment was undertaken by ISS Expedition 34 Commander Kevin Ford on 27 February 2013 (Fig. 4), with a second session undertaken by ISS Expedition 34 Flight Engineer Chris Hadfield on 12 March. Each experiment session consisted of the two parts of the CRUISE experiment and lasted a little less than 3 hours.

For both test subjects, the experiment run went nominally. For analysis purposes the sessions were covered by on-board video, a laptop data log including audio files (for voice recognition performance), and qualitative data through astronaut-filled questionnaires. Information from a space-to-ground conversation was also acquired to help understand where "side-talk" was an issue for voice recognition performance.

After returning to earth, the experiment protocol called for a post-mission session. The first post-flight session has now been conducted with Kevin Ford, and yielded more qualitative data and a good pro- and con-discussion was undertaken.

Preliminary Results

The Cruise 'Procedural Displays' experiment went very well and the concept behind it was strongly appreciated by the crew members who carried it out. After testing NASA astronaut Kevin Ford said that the Procedural Displays were "… *a great idea to streamline the execution of procedures, and minimize the chances for crew error. Instructions, commands, and data all together in one glance will be a big operational improvement for future space ops. It was great being part of this effort to kick off the next generation crew interface.*"

In addition, the participating crew members also came up with suggestions for improvement. In particular, keyboard shortcuts support was found to be important as a result of experiment execution in weightlessness. No such requirement had resulted from experiment execution during training and evaluation on ground. Furthermore, astronauts suggested providing quick access to background information (e. g. schematic drawings) on the technical systems with which the procedural displays interacted.

The Cruise 'Voice-Activated Procedure Viewer' experiment also went well, but proved more challenging as it involved a very real hands-on maintenance activity. Interaction with the viewer on the laptop is then very different than during an on-ground laboratory evaluation. This was exacerbated by limited training of voice command vocabulary, which led to crew members often just reverting to using keyboard commands instead of using voice navigation of the procedure viewer.

Furthermore, weightlessness clearly had an impact on the experiment: The floating headset cord was often found to be distracting. Speech recognition worked reasonably well; It was not negatively affected by the general noise level, but frequent "side talk" voice communication with ground caused a lot of failed attempts to parse the spoken words as commands. Therefore it was suggested that future 'Voice-Activated Procedure Viewer' versions should be required to be addressed explicitly by a name that does not sound too technical but is unlikely to collide with human names (maybe something like 'Genie'). Only if that name is detected in the audio input, the system would consider the following words as directed towards it and try to interpret them as commands.

That said the crew feedback is still positive concerning the direction the developments are taking. Concerning the Voice-Activated Procedure Viewer Kevin Ford added "*Working in zero gravity is challenging because you often use your hands for "walking" and working. CRUISE vaPV (Voice-Activated Procedure Viewer) will free our hands for ops, allowing us to be faster and more efficient with almost every task. This particular project is the first step toward voice activated space operations, and it will be cool watching it develop into a mature standard space capability.*"

Next Steps

The 'Procedural Displays' element of the demonstrator was felt to be much more mature than the 'Voice-Activated Procedure Viewer' and it is suggested to use Procedural Displays to control sub-system devices, for example the Standard Utility Panel operations. This activity is commonly performed by ground, but when using ISS as an analogue for a mission beyond LEO (including inherent communications delays), it would be ideal to include operations supported by procedural displays.

