Reduced Gravity Education Flight Program
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Reduced Gravity Education Flight Program Overview

The Reduced Gravity Education Flight Program provides a unique academic experience for undergraduate students and educators to successfully propose, design, fabricate, fly, and evaluate a reduced gravity experiment of their choice over the course of six months. The overall experience includes scientific research, hands-on experimental design, test operations, and educational/public outreach activities.

Objectives

- To provide students and educators with an outstanding educational opportunity to explore microgravity.
- To attract outstanding young scholars to careers in math, science, and engineering in general.
- To introduce young scholars to careers with NASA and in the space program in particular.
- To provide a platform for students and educators to understand how microgravity affects research and testing of serious science and engineering ideas.
- To provide an opportunity for both the general public and school children to discover educational and professional opportunities available at NASA.

Significant Outcomes

- Over 120 college undergraduates from 17 states (representing 19 different institutions) participated in the 2009 traditional undergraduate program. Twenty proposals were selected for the 2009 flight year. Fifteen projects focused on engineering concepts, four were physical science experiments, and one was a life science (including biology) experiment.
- Over 55 college undergraduates and faculty in the System Engineering Educational Discovery (SEED) program from 7 states (representing 7 different institutions) participated in the 2009 program. The projects in this flight week were all system engineering based.
- Over 35 K-12 educators from NASA Explorer Schools (NES) from 9 states (representing 10 different institutions) participated in the 2009 program. Eighteen applications were submitted for the 2009 flight year.
- The University of Michigan flight team presented at the 45th AIAA/ASME/SAE/ASEE Joint Propulsion Conference in Denver, Colorado in August. Their presentation will include their findings from their June microgravity flight.
- Boise State University’s flight team participated at the Idaho Capital Scholars that aims to recruit top high school juniors. The flight team used this to help promote engineering at BSU as well as demonstrate the opportunities that NASA provides to students.
- The University of Kansas gave 9 presentations over the course of the week that covered their group’s entire experience and work with local school’s science club students, reaching over 200 students.
- The flight team from Yale University participated in a Physics Olympics which was a competition for New England High School students in a number of physics related challenges and events.
- University of California at San Diego hosted an “Engineering Evening” with local high school students and parents that encouraged new high school students to consider engineering as a career and promoted the microgravity program.
- The 2009 Imagine Rochester Institute of Technology Festival drew more than 25,000 public visitors to the campus who took part in all-day activities. An estimated 500 people viewed the flight team’s booth and talked to the team members present. Many visitors also had questions regarding NASA programs available to students and the process leading up to their participation.
Program Overviews

Undergraduate Student Program

The Reduced Gravity Education Flight Program allows teams of undergraduate science and engineering students nationwide to propose, design, and fly a reduced gravity experiment.

The 2009 flights came from all over the United States, with participants from 17 states representing 19 different institutions. Twenty proposals were selected for the 2009 flight year. Fifteen projects focused on engineering concepts, four were physical science experiments, and one was a life science (including biology) experiment.

Overall, 19 of the 20 selected teams were able to complete their projects for flight. This included the first teams from the Oklahoma State University and Texas State University at San Marcos. This year’s participants in the NASA Reduced Gravity Education Flight Program Student Program reported to Ellington Field during March/April and June. The following pages contain abstracts about each project. Full final reports are available upon request.

To date, student teams from 49 states have flown. These include 2,800 undergraduate students from 167 universities.

Systems Engineering Education Discovery (SEED)

The Education Office offered a nationwide solicitation of student applications aimed at addressing systems engineering challenges within both microgravity and lunar gravity environments. Unlike the traditional reduced gravity flight program where students propose the research to be carried out, the NASA technical workforce identified ongoing projects that are systems engineering and reduced gravity related. Selected student groups were then paired with NASA research projects under the leadership of a NASA Principle Investigator to carry out scientific research, hands-on investigational design, test operations, and educational/public outreach activities.

In addition to student involvement, one university/college faculty member was invited to fly with each team. This helped to provide faculty members with teaching materials in their classroom and is used as a motivator to increase their students’ interest in systems engineering.

The 2009 flights came from all over the United States, with participants from 7 states representing 7 different institutions. Nineteen projects were submitted from NASA Johnson Space Center, Marshall Space Flight Center, Glenn Research Center, and White Sands Test Facility. Eight proposals were selected for the 2009 flight year. Overall, all 8 selected teams were able to complete their projects for flight. This year’s participants in the SEED Program reported to Ellington Field during March/April. The following pages contain abstracts about each project. Full final reports are available upon request.
**NASA Explorer Schools (NES)**

This “pipeline” strategic initiative promotes and supports the incorporation of NASA content and programs into science, technology, and mathematics curricula in classroom grades 4-9 across the United States. Targeting underserved populations in diverse geographic locations, NASA Explorer Schools will bring together educators, administrators, students and families in sustained involvement with NASA’s education programs.

Teams composed of full-time teachers and a school administrator develop and implement a three-year action plan to address local challenges in science, technology, and mathematics education. This customized professional development plan will be available based on needs assessments and delivered through on-site school services and via distance-learning networks. The Reduced Gravity Flight Program is one of the special opportunities offered to NES teams.

The 2009 flights came from all over the United States, with participants from 9 states representing 10 different institutions. Eighteen applications were submitted to NASA Johnson Space Center. Ten applications were selected for the 2009 flight year. Overall, the 10 selected teams were able to complete their projects for flight. This year’s participants in the NES Program reported to Ellington Field in February. The following pages contain abstracts about each project. Full final reports are available upon request.

**Special Opportunities**

The Special Opportunities flight week was offered to the Reduced Gravity Education Flight Program by NASA HQ as an evaluation week aboard the new contract aircraft. Given the increased aircraft size and unfamiliar capabilities, this offering allowed the Education Office to evaluate payload size constraints. As a stipulation to receiving this flight week, the Education Office agreed to identify participants for this opportunity who would normally not be eligible for our traditional programs. As a result, we were able to fly high school seniors, human test subjects, and teachers who are not members of the NES program.

The 2009 flights came from all over the United States, with participants from 12 states representing 13 different institutions or organizations. Overall, 13 of the 14 selected teams were able to complete their projects for flight. This year’s participants in the special opportunities flight week reported to Ellington Field in January 2009. The following pages contain abstracts about each project. Full final reports are available upon request.
Abstracts

Top, left: Educators experiencing hypoxia as a part of the Hypobaric Chamber Training. Middle, left: Students from Purdue University presenting to the Test Readiness Review Committee. Bottom, left: HUNCH program participant is taking data from his team’s ISS Wardroom crumb catching experiment. Top, right: A NASA Explorer School teacher exiting the microgravity aircraft. Middle, right: Students make final adjustments to their hardware in-flight before the parabolic maneuvers begin. Bottom, right: Staff members for the Hypobaric Chamber Training are controlling the chamber as the students inside experience hypoxia.
A major challenge in microgravity fluidics research is the deployment, capture, and control of droplets. Standard methods of creating droplets include quickly retracting a needle after forming the droplet, using two opposing needles and quickly retracting, which creates an unpredictable velocity in the droplet, and forming the droplet against a fiber, which does not allow it to form a sphere so that properties such as heat transfer are no longer uniform (Robinson, 2007). Last year, we began development of a technique to deploy and control water droplets using sound by manipulating the amplitude, frequency, and timing of a pair of opposed speakers. This technique would allow control of the fluid without requiring contact with the droplet, thus minimizing perturbations.

Particle dampers are mechanical damping devices that consist of an enclosed cavity filled with particles. When subject to vibration the momentum exchanges and frictional forces of these particles create a damping effect that can be optimized to suit a number of applications over a broad frequency and amplitude range. In space based applications these particle dampers could potentially serve as a robust and simple device to eliminate jitter in optical assemblies or other sensitive scientific equipment. However, particle dampers have never been tested in a microgravity environment, and modeling their performance in microgravity proves problematic, as their effectiveness is highly nonlinear and dependent on orientation with gravity. The proposed experiment provides data to characterize two variations of these dampers under microgravity conditions. Their performance will be compared to a control and ground based test. The experimental set up consists of the two particle damper configurations, and one mass model control, fixed to respective cantilever beams. These beams are driven over...
a frequency range centered on their first mode resonant frequency. Through the observation of their steady state response, a mathematical model is used to assess the damper performance. By repeating this test under a range of input amplitudes the degree of nonlinearity in the dampers is ascertained. The conclusions of this experiment will determine the feasibility of using particle dampers in space and provide reliable models on which to base further investigation or actual space based applications.

The College of New Jersey: Ewing, New Jersey
Using Fluorescent Dust to Obtain a Three-Dimensional Analysis of a Dusty Plasma Part II
Proposal ID: 2009-2395

In spite of their relatively unknown nature, dusty plasmas are found very commonly in astrophysical observations, such as planetary rings, as well as inside ground-based devices, including fusion reactors. Due largely to greater interest in the effects these dusty plasmas are having inside these ground-based devices, the field of dusty plasmas has been expanding very quickly. In order to learn more about these dusty plasmas, devices are beginning to be frequently brought into microgravity as many experiments can be run and results observed which cannot be recreated with the presence of gravity in the laboratory.

In spite of advances in many aspects of dusty plasma research, experiments continue to use laser-sheet methods, developed in 1994, to image and gather data on the dust clouds. This method meets limitations with the three-dimensional clouds as it can only get two-dimensional cross sections for analysis. Team DPX has been working with other methods of imaging these dusty plasmas, primarily the use of dust which, when exposed to ultraviolet (UV) radiation, will fluoresce. Through making the dust fluoresce, we are able to image the entire three-dimensional structure of the cloud simultaneously and homogeneously in ground-based experiments. This is a vast improvement over the limitations of the laser sheet, and we are working toward gathering sufficient data to prove its usefulness in comparative studies. Microgravity will allow us to test two important aspects of this imaging technique. First, we will be able to move the dust cloud further from the dust tray, simulating an isolated system. This way, any effects from the tray, such as reflections, will be eliminated, and the data from the laser sheet method and our UV imaging can be gathered and compared. We will be investigating different intensities of UV radiation as well in order to ascertain the most efficient value, allowing the entire cloud to be illuminated as much as possible but without affecting the interparticle spacing, the velocities of the particles, or other properties of the cloud. The second task will be a further test of a strange phenomena detected during prior student-directed work on dusty plasmas, wherein the particles gained a rotational velocity while in a direct current (DC)-glow discharge plasma. We will watch to see if this rotational motion can be recreated in the microgravity environment and if any correlation with the intensity of the UV radiation can be found.
Embry-Riddle Aeronautical University:  Daytona Beach, Florida  
*Project DIEMOS (Diaphragm Implemented Experiment to Model Oscillatory Slosh)*  
Proposal ID: 2009-2411

Over the years there have been several instances in which space-related research missions have ended abruptly due to the unpredictable effects of energy dissipation from spin-stabilized liquid propellant tanks. One such instance occurred with NASA’s very own Applications Technology Satellite 5 (ATS 5) in 1969. This spin stabilized spacecraft was sent into an uncontrollable flat spin that ended the mission just soon after it reached orbit. More recently, however, in March of 2007, SpaceX’s Falcon I rocket failed its second attempt at a successful launch. While the first stage of this rocket proved to be successful by taking it to a near orbital velocity and an altitude of 289 kilometers, the second stage proved disastrous due to fuel slosh caused by the liquid oxygen propellant. This oscillatory movement of the liquid propellant caused the rocket to roll unpredictably thus starving the second stage engine of fuel and thereby ending the mission. Over the years some theories on dampening these effects such as diaphragms/baffles have surfaced.

