

NASA/TM-2011-216158



# **NASA's Reduced Gravity Program**

## **Summary Report**

*Report prepared by*  
*Space Life Sciences Directorate*  
*Human Adaptation and Countermeasures Office*  
*NASA Johnson Space Center, Houston, TX*

National Aeronautics and  
Space Administration

Johnson Space Center  
Houston, Texas 77058

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October 2011

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## PREFACE

This document represents a summary of medical and scientific evaluations conducted aboard NASA's sponsored aircraft from June 2010 to May 2011. Included is a general overview of investigations manifested and coordinated by the Human Adaptation and Countermeasures Division. A collection of brief reports that describe tests conducted aboard the NASA sponsored aircraft follows the overview. Principal investigators and test engineers contributed significantly to the content of the report describing their particular experiment or hardware evaluation. Although this document follows general guidelines, each report format may vary to accommodate differences in experiment design and procedures. This document concludes with an appendix that provides background information concerning NASA's Reduced Gravity Program.



## Acknowledgments

The Space Life Sciences Directorate gratefully acknowledges the work of Sharon Hecht, Jacqueline M. Reeves, and Elisabeth Spector for their outstanding editing support and contributions to the overall quality of this annual summary report.

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NASA's Reduced Gravity Program  
Summary Report  
September 30, 2011

National Aeronautics and Space Administration  
Lyndon B. Johnson Space Center

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## **Overview of NASA's Reduced Gravity Flight Activities Sponsored by the Human Adaptation and Countermeasures Division**

As a summary for the year, 4 weeks were specifically reserved for flights sponsored from June 2010 to May, 2011. A total of 16 flights with approximately 32 parabolas per flight were completed. The average duration of each flight was 2.1 hours. The Reduced Gravity Program coordinator assisted principal investigators and test engineers of 9 different experiments and hardware evaluations in meeting the necessary requirements for flying aboard the NASA-sponsored aircraft and in obtaining the required seating and floor space. Support was provided to the Education Outreach Program during weeks in June, August, and September in 2010 and April 2011. A large ground crew from the respective academic institutions supported the in-flight experiments. The number of seats supported and number of different tests flown by flight week are provided below:

<b>Flight Week</b>	<b>Seats</b>	<b># Tests Flown</b>	<b>Sponsor</b>
June 21–25, 2010	24	2	Education Outreach Program
August 2–6, 2010	24	2	Education Outreach Program
September 27– October 1, 2010	36	3	FASTRACK
April 4–8, 2011	12	2	Education Outreach Program

Additional flights will be added throughout the remainder of calendar year 2011 to accommodate customers as needs arise.

## **Medical and Scientific Evaluations during Parabolic Flights**

**TITLE**

Education Outreach Program –  
Smart Resistive Exercise Device for Free Weight Simulation

**FLIGHT DATES**

June 24–25, 2010

**PRINCIPAL INVESTIGATOR**

Christina Vasquez, Texas State University, TX

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Billy Baccam, Austin Community College, TX  
Dustin Blymyer, Austin Community College, TX  
Mark Prado, Texas State University, TX  
Nathan Robson, Texas State University, TX  
Christina Vasquez, Texas State University, TX

**FACULTY ADVISOR**

Dr. Allen Underwood, Austin Community College, TX



## **GOAL**

We propose to construct and test a new type of resistive exercise device, which is designed to recreate, in a microgravity environment, both the resistance (that is, the “weight”) and the inertial properties of free weights.

To reproduce the positive effects that a free weight exercise regimen is known to have on the body, the system will produce a load created by a computer moderated partial vacuum instead of true free weights. The vacuum chamber will be attached to a manifold with two solenoid valves that will be computer controlled to regulate the pressure difference between the inside of the chamber and the ambient pressure of the surrounding environment.

## **PURPOSE**

The experiments purpose is to investigate a new way to simulate free weights in a microgravity environment. This is important to help offset the long-term effects that a microgravity environment can have on humans. An extended amount of time spent in a microgravity environment can lead to muscle and bone deterioration, as well as other side effects. To reproduce the positive effects that a free weight exercise regimen is known to have on the body, the system will produce a load created by a computer moderated partial vacuum instead of true free weights.

The system will use an oil-free vacuum pump to create the vacuum inside of a chamber; the difference in pressure between the outside ambient pressure and the chamber pressure will provide the resistive load. While the system is operational, sensors will provide data to the computer. The computer will close or open valves to provide a constant resistive load.

It is anticipated that this system will more accurately simulate free weights, and then methods currently employed. The device is based on a cylinder and piston arrangement whereby one side of the piston is maintained at ambient cabin pressure, while the pressure of the partial vacuum on the other side of the piston is continually re-adjusted by computerized feedback and control to mimic in all details the behavior of arbitrarily selected free weights in a normal gravitational setting.

This device addresses the long-standing and significant problems of muscle atrophy and bone deterioration due to lack of normal gravitational loading in spaceflight. The feedback and control algorithm takes input from sensors measuring pressure, acceleration, direction of motion, and applied force and calculates the pressure in the partial vacuum side of the cylinder required to produce the required simulated weight and inertial properties. Digital outputs based on the result of these calculations control solenoid valves, which act to adjust the pressure in the cylinder to the targeted value.

## **METHOD**

In-flight, before the first microgravity maneuver, the laptop and control application (a LabView VI) will be powered up by Team Member 1 as Team Member 2 starts the power supply, electronics, and vacuum pump then adjusts the manual valve on the valve manifold for first set

of test parameters. Team Member 1 will enter the first set of test parameters (desired simulated weight value) on the computer console.

During microgravity conditions of first parabolic maneuver, Team Member 3 will perform the following test sequence on the control lever:

- Lift halfway at uniform speed
- Hold briefly at middle
- Lift remaining way with acceleration
- Hold briefly at top
- Lower at constant speed to middle
- Lower remaining way with acceleration

Team Member 3 will halt program execution with all test data being automatically saved to file. In between free-fall periods, Team Member 1 will enter the next set of test parameters (that is, the new simulated “weight” value) and re-initiate program execution. Team Member 2 will adjust the manual control valve as required matching the new test parameters. Team Member 3 will execute lifting procedure as before during the free-fall period. The experiment will proceed in this fashion through the entire sequence of 10 simulated-weight values covering the dynamic range of the apparatus, and will repeat the sequence to the extent allowed by the number of parabolic maneuvers executed.

During the “lunar”, and “Martian” runs the control program will be changed to the lunar and Mars simulator programs which will simulate Earth free-weight response in a Moon-like or Mars-like gravitational environment.

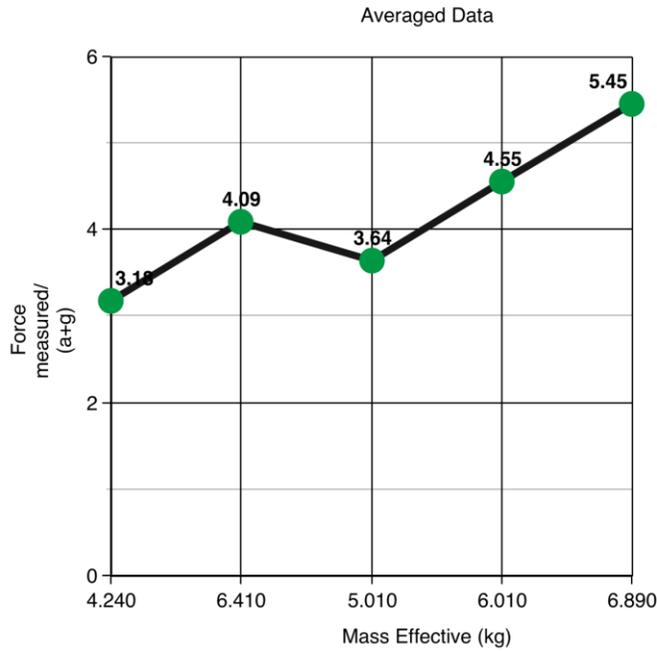
After conclusion of the last parabolic maneuver, the vacuum will be released via the safety release valve, the program will be terminated, and power will be switched off to the control valve. Power will be switched off to the amplifiers, to the 7.5 Volt power supply, and to the DVM. After a 5-minute cool off period at no vacuum, power will be switched off to the Pump. The laptop will be shut down and switched off to the power strip.

## **RESULTS**

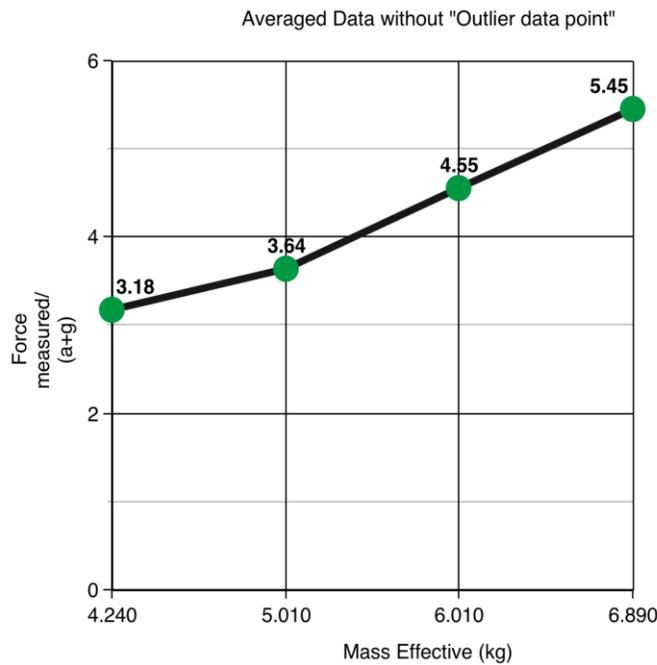
We analyzed the data from both flight days separately and then grouped the data together for a collective analysis. Below are graphs of the entire data collection. We had 1 data point that was outside of our ideal range.

Graphs with the outlier data point and another without the outlier data point are shown in Figures 1 and 2. We took out the outlier to demonstrate what the data would look like without that point in an ideal situation. We assume that something went wrong during that collection, because we compared that data to our other data points that were correlating properly with the formulas we used.

Note: From the graphs, we are looking for a correlation close to being equal to 1.



**Figure 1 - Slope=0.8656 kg/kg - Correlation =0.9949**



**Figure 2 - Slope=0.7342 kg/kg - Correlation=0.9041**

## CONCLUSION

We feel as though we had a tremendous amount of success with this experiment, despite having one outlying data point. That data point could be due to certain limitations on our equipment or with improper procedure of the experiment during flight.

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JSC2009E8571–8578

JSC2009E8567

JSC2009E8568

## VIDEO

Zero G flight week 21–25 June, 2010, TSR# 107733 M# 753071

Videos available from Imagery and Publications Office, NASA JSC.

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**TITLE**

Education Outreach Program – Aeroponics for Legume Food Growth Chamber

**FLIGHT DATES**

August 3–4, 2010

**PRINCIPAL INVESTIGATOR**

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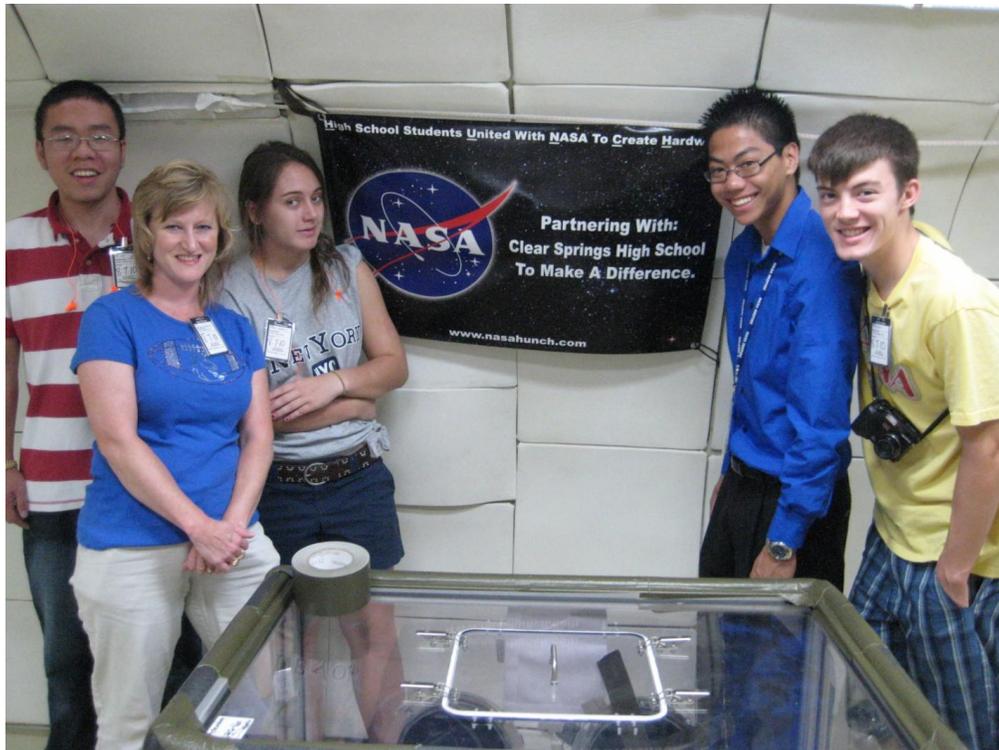
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## **GOAL**

The experiment tested an Aeroponics watering method used for sustaining plant growth in a food growth chamber. The Aeroponics design used a water misting system. The goal was to observe the water characteristics and how water attached to the legume roots during microgravity conditions.