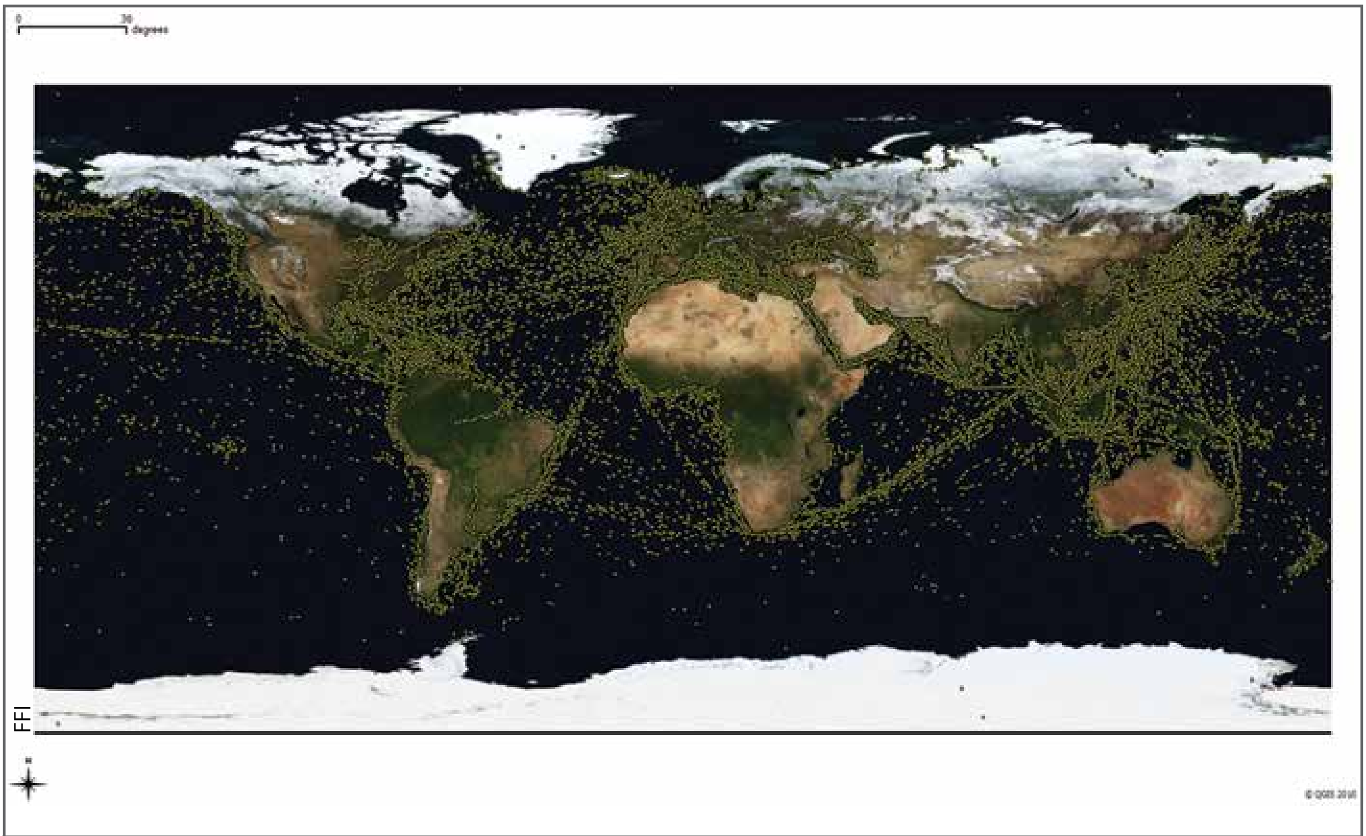
The Voice-Activated Procedure Viewer will benefit from additional design work, especially a microphone that does not tether the astronaut to the laptop is required, and the "side talk" issue must be resolved. Having solved those challenges a 2nd on-board evaluation should be undertaken.

Acknowledgements

This article has been compiled with the help of internal ESA sources and the valuable contributions of members of the CRUISE development and operations team: EADS Astrium (D), TNO (NL), Sybernet (IRL), Skytek (IRL).

→ MONITORING GLOBAL MARITIME TRAFFIC FROM SPACE:

The Vessel ID System Celebrates Three Successful Years on Orbit



↑ 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

The Vessel ID System on Columbus has been successfully monitoring maritime traffic from the ISS since 2010. With this technology demonstrator celebrating three successful years in service in June we take a look at the highlights of a busy period overlooking Earth's oceans.

The current ground-based Automatic Identification System or AIS, as specified by the International Maritime Organisation (IMO), is a ship and shore based broadcast system designed to monitor maritime vessels though only in coastal waters. This capability has been greatly expanded by the AIS for Columbus (known as the Vessel Identification System), which operates in the VHF maritime band. This has verified the capability of the system to be used as a method of tracking global maritime traffic from space and also incorporates maritime traffic in open waters.

The autonomous system picks up signals from standard AIS transponders carried by all international ships over 300 gross tonnes engaged on international voyages, cargo vessels over 500 gross tonnes not engaged on international voyages and all types of passenger ships mandated by the International Maritime Organization to carry AIS transponders.

The ISS is in an ideal location between 350 to 400 km altitude for space-based AIS signal reception which will provide the means to be utilised by multiple users.

The AIS ground coverage from the ISS is between approximately 68° north and 68° south. Consisting of an antenna assembly that was mounted on the outside of Columbus during a spacewalk in November 2009, as well as data relay hardware (the ERNO-Box) and a receiver mounted inside Columbus, the system has been active since June 2010. The operational phases with the first receiver from Norway (NORAIS), which is operated by FFI/Norway, have been extremely successful with data telemetry received by the Norwegian User Support and Operation Centre (N-USOC) in Trondheim, Norway via ESA's Columbus Control Centre in Germany.