Missouri University of Science and Technology:  Rolla, Missouri  
*Reduced Gravity Testing of a Refrigerant-Based Cold Gas Thruster*  
Proposal ID: 2009-2419

With the exorbitant cost that is needed to launch a payload into orbit, technology is being sought to make satellites more cost effective. With new developments in distributed space systems, satellites’ costs are being lowered while added redundancies are improving spacecraft reliability. However, distributed space systems must be able to control their relative dynamics to maintain formation flight while keeping proper orientation in orbit. One vital component to ensure the proper attitude and orbit corrections is the propulsion system. Previously, propulsion systems encountered many structural restrictions due to the physical design and safety regulation constraints that occur when integrated into the satellite. While other types of propulsion systems exist that have the potential to be used on a small satellites, many of these systems can introduce additional complexities, interferences, and safety concerns. One alternative is the use of a cold gas propulsion system. Cold gas systems have the additional bonus of being one of the simplest and safest systems that are currently being employed. In most cases, cold gas systems make use of an inert, non-toxic and non-flammable gas. Some common propellants are nitrogen, carbon dioxide, and xenon; however, these generally require high pressures and large volume storage to provide enough ΔV for the duration of the mission. One viable option is to use saturated liquids which can be stored at far lower pressures than a pure gas system as well as require smaller volumes in which to store the propellant. Saturated liquids, however, have not been widely used. Butane, for example, has been one of the few saturated liquids used, but due to its flammable nature, it is very undesirable and therefore has only been implemented in a few designs. Refrigerants, however, provide a non-flammable solution, but have only been used as a means to transfer heats in space-based systems. Since the idea of using refrigerants as a viable means of propulsion, more development is required. Further development can be achieved by further analyses of the fluid, as well as generating models of the fluid within a system. As a final test of viability, the refrigerant based system will be flown onboard student-built satellites. For this experiment, the refrigerant R-134a will be used as the propellant for a cold gas thruster system. The system will be mounted and tested in a sealed box and secured to NASA’s C-9B aircraft. The aircraft will be used to simulate conditions that cannot be duplicated in the laboratory setting. Pressure, temperature, and thrust data will be used to determine the effectiveness of the thruster system. The data gathered from the zero gravity flight will be compared to ground testing results to determine the effect that sloshing of propellant has on system performance. The results of the experiment will be used to further the understanding of refrigerant-based cold gas propulsion systems and aid in the integration of future cold gas systems in Missouri S&T designed satellites.
New Mexico State University: Las Cruces, New Mexico

Inertial Property Algorithm Verification
Proposal ID: 2009-2421

The necessity to accurately and efficiently calculate the changing inertial properties of a flying spacecraft is becoming more evident as on-orbit tasks and operations (such as rendezvous maneuvers, on-orbit refueling, hardware deployment, etc.) become progressively complex and aggressive. This is due to the fact that the control system of a spacecraft usually relies on the knowledge of these parameters to accurately control the spacecraft. A newly developed algorithm is proposed to identify a spacecraft's altered inertial properties by only requiring the excitation of the spacecraft by a robotic arm and measuring the resulting changes of the system's velocity. This robotics based method is preferable to other methods that require the use of thrusters to excite the spacecraft and the measurement of multiple parameters, which consumes fuel and generates more error due to the noise inherently generated from measurement systems. The goal of this project is to experimentally verify this algorithm in a 6-DOF microgravity environment.

Last year the Inertial Property Algorithm Verification (IPAV) experiment was performed onboard the microgravity aircraft in an attempt to experimentally verify this algorithm. Though the experiment was successful in many ways, some unforeseen hardware problems that occurred during the flight resulted in the loss of approximately two-thirds of the data. From that experiment, team members have learned a lot about the experiment and the related engineering process. They have new ideas that are anticipated to generate better results from a second test and are highly motivated to perform the experiment once again. This proposal is the result of such a desire.

Similar to last year, a single axis robotic arm mounted on the top of a rectangular box will be used to represent a mock-up spacecraft-robotic arm system. The robotic arm will be preprogrammed to perform maneuvers that will excite the mock-up system. The ratio of the robotic arm mass to the main body and the final orientation of the arm relative to the main body will be varied in order to identify the effects that these parameters have on the accuracy of the algorithm. In order to measure the dynamic behavior of the system, an orthogonal set of gyroscope, a tri-axial accelerometer, an encoder, and a camera will be used. Many improvements in both hardware and software have been made to the equipment design and to the test procedures to account for the lessons learned from the last flight. New ideas about outreach efforts are also proposed.

Oklahoma State University: Stillwater, Oklahoma

Deployment Dynamics of Inflatable Space Habitats in Microgravity Environments
Proposal ID: 2009-2399

Launch of space habitats suffer from limitations of volume constraints of current launch vehicles. The habitats must fit in a very small space, limiting the design volume of the habitat and its usefulness. One way to overcome this limitation is to use inflatable systems that pack in the payload and deploy in space for habitation. The primary benefit of deployable inflatable habitats is that they enable very large volumes to be packed in small volumes for launch. Reduced volume results in lower costs and increased options for launch vehicles. It also reduces costs since no on-orbit
construction is required. A deployable inflatable space habitat is ready for use immediately after deployment. The proposed experiment will investigate the deployment of an inflatable space habitat model under microgravity conditions. Data will include deployment shape, inflation pressure and reaction forces. The resulting data will be used to develop and verify models to design space habitats and their stowage and launch parameters.

**Portland State University:** Portland, Oregon

*Determination of the Influence of Capillary Effects on Two-Phase Flows in Microgravity in Non-Circular Conduits*

Proposal ID: 2009-2396

For fluid systems in which power comes at a premium, spontaneous phase separations facilitated by capillary effects provides an efficient and effective solution to spontaneous phase separation. This becomes particularly relevant in microgravity situations such as exist on spacecraft and the ISS. Heretofore, capillary solutions have been established for fluid systems with well-known and favorable wetting angles but have yet to be utilized for less favorable conditions. This project explores the possibility of implementing such capillary solutions in aqueous systems (i.e. life support) in which wetting angles can vary widely. The method of approach will be to study the effectiveness of various full-scale conduit cross-section geometries that employ a guiding interior corner when compared to various two-phase flow rate ratios. The apparatus will be designed and fabricated to allow for the observation of the flow behavior in the conduit, operated both in a 1-g environment and aboard NASA's low-g aircraft. The data will be collected via digital camera, followed by analysis of the flow characteristics of each trial. The 1-g experiments will serve as a baseline for comparison of the low-g trials. The results of this project should allow for a better understanding of capillary flow and enable design of passive fluid flow systems for unfavorable wetting conditions in microgravity.

**Purdue University:** West Lafayette, Indiana

*Formation of Various Droplet Topologies in Tubes with Variable Volumes and Cross-sections*

Proposal ID: 2009-2417

Two-phase liquid and gas systems occur in many situations from the human body to spacecraft fuel lines. Liquid droplets can form in the human body, causing asthmatic effects, and air bubbles can form in the blood stream, causing a stroke or even death, depending on the location. Spacecraft rely on hydrazine thrusters to correct attitude and position. Air bubbles in the fuel lines can cause the engine to sputter or misfire, creating delays in mission timing. The current experiment is to examine the topologies of liquid created by varying the contact angle and volume of a liquid, as well as test the numerical predictions made by Surface Evolver computational package. As Surface Evolver has unique capabilities, its results cannot be tested or verified against other computational packages and so must be compared to experimental results. The experiment attempts to form three different liquid topologies in a circular tube-an asymmetric droplet, axisymmetric annulus, and plug-and compare them to numerical predictions from Surface Evolver. The experiment will examine the topologies created in a flattened tube and an axisymmetric, buckled tube. Microgravity is required to create these topographies as Earth’s surface gravity causes hydrostatic effects which invalidate the results and force experiments into too many compromises.

**Rochester Institute of Technology:** Rochester, New York

*Modification of an Inkjet Printer for Improved Operation in Microgravity: Effects of Drop Tail Formation on Inkjet Printer Precision and Resolution*

Proposal ID: 2009-2432

We propose to study the effects of ink drop tail formation on drop trajectories and printed resolution of an inkjet printer in microgravity. This work will build on the findings of the RIT team who participated in the 2008
Reduced Gravity Student Flight Opportunities Program (RGSFOP). Inkjet technologies have been utilized in applications such as circuit board printing, bioprinting, and three-dimensional prototyping. It has been shown by the previous RIT team that basic functions of a piezo-electric inkjet print head are effective in microgravity to provide satisfactory resolution results for general print applications. High precision drop placement is necessary for scientific applications and this research proposes to characterize at such a level. Drop tails have the opportunity to form at different, arbitrary points along the circular aperture of the print head nozzle of most printers. The results of this tail placement affect drop trajectory, which will affect drop placement on the substrate and ultimately print resolution. This experiment will focus on analyzing drop shape and the location of the tail, as well as the effects of these characteristics on drop placement at the substrate and resolution. To facilitate data gathering, the printer tested previously in microgravity, an Epson C120, will be optimized to function normally in this setting. Optimization adjustments include stabilizing the print head carriage, enclosing paper trays, and assuring continuous ink supply to the print head. The experimental apparatus will consist of a laptop computer, two complete printers, and the drop imaging device (DID). The DID will consist of a high speed video camera and optical system to image an operating print head partially removed from secondary printers also contained on the DID. Video from the DID will show drop ejection, flight, and impact with paper, allowing analysis of each step.

Texas State University: San Marcos, Texas
Electrochemical Reduction of Iodohexane in Microgravity
Proposal ID: 2009-2416

Fundamental understanding of electrochemical reactions in microgravity environments is critical for sensor operation, optimized battery efficiency, and many other basic functions in a spacecraft. Gravitational forces play an important role in an electrochemical cell in developing convection currents. It is necessary to research how the effects of microgravity will change the operation of an electrochemical cell. As opposed to previous experiments flown by other groups that have focused on electrochemical gas generation, this experiment probes the effects of density driven convection in fluids. Specific goals of this experiment include: 1) to test the effect of different gravity environments on convection-driven current resulting from the electrochemical reduction of a dense organic reactant as a low density product is generated; 2) to model density-driven convection through the introduction of a visually traceable dye in different gravity environments. In order to inspire the next generation of scientists, complex and technical results of ongoing research must be presented in an accessible and interesting manner to the public. The results of this experiment will be presented through numerous outreach events in order to educate and inspire members of the surrounding community. Specific goals for our outreach program are: 1) to promote science education to elementary and middle school students through three annual events using hands-on density related experiments including videos from our flight; 2) to inform students at Texas State University and the community of San Marcos of the results of our experiment by means of websites, meetings, symposia, and newspaper articles.

University of Alaska Fairbanks: Fairbanks, Alaska
Small Satellite Stability and Control during Actuation of Small-scale SMA Deployment Mechanisms
Proposal ID: 2009-2410

An emerging response to the modern aerospace trend of "smaller, faster, cheaper," is the growing realm of "small satellites" whose dimensions are measured in centimeters rather than meters. These satellites face unique design challenges based on size, weight, and power limitations. To address these challenges and provide a functional bus for future small satellites to be built at the University of Alaska Fairbanks, a team
of student engineers seeks to optimize the design of two related small satellite tasks: attitude control and solar panel deployment. One means of alleviating a small satellite’s limited power supply is to deploy solar panels to increase the satellite’s power production capacity. For small satellites this is in turn a challenge; conventional deployment mechanisms utilize bulky, heavy, and power-hungry motors. Small satellites are in need of a low-mass, low-power means by which to deploy solar panels.

