The dawning of a new age of research…

International Space Station

Research Results Accomplishments: An Analysis of Results from 2012-2014 Addendum – October 2016

POCKOCMOC

International Space Station Research Results Accomplishments: 2012-2014

FOREWARD

In 2016, the International Space Station (ISS) partnership published the first-ever compilation of international ISS research publications resulting from research performed on the ISS through 2011. The *International Space Station Research Accomplishments: An Analysis of Results From 2000-2011* is a collection of summaries of over 1,200 journal publications that describe ISS research in the areas of biology and biotechnology; Earth and space science; educational activities and outreach; human research; physical sciences; technology development and demonstration; and, results from ISS operations.

The office of the ISS Program Scientist continues to capture and consolidate results among the ISS international partnership, and are reflected in this addendum to the original publication, as of October 1. However, still in work (and thus not reflected here) are several results summaries provided by our ISS partner, Roscosmos. Due to the large number of summaries received, Roscosmos results summaries will be posted in the January 2017 release of *International Space Station Research Accomplishments: An Analysis of Results Through 2016*

MEDAKA OSTEOCLAST

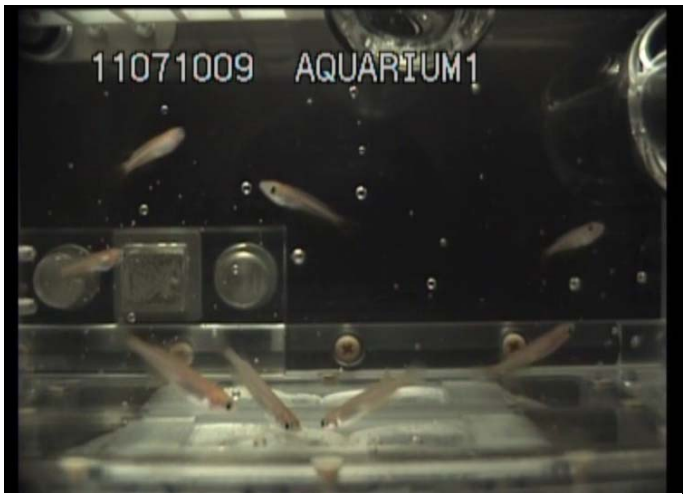
Research Area: Biology and Biotechnology: Animal Biology – Vertebrates
Expedition(s): 33 – 36
Principal Investigator(s):
- Akira Kudo, PhD, Tokyo Institute of Technology, Tokyo, Japan

RESEARCH OBJECTIVES

Enhancement of the activity of osteoclasts (bone resorbing cells) is assumed to cause the decrease of bone mineral density in space. Since medaka fish are a model animal for the life science research, the Medaka Osteoclast investigation studies possibly reveal the effects of microgravity on the activity of osteoclasts and the gravity sensing system of the vertebrate using medaka fish on board the ISS.

EARTH APPLICATIONS

Patients on bed rest, which causes limited mobility, and other patients with age-related osteoporosis suffer from loss of bone density. Results from Medaka Osteoclast can provide the data that may be used to develop new drugs and treatments for these patients.



Video Screen Shot of Medaka in the Aquatic Habitat onboard the ISS. Image courtesy of JAXA.

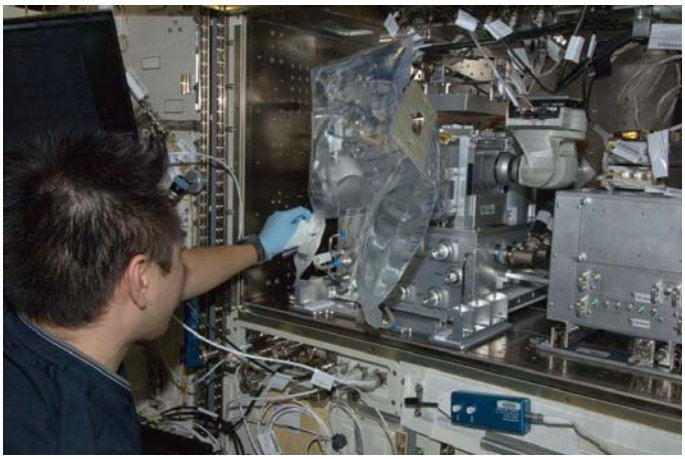
SPACE APPLICATIONS

Results from Medaka Osteoclast can provide insight into the molecular mechanism underlying loss of bone density during spaceflight. Using this information, scientists may be able to develop more effective countermeasures for clarifying the new mechanism of bone loss on future space missions.

RESULTS

Japanese medaka is a vertebrate fish species commonly used for scientific researches, because they are smaller than zebrafish in the genome size, can live in a much smaller area, and consume less food, water, and oxygen. This and the fact that the species have mated successfully in space make them ideal for raising from juvenile to adult in the Aquatic Habitat (AQH) system under the microgravity environment of the International Space Station (ISS). Scientists study the cellular activities of bone formation and resorption in the gravity sensitive pharyngeal region of medaka, which contains hundreds of teeth in the adult fish and where many osteoclasts (cells that break down bone tissues) are found. Observation shows the fish becoming accustomed to life under microgravity by displaying unique behaviors such as upside-down, vertical, and tight-circle swimming. In addition, it is found that the mating behavior at day 33 under microgravity is not different from that on earth. Interestingly, they tend to

become motionless at day 47, suggesting reduced muscle movement. Tooth development in terms of tooth germ formation is normal in the flight group. During 56 days in microgravity, the mineral density of the upper pharyngeal bone and the tooth region decreases about 24%, along with an increase in osteoclast volume compared to ground control fish. Taken together, results indicate impaired physiological function and reduced mechanical use of the body under microgravity, as well as osteoclast activation as an effect of stress caused by weightlessness. One study also examines the ovary, intestine, testis, liver, brain, and eyes, and focuses on the biological impact microgravity effecting on these fish organs. The analysis of 5345 genes from the six tissues reveals similar but highly tissue-specific changes. Eleven genes are up-regulated (the process by which a cell increases the quantity of a cellular component, such as RNA or protein, in response to an external stimulus-the opposite to down-regulation) in more than four of the tissues examined, indicating presence of the common immune system and stress responding to spaceflight. A few genes in the brain and eyes show response to the space environment. By contrast, more than 2,500 genes change their expression levels in the caudal (near the tail) part of the intestine, suggesting that this organ is highly sensitive to microgravity stress. Many genes are down-regulated in the liver without accompanying tissue abnormalities. No significant alterations in gene expression levels (i.e., more than a twofold difference) are detected in the ovary. However, expression levels of genes for egg envelope proteins are suppressed in the ovary, and oogenesis (creation of eggs) is slightly disrupted in space fish, even though body growth and maturation are not delayed. For the testis, structures such as spermatocytes, spermatids, and spermatozoa are similar between the flight and ground groups, suggesting that normal spermatogenesis is maintained during spaceflight. These results shed light on the mechanism underlying the regulation of bone physiology and organ tissue changes under microgravity.



JAXA astronaut Akihiko Hoshide assembling the Aquatic Habitat (ISS033E016607).

PUBLICATION(S)

Chatani M, Mantoku A, Takeyama K, Abduweli D, Sugamori Y, et al. Microgravity promotes osteoclast activity in medaka fish reared at the international space station. *Scientific Reports.* 2015 September 21;5(14172). doi: 10.1038/srep14172.

Murata Y, Yasuda T, Watanabe-Asaka T, Oda S, Mantoku A, et al. Histological and transcriptomic analysis of adult Japanese medaka sampled onboard the International Space Station. *PLOS ONE*. 2015 October 1;10(10): e0138799. doi: 10.1371/journal.pone.0138799.

This investigation is complete; however additional results are pending publication.

MicroRNA Expression Profiles in Cultured Human Fibroblasts in Space (Micro-7)

Research Area: Biology and Biotechnology: Cellular Biology
Expedition(s): 39 and 40
Principal Investigator(s):
- Honglu Wu, PhD, Johnson Space Center, Houston, TX

Research Objectives

The majority of cells in the human body are non-dividing cells that provide critical functions, from blood cells, to cells in different organs. Micro-7 studies how microgravity affects the genetic expression and physical shape of these types of cells for the first time. Understanding how these cells function in microgravity is a step toward understanding how organs, tissues, and the entire body change during spaceflight.

Earth Applications

Understanding the differences between cells' genetic expression on the ground and in microgravity can provide new insights into genetic regulation and signaling pathways. Micro-7 aims to explain the role of micro-RNA, a type of molecule involved in how genetic information is processed in a cell. Micro-RNA might be important in regulating how cells respond to the space environment, and data from Micro-7 could be compared with ground-based data to provide insight into miRNA's role in gene regulation. Understanding fundamental molecular processes in cells could provide new pathways for disease treatment, including potential new pharmaceutical products.

ISS crewmember Rick Mastracchio processes a Micro-7 BioCell Habitat with use of a Fixation Kit (ISS039E018752).

Space Applications

Human tissues and organs are made of non-dividing but functional cells. According to Earth-based experiments, non-dividing cells' genetic expression and micro-RNA profiles change in response to simulated microgravity. Micro-7 is the first space experiment to directly investigate how microgravity affects the gene expression and physical shape of fibroblasts, which are common tissue cells. Fibroblasts are critical for wound healing and tissue structure, so understanding how they function in space could provide crucial insight for future space missions.

Results

Among space radiation and other environmental factors, microgravity is undoubtedly the most significant stress experienced by living organisms during spaceflight and has been shown to influence gene expression (the making of useful products in the body to maintain life) patterns and protein levels in lab-grown cells. Early space studies with human fibroblasts (connective

tissue) have identified genes whose expression levels were modified as a result of spaceflight, but it was not known whether non-dividing cultured cells respond to the absence of gravity as well. In an experiment conducted onboard the International Space Station (ISS), growth inhibited human fibroblast cells were grown in space for 3 and 14 days, respectively, to investigate changes in gene and microRNA, or "miRNA," which are non-coding RNAs that play key roles in the regulation of gene expression in cells. Results of the experiment showed that on day 3, both the flown and ground cells were still growing slowly and the genetic changes seen with these cells were not space induced but related to cell growth. On day 14, when the cells had mostly stopped dividing and were in a resting state, the gene and miRNA expression profile of the flight sample was indistinguishable from that of the ground sample. Analysis of cytoskeletal (filaments and tubules within the cell) changes showed no difference between the flown and ground samples. Although the cells seem to multiply faster in space than they did on the ground, data suggest that in true non dividing human fibroblast cells in culture, microgravity has little effect on their gene and miRNA. This finding may provide a partial explanation for the different responses to microgravity between cells in the body and cells in culture since cells in living organisms in the true microgravity environment still experience mechanical forces from varying blood pressures that cells in culture do not experience.

PUBLICATION(S)

Zhang Y, Lu T, Wong M, Wang X, Stodieck LS, Karouia F, Story M, Wu H. Transient gene and microRNA expression profile changes of confluent human fibroblast cells in spaceflight. *FASEB: Federation of American Societies for Experimental Biology Journal.* 2016 February 25; epub: fj.201500121. doi: 10.1096/fj.201500121.

This investigation is complete; however additional results are pending publication.

NanoRacks CellBox Effect of Microgravity on Human Thyroid Carcinoma Cells (NanoRacks CellBox Thyroid Cancer)

Research Area: Biology and Biotechnology: Cellular Biology
Expedition(s): 39 and 40
Principal Investigator(s):
- Daniela G. Grimm, MD, Institute of Biomedicine, Aarhus University, Aarhus Denmark

Research Objectives

Finding new treatments for cancer requires detailed studies of tumor cells, but when cells are grown in a lab on Earth, gravity affects the way they grow and the shapes they take. NanoRacks-CellBox-Effect of Microgravity on Human Thyroid Carcinoma Cells (NanoRacks-CellBox-Thyroid Cancer) studies thyroid cancer cells in microgravity, which enables cells to grow in spheres or in single layers. These unique views of cell structure will be used to look for new biomarkers, which can be used to develop new drugs to treat thyroid cancer.