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

The system is capable of receiving ship information such as identity, position, course, speed, ship particulars, cargo and voyage information to and from other vessels and shore. The ground-based system uses Self-Organising Time Division Multiple Access technology to meet high broadcast rates and ensure stable and reliable ship-to-ship and ship-to-shore operations within ~40 NM zones. The system provides continuous operation and a high detection probability of AIS signals broadcast by maritime vessels.

Not only has the system greatly increased the AIS coverage in open seas, during the time in orbit the system has also undergone upgrades to improve the performance of the system even further. Data has been received by NORAIS in almost continuous operation and all modes of operation have worked well. The NORAIS Receiver has a sample mode that can collect the raw signal, digitize it and send it to ground for analysis of signal quality, which has proved very helpful in making additional improvements/ refinements to the system in crowded shipping areas where the possibility of disturbed signals or signal collisions can occur.

This has been used both to investigate the signal environment and to evaluate the performance of new receiver technologies on the ground. Several hundred data sets have been collected and processed with new candidate algorithms for next generation receivers.

Integrating AIS information with other satellite data, such as from remote-sensing satellites, should significantly improve maritime surveillance and boost safety and security at sea. Based on the payload designed for the Norwegian AISSat-1satellite, which was launched into a near polar orbit in July 2010 and provides similarly good data in the high north, the NORAIS Receiver is a software defined radio design operating across the maritime band from 156 to 163 MHz. The tuning of the NORAIS receiver to frequencies under consideration for allocation to space-based AIS has been carried out and NORAIS took part in international tests of these two proposed frequencies in October 2010, arranged by the US Coast Guard.

The main reason for covering more than the two current frequencies in use for AIS is to have the possibility to demonstrate the operational use of new channels in the maritime band being allocated to space-based AIS. Also, this configuration allows for characterization of the maritime VHF spectrum with respect to occupancy and interference. The software implementation allows for optimization of the receiver settings in orbit and also allows for upload of new signal processing algorithms.

Analyses and Performance:

Since the start of operations the results of analyses for the Vessel ID System have been very good and different improvements to the system have been made. In the first 118-day operations period nearly 30 million AIS messages were received from more than 60,000 different transponders. The number of decoded messages per day ranged from 200,000 up to 400,000 over the course of the first operations period. [1, 2]. In a summary made in October 2011 the total number of position reports received exceeded 110 million messages from more than 82000 different ships ID numbers.

As an addition to the original technical topics, operational experimentation has been included in the investigations. Near-real-time data transfer is crucial to meet the requirement to SAT-AIS set by ESA in cooperation with operational users. After an upgrade of the ground systems in the N-USOC, 10 days of near-real-time data showed that 80% of the messages collected in the period could be delivered through the station's communications network with data latency significantly less than 1 hour. The near-real-time data delivery is now part of routine operations since November 2011.

The original decoder algorithm developed by Kongsberg Seatex as part of the technology development contract with ESA was upgraded in January 2012, with the firmware uploaded to the NORAIS Receiver through the station's communications network,. The results showed nearly 100% increase in number of messages received per day in difficult areas such as the Mediterranean, Gulf of Mexico and in the South China Sea. Globally, an increase in the number of messages of 31% was achieved, with a 22% increase in the number of unique identifiers received per day. In addition it was seen that the new decoder was more resistant to the constant frequency interference experienced.

The decoder algorithm was further upgraded in June 2012 and February 2013 to make improvements in errors in received/ processed data. The first upgrade (focusing on 1-bit errors) yielded a 10% increase in the number of messages decoded, but required some post-processing to remove erroneously corrected messages. The second upgrade was an iteration of the first upgrade to correct only the bits of data with the least probability of being correct. In addition, 2 and 3 bit error correction was implemented. The improvement from the previous upgrade was not very significant, but the number of erroneously corrected messages could be reduced by only attempting to correct a set number of insecure bits, and not try to correct all bits like the previous upgrade.

The most recent upgrade in May 2013 implemented the decoder algorithm on 2 channels rather than one. In addition, a smarter adjustment of the signal level for each message decoded was implemented, yielding another 10 percentage point increase on the original results of the decoder upgrade for number of messages received per day respectively. The improvement for number of unique identifiers was around 5 percentage points.

The work on better algorithms continues. The results of the development will support the design and development of a space-based AIS system in general as well as the performance of the AIS receiver on the station.