To meet this challenge, engineering students at the University of Alaska Fairbanks have developed a solar panel deployment mechanism utilizing shape memory alloy (SMA). This lightweight, low-power system is also mechanically simple, with fewer failure points than a motor. The functionality of this system, however, cannot be tested in a gravity-limited environment; the unique research environment of the NASA Reduced Gravity Aircraft is required. Closely related to the challenge of panel deployment is the task of attitude control and satellite stability during deployment. The Alaska Microgravity Team has developed an attitude control system (ACS) which will stabilize the satellite prototype during deployment testing. The system’s ability to remain stable during deployment – and the power draw required to do so – will be measured and factored into the optimization of small satellite control systems. This information can be further applied to optimization of the deployment mechanism, leading to the improvement of two critical small satellite systems.

University of California San Diego: La Jolla, California
Freestream Behavior of Water in Microgravity
Proposal ID: 2009-2422

Designing a urine collection device (UCD) for use in space has been a complicated engineering problem since the beginning of the space program. There has been little research done on urine stream breakup, which behaves differently in microgravity than on the earth’s surface. NASA’s early missions to the moon proved that this problem could not be solved by diapers. The urine receptacle assembly (URA) was a critical piece of hardware designed to collect urine in missions after Apollo 8. It was lightweight and did not require the male astronauts to have direct contact with the apparatus, unlike previous models. However, the URA’s design resulted in splash back creating an unacceptable level of contamination on and around the hardware. Now that NASA has decided to go back to the moon, a lightweight UCD is needed to act as a contingency device in the capsule. In order to improve the URA, we propose a microgravity experiment to study urine free stream flow. We will define free stream flow as an undisturbed liquid jet from the exit of a pipe/tube. The break-up of the free stream will be simulated by sending water through models of both male and female urethras. We will use two high-speed cameras to monitor free stream break-up, droplet and liquid bridge sizes, and spray patterns. A flow meter will be used to monitor and record the rate at which water leaves the urethra models. Investigating free stream break-up patterns is essential to designing a more efficient and comfortable URA for astronauts. This experiment will provide valuable information to NASA’s Johnson Space Center to improve the URA for the future Constellation expeditions.
University of Colorado at Boulder: Boulder, Colorado

*Wilberforce Pendulum: A Study of Coupled Mode Systems in a Microgravity Environment*

Proposal ID: 2009-2391

The Wilberforce Pendulum Microgravity Team 2008-2009 (WPMT) is a group of CU engineering students who share a passion for igniting the interest of space and engineering careers for future generations. The WPMT will demonstrate the physics behind basic coupled modes through microgravity testing. The team will use two separate Wilberforce pendulum test apparatuses; one opened ended and one closed. Each apparatus will be designed so that the bending moment is constrained allowing the coupled mode to exist. WPMT's goal is to create educational videos which will both teach K-12 students about physics regarding pendulums outside of the influence of gravity and inspire them to set forth in careers involving space and engineering. The video created will be used to help facilitate lectures by giving visual means to the concept at hand.

University of Kansas: Lawrence, Kansas

*SMART-HAWKER2: A Smart Wire Actuated Robotic Arm and Docking Apparatus*

Proposal ID: 2009-2433

In 2006, a team of four students from the University of Kansas designed a space docking prototype from a concept using shape memory alloy (SMA) as the maneuvering mechanism. The design was accepted by NASA's Reduced Gravity Student Flight Opportunities Program (RGSFOP) for test flights aboard the C-9. The prototype underwent in-flight microgravity testing, and the results were utilized to build a new, advanced design. The next year, in 2007, a new prototype, based on the previous year’s concept was designed. The new design, named SMART-HAWKER, consisted of three independently moving arms testing four directional bending and, to incorporate the previous year’s design, twisting clockwise and counterclockwise. The new concept was thought to apply to robotic arms more so than docking.

Since the previous team has mostly graduated with their degrees, a new team was developed, named SMART-HAWKER2, to further research on the SMA actuator. We are four undergraduates from the University of Kansas from a diverse educational background. We want to continue the research on the robotic arm concept and apply our research to another docking mechanism concept.

Based on previous experiments, the mechanism’s material has been redesigned. Instead of being made of rigid materials, the device is constructed from a heat resistant fabric tube lined with a spring coil to maintain shape. These light, flexible materials will give the mechanism freedom to move to its full extent, and the SMA will be able to fully contract. The mechanism will be once again separated into three parts. This time, two sections will be dedicated to bending in four directions, and the third will contract. The new prototype is the next logical step in making robotic SMA technology a reality.

By changing the material, the device is given increased movement. By comparing the results of this experiment with those from past experiments, we can move in the direction of selecting more efficient designs. Weight concerns have always plagued NASA, for it takes large amounts of money to carry bulky equipment into space. The new materials provide a lighter and easily transportable method of the original design. The design can also be adapted for docking purposes because it is hollow and provides its own dampening processes when contracting.
University of Michigan: Ann Arbor, Michigan

*Determining the Performance of the Dry-Nanoparticle Field Extraction Thruster (NanoFET) Configuration in Microgravity*

Proposal ID: 2009-2425

The Nanoparticle Field Extraction Thruster (NanoFET) is a novel electric propulsion device being developed at the University of Michigan. NanoFET electrostatically charges and accelerates solid micro-/nano-particles to create thrust for small spacecraft. The goal of NanoFET is to leverage a single, flexible electric propulsion engine to enhance and enable a broad range of missions.

Team ZESTT is proposing to fly prototype versions of this thruster to test its feasibility and performance in microgravity. The team will work to design a prototype piezoelectric-based feed system for the Dry-NanoFET configuration with particles on the size scale of microns. The feed system’s feasibility under vacuum conditions in both terrestrial and microgravity environments will be demonstrated, and performance measurements (throughput, emission uniformity, and efficiency) will be taken to help determine the system design drivers and operational limits. Different configurations of this thruster will be first tested on the ground to determine the optimal charging sieve hole geometry, hole spacing, and the backpressure force on the propellant reservoir. Microgravity tests will be used to validate NanoFET performance models and define the operational parameters for future NanoFET designs.

University of Southern Maine: Portland, Maine

*Effects of Altered Gravity on Cellular Function*

Proposal ID: 2009-2426

Constellation, NASA’s mission to explore the surface of the moon, includes a manned moon base. More research needs to be done on the effects of altered gravity on cellular morphology and metabolism to make this a safe reality for the astronauts involved. Since research we completed at the 2008 Microgravity University showed an increase in DNA and chromosomal damage under conditions of hypergravity and microgravity, more experimentation needs to be done to confirm these results and determine if they are due to increased uptake of damaging ions and particles or a decrease in the efficiency of repair mechanisms during periods of altered gravity. The results of this inquiry will tell us more specifically how altered gravity affects DNA and chromosomes and how they become more susceptible to chemically-induced damage as a result. This research is useful because occupational exposure levels for astronauts working in altered gravity may need to be adjusted from the acceptable levels on Earth, and this research will help determine those levels. Future research will be based on counteracting the increased damage that cells experience in altered gravity. This may be done using nutraceutical therapies recently found to block some carcinogenic mechanisms or through use of a bowhead whale cell line that has proven to be resistant to chemically-induced DNA damage.
Washington University in Saint Louis: Saint Louis, Missouri

*Reduced Gravity Bandit Docking: An Automated Vision-Navigated Inspector Spacecraft*

Proposal ID: 2009-2392

Washington University (WU) is one of eleven schools developing a nanosatellite for the NASA / Air Force Research Laboratory (AFRL) University Nanosat-5 competition. The project is completely student run, including all aspects of design and creation. The mission of the WU nanosatellite Bandit/Akoya is proximity operations and repeatable docking of extremely small spacecraft in microgravity. The 3kg “Bandit” inspector free-flying craft is able to detach from the 29kg “Akoya” host spacecraft and maneuver in 6DOF at close range. Bandit is also able to redock using an extremely error-tolerant mechanism, which is the subject of this test. Though these are not explicitly unique abilities, the scale of Bandit/Akoya is unique. Each “Bandit” inspector free-flyer is only 3kg and $15,000, which makes it ideal for low cost, lightweight space operations. A small and inexpensive spacecraft could potentially have many applications, including on-orbit inspection, anomaly resolution, and possibly repair. A vehicle such as Bandit could take pictures of other spacecraft to analyze damage or determine relative positions for autonomous movements. At such low cost, the vehicle could be recaptured or could be expendable.

In recent years, advances have been made in inspection, relative maneuvering, and docking technology. In 2000, a satellite named SNAP-1, designed by Surrey Satellite Technology, transmitted images back to Earth after deploying from its launch vehicle. The 28-kg XXS-10 microsatellite satellite deployed by the AFRL also demonstrated line-of-sight guidance to within 100m of a target in 2000. In 2007, the United States Defense Advanced Research Projects Agency (DARPA) / NASA Marshall Space Flight Center’s Orbital Express demonstrated docking, refueling, and autonomous separation. Bandit is a contribution to a similar cause; we hope to demonstrate repeatability and extremely error-tolerant soft-docking.

Yale University: New Haven, Connecticut

*Void Deformation of Complex Plasma*

Proposal ID: 2009-2408

A complex plasma is a plasma with dust particles dispersed throughout. When it is created in microgravity, a void is formed as part of a three-dimensional crystalline structure within the plasma. This void is a region that remains free of dust particles due to an equilibrium state between Coulomb forces and ion-drag forces. On Earth, normal g-forces dominate the system, and the void is unable to form. The proposed experiment provides a quantitative measure of the dynamic behavior of these forces by observing the time-evolution of the crystalline structure and inter-particulate distances as a function of changing g-force. By analyzing a series rapid succession CCD images, we plan to measure an effective spring constant that will provide insight into the behavior of a dusty plasma in dynamic environments.
Boise State University: Boise, Idaho

Lunar Surface Traction Concepts for Pressurized or Unpressurized Manned or Robotic Rovers
Gravity Type: Lunar

As humans return to the moon to establish a sustained presence in preparation to go to Mars, there will be a need for a transportation system that can carry both humans and/or cargo between different points in the moon. Gravity plays a role on vehicle traction. The heavier the vehicle, the more costly it is to launch from the earth to the moon. The lighter the vehicle, the less traction and/or reduced structural integrity depending on materials used. Concepts are needed that are lightweight, compensate for lower moon gravity, and can take cargo (manned or unmanned) between different locations.

Students can test different traction concepts using a combination of materials. Traction concepts can be compared against the following criteria: different wheel designs, traction belt, legged vehicle, etc.

Items to consider: weight (less the better), structural integrity (pounds that can be carried), limits on nominal speed and acceleration, power consumption, adapting to terrain challenges, ability to change direction, traction, and sustained speed.

It involves two different disciplines - electrical and mechanical. A battery powered electrical motor, in combination with a mechanical traction system, will provide enough power and compensate for torque based on the weight of cargo being transported and the type of terrain the vehicle is moving across with an efficient use of power. In addition, using a comparison of advantages and disadvantages of designs according to specified criteria, the team can decide what to modify for a subsequent design cycle to create a better, light weight, sturdy design. In other words the teams need to determine what part of their design they need to optimize or sub optimize to obtain a solution that will yield the highest score against the given criteria.