Earth Applications

Thyroid cancer is the fastest-increasing cancer in the United States, mostly because new technology is allowing doctors to find it more easily, according to the American Cancer Society. Results from this investigation may reveal new biological markers for thyroid cancer, which could be used to develop new drugs to treat it.

Cell suspensions prepared in six spaceflight experiment containers flown to the ISS. Image Daniela Grimm.

Space Applications

Certain cell receptors and cell signaling mechanisms work differently in space, which affects how cancer cells grow. Microgravity enables cells to form three-dimensional clumps, which can be used to study tumor formation and to search for biological markers. These methods for studying cancer would not be possible in Earth's gravity, making the International Space Station a unique laboratory for studying cancer.

Results

In microgravity, many types of cells grow as a cluster of round cells rather than a sheet of flat cells as on earth. In an attempt to understand this behavior, scientists investigate the protein content and growth pattern of cells grown in both environments. Surprisingly, human thyroid cancer cells samples returned from the International Space Station (ISS) show no visual physical differences from the ground-control cultures. Protein analysis did not indicate significant differences between cells exposed to microgravity and their 1g controls, but suggest that an enhanced production of proteins surrounding the cells and a membrane protein caveolin-1, could possibly prevent them from spheroid formation. It is hypothesized that the unexpected result of the thyroid cancer cells not forming spheroids during their stay on the ISS is very likely due to a launch delay. The prolonged pre-incubation of the cells increases extracellular matrix

(ECM) proteins. It appears likely that a firm anchorage of ECM proteins in the cellular sheet could prevent spheroid formation. At the moment, it is not certain whether the observation is due only to a high cell density or also to up-or down-regulated cell components during the extended incubation period on ground. This finding is of high interest, because it shows possibilities to modify the effects of microgravity and may also explain why the formation of tubes surrounded by a single cell wall is delayed. Future comparative studies on cancer cells, which do or do not form spheroids when exposed to microgravity, may help to identify those proteins that trigger cellular alterations under microgravity.

PUBLICATION(S)

Riwaldt S, Pietsch J, Sickmann A, Bauer J, Braun M, et al. Identification of proteins involved in inhibition of spheroid formation under microgravity. *Proteomics*. 2015 September;15(17):2945-2952. doi: 10.1002/pmic.201500067.

Riwaldt S, Bauer J, Pietsch J, Braun M, Segerer J, et al. The importance of Caveolin-1 as key-regulator of three-dimensional growth in thyroid cancer cells cultured under real and simulated microgravity conditions. *International Journal of Molecular Sciences.* 2015 November 30;16(12): 28296-28310. doi: 10.3390/ijms161226108.

This investigation is complete; however additional results are pending publication.

In situ Observation of Growth Mechanisms of Protein Crystals and Their Perfection under Microgravity (Nano Step)

Research Area: Biology and Biotechnology: Macromolecular Crystal Growth
Expedition(s): 31 – 34
Principal Investigator(s):
- Katsuo Tsukamoto, PhD, Tohoku University, Sendai, Japan

Research Objectives

The In-situ Observation of Growth Mechanisms of Protein Crystals and their Perfection under Microgravity (Nano Step) investigation aims to clarify the relationship between crystal growth mechanism, surface morphology, and the perfection of crystals. Crystallization of proteins in microgravity yields crystals with better perfection than crystallization on Earth. The reason for this phenomenon has not been explained from a viewpoint of crystal growth mechanism.

Earth Applications

The understanding of crystal growth mechanisms will increase the perfection of various crystals and benefit the people on earth.

Space Applications

This experiment will increase the efficiency of protein crystal growth experiments in microgravity.

Japan Aerospace Exploration Agency astronaut Aki Hoshide,Expedition 33 flight engineer,services the Nano Step investigation (ISS033E007362).

Results

Laser interferometers have for the first time been employed in ISS to measure the growth rate of lysozyme crystals versus the driving force, supersaturation of solution to investigate the difference of crystal growth mechanisms in gravity and under microgravity. The Nano Step experiment revealed that space grown lysozyme crystals grow faster (!) than the Earth-grown crystals by 30-50%. This result completely conflicts with a preexisting assumption; “space-grown crystals are better because they grow slower under convection-free environment.” This faster growth in space was kinetically analyzed due self-purification of impurities during growth coupled with a reduction of an impurity mediated crystal growth mechanism.

Publication(s)

Fujiwara T, Suzuki Y, Yoshizaki I, Tsukamoto K, Murayama K, et al. Correction of the equilibrium temperature caused by slight evaporation of water in protein crystal growth cells during long-term space experiments at International Space Station. *Review of Scientific Instruments.* 2015 August;86(8): 083704. doi: 10.1063/1.4928491

Suzuki Y, Tsukamoto K, Yoshizaki I, Miura H, Fujiwara T. First direct observation of impurity effects on the growth rate of tetragonal lysozyme crystals under microgravity as measured by

interferometry. *Crystal Growth and Design.* 2015 August 31;15(10): 4787-4794. doi: 10.1021/acs.cgd.5b00456.

This investigation is complete; however additional results are pending publication.

NanoRacks Protein Crystal Growth – 1 (NanoRacks-PCG-1)

Research Area: Biology and Biotechnology: Macromolecular Crystal Growth

Expedition(s): 33 – 36

Principal Investigator(s):

- Carl W. Carruthers, Jr., PhD, NanoRacks, Webster TX

Research Objectives

NanoRacks-Protein Crystal Growth-1 (NanoRacks-PCG-1) is a proprietary protein crystal growth experiment that utilizes state-of-the-art on-the-ground PCG procedures and hardware.

Earth Applications

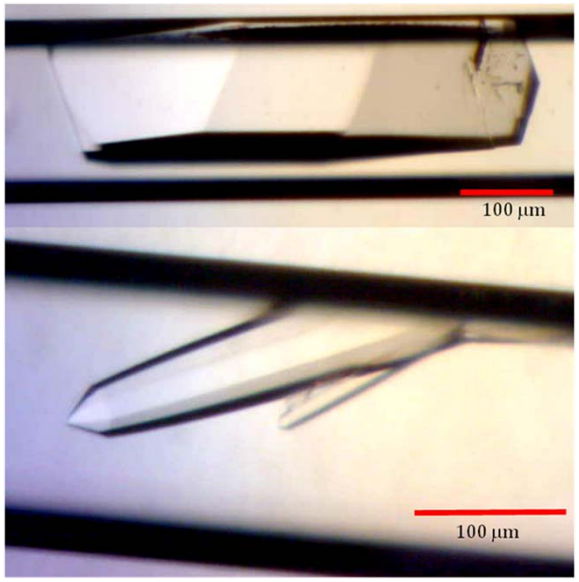
The applications of this investigation are proprietary.

Space Applications

The applications of this investigation are proprietary.

Results

The goal of this investigation is to grow protein crystals in space using a commercial off-the-shelf (COTS) high throughput method. Twenty five (25) CrystalCards™ are sent to the International Space Station (ISS), containing approximately 10,000 individual microgravity protein crystal growth (PCG) experiments housed in a 3U (10X15X20 cm) NanoRacks NanoLab™ - small cube modules that house science experiment on ISS. After 70 days on the ISS, returned cards show 16 of 25 (64%) having crystals, compared to 12 of 25 (48%) of the ground controls. Encouragingly, there are more crystals of apohPPAR-γ LBD (a protein which regulates glucose metabolism and production of fat cells) in the microgravity PCG cards than the ground controls cards. The experiment uses only a small quantity of seed protein of apohPPAR-γ LBD, as well as several PCG standards, to test hundreds of microgravity crystal growth conditions. Using CrystalCards™ also alleviates fluid containment difficulties with typical microgravity PCG experiments and the required layers of biohazard safety restriction on ISS. In addition, retrieval of crystals is easily performed by removing the card seal, or if the analyst desires, X-ray diffraction tests can be performed while the crystal stays in the card. With planned enhancements such as active temperature control and automated documentation systems, this method may provide new opportunities for researchers to use microgravity protein crystal growth as a tool for creating improved or novel models. Future research is needed to ensure that microfluidic devices like CrystalCards™ can consistently produce better crystals and good yield in microgravity, or even possibly enhance PCG technology.



Lysozyme (above) and Thermolysin (below) crystals grown in microgravity on the ISS. In collaboration with Carl Carruthers at Houston Methodist Research Institute, NanoRacks developed a new method of growing microgravity protein crystals, allowing researchers the possibility to grow more crystals with very little protein. Image courtesy of Carl Carruthers.

PUBLICATION(S)

Carruthers, Jr. CW, Gerdts C, Johnson MD, Webb P. A microfluidic, high throughput protein crystal growth method for microgravity. *PLOS ONE*. 2013 November 21;8(11): e82298. doi: 10.1371/journal.pone.0082298.

This investigation is complete; however additional results are pending publication.

NanoRacks Comparison of the Growth Rate and DNA Characterization of Microgravity Exposed Microbial Community Samples (NanoRacks-Project MERCCURI)

Research Area: Biology and Biotechnology: Microbiology
Expedition(s): 39 and 40
Principal Investigator(s):
- Jonathan Eisen, PhD, University of California Davis, Davis, CA,

Research Objectives

Microbial communities differ among people, buildings, cities and countries, even the International Space Station (ISS), and these differences can affect human health. NanoRacks-Comparison of the Growth Rate and DNA Characterization of Microgravity Exposed Microbial Community Samples (NanoRacks-Project MERCCURI) engages members of the public to collect samples from high-touch surfaces around the United States, from stairs at sports venues to hand railings at schools, and sends them to space to compare how various microbial communities grow on the ground and in microgravity. The investigation also studies the microbes found on high-touch surfaces on board the ISS.

Darlene Cavalier, the founder of Science Cheerleaders, swabs the crack in the Liberty Bell to collect microbes for NanoRacks-Comparison of the Growth Rate and DNA Characterization of Microgravity Exposed Microbial Community Samples (NanoRacks-Project MERCCURI). Microbiologists at the University of California, Davis cultured Bacillus megaterium from this swab, and are using it for an experiment aboard the ISS. Image courtesy of National Park Service.

Earth Applications

Citizen scientists collect microbe samples to be flown in space, in coordination with education programs facilitated by SciStarter.com, ScienceCheerleader.com, and their partners. Participation in the experiment exposes members of the public to basic information on microbial communities and microbiology, as well as the space program. Researchers also aim to convey that microbes are everywhere and can be beneficial as well as harmful to human health. The investigation paves the way for future advanced biology and pharmaceutical research in microgravity, as well as possible new treatments for diseases.

Space Applications

Many microbes grow differently in space, forming thick biofilms and reproducing faster. Examining how space flight affects microbe growth provides new insights into how gravity, fluid dynamics, and nutrient availability affect biofilm formation. The investigation also collects microbe samples from the ISS, which undergo DNA sequencing and growth analysis once they return to Earth. Understanding microbial communities on the station, and how they grow differently in microgravity and on the ground, helps researchers develop antibiotic countermeasures to safeguard crew health in space.