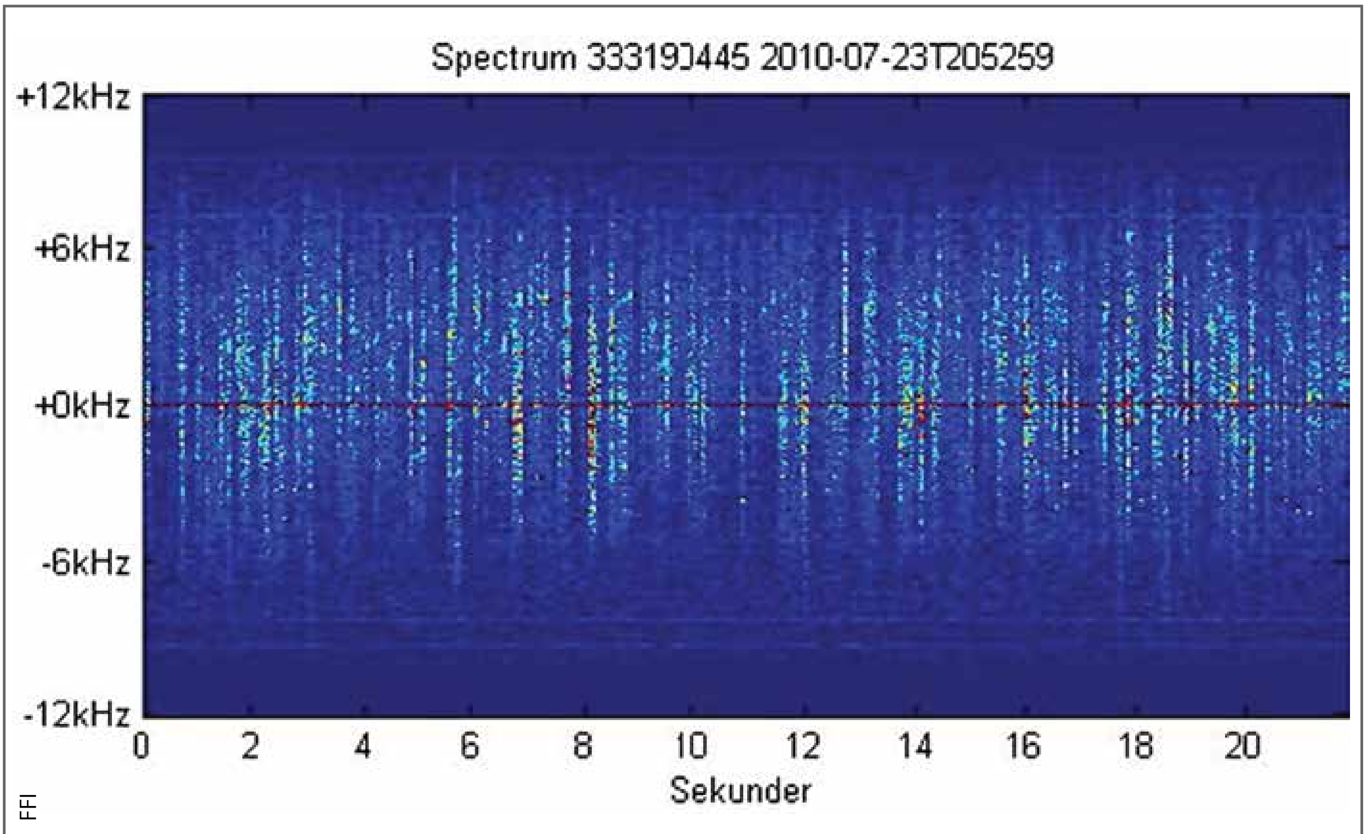
Even though the system was originally scheduled to be tested with two different receivers, one from Norway (NORAIS) and one from Luxembourg (LuxAIS), a problem with the second receiver has meant that the test has been on-going with just the one receiver from Norway, though in a very successful fashion. Currently a second generation of the Norwegian receiver with much higher performance is under development and planned to be deployed on the ISS around mid-2014.

Future:

The Vessel Identification System could potentially be beneficial to many European entities particularly in assisting them in law enforcement, fishery control campaigns, maritime border control, maritime safety and security issues including marine pollution survey, search and rescue and anti-piracy. Various service entities have already been asking to get access to the VIS data which is continuously acquired on Columbus.

1. *T. Eriksen, A Nordmo Skauen, B. Narheim, Ø. Helleren, Ø. Olsen, R. Olsen: Tracking Ship Traffic with Space-Based AIS: Experience Gained in First Months of Operations (2011)*
2. *A. Nordmo SkauenT. Eriksen: AIS Receiving System for Columbus (COLAIS) - Yearly Report 2010 for the COLAIS experiment with the NORAIS Receiver (2011)*

Note:
The Vessel ID experiment has been developed within the Systems, Software & Technology Department in ESA's Technical Directorate under GSTP funding.