## **OBJECTIVES**

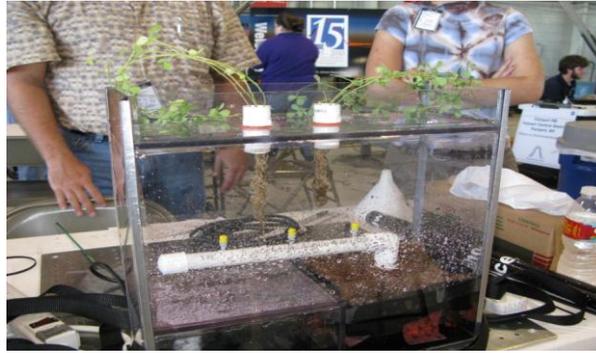
The objective of this experiment was to determine if the behavior of water from the Aeroponics misting system remains appropriate for sustaining plant growth during microgravity conditions. Modifications to the Aeroponics watering system will be determined by the results from this experiment.

## **METHODS AND MATERIALS**

Aeroponics is a type of watering system wherein the roots of the plants are directly sprayed with a nutrient solution. The roots are suspended at the base of the stem and therefore do not require soil or other media to anchor the roots for growth. Aeroponics is efficient compared to conventional growth systems because water is sprayed in a mist-like state, minimizing the amount water required for proper plant nutrition and growth. The excess water that is not absorbed by the plant roots is recycled to the misting system.

The experiment addressed whether microgravity conditions affect the ability of the misters to spray water onto the roots and if the water remained attached to the roots of the plants during 0-G. In a 1-G environment, water sprayed from misters onto plant roots continually dripped from the roots to the chamber's reservoir. This process allows for water to enter the plant through the roots in the presence of oxygen. This is important because if water accumulates on roots, without allowing roots to receive oxygen, the plant cannot survive. Plant roots need to transport water and nutrients in the presence of oxygen otherwise the uptake of water and nutrients will decrease growth and lead to plant death.

A Lexan box was constructed to contain the experiment. The misting system was constructed from a submersible water pump, PVC piping, and 3 adjustable misters that supplied water to the roots of 2 legume plants. These plants were inserted into PVC plant housing, which were mounted on a sheet of Lexan above and to the side of the 3 misters (Figure 1). Rockwool and silicon caulking were used to seal the plants into the PVC housing. A few drops of red food coloring were added to the water to make it easier to observe the water in the food growth chamber.



**Figure 1 - Food growth chamber.**

There were 2 flights within 2 consecutive days (August 3 and 4, 2010) in which the same plants remained in their housing. On the first flight, information was collected on how the water clung to the sides of the chamber. On the second flight information was collected on how the water clung to the roots of the plants. The following steps were followed for each parabola:

- Turn the submersible pump on at the beginning of the reduced-gravity maneuver.
- If the digital voice recorder or video camera is off turn them on.
- Record observations of water's behavior in the plant growth chamber and on the roots of the plants.
- Turn the submersible pump off at the end of the reduced-gravity maneuver.

There were no changes between the first and second flights in the procedures.

## **RESULTS**

The water completely fogged over the sides of the chambers making it difficult to see within the chamber (Figure 2). The water molecules clung together to form large pockets of water.



**Figure 2 - Food growth chamber in 0-G conditions.**

The water sprayed from the misters tended to spray straight up and somewhat missed the roots of the plants, which were located to the side of the sprayers (Figure 1).

The mister furthest from the water pump was not spraying water properly during the 0-G maneuvers.

It was observed that the water on the roots of the plants remained on the plants and did not drip off as was observed under nominal conditions on earth.

## **DISCUSSION**

We compared the behavior of water emitted from the misters under both 0-G and 1-G conditions. The water molecules from the misters in 0-G clumped together to form large droplets or bubbles as compared to the mist that was produced under 1-G conditions. The water clung to the sides of the chamber and made it difficult to see into the chamber. The water from the misters sprayed straight up, under 0-G conditions; instead of spraying more to the sides as was observed during normal earth conditions. Under normal gravity conditions, all three misters received an adequate supply of water and functioned properly; however, under 0-G conditions the furthest mister from the pump did not maintain a proper spray of water.

The water on the roots formed large drops of water that remained clinging to the roots. Water on the roots during normal gravity conditions continually dropped from the roots to the bottom of the chamber. The behavior of the water was what we hypothesized would happen in reduced-gravity situations.

## **CONCLUSIONS**

The goal for this experiment was to determine if the three Aeroponics misters would supply plants with the appropriate amount of water to their roots under 0-G conditions. The supply of water must be regulated to the roots, since excess water would deprive the roots of oxygen and an inadequate supply of water would deprive the plants of water and nutrients required for optimal growth. Based on the observations of this experiment the Aeroponics system will need to be modified. First, the misters should be placed directly under the plants and not off to the sides. Second, a stronger pump will be needed to supply all three misters with the appropriate amount of water. Third, a fan or some type of device to remove the water from the roots of the plants will be needed to insure the plant roots are not continually immersed in water, which would deprive the roots of oxygen. It was suggested by other researchers that a drop of detergent or Rain-X could be added to the water to keep the water from clinging to the sides of the chamber as well as the roots of the plants. Fourth, a watering system that uses a finer mist, such as a humidifier, may be better suited for the 0-G environment; because of the nature of water molecules to cling in a reduced-gravity environment.

## **REFERENCES**

Bibliographic information was not available.

## **PHOTOGRAPHS**

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JSC2010E112381-JSC2010E112383  
JSC2010E112373

## **VIDEO**

Zero G flight week 2–6 August, 2010, Master/TSR: 756787/108890

Videos available from Imagery and Publications Office, NASA JSC.

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## **TITLE**

FASTRACK Program – FASTRACK – Measurement of Vestibulo-ocular Function without Eye-Movement Recording

## **FLIGHT DATES**

September 28–August 1, 2010

## **PRINCIPAL INVESTIGATOR**

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## **COINVESTIGATORS**

Kara Beaton, The Johns Hopkins University, School of Medicine, Baltimore, MD  
Michael Schubert, The Johns Hopkins University, School of Medicine, Baltimore, MD  
Dale Roberts, The Johns Hopkins University, School of Medicine, Baltimore, MD



NASA Photo: JSC2009xxxxx

## **GOAL**

Our overall goal was to validate the performance, in a realistic space-analog environment, of a device to assess one aspect of sensorimotor function. We anticipate that eventually this device will form part of an integrated battery of portable and rapid tests to assess sensorimotor function before, during, and after spaceflight.

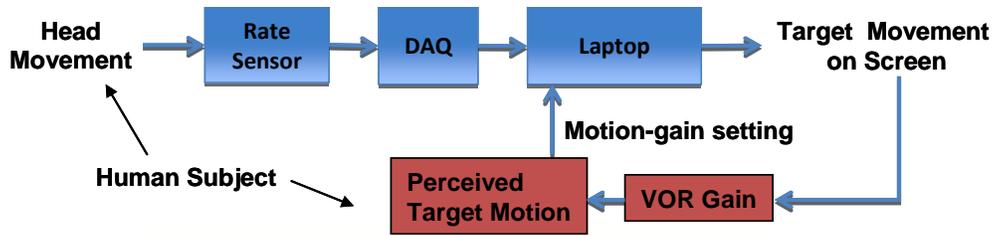
## **OBJECTIVES**

Long-duration spaceflight adversely affects many aspects of sensorimotor function, which can have serious implications on manual-control tasks and piloting performance, especially during maneuvers involving g-level transitions. The vestibular system provides information for spatial perception, postural reflexes, and coordination of motor control. One component of the vestibular apparatus transduces linear acceleration, including gravity. Exposure to weightlessness during spaceflight provides conflicting information to these sensors, leading to many of the sensorimotor disruptions found during and after flight: motion sickness, disorientation, oscillopsia, and postural and locomotor deficits.

One of the most fundamental vestibular functions is control of the motion of the eyes during head movements so that stable vision can be maintained. The accuracy of this vestibulo-ocular reflex (VOR) is typically measured by recording eye movements during controlled head movements. We know from actual measurement of eye movements in parabolic flight that their reflex control is altered in different g levels (Karmali & Shelhamer 2010). With head movements made in the pitch plane, the acute effects of different gravity levels can be found, as relevant to spaceflight. However, eye-movement measurement can be time-consuming, expensive, and invasive, often requiring specialized training for proper configuration and operation of delicate equipment. We designed a protocol to test in parabolic flight a new device that assesses vestibulo-ocular function without the need to measure eye movements directly. As the head is moved, if the eyes do not move appropriately to stabilize eye position, a visual target will undergo illusory motion (oscillopsia), proportional to the amount by which eye motion is deficient in compensating for head motion. Our device measures head motion and uses it to control target position; the subject controls the gain of target motion (relative to head motion) in order to reduce the apparent motion of the target to zero. This provides a surrogate measure of vestibulo-ocular function.

## **METHODS AND MATERIALS**

The study consisted of an evaluation of this novel device in parabolic flight. Test subjects made head and eye movements while viewing a visual target presented on a head-mounted display (Figure 1). During head motions, a rate sensor attached to a biteboard measured head movement, and used it to control the motion of a visual target on the display. The subject controlled the gain of the head-motion/target-motion process through a gain-setting knob, adjusting the gain as necessary so that the target appeared to be stationary when the head moved (pitching head movements). The effects of g level were determined by comparing responses from identical motions in 0 g and 1.8 g. Testing in lunar gravity levels also provided a realistic test of the device and procedures, since assessment of sensorimotor function upon landing on these bodies is highly desirable.

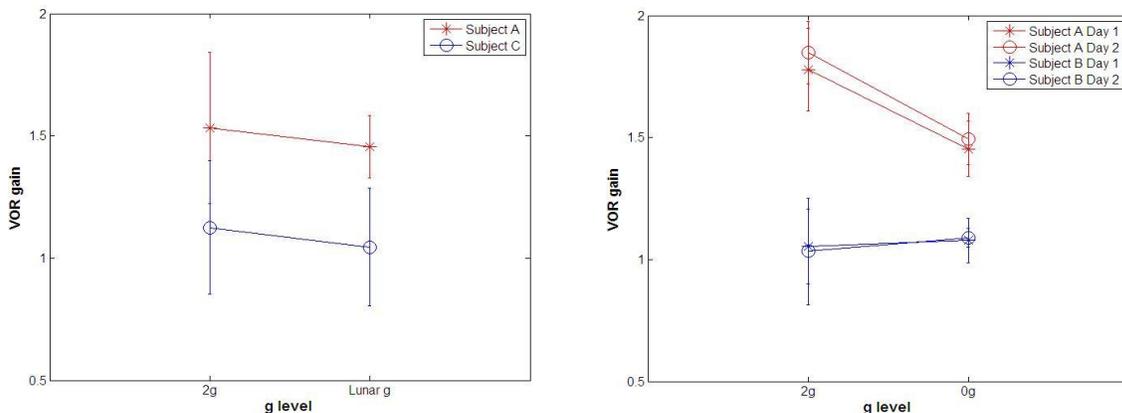


**Figure 1 - Diagram describing the way data is collected.**

## RESULTS

Flight testing was very successful. Hardware and software performed flawlessly, although shortcomings in the current design were noted. Most notably, interaction between operator and subject was sometimes cumbersome, which has motivated us to consider a subject-operated device as a future modification. The other major finding regarding the device itself is that the task that the subject must perform is not as intuitive as we had hoped. Subjects attempted to interpret the visual target dot on the head-mounted display as existing “beyond the display” – perhaps projected onto the opposite wall of the aircraft – but this proved difficult due to ambient lighting and glare on the display, drift of the target due to imperfect head-movement sensors, and the overriding mental set that clearly placed the target on the nearby headset. All of these issues are correctable with hardware refinements.