RESULTS

It has been determined that the interior of the International Space Station (ISS) has a microbial community similar to the inside of buildings on Earth. Previous work growing bacteria in space has focused on species known to cause illness such as *E. coli*, *Salmonella*, and *Pseudomonas aeruginosa,* and less attention has been paid to the harmless microbes around us. Although concern about pathogens in spacecraft is very important, it should be emphasized also that the ability of a pathogen to survive outside a host and to infect are both dependent, at least in part, on the co-existing community of benign microbes. This study, part of Project MERCCURI (Microbial Ecology Research Combining Citizen and University Researchers on ISS), takes samples, usually with collaboration of the public, from human-associated surfaces (e.g., toilets, doorknobs, railings, floors, etc.) at a variety of locations around the United States. A wide variety of bacteria were cultured from these samples, and 48 harmless strains were selected for comparing growth on the ISS versus on Earth. The vast majority of species tested in this experiment have also been found previously from environmental surveys of the ISS. Of the 48 strains sent to the ISS, 45 of them showed similar growth. Only three bacteria showed a difference: *Bacillus safensis*, *Bacillus methylotrophicus*, and *Microbacterium oleivorans*, and only one strain showed significantly different growth in space. Bacillus safensis grew 60% better in space than on Earth. Further work on *Bacillus safensis* could lead to interesting insights on why this strain grew so much better in space.

PUBLICATION(S)

Coil DA, Neches RY, Lang JM, Brown W, Severance MT, et al. Growth of 48 built environment bacterial isolates on board the International Space Station (ISS). *PeerJ.* 2016 March 22;4: e1842. doi: 10.7717/peerj.1842.

This investigation is complete; however additional results are pending publication.

BIOLOGICAL RESEARCH IN CANISTERS – 17 – 2: UNDERSTANDING ANOXIC RESPONSE IN ARABIDOPSIS (BRIC-17-2)

Research Area: Biology and Biotechnology: Plant Biology
Expedition(s): 33 and 34
Principal Investigator(s):
- Simon Gilroy, PhD, University of Wisconsin, Madison, WI, United States

RESEARCH OBJECTIVES

The Biological Research in Canisters (BRIC) hardware supports a variety of plant growth investigations. The Biological Research in Canisters-17-2: Understanding Anoxic Response in *Arabidopsis* investigation focuses on the growth and development of *Arabidopsis* seeds in microgravity. Specimens are preserved with a chemical fixative and returned to the ground for post-flight evaluation.

EARTH APPLICATIONS

As with all basic research, an improved understanding of basic growth phenomena has important implications for improving growth and biomass production on Earth and thus will benefit the average citizen.

SPACE APPLICATIONS

The BRIC-PDFU hardware provides the capability to grow seedlings and cell cultures, deliver water and RNAlater in one piece of hardware without the need for a glovebox. This approach minimizes resources such as volume, mass and crew time.

RESULTS

In preparation for the BRIC-17-2 investigation for flight, several ground studies were conducted. During one of these studies perhaps for the first time, calcium ion flux in plant cells moving in a wave-like manner through a plant's outer root cell layers as a response to saltwater exposure, similar to a signal (action potential) being transmitted along nerve cells in animals (both processes involve ion migration and the opening of ion channels in cellular membrane in response to a stimulus, although nerve transmissions are much quicker) was visually observed. Such propagating Ca^{2+} waves provide a new mechanism for the rapid integration of activities throughout the plant body. These results suggest that, although plants do not have a nervous system, they do possess a sensory network that uses ion fluxes moving through defined cell types to rapidly transmit information between distant sites within the organism.

PUBLICATION(S)

Choi W, Toyota M, Kim S, Hilleary R, Gilroy S. Salt stress-induced Ca2+ waves are associated with rapid, long-distance root-to-shoot signaling in plants. *Proceedings of the National Academy of Sciences of the United States of America.* 2014 April 29;111(17): 6497-6502. doi: 10.1073/pnas.1319955111.

This investigation is complete; however additional results are pending publication.

MOLECULAR BIOLOGY OF PLANT DEVELOPMENT IN THE SPACE FLIGHT ENVIRONMENT (CARA)

Research Area: Biology and Biotechnology: Plant Biology
Expedition(s): 39 and 40
Principal Investigator(s):
- Anna-Lisa Paul, PhD, University of Florida, Gainesville, FL

RESEARCH OBJECTIVES

The Characterizing Arabidopsis Root Attractions (CARA) experiment looks at mechanisms at the molecular and genetic level that influence the growth of a plant's roots in the absence of gravity, and how those change with or without light. Researchers expose one set of seedlings to light, keep another set in the dark, and then examine how each environment influences the patterns of root growth. Some of the plants are also imaged with the Light Microscopy Module on orbit, and at the end of the experiment, all plants are harvested by the astronaut, and preserved for their return to Earth in order to evaluate genes associated with plant responses on orbit.

ISS crewmember Steve Swanson harvests plant specimens from the CARA investigation (ISS039E020887).

EARTH APPLICATIONS

This investigation provides a deeper understanding of the biological response of an organism to a novel environment. Novel environments provide unique insight to how plants can adapt or be adapted to challenging environments on earth, including marginal or reclaimed lands and lands that are recovering from extreme environmental assault such as mining or industrial intrusion.

SPACE APPLICATIONS

CARA provides a deeper understanding of the fundamental mechanisms behind the cell growth patterns of roots growing in a novel environment that, one which lacks the normal stimulus of gravity. This knowledge can contribute to the development of plants that are better adapted to spaceflight and other altered gravity environments – like the moon and Mars. The ability to grow healthier plants in microgravity will make it possible to use them more effectively in future efforts to explore and colonize space. Additionally, the focus of this experiment builds on previous flight data and tests hypotheses that arose directly from earlier ISS experiments of this research team. This cycle of experimentation and hypothesis-driven science is precisely the model on which CASIS and NASA see the utilization of the ISS being built as a scientific laboratory platform.

RESULTS

On Earth, plant growth is primarily guided by light and gravity. Indeed, it has long been thought that for many of the growth patterns exhibited by plant roots, gravity was required. Research

on the ISS has shown that many of these processes are in fact independent of gravity, but scientists are still learning about how plants "know" how to grow without it. Part of this research is investigating how well-characterized plant hormones that function in cell elongation and division – like auxin and cytokinin – work to guide plants in an environment without gravity to act as a cue for where these hormones should be synthesized or repressed. On Earth, auxin (which promotes cell elongation) plays a major role in guiding roots to maintain growth in the direction of the pull of gravity. When a root is growing perfectly vertical (with the tip "down" on Earth) auxin is distributed uniformly through the central region of the root tip, and cell elongation occurs evenly and the root continues its downward growth. However, if the gravity vector is disrupted, as by turning a vertically gown plant on its side, the distribution of auxin shifts so that cell elongation is promoted on the side of the root facing away from the pull of gravity. Those cells elongate until the tip is again pointing down, and the gradient of auxin is again uniformly vertical. Meanwhile, cytokinin is promoting cell division to keep renewing the cells of the root tip as it grows. This scenario describes what happens to the distribution of auxin when the direction of the gravity stimulus is changed on Earth, but what happens if the gravity stimulus is removed all together? Scientists were able to watch the distribution of auxin and cytokinin in roots grown on the ISS by following the distribution of fluorescent markers in real time, the objective being to determine whether gravity plays a direct role in establishing the auxin-mediated gravity-sensing system in primary roots.

The current results are from two independent experiments: CARA (Characterizing Arabidopsis Root Attractions) and APEX-03-2 (Advanced Plant Experiment 03-2), which were each completed at different times aboard the International Space Station (ISS). The fluorescent markers were created by making a "reporter gene" composed of a green glowing gene from a jellyfish linked to either an auxin or cytokinin sensor, and then inserting the reporters into plants. Any cells which were actively using auxin or cytokinin would glow green. Scientists were able to view live the distribution of auxin and cytokinin in growing Arabidopsis thaliana plants on the ISS with the Light Microscopy Module (LMM), a specialized fluorescent microscope on the ISS built specifically to work with samples in microgravity. The images from the plant on orbit were compared with control plants imaged on the ground. In addition, spaceflight-grown plants and their ground controls were preserved and also examined post flight. Results showed that space grown plants displayed the normal ground "vertical" distribution of auxin in the primary root. These data suggest that the establishment of the auxin-gradient system, the primary guide for gravity signaling in the root, is not affected by weightlessness, but rather that auxin gradients in the primary root are fundamentally developmental, and those developmental auxin gradients were then coopted to be sensitive to gravity responses.

However, the cytokinin distribution in the root tip differs between spaceflight and the ground controls, suggesting spaceflight-induced features of root growth may be cytokinin related. Thus, spaceflight appears benign to auxin and its role in the development of the primary root tip, whereas spaceflight may influence cytokinin-associated processes. The role of auxin in structures other than the root tip bears investigation, as auxin-regulated genes are seen to change in expression during spaceflight, when examining the root as a whole, and root appearance is also influenced by spaceflight. The value of the present study is in having cell-

specific visual markers to identify where in the root potential spaceflight auxin-regulated changes do occur.

PUBLICATION(S)

Ferl RJ, Paul A. The effect of spaceflight on the gravity-sensing auxin gradient of roots: GFP reporter gene microscopy on orbit. *npj Microgravity.* 2016 January 21;2:15023. doi: 10.1038/npjmgrav.2015.23

This investigation is complete; however additional results are pending publication.

COMMERCIAL GENERIC BIOPROCESSING APPARATUS SCIENCE INSERT – 06 (CSI-06)

Research Area: Educational Activities and Outreach: Classroom Versions of ISS Investigations

Expedition(s): 37 – 40

Principal Investigator(s):

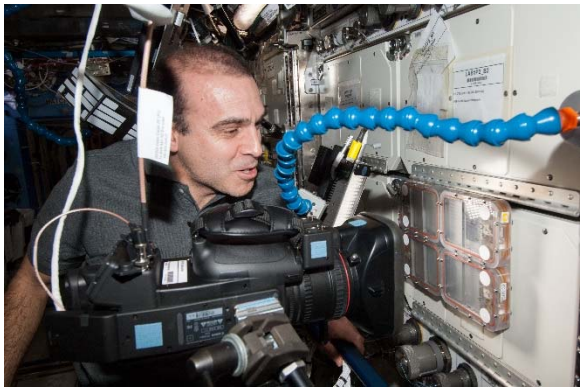
- Deborah Gordon, PhD, Stanford University, Stanford, CA

RESEARCH OBJECTIVES

Commercial Generic Bioprocessing Apparatus Science Insert – 06: Ants in Space (CSI-06) compares behavior differences in groups of ants living in normal gravity and microgravity conditions. It measures how the interactions among ants in a group depend on the number of ants in a given area. These interactions may be important in determining group behavior. Cameras record ants living on the International Space Station, and software analyzes their movement patterns and interaction rates. Students in grades K-12 observe the videos in near real-time as the ISS experiment and conduct their own classroom experiments as part of a related curriculum.

EARTH APPLICATIONS

Ant colonies do not have centralized leaders; instead, ants coordinate their behavior according to cues from nearby ants. This behavior is being used to design computer programs that can control swarms of robots. CSI-06 investigates whether microgravity alters the behavior of ants in a colony. The investigation also provides an opportunity for educators and students in grades K-12 to participate in life science experiments operating on the International Space Station.



ISS crewmember Rick Mastracchio uses a video camera to photograph the Ant Forage Habitat (ISS038E029065).

SPACE APPLICATIONS

The investigation brings information about life science research being conducted by the space program to students in grades K-12, generating interest in science, technology, engineering and mathematics (STEM) fields. Results from CSI-06 could also provide insight into ant behavior or swarm intelligence, or how the simple actions of individuals add up to the complex behavior of a group. Understanding swarm intelligence helps create mathematical procedures for solving complex human problems, such as routing trucks, scheduling airlines, or telecommunications efficiency.