Establishing a base on the moon in preparation to do the same for a Mars mission requires a transportation system that humans can rely on to get from one point to another or carry cargo a certain distance within the surface of the moon and subsequently Mars.

NASA Technical Contact: Pedro Curiel – Johnson Space Center Constellation Program Systems Engineering and Integration Office

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Carthage College: Kenosha, Wisconsin

*Angle of Repose of Lunar Simulants in Reduce Gravity*

Gravity Type: Lunar

Special technologies that extract and replenish vital resources, such as oxygen, from the lunar regolith or soil, known as In Situ-Resource Utilization (ISRU) technologies, will be vital for sustaining long duration lunar outpost missions. A key supporting operation for these technologies will be the handling of the lunar soil for storage or direct use in processors. The handling of powder and grains in terrestrial applications is often hampered by great inefficiencies and failures. Operations on the moon will require that we try to overcome these inefficiencies and failures in order to make ISRU technologies viable. One of the important material properties to consider is the angle of repose of the lunar regolith, which is also strongly gravity dependent. The angle of repose is a key property in the stability of heaps and piles and in the flow of granular materials. In storage hoppers, for example, the static and dynamic angle of repose of the lunar regolith will have a strong effect on the flow behavior and flow cessation of the granular solids. Excavation of the lunar regolith also relies on the flowability, which depends on these angles, of the lunar regolith into and out of the excavator bucket. More generally, most processes involving the flow of the lunar regolith material will be affected by this material property.

This study will provide data to support excavation and materials handling studies for oxygen production systems being modeled under the ISRU Systems Engineering task.

Determining the properties of lunar simulants is important in establishing their usefulness in testing lunar demo and hardware concepts for the ISRU project. In this case, a reduced gravity experiment is needed to assess the effect of gravity level on the static and dynamic angle of repose of lunar simulant soils. The different simulants of interest will be provided to the university team for testing. The experiment must be able to determine the precise static and dynamic angles of repose of each simulant, mainly under lunar gravity and other gravity levels for comparison. Several repeated experiments for statistical purposes will be required.

NASA Technical Contact: Juan Agui – Glenn Research Center Office of Biological and Physical Research

Ohio State University: Columbus, Ohio

*Correlation of 1-g Aerospace Materials Flammability Data with Data in Reduced or Microgravity Environments*

Gravity Type: Lunar

Correlation of ground 1-g materials qualification flammability tests with microgravity data is of crucial importance to determine if the ground test data is conservative when applied to spacecraft microgravity environments. The current NASA STD 6001 Test 1 data is mostly conducted in 30% oxygen at 10.2 psia, which is considered as the “worst expected” condition in spacecraft from a flammability point of view. Ground data taken under fixed conditions is not amenable to be correlated with microgravity environments; due to lack of information, NASA STD 6016 assumes a one-to-one correlation,
which may not be realistic. Determination of real correlations between materials flammability in ground and in microgravity environments is important to determine the safety factors involved when selecting aerospace materials. NASA WSTF developed a method to determine the Maximum Oxygen Concentration (MOC) at which a material would self-extinguish; the approach has been used to qualify materials for the Constellation Program. This approach allows quantitative correlations between the 1-g and microgravity flammability data.

Materials flammability is a major spacecraft safety concern. Knowing the fire safety factors will lead to decreased possibility of a catastrophic fire event. Hypoxia, decompression sickness (DCS) prevention during an EVA, and materials flammability are major criteria for selecting the spacecraft environment. Prior to an EVA, the astronauts have to be exposed to enriched oxygen at lower total pressure; oxygen enrichment results in increased materials flammability. Knowing how materials flammability changes with environment changes will allow adequate precaution during these operations. In addition, any instance which may result in increased cabin oxygen concentration will allow mitigation by knowing which spacecraft components are most at fire risk.

Correlation of laboratories test data to real-life conditions is necessary for any materials flammability evaluation method; although, it has an increased importance for spacecraft applications because of potential steep penalties for incorrect assumptions. The approach and technology development during this project is likely to have broad applicability.

NASA Technical Contact: David Hirsch – White Sands Test Facility Test Materials

University of Colorado at Boulder: Boulder, Colorado
Sustainable Water Management Technologies for the Lunar Outpost
Gravity Type: Lunar

Terrestrial water treatment systems and spacecraft water treatment systems share similar requirements and methods. While spacecraft treatment systems are often designed to process urine to potable standards, there are technologies terrestrial designed to address ground and ocean water contamination with similar requirements. Such treatment systems appropriate for the developing world may also be appropriate for the Lunar Outpost, given that the Outpost will require rugged equipment operating in a harsh environment with limited local resources. This project proposal may include scaled versions of terrestrial water treatment systems for treating brine water in developing countries applied to the lunar outpost in a 1/6th gravity environment using local resources such as lunar regolith simulant.

Life support on the moon will have to take advantage of in-situ resources and consist of a fully integrated system with humans, habitat, and environment playing system roles. Additionally, terrestrial water treatment systems are feats of systems engineering that can be applied to the lunar outpost.

Exploration Life Support systems must make use of local resources and be sustainable for long term use. This is a new approach for spacecraft, and lessons can be taken from terrestrial life support systems and applied to exploration-class systems.

NASA Technical Contact: Johanna Goforth – Johnson Space Center Space Suit and Crew Survival Systems Branch
In anticipation of the development and design for the next generation ExtraVehicular Activity (EVA) suits for Constellation missions to the moon, the Human Research Program is conducting preliminary studies to examine feasibility issues associated with extended continuous use of EVA suits of up to 144 hours. Such a requirement is imposed to tackle the emergency situation that would occur if the spacecraft cabin atmosphere becomes unsuitable to sustain life. A partial or complete loss of cabin pressure or spacecraft fire could render the cabin atmosphere incompatible. The time requirement is being driven by the total transit time to and from the moon and addresses the theoretical maximum time required if the cabin pressure were lost shortly after the trans-lunar injection burn.

Typical terrestrial injections of medication involves expelling any residual gas bubble from the syringe barrel and adjusting the amount of medication to the required dosage by expelling extra medication into the environment. Typically, the syringe is aligned parallel to the gravity vector so that gravity can assist pushing the bubble to the top. In order to mitigate the effects of the microgravity environment, it has been proposed to place the syringe within a sling and swing it in a circular fashion. However, limited space with the crew cabin and limited mobility within the suit may preclude full rotations from being completed. It is proposed that a platform be developed that can quantify the requirements to attain the necessary bubble displacement in either a 90 or 180 degree circular arc. Control parameters will also include initial bubble size and syringe barrel inner diameter. A separate portion of the investigation is to examine the rate of syringe plunger depression in terms of generating a liquid jet versus a liquid seep at the needle outlet.

There are human factor issues regarding penetration of the suit. Even with a specially designed suit portal, there will be at least one or two layers that need to be penetrated. Furthermore, there will be an opening through other layers of the suit that may need deeper penetration if it is misaligned. Long syringe needles would be required to penetrate the suit and the necessary human tissue layers. Control parameters would include resealable portal diameter, the diameter and length of the internal suit opening, and the needle length.

Finally, there will be several “fabrics” that will be pierced by the needle. Among these are the resealable membrane in the port and potentially webbing from the thermal undergarment and quite possibly the Maximum Absorpancy Garment (MAG). The shearing apart of these fabrics and potential injection through the skin could have significant health consequences. While it is possible to gather data regarding the disintegration of the fabric in normal gravity, it is desired to determine the conditions that would result in debris becoming attached to the needle and eventually penetrating the skin. The experiment should be designed whereby the fabric is positioned orthogonal to the camera field of view. Penetrations through the fabric would be recorded with the objective being to track any debris that is shed by the fabric.

NASA Technical Contact: John McQuillen – Glenn Research Center Office of Biological and Physical Research
**University of Nebraska at Lincoln**: Lincoln, Nebraska  
*Flow of Granular Lunar Soil Simulant through a Hopper*  
Gravity Type: Lunar

Lunar soil is much different from terrestrial soil, consisting of a large percentage of very fine particles. Lunar soil also contains very irregular and jagged particles formed from the sintering together of broken grains during micro-meteorite bombardment. NASA has soil simulants that replicate the unique characteristics of lunar soil. It is known that the flow of lunar soil and lunar simulant soil is very different from terrestrial soil. Flow characteristics of lunar soil in the 1/6 gravity of the moon is needed for engineering of lunar outpost facilities. The “Systems Engineer” for the team will obtain science requirements for the experiment from the Principal Investigator and will be used to translate user (science) requirements into engineering solutions and hardware concepts to achieve the desired measurements and results. The experiment would involve the design of a transparent closed container containing a “V” shaped hopper with an opening. The rate of flow through the hopper provides information about the flow characteristics of the soil. Several different soils should be tested in 1-g and in 1/6 g with the “V” hopper. Soils will include JSC-1A lunar simulant, NU-LHT, sand, and glass spheres.

Tests should involve the filling of the “V” hopper with a known mass (volume), opening of the bottom, and recording of video of the soil flowing out of the hopper along with the recording of the time on the video. The test cell will permit the reuse of the sealed sample container by inverting the cell to refill the “V” hopper. The design will require scaling the size of the test apparatus to utilize the quantity of soil available. The primary science objective will be to record the time for soil to flow through the hopper in 1/6 g and compare with 1 g. The secondary science objective will be to compare the flow times of different soils. Another secondary science objective will be to record the shape of the pile of soil that forms as it falls through the hopper. A limited number of previous experiments have been performed in 1/6 and 1-g.

NASA Technical Contact: Edwin Ethridge – Marshall Space Flight Center Ceramic Materials

**University of Nebraska at Lincoln**: Lincoln, Nebraska  
*Surface Habitat 1/6g Suitlock Evaluation*  
Gravity Type: Lunar

One of the major challenges of exploring the lunar surface is ensuring safe crewmember entry and exit of the lunar habitat. Initial airlock concepts provided an area large enough for crewmembers to prepare for extravehicular activities (EVAs), maintain space suit hardware when not in use, and don and doff the EVA suits. However, the size of this design is prohibitive due to the large volume required for the space and, therefore, the large amount of gases to maintain pressure of the airlock and the loss of these gases during depressurization for EVA. The suitlock concept combines the aspects of a suit donning stand with a smaller

*UNL students and NASA mentor, Heather Paul from Johnson Space Center work on their experiment.*
airlock design with the added advantage of limiting exposure of the crew and habitat to lunar dust and other contaminants brought in after an EVA. While the smaller size is advantageous, a major concern of the design is providing safe return to the habitat for an incapacitated crewmember. This project will evaluate the floor space and volume requirements involved with donning and doffing two EVA suits in the suitlock configuration. In addition to evaluating the space requirements of the suitlock, this project will analyze the operational procedures to assist an incapacitated crew member safely back into the habitat.

NASA Technical Contact: Heather Paul – Johnson Space Center Space Suit and Crew Survival Systems Branch

Washington University in St. Louis: Saint Louis, Missouri

*Effects of Lunar Dust on Solar Panel and Radiator Materials*

Gravity Type: Lunar

The adverse effects of lunar dust on solar panels could potentially be very detrimental for extended-stay missions on the moon. The lunar dust could block light to the solar panels, thereby decreasing the power output of the solar cells. Decreased power could result in reduced mission objectives, and it could adversely affect the safety of the flight crew.