Even with these difficulties, we obtained quality data that demonstrate the validity of our approach. Two experienced subjects, and one naïve subject, made consistent and reliable gain settings which we can relate to underlying sensorimotor function. Two other naïve subjects either could not perform the task due to motion sickness, or had difficulty interpreting the instructions, which provides us with important information on how to design and explain the procedures to our subjects (Figure 2).



**Figure 2 - Left: VOR gain as assessed with new nulling device, for 2 subjects, in hyper-g and lunar-g. Right: VOR gain for 2 subjects, in hyper-g and 0-g.**

In each case, gain is expected to be lower in the reduced-gravity levels due to a reduced otolith contribution, and higher in the hyper-gravity levels. In 3 of 4 subjects this is the case. The subject who did not match this pattern (B) was also the only subject to fly without motion-sickness medication, a connection that we hope to investigate.

## **DISCUSSION**

The flight tests were productive and extremely helpful. Most notably, we confirmed our previous findings that in un-adapted subjects, pitch-VOR gain is higher in hyper-g and lower in reduced-g. We benefited by the ability to fly 2 lunar flights before the 0-g flights. This allowed us to practice with the device in an operational setting, and refine our protocols, before testing in the more critical 0-g flights. Even so, we were able to obtain relevant data in the lunar flights. The results verify that the device can make the desired measurements in the demanding flight setting, while identifying some areas where design improvements are needed.

## **CONCLUSION**

We continue the development of this device, with special attention paid to the shortcomings revealed during the flights, noted above. Specifically, a better head-mounted display, improved software to allow the subject to use the device alone, and a more intuitive task are being explored. We anticipate making these changes and testing the improved package during future flights.

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Karmali F, Shelhamer M. Neurovestibular considerations for sub-orbital space flight: A framework for future investigation. *J Vestib Res* 2010;20:31–43.

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## **PHOTOGRAPHS**

NASA Photo: JSC2009xxxxx

## **VIDEO**

Zero G flight week 9/27 – 10/1/2010 Master/TSR: 103823

Videos available from Imagery and Publications Office, NASA JSC.

**TITLE**

The CEL-C2 Biochip: An Advanced Technology for Fundamental Space Biology Research

**FLIGHT DATES**

September 27–October 1, 2010

**PRINCIPAL INVESTIGATORS**

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Pedro Jofre, Purdue University, West Lafayette, IN

Kachi Odoemene, Purdue University, West Lafayette, IN

Andrew Hermann, Purdue University, West Lafayette, IN

## GOAL

The aim of our work is to optimize the Cell-Electrophysiology Lab-on-a-chip (CEL-C2) technology as a general-purpose fundamental space biology research tool. This biochip was designed with the specific scientific aim of understanding the gravity sensing behavior of unicellular spores of the fern *Ceratopteris richardii*. Particularly, we are interested in investigating the calcium current produced by the spores respond to gravitational force, and how it affects the growth and overall physiological phenomena of the fern spores.

## OBJECTIVES

The research has two specific objectives: 1) The technology objectives, and 2) The life science objectives.

The Technology Objectives (TO) focus on characterizing the performance of the biochip and its associated hardware. Test the sensing performance of the CEL-C2 biochip towards calcium sensing during rapid changes in gravity. The stability of the response of all the electrodes towards a fixed concentration of calcium will be noted in 1-g, micro-g, and 2-g phase of the flight. Important characterization parameters are sought, which includes:

- Variation in Nernst slope (key calibration parameter) of each biochip electrodes during rapid changes in gravity
- Sensing drifts
- Any variations in resolution of data collected during flight with the optimized data acquisition (DAQ) system
- Reliability and reproducibility of the biochip in aspects pertaining to electrical, electrochemical and mechanical elements of the biochip.

The Science Objectives (SO) focuses on building upon existing knowledge of the fern *Ceratopteris richardii* biological system. We are interested in outlining the molecular machinery, specifically the ion channels and associated calcium pumps.

- Determine gravity-sensing threshold of *Ceratopteris richardii* fern spores during sustained exposure to rapidly changing levels of gravity.
- Outline the molecular machinery involved in gravity-sensing through concurrent calcium transport measurements on wild type and gene knockout mutant fern spores as well as various drug treated spores.

## METHODS AND MATERIALS

The design of the CEL-C2 biochip is shown in Figure 1. The overall chip dimension is 10 mm × 11 mm and consists of 15 pyramidal wells that are 150 μm in width and length. The geometric design of the biochip is based on the size of the target fern spore. It is important that fern spore in the wells are located only 10 μm from the sensing electrodes. Each well has 4 electrodes leading into it at the 4 poles. Since there are 15 wells, and 4 electrodes protruding to each well, there are a total of 60 electrodes in all. The number of electrodes is based on the maximum possible number of electrodes that could be handled by a DAQ system that was developed in parallel with the biochip. In the CEL-C2 biochip, these electrodes were silver (Ag), similar to its first generation biochip – CEL-C (ul Haque, et al. 2007). The electrodes lead to the corner of the biochip, are terminated in gold (Au) bonding pads. The biochip electrode leads are insulated with

an SU-8 layer which also forms a fluidic well around each pyramidal well on the silicon (Si) substrate.

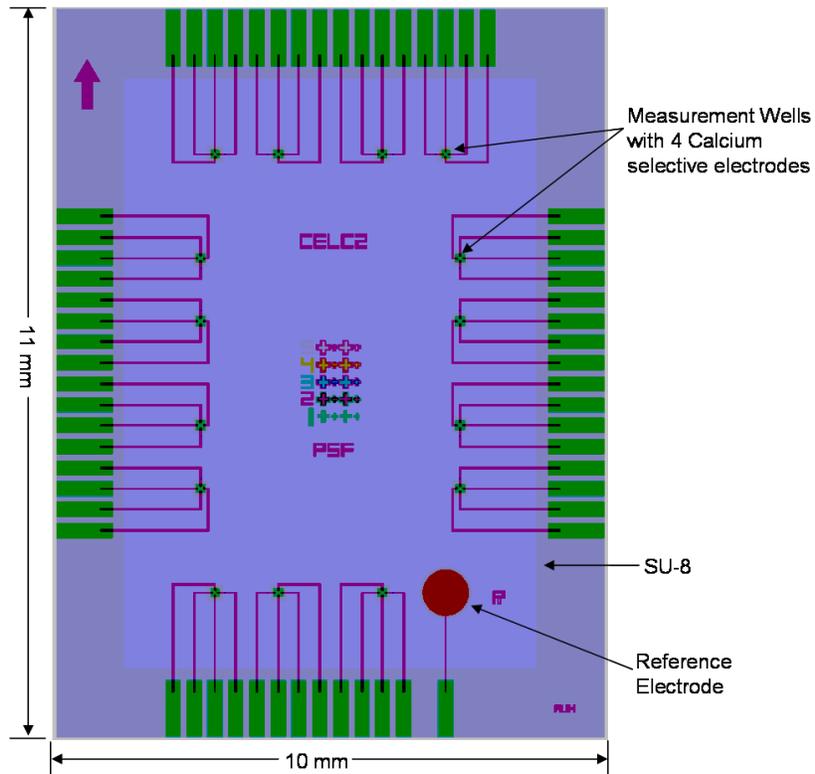


Figure 1 - Top view of the final design of the second generation CEL-C biochip.

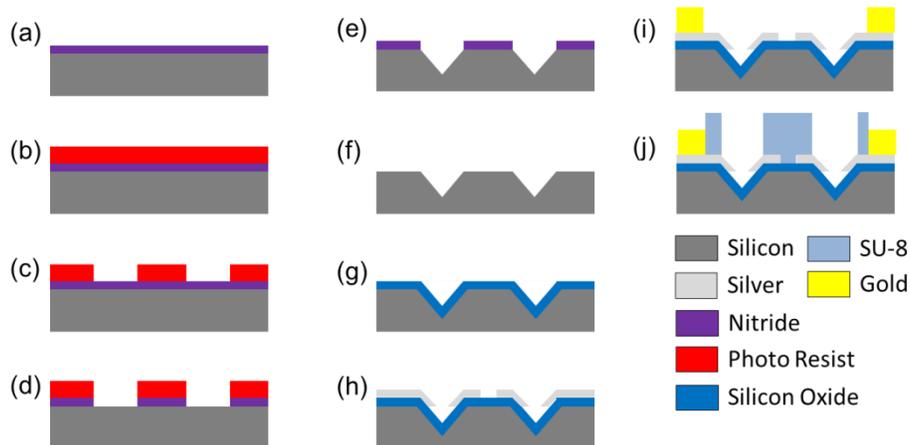
The Ag electrodes are treated with chloride bleach to yield Ag/AgCl electrodes, which the AgCl acts as an ion to electron transfer layer. The Ag/AgCl electrodes are coated with ion selective membrane, which are selective only towards ion of interest – in this case  $\text{Ca}^{2+}$ .

### *Ion-Selective-Electrode (ISE) Membrane*

ISE membrane main components consist of ionophores – neutral carriers which can extract ions of interest from solution, plasticizer or membrane solvent – membrane solvent that acts together with tetrahydrofuran (THF) as the main solvent, lipophilic ion exchangers – compounds that are used to ensure perm-selectivity of membrane and prevent ions of opposite charge than the target ion entering the membrane, membrane matrix – mechanical support matrix to the entire membrane structure which usually consist of polymer such as Polyvinyl carbonate (PVC) or Polyurethane (PU), and additives, – additional compounds used to lower membrane resistance.

### *Fabrication of the CEL-C2 Biochip*

The CEL-C2 biochip was fabricated at Purdue University Birck Nanotechnology Center. A multi-step silicon bulk micromachining and surface micromachining were employed in the fabrication of the CEL-C2. A 4-mask step process was used to fabricate the CEL-C2 biochip, and the key steps in fabrication process are illustrated in Figure 2.



**Figure 2 - Key steps in the fabrication process flow of the CEL-C2 device.**

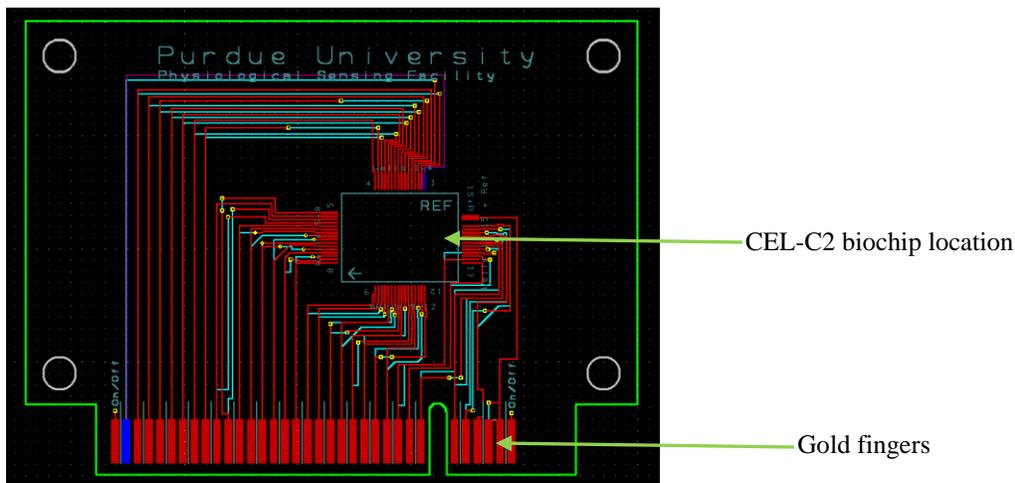
Fabrication is carried out on a single-side polished 4 in. [100] silicon wafer. The steps are outlined as follows:

1. A 3500 Å thick nitride silicon wafer was used as the substrate. The nitride layer acts as a mask layer for subsequent anisotropic silicon wet etching which defines the pyramidal wells.
2. Positive photoresist was spin-coated onto the wafer.
3. Photolithography was conducted to define the wells.
4. Plasma reactive ion etching was used to remove unmasked nitride layer.
5. Potassium hydroxide wet etching was performed to create terminated pyramidal wells in the silicon wafer.
6. Plasma reactive ion etching was used to remove nitride layer.
7. Plasma enhanced chemical vapor deposition was performed at 300°C.
8. A second photolithography was employed to define Ag electrodes. A 50 nm/150 nm thick Ti/Ag layer was patterned on the wafer via lift-off technique. In order to create a perfect lift-off, the photoresist was soaked in chlorobenzene – an aromatic organic compound, to create a photoresist profile that eased the removal of unwanted metal layer. An acetone gun was used to aid in removal of unwanted metal.
9. A third photolithography step was employed to define 500 nm thick Au metal contacts to the Ag electrodes.