RESULTS

During CSI-06 the ants did not perform collective search as effectively in microgravity as they did in the ground controls. Because ants in microgravity did not use straighter paths or traverse more distance when the area to be searched expanded, they did not search the area thoroughly. In microgravity there were more regions of the arena that were never, or very rarely, visited by any after the barrier was opened, and the mean number of ant visits to each part of the search area was lower than on Earth. On Earth as the area to be searched expanded,

the ants spread out more to cover it; on the ISS the ants did not spread out or spread out much less than they did on Earth. In microgravity the ants tended to traverse less ground and take more convoluted paths when the area to be searched expanded. By repeating this experiment on Earth with different species of ants, we are likely to discover many new distributed algorithms for collective search, and to learn about how evolution has shaped collective behavior in response to local conditions. It would be especially interesting to examine the search behavior of the many tropical ant species whose behavior has never been studied.

PUBLICATION(S)

Countryman S, Stumpe MC, Crow SP, Adler FR, Greene M, Vonshak M, Gordon D. Collective search by ants in microgravity. *Frontiers in Ecology and Evolution*. 2015 March 30; 3(25): 10 pp. doi: 10.3389/fevo.2015.00025.

This investigation is complete; however additional results are pending publication.

NanoRacks – National Center for Earth and Space Science – Aquarius (NanoRacks-NCESSE-Aquarius)

Research Area: Educational Activities and Outreach: Student Developed Investigations

Expedition(s): 31 and 32

Principal Investigator(s):

- Jeff Goldstein, PhD, National Center for Earth and Space Science Education, Ellicot City, MD

Research Objectives

The NanoRacks-National Center for Earth and Space Science Education-Aquarius (NanoRacks-NCESSE-Aquarius) investigation is the result of a commercial Science Technology, Engineering and Math (STEM) education program overseen by the National Center for Earth and Space Science Education (NCESSE), called the Student Spaceflight Experiments Program (SSEP).The payload includes 15 science experiments from 12 school districts across the United States. Student teams design their own experiments using flight approved fluids and materials and are flown in a NanoRacks Module.

Earth Applications

SSEP is about a commitment to student ownership in exploration, to science as journey, and to the joys of learning. For school districts, even individual schools, it provides an opportunity to implement a systemic, high caliber, and historic STEM education program tailored to community need. SSEP is about immersing and engaging students and their teachers in real science, on the high frontier, so that students are given the chance to be scientists, and experience science firsthand.

Space Applications

SSEP is designed to be a keystone initiative for U.S. National STEM education, and to help inspire America's next generation of scientists and engineers. Inspiring the next generation is key to ensuring the future of space flight.

Results

The NanoRacks-NCESSE-Aquarius was a suite of fifteen distinct investigations designed by students across the country utilizing the NanoRacks hardware to perform microgravity investigations onboard the ISS. The investigation titled the Physiological Effects of Microgravity and Increased Levels of Radiation on Wild-Type and Genetically Engineered Caenorhabditis elegans utilized the fluids mixing enclosure (FME), which supports short-duration life science experiments. Unfortunately, due to a flaw in flight procedures the FME was not properly activated. Despite this failure, a valuable lessons learned from this investigation was to create a transparent FME to verify activation for any future experiments.

Publication(s)

Warren P, Golden A, Hanover J, Love D, Shephard F, Szewczyk NJ. Evaluation of the Fluids Mixing Enclosure System for Life Science Experiments During a Commercial

Caenorhabditis elegans Spaceflight Experiment. *Advances in Space Research*. 2013 June; 51(12):2241-2250. doi: 10.1016/j.asr.2013.02.002.

This investigation is complete; however additional results are pending publication.

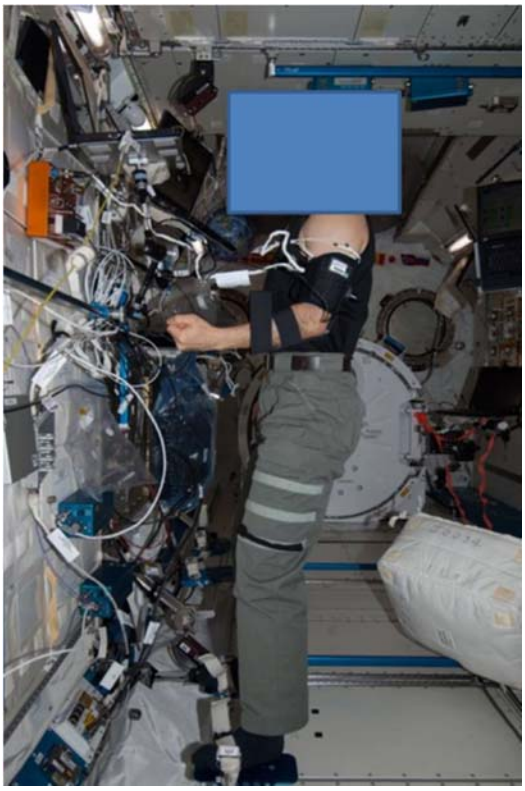
Effect of the hybrid Training Method on the Disuse Atrophy of the Musculoskeletal System of the Astronauts Staying in the International Space Station for a Long Term (Hybrid Training)

Research Area: Human Research: Bone and Muscle Physiology
Expedition(s): 37 – 40
Principal Investigator(s):

- Naoto Shiba, MD, PhD, Kurume University School of Medicine, Fukuoka, Japan

Research Objectives

A "hybrid training" approach has been developed to counter the atrophy of bone and muscle experience by crewmembers aboard the International Space Station (ISS). This novel approach uses the contraction produced by applying electrical stimulation to the opposite muscle which will in turn resist the voluntary contraction of the active muscle. This Effect of the Hybrid Training Method on the Disuse Atrophy of the Musculoskeletal System of the Astronauts Staying in the International Space Station for a Long Term-initial verification in ISS Hybrid Training System (HTS) can be a useful alternative for the standard exercise training device on the ISS. Additionally, there is potential for being a useful training device in smaller spacecraft for exploration class manned missions beyond Low Earth Orbit.



ISS crewmember attached the hybrid trainning system in the ISS for the this experiment. (Courtesy by NASA and JAXA).

Earth Applications

Muscle loss is a serious health issue for the elderly and post-operative patients who are blocked from proper exercise for various reasons. Hybrid activities using exercise plus electrostimulation may prove more valuable than electrostimulation alone for patients and other people with reduced exercise opportunities. Hybrid Training has had promising results in trials after leg surgeries and with Antarctic research teams who have reduced exercise opportunities during the winter.

Space Applications

Muscle atrophy during microgravity has long been recognized as a serious challenge to crew health. While crews exercise regularly each day to counteract its effects, the results are less satisfactory than 1g exercise on Earth. It is hoped that Hybrid Training will stimulate a better response and lead to healthier muscle maintenance while in space.

RESULTS

Results of Hybrid Training showed the orbital operation capability and utility, and the possibility in preventive effect of the hybrid training system (HTS) on an ISS crewmember's musculoskeletal atrophy. Initial flight data together with the ground data obtained to date will be taken to future planning of human space exploration. HTS may be useful in keeping long-duration space explorers fit as they travel beyond low Earth orbit.

PUBLICATION(S)

Shiba N, Matsuse H, Takano Y, Yoshimitsu K, Omoto M, et al. Electrically stimulated antagonist muscle contraction increased muscle mass and bone mineral density of one astronaut - Initial verification on the International Space Station. *PLOS ONE*. 2015 August 21; 10(8): e0134736. doi: 10.1371/journal.pone.0134736.

This investigation is complete; however additional results are pending publication.

SONOGRAPHIC ASTRONAUT VERTEBRAL EXAMINATION (SPINAL ULTRASOUND)

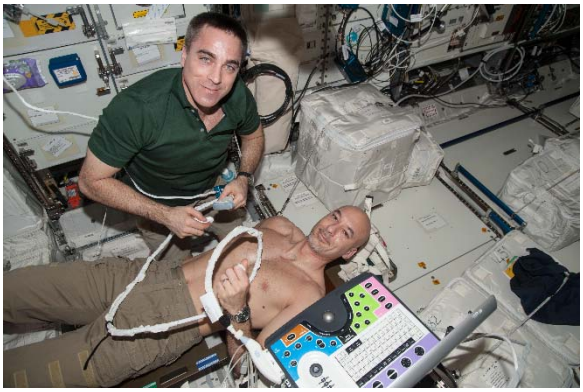
Research Area: Human Research: Bone and Muscle Physiology
Expedition(s): 33 – ongoing
Principal Investigator(s):
- Scott A. Dulchavsky, MD, PhD, Henry Ford Hospital, Detroit, MI

RESEARCH OBJECTIVES

Sonographic Astronaut Vertebral Examination (Spinal Ultrasound) aims to use ground and space-based studies to characterize spinal changes during and after spaceflight. Ground based pre- and post-flight MRI and high fidelity ultrasound, combined with in-flight ultrasound will be used to characterize and assign a mission health risk to microgravity-associated spinal alterations for back pain and potential injury. This research will determine the accuracy of MRI and musculoskeletal ultrasound in characterizing the anatomy of the vertebral unit and develop novel imaging and training methodologies.

EARTH APPLICATIONS

The American Institute of Ultrasound in Medicine issued the following statement on April 6, 2009 concerning non-operative, spinal and paraspinal ultrasound: "There is insufficient evidence in the peer-reviewed medical literature establishing the value of nonoperative spinal/paraspinal ultrasound in adults. Therefore, the AIUM states that, at this time, the use of non-operative spinal/paraspinal ultrasound in adults (for study of intervertebral discs, facet joints and capsules, central nerves and fascial edema, and other su btle paraspinous abnormalities), for screening, diagnostic evaluation, including pain or radiculopathy syndromes, and for monitoring of therapy has no proven clinical utility. Nonoperative spinal/paraspinal ultrasound in adults should be considered investigational. The AIUM urges investigators to perform properly designed research projects to evaluate the efficacy of these diagnostic spinal ultrasound examinations". There has been no pressing need for the use of ultrasound in spinal examination of adults in the standard clinical setting due to the availability of advanced imaging in developed nations and the common agreement that MRI imaging is the preferred method of spinal characterization. Prior to the ground breaking research conducted during the ADUM experiment and working with the ISS lab, there were no peer reviewed journal articles on the use of lung ultrasound for the detection of pneumothorax in clinical evaluation; X-ray and clinical evaluation were the standard. During the ADUM investigation, this investigative team introduced clinical evidence that ultrasound could be used for detection of normal lung function and for the detection of pneumothorax. Today, ultrasound is used for pre-hospital clinics and emergency room settings worldwide.



ISS crewmembers Chris Cassidy and ESA astronaut Luca Parmitano participating in the Spinal Ultrasound investigation (ISS036E035761).

SPACE APPLICATIONS

This project will provide longitudinal, real-time data regarding adaptation of the vertebral unit during long-duration spaceflight that will contribute to countermeasure development, astronaut health, and mission completion. The ability to assess crewmembers' musculoskeletal systems is critical to guide countermeasures, provide functional data for high risk or high impact activities, and assess acute injuries which may occur during exploration class spaceflight or during return to Earth. This project will provide essential data and methods to quantify the risk of spine related complications for crewmembers following long duration spaceflight exposure. Astronaut-performed ultrasound examinations on the ISS have demonstrated that diagnostic quality images can be obtained with targeted training; the procedures developed and verified through this investigation will provide novel capabilities to enhance crew health for long duration space missions.

RESULTS

In remote environments without access to MRI and CT (the mainstream standard in terrestrial care), ultrasound may prove a reasonable choice for a focused examination. The Spinal Ultrasound investigation yielded a reproducible standardized ultrasound technique to visualize the cervical and lumbar vertebrae to evaluate the intervertebral discs and evaluate spine-related complaints or injury. The technique produced consistent results that compare favorably with MRI standards. The remotely guided ultrasound concept, with crew medical officers or comparably trained first responders as operators, is an important and clinically relevant advancement in space medicine; the addition of spinal ultrasound provides an additional tool with profound ramifications for emergency or clinical medicine.