↑ The spectrum versus time for 22 seconds of a sampled AIS data. The messages can be seen as vertical lines. Approximately 150 messages are decoded from the data

→ DETERMINING ASTRONAUT ENERGY REQUIREMENTS:

A look at the Energy experiment

Optimal planning for human spaceflight missions both now and in the future is essential in order to maximise available resources and secure the maximum return on many different levels both scientific and financial whilst at the same time securing the health and safety of crew members. The Energy experiment, which started with André Kuipers in 2012 is such an experiment addressing these issues by helping to determine the energy balance/requirements of astronauts on long-duration space missions.

↑ ESA astronaut André Kuipers with food items on the ISS

This experiment is determining the energy requirements of astronauts during long-term spaceflight by combining cardiopulmonary measurements from astronauts with recorded activity levels and dietary intake, and analyses of biochemical markers. As weightlessness has a negative influence on energy balance/requirements this experiment will be extremely helpful in planning for future human exploration missions.

For such missions outside of low-Earth orbit, the resources that will need to be launched will be much more extensive than for current ISS missions, as the greater timescales involved will drive the need for more crew supplies (food, medical, logistics etc), more propellant, more scientific equipment and samples, and more spare parts. It is obvious considering a maximum launch mass of a vehicle, the more mass you have in one area means the less you have in another and crew food supplies will be an extensive part of initial launch mass.

↑ Food containers for the Energy Experiment

For this reason the Energy experiment is determining the energy balance in astronauts in order to derive an equation for astronaut energy requirements to optimise this area of mission planning for the future by launching sufficient but not excessive food supplies. This optimisation will assist in maximising the amount of scientific supplies and samples that can be launched and hence maximise scientific return from future missions.

Deriving Energy Requirements

On Earth different techniques exist for measuring energy expenditure/production in humans such as indirect calorimetry which measures oxygen consumption (and carbon dioxide production) as energy is released when oxygen combines with carbohydrates, fats, or proteins in the body. This is normally undertaken under laboratory conditions.

↑ Indirect calorimetry undertaken during a bed rest study in 2013

Another method is tracking the excretion of imbibed doubly-labelled water (i.e. containing safe and stable isotopes of hydrogen and oxygen) from the body. The labelled oxygen is removed from the body in the form of water and carbon dioxide, the labelled hydrogen only in the form of water. The difference between the loss of hydrogen and the loss of oxygen provides a measure of carbon dioxide fluctuation. This can be used to calculate energy expenditure and can be carried out during normal activities.

This second method is being utilised in orbit for the Energy experiment. A start point in calculation is splitting energy expenditure into three component parts: the Resting Metabolic Rate, Diet Induced Thermogenesis, and Physical Activity. The first part is the minimum amount of energy the body requires at complete rest. The second is the amount of energy used in the digestion, absorption and transportation of nutrients around the body and accounts for about 10% of total energy intake in humans on Earth. The final part includes the additional energy expenditure above the first two components due to physical activity. These three components added together provide the total energy expenditure.

↑ The Waste and Hygiene Compartment in the US Orbital Segment of the ISS. Urine from the Compartment is processed through the Water Recovery System Racks to reclaim water

On Orbit

The experiment started on orbit in May 2012 with André Kuipers as the first test subject (and Don Pettit as the control subject). Kuipers wore an activity sensor armband for the duration of the 11-day experiment to measure physical activity. He consumed dedicated food on the first day of the experiment and a baseline drinking water sample was taken from the Potable Water Dispenser (from which Kuipers and Pettit drank for the duration of the experiment). The two astronauts also had to use the Waste and Hygiene Compartment in ISS Node 3 (in order to more efficiently track excreted hydrogen/oxygen) as the

↑ JAXA astronaut Aki Hoshide conducting an Oxygen Uptake Measurement as the 2nd test subject of the Energy experiment in the Columbus laboratory of the International Space Station on 6 October 2012

↑ The SpaceX-1 Dragon spacecraft landing module shortly after arriving at a port near Los Angeles on 30 October 2012 following splashdown in the Pacific Ocean. Samples for André Kuipers for the Energy experiment were on board

Water Recovery Racks in Node 3 reclaim water from urine from the Waste and Hygiene Compartment which is processed into drinking water which is dispensed through the Potable Water Dispenser.