10. Finally, SU8 – a clear polymer layer, was patterned in the final mask step. The SU8 layer serves to both insulate the electrodes and a cell to allow fern spores to be localized.

### *CEL-C2 Interface Development*

A high-density, low-cost and high throughput signal preprocessor and data acquisition system was developed to interface with the CEL-C2 biochip. The development of the Printer Circuit Boards (PCBs) was accomplished using Advanced Circuit's PCB Artist program. The pre-fabrication of the circuit board layout is shown in Figure 3. The final design consists of gold fingers which allow the chip to be seated into a cartridge vertically, absolving moving parts in the final product. The CEL-C2 biochip is located at the center and is wire-bonded onto the PCB.



**Figure 3 - Prefabrication of CEL-C2 interface chip. This view shows all the layers in the Interface v4.5 printed circuit board. This interface board is designed to place differential circuits opposite each other (front and back).**

### *CEL-C2 Software Development*

MathWorks® MATLAB writing environment was used to create the CELC program. The goals of the program were established and broken up into sub functions, and each program was prototyped.

### *CEL-C2 Hardware Development*

The signal generated by the CEL-C2 biochip is the membrane potential across the ISEs and measured by the electrodes. Factors that are deemed important in the design were response time, sensitivity, and noise reduction. Based on the Nernst equation pertaining to  $\text{Ca}^{2+}$  sensing with the ISE, the potential difference is 28 mV per decade change in  $\text{Ca}^{2+}$  ions concentration. The sampling of the DAQ system could be adjusted to fit the change in the biological phenomena. The response time could also be adjusted by changing the thickness of the ISE membrane – the thicker the membrane, the slower the response time.

Pre-amplification is necessary to isolate different biological signals. Amplified signals are less susceptible to noise, and various trends could be analyzed. The amplified circuit is designed to amplify signals from each electrode in parallel. It must also have an output range that does not exceed the capability of the DAQ.

### *Process before Flight Experiments*

Data acquisition hardware (DAQ) was screwed to the floor of the flight experimental cabin pre-flight and will remain there during the duration of the flight schedule. Each well of the CEL-C2 biochip was loaded with a single spore. The fluid reservoir was filled up with 1% Agar supplement culture medium and the cap screwed on. The medium solidified, holding the spores in place. The CEL-C2 biochip was interfaced with the PCB, enclosed inside a Faraday cage and taken aboard. Prior to start of the parabolas, this package was interfaced with the DAQ with simple cable connectors. The system automatically collected and displayed real time data for the duration of the flight. Figure 4 shows the CEL-C2 hardware system secured to the Zero-G plane floor.



**Figure 4 - The CEL-C2 hardware system secured to the Zero-G plane floor.**

## **RESULTS AND DISCUSSION**

The current design serves as a test bed for future flight experiments. We conducted several ground tests with the goal to both troubleshoot and provide explanation to the phenomena observed during the flight experiments. The errors in the results obtained from the flight experiments could be due to 3 major factors:

- Non-optimal germination condition of fern spores
- Failure of the ISE membrane
- Inadequate ISE membrane conditioning time

### *Non-Optimal Germination Condition Of Fern Spores*

Fern spores require specific condition for optimal germination (e.g., temperatures between 37°C and 44°C are generally best for germination). Due to unforeseen conditions, the aluminum also acted as a heat sink, lowering the temperature of the biochip to well below acceptable levels. Since fern spores required specific conditions for optimal germination, we were not able to collect meaningful biological data. Key characterization parameters obtained during flight experiments might vary due to these unforeseen variables.

### *Failure of the ISE Membrane Layer*

Solid-state ISE are prone to drift – a change in potential measured without actual change in the primary ion concentration (Bobacka, et al. 2008; Bakker, et al. 2008). The ISE membrane recipe that was drop coated on the CEL-C2 biochip did not contain polyurethane, a polymer that increases the adhesion of membrane matrix to silicon/silicon oxide substrate (Piao, et al. 2003). Due to this, there is possibility that there is a leakage of ions at the Ag/AgCl – ISE interface. This builds unwanted aqueous layer, creating unwanted signals. Also, a complete removal of the ISE layer due to the lack of adhesion could occur. A complete characterization and improved recipe of the ISE is needed.

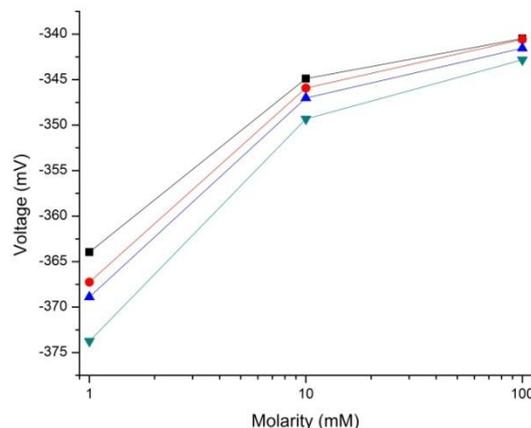
### *Inadequate ISE Membrane Conditioning Time*

The ISE membrane should be left in the calcium conditioning solution prior to measurements. The conditioning solution, which consists of 10  $\mu$ M CaCl + 100 mM NaNO<sub>3</sub>, is necessary to activate the membrane (Konopka, et al. 2004).

### *Current Work*

We are currently designing an enclosure for the CEL-C2 biochip that acts as both a Faraday cage and at the same time should insulate the biochip. We have tested biochips that were coated with two types of ISE membrane, one with PU and one without. The Nernst slopes was averaged to be ~28 mv with decades of change in calcium ion concentration (Figure 5). This value is consistent across all fabricated biochips. We are also testing the change in Nernst slope with varying conditioning time.

Several factors could contribute towards measurement drift. Previously, a nano-injector was used to deposit pico-liter volumes of ISE membrane solution into the etched pyramidal wells. We found that this is not a reliable technique; mainly this method produces non-uniform and unknown membrane thickness. We replaced the drop-coating technique by spin coating technique. The spin-coating technique creates a thin film on the entire biochip with known thickness. This is followed by a vacuum suction – allowing the ISE membrane solution to enter into the wells and solidify uniformly onto the electrodes. Furthermore, to increase adhesion, the biochip was silanized before ISE membrane solution deposition. The silanization process is to create bonds across the interface between biochip surface and organic components in the ISE membrane solutions. We are also characterizing several alternative ISE membrane recipes.



**Figure 5 - Calibration curves from ISE electrodes from a single well. Electrode output was measured against Ag/AgCl reference electrodes. Calibration solutions are 1, 10, and 100 mM CaCl<sub>2</sub>. Though a slight drift is observed, the result is consistent over several measurements.**

### *Future Work*

Conducting polymers (CP) will be used to replace AgCl layer as an ion to electron transducer. This is because the AgCl layer is easily depleted overtime. The conducting property of CP is because of their capability to undergo rapid redox reaction – shuttle between a reduced and oxidized state (Michalska 2006). The CP has advantage of creating long lifetime solid state ISEs (ul Haque 2010).

## **CONCLUSION**

We have improved the fabrication of the biochip, and optimized the hardware and software capability. We have tested the capability of the CEL-C2 biochip in microgravity environment, with identified difficulties. The redesigned CEL-C2 biochip system with associated hardware and software were functional and the flight experience served as a test bed for further experiments. Due to the nature of the work that is also oriented towards life science, more controlled experiments are needed to understand the dynamics of the intrinsic calcium current in the fern spores cellular system. This includes creating a suitable environment for spores' germination during flight conditions, optimizing the ISE membrane recipe and deposition techniques on the biochip, and overall reliability test of the CEL-C2 biochip.

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## **VIDEO**

Zero G flight week 9/27 – 10/1/2010 Master/TSR: 883287/109683

Videos available from Imagery and Publications Office, NASA JSC.

**TITLE**

Universal In-Flight Health Diagnostic Technology: The rHEALTH Sensor

**FLIGHT DATES**

September 29–October 1, 2010

**PRINCIPAL INVESTIGATOR**

Eugene Chan, DNA Medicine Institute (DMI), Boston, MA

**COINVESTIGATORS**

Candice Bae, DNA Medicine Institute, Boston, MA  
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Terri McKay, Glenn Research Center, Cleveland, OH  
Emily Nelson, Glenn Research Center, Cleveland, OH  
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Julia Zimmerman, DNA Medicine Institute, Boston, MA



## **GOAL**

With the retirement of the Space Shuttle, the return of biological samples from the International Space Station (ISS) will be challenging, if not impossible, due to significant volume limitations on the Soyuz. If human presence in space is to continue and astronauts are to travel deeper into space, a convenient and efficient means to monitor astronaut health is necessary. We are developing a universal diagnostic technology, called the rHEALTH sensor, designed to shrink the work of a hospital laboratory into a handheld device and to require only a single drop of blood. The device ultimately aims quantify key blood factors, such as complete blood counts, electrolytes, and various biomarkers. We wished to demonstrate the early functionality of our sample loading system, microfluidic chip, and rHEALTH prototype under lunar and zero gravity conditions.

## **OBJECTIVES**

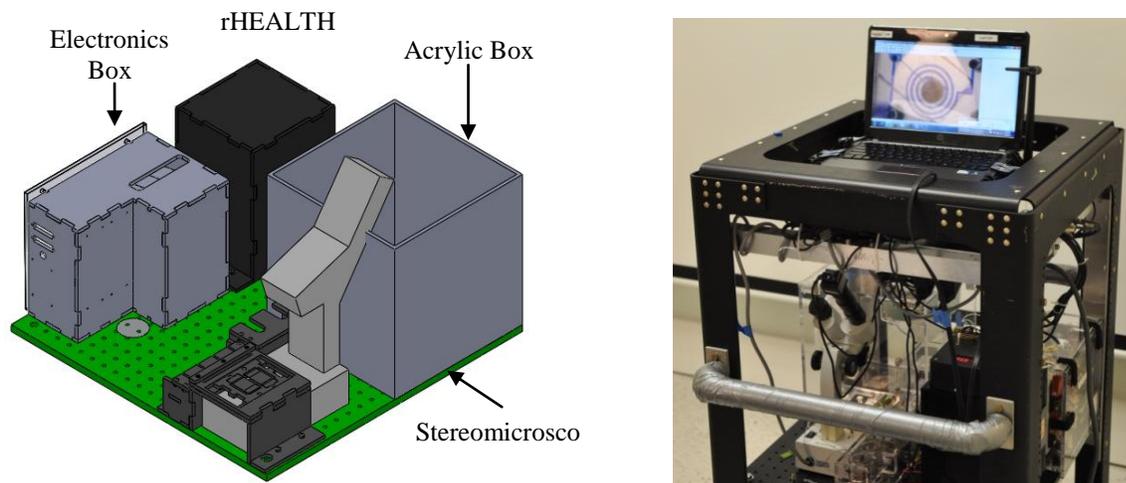
For a universal blood sensor to be practical for spaceflight, it needs to be simple, easy-to-use, and fully integrated from sample acquisition through analysis. Manual pipetting steps, such as required for dilution and mixing, add unnecessary complexity to any on-orbit analysis. The rHEALTH device is designed to be a fingerstick to analysis device that simplifies analyses on a single drop of blood. We separately tested the major components of our rHEALTH sensor in 3 separate Technical Objectives.

1. Technical Objective 1 (TO1) was to assess the ability of microfluidic chips used in the device to adequately and quickly mix dye solutions and blood on microliter scales. Microfluidic mixing is a critical function of the device because blood specimens will need to be adequately mixed with detection reagents and diluents prior to analysis. Second, we desired to test the effects of air bubbles in our microfluidic device since bubbles behave differently in reduced gravity than at 1g.
2. Technical Objective 2 (TO2) was to assess the ability of the rHEALTH detector to detect fluorescent calibration beads, nanostrips, and human blood cells. Nanostrips are unique reagents developed at DMI that allow for massive assay multiplexing in the rHEALTH sensor.
3. Technical Objective 3 (TO3) was to assess whether a human using the device could successfully use our proprietary capillary loader to send samples to the rHEALTH sensor. A successful capillary loader bridges the macro- to micro- interface in our microfluidic system. The goal was to repeat the same 3 objectives at both lunar and zero g conditions to determine any g-effects on the rHEALTH technology.