PUBLICATION(S)

Marshburn TH, Hadfield CA, Sargsyan AE, Garcia KM, Ebert D, Dulchavsky SA. New Heights in Ultrasound: First Report of Spinal Ultrasound from the International Space Station. *Journal of Emergency Medicine.* 2014 January; 46(1):61-70. doi: 10.1016/j.jemermed.2013.08.001.

This investigation is ongoing and additional results are pending publication.

SKIN-B

Research Area: Human Research: Crew Healthcare Systems
Expedition(s): 7 and 8
Principal Investigator(s):
- Ulrike Heinrich, University of Witten, Witten Germany Roberto

RESEARCH OBJECTIVES

The Skin-B experiment will improve our understanding of skin aging which is slow on Earth but very much accelerated in space. This will also provide insights into the aging process in other (similar) bodily tissues in general. This could help in determining impact on astronauts on future missions to the Moon and Mars for example where environmental conditions are more challenging.

EARTH APPLICATIONS

The Skin-B investigation aims to clarify how the skin, as model for other organs, alters and if or how quickly a regeneration of the skin takes place. Experimental data gathered on the ISS can be translated in order to provide an insight into the mechanisms by which all organs covered with epithelial and connective tissue adapt and age over time and under the physical stress imposed by the environment. Gaining an understanding of tissues change process should allow for better diagnostic and treatment on ground.

SPACE APPLICATIONS

The Skin-B investigation will contribute to a better understanding of skin aging mechanisms which are slow on Earth (therefore nearly impossible to study efficiently) but very much accelerated in weightlessness. Not only will this provide information on the mechanisms behind how skin adapts/regenerates under the influence of weightlessness and the environmental conditions in spacecraft on long-duration missions, it also provides a model for the adaptive processes for other organs in the body. Furthermore the data gathered will act as a research footprint for comparative purposes with astronauts on future human exploration missions outside of low-Earth orbit where environmental conditions are more challenging.

ISS crewmember Luca Parmitano wears communication headgear while connecting the Skin B instruments (ISS036e034959).

RESULTS

Skin impairments are a frequent health problem during space missions. The Skin B investigation monitored the physiological changes of skin during long duration space flights. An accelerated skin ageing was not observed; however, significant changes of the epidermis as well as of the dermis occurred. In particular, a thinning of the epidermis was observed on ISS crewmembers. The thinning is likely due to a decreased turnover of epidermal cells. That means skin cells may be gravity-dependent. It has been shown that melanocytes are sensitive to gravitational forces,

in particular intracellular cyclic Guanosine MonoPhospate (cGMP). Additional skin measurements on astronauts are required before long-duration space exploration beyond low Earth orbit begins.

PUBLICATION(S)

Konig K, Weinigel M, Pietruszka A, Buckle R, Gerlach N, Heinrich U. Multiphoton tomography of astronauts. Multiphoton Microscopy in the Biomedical Sciences XV. Proceedings of SPIE. San Francisco, California; 2015 March 5. 93290Q. doi: 10.1117/12.2078823

This investigation is complete and all results are published.

BIOCHEMICAL PROFILE (BIOCHEM PROFILE)

Research Area: Human Research: Integrated Physiology and Nutrition
Expedition(s): 37 – ongoing
Principal Investigator(s):

- Scott M. Smith, PhD, Johnson Space Center, Houston, TX

RESEARCH OBJECTIVES

The Biochem Profile experiment tests blood and urine samples obtained from astronauts before, during and after spaceflight. Specific proteins and chemicals in the samples are used as biomarkers, or indicators of health. Post-flight analysis yields a database of samples and test results, which scientists can use to study the effects of spaceflight on the body.

EARTH APPLICATIONS

An improved understanding of the biochemical effects of microgravity could also help patients with limited mobility on Earth, such as those on bed rest. Understanding how various physiological systems respond and interact to changing gravity conditions could help physicians design different treatments or exercises for people with limited mobility.

SPACE APPLICATIONS

The human body changes in various ways in microgravity, and the Biochemical Profile experiment establishes a database of key metabolic differences that can be detected using blood and urine samples. The database will improve efforts to understand and reduce the risks associated with long-duration space missions. Scientists can also test the effectiveness of possible countermeasures like exercise and nutrition, which will improve recommendations for future long-duration and exploration missions. The Biochemical Profile also assesses a broad population of crewmembers for the first time, identifying issues specific to groups like men and women, repeat long-duration travelers and others. Establishing a chemical profile of the body's response to spaceflight will help scientists understand how different systems in the body interact in microgravity in different groups of people.

ISS crewmember Michael Hopkins, Expedition 37 flight engineer, prepares to insert samples into a Minus Eighty Laboratory Freezer for ISS (MELFI) dewar tray in the International Space Station's Destiny laboratory (ISS037E010720)

RESULTS

The Biochem Profile investigation examined many biomarkers in samples collected from ISS crewmembers. Analysis of the bone biochemistry is consistent with previous studies, despite confounding factors, including sex, dietary intake, exercise devices, pharmacological countermeasures, and mission duration, the regulation of bone and calcium homeostasis appears intact. Nutritional support is integral to success of microgravity countermeasures,

although important questions remain about the effect of the exercise-induced remodeling on bone strength and fracture risk.

We know that magnesium is a critical nutrient, with many important functions. On Earth magnesium homeostasis can be altered by disease and medication use, Biochem Profile documents that despite consistent and significant alterations in urinary magnesium after space flight, tissue stores of the mineral are maintained, and inflight data reveal increased serum and urinary magnesium. Thus, there is no general cause for concern about magnesium deficiency in long-duration space explorers. Additional studies are needed to better understand the role of magnesium in long-duration space explorers and to better define the nutritional requirement for magnesium in future space explorers.

PUBLICATION(S)

Smith SM, Heer MA, Shackelford LC, Sibonga JD, Spatz JM, Pietrzyk RA, Hudson EK, Zwart SR. Bone metabolism and renal stone risk during international space station missions. *Bone.* 2015 October 8; 81: 712-720. doi: 10.1016/j.bone.2015.10.002.

Smith SM, Zwart SR. Magnesium and space flight. *Nutrients.* 2015 December 8; 7(12): 10209-10222. doi: 10.3390/nu7125528.

This investigation is ongoing and additional results are pending publication.

PERSPECTIVE REVERSIBLE FIGURES IN MICROGRAVITY (REVERSIBLE FIGURES)

Research Area: Human Research: Nervous and Vestibular Systems
Expedition(s): 31 – 40
Principal Investigator(s):
- Gilles Clement, PhD, International Space University, Strasbourg, France

RESEARCH OBJECTIVES

The Perspective Reversible Figures in Microgravity (Reversible Figures) experiment is improving our knowledge of how astronaut perception is altered in space, where gravity cannot help with orientation. This could help in finding/developing countermeasures alleviating any disorientation experienced by astronauts especially during key activities such as spacewalks and docking/undocking of spacecraft.

EARTH APPLICATIONS

The same alterations in 3D visual perception in weightlessness are also seen in vestibular defective patients on Earth. Disturbances in 3D visual perception may influence the ability to accurately perform perceptual-motor tasks such as those involved in grasping objects, controlling vehicles or robotic arms, and extra-vehicular activities. Thus, understanding how adaptation to changing gravity affects the way an object is perceived is relevant for both fundamental and clinical research on Earth and for human space exploration.

SPACE APPLICATIONS

It is hypothesized that the adaptive changes in the processing of gravitational information by th e neurovestibular system during space flight may cause changes in 3D visual perception. Several reports indicate that the visual tracking abilities, perception, and reaction time deteriorate in crewmembers. This could have important consequences on the crew performance while in flight, including impaired psycho-motor ability, experimental error, or other various behavioral disturbances. Indeed, misperception of the environment in microgravity effects crewmember performance on sensory-motor tasks (such as operation of robotic arm), spatial orientation, and navigation. Understanding whether the perception of ambiguous figures is affected by microgravity might help taking this into account for specific tasks to be executed by humans in microgravity.

ISS crewmember Michael Hopkins during Reversible Figures investigation (ISS038E001281).

RESULTS

After adaptation to microgravity, ISS crewmembers developed larger depth perception instability, manifested by an equal probability for seeing each 3D interpretation after three months in space. ISS crewmembers were tested before, during and after flight to the ISS. The reaction time decreased

throughout the sessions, thus indicating a learning effect. However, the time to first percept reversal and the number of reversals were not different in microgravity and after the flight compared to before the flight. On Earth, when watching depth-ambiguous perspective figures, all subjects reported seeing one three-dimensional interpretation more often than the other. In microgravity this asymmetry gradually disappeared and after 3 months in microgravity both interpretations were seen for the same duration. These results indicate that the perception of illusory depth is altered in ISS crewmembers during space flight. This increased depth ambiguity is attributed to the lack of the gravitational reference and the eye-ground elevation for interpreting perspective depth cues.

PUBLICATION(S)

Clement G, Allaway HC, Demel M, Golemis A, Kindrat A, etc. Long-duration spaceflight increases depth ambiguity of reversible perspective figures. *PLOS ONE*. 2015 July 6; 10(7): e0132317. doi: 10.1371/journal.pone.0132317.

This investigation is complete; however additional results are pending publication.

Prospective Observational Study of Ocular Health in ISS Crews (Ocular Health)

Research Area: Human Research: Vision
Expedition(s): 35 – ongoing
Principal Investigator(s):
- Christian Otto, Universities Space Research Association, Houston, TX

Research Objectives

Crew members' bodies change in a variety of ways during space flight, and some experience impaired vision. The Prospective Observational Study of Ocular Health in ISS Crews (Ocular Health) protocol gathers data on crew members' visual health during and after long-duration space station missions. Tests monitor microgravity-induced visual impairment, as well as changes believed to arise from elevated intracranial pressure, to characterize how living in microgravity can affect the visual, vascular and central nervous systems. The investigation also measures how long it takes for crew members to return to normal after they return to Earth.

Earth Applications

Ocular Health provides insight into structural changes that can occur in the eyes and nervous system, which could be relevant for patients suffering from a wide range of ocular diseases, such as glaucoma. It also provides data that could be used to help patients suffering from brain diseases, such as hydrocephalus and high blood pressure in the brain.

Space Applications

ISS042e033950 - NASA astronaut Terry Virts performs an Ocular Ultrasound self-scan to obtain images of the optic nerve and globe of the eye.

Results from Ocular Health address several gaps in current knowledge, including physical and functional changes in the eyes during and after spaceflight. Systematic measurements of the visual, vascular, and central nervous system can inform future research, and develop countermeasures to safeguard crew members' vision. In addition, results can demonstrate the potential risk for crews on long-duration space missions. If microgravity is entirely or partially responsible for changes to the visual system, crews operating on missions five times longer than current space station expeditions may be negatively impacted.

Results

A retrospective review of data of ISS crewmebers from 2009 – 2012 demonstrated that the etiology of visual change in space explorers remains unresolved, microgravity-induced intracranial hypertension continues to be implicated in the pathogenesis. Ultimately, there may be a plethora of anatomic and physiology risk factors that will determine an astronaut's

sensitivity to developing visual abnormalities either through modulation of the intracranial pressure pathway or in combination with other factors.

PUBLICATION(S)

Kramer LA, Hasan KM, Sargsyan AE, Wolinsky JS, Hamilton DR, Riascos-Castaneda R, et al. Mr-derived cerebral spinal fluid hydrodynamics as a marker and a risk factor for intracranial hypertension in astronauts exposed to microgravity. Journal of Magnetic Resonance Imaging. 2015 December; 42(6):1560-1571. doi: 10.1002/jmri.24923.

This investigation is ongoing and additional results are pending publication.