Even during the short-duration Apollo sorties in the 1960’s, lunar dust contamination was evident. In addition, the Mars Exploration Rover solar panels showed a significant decrease in power output due to the effect of Martian dust covering the panels. In future missions, it is possible that lunar dust will have an even greater adverse effect due to its composition and electrostatic attraction properties. A method of removing lunar dust from solar panels would be extremely beneficial to the Constellation Program. Existing research has focused on using electrostatic charges to remove dust. We wish to explore other possible solutions during our simulated lunar gravity test flight.

The primary objective of our lunar gravity test flight is to determine the effects of tilting the solar panels with respect to the gravity vector to remove lunar dust simulant, thereby increasing solar panel power output. The secondary objective is to determine the effects of vibrating the solar panel to remove the lunar dust simulant, thereby increasing solar panel power output. Our hypothesis is that both the solar panel tilting and solar panel vibration will remove enough dust in the 1/6th gravity environment to allow the solar panel to function within 75% of the “clean” performance.

NASA Technical Contact: Timothy Pelischek – Johnson Space Center Engineering Systems Architecture and Integration Office
Broadmoor Middle Laboratory School: Shreveport, Louisiana

*How Does Gravity Affect Gyroscopes?*

The experiment investigates how gravity affects the performance of gyroscopes. This will involve measuring the relative speed of a running gyroscope and correlating its rate of change in revolutions per minute with the force of gravity acting upon it during the course of the experiment. Using LEGO Mindstorms NXT robotics kits and gyroscopes, we will construct robotic modules that will use electric motors and wheels to spin up the gyroscope. The NXT will then measure the gyroscope’s rate of speed via a light sensor and contrasting colors on the surface of the gyroscope’s wheel. The NXT will also measure the G-forces acting upon the unit with an on-board accelerometer. All of this data will be recorded into the NXT’s memory and stamped using its datalogging function. This data will then be downloaded to a laptop computer, and the three variables—speed, g-forces, and time—will then be plotted and graphed for analysis. Our experimental results should show us how differing gravities have different effects on the gyroscope’s rate of spin.

Broughal Middle School: Bethlehem, Pennsylvania

*To Fizz or Not to Fizz: Mentos and Diet Coke*

This experiment involves studying increased nucleation points on a Mentos candy when placed into Diet Coke in microgravity. We will be studying the difference of volume and rate of foam evolution between gravity and microgravity environments. The students will learn about vapor/liquid separation, phase change, chemical reactions, and surface tension. Under conditions of normal gravity (ground-based control), micro-gravity, and hyper-gravity, we will measure: the volume and volumetric rate of foam evolution; the volume of liquid suspended in foam (following foam collapse); the pressure increase and pressurization rate (an indication of reaction extent and rate); and finally the qualitative observation of bubble nucleation around the Mentos. We will measure the volume of foam and pressure as a function of time and variation of Mentos surface area. Foam will be discharged and contained in the upper vessel of the apparatus. Our design includes two clear vessels: one filled 16.9 oz Diet Coke product bottle and one empty 2-liter bottle, connected with a ball valve, which will also serve as the release mechanism for the Mentos tablet. The 2-liter bottle will be marked with graduations calibrated to volume and will be used to contain and measure the foam formed during reaction. While the reaction occurs, we will digitally record a video of foam evolution with a timer function. Following initial reaction, the top vessel will be isolated, then following foam collapse (and return to 1G), the amount of liquid will be measured. This will allow us to determine the vapor/liquid ratios in the different foams.
**Dr. Rodriguez Elementary:** Harlingen, Texas

*To Float or Not to Float*

Small spherical objects will be dropped in clear handsoap to test the time it takes them to sink or float in gravity, hypergravity, and in microgravity. By comparing the results, we can determine if gravity affects how objects move through the liquid. Students will perform a series of pre-flight investigations. They will gather a variety of spherical shaped objects of different sizes and mass. They will measure and record the mass and volume of each item.

Students will set up investigations using containers filled with soap to determine if the objects will sink or float when dropped into the containers from a measured drop height. They will use stop watches to record the time it takes for objects to sink or float. They will compare the results of their investigations and draw conclusions about what factors make objects sink or float. Teachers will help students understand concepts of mass, volume, density, and gravity so that students can use the proper vocabulary to describe the conclusions derived from their observations.

**Capitol Region Education Council:** East Hartford, Connecticut

*Kaleidoscopes in Space!*

The purpose of this experiment is to determine the effects of different levels of gravity on the sphere packing problem, also known as the Kepler Problem. Gravity can influence the arrangement of the close packing of spheres and the rate at which it occurs.

To test the rate and arrangement of the close packing of spheres, we have devised an experimental setup consisting of two parallel sheets of Plexiglas that are very close together with small circular discs in between them, as well as a camera that is mounted to take pictures of the spheres at regular intervals. Discs are used instead of spheres in order to restrict the experiment to two dimensions and facilitate photographic data. Either on the ground or in variable gravity conditions, the whole assembly is rotated so that the discs fall amongst each other and arrange themselves into the closest possible state. The camera will take pictures at known intervals to record this. The pictures will be analyzed to determine the initial and final distances between the discs and the rate at which they move into their final configuration, if there is one.

This data has implications in packing as well as material science. Problems may be created in packing materials if particles do not reach their maximum, most efficient density in reduced gravity. Scientists will have to overcome this problem in order to build colonies and systems in different gravitational fields. Also, materials may lose their strength if their density changes due to differences in their close packing systems that result from reduced gravity. Our results will provide insight into the packing of materials in reduced gravity and help address these issues.
Harding Middle School: Des Moines, Iowa

*Testing the Magnetic Field in Reduced and Hyper Gravity*

The Harding Middle School Reduced Gravity Opportunity team is conducting an investigation to provide students with an opportunity to gain a greater understanding of magnetism. The scientific process enables students to identify how a magnetic field is affected by changes in gravitational force. This investigation involves students researching the concepts of force, gravity, and magnetism. The experiments will involve magnets and iron filings contained in two different boxes, one box filled with air and the other filled with water. The effects of the different levels of gravitational force will be tested on different variables including shapes of magnets (bar, round, and u-shaped), location of the magnet (internal and external), and the size of magnet (large and small). In reduced gravity, the students hypothesize the magnets will not have an effect on the iron filings, and there will be no visual magnetic field. Visual data will be collected and recorded and the flight results compared to the results from ground testing by students in Harding classes.

Middle School at Parkside: Jackson, Michigan

*Electromagnets in Microgravity*

The students at The Middle School at Parkside hope to answer the question, “How will metals react around magnets in various gravitational environments?” We have conducted experiments with different magnets in one-G environment. We are learning how to make an electromagnet and the devices in which they are used. We will use our new knowledge of electromagnets to pick up two different metal objects and compare their performance in different gravity environments. We hope to determine if the amount of wire wraps on an electromagnet will have an effect on its performance in different gravitational environments. We have three hypotheses. Student hypothesis number 1: the electromagnet will have an exaggerated lift during free-fall as a result of the current traveling through it. Student hypothesis number 2: The electromagnet shape will be a contributing factor on how it functions in different G-forces. Student hypothesis number 3: In a micro-gravity environment, where there is essentially no relative effect of gravity, electromagnets should be affected by exhibiting changes in behavior. This is because energy is transmitted via particles, and particles are affected by gravity.

Our experimental setup is an extension of last year’s reduced gravity experiment. We will be collecting data on the performance of the electromagnets in one-G, in micro-G, and hyper-gravity conditions. We will also be measuring the vertical lift of the metal objects in a tube containing the electromagnet in the different gravity environments.

The experimental hardware consists of the following items: (a) An electromagnet constructed of a nail wrapped in wire. (b) A clear plastic tube that houses the electromagnet. This allows it to move freely as the plane maneuvers through the parabolas. (c) A power source for the electromagnets consisting of a 3 x 3 series and parallel configuration of 6 D-Cell batteries. During flight, the teachers will be recording data on the vertical lift of the metal objects in the tubes on a data table created by students. They will also be able to record the performance of the electromagnets using video cameras and still photography during flight to share with us when we return to the school in order to assist us with our data analysis. In addition, the data collection in one-G will consist of the electromagnet connected to our classroom Micro Lab equipment in where we can observe its voltage.
Oceanair Elementary School: Norfolk, VA

What is the Effect of Gravity on Density?

Our fifth grade students are investigating the effect of gravity on density. The students will be assessing how various materials react when they are subjected to different gravitational forces. While the density of the materials remains the same, will the materials continue to act in the same manner whether the density columns are tested at 1G, hypergravity, or at microgravity? The students have selected materials of distinctly different densities to test to see what their response will be to the change in gravitational force.

We will work to solve our problem by designing density tubes that we can use to compare and record data from. One tube will use liquids of different densities, oil, water, and corn syrup. Another tube will have materials that are generally denser than water, small rocks, sand, and soil. The materials in this tube will be placed in water to create a sediment tube. We will also construct a third tube in which materials will be suspended within the fluids to see how they react to changes in gravity. We will first conduct our experiment at ground level with each student recording the data in a journal. After the zero gravity flight, the students will analyze the results of each test and draw conclusions about the effect of gravity on density.

Even though a material’s density remains the same, the material’s reaction to gravitational change could affect materials that are used in space flight.

Sequoia Middle School: Porterville, CA

Magnetic Propulsion

The students foresee that sometime in the future magnetic force will be used as a type of propulsion for Earth and space based vehicles or as a source of clean energy production in use with continuous electricity. By using Newton’s first and third laws, we are comparing magnetic force at three different angles and multi-gravitational fields, micro-g, hyper-g, and Earth’s gravity. We are using three different angles: one an acute angle, one at a right angle (a vertical test), and one at a straight angle (a horizontal test).

In order to solve the problem, we are going to conduct an experiment using ring magnets placed on a rod to measure the distance they repel each other. One will be fixed to the base of the rod. The other will be free-floating. The free-floating magnet will be positioned and held against the fixed magnet then released. We will have three different fixed rods in our container. One rod will be set at a right angle from the base, the second rod will be at an acute angle from the base, and the third rod will be placed parallel to the base of the container. For a more precise measurement, we will use a video camera to record the distance they travel and where they actually settle. We will then plot the results on a graph to compare the magnitudes of the three different forces.

We predict that in regular gravity we will record the longest distance on the straight angle, followed by the right angle and then the acute angle. We believe that in micro-gravity we will record the longest distance,
probably traveling the entire length of the rod, and in hyper-gravity we will record one-half the distance of regular gravity, for all three angles.

**Solon Springs Schools:** Solon Springs, WI  
*Projecting Projectiles*

The investigation, Projecting Projectiles, will experiment with Newton’s first law of motion as it relates to the physics of trajectories. How does the angle of trajectory affect the path it will take in reduced gravity? In physics, the ballistic trajectory of a projectile is the path that a thrown or launched projectile will take under the action of gravity, neglecting all other forces, such as friction from air resistance or propulsion under the influence of Earth’s gravity.

Our current plan for our experiment will take a basic toy crossbow and will use this along with Velcro darts. We will mount the crossbow on a camera tripod which will allow us to change the angle of trajectory. We will take aim at a coordinate grid target made of Velcro. We will have several trials. Each parabola we will set the angle of trajectory at a certain degree and will attempt to project three color coded projectiles (darts). Angles we are interested in experimenting with will be -6, -4, -2, 0, 2, 4, and 6 degrees, each time at a distance of 6-8 feet. As data are collected and parameters are imposed upon us, these may change.

We start out by explaining our experiment to grades 4-8. They will begin by hypothesizing possible outcomes of the experiment. At a Family Night in November, we will have our experiment set up at one of our stations to collect data for our baseline. We will also be conducting our experiment in classrooms in the Spooner School District and adding this data to the baseline. This data will be organized into graph form within the 4th through 8th grade math classes and displayed. After the experiment is conducted in microgravity, additional graphs will be constructed for use of comparisons.