## **MATERIALS AND METHODS**

General Test Rig Set up and Operation. Our test rig comprised of 5 major components: the prototype rHEALTH sensor, a stereomicroscope, an acrylic glove box, an electronics box, and a laptop (Figure 1). With the exception of the laptop, these items were screwed down to a microscope breadboard plate. This plate was then fitted to a vertical equipment rack that was bolted to the floor of the Zero-G aircraft. The laptop was attached to the top of the rack. The experiments were primarily operated through the laptop, which controlled various devices throughout the rig via custom National Instruments LabVIEW programs, and recorded all data. All information sent to and from devices was set to relay through USB data acquisition cards in the electronics box. Sample flow to all locations occurred through microbore tubing and a valve

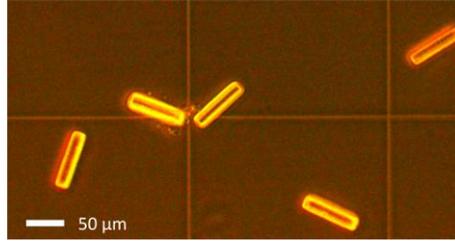
system. Flow was driven by a miniature air pump and a differential pressure sensor was used to measure the average pressure drop across the chip over 0.1 second intervals. All experiments were performed under both lunar and microgravity conditions.



**Figure 1 – Major test rig components and rack. (A) The prototype rHEALTH sensor, a stereomicroscope, an acrylic glove box, an electronics box were screwed to an optical breadboard plate. (B) The laptop rested above these other four components on a vertical equipment rack. The rack served to mount the equipment ergonomically for the experiments.**

*Technical Objective 1 (Microfluidic Mixing).* Mixing demonstrations were performed in microfluidic chips resting outside the rHEALTH and mounted beneath the stereomicroscope to allow for monitoring of mixing activity. Two mixing demonstrations were performed: (1) blue + yellow dye mixing, and (2) red blood cells (RBCs) + phosphate buffered saline (PBS) mixing. For each demonstration, samples were driven to chips by differential pressures supplied by the pump. Desired pressure values (1.5, 2.0, 3.0, 4.0, 5.0, and 6.0 psi) were dictated through our TO1 LabVIEW program. Each pressure point lasted at least one parabola. A color CCD camera captured video of the mixing process through the microscope eyepiece. Mixed samples were channeled out of the chips and through a flow meter to capture flow rate for the lunar flights, and flow rates were approximated by visually measuring fluid flow for the zero gravity flights. Pressure, video, and flow readings were synchronized with readings from an accelerometer by an external trigger in a TO1 LabVIEW control program. To study the effect of air bubbles, air was automatically injected into the blood-saline demonstration, and the system was then allowed to return to the mixing state.

*Technical Objective 2 (rHEALTH Fluorescence Detection).* Fluorescent calibration beads (~4.24 beads/ $\mu$ L), fluorescently labeled nanostrips (produced at DMI), and fluorescently stained human white blood cells (100x diluted) were run through the rHEALTH for detection. Samples were driven to the rHEALTH at a desired differential pressure of 2 psi, each for several parabolas, and separated by a 1x PBS wash of the system lasting at least 2 parabolas. Within the rHEALTH, a laser and a detector captured time-of-flight signals from the particles flowing through the rHEALTH's flow channel (Figure 2).



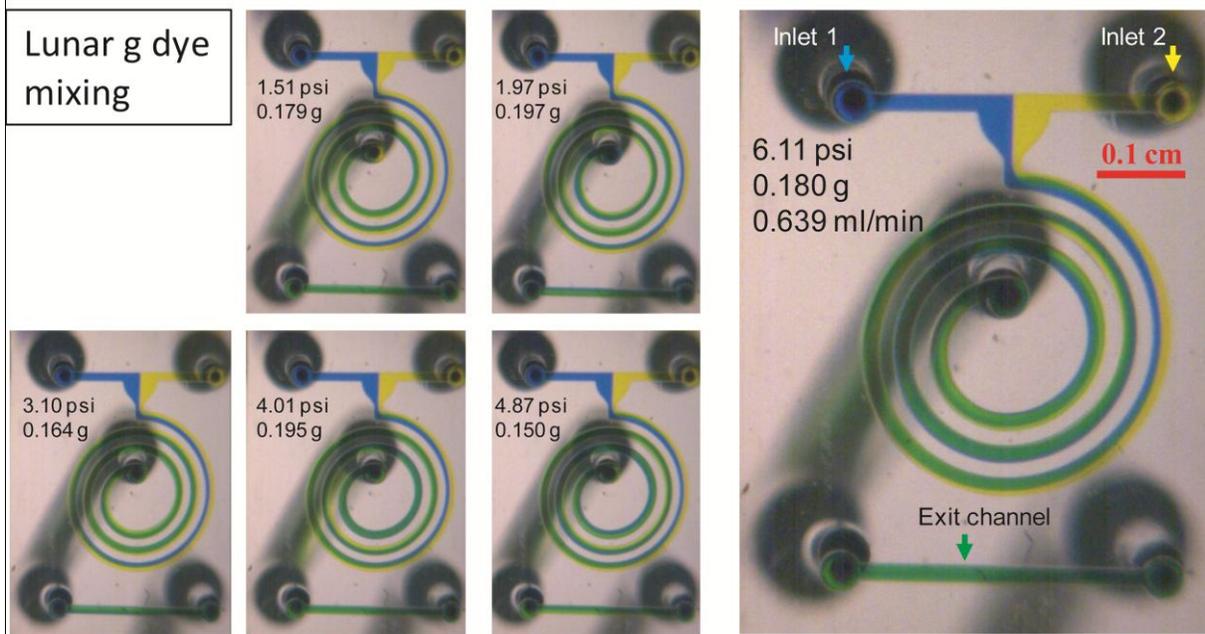
**Figure 2 - Darkfield image of nanostrips.**

*Technical Objective 3 (Sample Loading).* Within the confines of the acrylic box, a drop of simulated blood (fluorescent beads mixed with blue food coloring) was loaded onto a fingertip using a pre-loaded blunt end syringe. This sample resided on the finger until the aircraft reached reduced-gravity conditions, at which point, the sample was picked up using a plastic capillary tube in a custom holder. The sample was loaded into our proprietary capillary loader system and 1x PBS at 2 psi was utilized to drive the sample into the rHEALTH for detection. This process was repeated 3-5 times for both lunar and zero gravity.

## **RESULTS AND DISCUSSION**

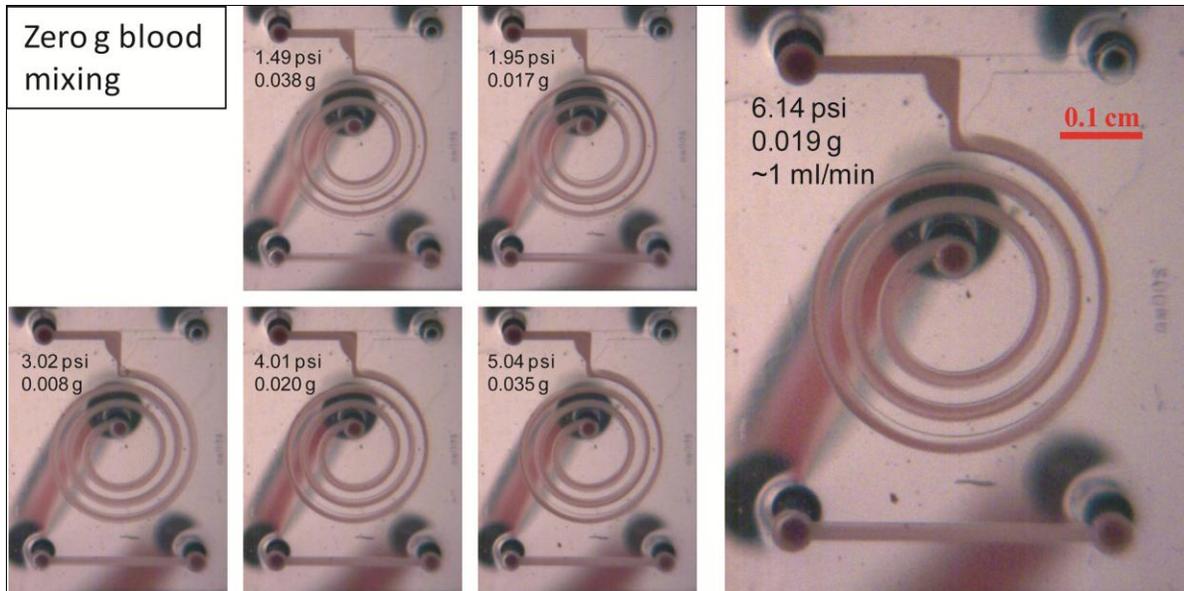
We successfully collected data for all 3 technical objectives in lunar and zero gravity. The flights provided us with significant, high-quality data for assessing the performance of each technology area. Microfluidic mixing, rHEALTH detection, and sample loading functioned well in reduced gravities.

*Technical Objective 1. General:* Synchronized pressure, accelerometer, and video readings were captured as desired aboard both the lunar and zero-g flights for both dye mixing and blood-saline mixing. Synchronized flow rate meter readings were captured for the lunar gravity experiments. Gravity Conditions: Parabolas were preceded with a period of level flight and, in some of the mixing experiments, were interrupted midway with a second period of level flight. Otherwise, gravity conditions alternated between periods of high gravity ( $>1.5$  g) and low gravity ( $\sim 0.17$  g for lunar-g,  $<0.1$  g for micro-g, lasting approximately 30 seconds per parabola). Mixing. Figure 3 shows the summary images from the lunar g mixing experiments, from 1.51 to 6.11 psi.



**Figure 3 – Lunar g dye mixing. Images of microfluidic mixing chip at various pressures and measured g-levels. The blue and yellow dyes combine in the T-junction, mix in the spiral, and enter the exit channel where they are analyzed.**

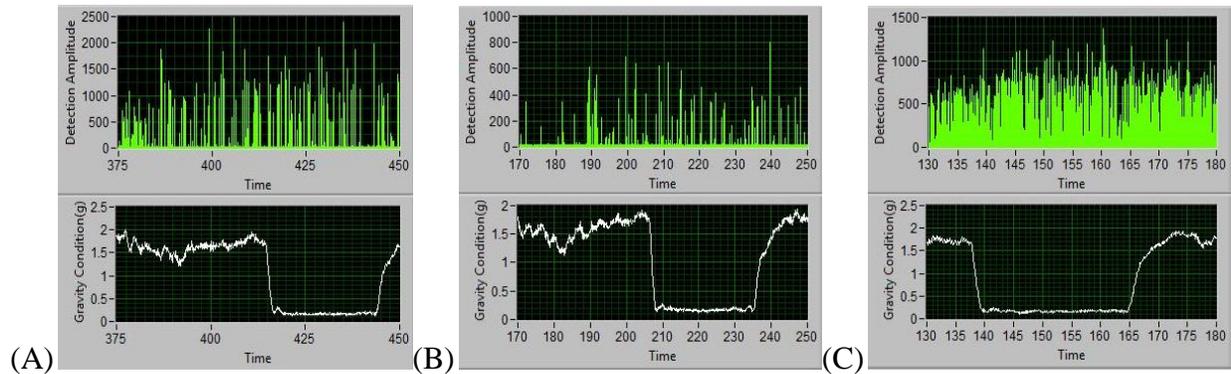
The g-level is shown in each figure. Blue dye was introduced into inlet 1 and yellow dye into inlet 2. Equal pressures were applied to the both inlets. Mixing is evidenced by green. Mixing is observed in the spiral at all the pressures. Further mixing is observed after the sample passes through the drain tubing, which connects the center of the spiral to the detection channel. We performed blood mixing experiments, which combined red blood cells and saline. Since blood cells have virtually no diffusion, these experiments were a stringent test of our mixing geometries. Figure 4 shows blood saline mixing in microgravity for pressures 1.49 to 6.14 psi. Red blood cells and saline were combined in the T-junction and mixed in the spiral and drain channels. Increased mixing was observed before and after the spiral and also at higher pressures. Similar results were attained for lunar g blood mixing, microgravity dye mixing, and mixing at 1 g.