CRYSTAL GROWTH OF ALLOY SEMICONDUCTOR UNDER MICROGRAVITY (ALLOY SEMICONDUCTOR)

Research Area: Physical Science: Materials Science
Expedition(s): 35, 36 and 39 – 42
Principal Investigator(s):

- Yuko Inatomi, Japan Aerospace Exploration Agency, Tsukuba, Japan

RESEARCH OBJECTIVES

The Crystal Growth of Alloy Semiconductor Under Microgravity (Alloy Semiconductor) investigation at the ISS is to make clear the factors for crystal growth of a high-quality bulk alloy semiconductor by investigating (1) solute transport in liquid and (2) surface orientation dependence of growth kinetics under microgravity and terrestrial conditions.

EARTH APPLICATIONS

High-quality crystals with tunable properties are desirable as substrate materials for various electronic and optoelectronic device applications. InGaSb ternary alloys have tunable physical properties between their binary counterparts InSb and GaSb in the infrared region. Although they are suitable for making thermophotovoltaic (TPV) devices and infrared (IR) detectors, growth of high-quality InGaSb crystals, over a wide range of indium composition, is a difficult task. Therefore, growth of high-quality ternary alloys for device applications requires pre-knowledge of growth parameters, such as dissolution, mass and heat transport, and the kinetics involved in growth. These studies will ultimately shed light on how higher quality crystals may be derived from other materials or incorporated into other devices such as solar cells.

RESULTS

Four ampoules with various GaSb seed and feed crystal orientations were sent to the ISS, aiming to study the orientation-dependent growth properties of ternary alloys. A the first experiment, $In_xGa_{1-x}Sb$ alloy crystal was grown under µG at the ISS using a GaSb (111)A/Te-doped InSb/GaSb (111)A sandwich sample using a vertical gradient freezing method. A similar experiment was conducted under 1G on Earth. The dissolution and growth processes of µG and 1G samples were comparatively analyzed. The kinetics played a dominant role in the dissolution process under 1G, as steps were observed at the peripheries of the seed interface. The seed interface of the µG sample was highly symmetric and slightly concave. The growth started at the peripheries under 1G, which can be explained using the calculated flow velocity of the solution at high temperature. The growth rate was higher under µG compared with 1G. The quality of the µG sample was better, as low EPD was observed compared with the 1G sample. The suppressed convection under µG affected the dissolution and growth process of this alloy semiconductor. Analysis of the other space samples is in progress.

PUBLICATION(S)

Inatomi Y, Sakata K, Mukannan A, Rajesh G, Kumar VN, et al. Growth of InxGa1−xSb alloy semiconductor at the International Space Station (ISS) and comparison with terrestrial experiments. *npj Microgravity*. 2015 August 27; 1: 15011. doi: 10.1038/npjmgrav.2015.11.

This investigation is complete; however additional results are pending publication.

BURNING AND SUPPRESSION OF SOLIDS – II (BASS-II)

Research Area: Physical Science: Combustion Science
Expedition(s): 37 – 40, 43, 44, 47 – ongoing
Principal Investigator(s):

- Sandra L. Olson, PhD, Glenn Research Center, Cleveland, OH

RESEARCH OBJECTIVES

The Burning and Suppression of Solids –II (BASS-II) investigation examines the burning and extinction characteristics of a wide variety of fuel samples in microgravity. The BASS-II experiment will guide strategies for materials flammability screening for use in spacecraft as well as provide valuable data on solid fuel burning behavior in microgravity. BASS-II results contribute to the combustion computational models used in the d esign of fire detection and suppression systems in microgravity and on Earth.

Image taken during a BASS-II investigation flame test (ISS038E049143).

EARTH APPLICATIONS

In outer space, fuels burn as oval balls rather than with an upward pointed cone flame as they do on Earth. This simpler combustion process enables researchers to evaluate computer models of fuel burning. These models can then be used to more accurately study flames on Earth, such as in wildfires, building fires, energy recapture from waste recycling, and other combustion problems.

SPACE APPLICATIONS

A primary goal of BASS-II is improved spacecraft fire safety, improved understanding of combustion in space and how to avoid it. If you're on a mission far from Earth, a fire can be catastrophic. BASS-II helps engineers select the safest materials and improve firefighting methods on future space missions.

RESULTS

They also found that how deep or thick the bed of fuel is does not affect the minimum speed of air required for flame-spread. However, the deeper or thicker the bed of fuel is, the slower the flame spread. Scientists consider a bed of fuel to be thin if the flame heats all the fuel. Otherwise, they consider the bed of fuel to be thick. In space, the critical thickness for the fuel poly-methyl methacrylate (PMMA), in ambient air, is 5.2 millimeters. Scientists also found that if the flame spreads faster if the fuel burns on two sides, compared to one.

Among the several fuel samples tested, the results included the observation that the vast majority of the oxygen consumed went into carbon dioxide. However, different fuel samples, depending which way the air was blown, had different ratios of carbon monoxide to carbon dioxide. Most of the flames had much higher rations of carbon monoxide to carbon dioxide, than flames on the Earth. That meant the flames were not as efficient as flames on the Earth.

Overall, the flames did not receive enough air to burn all of the fuel. Some fuel ended up as soot, some as carbon monoxide, and some as unburned hydrocarbons.
Another team used a composite cotton-fiberglass fabric blend as a fuel. When they decreased the air speed during some of the tests, the flame would go out when the air had more oxygen in it. This happened when the air was moving in a range of 1 and 5 centimeters per second. The higher the speed of air, the lower the amount of oxygen was at when the flame would go out. When the team graphed their results, the found that the shape of the boundary, where air speed and oxygen amount matched with the flame going out, supported the prediction made by earlier theoretical models.

In addition to finding the limits at which the flame would go out, they team recorded the sequence of sample ignition, flame growth, steady spread, and final decay. Also as part of the BASS-II experiment, ground teams burned cylindrical rods of PMMA. They found that the flames would go out when the speed of moving air became sufficiently slow that the flame could no longer generate enough heat. The flame had to generate enough heat to make up for the heat lost to conduction into the PMMA rod, and radiation. The team also found that when the flame blew out, the temperature of the flame was constant. This was the case regardless of the oxygen concentration or of how much the flame stretched. They determined that the temperature was critical in determining whether the flame quenched.

The understanding of burning and combustion is crucial for future long-duration missions beyond low Earth orbit. Testing how materials ignite and smolder in microgravity is essential for choosing everything for future spacecraft, from windowpanes to wire insulation, which will travel on longer-term missions to Mars or other destinations. The BASS-II results contribute to the combustion computational models used in the design of fire detection and suppression systems in microgravity and on Earth.

PUBLICATION(S)

Bhattacharjee S, Laue M, Carmignani L, Ferkul PV, Olson SL. Opposed-flow flame spread: A comparison of microgravity and normal gravity experiments to establish the thermal regime. *Fire Safety Journal.* 2016 January; 79: 111-118. doi: 10.1016/j.firesaf.2015.11.011.

Olson SL, Ferkul PV. Microgravity flammability of PMMA rods in concurrent flow. *9th U.S. National Combustion Meeting,* Cincinnati, Ohio; 2015 May 17-20 11 pp.

Shah TJ, Miller FJ, Olson SL, Wichman I. Modeling and analysis of intermediate thickness PMMA sheets burning in microgravity opposed flow. *Western States Section of the Combustion Institute Fall 2015,* Provo, Utah; 2015 October 5-6 9 pp.

Olson SL, Ferkul PV, Bhattacharjee S, Miller FJ, Fernandez-Pello C, Link S, Tien JS, Wichman I. Results from on-board CSA-CP and CDM sensor readings during the Burning and Suppression of Solids–II (BASS-II) Experiment in the Microgravity Science Glovebox (MSG). *45th International Conference on Environmental Systems,* Bellevue, Washington; 2015 July 12-16 9 pp.

Zhao X, T'ien JS, Ferkul PV, Olson SL. Concurrent flame growth, spread and extinction over composite fabric samples in low speed purely forced flow in microgravity. *9th U.S. National Combustion Meeting,* Cincinnati, Ohio; 2015 May 17-20 9 pp.

This investigation is ongoing and additional results are pending publication.

GROWTH OF HOMOGENOUS SIGE CRYSTALS IN MICROGRAVITY BY THE TRAVELLING LIQUIDOUS ZONE METHOD (HICARI)

Research Area: Physical Science: Materials Science
Expedition(s): 33 – 40
Principal Investigator(s):
- Kyoichi Kinoshita, Japan Aerospace Exploration Agency, Tsukuba, Japan

RESEARCH OBJECTIVES

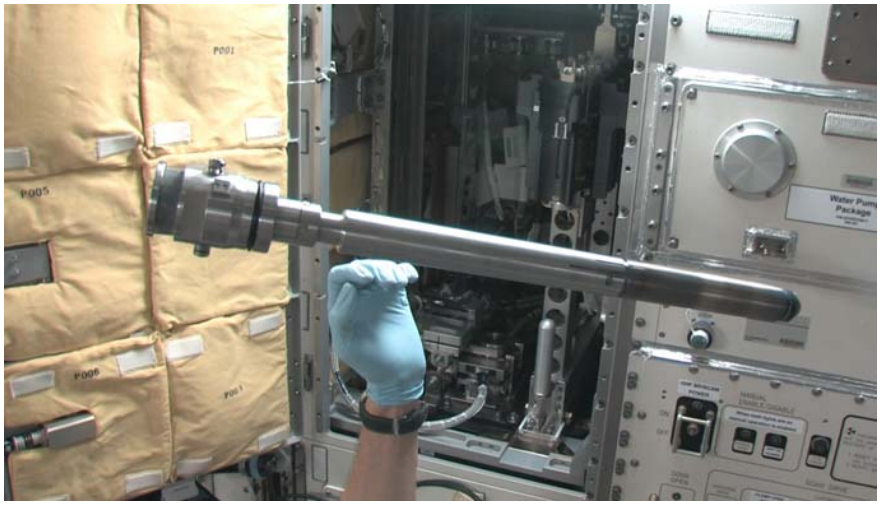
The materials science investigation Growth of Homogeneous SiGe Crystals in Microgravity by the Travelling Liquidous Zone Method (Hicari) aims to verify the crystal-growth by travelling liquidous zone method, and to produce high-quality crystals of Silicon-Germanium (SiGe) semiconductor using the Japanese Experiment Module-Gradient Heating Furnace (JEM-GHF). Once this method is established, it is expected to be applied for developing much efficient solar cells and semiconductor-based electronics.

EARTH APPLICATIONS

SiGe bulk single crystals are promising as substrates of high mobility electronic devices; higher electron mobility for Si thin films and higher hole mobility for Ge thin films both epitaxially grown on SiGe substrates are expected by the induced strain in thin films due to lattice mismatch between films and SiGe substrates. Therefore, fabrication of high speed CPU using CMOS devices on SiGe substrates is possible if large and high quality SiGe bulk crystals can be grown on the ground. The knowledge and information on the TLZ growth obtained by space experiments should be utilized for this purpose.

SPACE APPLICATIONS

SiGe are also promising as thermoelectric materials. So far, SiGe polycrystalline thermoelectric power devices were used in space exploration missions such as Voyager (1977), Galileo (1989), Ulysses (1990), Cassini (1997), and New Horizons (2005). If high purity bulk crystals are grown, higher electron mobility is possible and device performance will be much improved compared with present SiGe devices since high specification devices require high electron mobility.



Video screen shot of a levitating sample cartridge removed from the Gradient Heating Furnace in the ISS.