On the second day a baseline urine sample was provided by Kuipers prior to imbibing a Double Labelled Water isotope. Oxygen Uptake Measurements were undertaken on Kuipers at rest using the ESA/NASA Pulmonary Function System in Columbus in order to measure the Resting Metabolic Rate. The Pulmonary Function System analyses exhaled gas from astronauts' lungs to provide near-instant data on the state of crew health.

After consuming a dedicated breakfast Kuipers carried out additional Oxygen Uptake Measurements to measure Diet Induced Thermogenesis and thereafter to measure energy expenditure due to physical activity. He also provided additional urine samples (along with Pettit) to determine what level of Double Labelled Water is directly excreted from the body. For the remainder of the 11-day period, Kuipers logged his dietary intake (daily) and provided urine samples every other day (along with Pettit) and water samples were taken.

The urine samples from Pettit will be used to correct for recycling of Double Labelled Water through the Water Recovery System (and hence the Potable Water Dispenser). At the end of the experiment period the data gathered will allow for the determination of Kuipers Total Energy Expenditure which will in turn allow for the calculation of the Activity Energy Expenditure. These results can then be compared with the activity sensor data and help with deriving an equation for the energy requirements of astronauts.

With completion of on-orbit activities by Kuipers, the Energy experiment has been subsequently carried out by three more astronaut test subjects on the ISS. JAXA astronaut Akihiko Hoshide completed the experiment in October 2012 and NASA astronaut Tom Marshburn and CSA astronaut Chris Hadfield both completed 11-day sessions of the experiment in April 2013. These sessions followed the same protocol as Kuipers (though with no control subject as recycling levels had already been calculated from Pettit).

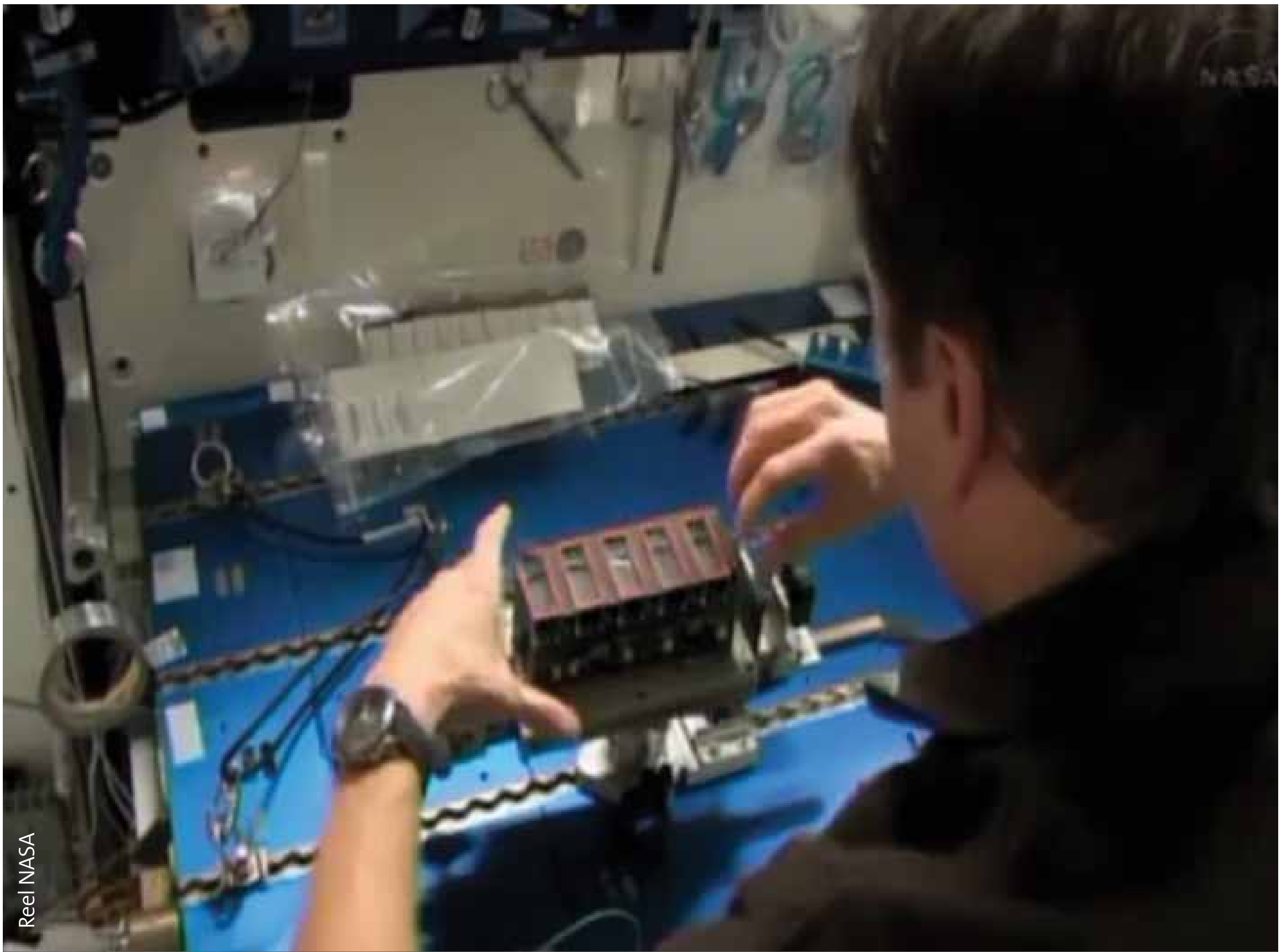
Water and urine samples for the Energy experiment for ESA astronaut André Kuipers (as the first test subject) and for NASA astronaut Don Pettit (as the control subject) were returned to earth on the SpaceX-1 Dragon spacecraft, which splashed down in the Pacific on 28 October 2012, with the samples arriving in Europe a few days later. Samples for Hoshide were returned on SpaceX-2 which splashed down at the end of March 2013.