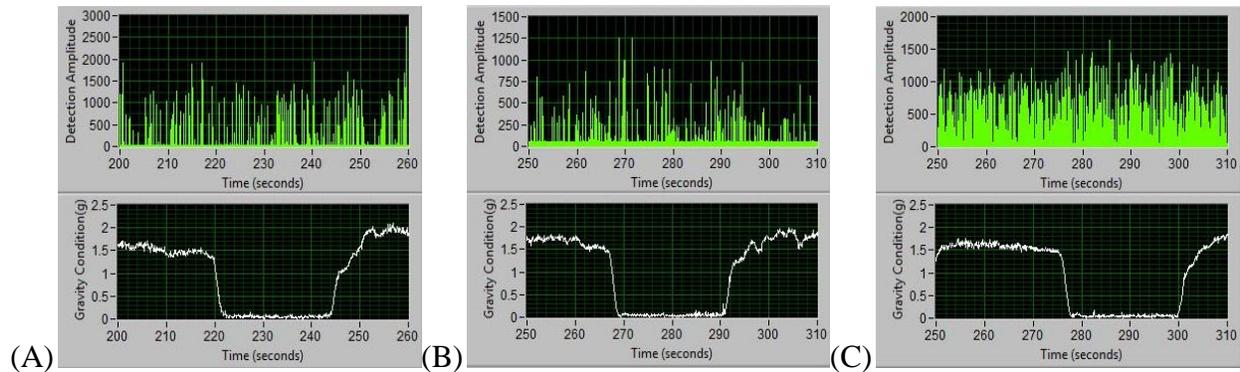
**Figure 4 - Blood saline mixing at microgravity. Blood mixing is observed with increasing pressure at the microgravity levels indicated.**

Comparison with images at 1.8 g demonstrate that shifts from high to low gravity, and from low to high gravity did not affect the mixing process. Bubble Experiment: Comprehensive analysis of video data provided no convincing evidence that reduced gravity conditions compromise the ability of bubbles to pass through the microfluidic chips. Different sized air bubble pass through the system readily.

*Technical Objective 2. General:* Detection results were captured for each sample generally for 3 parabolas each as desired during both the lunar and microgravity flights. Gravity Conditions: The gravity conditions were similar as for the first objective. Detection: Robust signal detection was observed for all samples tested under lunar (Figure 5) and microgravity (Figure 6) conditions. We did not observe any changes in performance of our rHEALTH detection at the ranges of g-levels tested. Furthermore, we did not observe any adverse effects of vibration from the airplane. Vibration is experienced on takeoff and landing. Peak heights were similar on the lunar and zero gravity flights. The peak counts were dependent on the input concentration of the sample and were consistent between the samples analyzed for both lunar and microgravity. The results demonstrate that reduced gravities do not impact the optical system or the passage of the particles through the laser detection region.

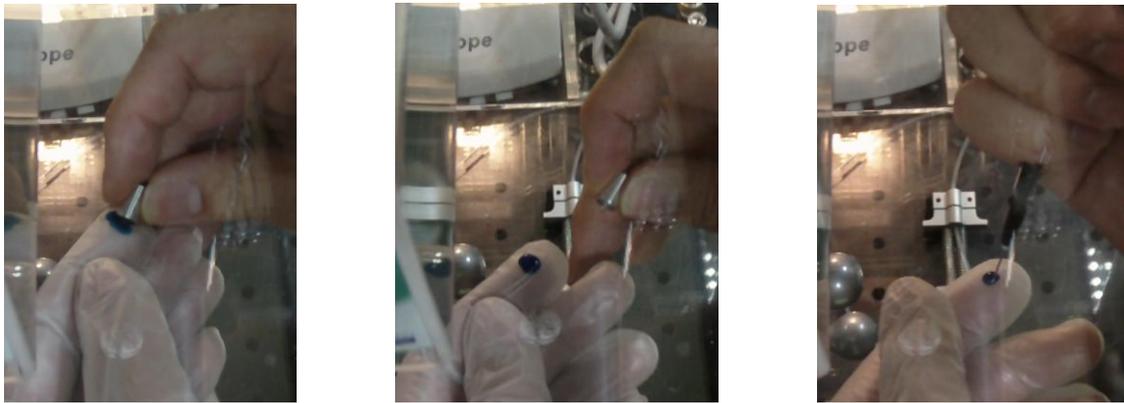


**Figure 5 - Lunar gravity rHEALTH detection; (A) fluorescent beads, B. nanostrips, and (C) human white blood cells.**

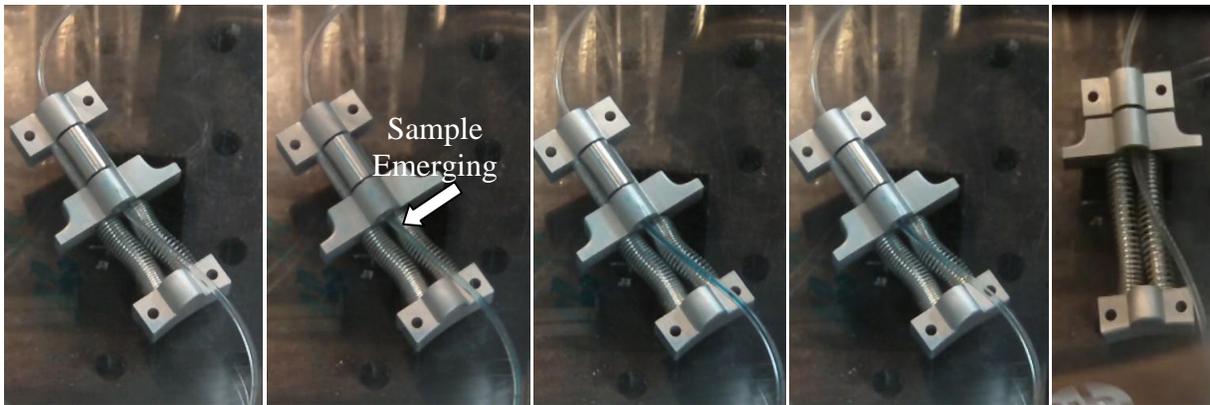


**Figure 6. Microgravity rHEALTH detection. (A) fluorescent beads, (B) nanostrips, and (C) human white blood cells.**

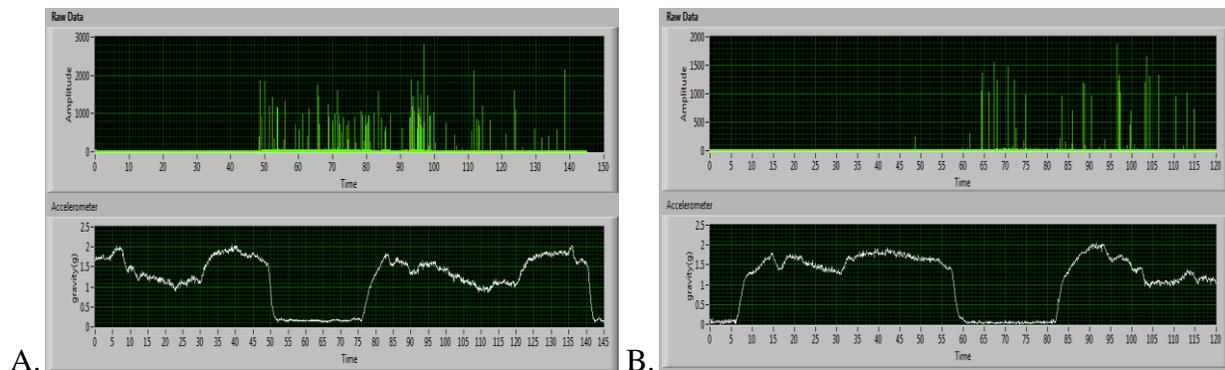
*Technical Objective 3. General:* Capillary loading was successfully repeated several times under both lunar and microgravity conditions. *Gravity Conditions:* An example under lunar gravity conditions is shown in Figure 7. During high gravity conditions (up to 2g), sample drops flattened out on the finger tip. The sample remained on the finger at all times due to surface tension. *Sample loading.* Under both reduced gravity conditions, loading was accomplished with success comparable to that achieved under 1g conditions. Once the capillary was loaded, it was successfully placed within the capillary loader device and outflow was observed once 1x PBS started to drive the sample towards the rHEALTH. Sample flow from the loader under microgravity conditions is shown in Figure 8. The in-line nature of the capillary loader allowed it to be analyzed by the rHEALTH sensor shortly after loading (Figure 9).



**Figure 7 – Capillary loader and loading under lunar-gravity conditions. User was able to successfully load capillary under reduced gravity conditions. Center image shows drop flattening under high-g conditions.**



**Figure 8 – Sample flow from capillary loader. The blue dye/fluorescent bead sample is shown emerging from the sample loader in the sequential image frames.**



**Figure 9 - Example sample detection data for TO3. Samples loaded under (A) lunar gravity and (B) microgravity conditions reached for rHEALTH for detection.**

## CONCLUSION

While a full effort to perform a comprehensive and quantitative analysis of our experiments is underway, we can reasonably conclude that the major technology components (sample loading, micro fluidic mixing, and rHEALTH detection) remain uncompromised in reduced gravity conditions. Furthermore, the system is insensitive to vibration, g-level changes, and cabin

pressure variations. These results provide insight into the suitability of the rHEALTH technology for analyzing biological samples in space. From these studies, a fully integrated rHEALTH can be developed to assess the health status of ISS crew members.

## **ACKNOWLEDGEMENTS**

The work described here was supported by the NASA SBIR Contracts NNX09CA44C, NNX10CA97C, and NNC11CA04C. The human blood collection was performed using NASA IRB Protocol # SA-10-008. Special thanks to the Facilitated Access to the Space Environment for Technology 2010 Program, the NASA Reduced Gravity Office, the Human Adaptation and Countermeasures Division, Glenn Research Center, Zin Technologies, and the Human Research Program.

## **PHOTOGRAPHS**

JSC2010e169440-1  
JSC2010e169448  
JSC2010e169474  
JSC2010e169485  
JSC2010e169491-22  
JSC2010e170483-91  
JSC2010e170540-42  
JSC2010e170629-37

## **VIDEO**

Zero G flight week 9/27 – 10/1/2010 Master/TSR: 883287/109683

Videos available from Imagery and Publications Office, NASA JSC.