RESULTS

Total of four SiGe crystal growth experiments aboard the ISS as shown in Fig. 1 were successfully performed for evaluating a two-dimensional growth model of the TLZ method and for obtaining insights into large homogeneous SiGe crystal growth conditions. The TLZ growth requires diffusion limited mass transport in a melt and experiments in microgravity are essential. Although a little deviation from the expected axial compositional uniformity due to emissivity change of the cartridge surface is observed, homogeneous SiGe crystals are grown. Over all axial growth rate is consistent with the one-dimensional TLZ growth model prediction. However, radial growth rates are different from the two-dimensional growth model prediction. The difference is closely related to the flat interface shape in space grown crystals compared with the terrestrial ones and the radial compositional uniformity is much better than those of terrestrially grown crystals. Suppression of convection in a melt is favorable for obtaining flat freezing interface and is beneficial to large homogeneous SiGe crystal growth.

PUBLICATION(S)

Kinoshita K, Arai Y, Inatomi Y, Tsukada T, Miyata H, Tanaka R, Yoshikawa J, Kihara T, Tomioka H, Shibayama H, Kubota Y, Warashina Y, Ishizuka Y, Harada Y, Wada S, Ito T, Nagai N, Abe K, Sumioka S, Takayanagi M, Yoda S. Compositional uniformity of a $Si_{0.5}Ge_{0.5}$ crystal grown on board the International Space Station. *Journal of Crystal Growth.* 2015 June; 419: 47-51. doi: 10.1016/j.jcrysgro.2015.02.086.

Kinoshita K, Arai Y, Inatomi Y, Tsukada T, Adachi S, Miyata H, Tanaka R, Yoshikawa J, Kihara T, Tomioka H, Shibayama H, Kubota Y, Warashina Y, Sasaki Y, Ishizuka Y, Harada Y, Wada S, Harada C, Ito T, Takayanagi M, Yoda S. Growth of a Si0.50Ge0.50 crystal by the traveling liquidus-zone (TLZ) method in microgravity. *Journal of Crystal Growth.* 2014 February; 388: 12-16. doi: 10.1016/j.jcrysgro.2013.11.020.

Kinoshita K, Arai Y, Tsukada T, Inatomi Y, Miyata H, Tanaka R. SiGe crystal growth aboard the international space station. *Journal of Crystal Growth.* 2015 May; 417: 31-36. doi: 10.1016/j.jcrysgro.2014.09.048.

This investigation is complete; however additional results are pending publication.

SELECTIVE OPTICAL DIAGNOSTICS INSTRUMENT – DIFFUSION COEFFICIENTS OF MIXTURES (SODI-DCMIX)

Research Area: Physical Science: Fluid Physics
Expedition(s): 37, 38, 47 – ongoing
Principal Investigator(s):
- Ziad Saghir, PhD, Ryerson Polytechnic University, Toronto, Ontario, Canada

RESEARCH OBJECTIVES

The main objective of the Selective Optical Diagnostics Instrument (SODI-DCMIX) is the measurement of the diffusion coefficients of selected ternary mixtures, taking advantage of the reduced gravity environment available on board the ISS. A combination of different and complementary techniques are used to characterize flight candidate samples among water-based and hydrocarbon mixtures. Experimental results from space experiments, performed in the Selectable Optical Diagnostic Instrument, are used to test thermodiffusion theories and develop physical and mathematical models for the estimation of thermodiffusion coefficients.

EARTH APPLICATIONS

Understanding the fundamentals of thermodiffusion and thereby being able to predict its effects is of direct interest for example to oil companies that use computer simulations to model underground oil reservoirs and to optimize their exploitation.

SPACE APPLICATIONS

This investigation is applied to new scientific knowledge, and not specifically to advances in space exploration.

RESULTS

SODI DCMIX studies the Soret effect. The Soret effect is the movement of heat and mass that is caused by a difference in temperature. This is different from convection, where hotter, less dense matter rises upward compared to cooler, denser material. Gravity attracts denser matter more than less dense matter. To measure the Soret effect, you have to measure the changes in heat and mass, while avoiding the effects of gravity. That is why the SODI experiment is in space, on the ISS, to study the Soret effect.

Three chemicals, THN, IBB and nC12, were mixed and contained within cells, which were flown to ISS. These three chemicals are similar to the chemicals that are found in oil reservoirs. From December 2011 to January 2012 they were studied as a part of the SODI investigation.

The first set of sample cells performed well. It was determined that a good design for controlling temperatures was achieved. Another set of samples showed that the chemicals separated in the same way, in two separate attempts; because of this, the sessions could be repeated in a way that makes the data useful.

During other sessions it was shown that THN separated towards the hotter side of the cell,

while IBB and nC12 separated towards the cooler side. By comparing the samples, the teams were able to find the number that measures the Soret effect for those chemicals.

Understanding the Soret effect benefits us on Earth because it occurs in places like oil reservoirs, underneath the Earth's surface. The more we know about the Soret effect, the more we can learn about oil reservoirs.

PUBLICATION(S)

Ahadi A, Saghir MZ. The microgravity DSC-DCMIX1 mission onboard ISS: Experiment description and results on the measurement of the Soret coefficients for isobutylbenzene, dodecane, tetralin ternary hydrocarbons mixtures. *Experimental Thermal and Fluid Science.* 2016 June; 74: 296-307. doi: 10.1016/j.expthermflusci.2015.12.020.

Ahadi A, Saghir MZ. Contribution to the benchmark for ternary mixtures: Transient analysis in microgravity conditions. *European Physical Journal E.* 2015 April 27; 38(4): 10 pp. doi: 10.1140/epje/i2015-15025-4. PMID: 25916230.

Mialdun A, Shevtsova V. Temperature dependence of Soret and diffusion coefficients for toluene–cyclohexane mixture measured in convection-free environment. *Journal of Chemical Physics.* 2015 December 14; 143(22): 224902. doi: 10.1063/1.4936778.

Bou-Ali A, Ahadi A, de Mezquia DA, Galand Q, Gebhardt M, et al. Benchmark values for the Soret, thermodiffusion and molecular diffusion coefficients of the ternary mixture tetralin+isobutylbenzene+n-dodecane with 0.8-0.1-0.1 mass fraction. *European Physical Journal E.* 2015; 38(30). doi: 10.1140/epje/i2015-15030-7.

Ahadi A, Saghir MZ. Determination of the glass wall effect in optical measurement of temperature in liquid using Mach–Zehnder interferometer. *Applied Optics.* 2015 May; 54(13): D74-D81. doi: 10.1364/ao.54.000d74.

Mialdun A, Legros J, Yasnou V, Sechenyh V, Shevtsova V. Contribution to the benchmark for ternary mixtures: Measurement of the Soret, diffusion and thermodiffusion coefficients in the ternary mixture THN/IBB/nC_{12} with 0.8/0.1/0.1 mass fractions in ground and orbital laboratories. *European Physical Journal E.* 2015 April; 38(4): 112. doi: 10.1140/epje/i2015-15027-2. PMID: 25916232.

Galand Q, Van Vaerenbergh S. Contribution to the benchmark for ternary mixtures: Measurement of diffusion and Soret coefficients of ternary system tetrahydronaphtalene-isobutylbenzene-n-dodecane with mass fractions 80-10-10 at 25 °C. *European Physical Journal E.* 2015 April 27; 38(4): 10 pp. doi: 10.1140/epje/i2015-15026-3.

Khlybov OA, Ryzhkov II, Lyubimova T. Contribution to the benchmark for ternary mixtures: Measurement of diffusion and Soret coefficients in 1,2,3,4-tetrahydronaphthalene,

isobutylbenzene, and dodecane onboard the ISS. *European Physical Journal E.* 2015 April 27; 38(4): 16 pp. DOI: 10.1140/epje/i2015-15029-0.

Mialdun A, Minetti C, Gaponenko Y, Shevtsova V, Dubois F. Analysis of the thermal performance of SODI instrument for DCMIX configuration. *Microgravity Science and Technology.* 2013 February 6; 25(1): 83-94. doi: 10.1007/s12217-012-9337-2.

Ahadi A, Van Varenbergh S, Saghir MZ. Measurement of the Soret coefficients for a ternary hydrocarbon mixture in low gravity environment. *Journal of Chemical Physics.* 2013; 138(20): 204201. doi: 10.1063/1.4802984.

This investigation is ongoing and additional results are pending publication.

CREW USER INTERFACE SYSTEM ENHANCEMENT (CRUISE)

Research Area: Physical Science: Fluid Physics
Expedition(s): 33 – 36
Principal Investigator(s):

- Mikael Wolff, European Space Agecny, Noordwikj, Netherlands

RESEARCH OBJECTIVES

Crew autonomy for human exploration missions beyond LEO will require new crew information systems on-board. In non-space domains, as well as in commercial mass markets, many of the required building blocks for future crew assistants are already deployed; e.g. voice assisted user interfaces, and electronic instructions with command and control elements integrated therein. We believe that indeed also current Columbus flight operations can benefit from improvements of on-board crew operations support tools. The Cruise technology demonstrator (CRUISE) is a first step towards the deployment of such tools on Columbus, whilst preparing integrated ePartner solutions for exploration missions.

EARTH APPLICATIONS

The technologies used within this research are already used as a means to improve performance on Earth.

SPACE APPLICATIONS

With the nature of the work as an astronaut, any advances in technologies, or in procedures and protocols using such technologies, will help to improve mission efficiency and performance and make the lives of astronauts more comfortable in orbit, especially during longer-duration human exploration missions outside of low-Earth orbit. This type of research not only serves to improve astronaut efficiency on such missions, it also serves to improve astronaut autonomy which is a necessity for such future missions where communications delays will become a key factor.

RESULTS

The conclusions of the on-orbit tests and post-test evaluations from crewmembers were that the Procedure Display was a simple interface and it was fast. Concerns were identified with overall loss of situational awareness especially in the case if an error occurred or if a crewmember needed to back up to a previous task step. Concerns with the voice activated interface due to the limitation of using a headset that was cabled to the laptop and therefore limiting movement for the crewmember. A suggestion was made to upgrade headset microphone to a Wi-Fi or Bluetooth system for the headset.

PUBLICATION(S)

Smets N, Neerincx M. CRUISE Evaluation Report. *TNO*; 2013 November.

This investigation is ongoing and additional results are pending publication.

DEPARTMENT OF DEFENSE SYNCHRONIZED POSITION, HOLD, ENGAGE, REORIENT EXPERIMENTAL SATELLITES – RESONANT INDUCTIVE NEAR-FIELD GENERATION SYSTEM (DOD SPHERES-RINGS)

Research Area: Technology Development and Demonstration: Communication and Navigation

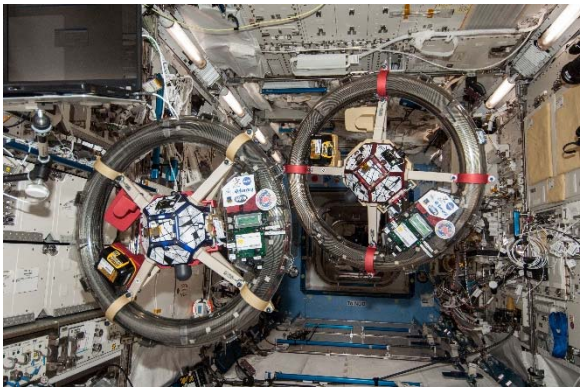
Expedition(s): 35 – 40

Principal Investigator(s):

- Raymond J. Sedwick, University of Maryland, College Park, MD

RESEARCH OBJECTIVES

The Department of Defense SPHERES-Resonant Inductive Near-field Generation System (DOD SPHERES-RINGS) uses two small, self-contained satellites (SPHERES) fitted with donut-like rings (RINGS) to test wireless power transfer and formation flight using electromagnetic fields. The RINGS hardware are equipped with aluminum coils and current control systems and are mounted onto the SPHERES vehicles. The investigation provides insight for the Department of Defense and NASA to develop a new control method for clusters of multiple satellites, and demonstrates the ability to wirelessly transfer power across a medium distance, which could provide greater flexibility of future satellite cluster architectures.