Upon completion of our reduced gravity experience, our hope is that our students will have a better understanding of microgravity and its effects on projecting projectiles. We would also hope that our students will have a more thorough understanding of trajectories and will be able to utilize this knowledge while hunting.

**Vintage Math, Science, and Technology Magnet:** North Hills, CA  
*Effects of Microgravity on the Rate of Movement of Viscous Liquids*

The students in our Reduced Gravity Flight Club want to know how microgravity will affect the separation of two immiscible liquids – oil and water. Different oils (olive, canola, baby, mineral) will be tested, timed, and observed. Students will measure equal volumes of oil and colored water and place them in a clear container. The container will then be sealed. Through agitation (either by hand or by device), the liquids will be mixed. Students will record the length of time it takes the liquids to separate into layers in the classroom, in microgravity, and in hypergravity.

Students will make observations about the appearance of the liquids in order to answer questions: Will the directionality of the layers change? Will there be layers? Will the liquids separate as bubbles only (as they initially do when mixed on Earth)? Students will take notes and take photos and/or video footage.

By comparing the results of the experiment conducted in microgravity to the results obtained through their trials at school, students will be able to understand how these immiscible liquids are affected by microgravity.
### Special Opportunities – By State
* First Time Participant (institution)*

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### High School United with NASA to Create Hardware (HUNCH): Clear Lake, Texas
*International Space Station Wardroom Table*

HUNCH program is managed at Marshall Space Flight Center in Huntsville, Alabama, and Johnson Space Center in Houston, Texas. Students and educators for this project represented Clear Lake High School.

The ISS needs a wardroom table: a table for everyone to sit and eat simultaneously. The table also needs to collect the stray crumbs from meals so that crumbs would not float around and get inside sensitive equipment. The HUNCH Team designed a table integrated with a crumb catcher running through the table’s center. The HUNCH Team needed to determine if the crumb catcher portion of the Wardroom Table worked in low gravity.

### Missouri University of Science and Technology: Rolla, Missouri
*Studying Arc Welding in Microgravity Conditions*

The Miners in Space Weld Team of Missouri University of Science & Technology (MS&T) is devoted to performing research on MIG welding in microgravity conditions to better understand the changes in the properties of a weld in a space environment. During the microgravity flights aboard the Boeing 727, the team was also asked to test the overboard ventilation system and the aircraft power supply during standard research operations.

### National Space Biomedical Research Institute (NSBRI)
*Sensorimotor Adaptation to Ambiguous Inertial Motion Cues: Tactile cueing as a gravitational substitute for spatial navigation*

NSBRI represted Universities Space Research Association, University of California, Los Angeles (Los Angeles, California), Johns Hopkins University College of Medicine (Baltimore, Maryland), Texas A&M University (College Station, Texas), Rice University (Houston, Texas), University of Texas Medical Branch (Galveston, Texas), Ohio University (Athens, Ohio) and Stanford University (Stanford, California).

Our first objective was to examine how spatial navigation was impaired during parabolic flight. We hypothesized that one’s ability to report their orientation and point toward targets around them would be impaired during the microgravity phase of parabolic flight compared to 1g control trials obtained on
the ground. Our second objective was to examine how vibrotactile cueing of down relative to the aircraft improved spatial navigation. We hypothesized that tactile cueing would provide an effective gravitational substitute during the microgravity phase of parabolic flight that would improve spatial navigation ability. A third independent objective was to examine the overall shape of the heart and blood flow velocity in the left ventricle in response to changes in gravitational loading using portable echocardiography. We hypothesized a proportional increase in the sphericity of the left ventricle as a function of g-load.

**Purdue University: West Lafayette, Indiana**

*Investigation of Fluid Geysering and Attached Droplet Formation*

In zero g, many applications exist in fluid transfer in which either a geyser or an attached droplet is preferred. Tank filling in zero gravity is a prime example of when an attached droplet is desired and a geyser is extremely unfavorable. Geysering in tank filling is generally not desired because the incoming fluid can float into the air vent. This behavior is due to the tank being filled by removing another fluid such as air from the tank while simultaneously filling the tank with a different fluid. Also, geysering is not very desired in the case that a gaseous fluid is used to pressurize a liquid fluid. If the fluid geyseres while being pumped into the tank, the mixture can become quite homogenous; therefore when the fluid is removed from the tank, the pressurizing gas will also be removed in high quantities.

The main tool to determine when a fluid will geyser or remain as an attached droplet is the Weber number. The Weber number is the ratio of the dynamic pressure of the flow to capillary pressure jump due to surface tension. Historically, to have an attached droplet, a Weber number of much less than one would be chosen. Achieving this low Weber number can only be achieved by either reducing the velocity of the liquid or by increasing the surface tension of the liquid, which is quite often not a possibility. However, the fluid could be pumped in at higher speeds if the transition velocity, the velocity where the fluid no longer forms an attached droplet and instead forms a geyser, could be determined. Our hypothesis is that the fluid will geyser at a transition velocity corresponding to a Weber number of around 1.

**Texas Aerospace Scholars Team #1: Houston, Texas**

*Transpiration Rate in Reduced Gravity*

Texas Aerospace Scholars is a program managed at Johnson Space Center in Houston, Texas. Educators for this project represented Sam Houston Middle School (Amarillo, Texas), Cinco Ranch High School (Katy, Texas) and Amarillo College (Amarillo, Texas).

A plant transports water from its root system to other parts of the plant through a process called transpiration. If a root is sitting inside of a solution containing inorganic ions and water, the root cells will pump the ions into the xylem producing a hypertonic solution inside the xylem. The cell walls of the plant are permeable to water, and due to the newly formed concentration gradient between the xylem and its exterior, water moves into the xylem by osmosis (Campbell 644). The water in the xylem is pushed up a short distance by root pressure, but the primary mode of transportation is by means of transpiration.
Transpiration occurs when a water molecule leaves the leaf through a stoma. The cohesion of water molecules, by hydrogen bonding, forms a chain of water molecules from the stomata, through the xylem, and down to the root system. A concentration gradient forms between the inside of a leaf and the surrounding air when the leaf contains more water than the air. When a stoma opens, a water molecule will be pulled off from the chain due to diffusion. The tension caused by this pulls the other water molecules in the chain up through the xylem. The question addressed in this experiment was whether or not gravity affects the rate of transpiration.

**Texas Aerospace Scholars Team #2: Houston, Texas**

*Motion, Earth, Moon and Mars – MeMs*

Texas Aerospace Scholars is a program managed at Johnson Space Center. Educators for this project represented Vela Middle School (Harlingen, Texas), Elkins High School (Missouri City, Texas) and San Jacinto College North Campus (Houston, Texas).

The concepts of force and motion, particularly changes in acceleration due to gravity, are often difficult for students at all levels to comprehend. The experiment conducted during the reduced gravity flights will provide first hand knowledge of the effects of gravity on the motion of a 1-inch ball bearing rolling down a clear acrylic tube. As the ball bearing rolled down the tube, four photovoltaic gates captured data to calculate speed and acceleration of the ball bearing at the varying gravitational levels. Students will be able to view videos of the ball bearing rolling down the tube in reduced gravity. They will also be able to view the data collected and see how the various gravitational forces affected the speed of the ball bearing. This should aid the students in gaining a clearer understanding of two of Newton’s Laws. This data should also allow students the opportunity to gain a better understanding of what ‘gravitational force’ actually means. The videos of the experiment in the micro-gravity environment also allow the students to see the experiment as it would actually happen. They do not have to make assumptions about what might happen.

Several pre-lessons were conducted with students during which they followed the same procedures as those done on the micro-gravity flights. They also made predictions about what data the experiment in flight would indicate. Post-lesson outreach should confirm their predictions.

**Texas Aerospace Scholars Team #3: Houston, Texas**

*Teaching from a Microgravity Environment: Experiments Using a Pendulum, Simple Harmonic Oscillator, and a Glider*

Texas Aerospace Scholars is a program managed at Johnson Space Center. Educators for this project represented Tarrant County College (Hurst, Texas) and South Plains College (Levelland, Texas).

The primary objective for this experiment was to record data in both reduced and hyper-gravity conditions, which can then be used by students to enhance their understanding and verify predictions they make. As teachers, we know that students will remember a concept they “discover” for themselves much longer than words from a lecture or a textbook. Harmonic oscillation occurs commonly in everyday life. Some examples are trees swaying in the wind, automobile suspensions, guitar strings, and clock pendulums. It is such an important form of motion that the harmonic oscillator is discussed in every introductory physics course and physics textbook. In addition, most laboratory manuals have an exercise on harmonic oscillation. College physics students will be exposed to the harmonic oscillator but typically only in the environment of Earth-normal gravity (9.81 m/s²).
This experiment extended the investigation of harmonic oscillation to low gravity conditions aboard microgravity research aircraft. A pendulum and a spring driven harmonic oscillator (standard case studies of harmonic oscillation) were set up along with a timer and a camcorder. The pendulum and harmonic oscillator were released under hyper-gravity, low-gravity, and microgravity conditions and their behaviors recorded. The video-recorded results will be studied by introductory physics students as an extended version of the harmonic oscillator laboratory exercises regularly performed in their classes.

A secondary objective was to study the behavior of a glider under low-gravity and microgravity. In the classroom, students can predict the behavior of the glider and then watch the recorded video to see if their predictions were correct. Since harmonic oscillators are routinely studied in introductory physics courses, the purpose of this experiment was to examine the behavior of these systems in reduced gravity and microgravity. The experiments were video-recorded. These video-recordings will be incorporated into introductory physics laboratories in order for students to observe and collect data from the video-recordings to supplement their studies of these systems. The video-recordings will also be available to other institutions and school districts for use by their students and faculty.

**Texas Southern University**: Houston, Texas

*Metallized Carbon Nanotubes Produced in Reduced Gravity Conditions*

Carbon nanotubes (CNTs) are considered a cornerstone for future scientific research and advance aerospace material development, because they exhibit: i) extraordinarily high electrical and thermal conductivity, ii) chemical and thermal stability, and iii) extremely high tensile strength and elasticity. However, currently there are major complications of processing CNTs into macromolecular systems: 1) CNTs preferentially aggregate into bundles of different sizes; 2) CNTs vary greatly in length and diameter; 3) CNTs possess a range of helicities that result in a wide range of physical properties, especially the electrical conductivity; 4) defects occur both at the tube ends as well as on the sidewalls; and 5) low surface polarity of CNTs exhibit poor wetting and dispersion in polymer matrices and poor phase-compatibility in the interface, especially with polar polymers such as epoxy resins. As a result, in order to take full advantages of individualized CNT's exceptional properties and achieve outstanding structural or functional aerospace materials, engineering design of nano-tubular functionalization is a must.

The goal of this research was to study the effects of reduced-gravity on TSU's proprietary nanotechnology that deposits atomic metallized nanostructures promptly on the surface of CNTs. We proposed to deploy TSU's new technology (patent pending) which offers ideal scalable platform, where metal nanostructures are promptly (approximately 1.1 seconds scan time) deposited on CNT surfaces with great manageability and reproducibility to systematically explore and compare reduced-gravity synthesized metallized carbon nanotubes (rgm-CNTs) with metallized CNTs (m-CNTs) synthesized in normal gravity. Thus, silver (Ag) rgm-CNTs were synthesized; however, their morphological structure, electrical, mechanical, and thermal properties have not been completely characterized at this point.
The proposed hypothesis was that electrochemical deposition of atomic Ag nanostructures in reduced-gravity conditions will enhance the electrical, thermal, and mechanical properties of rgm-CNTs because of the potential unique spatial character of electrochemical deposition in reduced-gravity conditions.