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**TITLE**

H2U Food Growth Chamber

**FLIGHT DATES**

Flight Days: April 5–6, 2011

**PRINCIPAL INVESTIGATOR**

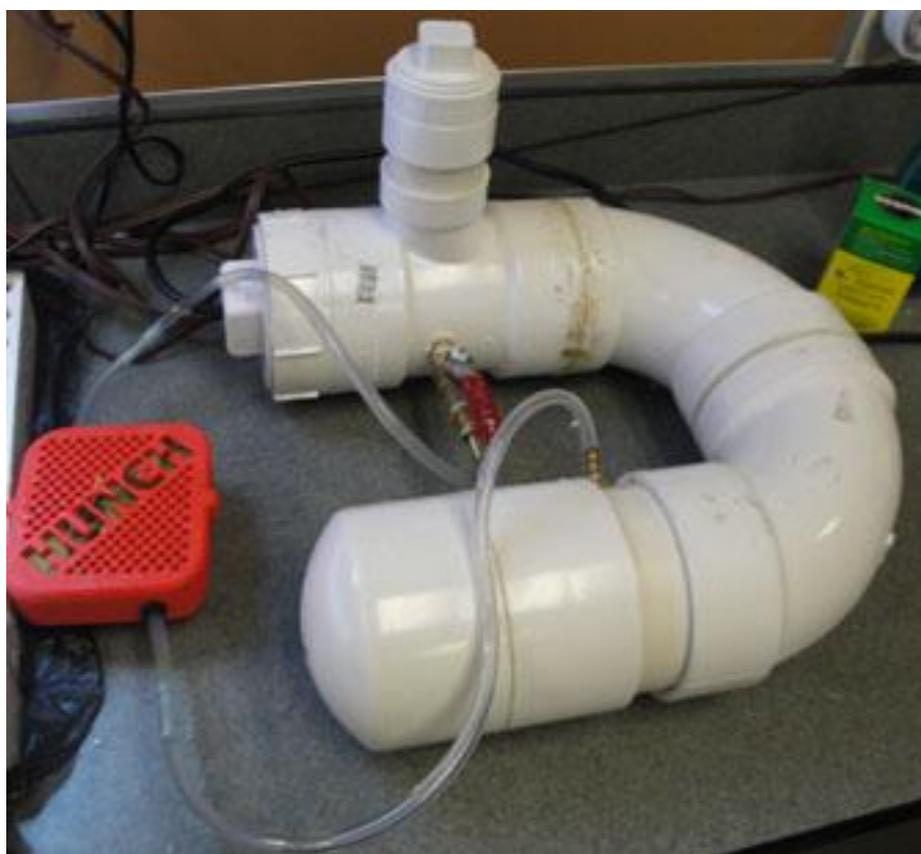
Nate Olsen, Warren Tech, Lakewood, CO

**COINVESTIGATORS**

James Harberer

Garrett Lipker

Tristan Babcock



## GOAL

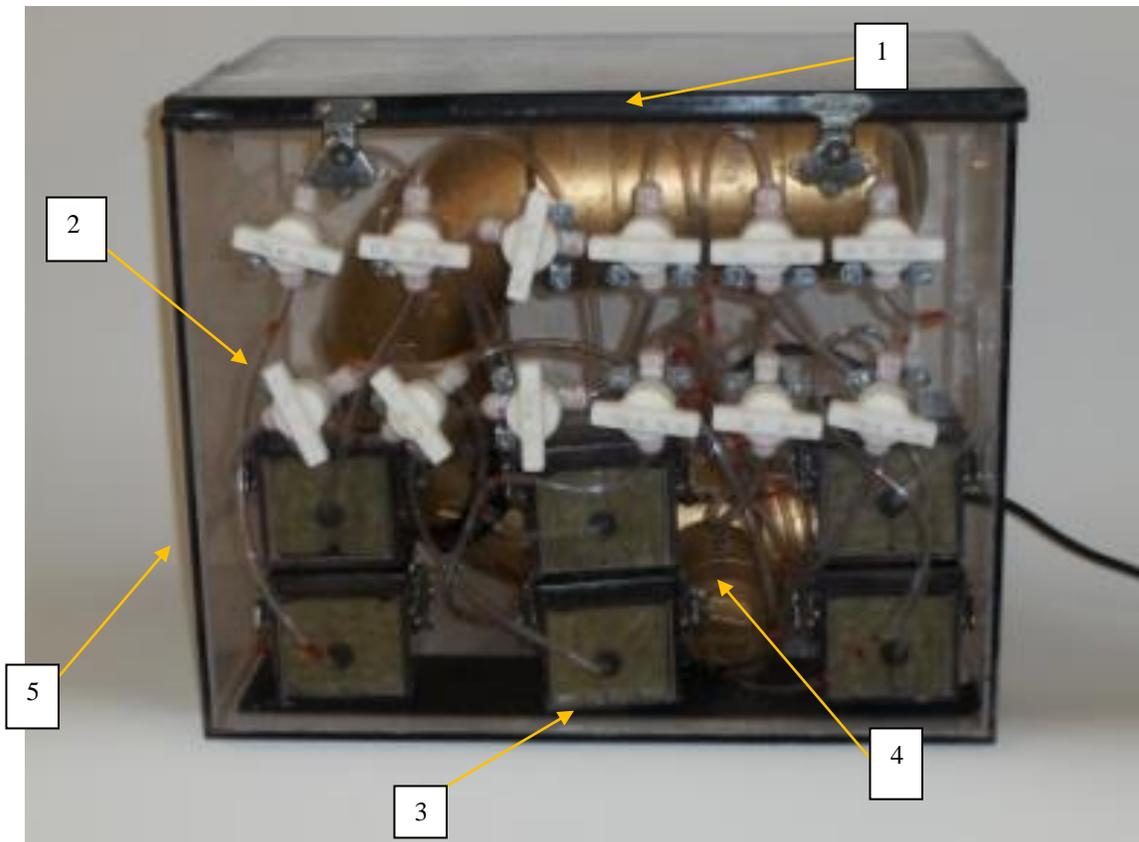
To provide an environment to sustain long-term growth of plants in zero gravity.

## OBJECTIVES

To create a food growth chamber capable of growing Tiny Tim tomatoes and lettuce, supported by our artificial green house. The food growth chamber was developed to reduce the need for food re-supply in space, especially for long-duration missions. The experiment tested the water dispersion in a microgravity environment, because without the proper watering of the plants they will not survive. We observed the water dispersion through a Rockwool cube to perfectly saturate it enough for a plant to grow.

## METHODS AND MATERIALS

Hydroponics systems are when the plant is being watered through a substitute growing medium, such as Rockwool, to transform the plant into a constant water environment. By doing so there will be no shock to the plant when in a microgravity environment and it is suddenly watered. The hydroponics experiment is contained inside a box constructed from Lexan that will be placed inside a NASA Reduced Gravity Office Glove Box to provide the double containment of the water that is required. The experiment relies on a submersible water pump, PVC piping, and hoses drilled with different size holes to water the Rockwool. The 6 containers will be stacked in columns of 2 to save space and also make the visibility of the Rockwool containers easier to see when the hydroponics system pump is running.



1. PVC Water tank
2. Hose
3. Lexan containers with Rockwool
4. Pump (Within the PVC)
5. Lexan Box

## **RESULTS**

The water dispersion through the Rockwool cube gave us great results. It helped us as a team to find out how water behaves in a microgravity environment. We learned that our tank soon turned into a vacuum, which pulled the water towards the pump. The results of the microgravity flight helped answer the question of will water return to the pump.

### *Challenges*

There were a few challenges during the Zero-G flight. One of the biggest problems that we faced was a power outage that stopped our whole experiment from running. With no power our data collected from that day was not as sufficient and accurate. Some minor problems that also occurred were the valve handles that were printed from the 3D printer would break off inside the Lexan box because of some miss handling of them. Our final problem was the food coloring. With the food coloring of the water not acting in the correct way, it was impossible to see the water flow through the container and at times we were unsure if the water really was flowing.

### *Successes*

In the flight, we experienced a success in all of our questions that we created before the flight. One of the biggest questions was would the water transfer from the top of the PVC container all the way down to the bottom to keep a continuous flow of water. This question was answered with a great accomplishment of creating a vacuum like container pulling all water towards the pump to keep watering flowing. Another question we encountered was would the water disperse evenly throughout the Rockwool cube? This also was a question that was answered as an accomplishment for our design. While floating around in a microgravity environment the water dispersed through the Rockwool cube in a circular like pattern extending out from the center of the hose. With all of our major questions of this experiment being a great success, we were ensured that this was an experiment that would work in space.

## **CONCLUSION**

All of our questions were answered and our watering system was efficient in a microgravity environment. Our future ideas and questions that we plan to test is the perfect watering amount for plants. With the question being unknown at the moment it is in our further conquest to find the answer and hope to test it out.

## **ACKNOWLEDGMENTS**

Florence Gold for all her great support that led to the success of the project. With her intelligence and funding for our project, we could not be at half of what has been created. With her great ideas we were able to change and form new ideas that helped to create this amazing experiment.

Dr. Madrid we would like to graciously thank for his great knowledge of the Zero-G plane and all the technical problems that could occur. With his help we were able to finish parts of the TEDP and fill in some of the blanks that us students could not.

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**TITLE**

HydroFuge Growth Chamber

**FLIGHT DATES**

Flight Days: April 7–8, 2011

**PRINCIPAL INVESTIGATOR**

Matthew Brown, Lakewood High School, Lakewood, CO

**COINVESTIGATORS**

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## **GOAL**

To create a unique, functional plant growth chamber using centrifugal technology to produce an ideal environment for vegetation under microgravity conditions.

## **OBJECTIVES**

A common problem in space is that the water retention on the roots and lack of gravity prevents the water from dripping off, causing the plants to drown or develop disease such as Root Rot. The main project objective was to develop a solution to this issue. Testing Tiny Tim Tomatoes, the chamber used a centrifuge to flick the water off of the roots, while simultaneously simulating gravity through the forces of inertia.

The Zero-G flight objectives were to find the optimum speed for the centrifuge spinning the entire plant and to observe the system functionality (including water tank, micro pump, motor, aerator and distributor, and control panel).

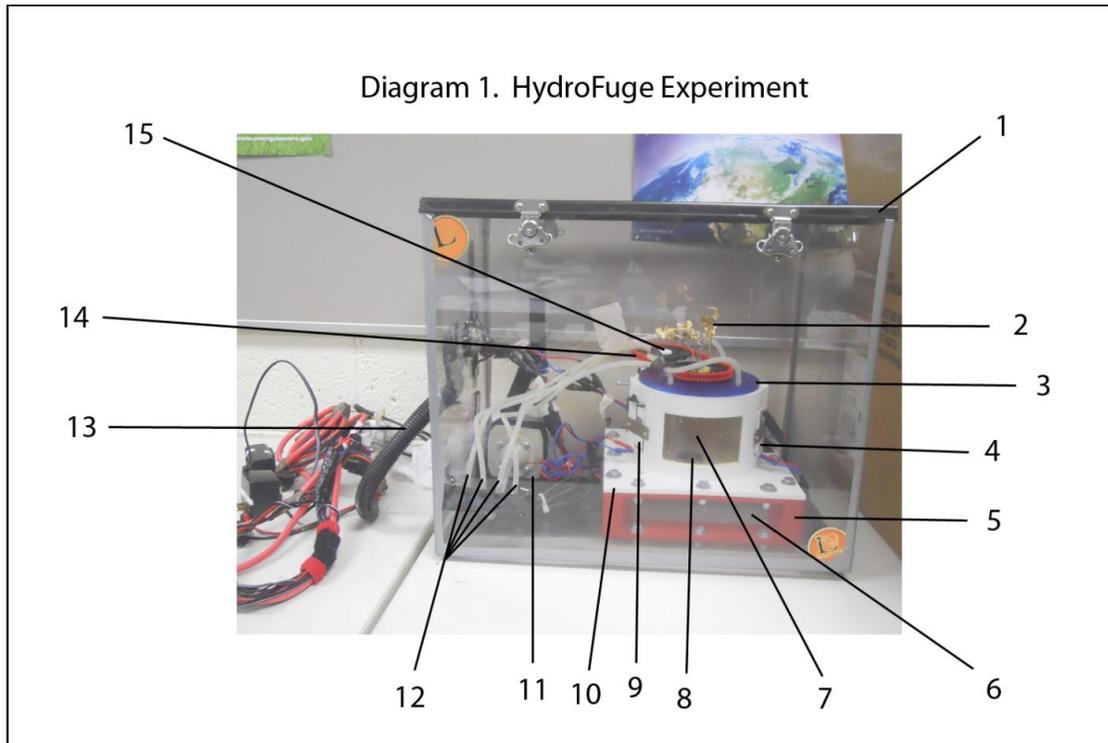
Ultimately, we plan to provide alternative, fresh food sources for astronauts in space as well as evaluate the psychological benefits of flora in a sterile environment. We hope to actualize this concept through a personal plant growth chamber for astronauts.

## **METHODS AND MATERIALS**

Our system, HydroFuge, is based on the concept of aeroponics, a plant system that suspends a plant in air and sprays the roots with a nutrient/water solution. The chamber is comprised of numerous parts. The plant is rotated by a bearing spun by a motor and adjustable chain functions as a centrifuge. The roots hang inside the water-tight chamber, where a mister sprays the roots. Once there is water on the roots, the centrifuge spins the plant and flicks the water from the roots to the sides of the plant chamber. An aerator pumps air through the air distributor, into the chamber, forcing the water down the sides of chamber and sloped surface of the chamber through a check-valve. The water then goes into a sealed water chamber to be recycled by the micro pump sending water to the mister.