With the first four subjects (and one control subject) complete, another five test subjects are required to complete the experiment. The next planned test subject is ESA astronaut and Expedition 36/37 crew member Luca Parmitano who was launched to the ISS at the end of May.

↑ ESA astronaut Luca Parmitano who will become the next test subject of the Energy experiment

→ GROWING COOPERATION IN BIOLOGY RESEARCH:

First 'Seedling Growth' Experiment Completed on the ISS

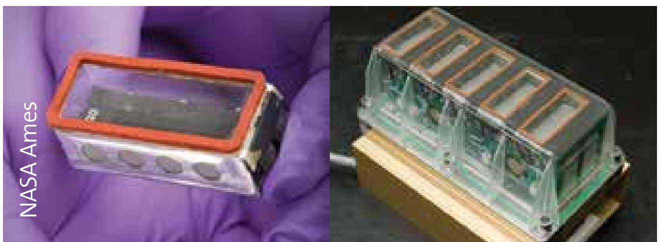


↑ Processing of the sample cassettes on the ISS for the Seedling Growth 1 experiment

The first part of the joint ESA/NASA Seedling Growth experiment came to a successful conclusion on the ISS in May 2013 following processing in the European Modular Cultivation System in ESA's Columbus Laboratory. This not only aims at improving our knowledge of plant growth processes in space and on Earth, but also provides another positive example of the increasing cooperation that exists between ESA and the ISS Partner Agencies.

The evolution of life on Earth has taken place within an environment where gravity is omnipresent. Living organisms have adapted to its presence and accommodated this variable in both their structure and their function. In particular, plants have evolved highly sensitive and selective mechanisms that detect and respond to gravity changes. Gravity plays a central and very important role during plant growth because it stimulates a negative response in the shoot that orientates it towards the source of light, and a positive response in the root that causes it to grow down into the soil, thus providing support and nutrient acquisition.

Plants have an important task in space missions, thanks to their ability to provide fresh food, to recycle carbon dioxide



↑ Examples of hardware from Tropi experiment, also used for Seedling Growth experiment. Left: Seed Cassette. Right: Seed Cassettes and experiment hardware inside a European Modular Cultivation System experiment container into breathable oxygen and to process wastes. This ability may support astronauts who will live in space for months at a time. Understanding how plants can adapt to micro- and low-gravity environments will help researchers to provide a complete and sustainable human life support in space. This insight also may lead to significant advances in agriculture on Earth, as researchers continue to gain new knowledge of how plants grow and develop at a molecular level.

↑ Dwarf (top) and normal (bottom) Arabidopsis plants

“Seedling Growth” is a shining example of research based on a fruitful ESA-NASA collaboration and initiative, as it originated from the merging of two independent proposals selected from International Announcement of Opportunity published in 2009. The scientific Principal Investigators are the European scientist Dr. F.J. Medina from the Centro de Investigaciones Biológicas (CIB-CSIC) in Madrid (Spain), coordinating a Spanish-French team involving three different laboratories, and the US scientist Prof. John Z. Kiss from the University of Mississippi. The collaboration between ESA and NASA not only provides a positive symbol of cooperation on such scientific research ventures, it also helps to optimise on-orbit (crew/facility time etc) and ground resources which have positive financial implications, as well as helping to expand the knowledge base focussing together on specific research activities.