DOD SPHERES-RINGS satellites floating in the ISS (ISS037E026265).

EARTH APPLICATIONS

Wireless inductive power transfer is already being used in electronics and household items such as cell phones and toothbrushes. Broadening this approach to include resonance can increase the efficiency and transfer distance to benefit future urban robotics and sensors, as well as support more efficient underwater communications systems. DOD-SPHERES-RINGS investigates methods and hardware necessary for improving wireless power transfer.

SPACE APPLICATIONS

The DOD-SPHERES-RINGS investigation is the first space-based demonstration of electromagnetic formation flight and wireless power transfer. Hardware and computer control software for the DOD-SPHERES-RINGS investigation demonstrate autonomous plume-free, propellant-free movements of spacecraft. Power transfer by resonant induction (an improvement over cordlessly charging your phone or toothbrush on a charging pad or cradle) and the use of electromagnetic fields for satellite control are approaches that can eliminate the need for consumables (propellant) and provide more flexibility to system architectures. These have the potential to substantially increase the operating lifetime of the cluster, reduce system mass and reduce operating risks, all of which can contribute to greater return on investment. The wireless power transfer experiment also aids in establishing the hardware required to power future robotics systems, sensors and communications equipment.

RESULTS

Two SPHERES-RINGS assemblies were tested on board the ISS. The first set of tests involved a configuration where one of the SPHERES-RINGS assemblies was fixed to the module wall in order to check out the wireless power transfer and electromagnetic formation flight capability. Thrusters were not used during these tests. Both coils were activated and power transfer of 30% efficiency was successfully achieved. The test also demonstrated the ability for the two resonant coils to command and maintain a constant 180° phase relationship between the magnetic fields of the respective assemblies. The free floating SPHERES-RINGS assembly was moved to an approximate initial position by a crew member. Both SPHERES-RINGS were allowed to attract and repel using only magnetic dipole interactions. This provides the concept that the SPHERES-RING assemblies were able to actuate vehicles using electromagnetic fields.

PUBLICATION(S)

Porter AK, Alinger DJ, Sedwick RJ, Merk J, Opperman RA, Buck A, et al. Dual-purpose resonate actuators for electromagnetic formation flight and wireless power transfer. *AIAA Guidance, Navigation and Control Conference,* National Harbor, Maryland; 2014 January 13-17 18 pp.

Porter AK, Alinger DJ, Sedwick RJ, Merk J, Opperman RA, Buck A, et al. Demonstration of electromagnetic formation flight and wireless power transfer. *Journal of Spacecraft and Rockets.* 2014; 51(6):1914-1923. doi: 10.2514/1.A32940.

This investigation is complete; however additional results are pending publication.

OPTICAL PAYLOAD FOR LASERCOMM SCIENCE (OPALS)

Research Area: Technology Development and Demonstration: Communication and Navigation
Expedition(s): 39 – ongoing
Principal Investigator(s):
- Michael Kokorowski, Jet Propusion Laboratory, Pasadena, CA

RESEARCH OBJECTIVES

The Optical PAyload for Lasercomm Science tests the potential for using a laser to transmit data to Earth from space. Instead of being broadcast on radio waves, data is packaged onto beams of laser light and hardware on the International Space Station will point the laser to a receiver station on the ground. Radio waves transmission is limited by the speed that it can transfer data, but beaming information packages with lasers can greatly increase the amount of information transmitted over the same period of time.

EARTH APPLICATIONS

The fastest commercial communication links on Earth use optical (or laser) fiber to transmit information. Using laser in space without this fiber is another method. Fast laser communications between Earth and spacecraft like the International Space Station or the Mars rover Curiosity could enhance their connection to the public. OPALS is also used to educate and train NASA personnel.

SPACE APPLICATIONS

Modern spacecraft orbiting Earth and other planets are equipped with advanced science instruments collecting large amounts of data, which can take a long time to send back. Optical communications uses laser beams to transmit data instead of radio waves. Laser beams are more narrowly focused than radio waves and they can transmit data at a faster rate. A primary challenge is accurately pointing the laser beam from space to its target on Earth.

RESULTS

The use of an Adaptive Optics (AO) test bed hardware supplied by the Boeing Company which was incorporated into the OPALS ground telescope system, was successful in demonstrating its ability to correct wave-front distortions induced by random atmospheric turbulence on the optical downlink from the ISS to the ground receiving system. This demonstrated the potential for increasing the data rate of the laser data transmission received from the orbiting ISS OPALS hardware by using a small area detector in the ground receiver. The use of the AO to perform this correction on an optical link from a fast slewing low Earth orbiting spacecraft underscores its critical role, particularly when attempting to achieve high data rates for daytime operations when high levels of atmospheric turbulence are present. This indicates that potential high data rate space to ground optical communications are possible for operational use in future designs.

PUBLICATION(S)

Wright MW, Morris JF, Kovalik JM, Andrews KS, Abrahamson MJ, Biswas A. Adaptive optics correction into single mode fiber for a low Earth orbiting space to ground optical communication link using the OPALS downlink. *Optics Express.* 2015 December 28; 23(26): 33705-33712. doi: 10.1364/OE.23.033705.

This investigation is ongoing and additional results are pending publication.

MICROFLOW 1 TECHNOLOGY DEMONSTRATION (MICROFLOW1)

Research Area: Technology Development and Demonstration: Characterizing Experiment Hardware

Expedition(s): 33 – 36

Principal Investigator(s):

- Luchino Cohen, Canadian Space Agency, Longueuil, Quebec, Canada

RESEARCH OBJECTIVES

The Microflow 1 technology demonstration (Microflow1) investigation provides the first performance test of a miniaturized flow cytometer in the microgravity environment of the International Space Station (ISS). Flow cytometry is a technique that focuses fluids (blood or other body fluids) into a controlled stream that enables researchers to quantify specific molecules and monitor physiological and cellular activity. The goal of this testing in microgravity is the development of a small and safe instrument that could be used for real-time on-board biological analysis. It may be later certified for real-time medical care and monitoring during space flight.

EARTH APPLICATIONS

The project will lead to technology transfer and economic benefits through greater efficiency and flexibility in health care delivery and in agricultural support.

SPACE APPLICATIONS

During space missions in low Earth Orbit or beyond, several situations could lead to a medical emergency. It will be critical to quickly determine whether evacuation is required or not, when possible. The Crew Medical Officer will need accurate real-time clinical data based on molecular diagnostics as it is currently the case on Earth. Availability of a micro-flow cytometer on board could enable real-time data collection and reduce requirements for sample return on Earth.

ISS crewmember Chris Hadfield holding the Microflow investigation (ISS034E062717).

RESULTS

Sample analysis by the Microflow1 unit aboard the ISS produced identical results as the ground unit, despite vibrations of a rocket launch and weightlessness environment. This demonstration confirmed that the technology could be developed into a robust bio-analysis platform aboard the ISS to study blood cells and other components during space flight.

PUBLICATION(S)

Dubeau-Laramée G, Rivière C, Jean I, Mermut O, Cohen L. Microflow1, a sheathless fiber-optic flow cytometry biomedical platform: Demonstration onboard the International Space Station. *Cytometry Part A*. 2014 April; 85(4): 322-331. doi: 10.1002/cyto.a.22427.

Cohen LY, Vernon M, Bergeron MG. New molecular technologies against infectious diseases during space flight. *Acta Astronautica*. 2008; 63: 769-775. doi: 10.1016/j.actaastro.2007.12.024.

This investigation is complete and all results are published.

SYNCHRONIZED POSITION, HOLD, ENGAGE, REORIENT EXPERIMENTAL SATELLITES - VISUAL ESTIMATION FOR RELATIVE TRACKING AND INSPECTION OF GENERIC OBJECTS (SPHERES-VERTIGO)

Research Area: Technology Development and Demonstration: Small Satellites and Control Technologies

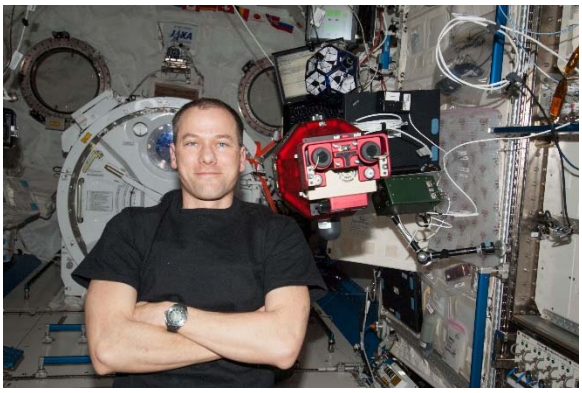
Expedition(s): 33 – ongoing

Principal Investigator(s):

- David W. Miller, PhD, Massachusetts Institute of Technology, Cambridge, MA

RESEARCH OBJECTIVES

The Synchronized Position, Hold, Engage, Reorient, Experimental Satellites – VERTIGO (SPHERES-VERTIGO) investigation uses the SPHERES facility free-flying satellites and is designed to demonstrate and test, in a complex environment, enhanced technologies and techniques related to visual inspection and navigation. This effort incorporates hardware and software that enables multiple SPHERES to construct three dimensional (3D) models of a target object. Additionally, this investigation explores how well the SPHERES free-flyers then perform relative navigation solely by reference to these 3D mode ls.



ISS crewmember Tom Marshburn conducting the SPHERES-VERTIGO investigation onboard ISS (ISS034E056099).

SPACE APPLICATIONS

The ability to create a three-dimensional model of an unknown object in space using only one or two small satellites is an enabling technology applicable to a wide range of space missions. One of the program's planned principal contributions is to determine how to perform autonomous inspection and mapping of a tumbling and spinning object. Although many spacecraft that are launched today are three-axis stabilized, there is a significant number of spacecraft that were designed to be spin-stabilized. A few examples are the Hughes Spacecraft 376, which was spun at 50 rotations per minute (RPM). Additionally, the interplanetary cruise stages of DAWN, JUNO and MSL were spun at 48, 5 and 2 RPM respectively.

RESULTS

The SPHERES-VERTIGO test runs were conducted aboard the ISS on February 26 and March 12 of 2013 during Expedition 34. The first test revealed problems due to higher than expected velocity measurement noise levels via the stereo camera system which caused too many thruster firings. Adjustments were made and tests were continued. Despite a few anomalies, the SPHERES vehicle with the VERTIGO stereo camera installed was able to demonstrate a complete autonomous circumnavigated inspection trajectory around a target object.

PUBLICATION(S)

Fourie D, Tweddle BE, Ulrich S, Saenz-Otero A. Flight results of vision-based navigation for autonomous spacecraft inspection of unknown objects. *Journal of Spacecraft and Rockets.* 2014 May 8; epub: 11 pp. doi: 10.2514/1.A32813.

Fourie D, Tweddle BE, Ulrich S, Saenz-Otero A. Vision-based relative navigation and control for autonomous spacecraft inspection of an unknown object. *2013 AIAA Guidance, Navigation, and Control Conference,* Boston MA; 2013 August 19-20 17 pp.

This investigation is ongoing and additional results are pending publication.

Canadian Space Agency
http://www.asc-csa.gc.ca/eng/iss/default.asp

Japan Aerospace Exploration Agency
http://iss.jaxa.jp/en/

National Aeronautics and Space Administration
http://www.nasa.gov/iss-science/

European Space Agency
http://www.esa.int/esaHS/iss.html

Roscosmos – Russian State Space Corporation
http://knts.tsniimash.ru/ru/site/CenterInfRes.aspx
http://www.energia.ru/english/index.html