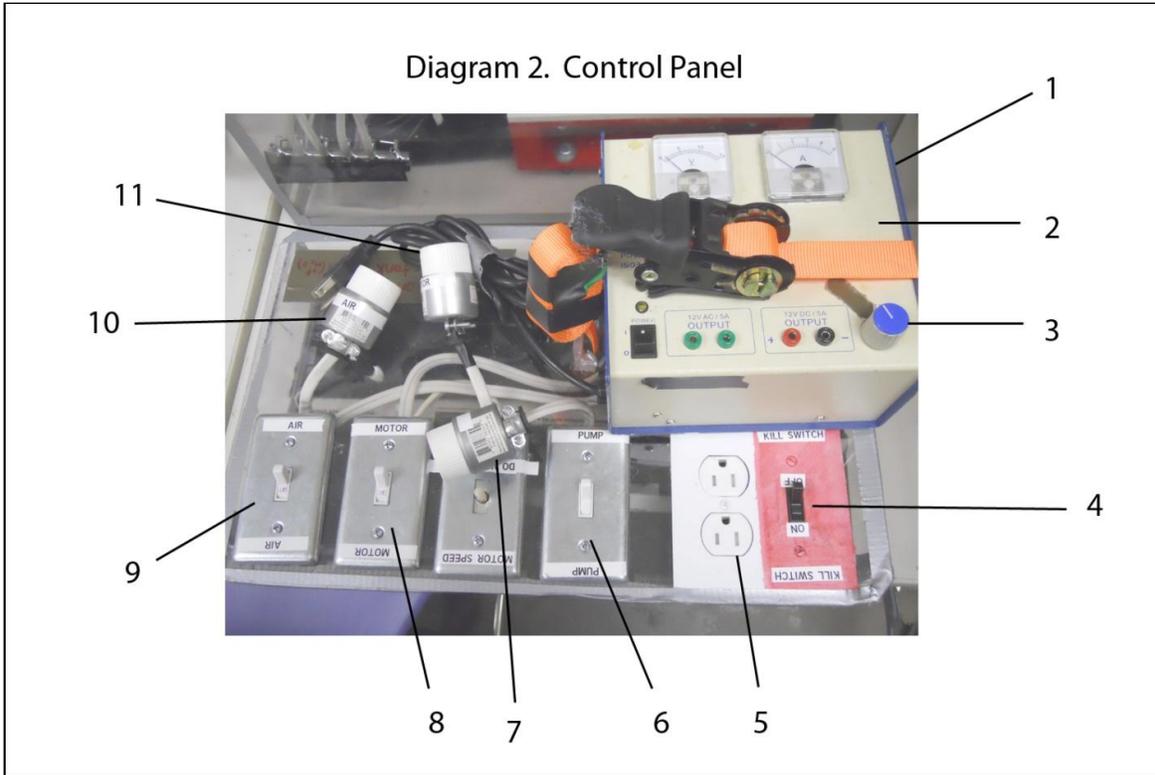
The system is contained inside a 2 × 3 × 3 foot Lexan box placed inside a NASA Reduced Gravity Office Glove Box to provide the required double containment. The primary system parts (centrifuge container with root chamber and water chamber) were printed in a Dimension 3D printer out of ABS plastic. The two parts were then sealed with silicone caulk and bolted together using 12, 5/16 in. zinc-plated, hex head bolts. The plant was placed inside a sealed, steel bearing. The steel bearing was spun by an ABS chain controlled by a motor. The aerator, placed inside the Lexan box outside of the actual system was an ActiveAqua air pump. Vinyl plastic tubes were attached to the aerator and led to holes in the top chamber into the root chamber to distribute air in order to push the flicked water back into the water chamber. Windows were installed in the root chamber and water chamber to allow for observations during the flight. These were made out of sheets of polyurethane that were then silicone caulk-sealed. LED lights (1.5 in. × 0.5 in.) were also installed on both the root and water chambers to make the specimen more visible during the experiment. A mister with a nozzle was installed in the bottom of the root chamber to mist the roots. A 2-in. ABS plastic check-valve was fitted in the bottom center of the root chamber to send through the valve into the chamber. In the water chamber, a

submersible-micro pump was secured to the bottom using Velcro. The 14 mm × 14 mm × 28 mm pump ran on 12 VDC power and pumped 250 mL a minute. The entire system was managed from the control panel, attached to the floor of the plane using Velcro. The structure of the control panel was created out of Lexan, with labeled switches made out of metal light-switch wall panels for the lights, micro pump, aerator, and kill switch, and a dimmer switch for the motor to control the centrifuge's speed.



- |                                 |                        |
|---------------------------------|------------------------|
| 1. Lexan box                    | 9. LED light           |
| 2. Plant in bearing             | 10. Plant root chamber |
| 3. Air distributing chamber cap | 11. Aerator            |
| 4. LED light                    | 12. Air tubes          |
| 5. Water tank                   | 13. Wire harness       |
| 6. Submersible pump             | 14. Adjustable chain   |
| 7. Mister                       | 15. Rotating gears     |
| 8. Check-valve                  |                        |

Diagram 2. Control Panel



- |                                     |                         |
|-------------------------------------|-------------------------|
| 1. Panel power supply plug (behind) | 7. Pump outlet          |
| 2. Motor power supply               | 8. Motor power switch   |
| 3. Motor speed adjustment           | 9. Aerator power switch |
| 4. Kill switch                      | 10. Aerator outlet      |
| 5. LED lights outlet                | 11. Motor outlet        |
| 6. Pump power switch                |                         |

## RESULTS

System/Part	Function of System	Appearance	Efficiency	Errors	Needed Changes
Plants	Plants are spun in centrifuge and water tension on the roots is observed	Top half of plant visible through Lexan box and roots visible through root chamber window. Roots looked tangled and clumped.	Flight Day 1, plant was inefficient because of size and root length (became tangled, broke, and ruined the micro pump). Flight Day 2 proved more efficient with a smaller plant	Roots too long; plant height limited by space-restrictions	Solution for plant roots such as a pump filtration system; more versatility for varying plant sizes

<b>System/Part</b>	<b>Function of System</b>	<b>Appearance</b>	<b>Efficiency</b>	<b>Errors</b>	<b>Needed Changes</b>
Water Removal (Aerator & Distributor)	The aerator and distributor forces the water from the sides of the chamber to the bottom through the check-valve to recycle the water	Air distributing tubes floated around the Lexan box	Water removal worked but was not efficient because there was not enough pressure to remove all of the water	Better secure the air distributing tubes so they do not interfere with the plant	Air pump with a higher pressure; elimination of/better securing of distribution tubes in microgravity
Water/Watering system (micro pump & mister)	Water is kept in the water chamber where it is pumped through the micro pump to a mister to water the plant roots, and then recycled back into the chamber	Water was dyed green with food coloring for visibility and the system remained water sealed for the duration of the experiment. The water formed what appeared to be a large bubble under microgravity.	Water mister and micro pump did their job but did not efficiently water the plant	Due to micro-gravity and complications, the pump and mister produced globs of water much of the time	Pump filtration system is necessary; pump with a higher pressure should be used in future
Centrifuge	Swiftly rotates the entire plant to remove water from the roots in microgravity	Spun smoothly at each speed variance	Very efficient, needed little force to flick all of the water off roots	Because of complications with the pump and time spent fixing it, flyers were unable to find the exact optimum speed. However, it was discovered that the speed is much less than we originally thought, and in the first day flight, the plant was damaged by the speed of the spinning	Lower speeds will be used to flick water off of the plant. In terms of functionality, the centrifuge worked as hypothesized
Control Panel	Contains all of the switches for manual control of each part of the system as well as the emergency kill switch	Located on the outside of the glove box, attached to the floor with Velcro	Very efficient, was easy to use	Under the 2-G force, the Lexan of the control panel was not built in a way that was sturdy enough to withstand both days of flight. As such, it cracked	Use a stronger material with a more durable design for future trials

## **DISCUSSION**

### *Challenges*

There were numerous unanticipated challenges that arose during the flight. The most pressing issue was the lack of a filtration system for the micro pump. On the first flight day while testing a plant at a higher speed, the roots were too long and became caught in the check-valve, severing the roots and polluting the water with root particles. This matter clogged the micro pump and resulted in the malfunction of the misting system, and thus, making it difficult to perform the experiment. On the same flight, the air distributor tubes detached from their secured places on the exterior of the plant chamber, and then became tangled with the tall, spinning, tomato sprout. The result was a decapitated tomato plant. Furthermore, neither the aerator nor the micro pump was strong enough to perform their tasks efficiently. The aerator distributed the air but the pressure was not high enough to force all of the water in the root chamber through the check-valve. The micro pump, even after it was replaced for the second flight, did not have enough pressure to mist the plant proficiently. On some trials, the water from the mister would glob due to lack of pressure or an obstruction of water flow, as opposed to a forceful dispersion of the solution as seen on trials under gravity.

### *Successes*

Despite the numerous challenges the team experienced, overall the experiment was a great success and provided numerous concepts for future innovation. Conceptually and in terms of overall functionality, the system worked as we had hoped. Using centrifugal force was determined to be an efficient solution to the original problem of removing excess water from the plant roots. Other successes include the LED lights were excellent in making the observation and video documentation of the experiment very clear, as well as the control panel's simplicity and usability. The team also considers the challenges successes, because with the knowledge that was gained, we can innovate a better system that can perhaps be used in space in the future. After talking with numerous astronauts such as James Voss and Dorothy Metcalf-Lindenburger, it was determined that astronauts in space would love to be able to take care of plants and possibly have a fresh food source. As such, from the information gathered from these flights, the team is considering taking the project in the direction of a personal plant growth chamber for astronauts on future ISS flights.

## **CONCLUSION**

The experience we had on the Zero G plane was certainly enlightening as to what is realistic concerning our experiment and what is not. We learned that plant size is integral to the success of the experiment, as a plant that is too large interferes with the operation of all of the components of the system. It was especially problematic when the roots got caught in the check-valve at the bottom of the reservoir because little pieces were severed and got sucked up into the micro pump. The micro pump was another problem we encountered. Although it was neat that such a small pump had so much power, it wasn't enough power for what we needed it to do, especially because we had enough space in our Lexan box to have a bigger and stronger pump. We also needed a filter to ensure that no particles got sucked into the pump. We also learned that we needed a stronger source of air to push the water off the walls of the chamber, as the aerator was ineffective in microgravity.

The outreach items we chose to use primarily were a slinky, a foam dart gun, and small foam gliders. The gliders were interesting to observe with the lack of resistance, especially because they were not very effective on the ground with full gravity. The foam dart gun had a similar effect as the gliders. The slinky was also interesting due to the way it compressed and reacted when moved without the presence of gravity.

## **ACKNOWLEDGMENTS**

The Lakewood High School HUNCH team would like to thank our teacher and sponsor, Mr. Brown, for introducing us to this amazing project, helping us along, and making all of it possible. We would also like to thank our mentor, Mrs. Gold, for her invaluable assistance throughout the process, our team and teachers, Mr. Olsen, Mr. Snare, and Mr. Shaw, over at Warren Tech for bringing HUNCH to Jefferson County and making it all that they can make it, our sponsors, The Big Tomato and Dimension 3D Printing, for their generosity and support, and the astronauts that we have talked with that encourage us in our endeavor. Also we would like to thank all of our parents for being there and accommodating the large amounts of time we spend beyond school hours to design and produce the experiment.

We would like to express our gratitude to the Reduced Gravity Office and the HUNCH program for this amazing opportunity. We sincerely appreciate the support in producing, conducting, and adapting our experiment, as we work to make a personal plant chamber.

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## **Appendix**

## **Background Information about the C-9 and the Reduced-Gravity Program**

The Reduced-Gravity Program, operated by the NASA Johnson Space Center (JSC), provides engineers, scientists, and astronauts alike, a unique opportunity to perform testing and training in a weightless environment but without ever having to leave the confines of the Earth's orbit. Given the frequency of Space Shuttle missions and the construction and habitation of the International Space Station, the Reduced-Gravity Program provides a truly ideal environment to test and evaluate space hardware and experimental procedures prior to launch.

The Reduced-Gravity Program was established in 1959 to investigate the reactions of humans and hardware during operations in a weightless environment. A specially modified turbojet, flying parabolic arcs, produces periodic episodes of weightlessness lasting 20–25 seconds. The aircraft is sometimes also flown to provide short periods of lunar (1/6) and Martian (1/3) gravity. Over the last 50 years, over 100,000 parabolas have been flown in support of the Mercury, Gemini, Apollo, Skylab, Space Shuttle, and Space Station programs.

Excluding the C-9 Flight Crew and the Reduced Gravity Program Test Directors, NASA's C-9 aircraft accommodates seating for a maximum of 20 other passengers. The C-9's cargo bay provides a test area that is approximately 45 feet long, 104 inches wide, and 80 inches high.

NASA has transitioned to using Zero G Incorporated's 727 aircraft, which will hold up to 30 investigators. Zero G's 727 is nearly identical in size and volume to the KC-135 aircraft previously used by NASA to support the Reduced Gravity Program. This Boeing 727 has a larger cargo door to accommodate large payloads and provides a test areas that is approximately 70 feet long, 140 inches wide, and 86 inches high.

Both aircraft are equipped with electrical power for test equipment and photographic lights. When requested, professional photography and video support can be scheduled to document activities in-flight.

A typical flight lasts 2 to 3 hours and consists of 30 to 40 parabolas. The parabolas are flown in succession or with short breaks between maneuvers to allow time for reconfiguration of test equipment.

For additional information concerning flight weeks sponsored by the JSC's Human Adaptation and Countermeasures Division or other Reduced-Gravity Program opportunities, please contact:

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Explore the Zero Gravity Experiments and Aircraft Operations Web pages at:  
<http://zerog.jsc.nasa.gov/>      <http://jsc-aircraft-ops.jsc.nasa.gov>

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