↑ Seedling Growth experiment equipment and samples were launched to the ISS on SpaceX-2 shown here during berthing manoeuvres with the ISS on 3 March 2013

The Seedling Growth experiment is divided into three parts, each one involving a separate spaceflight. Each part is composed by a number of runs, varying from two to four. Seedling Growth builds on previous space flight experiments with Arabidopsis thaliana seeds and studies the effects of various gravity levels on the growth responses of plant seedlings (roots and shoots; wild type and mutants).

The experiment equipment and samples for the first part (Seedling Growth-1) were launched on the SpaceX-2 spacecraft on 1 March 2013 (arriving at the ISS two days later). Following the installation of the experiment containers in the European Modular Cultivation System in Columbus, the experiment started on 21 March. For the first four runs similar procedures were followed. Ground commanding hydrated the seeds in the experiment containers to start the experiment run and hereafter the seeds were kept at 1g (on a centrifuge) with white light for 4 days to allow them to germinate and grow. On the fifth day, the centrifuge was either stopped (0g for run 1) or

↑ Top: Exchange of Experiment Container in the European Modular Cultivation System on the ISS during Expedition 14. Bottom: Tropi experiment container shown stimulating Arabidopsis seedlings with blue and red light

slowed (0.1g for run 2, 0.3g for run 3, 0.8g for run 4) to expose the seedlings to differing gravity levels, and at the same time, providing photostimuli (either red or blue light from the side) for 2 days whilst observing seedling growth. The fourth run of Seedling Growth run was successfully completed by 24 May. For each run, once completed the samples were placed in one of the MELFI freezer units. These samples will remain on orbit until their return on the SpaceX-3 spacecraft at the end of the year.

Once on ground the samples will be sent for genomic analysis at the science team laboratories. The next parts of the experiment (Seedling Growth-2 and Seedling Growth-3) are foreseen to be flown in 2014 and 2015. The experiment specific equipment used throughout this project derives from the "Tropi" experiments (Tropi-1, STS-121 and Tropi-2, STS-130). Since this hardware was not developed to perform chemical fixation inside the seed cassettes, a new complementary device called the "Fixbox" is being developed by ESA with this purpose to be used during Seedling Growth-3, allowing for post-flight analysis with microscopy techniques using both confocal and electron microscopes.
In previous experiments, Dr. Kiss obtained interesting results about the photoreceptors responsible for the Arabidopsis seedlings growing in the direction of the light source when grown in microgravity. Additionally, the growth, development, and the light-sensing curvature of plants in the response to varying qualities of light were analysed. It is thought that red light sensing, known in more primitive plant phyla, is masked by normal Earth gravity (1g) conditions in higher plants. It is also proposed to investigate the fundamental interactions between red and blue light signal pathways, and how they are affected by gravity, as those signal pathways are vital to the regulation of cell growth and proliferation.

Seedling Growth-1 and part of the Seedling Growth-2 focus on the signal transduction phase, or how the plant cells react to light. Furthermore, the interaction between the red and blue light signalling pathways is investigated by using mutants with modified auxin hormone characteristics in the sensing pathways in the last run of Seedling Growth-2 and in Seedling Growth-3. The contribution of the light stimuli to the regulation of cell growth, and proliferation, is evaluated by further analysis. Additionally, with the use of the European Modular Cultivation System, it is possible to compare how the light receptors of the plants are influenced by fractional gravity, as the European Modular Cultivation System has a variable speed centrifuge that simulates the reduced or fractional gravity levels that can be found on the Moon and Mars.

The successful conclusion of Seedling Growth 1 bodes well for the two future experiments in the Seedling Growth experiment series. The results of this research will build on previous research in this area, improving our understanding of plant development mechanisms to provide insights into the cultivation of plants during space flight on long-term missions and improving crop production and agricultural yields on Earth.

CONTACT

ESTEC
The Netherlands
+31 71 565 3597
HSO.Science.Newsletter@esa.int

EDITORIAL TEAM

Chief Editor: Martin Zell
Head of the ISS Utilisation and Astronaut Support Department
Editor: Jon Weems
Designer: Karen Oldenburg

An ESA Human Spaceflight and Operations Production

This science newsletter has been compiled, and written by the ISS Utilisation and Astronaut Support Department of ESA's Directorate of Human Spaceflight and Operations with layout and production undertaken by the Promotion Office of ESA's Directorate of Human Spaceflight and Operations. It has been compiled from internal ESA sources. Unless otherwise stated images have been supplied by ESA and NASA.