**Texas Space Grant Consortium LiftOff Alumni: Austin, Texas**

*Challenger’s Lost Lessons*

Texas Space Grant Consortium is managed in Austin, Texas. Educators for this project represented Round Rock Independent School District (Round Rock, Texas), ERA Independent School District (Era, Texas), Judson Independent School District (San Antonio, Texas), Hutto Middle School (Hutto, Texas) and Sunray Independent School District (Sunray, Texas).

This purpose of our investigation was to adapt and demonstrate Christa McAuliffe’s experiments on Newton’s Laws of Motion and Magnetism that were to be taught from the space shuttle Challenger mission in 1986. As educators we saw this reduced gravity flight as an opportunity to introduce a new generation of students to the first teacher in space and how to conduct scientific experiments in a weightless environment. To demonstrate Newton’s Laws we used a billiard ball and a ball half its weight and size. If the balls are dropped on Earth at the same time and same distance from the ground, they will touch the ground at the same time. The force of gravity has an effect on these objects that creates this reaction. According to Galileo, gravitational acceleration from the force of gravity is equal for all bodies regardless of mass. While onboard the reduced gravity flight, we had access to various forces of gravity and predicted the billiard ball and smaller billiard ball half its size should react differently. Our prediction was that while falling the smaller ball would travel twice as fast and when propelled would accelerate and twice the rate.

![Margaret Baguio (TSGC) holds up a bottle that contains metal shavings that are attracted by a magnet in microgravity.](image)

If you look at the equation for the force of gravity, you can see why the acceleration will be different, while that from gravity is not. The equation for the force of gravity is: \( F_g = G \times \frac{M_e \times M_o}{R_e^2} \) where \( F_g \) = Force from gravity; \( G \) = Gravitational constant; \( M_e \) = Mass of Earth; \( M_o \) = Mass of object and \( R_e \) = Radius of Earth. We also know from Newton that for any object we can set \( F = m \times a \). When we do this for the force from gravity we get \( G \times \frac{M_e \times M_o}{R_e^2} = M_o \times a \). The interesting thing here is the mass of the object shows up on both sides of the equation. Therefore they cancel, and that is why all objects fall toward Earth at the same rate due to the force of gravity. Since the force we are putting on the object will be the same for both balls (we do not change the settings of the robot based on the mass), and the mass of the balls is different, we would expect the resulting acceleration to be different.

According to Newton’s 3rd Law, \( (F)orce = (M)ass \times (X)times (A)cceleration \). The two balls will be catapulted along similar paths at the same time. Since the normal effects of gravity are eliminated because everything is accelerating at the same rate, the force we create will be the same for both objects, and we can observe this force in an isolated manner. The billiard ball has twice the diameter and mass of the miniature billiard ball which, according to our formula, would exhibit twice the acceleration.
To create some quantitative data, the same method of measurement that Christa McAuliffe used on the original experiment was used. A 110 cm long measuring tape was attached to the bottom of the Plexiglas chamber. When the balls were propelled along the chamber, a video recorded the changes along the measuring tape. When solving for acceleration, 

\[ \text{Acceleration} = \frac{\text{Force}}{\text{Mass}} \]

the force applied is the same, and the mass of the billiard ball is twice the size of the small ball therefore yielding the result of twice the acceleration of the billiard ball. We believed the small billiard ball would outdistance the larger billiard ball on the measuring tape. For Newton’s original formula to be proven accurate, the amount of time each projectile was observed would also be consistent and equal. Additionally, if those objects were to hit a solid object and ricochet off in the opposite direction, the velocity of these objects should remain in a 2:1 ratio because the amount of force applied to the solid objects was equal.

Using the Lego Mindstorms NXT kits, a robot was built and programmed to apply equal amounts of force to both objects simultaneously. The brick/brain of the robot sat in the middle of the container, and legs extended beside the brain pushed the balls forward when triggered with the light sensor mechanism. Using the wall of our chamber and our robot, we wanted to prove that when two objects are ricocheted off a surface with the same force and time, the velocity will continue in a 2:1 ratio. This experiment is an extension of Christa McAuliffe’s Newton’s Laws Lost Lesson.

The purpose of the Magnetism investigation was to utilize two common magnets that are primarily used in society today (Neodymium and Alnico) to demonstrate the characteristics of attraction and repulsion of like and unlike poles and to observe what happens to the metal filings as they pass through the various g forces of microgravity, simulated lunar gravity, and Martian gravity. It is our goal that this lesson will be used as a demonstration in educational settings when studying magnetism. We used the Challenger Lost Lessons Magnetic Chamber as a base and guide. We introduced the Neodymium magnet since it was developed in the 1980’s and not widely used in 1986 when Christa McAuliffe was to fly but is common in computers today. We also hope that this study may be an aide in future hardware and equipment using magnets in space exploration.

University of Houston at Clear Lake: Houston, Texas

Effects of Center of Gravity Location on Locomotive Biomechanics: Implications for Space Suit Portable Life Support System Design

In February of 2003, President George W. Bush of the United States declared the new vision for the American space program. He directed the National Aeronautics and Space Administration (NASA) to refocus its efforts and resources toward exploration-class missions. This vision involves completion of the International Space Station (ISS) and retirement of the Space Shuttle by the year 2010 and the development of new vehicles and hardware to return humans to the moon by 2020. The United States also plans to send humans to Mars. To fulfill this vision, NASA is using lessons learned from previous exploration programs and experience from long duration missions on the ISS to design systems that will enable safe human exploration in these reduced gravity environments.

Experience from long duration spaceflight onboard Skylab, Mir, and the ISS demonstrates that exposure to microgravity causes a variety of detrimental physiological changes to the human body, including loss of bone mineral density, skeletal muscle, and aerobic capacity. After only four days of spaceflight, catabolic bone markers are increased, and after fourteen days, losses of muscle cross-sectional area occur. Longer duration exposure to microgravity results in bone remodeling with significant losses of bone mineral density in the weight-bearing areas of bones (i.e. the calcaneus, greater trochanter, femoral neck, and pelvis). Losses of muscle mass and neuromuscular disturbances result in decreases in muscular strength and endurance. Aerobic capacity is also compromised during spaceflight due to changes in blood volume and aerobic deconditioning.
These physiological changes will be hazardous to humans, especially when working in the reduced gravity environments of the moon and Mars. Decreased bone density in weight-bearing bones could result in fractures, which is problematic considering the limited medical support that will be available during these missions. Losses of aerobic capacity and muscle strength and endurance could inhibit an astronaut’s ability to perform extravehicular activities (EVAs) which may require several hours of high metabolic activity.

Space suit design is a critical element of human space exploration. The challenge of returning humans to the moon by 2020 has necessitated the development of a new space suit system that will enable efficient and effective movement on the lunar surface during EVA. The space suit system consists of the pressure garment and life support subsystems, each of which have their own unique design challenges.

Designs for the Portable Life Support System (PLSS) for lunar exploration have gone through several iterations. The focus of recent design efforts has been on packaging the thermal, ventilation, and oxygen subsystem components with emphasis on mass and volume reduction for the overall architecture, as well as optimization of center of gravity (CG).

While the safety of the astronaut is of utmost importance in design of the space suit system, there is a significant human performance element to it as well. It is essential to understand the biomechanical consequences of changing the PLSS CG location in order to speculate on the potential for injury and/or the rising metabolic demand associated with each CG location. With previous evidence suggesting that humans lose bone, muscle, and aerobic capacity in microgravity environments, these data will be important to understand the potential forces that could be imparted to the skeletal system during suited EVAs. Additionally, because human physiology adapts specific to the imposed physical demands, it may be necessary for crewmembers to perform locomotive exercise with simulated gravitational force acting on their body to prepare for work on the surface of the moon and Mars while in transit to these destinations.

Therefore, the proposed research quantified the effect of varying CG location of the PLSS on locomotive biomechanics in a lunar and Mars reduced gravity environment. Additionally, comparisons were made of the lunar and Mars data to microgravity test conditions in which CG was also varied, but resistance bands with a force equivalent to 1/3 and 1/6g times the subject’s body weight were attached to the test subject and test equipment.

University of North Carolina at Pembroke: Pembroke, North Carolina

*Human Immune Complex Formation Rates in Microgravity*

During the past decades of space travel, it has been determined that the human immune system is compromised during extended periods in the environment of orbital flight. The goal of our research was to determine what effect the force of gravity has on the rate at which immune complexes are formed.

We considered the following question for our principle investigation with this project: “What is the dependency of immune complex formation rates on gravitational force, if any?” We hypothesized that gravitational forces...
would change the convection flow within the fluid thus preventing the immune molecules from interacting the way they normally do. Thus we predicted that the reaction rate would decrease in a reduced gravitational environment due to less molecular interaction. In an attempt to prove our hypothesis our research group, The Weightless Lumbee’s from The University of North Carolina at Pembroke, conducted a human immune complex formation reaction in the 0-g portions of the parabolic flight path flown by and NASA’s research aircraft. The reaction rates from these flight samples were then compared to ground truth experiments.

**Undergraduate Student Research Program Team #1**: Houston, Texas

*Magnetism in Microgravity*

Undergraduate Student Research Program is managed at Johnson Space Center. Students for this project represented Thomas Nelson Community College (Hampton, Virginia), University of Missouri (Columbia, Missouri), University of Colorado at Boulder (Boulder, Colorado) and University of Texas at Austin (Austin, Texas).

The goal of this investigation was to provide a clear understanding of key concepts that pertain to magnetism by using gravitational force as a variable. This relationship was emphasized so that individuals could truly understand the related theories and formulas. In this endeavor the investigation consisted of two main experimental topics: magnetic field lines and magnetic repulsion. The main purpose of the investigation was to produce an education outreach video that clearly showed the visual results of the experiments conducted onboard the flight. This video will be distributed to high school and universities across the nation for use as a classroom aid for physics courses. The flight experiment footage is currently still being edited and compiled. The final video product is set for release at a later date.

**Undergraduate Student Research Program Team #2**: Houston, Texas

*Vortex Structures in Simulated Microgravity*

Undergraduate Student Research Program is managed at Johnson Space Center in Houston, Texas. Students for this project represented University of Texas at Austin (Austin, Texas), Utah State University (Logan, Utah), Embry-Riddle Aeronautical University (Daytona Beach, Florida), Florida Institute of Technology (Melbourne, Florida) and Oklahoma State University (Stillwater, Oklahoma).

This experiment is being flown as part of the January Educational Reduced Gravity Program and consists of students in the Undergraduate Student Research Program (USRP). The experiment chosen investigates the changes to fluid vortices in different gravitational fields. This particular experiment has not flown before. Vortices in a fluid medium of sufficient strength will develop a characteristic, axisymmetric free surface boundary shape. This shape serves to visually define the vortex, for single fluid medium, and is a useful metric for making structural observations about the vortex itself.

A vortex generated within a cylinder by a rotating body, such as a magnetic stir bar, will develop a complex structure due to turbulent flow and localized interactions associated with the periodic motion of the stirring body itself. However, the structure can be simplified for experimental purposes into two flow regions: a rigid fluid-body core, within which the fluid experiences forced rotation and an outer region where the rotation is free (irrotational). The viscosity of the fluid ensures that there is no discontinuity in the velocity profile as a function of radius from the center, and circulation develops within the flow.
Appendixes

Top, left: Students working on trading out components during a turn mid-flight.  Middle, left: Flight team take a team photo prior to flight.  Bottom, left: Educator gives the thumbs up as she enters in the microgravity aircraft.  Top, right: Educators in flight working with their experiment.  Middle, right: Flight team going over their in-flight procedures with former Astronaut Barbara Morgan.  Right, bottom: USRP student monitors the progress of their experiment mid-flight.
### Selected Engineering Proposals

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### Selected Physical Science Proposals

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### Selected Life Science (Including Biology) Proposal

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## Appendix 2 – SEED Program Proposals at a Glance

### Selected Engineering Proposals

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<td>Surface Habitat 1/6g Suitlock Evaluation</td>
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<tr>
<td>Washington University in St. Louis</td>
<td>Effect of Regolith on Solar Panels</td>
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Appendix 3 – Demographic Data

Top, left: Students working on the experiment during a parabola. Middle, left: Yale University flight team experiencing microgravity for the first time. Bottom, left: Advisor monitoring his team’s experiment in flight. Top, right: Flight team taking a team photo prior to flight. Middle, right: Flight team floating with their experiment in microgravity. Bottom, right: Flight team watching their hardware float in microgravity.
Combined Undergraduate Students Demographic Information (UG & SEED)

Program Participants by Gender

- Female: 72%
- Male: 28%
- Total: 121

Participants by Ethnicity

- African American: 6%
- Asian: 7%
- Hispanic/Latino: 19%
- Caucasian: 19%
- Native American: 4%
- Other/No Response: 6%
- Total: 63%

Academic Disciplines for Participants

- Aerospace Engineering: 38
- Physics: 16
- Electrical Engineering: 12
- Mechanical Engineering: 31
- Chemistry: 8
- Biology/Biomedical: 9
- Other: 23

Academic Levels of Participants

- Freshman: 40%
- Sophomore: 23%
- Junior: 12%
- Senior: 10%
- Grad/Other: 9%
- Other: 6%

Program Experience of Participants

- Summer: 75%
- Year: 25%
Undergraduate Students Demographic Information

Program Participants by Gender

Participants by Ethnicity

Academic Disciplines for Participants

Academic Levels of Participants

Program Experience of Participants
NASA Explorer School Educators Demographic Information

Program Participants by Gender

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Participants by Ethnicity

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Academic Disciplines for Participants

Academic Levels of Participants

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<td>Administrator</td>
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Education Level of Participants

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<td>Bachelor's Degree Plus Hours</td>
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<tr>
<td>Masters Degree</td>
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<tr>
<td>Masters Degree Plus Hours</td>
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Appendix 4 – Participant Comments

Program evaluations were collected post-flight. Educators, students, and faculty overwhelmingly praised the program for providing a rare real world hands-on engineering experience for K-12 and undergraduate students. A few of the educator and student responses follow.

• “With this program available, especially to smaller institutions such as mine, it gives a first hand experience that opens our mind and curiosity to NASA that would have not been present without this opportunity.”

• “The biggest benefit from the reduced gravity program is getting communities and students excited and interested in math, science, technology, and the experimental process. If every group takes what they learn and brings it back to their school, city, and state, it is a way for the real impacts of NASA to be seen outside of just the Houston area. This is an excellent opportunity for students to learn what it takes to complete a scientific project. From funding to experiment execution, from developing an idea to modifying it on the plane, it gives them a sample of what experimental science is like outside the classroom.”

• “This was one of the best experiences of my life. The RGSFOP requires students to develop skills rarely cultivated in undergraduate students: coming up with original ideas for sophisticated experiments, submitting proposals to a government organization, and designing and building complicated projects independently, and developing working relationships with real engineers. The NASA employees involved in this program are great: they want to talk to students about their projects and other interests. My experience in the program makes me wish I could go back and become an engineer just so I could work on the types of projects NASA does.”

• “The opportunities to experience, first hand, the effects of microgravity, as well as hypergravity are extremely valuable to me. Also, the physio. day and chamber were experiences that will stay with me forever. I will be able to share this with so many people during my career. The tours and info. taken from them really help to make the world from a small town point of view bigger. Helping students to see the various opportunities that NASA has to offer broadens their view.”

• “Working with other individuals on a physical experiment provides much greater learning opportunity than could ever be achieved in the lecture. Designing and manufacturing the experimental components taught the importance of designing with manufacturability in mind and has also demonstrated the importance of developing a good design in advance (cost reduction, etc).

• “Another part of the program that I found invaluable was a first hand opportunity to experience NASA. It was definitely an amazing opportunity meeting the people and observing the inter-workings of NASA.”

• “I have learned so much in this program! I am not an engineer, so putting together proposals, technical reports, and actually hands on building was a new feat for me. I am also the team lead, so I have learned to collaborate and compromise with many different ideas and opinions. Not only have I learned from my research, but the steps and management of making it to Houston to fly have been a great learning experience in itself. I believe I have learned more in just these few months than I could have in any classroom.”

• “The opportunity for students to construct an experiment and be able to prove its safety for use aboard the NASA aircraft was very valuable. As an engineer it was very valuable to work on an interdisciplinary project where I had to work with people to get our project done.”

• “Please keep this program! It's a valuable education opportunity and one of the coolest things out there!”

“\textit{I thank you for making this ‘once in a lifetime’ experience possible for me. I promise to use it and make the most of it.”}
Appendix 5 – Summary Participation

PARTICIPATING STATES: 1997 – 2009

Forty-nine (49) states have participated in the Reduced Gravity Education Flight Program plus DC and Puerto Rico. The one state that has yet to participate is Delaware.
Appendix 6 – 1997-2009 Participating University Status

2,800 Student Flyers (does not include ground crew)
167 Institutions / 619 Teams / 49 States (plus DC & Puerto Rico)

**Institution Participation:**

<table>
<thead>
<tr>
<th>Institution</th>
<th>State</th>
<th>University/Institute</th>
<th>State</th>
<th>University/Institute</th>
</tr>
</thead>
<tbody>
<tr>
<td>AK  Univ of Alaska Fairbanks</td>
<td>FL</td>
<td>Florida A&amp;M Univ</td>
<td>MD</td>
<td>Johns Hopkins University</td>
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<tr>
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<td>MD</td>
<td>Univ of Maryland-College Pk</td>
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<td>FL</td>
<td>Saint Leo College</td>
<td>ME</td>
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</table>

Two teams from the University of Nebraska at Lincoln pose for a picture with the reduced gravity aircraft.

2009 participants are highlighted in green.
Appendix 7 – About the Microgravity Aircraft

The NASA-JSC Reduced Gravity Research Program flies on a modified Boeing 727 aircraft. The aircraft is crewed by a pilot, a copilot, a flight engineer, and two reduced gravity test directors. For the student campaign, a flight doctor, two video crew members and two photographers are also on board. Most test equipment is bolted to the floor using 20-inch tiedown grid attachment points.

The reduced gravity aircraft generally flies 30 parabolic maneuvers over the Gulf of Mexico. This parabolic pattern provides about 30 seconds of hypergravity (about 1.8G-2G) as the plane climbs to the top of the parabola. Once the plane starts to “nose over” the top of the parabola to descend toward Earth, the plane experiences about 25 seconds of microgravity (0G). At the very top and bottom of the parabola, flyers experience a mix of partial G’s between 0 and 1.8 (called “dirty air”).
Appendix 8 – Program History

Reduced Gravity Program Beginnings: In 1995, Ellington Field’s Aircraft Operations Chief, Bob Naughton, accompanied NASA’s reduced gravity aircraft to Europe to fly the European Space Agency’s student parabolic flight campaign. Mr. Naughton, impressed with the success of ESA’s flights, discussed the idea of a US parabolic flight campaign with NASA Headquarters and Johnson Space Center managers. Headquarters Education Chief Frank Owens liked the idea, as did (then) Deputy JSC Director George Abbey. In the summer of 1995, Abbey and Owens (with the support of the Texas Space Grant) prototyped the first US student parabolic flights.

1995 A pilot program was designed to provide a reduced gravity research opportunity for four teams of college seniors and graduate students from Texas’ Rice and Texas A&M universities. The pilot program was called SURF (Students Understanding Reduced Gravity Flight).

1996 The program was repeated during the summer of 1996, again with four teams from Texas institutions: Lamar University, Rice University, Texas A&M University and the University of Houston. In the fall of 1996, SURF was renamed “Reduced Gravity Student Flight Opportunities Program (RGSFOP)” and expanded to include universities nationwide.

1997 Spring 1997 flights provided research opportunities for twenty-three teams from fifteen states. For the first time, journalists were permitted to fly as “team members.”

1998 The RGSFOP doubled program “slots” in 1998 to include forty-seven participating teams from thirty-seven institutions in twenty-four states.

1999 A second yearly competition was born in 1999, which allowed for flights in both spring and summer. Forty-four teams from thirty-three institutions in twenty-one states participated during summer 1999.

2000 RGSFOP hosted 48 teams in March 2000. Because of KC-135 maintenance delays, 34 teams selected to participate in the Summer 2000 program were shifted into Spring 2001 program slots.

2001 Forty-eight teams participated in the Spring 2001 RGSFOP. Thirty-three teams were those shifted from the Summer 2000 program; the remaining fifteen teams were selected during the Spring 2001 competition.

2002 The Aerospace Academy (a division of San Jacinto College) accepted administrative responsibilities for the Reduced Gravity Student Flight Opportunity Program. The Microgravity University Office was born. A program coordinator and deputy coordinator, under the direction of Dr. Donn Sickorez, assisted the fifty-one teams who participated in the Spring and Summer flight weeks for the 2002 campaign.

2003 A record number of seventy-two teams were chosen to participate. Among these were seventeen first-time institutions and eleven minority teams. In addition, the program experienced an increase in minority participation.

2004 The RGSFOP extended offers to participate to sixty-nine student teams. Three NASA Explorer Schools and one Informal Education team were also invited to participate as part of a pilot program. Although the student program has been in existence in some form for nearly a decade, it is continuing to reach new audiences. This year, six new institutions and seven minority institutions were among the selected teams. This was also the last student group to experience reduced gravity on the KC-135.

2005 The program moved to the C-9 aircraft. Modifications and issues with the aircraft caused delays and cancellations. In all, only ten teams and thirty-two students flew. Teams were rolled over to the 2006 program.

2006 Flights returned to normal, as sixty-five teams are selected from 2005 and 2006 proposals. The first teams from Kansas, Pittsburg State and University of Kansas, fly their experiments. In addition, the first full group of museums and science centers are flown.

2007 In addition to the typical zero gravity parabolas, the student program’s first lunar gravity experiments are flown. Lamar University, Michigan Technological University, and University of Missouri-Rolla flew experiments for 30 parabolas at 1/6G. Experiments ranged from lunar dust removal to welding.

2008 Two additional programs were added: Network of Educator Astronaut Teachers (NEAT) and the Systems Engineering Educational Discovery Program (SEED). Three states were also added to the participating states (Nebraska, Alaska, and Maine).

2009 The program moved to a Boeing 727 aircraft. Through the special opportunities flight week, internal partnerships were explored as well as revisiting the policies of human-testing and the high school program.
FOR MORE INFORMATION, PLEASE VISIT:
http://microgravityuniversity.jsc.nasa.gov